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DISTRIBUTED SOURCE CONNECTION AND OPERATION IN THE ELECTRIC POWER SYSTEM OF MONTENEGRO

Study No. 2121

ELEKTROINŠTITUT MILAN VIDMAR

Ljubljana, september 2012

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SUMMARY

The Study analyses the regulatory situation and the existing Acts governing the area of distributed sources (DI) connection to the electric power network of Montenegro. The development plans are verified for the transmission network. The methodology for the analysis of DI connections to the network is conducted according to the regulatory situation and recommendations for the changes in technical regulations. Therefore, also the recommendation for DI connection to the network is provided. For the practical application of methodology and recommendation, the Study analyses the technically and economically establishes the connections of large number of different types of DI to the distribution network with various Montenegro Government tenders. Finally, the Study is supplemented also with the instructions and documents for the workers of the company Elektroprivreda Crne Gore who will conduct the analyses of DI connection to the network by applying the program package PSS®SINCAL.

Key words: distributed power sources, small power plants, electric power system of Montenegro, connection and operation of distributed power sources, distribution network, technical rules, technical recommendation, provision analysis, network analysis

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LIST OF ABBREVIATIONS

APU	automatic reclosing
BIH	Bosnia and Herzegovina
CGES	Montenegrin Electrical Transmission System AD
DI	Distributed source, small power plant
DIST	distribution
DS	distribution system
DV	transmission line
EES	electric power system
EPCG	Montenegrin Electric Enterprise *Elektroprivreda Crne Gore AD Nikšić*
EU	European Union
G	generator
HE	hydroelectric power plant
ISME	Institute for Standardization of Montenegro
ME	small power plant
mHE	small hydroelectric power plant
NN	low voltage
OD, ODS, DSO	distribution system operator
RTS, SBS, SS	decoupling substation
SCADA	(eng. *Supervisory Control and Data Acquisition*) system for measuring, monitoring, and control of industry systems
TE	thermal power station
TP	technical recommendation
TS	substation
VE	wind power plant
VN	high voltage

LIST OF SYMBOLS

P_{OP}	active power (customers)
P_{max}	maximum active power
P_{min}	minimum active power
P_{DI}	distributed source active power
P_{TR}	active power via transformer
Q_{OP}	load reactive power (customer)
Q_{DI}	distributed source reactive power
Q_{TR}	reactive power via transformer
W	energy

EXECUTIVE SUMMARY

Regulatory status in Montenegro relating to the connection and operation of distributed power sources in the electric power network and theoretical grounds for the preparation of new regulations

Chapter 1 includes the analysis of acts, rules and standards relating to the small power plants (DI) connection to the distribution network. The problems are stressed that can occur, if the existing rules and recommendations for DI connection to the distribution network are not refined and updated.

Energy Act is written clearly and in a modern European spirit thus serving as a good foundation for statutory instruments regulating the area of distribution power sources connection to the distribution system of Montenegro.

According to the available data, the systems for data acquisition on the supply quality and submission of this data to the Agency have not been established yet.

Technical recommendation num. 16: General technical provisions for connection of small power plants to the electro-distribution network of the Republic of Serbia are considered a good basis for technical characteristics and technical standards for the connection of power plants to the electrical electro-distribution system of Montenegro. TP-16 should include some changes and updates to provide a good basis for new *Rules on connection* (hereinafter referred to as: *Recommendation*).

Situation analysis and verification of development plans for electric power transmission network

Chapter 2 recapitulates the important development plans and current development studies relating to transmission and distribution network of Montenegro with the emphasis on the areas pertaining to the analysed distributed sources. The assessed average yearly electric power consumption in the following years is 1.33 %, whereas the average yearly growth of peak load in the system equals 1.51 %.

It can be concluded that for the examined period the 110-35-10 kV system preserves its predominance in the distribution network. The reason for this lies in a long period (approximately 30 years) that is required for the economically acceptable conversion to 20 kV voltage level from the start of 20 kV installation implementation into the system to the actual operation of the whole network at 20 kV.

Development plans do not include the massive increase of the distributed sources in the next couple of years. The analyses in the study show that the existing network has to be reinforced with more than 200 km of 10 kV and 35 kV lines and with the installation of several new SBS with the estimated investment cost about 20,000,000 EUR just to complete the projected number of source connections.

Since the sped-up integration and additional areas with mHE together with the integration of photovoltaic and wind power plants are projected for the coming years, it is necessary to refresh or redefine the development strategy, starting with the distribution network.

Methodology for elaboration of distributed sources in Montenegro

Chapter 3 explains the methodology applied in the analysis for the connection of distributed sources (DI) to the electric power network. The connection process is shown in the Figure 0.1 in detail.

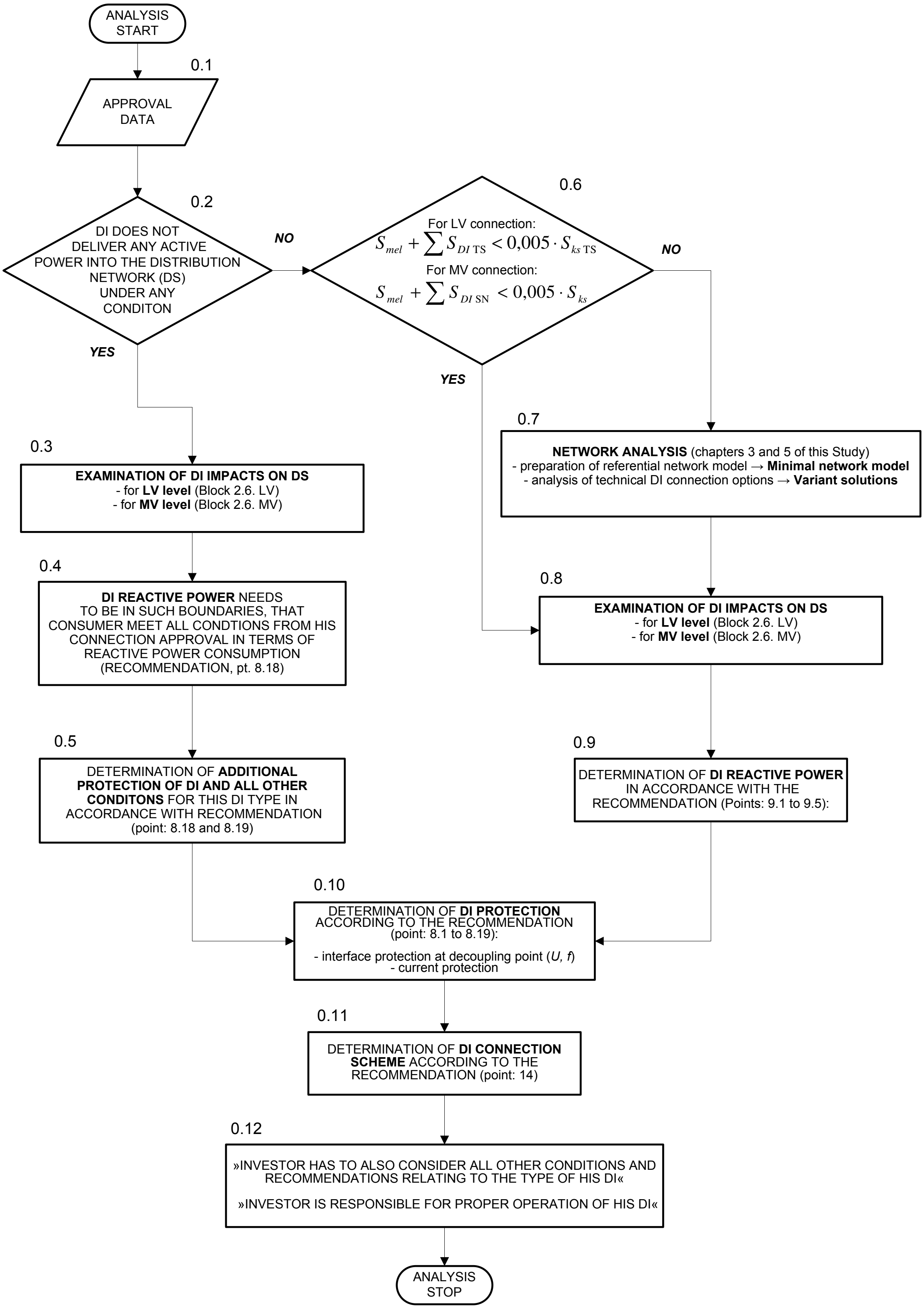


Figure 0.1: Schematic presentation – Analysis sequence for DI connection to the network

The entire methodological process basically consists of five sections:

- determination of the level (depth) of the required analysis
- preparation of the network model
- determination of the parameters at the DI connection point
- analysis of technical possibilities for DI connection to the network
- economic analysis.

The network model trying to represent the real physical network situation is a key for reliability and correctness of network analyses. It is formed by applying the suitable program applications that provide the execution of analyses in the transmission and distribution network. The model is established on the basis of topological and attributive data of electric power elements and used for the analysis execution. The network topology represents the interconnection of elements (lines, transformers), whereas the attributive data defines the physical characteristics of individual elements.

The analysis of technical possibilities of DI connection to the network, according to the rules and criteria of the *Recommendation* regarding this area, includes the selected distributed sources. By conducting the analyses of network structure and the most unfavourable situations (maximum load and minimum DI production, minimum load and maximum DI production) it is determined whether this network structure with the determined input criteria (geographical position with spatial limits, economic development, load prognosis) meets technical plan criteria. Normal operation statuses and situations with single outages (criterion N-1) for the selected network structure are monitored consistently. The reinforcement and adjustment of the network is opted for when the network exceeds the criteria of planning. In case of different options for reinforcement and adjustment, every process of development needs to be examined individually, i.e. *variantly*.

DI can be connected to the network, if the operation reliability and quality of electric power supply to end customers are not impeded. In this context, the basic criteria for network analysis of DI connection are:

- *DI in the network should not cause clogging (criterion on permitted loads in the network),*
- *DI in the network should not significantly impede load conditions at consumers' points (criterion on permitted voltages in network).*

To provide normal operation in terms of line disturbances in the electric power system, the evaluation of potential disturbances of DI in DS should also be included in the process of analysing the possible DI connections to DS.

The Study defines the sequence of operations that help ODS (distribution system operator) to establish whether DI connection to the network is permitted or not in terms of disturbances. On the basis of line disturbances evaluation, ODS needs to establish whether DI can be connected to DS or its connection cannot be implemented since it does not meet the conditions providing the normal network operation.

A full disturbance evaluation analysis and DI compliance with the *Recommendation* criteria in terms of disturbances need to be conducted and established by the project designer applying detailed data on DI and observing the demands set by ODS.

Technical recommendation for distributed sources connection in Montenegro

There are rules given in Chapter 4 for the connection and operation of DI in DS (*Recommendation*).

The *Recommendation* relates to the basic technical requirements for small 10 MW power plant connections to DS with the nominal voltage 0.4 kV (1kV, LV network), 10 kV, 20 kV or 35 kV. The *Recommendation*, specifically its conditions for connections and connection point implementations in DS, applies for ME construction (projecting and construction) or the reconstruction of the existing ME.

The Recommendation has the following goals:

- establish the basic criteria for the assessment of ME connection possibilities according to DS characteristics and ME type, power and method of operation
- establish standard connecting methods
- determine the method and point of electric energy and power measurement
- determine the selection of types and characteristics of protective devices and decoupling apparatus
- establish the method for reactive power compensation in ME
- establish the procedure and sequence of activities from applying for to the ME connection to DS with necessary documents and forms
- establish the method and conditions for ME activation and parallel operation with DS
- establish the method of ME operation management

Not part of recommendation:

- ME construction
- ME management (manual and/or automatic)
- ME with exclusive isolated operation

The *Recommendation* is in tune with the important technical regulations, established global standards and technical recommendations in terms of development and implementation of contemporary technical solutions for this type of electric power facilities. If the given limits or restrictions from the Recommendation, based on the current technical status (technical status is regulated by IEC and EN standard in the field of line disturbances), are followed it is expected that the network voltage in the distribution network will meet the criteria set by the important standard MEST EN 50160 in force in Montenegro.

The *Recommendation* unambiguously defines the limits of the permitted line disturbances caused by DI. ODS follows these limits for the DI connection approval. The aim of DI designers is to project DI to meet the approval conditions. In this regard the project designer can apply formulas from the *Recommendation* to calculate DI impact on the network and establish the compliance with the criteria set by ODS.

Network analyses of distributed source connections to the distribution network

In terms of methodology, Chapter 5 offers complete network analyses of distributed source connections to the distribution network of electric power system of Montenegro. Small power plants in the river beds of Lima, Komarnica, Piva, Tara and Zeta with the total installed power of 87.3 MW are analysed. The impact of various distributed sources on the distribution network operation is explained. There are also the analyses of small hydroelectric power plant on the river Zaslapnica, photovoltaic plant Čevo and wind power plant Birska Gora.

The type of distributed source generator is important for more detailed operation analyses of individual distributed source impacts, conducted by the DI project designer. This project analysis deals with flickers on the DI side and harmonic voltage, local voltage disturbances and regulation of reactive power (U –Q characteristics) by applying the formulas stated in the *Recommendation*. That is why they are not considered important for this study which defines the network analysis.

All power plants have to meet all conditions defined in the *Recommendation* for DI connection to the Montenegro network. Moreover, the network connection analysis is conducted for every power plant providing more detailed information on necessary connection measures. General impacts of distributed sources on the distribution network operation are explained and analysed together with suggested actions in network operation (voltage regulations, protective adjustments, impact on electric power quality, reliability). The opinion is given on network points for the execution of measurements on distributed sources (the start and end of the connection line).

The main difficulties in the network operation cause voltage changes due to load oscillations. In situations with high loads (during working days) the voltages are low due to higher voltage drops, whereas in the periods with low loads they are high. Voltage deviations are reported due to static voltage regulation by adjusting the transformer taps in substations where the voltage is compensated for average load values. In case of distributed source operation in MV and LV network, the power flow is alternating, causing more voltage changes in the distribution network. The intensity of changes depends also on the network configuration and power. The management of voltage changes is conducted by active voltage regulation at 110/35 kV substations or with lower impedance through network reinforcement.

Voltage statuses would be much better, if there were a possibility to automatically regulate the voltage on 10 kV busbars SBS 35/10 kV. Significantly bigger integration with smaller connection costs could be achieved by gradual conversion to voltage level of 20 kV with automatic voltage regulation and by converting the 35 kV network to 110 kV or 20 kV. In this context, the Study suggests the preparation of the integral strategy in Montenegro for conversion to 20 kV voltage level and gradual disuse of 35 kV and 10 kV levels.

Experience shows that the conversion is a long-term process lasting from 10 to 20 years or even longer. The projected distributed sources analysed in this Study need to be connected to the network as soon as possible (in this or the following years). For this reason the analysis of conversion to 20 kV in due to the connection of these sources is not consistent. However, all submitted solutions for network connections and development in this analysis project or allow a simple potential conversion to 20 kV.

All suggested reinforcements are stated with investment cost estimates caused by connections of individual distributed sources. The following table shows the total length and number of new/reconstructed lines and substations with the estimated costs for connection of all mHE to 10 kV and 35 kV distribution networks. The average cost of mHE connection is about 220 € for one kW of installed power.

Table 0.1: Summary of investments in the distribution network due to mHE connection.

		TOTAL LENGTH, NUMBER	INVESTMENT ESTIMATE (€)
10 kV	lines	109 km	5,120,000
	decoupling stations	2	510,000
		total 10 kV	**515,12**
35 kV	lines	116 km	12,050,000
	SBS 35/10 kV	3	1,450,000
	new TR 35/10 kV	3	195,000
		Total 35 kV	**13,695,000**
		TOTAL COSTS OF 87.1 MW MHE CONNECTION TO DISTRIBUTION NETWORK	**19,325,000**

Network preparation and analyses in PSS®Sincal

Chapter 6 gives instructions and provides the knowledge needed for network preparation and analysis in the program package PSS®SINCAL. Various analytical approaches are shown that can be applied for distribution and transfer network planning in terms of the inclusion of distributed sources.

Engineers can now conduct analyses independently and thus improve the knowledge in this field. Acquired knowledge and continuous work on concrete connection problems will provide a competent mastering of this complex issue.

Summary of study conclusions

Montenegro has a relatively modern Energy Act and certain technical characteristics of DI connection to DS are recapitulated in *Technical Recommendation 16* which is currently in force also in Montenegro. Based on the analysis of current legal acts and statutory instruments, the issues were established that need to be changed and updated in the existing documents to provide such a legal situation that would enable DI connection to DS in line with the situation of Montenegro DS. Also the development plans of electric power system of Montenegro were verified.

The methodology sets clear and unambiguous rules together with the necessary sequence of operations for conducting network analysis of DI connection to DS and the control of DI impacts on DS in terms of line disturbances. This provides the possibility for the analysis of DI connection to DS.

Technical conditions referring to DI connection and operation are given in the *Recommendation* with the new additional elements that provide faster and safer connection with minimum disturbances in DS.

Then the connection of various ME from several tenders issued by the Government of Montenegro is analysed that include awarded concessions for renewable electric power sources. Results of this Study provided topological and attributive digital network models of Montenegro DS that were then submitted to EPCG for the areas with analysed new power plants.

1. REGULATORY STATUS OF MONTENEGRO ON THE CONNECTION AND OPERATION OF DISTRIBUTED SOURCES IN THE ELECTRICAL POWER NETWORK AND THEORETICAL BASES FOR ESTABLISHING NEW RULES

The first part deals with analytical examination of the existing laws, regulations and standards that refer to the field of connecting small distributed sources (Distribution Systems) to the distribution networks. The special focus is paid to the problems that may occur, if the existing rules and recommendations for connecting DS to the distribution networks are not properly dealt with and revised.

1.1. Analytic display of the existing regulations regarding the connection and operation of distributed sources in Montenegro

The document begins with the analysis of laws, followed by the examination of regulations and recommendations and concludes with the analysis of standards that represent a state of technical equipment in a certain area.

1.1.1. Laws

The laws are general government documents that define the basic principles, regulations, legislation, obligations and relations among government representatives.

1.1.1.1. Energy Law

The Energy Law [1] represents the general law in the field of energy in Montenegro.

This Law defines: energy operations and terms together with the proceedings of quality and safe electrical power supply to the end-customers; public services and other operations in the field of energy regarding Montenegro; methods of organization and function of the electrical power and natural gas market; methods and terms of use of renewable energy sources and co-generation: efficient energy transmission and distribution in the production industry sector, as well as other energy issues.

Here are the sections of the *Energy Law* relevant for the subject matter.

Article 2

Energy activities in accordance with this Law are as follows:

1) ***generation of electricity;***
2) *transmission of electricity;*
3) ***distribution of electricity;***
4) ***supply of electricity;***
5) *organization of electricity market;*

Authorities of the Agency

Article 38

(3) The Agency shall set:

1) *tariffs for supply to vulnerable customers;*
2) ***minimum standards regarding quality of supply, including as follows:***
   - ***quality of service****, specifically regarding the time taken by transmission and distribution system operators for electricity and gas to make connections and repairs;*
   - ***continuity of supply;***
   - ***voltage quality*** *for electricity and quality of gas;*

Dispute resolution and decision about objections and complaints

Article 49

(1) The Agency shall decide about complaints relating to:

1) *an act of the transmission or distribution system operator about denial of access, i.e. connection to transmission or distribution system;*
2) *terms and conditions from a connection consent;*

Production of electricity from renewable energy sources

Article 72

(1) Energy undertakings shall implement measures aimed at increasing a contribution of electricity generated from renewable energy sources to the total electricity generation.

(2) Based on the program for development and usage of renewable energy sources, i.e. the program for development and usage of high-efficiency cogeneration from the articles 17 and 19 herein, the Government shall determine a minimum share of electricity generated from renewable energy sources in the total electricity supply which shall be taken over by each supplier of electricity.

Rights, duties and responsibilities of electricity Distribution System Operator

Article 88

(1) Electricity Distribution System Operator shall:

1) *operate and maintain, modernize, upgrade and develop the electricity distribution system;*
2) *ensure reliable and efficient electricity distribution services;*
3) *provide distribution system users with clear and precise information regarding conditions for service, and specifically information about access to distribution system, including technical, contracted and available capacities, while ensuring confidentiality of information and data considered confidential pursuant to the Law;*
4) *prepare ten year development plan for the distribution system, from the article 41 paragraph (1) clause 4) herein, harmonized with the Energy Development Strategy, the Action plan i.e transmission system development plan, that shall be updated at least every three years, and submit it to the Agency for approval;*
5) *prepare annual investment plans from the article 41 paragraph (1) clause 2) herein, taking into consideration requirements of the system users, which shall be harmonized with the existing ten year development plan for the distribution system and the spatial-planning documents and shall submit them to the Agency for approval;*
6) *specify conditions for connection of users to the distribution system, in conformity with the*

methodology from the article 39 (1) 1) herein;

7) *meter electricity used by final customers, on its area of service and maintain the meters in proper working conditions in order to ensure accurate metering of electricity consumed;*
8) *establish a methodology for connection to electricity distribution systems and submit it to the Agency for approval;*
9) *set prices of connection to the distribution system on the basis of the methodology from the article 39 paragraph (1) clause 1) herein and shall submit them to the Agency for approval;*

…

(4) Distribution system operator shall:

1) *apply best practices in order to ensure security of supply and reliability of distribution system operation;*

Exchange on a connection point

Article 90

(1) Generator of electricity from renewable energy sources in facilities of up to 20 kW installed capacity or in high-efficiency cogeneration in facilities of up to 50kWe installed capacity shall have a right to exchange electricity that it delivers to the system or takes from the distribution system during a year.

(2) The difference in energy levels from the paragraph (1) of this article shall be established and billed on an annual basis.

(3) Mutual relations between distribution system operator and generator from paragraph (1) of this article, including compensation for the difference from paragraph (2) of this article, shall be regulated with an agreement with minimum 7 years duration.

(4) Technical conditions, connection standards, protection system, quality of energy as well as other important matters shall be specified in a regulation of the distribution system operator.

Electricity Distribution Grid Code

Article 91

(1) The operation of the electricity distribution system shall be regulated with the Distribution Grid Code that is established by the electricity distribution system operator for the territory specified in a license.

(2) The Code from the paragraph (1) herein shall regulate specifically:

1) *maintenance and development procedure for distribution systems;*
2) *planning procedures and technical conditions for planning;*
3) *operation and functioning of distribution system;*
4) *technical requirements for connection to the distribution system and interconnection with other systems;*

Access to Electricity Distribution System

Article 101

(1) Electricity distribution system operator shall provide non-discriminatory third party access to electricity distribution system within the limits of distribution capacities and technical rule requirements.

(2) Electricity distribution system operator may deny access to the system in case of lack of capacity or if allowing of access to distribution system could jeopardize carrying out of public services from the article 68 herein.

(3) In the procedure of decision making about access to system, distribution system operator shall apply provisions of the General Administrative Procedure Law.

XIII. CONNECTION TO THE TRANSMISSION OR DISTRIBUTION SYSTEM

Article 141

(1) A facility shall be connected to electricity or gas transmission or distribution system on the basis of a consent for connection issued by a transmission or distribution system operator.

(2) Transmission system operator or distribution system operator for electricity or gas shall issue consent for connection referred to in paragraph (1) of this article if there are no technical constraints in the transmission or distribution system, and if the devices and installations of the facility to be connected comply with requirements established by the Law, technical and other regulations.

Article 142

(4) Costs of development of system studies shall be borne by electricity or gas transmission or distribution system operator, and costs of preparation of connection reports shall be borne by a system user.

Article 143

(1) The consent for connection of a facility to electricity or gas transmission or distribution system shall specifically include: requirements for connection, including the place of connection and connection costs assessment, a manner of connection, technical terms and conditions for connection and a deadline for connection, as well as the place and manner of metering of delivered energy.

(2) The technical and other conditions from the paragraph (1) of this article shall be specified in line with technical and other regulations.

(3) Technical regulations relating to requests for construction, maintenance and use of energy facilities shall be issued by the Ministry.

Article 144

(1) The Transmission or Distribution System Operator shall verify compliance with requirements from the consent for connection and shall enter into the Contract for connection of a facility with a system user.

(2) The contract referred to in paragraph (1) from this article shall be concluded in writing and shall specifically include the following elements:

1) *Rights and obligations of the Contract Parties with respect to the connection and maintenance of the connection device;*
2) *Technical and operational characteristics of a facility;*
3) *The manner of operation and operational conditions of the system;*
4) *Specification of adverse back effects from installed devices;*
5) *The rights and obligations concerning the quality of electricity or gas;*
6) *Electricity or gas metering methods in connection points;*

Article 149

(1) If due to technical constraints it is not possible to connect system user's facilities to the transmission or distribution system and in case the development plan of the system does not envisage construction of required infrastructure, or in case this infrastructure is planned for the later period, the system user-investor may build at this own expense the connection infrastructure.

Article 151

The electricity transmission or distribution system operator shall give priority to connection of a facility for generation of electricity from renewable energy sources provided that technical conditions permit this.

XXV. TRANSITIONAL AND FINAL PROVISIONS

Article 194

(6) Minimum quality standards for electricity supply from the article 38 paragraph(3) clause 2) indents 1 and 3 herein, shall be established within one (1) year from the date of entry into force of this Law, and those from the article 38 paragraph(3) clause 2) indent 2, shall be established within two (2) years from the entry into force of this Law. Until establishment of such standards, transmission and distribution system operators shall be responsible to establish systems for collection of data on quality of supply and to send those data to the Agency.

1.1.1.2. Summary of the Energy Law

Production, distribution and electrical power delivery are regarded as **Energy Operations**.

Energy Regulatory Agency of Montenegro (the Agency) among other things determines also the minimum quality of delivery comprising of special quality services, uninterrupted delivery and quality of electrical power voltage. Furthermore, the Agency decides on the appeals against the decisions of distribution system operators to reject them the access or connection to the distribution system, and also discusses the terms for their approval respectively.

The Law imposes the power operators to undertake the measures for increasing the part of power production from **the renewable power sources** in view of total energy production.

The electrical power distribution system operator is obliged to provide the conditions for connecting the users to the electrical energy distribution system in accordance with the methodology. It determines the methodology for electrical power distribution system connections and submitting it to the Agency for approval. The operator is also obliged to apply the best practical experience in terms of ensuring the safety of delivery and distribution system reliability.

The producer of electrical power from the renewable energy sources with the installed power up to 20 kW or highly efficient plants for co-production with installation power up to 50 kWe has the right to partial exchanges of electricity which is on the yearly basis powered into or out of the distribution system. Technical conditions, connection standards, protection system, energy quality as well as other issues regarding the exchange are defined by the rules of the distribution system operator.

The operation of the electrical power distribution system is governed by the regulations regarding the operation of distribution system defined by the operator of electrical power distribution system. Among other things the regulations principally govern: method of planning and technical conditions for planning and technical conditions for distribution system connections.

The operator of electrical power distribution system is obliged to **provide indiscriminating approach to electrical power distribution system** within the limits of distribution capacities in accordance with technical regulations. However, the operator can also **reject the system access** due to insufficient capacity or if the approval of distribution system access should jeopardize the provision of public services.

The connection of facilities to the electrical power distribution system is conducted on the basis of **the connection approval** issued by the operator of distribution system. The operator of electrical power distribution system has to issue the connection approval, **if there are no technical constraints in the distribution system**, and also if **the equipment and installations of the facility in question meet all terms and conditions according to relevant laws, technical regulations and other provisions.**

The connection approval for a facility to the electrical power distribution system among other provisions consists of terms and conditions for the connection including the point of connection, the method and **technical conditions** provided in accordance with technical and other provisions.

The distribution system operator ensures the fulfilment of conditions regarding the connection approval and concludes **the connection agreement** for a facility with the system user. The connection agreement includes: technical and operational characteristics of the facility; the methods and conditions of system operation; specification of negative rebound effects of the installed devices; rights and obligations regarding electrical power quality and the method of electrical power measuring at the connection points.

The electric energy distribution system operator shall defray **the costs of system analyses preparation,** whereas **the costs of connection study preparation** fall under the domain of the system user.

If due to **technical, work schedule or weather constraints, the connection of system users' facility to the distribution system is not possible**, the system user – investor can on their own expenses construct the infrastructure for the connection.

The electrical power distribution system operator is bound to **provide priorities** for the connection of power plants from **the renewable energy sources,** if technical conditions so permit.

On **30.4.2011** the minimum standards of the quality delivery of electrical power for **quality services** and **quality voltage** have entered into force; whereas on **30.4.2012** the minimum quality for **uninterrupted voltage delivery** were added. So now the **distribution system operator is obliged to have the systems for data collection on the quality of supply and then submit them to the Agency**.

Summary:

The Energy Law is written unequivocally and in a high contemporary European spirit as to provide good basis for Bylaws in the field of connecting distribution power sources to the distribution system of Montenegro.

According to the available information, the systems of data collection on delivery quality and submitting of these data to the Agency have not yet been established.

1.1.2. Code of Rules

The Code of rules is a bundle of Bylaw documents that offer precise technical specification of the issues generally defined in the laws. The only relevant Code of rules in Montenegro which gives technical specification of small power plant connection to the distribution network is *Code of rules on technical conditions for connection of small power plants to the electro-distribution network.*

1.1.2.1. Code of rules on technical conditions for connection of small power plants to the electro-distribution network

Code of rules on technical conditions for connection of small power plants to the electro-distribution network [2], 2007 regulates the field of technical conditions for connection of new small power plants of 10 MVA power and small hydroelectric power plants (hereinafter referred to as “mHE”) the reconstruction of which influences the change of connection conditions and execution of the connection terminals.

In regard to technical characteristics of the connection, this Code of rules is regarded as elementary having only two underlined characteristics:

III. ELECTRIC ENERGY QUALITY

Article 11

Small power plants are connected to the electro-distribution system in accordance with standard demands for electrical power quality and reliability of operation or power delivery to the existing electrical power system users.

Article 12

The electric energy produced in mHe and delivered to the customers has to be of nominal voltage and frequency. The network frequency is 50 Hz ± 5 Hz (hertz). The permitted voltage deviation at the point of power delivery from the standard voltage at the connection terminal of a small power plant to the electro-distribution system under normal operation conditions is: at low voltage of 230/400 V from +10 % to -10 %, at medium voltage ±5 %.

The permitted change of voltage after activation or deactivation of the generator of electro-distribution system equals: in low voltage network: ± 6 % of nominal voltage (231/400 V), at medium voltage network: ± 2% of nominal voltage (10 kV; 20kV; 35 kV).

Summary:

These two Articles of the Code of Rules are really insufficient to base the implementation of the connection to the distribution network of the Republic of Montenegro.

1.1.2.2. Temporary Code of distribution

Temporary Code of distribution [3] is a document adopted by the Board of directors of the Electric Power Company of Montenegro (Elektroprivreda Crne Gore AD Nikšić).

Temporary Code of distribution among other things defines technical rules for minimum standards regarding technical planning and operational conditions for connection of users to the distribution network and interconnection with other networks.

The Subchapter III B contains the **Conditions for connection of small power plants**. This Subchapter discusses in detail the conditions for connection of small power plants of 10,000 kVa power that are connected to the distribution network or facilities with requested connection permit.

Due to great amount of text, only the summaries of the Articles are included and commented on.

Article 48 – Principal connection schemes

This Article discusses the Principal connection schemes and permitted voltage drops for two schemes. A general description of principal schemes is drawn up to allow the power plant to be connected in the way suitable for network and also distribution system operator (DSO).

The only unsatisfactory matter in the descriptions of schemes is that **only synchronous and asynchronous generators are being classified** (there are no other types!) and that they are defined in terms of possible connection voltage (e.g. the High voltage level only above 250 kVA).

> *48.6. The power plant connection to the general scheme A or B has to be designed to prevent the voltage drops of more than 3 % of nominal voltage between the power plant and the connected substation during maximum operation values and power factor 0.9.*

The point 48.6 discusses the voltage drop only on the basic level and **does not consider the actual network situation and number of power plants in this network**. Also the Article does not mention **the type of 0.9 power factor** (inductive, capacitive or overexcited, underexcited).

Article 49 – Distribution point and
Article 50 – Switching devices of distribution point

These two Articles very profoundly define all the means that are required at the distribution point and all the offered possibilities.

Article 51 – Protection equipment and tap point insulation

Points 51.1 and 51.2 do not mention the possibility of making electrical protection by applying safety fuses.

The Point 51.4 lacks the specification of exact configurations (values and time) for overvoltage, undervoltage, overfrequency and underfrequency protection. The rest seems acceptable.

Article 53 – Reactive energy compensation

The Point 53.1 does not include the meaning of $\cos\varphi \geq 0.95$ in the individual operation regimes. In regard to receiving the energy this is definitely the inductive regime. However, in regard to energy output it has to be defined whether this $\cos\varphi \geq 0.95$ is inductive, capacitive or overexcited, underexcited.

1.1.3. Recommendations

There are no recommendations issued in the Official Gazette of Montenegro and therefore they could not be considered as the valid legislation in Montenegro. Later in the study, various recommendations of foreign countries can help us define recommendations for connection of small power plants in Montenegro.

However, *Technical recommendation number 16 (TP-16)* [4] is used for connection of small power plants to the distribution network in Montenegro. The recommendation used as a reference for connection of small power plants to the distribution network of the Republic of Serbia shall be used. This recommendation is unofficially applied also in Montenegro.

1.1.3.1. Technical recommendation number 16 (TP-16)

Technical recommendation num. 16: General technical provisions for connection of small power plants to the electro-distribution network of the Republic of Serbia [4] is drawn up for connection of small power plants to the electro-distribution network of the Republic of Serbia.

Since this recommendation consists of long text and numerous schemes, it shall be commented on only in general, without quoting the individual Articles.

Many parts are the same as in *Temporary distribution code* [3] that has already been commented on.

General comments regarding TP number 16.

There are only superficial comments on the voltage drop, **without considering the actual situation in the network and the number of power plants connected to it**. Similarly, the **type of power factor 0.95** is not stated (inductive, capacitive or overexcited, underexcited).

The criterion of permitted power of DI (distribution infrastructure) is set too high when considering that no attention is paid to the already connected power plants to the network, but rather only the new power plant.

Criterion of flickers and harmonics is also not regarded in the network situation and other power plants.

System protection. There lacks a specification of exact configurations (values and time) for overvoltage, undervoltage, overfrequency and underfrequency protection.

Three-pole automatic reclosing. The conditions for operation of automatic reclosing on the network with connected power plants need to be more specifically defined.

Connection schemes with elements are very helpful for better conception of the connection terminal installation.

Summary:

***Technical recommendation num. 16: General technical provisions for connection of small power plants to the electro-distribution network of the Republic of Serbia* are considered as a good basis for technical characteristics and technical standards for connection of power plants to the electrical power distribution system of Montenegro. TP-16 should include some changes and amendments to provide the prevention of problems stated in the comments and analysed further on in the study.**

1.1.4. Standards

Standards are documents that determine technical criteria in a certain field. If there are no referential or other types of standards, the standards for a certain field should be applied according to the vertical organization of superior acts.

The shows the list of necessary standards that define the provisions of connection of small power plants to the distribution network and their status in Montenegro, source: ISME (Institute for standardization of Montenegro) [5].

Table 1.1: The list of necessary standards that define the provisions of connection of small power plants to the distribution network and their status in Montenegro [5].

Standard	Status
EN 50160	**accepted** MEST
IEC 60038	not **yet accepted** MEST
EN 50438	not **yet accepted** MEST
EN 61000-2-2	**accepted** MEST
EN 61000-2-4	**accepted** MEST
IEC/TR2 61000-2-5	not **yet accepted** MEST
EN 61000-2-12	not **yet accepted** MEST
EN 61000-3-2	**accepted** MEST
EN 61000-3-3	**accepted** MEST
IEC/TR2 61000-3-4	not **yet accepted** MEST
IEC/TS 61000-3-5	not **yet accepted** MEST
IEC/TR3 61000-3-6	not **yet accepted** MEST
IEC/TR3 61000-3-7	not **yet accepted** MEST
IEC 61000-3-8	not **yet accepted** MEST
EN 61000-3-11	**accepted** MEST
EN 61000-3-12	**accepted** MEST
EN 61000-4-7	**accepted** MEST
EN 61000-4-15	not **yet accepted** MEST
EN 61000-4-30	not **yet accepted** MEST
EN 60034	**accepted** MEST

1.2. Analysis of problems that could arise after the activation of distributed sources in Montenegro due to deficiencies of the existing rules and recommendations

In the previous Subchapter the situation of regulatory acts was analysed. The deficiencies of certain documents have already been stated in the comments. This subheading includes the analysis of consequences if these deficiencies are not done away with.

1.2.1. Examples of network voltages

The electro-distribution network is designed to deliver electricity to the costumers. When the producers of electrical power (power plants) are connected to the network, primarily the problems of network voltages may occur.

Transformers in the middle voltage and low voltage network are adjusted so that the voltage at the minimum network load is at the costumer point on the maximum permitted level, but at maximum planned consummation on the minimum permitted level. When the local production of electrical power is connected to the network these voltage levels are interrupted (too high voltage) and already **a small amount of active power plant power (not to mention a reactive power) can have a great effect on network voltages**.

Sometimes (small power) it is sufficient only to readjust the transformers (by tapping) in the network, but in the majority of cases the new investments in the network are necessary.

The situation can be improved, if the reactive power is deducted simultaneously from the injection of operation power. This has a positive effect on network voltages, but on the other hand can cause different kind of problems.

1.2.2. Reactive power

The analysis of Acts showed that only the reactive power under power factor or *cos φ* power is defined for generators. It is not defined whether this is inductive, capacitive power or overexcited, underexcited generator. This can lead to the situation presented in the Figure 1**.**

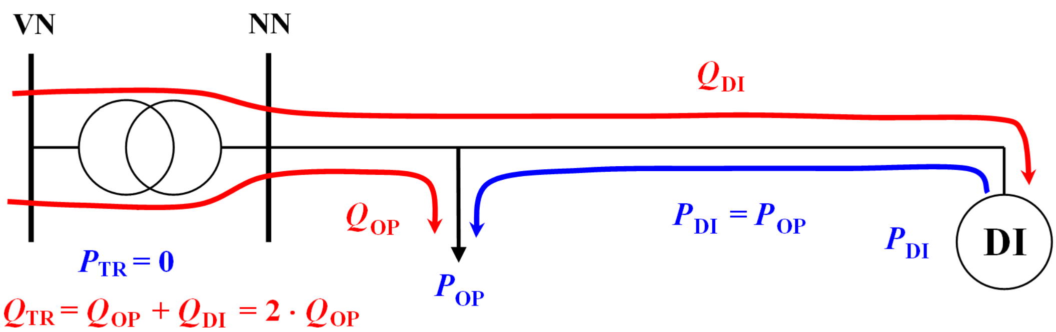


Figure 1: Network situation with the generator (DI) of distributed source delivering the active power to the network but not receiving (drawing) the reactive power.

The Figure 1 shows the situation where the power plant produces active power to compensate the complete operation power consummation at the feeder. But this drains the reactive power from the network. Thus at zero current of operating power through the transformer, the reactive power through the transformer is doubled as it was prior to the connection to the distribution system. However, this reactive power has to be produced at the high voltage side of transformer and transmitted to the low voltage side and then also "transported" to the costumer, or in this case to the distributed source.

But during transmission of reactive power via (especially) inductive network elements there occur **considerable voltage drops** causing the consistency of the proper voltage profile along the whole network to be achieved even harder. Also **the excessive drawing of the reactive power from the transmission system** is not taken positively by the transmission system operator.

The situation can be improved by installing the compensation capacitors on the low voltage side of transformer. However this causes unnecessary risks of ferro-resonance occurrences in the network.

Due to voltage occurrences in the network and reactive power of distributed sources this characteristics of reactive power should be regulated for power plants to deliver more reactive power into the network but without impairing voltage in the network at the same time.

1.2.3. Operation of automatic reclosing

The system of automatic reclosing is one of the fundamental systems in the middle voltage network that significantly provides the prevention of preliminary disturbances and thus improves the quality of electrical power delivery to the costumers and producers.

If the protection (under- and overvoltage, and under- and overfreqeuncy) is not exactly defined (values and time), this can cause **the operation disturbances of automatic reclosing** and also **generator defects**. Also the operation conditions of automatic reclosing at the substations have to be precisely determined.

1.2.4. Connector disturbances (flickers and harmonics)

The absence of technical standards requires that the connector disturbances are addressed **only through generally defined disturbances of individual sources** but without considering the actual situation in the network. This can lead to the situation where it is possible to connect a certain power plant according to the existing rules, but with the current situation in the network already exceeding the limits that are defined for quality voltage in the rules and standards.

1.2.5. Criterion of permitted power

Distributed sources of small power can be connected to the distribution network, but only on the basis of permitted power calculation. The power rates (power plants and networks) are in practice evident also in the influence of the power plant on the voltage profile in the network. It is thus disadvantageous, if allowed, to connect the power plants with **higher power in comparison to the network power** without other examinations.

This can have negative effects on the network because, in our opinion, this connection standard has the **exceeding permitted limits** for situation with some types of generators, where the reactive power of power plant is not specifically defined. Moreover, other power plants connected to the network are not taken into account as well.

1.2.6. Classification of power plant types and voltage levels

The table of classification of possible types of power plants and permitted voltage levels of power plant connections is not perfect since it only classifies two types of power plants: with synchronous and asynchronous generators. There are no other types of generators listed. This is not in accordance with the current situation, where there is the increasing number of power plants connected with conductors (mainly photovoltaic) **that are not defined in the table** as types of generators. This can lead to connection problems of these types of generators.

There also exists the **limit for power plant connection to the middle voltage network** with the limit set at 250 kVA. However, it would be better that the relevant decision is made during the process of project designing and after the analysis of technical and economic characteristics of a power plant.

1.3. Theoretical basis for new Code of rules for connection of distributed sources in Montenegro

Due to problems that could emerge during the connection of distributed energy sources in Montenegro, the new *Code of rules for connection of distributed sources in Montenegro* (*Code*) has to be drawn.

This *Code* should be based on **good practices of countries** (especially from EU) that have approximately similar network situation as Montenegro and have the necessary experience in the field of connection of distributed sources to their networks.

New *Code* has to do away with deficiencies of the old set of rules and recommendations in the following fields:

- **Reactive power** and cooperation of distributed sources in **the regulation of voltage at the feeders.**
- Definition of **exact configurations** (values and time) **of voltage and frequency protection** at the distribution point.
- Definition of conditions of **automatic reclosing operation at the feeders** with distributed sources.
- Permitted connector disturbances (mainly flickers and high harmonics) have to be defined as **to include also the current network situation and the limits of permitted disturbances in the network**.
- Criterion of **permitted connection power** has to be applied to the network situation and voltage regulation by the distributed sources.

- Power plant classification has to be executed to prevent **the differences between various types of generators** in the power plants and to include also the new technologies available on the market.
- The selection of voltage level of the distributed source has to be acceptable for the **network and power plant, and also technically and economically legitimate**.

In view of Montenegro becoming an EU member, there are several agreements concluded between Montenegro and EU: *Stabilization and Association Agreement* and *Interim Agreement on trade and trade-related issues*. By signing the Stabilization and Association Agreement with the EU, Montenegro has formally concluded the agreement on association with the European Union and Member states, thus assuming the responsibility for its European future.

In this respect it is unavoidable for the new Code of rules for connection of distributed sources to be drawn up and based on the European, i.e. "*New Approach*" principle. The New Approach principle is based on the directives, whereas for connection of electrical power distributed sources, the **LVD**[1], **EMC**[2], **MS**[3] and **GAD**[4] are most frequently mentioned. In the Member state or candidate country the legal basis for directives is made with a certain Code of rules on the Ministry level. Afterwards, the accordance with technical standards, constantly following the state of technology, sufficiently provides the compliance with the defined directives or Code of rules.

1 **LVD -** Directive 2006/95/EC of the European Parliament and of the Council of 12 December 2006 on the harmonisation of the laws of Member States relating to Electrical Equipment designed for use within certain voltage limits.

2 **EMC** - Directive 2004/108/EC of the European Parliament and of the Council of 15 December 2004 on the approximation of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC.

3 **MS** - Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC.

4 **GAD** - Directive 2009/142/EC of the European Parliament and of the Council of 30 November 2009 relating to appliances burning gaseous fuels

2. ANALYSIS OF SITUATION AND VERIFICATION OF DEVELOPMENT PLANS FOR ELECTRIC POWER NETWORK

To conduct the Study of connection and start-up of distributed production units operation in the electrical power system of Montenegro, the summary of valid development plans and current development studies is presented in the continuation.

The study anticipates gradual inclusion of small hydroelectric power plants (HE) in the period by 2015 in the areas of Municipalities Šavnik, Bjelo Polje, Berane, Andrijevica, Plav, Kolašin, Nikšić and Plužine. Therefore, the summary of development plans focuses on the relevant period and proposes the increase of transfer and distribution network in the areas with the projected connection of new small HEs.

The summary of development plans is drawn up on the basis of the following documents:

- *Energy Sector Development Strategy of the Republic Montenegro by 2025, Expertise bases, Book D – The developmental plan of electrical power system of the Republic of Montenegro (Master plan), Ljubljana, 2006* [6].
- *Investments plans in 35 kV network EPCG, FC Distribution, for the period 2012 -2016. Internal material, 2010* [7].
- *A 5-year CGES plan, 2011 – 2016 Plan, internal material, 2010* [8].
- *Final gross energy consumption of Montenegro 2011*, Podgorica, December 2010 [9].

2.1. Energy grounds

2.1.1. Load prognosis

The movements of prognostic electrical energy consumption together with maximum and minimum loads in the system for the period 2005-2025 is shown in Table 2.1 and Figure 2. The prognosis of the average increase of electrical power consumption in the projected period equals 1.33 %, whereas the annual increase of the maximum load in the system is 1.5 %.

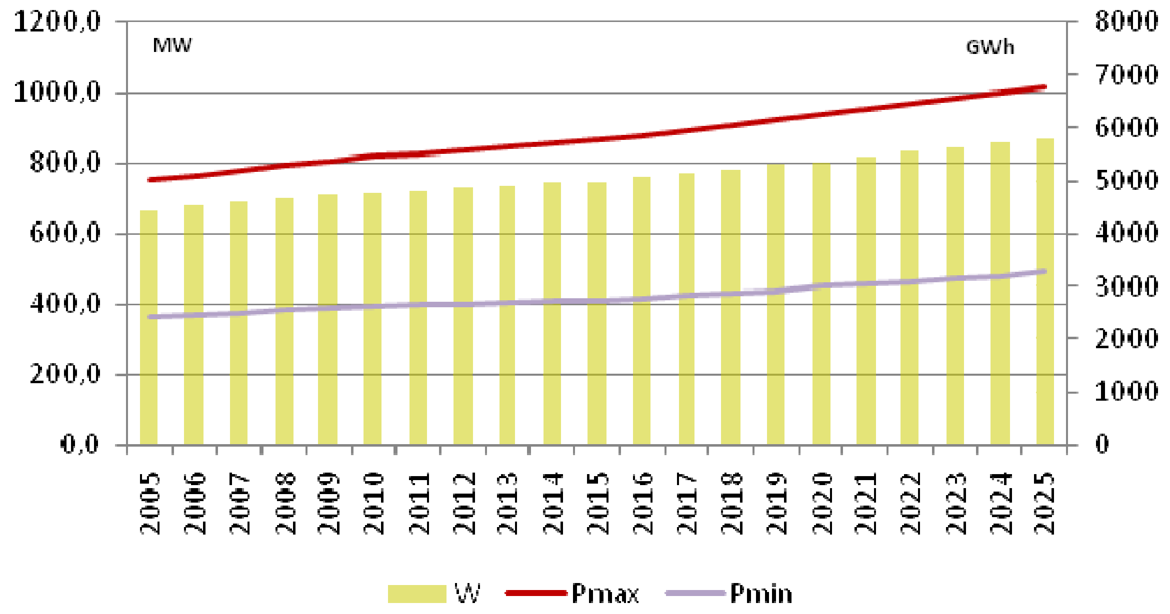


Figure 2: Graph of consumption and load values prognosis for the period 2005-2025.

Table 2.1: Prognosis of consumption, minimum and maximum load values in the electrical power system of Montenegro for the period 2005 – 2025.

Year	***Pmax*** MW	***Pmin*** MW	***Pmax DIST*** MW	***W*** GWh
2005	752.1	361.3		4443
2006	764.8	367.4		4518
2007	777.8	373.6		4594
2008	791.0	380.0		4672
2009	804.4	386.4		4751
2010	818.0	391.1	572.0	4765
2011	826.9	395.4		4817
2012	836.0	399.7		4870
2013	845.1	404.1		4923
2014	854.3	408.5		4976
2015	863.6	407.9	615.0	4982
2016	878.0	414.7		5065
2017	892.6	421.6		5150
2018	907.4	428.6		5235
2019	922.6	435.8		5323
2020	937.9	447.4	689,0	5372
2021	953.0	454.6		5458
2022	968.3	461.9		5546
2023	983.9	469.3		5635
2024	999.7	476.9		5726
2025	1015.8	491.1	767	5791

2.1.2. Existing and planned production capacities

There are three main production units in the electrical power system of Montenegro: Perućica and Piva hydroelectric plants, and Pljevlja thermal power station. Apart from these, the system includes also seven small hydroelectric power plants but with relative small output in terms of capacities and production. The total installed power of the power plants in the system equals 868 MW, whereas the threshold power is 849 MW. HE Perućica and Piva mainly cover the maximum and partly daily peak part of load curve, whereas TE Pljevlja is typically baseload-peak power plant.

Table 2.2: Development scenarios of electrical power system [6].

SCENARIO	DESCRIPTION
S – 0	The initial development scenario which does not include the partial river Tare diversion into the river Morača and ensures the imported electrical power delivery without restrictions, allows for the construction of coal power plant, but does not anticipate the significant inclusion of renewable power sources into the source structure for covering the electrical power consumption.
S – 1	The difference in comparison with the initial scenario is in the possibility of HE Koštanica construction or the power exploitation of the part of river Tara by diverting it to the river Morača.
S – 1 – 1	The principles are basically the same as for S-1, only with maximum allowed share of electrical power import for covering the consumption limited to 10 % to provide the defined level of electrical power self-supply.
S – 1 – 2	Compared to the scenario S-1-1, accept for maximum import share of 10 %, this scenario does not allow the construction of new coal power plants.
S – 1 – 3	Compared to the scenario S-1, the complete self-sufficiency of the electric energy production is not expected after 2011. Although this scenario is considered as extremely unreal, it is interesting to think about its implications.
S – 2	**Compared to the initial scenario (S-0), the difference is in the introduction of numerous stations of electrical power production that use renewable energy sources. Thus, within the scope of planned period, this scenario projects the construction of new 30 MW small power plants, 20 MW wind farms and 10 MW thermal power plant in which the waste is incinerated.**
S – 2 – 1	As in S-2 the share of electric energy import for consumption coverage is limited to 10 %.
S – 2 – 2	Compared to the scenario S-2-1, the construction of new coal power plants is not allowed.

The production of electrical power system of Montenegro suffices for 90 % of electrical power demand. Therefore the deficit has to be compensated by the import from neighbouring systems of Serbia and Bosnia and Herzegovina. This data relates to 2010. The total production of that year: the production share of HE Piva equalled 31 %, HE Perućica 34 %, and TE Pljevlja 35 %.

In the process of planning new production units, there exist numerous parameters that cause some uncertainty in the realization of individual projects. Table 2.2 shows current development scenarios of production units for covering the electrical power demand in the electrical power system of

Montenegro. Apart from the scenario S-0, the most realistic scenario is considered to be S-2 which is highlighted and includes the implementation of renewable energy sources.

The key questions are:

- The option of constructing new coal power plants.
- The level of "electrical power autonomy" of Montenegro (the level of self-sufficiency or the amount of relying on the electrical energy import).
- The option of new hydroelectric power plants.
- Share of renewable sources of electrical energy in the total consumption provision.
- The effect of new energy sources on the environment and possibility of coordination with domestic and international legislative regulations that deal with the environment protection.

2.2. Construction plan of the distribution network by 2015

The last 15 years have not witnessed major investments into the distribution network of Montenegro. In 2010 the new 400 kV interconnection line Podgorica – Tirana has started to operate. This line enables better integration with the neighbouring Albanian EES.

In regard to the analysis of the existing operation situation in the Energy Sector Development Strategy of the Republic of Montenegro by 2025, the following critical regimes in EES can be summarized:

- *Unavailability of the power plants in Montenegro and eastern Bosnia and Herzegovina results in the shortfall on 220 kV line Pljevlja – Mojkovac KT – Podgorica 1*. In this case the northern part of Montenegro is powered by SBS Podgorica 1 and 2, causing the increase of shortfalls and high voltage drops on the line Trebješica, Andrijevica, Berane, Bijelo Polje. The solution of this problem is the construction of the transformer substation 400/110 kV in Ribarevine (Bijelo Polje).
- *The shortfall on individual 110 kV lines in the coastal area of Montenegro*. The power supply of coastal area is executed through SBS Podgorica 1 and SBS Trebinje which makes the whole line very prone to the potential disturbances and shortfalls on individual lines. The situation is improved with the construction of Podgorica – Cetinje line (2004). Further solution to the problem is seen in the construction of 110 kV lines HE Perućica – Kotor – Tivat, Budva – Bar 2, and Bar – Ulcinj 2.
- *The shortfall on the 400 kV transmission line Podgorica 2 – Ribarevine*. The high loads on this line can cause overload on the parallel 220 kV connection Pljevlja 2 – Mojkovac KT – Podgorica 1.

In order to provide the reliable operation of the system, the study *Energy Sector Development Strategy of the Republic of Montenegro by 2025* [6] suggests a plan of transmission network load increase, shown in Table 2.3. The long-term development of the transmission networks primarily depends on the increase of system loads and construction of new power plants in Montenegro.

Table 2.3: The load increase of transmission network by 2015 [6].

PERIOD	LOAD INCREASE SUGGESTION
By 2010	- **400/110 kV transformer substation in Ribarevine (150 MVA)** - Expand RP 400 kV Ribarevine by one 400 kV transformer bay and 110 kV busbar at SBS Bijelo Polje by one 110 kV transformer bay - SBS 110/35 kV Kotor (2x20 MVA) and 110 kV transmission line Tivat – Kotor, - Expand SBS Tivat by one 110 kV transmission line, - Expand SBS 110/35 kV Ulcinj by one 20 MVA transformer and replace the existing 20 MVA transformer with new one of the same connection type. Expand 110 kV busbars by one 110 kV transformer bay - Expand the installation 220 kV SBS Pljvalja by one transformer bay in case of TE Pljevja 2 construction - Introduction/implementation of 220 kV transmission line Pljevlja 2 – Mojkovac KT – Podgorica 1 in SBS 220/110 kV Mojkovac - **SBS 110/x kV** Podgorica 5, **Kolašin**, Nikšić – Kličevo and Virpazar - 110 kV transmission line KAP – Podgorica 5, and expand the KAP installation by one 110 kV - CL 110 kV Podgorica 3 – Podgorica 5, and expand the installation of Podgorica 3 by one 110 kV transformer bay - 110 kV transmission line Bar – Ulcinj 2, and expansion of 110 kV installation SBS Bar and SBS Ulcinj by one transformer bay - Introduction/implementation of 110 kV transmission line Podgorica 1 – Bar in SBS Virpazar, and - **Start the operation at the nominal 110 kV voltage of the transmission line Mojkovac – Kolašin, and the expansion of SBS Mojkovac by one 110 kV transformer bay** - Start of operation at the nominal voltage of a section of the line Nikšić – Brezna to SBS Nikšić – Kličevo, including the expansion of SBS Nikšić by one 110 kV transformer bay
By 2015	- **Construction of SBS 110/x** kV Roțaje, Brezna, Buljarica, **Zabljak** and Tuzi - Execute introduction/implementation of 110 kV transmission line Budva – Bar in SBS Buljarica - Start of operation at the 110 kV voltage of the transmission lines Berane – Roțaje, Nikšić – Brezna and **Pljevlja 1 – Zabljak** - **Expand SBS Berane by one 110 kV transformer bay** - Expand SBS Nikšić-Kličevo by one 110 kV transformer bay - Expand SBS Pljevlja 1 by one 110 kV transformer bay - Construct 110 kV transmission line Podgorica 1 – Virpazar - Expand SBS 1 and SBS Virpazar by one 110 kV transformer bay - Construct 110 kV transmission line HE Perućica – Kotor, length 40 km - Expand SBS Perućica and SBS Kotor by one 110 kV transformer bay

Presented load increases are in domain of the management boards of projected small HE

More realistic plan of transmission network is presented in the Table 2.4 which summarizes the investment plans of the company CGES. In comparison with the suggested strategy, the plan includes a significantly smaller amount of load increase. The new 400 kV node SBS 400/110 kV Lastva is planned. The node is integrated in the 400 kV transmission line Podgorica – Trebinje and new 400 kV interconnection with neighbouring BiH, 400 kV transmission line Pljevlja – Višegrad.

Table 2.4: Network load increase by 2015 – CGES plan [8].

PERIOD	LOAD INCREASE PLAN
2010-2015	- SBS 110/35/10 kV Kotor (2x20 MVA) and 110 kV transmission line Tivat – Kotor, - input/output terminal of 220 kV transmission line Pljevlja 2 – Mojkovac KT – Podgorica 1 in SBS 220/110 kV Mojkovac - SBS 110/x kV Podgorica 5 and with connection to the 110 kV network - SBS 400/110 kV Lastva, input/output terminal in the 400 kV transmission line Podgorivca 2 – Trebinje - Construction of 400 kV transmission line Pljevlja – Višegrad - Construction of SBS 110/35 kV Nikšić (Kičevo) with 110 kV transformer bays - Construction of SBS 110/ kV Zeta - Construction of 110 kV transmission line Podgorica 5 – Zeta - Construction of 110 kV transmission line Podgorica 2 - Smokovac - **Construction of SBS 110/35 kV Žabljak** - Start of operation at 110 kV voltage of **Pljevlja 1 – Zabljak transmission line** - **Construction of SBS 110/35 kV Kolašin** - **Start of operation at 110 kV voltage of Mojkovac – Kolašin transmission line** - 110 kV transmission line Virpazar – Ulcinj - 110 kV transmission line Vilusi – Herceg Novi - input/output terminal SBS 110/x kV Vilusi and reconstruction 110 kV transmission line Nikšić – Bileća - **Construction of SBS 110/35 kV Brezna with 110 kV transformer bays** - Construction of 110 kV transmission line Lastva – Kotor - Construction of 110 kV transmission line Virpazar – Zeta - Construction of SBS 110/x kV Podgorica 5 with 110 kV transformer bays

Presented load increases are in domain of the management boards of projected small HE

2.3. Construction plan of distribution network by 2015

In the system of Electric Power Company of Montenegro the distribution network consists of the following elements:

- 35 kV lines,
- 35/10 kV transformer substation,
- 10 kV installation in 110/10 kV transformer substations,
- 10 kV lines,
- 10/0.4 kV transformer substations,
- Low voltage lines.

The purpose of development plan of distribution network is to achieve proper dimensioning of reliable operation and maintaining electrical energy quality parameters in accordance with standards, and synchronization of distribution network operation and connected units of distribution network users. The development plan of distribution network has to provide the satisfactory level of service quality for the network users in case of potential major disturbances. The purpose of development plan of distribution network is also to provide the operation of electrical energy market by providing the unbiased approach to the distribution network according to defined conditions.

The construction of new SBS 35/10 kV and 35 kV transformation lines is in short-term cheaper but often does not provide a long-term solution. In the long-term, the goal is to transform the existing system into the system with one middle voltage level (20 kV) and one single direct transformation (100/20 kV). Thus the network development with long-term middle voltage divided into two partly linked principles: gradual substitution of voltage level 10 kV with 20 kV and gradual integration of direct transformation 110/10(20) kV and abolition of 35 kV network.

It can be concluded that in the mentioned period, the 110-35-10 kV system remains the major part of the distribution network. The reason for this is the fact that a longer period (30 years) is needed for economically acceptable transformation to the voltage level 20 kV, i.e. from the start of systematic 20 kV equipment installation to the actual operation of the whole network at 20 kV voltage.

The investment plan of EPCG FC Distribucija in the distribution network by 2015 in the broader area of the projected small HE is shown in the Table 2.5: Investments in the distribution network by 2015 in the broader area of small HE connection – EPCG FC Distribucija plan [7].

Table 2.5: Investments in the distribution network by 2015 in the broader area of small HE connection – EPCG FC Distribucija plan [7].

PERIOD	LOAD INCREASE PLAN
2011-2015	- Reconstruction of SBS 35/10 kV Danilovgrad - Reconstruction of SBS 35/10 KV Žabljak (due to old 35 kV installations and adjustment of SBS for remote control (SCADA)) - Reconstruction of SBS 35/10 kV Plav (investment is realized due to fulfilment of technical standards) - Reconstruction of SBS 35/10 kV Berane 2 (investment is realized due to fulfilment of technical standards) - Reconstruction of SBS 35/10 kV Brezna (due to old 35 kV installations and adjustment of SBS for remote control (SCADA)) - Reconstruction of SBS 35/10 kV Andrijevica (investment is realized due to fulfilment of technical standards) - Reconstruction of SBS 35/10 KV Šavnik (due to old 35 kV installations and adjustment of SBS for remote control (SCADA)) - Reconstruction SBS 35/10 kV Gusinje (investment is realized due to fulfilment of technical standards) - Reconstruction of 35 kV transmission line Židovići – Gradac – Šula – river Tara (investment is realized due to decrease in number and duration of shortfall) - Reconstruction of 35 kV transmission lines Ribarevine – Šćepanica (investment is realized due to decrease in number and duration of shortfall) - Reconstruction of 35 kV transmission lines Andrijevica – Plav (investment is realized due to decrease in number and duration of shortfall) - Reconstruction of 35 kV transmission lines Plav – Gusinje (investment is realized due to decrease in number and duration of shortfall) - Reconstruction of 35 kV transmission lines Ribarevine - Medanovići (investment is realized due to decrease in number and duration of shortfall) - Construction of SBS 35/10 kV Pljevlja III (investment is realized due to the increase in capacities.)

3. METHODOLGY FOR ELABORATION OF DISTRIBUTED SOURCES IN MONTENEGRO

This chapter includes the analysis of methodology for connection of distributed sources (ME) to the distribution system of Montenegro. It starts with detailed list of procedures for network analysis and determination of technical possibilities for distributed sources connection.

The chapter ends with the description of connection conditions for the investors and the process of connection permit issue.

3.1. Algorithm for the analysis of distributed sources connection

The entire methodological process consists of four sections:

- Determination of the level (depth) of the required analysis (diagram)
- Network model preparation (diagram),
- Determination of parameters at the point of production unit connection (diagram),
- Analysis of technical possibilities of distributed production units connection (diagram),
- Economic analysis (diagram).

Also the procedure is provided that includes the investor's demands for connection approval together with the issue of connection permit.

Figure 3 shows the schematic representation of the analysis sequence for DI connection to the network.

The analysis for DI connection to DS serves as an examination of possibilities of DI connection to the network in order to provide normal operation of DI and other ME, as well as consumers, in the network and guarantees that the power supply to consumers remains unhindered.

The basis of this analysis is that normal operation of all DI in the network can cause voltage changes in this network of 0.5 % without any damaging impact on voltage conditions in the network (Block 0.6 in the Figure 3). This means that DS can always withstand the maximum voltage impact of 0.5 % in the network compared to the nominal value. The first approximation of the relative voltage change can be conducted with a relative power change in extreme situations. Thus, in terms of analysis execution, two conditions can be provided that are needed for DI connection to DS.

MV level: There is no need for the detailed network analysis (Block 0.7 in Figure 3), if the following condition is fulfilled:

$$S_{mel} + \sum S_{DI\,\mathrm{SN}} < 0.005 \cdot S_{ks} \qquad 3.1$$

where:

S_{mel} – ME nominal power, connected to the network,

$S_{DI\ SN}$ – power of the existing DI in the network, to which ME is connected. This power encompasses all existing DI that are fed from DS via the same busbars in SBS as ME.

S_{ks} – Short-circuit power at the ME connection point to DS. When calculating the short circuit power only those short circuit currents have to be observed that are connected to the electric power network at voltage levels 110 kV or higher.

Thus the power of all DI that can be potentially connected to MV network DS, but without the need for detailed network analysis, should be smaller than 0.5 % of short circuit power at the relevant connection points. The short circuit power calculation should include only those short-circuit currents that are connected to the electric power network at voltage levels 110 kV or higher.

If the condition of the equation 3.1 is not fulfilled, the detailed analysis needs to be conducted.

LV level: Detailed network analyses (Block 0.7 in Figure 3) are unnecessary, if the following condition is met:

$$S_{mel} + \sum S_{DI\,\mathrm{TS}} < 0.005 \cdot S_{ks\,\mathrm{TS}} \qquad 3.2$$

where

S_{mel} – ME nominal power, connected to the network,

$S_{DI\ TS}$ – power of the existing DI in the network, to which ME is connected. This power encompasses all existing DI that are fed from DS via the same busbars in SBS as ME

$S_{ks\ TS}$ – short circuit power in the SBS network at the point of the longest feeder from this SBS that is 2/3 of the total line length distant from this SBS. The short circuit power calculation should include only those short-circuit currents that are connected to the electric power network at voltage levels 110 kV or higher.

Thus, the power of all potential DI connected to a LV network DS, but without the necessary detailed network analysis, needs to be smaller than 0.5 % of the short circuit power in this SBS network. To calculate the short circuit power in SBS network the longest line is used, where the short circuit power is calculated at the point of this line that is by 2/3 of the line length distant from SBS. This value encompasses all DI that are connected to the SBS network. The short circuit power calculation should include only those short-circuit currents that are connected to the electric power network at voltage levels 110 kV or higher.

The detailed network analysis needs to be conducted, if the condition from the equation 3.2 is not met.

The network analysis is also unnecessary for MV and LV level, if new ME acts only as the protective element to provide the supply for customer and without the aim to supply the active power in DS but to support the consumer, or DI role is only to decrease the consumption of active power of a certain consumer (Block 0.2 in Figure 3). Such ME must not deliver active power to DS. Therefore, this kind of ME is given different reactive power characteristics and additional protection (Block 0.4 and 0.5 in Figure 3).

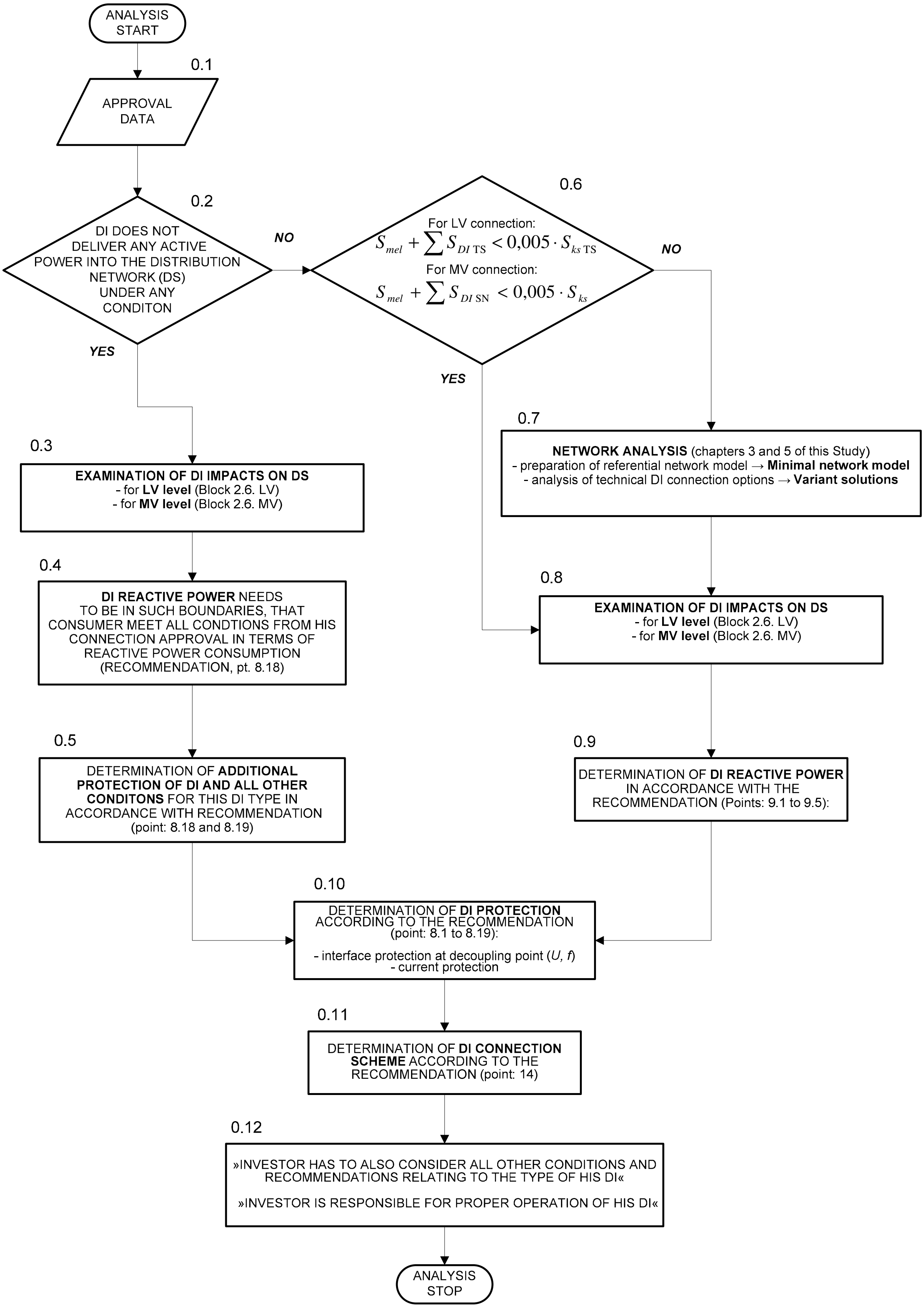


Figure 3: Schematic presentation – Analysis sequence for DI connection to the network

In any case and for all DI the examination of DI impacts on the network need to be conducted (Block 2.6, Figure 9). The reactive power needs to be determined for all DI that deliver active power in the network (Block 0.9, Figure 3). DI protection (Block 0.10, Figure 3) and connection scheme (Block 0.11, Figure 3) should be defined for all DI.

Every investor should be clearly informed that the DI operation falls under his full responsibility and that he needs to consider all points from the *Recommendation* that are general or refer to his type of DI, although they could not be specifically stated in the DI connection permit.

3.1.1. Preparation of referential network model

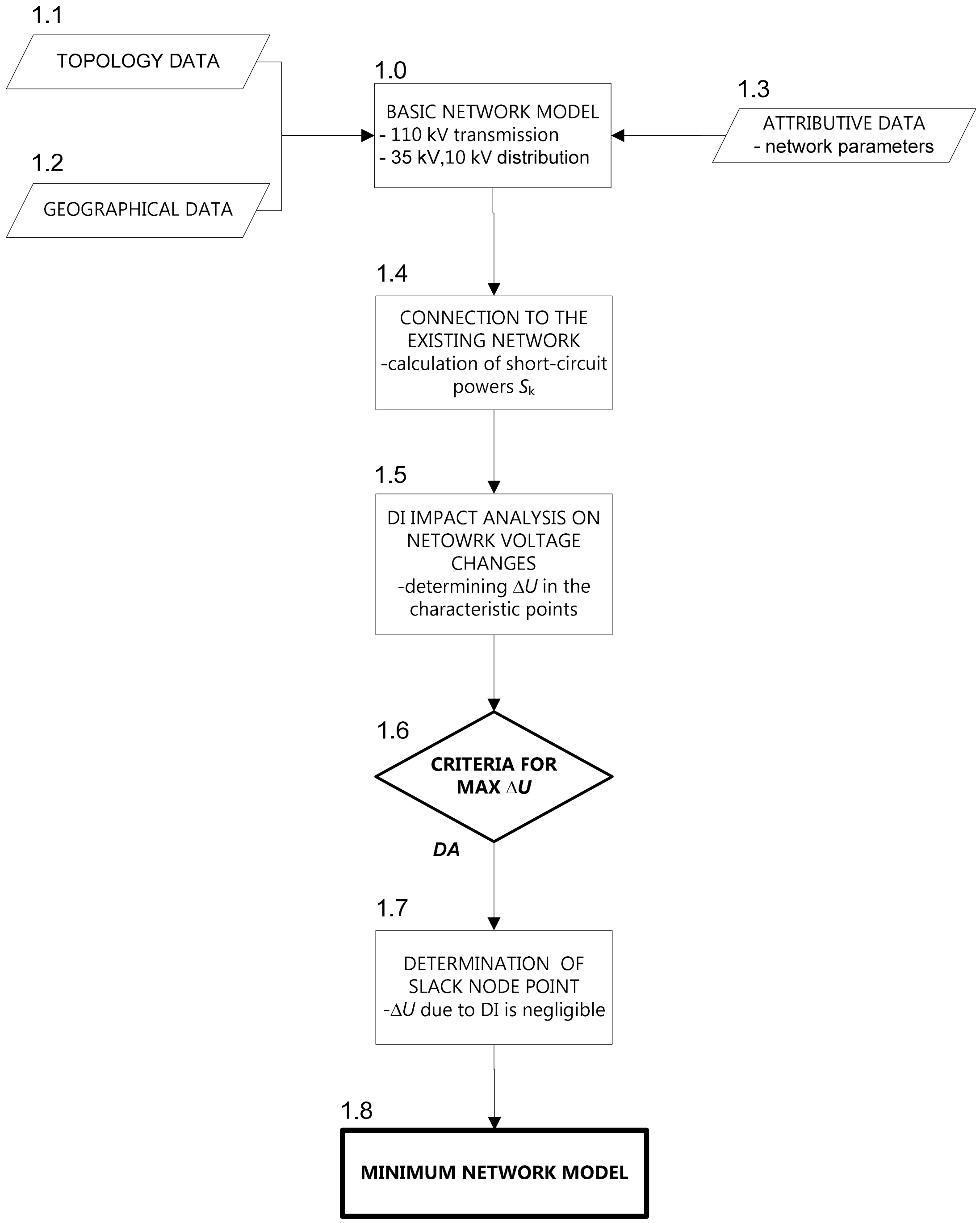


Figure 4: Schematic presentation – Criteria for preparation of the network model for DI connection analysis.

The network model that realistically describes the physical network is crucial for credibility and correctness of network analysis. It is designed by applying the proper program application which enables to conduct the analysis of the transmission and distribution network. The main contents and the process of model designing are shown in the Figure 4.

The model (1.0) is based on the basis of topologic (1.1) and attributive (1.3) data of electro-energetic elements. The network topology represents the method of element interconnections (conduits, transformers). With attributive data the physical features of individual elements are defined. The minimum attributive dataset for individual elements is shown in the Table 3.1. Geographical data (1.2) are the data on the element locations and are not obligatory. However they provide more efficient network model designing and the application of the advanced spatial analyses in the process of network analysis and planning.

Table 3.1: Minimum attributive dataset by network elements

Network element	**Attributive data**
Node (RTS, RS, TS)	- Node type (balancing bus, load bus) - Nominal voltage U_n - Target voltage U_s - Load data (nominal power S_n, operation power load P_B, reactive power load Q_B, power consumption W_l)
Nodes (generators)	- Node type (generator) - Nominal voltage U_n - Target voltage U_s - Production data (operation power production P_G, reactive power production Q_G)
Conduits	- material - length l - operating resistance R - impedance X, susceptance BC - couplings (switch, disconnector)
Transformers	- nominal power U_n, - short circuit voltage u_k, - losses in copper P_{Cu} and iron P_{Fe} - primary U_{n1}, secondary nominal voltage U_{n2} - step regulations, number of tappings - operating resistance R - impedance X, susceptance BC - couplings (switch, disconnector)

For the purpose of distributed production units analysis it suffices to model the middle voltage distribution networks with 110 kV distribution network (1.0).

Every change in the middle voltage network causes the voltage change in low voltage network which the majority of users is connected to. This is why the model, regardless of the projected voltage level of DI connection, has to also include the low voltage network, at least to the level of SBS SN/0.4 kV, together with the appurtenant distribution transformers and load.

The proper regulation tapping has to be determined for the distribution transformers. The appropriate installation of tappings is crucial for determining the actual voltages in the low voltage distribution network. In case the voltage is unknown it should be determined with simulations of average loads and simulations of automatic regulation of distribution transformers in the corresponding "Load Flow" application.

3.1.1.1. Problem of the minimum network model scope in the analyses of distributed sources connection to the distribution network

When analysing the effects of DI on the distribution network operation the question arises already before conducting the analysis: how does the source with its nominal power S_{DI} actually influence the voltage change. The solution to this issue can be defined as the **problem of the minimum model scope** and it is deemed important due to various reasons:

- Smaller scope of necessary input data,
- Higher precision and consistency of the analysis results,
- Controlling the risk of DI connection to the reliable network operation,
- Consistent determination of eventual investments in the network due to DI connection,
- Efficient and quick analysis of the DI connection effects on the network operation.

In the network node, where the voltage changes minimally due to DI operation, its influence can be negligible. In other words, this point represents the slack node for the DI with substitutive impedance Z_{KM} = 0 Ω. For electrically distant points, i.e. in the topological sense after the point of slack node, DI has the smaller influence and causes smaller voltage oscillations at best.

The permitted limit of change is determined by *the criterion of permitted maximum voltage change Δu_{TM} due to DI operation at the point of slack node* (**criterion for determining the point of slack node**). Here, there are two kinds of networks, i.e. interconnected and radial.

Criterion for determining the point of slack node (permitted voltage change Δu_{TM} in the TM point due to DI operation):

- **INTERCONNECTED NETOWRKS: Δu_{KM} = 0.01**
- **RADIAL NETOWRKS OR OPEN-MESH NETWORKS: Δu_{KM} = 0,005**

In case there are many (N) DI in the network, every (i) DI causing voltage change Δu_{TM_i} in the network should be included. The permitted voltage change Δu_{TM} is the sum of all (N) DI effects:

$$\Delta u_{KM} = \sum_i^N \Delta u_{TM_i} < 0.005 = \boldsymbol{K_{\Delta U}} \quad - \quad radial\ networks \tag{3-1}$$

$$\Delta u_{KM} = \sum_i^N \Delta u_{TM\_i} < 0.01 = \boldsymbol{K_{\Delta U}} \quad - \quad interconnected\ networks$$

To determine the minimum network model scope it is necessary to find the point of slack node in the connection analysis of one or more DI to establish the influence of the whole remaining network after that point. It is reasonable to place the slack node in one of network *reference points* with the provided selectivity of protection elements operation or voltage regulations. Due to more precise determination of operation statuses it is recommended that these points offer also the measured data.

Referential points are normally:

- Busbars in SBS (primary and secondary), RS;
- Nodes with the installed remote conduit switches.

When determining the points of slack node the following is assumed:

- Slack node voltage is constant, U_{KM} = const
- Slack node impedance is negligible, $Z_{KM} = 0\ \Omega$.
- Slack node represents the balancing bus.

3.1.1.2. Determination of voltage changes due to DI connection to the slack node referential points

To determine the point of slack node it is first necessary to establish the voltage changes Δu_{Ri} due to DI connection to referential network points. Slack node is set at the referential point closest to DI and at the same time meets the criterion $\boldsymbol{K_{\Delta U}}$ to determine the slack node point. With thus determined slack node point the minimum network model is defined.

For easier understanding the process of voltage changes calculations at referential points, the basic network model is assumed according to the Figure 5 DI is connected via the low voltage feeder to the low voltage busbars SBS A. SBS A is supplied via A feeder from SBS A 35/10 kV with the backup provided by the B feeder.

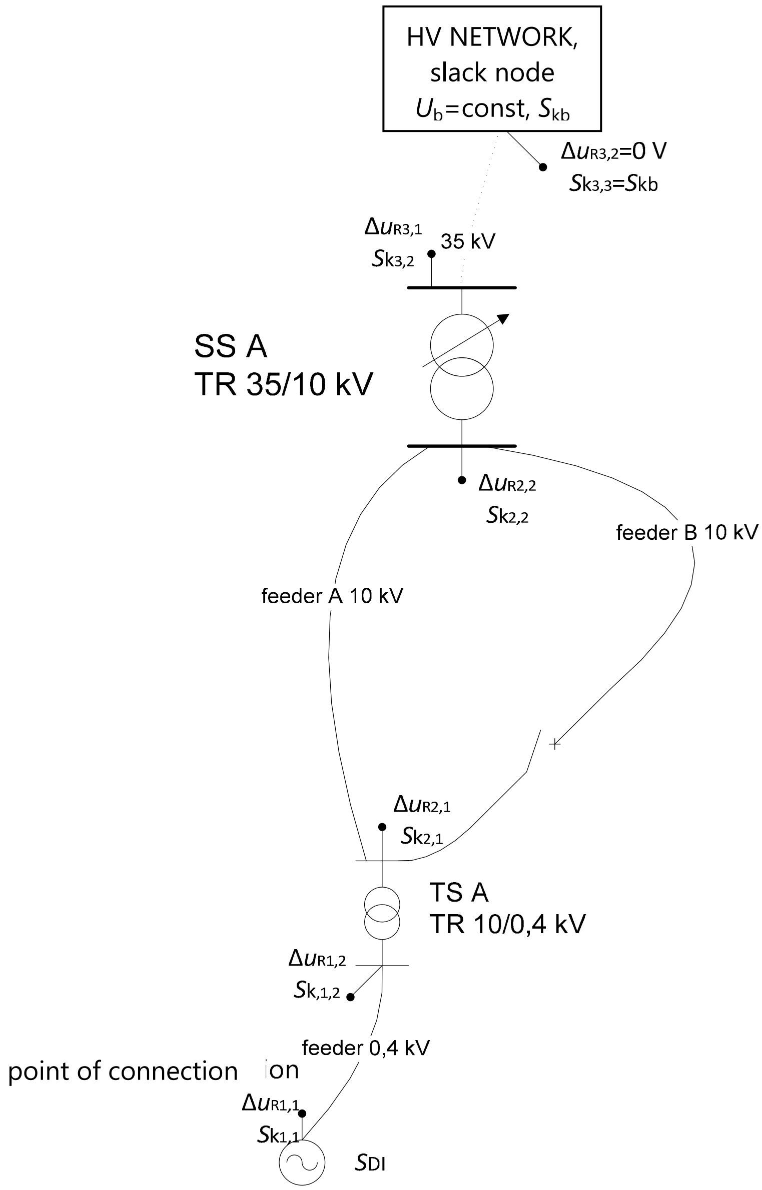


Figure 5: Basic network model

Explanations regarding the process implementation:

- The basic model also includes a part of 110 kV supply network with the properly distant balancing point of constant voltage (U_b = const). Basically the balancing point in the first approximation represents the slack node to be drawn close to the DI during the process.
- **If it turns out that the voltage change due to DI is higher than the criterion of determining slack node point, the source has no distribution significance but it is a mere typical production source for which the dispatching is conducted. Such source calls for broader analysis of connection to the network**.
- The analysis should consider the network from the DI point of connection to higher voltage levels. Therefore, the longest electrical path is included that could be restored at the emergency voltage situations (reserve voltage). For the example in the Figure 5 it is necessary to include the electrically longer path with the established reserve supply via B 10 kV feeder.

- Where possible the option of automatic regulation on the secondary transformer voltage is implemented. The voltage regulation is modelled with parallel voltage sources the supply of which is superimposed on nominal voltage drop on the regulation transformer. Due to longer time constant of voltage regulator, the regulation is allowed up to a half of the whole regulation scope.
- The contribution of the individual DI is separately analysed in the basic network model. Its contribution is superimposed on the contributions of other sources.

The analysis for determining the minimum model scope gives the impedance network model without load. The scheme with **reduced** voltages, currents and impedances on DI voltage level is shown in the Figure 6. The response of the substitutive connection to the initiated power S_{DI} is monitored.

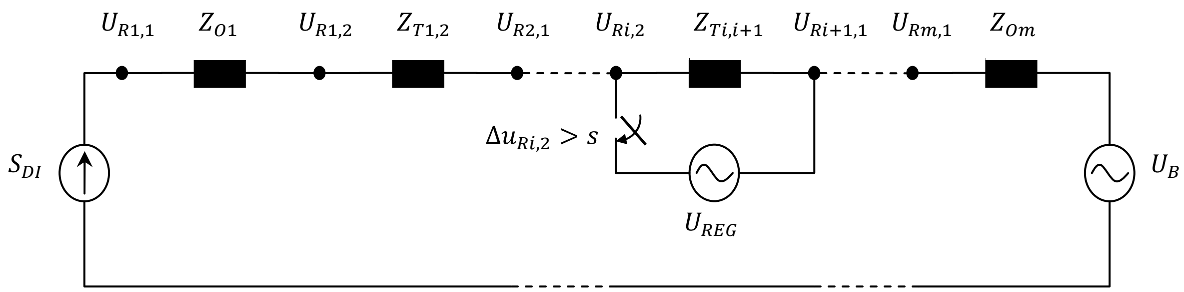


Figure 6: Substitutive connection of the reduced impedance model network to the DI voltage level connection.

The variables in the substitutive scheme are referential voltages $U_{Ri,1}$., $U_{Ri,2}$, i = 1.2,...m which are used to calculate voltage changes Δu_{Ri}. With the indicator i the voltage level is denoted. The first level to which the DI is connected is the level of balancing bus. The first level should have all the values in the calculations reduced. The Designation 1 marks the limit point of i-level network, whereas Designation 2 represents the initial point of the voltage i-level.

Established values in the substitute network scheme:

- Network impedance within the voltage i-level: Z_{Oi}, i = 1.2,...m,
- Transformer impedance between two voltage i-levels, i+1: $Z_{Ti,i+j1}$
- Nominal transformer ratio between two voltage levels $p_{Ni,i+1}$,
- Voltage regulation rate $s_{i,i+1}$ of the transformation for automatic regulations between i-level voltage, i+1,
- Maximum number of regulation switches $N_{MAXi,i+1}$ of transformation between the i-levels, i+1,
- Nominal ratio $p_{i-1,i}$ of transformation between i-level 1 and i,
- Voltage in the selected balancing bus U_B,
- DI power S_{RV}.

3.1.1.3. Calculation process

Network impedances Z_{Oi} and transformations $Z_{Ti,i+1}$ are calculated according to equations (3-2) – (3-4) on the basis of the known three-pole short circuit connections S_{ki} at the referential network points which are used for the calculations of short circuit connection impedances Z_{ki} (equation (3-2)).

$$Z_{ki} = \mathrm{c}\frac{U_{Ni}^2}{S_{ki}}, \quad \mathrm{c} = 1{,}1 \quad \rightarrow \text{increase voltage factor due to short circuit} \tag{3-2}$$

$$Z_{Oi} = \frac{1}{\prod p_{\mathrm{i-1,i}}^2}\left(Z_{\mathrm{ki,1}} - Z_{\mathrm{ki,2}}\right), \tag{3-3}$$

$$Z_{Ti,i+1} = \frac{1}{\prod p_{\mathrm{i-1,i}}^2}\left(Z_{\mathrm{ki,2}} - \frac{1}{p_{\mathrm{i,i+1}}^2} Z_{\mathrm{ki+1,1}}\right) \tag{3-4}$$

Network model in the Figure 6 can be simplified according to the scheme in the Figure 7.

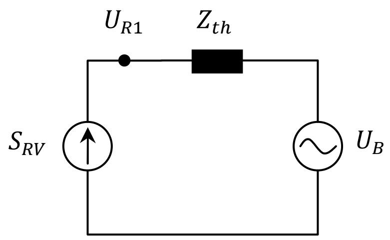


Figure 7: Simplified Thevenin network model

$$Z_{\mathrm{th}} = \sum(Z_{\mathrm{Oi}} + Z_{\mathrm{Ti,i+1}}) = Z_{\mathrm{k1,1}} - \frac{1}{\prod p_{\mathrm{i-1,i}}^2} Z_{\mathrm{kB}} \tag{3-5}$$

$Z_{\mathrm{k1,1}}$ – short circuit impedance at the point of DI connection
Z_{kB} – short circuit impedance in balancing bus

We want to establish the voltage U_{R1} at the DI connection point:

$$U_{\mathrm{R1,1}} = Z_{\mathrm{th}} I_{\mathrm{RV}} + \frac{1}{\prod p_{i-1,i}} U_{\mathrm{B}} \tag{3-6}$$

We get quadratic equation that includes the positive root for the final solution:

$$U_{\mathrm{R1,1}} = \frac{\frac{1}{\prod p_{i-1,i}} U_{\mathrm{B}} + \sqrt{\left(\frac{1}{\prod p_{i-1,i}} U_{\mathrm{B}}\right)^2 + \frac{4}{\sqrt{3}} Z_{\mathrm{th}} S_{\mathrm{RV}}}}{2} \tag{3-7}$$

Voltage drops in the network ΔU_{Oi} and transformation $\Delta U_{Ti,i+1}$ are determined with the voltage distributor:

$$\Delta U_{\mathrm{Oi}} = \frac{Z_{Oi}}{Z_{th}}\left(U_{\mathrm{R1,1}} - \frac{1}{\prod p_{i-1,\mathrm{i}}} U_{\mathrm{B}}\right), \quad \Delta U_{\mathrm{Ti,i+1}} = \frac{Z_{Ti,i+1}}{Z_{th}}\left(U_{\mathrm{R1,1}} - \frac{1}{\prod p_{i-1,\mathrm{i}}} U_{\mathrm{B}}\right) \tag{3-8}$$

Referential voltages in the network are simply recursive calculated from the voltage drops:

$$U_{\mathrm{Ri+1}} = U_{\mathrm{Ri}} + \Delta U_{\mathrm{OTi}} \tag{3-9}$$

If there is the automatic voltage regulation present between two voltage levels, the effect of DI on the higher voltage level is lower due the voltage drop compensation. The regulation is activated when the ratio between the calculated referential voltage and nominal (desired) voltage on the secondary transformation exceeds the value of regulation rates *in* (3-10). The figure of substitutive connection Figure 6 shows that in this case the coupling is activated to establish the parallel connection with compensation voltage U_{REG}.

$$N = \frac{(1-\frac{U_{\mathrm{Ri,2}}}{U_{\mathrm{Ni}}})}{s_{\mathrm{i,i+1}}} > s_{\mathrm{i,i+1}} \tag{3-10}$$

$$U_{\mathrm{REG}} = N s_{\mathrm{i,i+1}} U_{\mathrm{Ri,2}} \tag{3-11}$$

The corrected voltage of referential voltage due to regulation:

$$U_{\mathrm{Ri,2}} = U_{\mathrm{Ri,2}} - U_{\mathrm{REG}} \tag{3-12}$$

In the same manner the calculation for all remaining DI is repeated. Finally there remains only the calculation of voltage changes at the referential points which are compared to the criterion $\boldsymbol{K_{\Delta U}}$ (Point 1.6 in the diagram in the figure Figure 4).

$$\boxed{\sum \Delta \boldsymbol{u}_{\mathbf{Ri}} = \sum(\mathbf{1} - \frac{\boldsymbol{U}_{\mathbf{Ri}}}{\boldsymbol{U}_{\mathbf{Ni}}}) < \boldsymbol{K}_{\Delta \boldsymbol{U}}} \tag{3-13}$$

Slack node is placed at the referential point closest to the DI and also meets the criterion for determining the slack node point (Point 1.7 in the diagram in the Figure 4). Thus the minimum network model for DI analysis is determined.

3.1.2. Analysis of technical possibilities of distributed sources connection

Prior to the start of research, the basic grounds are set to be used in the analysis as input parameters. Thus from the very beginning the adequate network model (1.5), the accuracy of the analysis with the referential year (2.10), and load forecast (2.3) are established as the basis for the calculations of electricity situations.

The technical part of analysis methodology of distributed sources connection is shown in the Figure 8. According to the rules of the network connections (2.6) the selected distributed sources (2.5) are included. By analysing couplings in the network structure (2.1) and operation conditions (2.2, 2.4) the designed network and its input parameters (geographical position with spatial limitations, economic development, load prognosis) are checked to meet technical planning criteria (2.7).

In every period the normal operational conditions (hereinafter referred to as "NPS") together with single losses-of-voltage (N-1 criterion) are verified for the selected network structure. If the network exceeds planning criteria the network reinforcement and adjustment is opted for (2.8). In case there are different options for reinforcement and adjustment, each and every development solution needs to be dealt with individually, i.e. *variantly* (2.11).

The examinations are conducted in time intervals (2.10) that are adjusted to the level of consumption increase and relevant conditions directly influencing the network development. These are normally 5-year intervals. In case of considerable changes that could have influenced the network operation, the examinations are conducted for the period of anticipated changes (e.g. the construction of new RTS or new line).

The following situations are analysed (2.2):

- **maximum use of distribution network, minimum distributed sources production,**
- **minimum use of distribution network, maximum distributed sources production.**

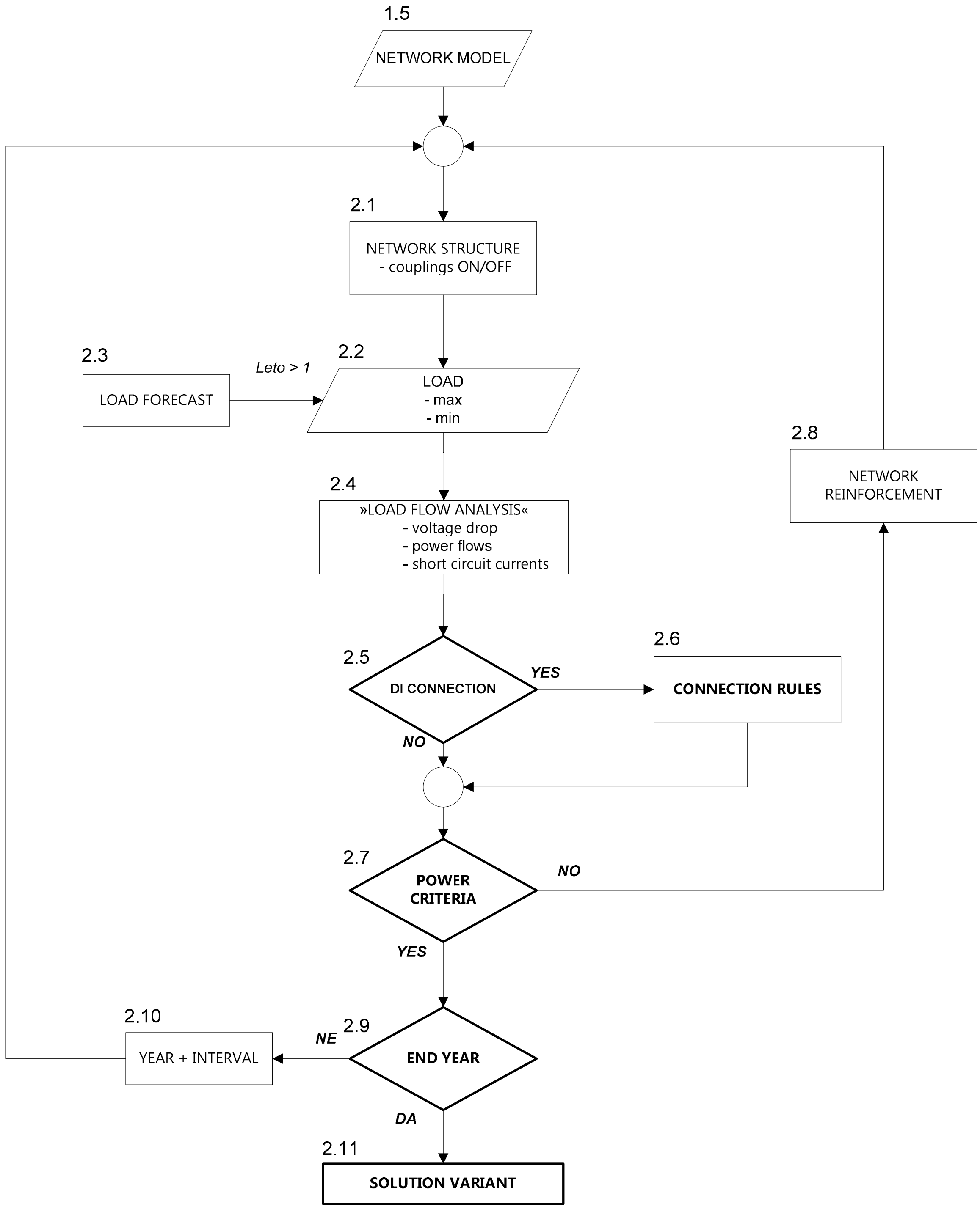


Figure 8: Scheme – Process of analysing technical possibilities of distributed sources connection

3.1.3. Energy planning criteria

DI can be connected to the network, if the operation reliability and quality supply of electrical power to the final customer are not jeopardized. This means:

- **DI in the network must not cause obstructions**
- **DI in the network must not substantially impair the voltages at the customer connections.**

Since the customers are connected to the 0.4 kV low voltage network, the voltage criterion limits the voltages in the low voltage network. In the middle voltage network the voltage change is allowed which does not exceed the voltage criterion in the low voltage network.

The European standards or regulations define the following voltage scopes at the consumer points:

- MV network
  - *Voltage change max ± 10 % of nominal voltage*
- LV network
  - *Voltage change max ± 10 % of nominal voltage in emergency voltage conditions up to -15 % of nominal voltage.*

When designing the network, the permitted voltage changes need to be additionally limited with the criterion. Apart from permitted voltage limits at the consumer point, the regulation of voltages at energy (HV/MV) and distribution transformers (MV/LV) has to be included. Also the voltage drop in the LV network has to be considered that is normally not modelled from the LV busbars TP on. The supply of an individual DI increase of voltage profile also must not exceed the total permitted field of regulated changes.

In regard to the DI operation also the DI regulation statics has to be taken into the account that defines the voltage regulation with the reactive power production (U-Q characteristics, figure). According to the statics, DI more difficultly maintains this voltage at the point of connection, as it was the case before the connection. In this case the voltage profile in the network does not change due to DI. Because DI operation increases the voltage in the point of connection, DI maintains the desired voltage with reactive power consumption according to the statistical curve. This provides the proper voltage profile in the network, but on the other hand it also additionally increases the network load with reactive power. Thus the analysis includes the DI operation with cosϕ=1. In regard to the network voltage this provides poor operation situations (higher voltages than those that could be provided with consistent consideration of DI statics).

Therefore two criteria for loads and voltages are set for planning the network with DI.

- **Criterion of permitted loads K_S:**

  Line and transformer loads in the situation with maximum DI load and production should not exceed:

  - 100 % thermal loads S_{th} for the lines,

$$\boxed{K_{S\_V}: S_V \leq S_{th}} \quad (3\text{-}14)$$

- 120% thermal loads for the transformer.

$$\boxed{\boldsymbol{K}_{\mathbf{S\_TR}}:\ \mathrm{S_{TR}} \leq 1{,}2 \cdot \mathrm{S_{th}}} \tag{3-15}$$

- **Criterion of permitted loads in LV network $K_{U\ NNO}$:**

The scope of permitted loads in the LV network:

$$\boxed{\boldsymbol{K}_{\mathbf{U}\mathrm{\_NNO}}:\ 0{,}4\mathrm{kV} \leq U < 0{,}42kV} \tag{3-16}$$

The voltages on higher voltage levels can be changed only to guarantee the voltage in the whole LV network to be within the criterion $K_{U\ NNO}$, but not higher than those permitted by the standards or rules on distribution network operation.

3.1.4. Examination of DI impact on LV network (Block 2.6 LV)

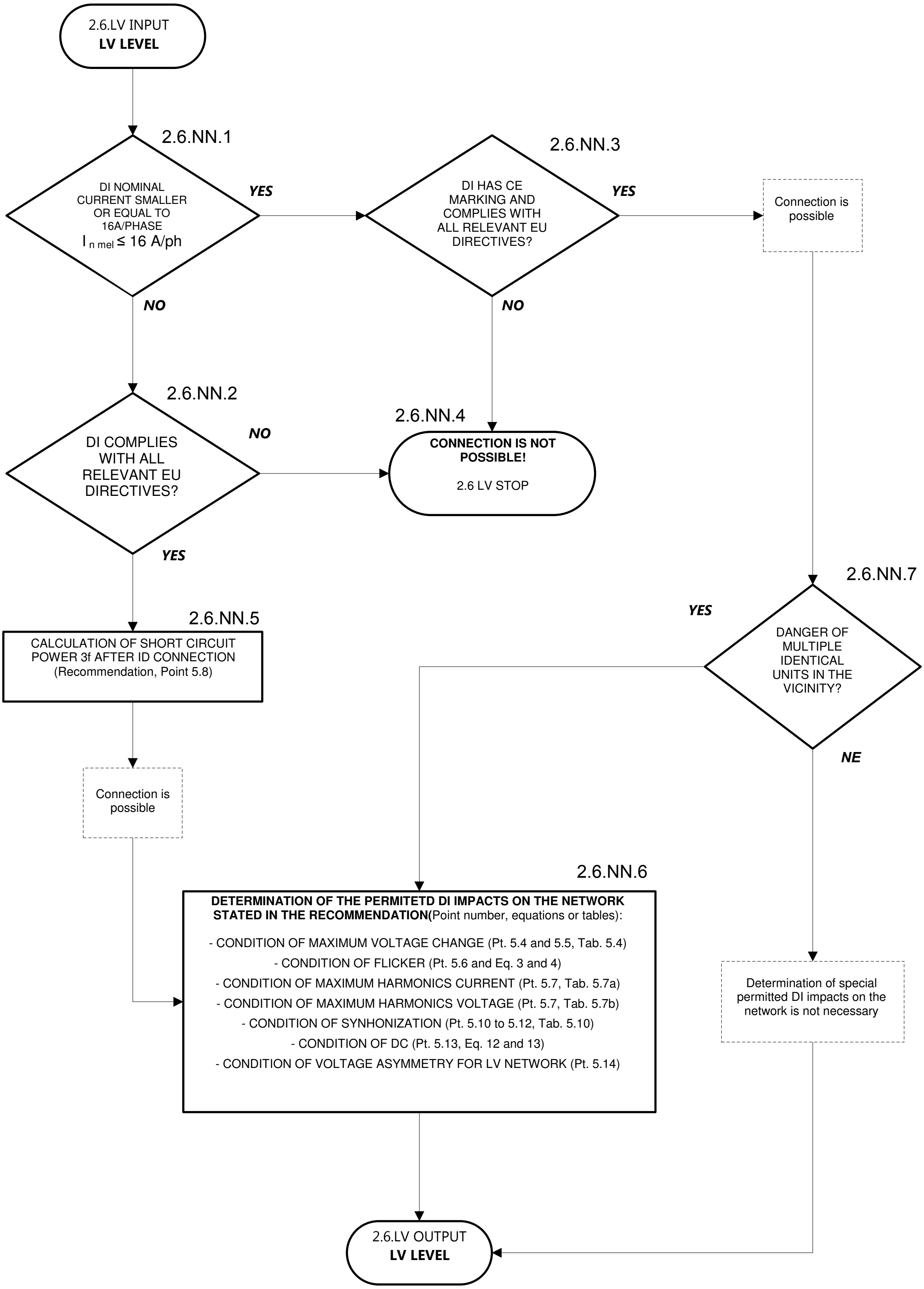


Figure 9: Schematic presentation – Examination of DI impacts on the network for DI connection to LV network DS

Figure 9 shows the diagram of current for the examination of DI impact on LV network and determination of other parameters that ME needs to fulfil.

According to the DI data, it is established whether DI fulfils the condition of nominal DI current being lower or equal to 16 A per phase (Block 2.6.LV.1). If this is confirmed and DI has a CE marking supported by the permit statement or some other approved technical documentation which indicates that DI meets all the relevant EU Directives (Block 2.6.LV.3), then the connection of such DI to DS is possible. If it is established that there is no danger of the simultaneous operation of multiple identical devices in the vicinity (on the identical LV busbars in SBS) (Block 2.6.NN.7) than the determination of special permitted DI impacts on DS is not necessary.

If the nominal current of the analysed DI is not lower or equal to 16 A per phase (Block 2.6.LV.1), DI can also have the CE marking or has some other approved technical documentation that shows that DI complies with all relevant EU Directives (Block 2.6.LV.2). Thus, the DI can be connected to DS. The three-phase short-circuit power calculation follows after DI connection (Block 2.6.LV.5.). If it is established that new short circuit power in the network with the connected DI exceeds the limit values of network installations, the relevant measures from the Recommendation have to be utilized.

The permitted impacts on the LV network (Block 2.6.LV.6) are determined for DI that has its nominal current higher than 16 A per phase and DI that has nominal power smaller or equal to 16 A per phase as well as there is danger of the operation of multiple identical devices in the vicinity.

The connection is not permitted (Block 2.6.LV.4) for every DI that is planned to be connected to DS on LV level and has no approved CE marking or any other approved technical documentation (Blocks 2.6.LV.2 and 2.6.LV3) that would show that it complies with relevant EU Directives!

3.1.5. Examination of DI impacts on MV network DS (Block 2.6.MV)

Figure 10 shows the diagram of current for the examination of DI impact on MV network and determination of other parameters that ME needs to fulfil.

If the analysed DI has the approved technical documentation confirming that it fulfils all relevant EU Directives (Block 2.6.MV.1), then the connection of this DI to DS is permitted. After DI connection there follows the calculation of new three-phase short-circuit power (Block 2.6.LV.3.). If it is established that new short circuit power in the network with the connected DI exceeds the limit values of network installations, the relevant measures from the Recommendation have to be utilized.

The permitted impacts of every DI, connected to MV network, on the MV network are determined (Block 2.6.MV.4).

The connection of every DI that is projected to be connected to DS on MV level and has no approved technical documentation confirming that it meets relevant EU Directives (Block 2.6.MV.) **is not permitted**! (Block 2.6.MV.2).

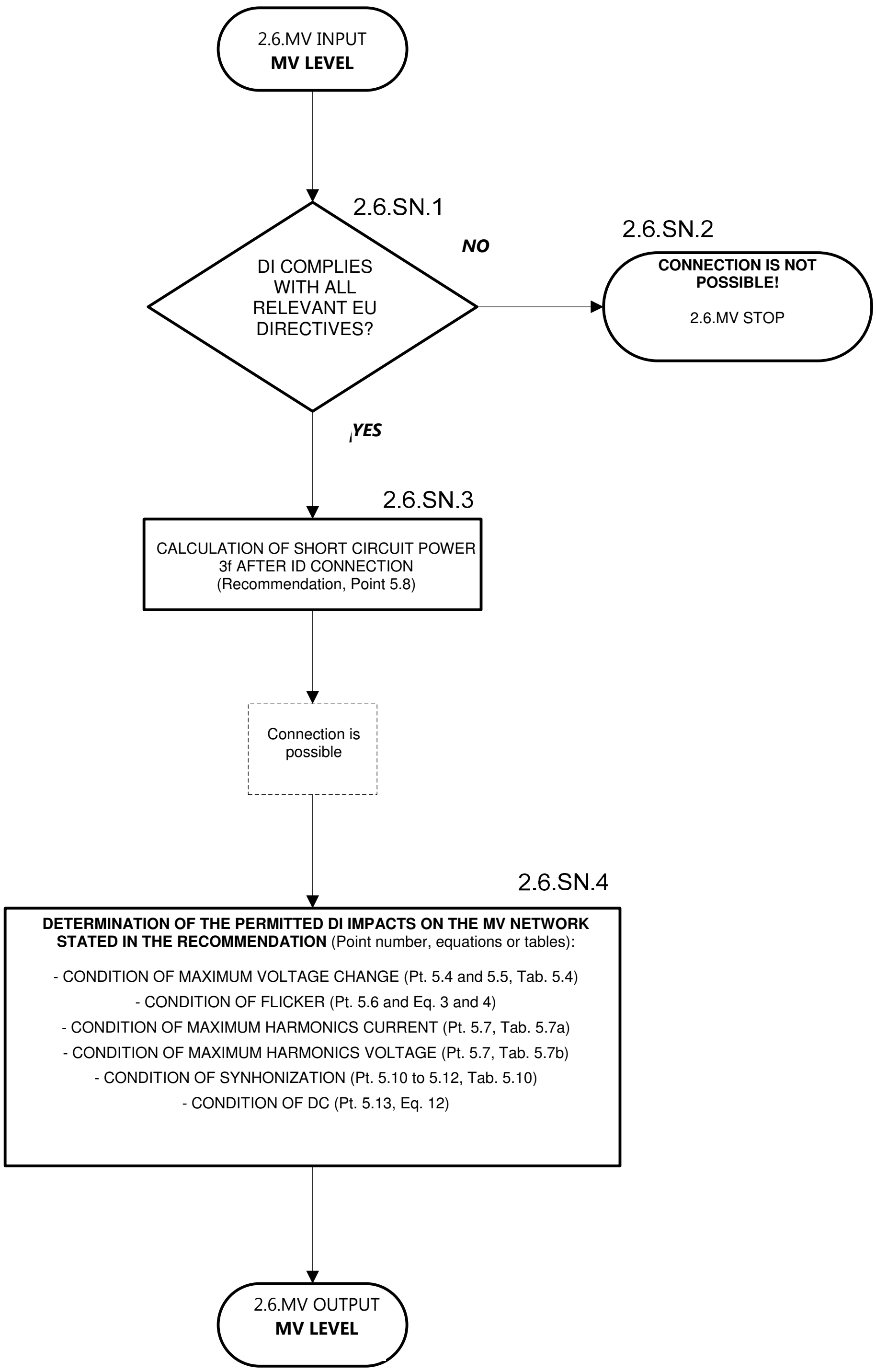


Figure 10: Schematic presentation – Examination of DI impacts on the network for DI connection to MV network DS

A practical examination of DI impact on DS is shown in Chapter 5 of this Study with the complete analyses of connection to network for several different types of DI.

3.1.6. Economic analysis

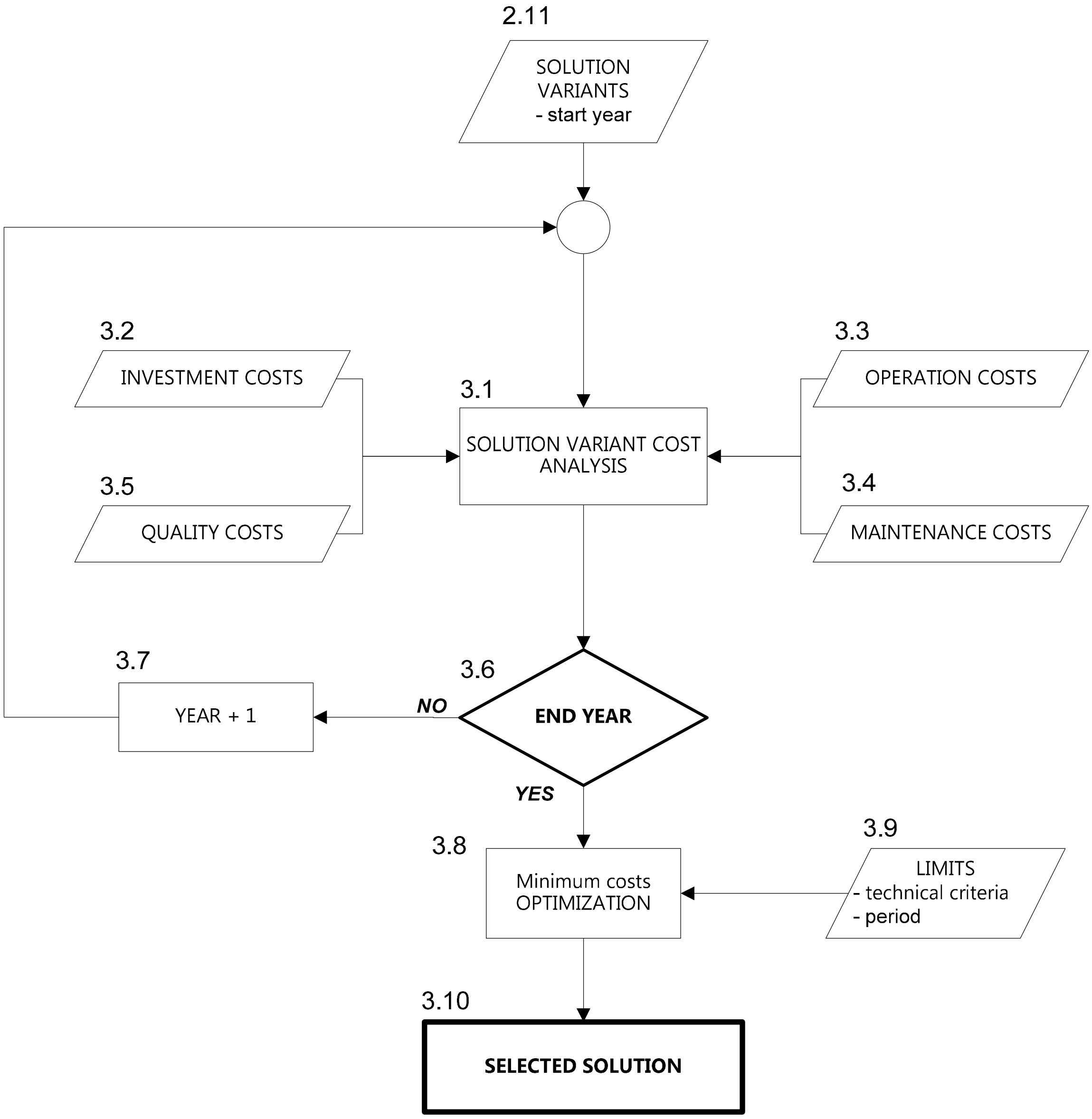


Figure 11: Scheme – Economic analysis.

The last part of the research is **Economic analysis of technical variants** that evaluates the value of overall variant costs in the selected period (3.1). The costs are generally divided into initial investment costs (3.2), operation costs (3.3), electrical power quality costs (3.4) and maintenance costs. All these types of costs are given a common denominator according to the revaluation methods and are selected by variants. By taking into the account the minimum total costs, technical and weather limits (3.9) the most suitable variant (3.10) is selected according to the optimization procedure (3.8). In this way the established variant provides the most inexpensive long-term investment in the network development with all technical planning criteria providing the consumer with reliable and quality electrical power.

3.2. Order of the procedure for connection permit issue

The Figure 12 shows the order of the procedure for the permit issue of ME connection to the DS.

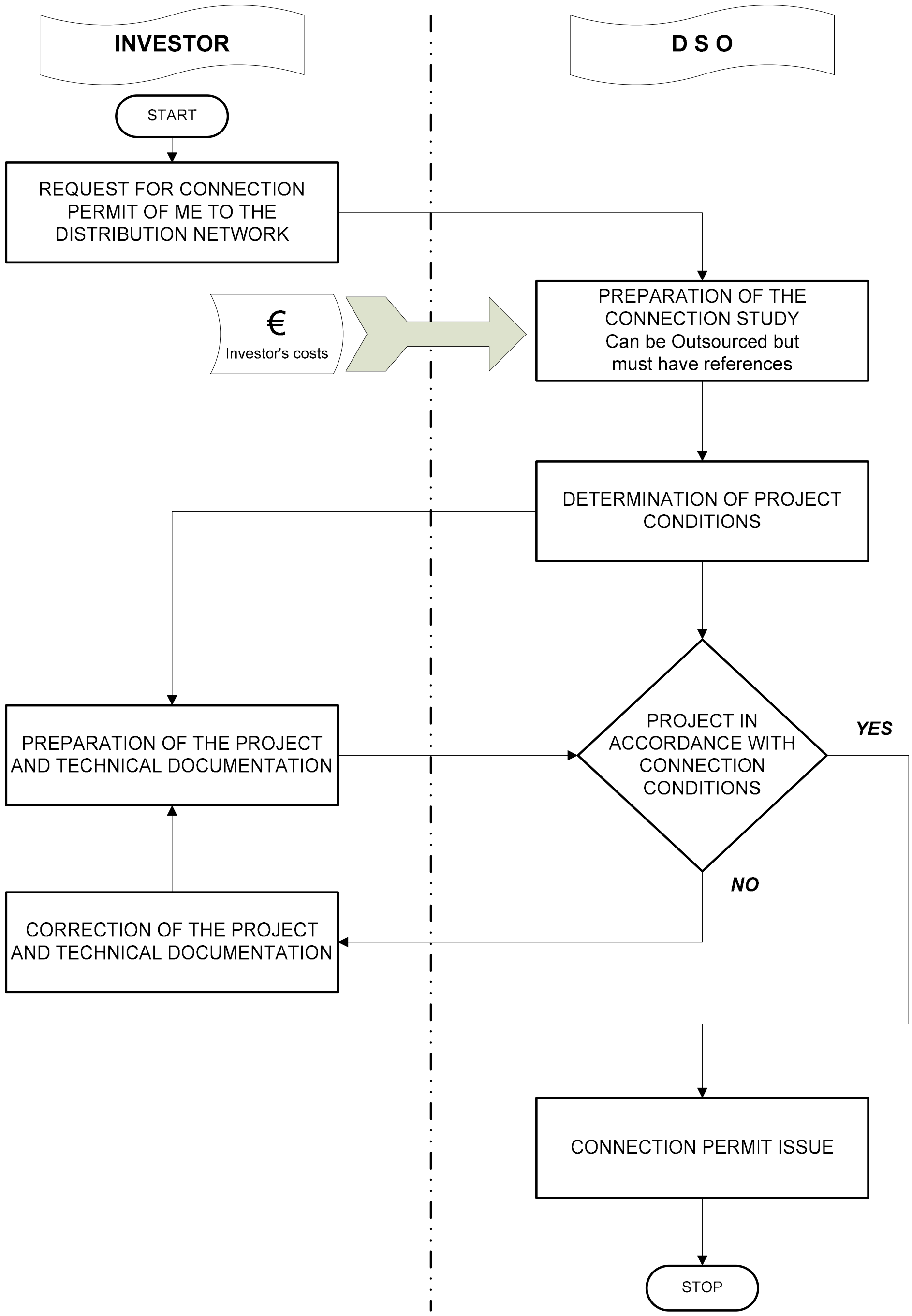


Figure 12: Submitted procedure order for the permit issue of the ME connection to the DS.

3.3. Request for the permit of ME connection to the DS

According to the Request for the connection permit, the investor has to provide those **technical source data** that are relevant for the network connection. The distributed source can have several production units generating electrical power.

3.3.1. Technical data of ME and source production units

- Manufacturer and type of unit.
- Number of identical units in the scope of this source for each type of unit (by construction).
- Type of unit:
  - synchronous generator,
  - asynchronous generator,
  - static inverter plant,
  - other: ________________.
- Unit connection to the network:
  - single phase,
  - three phase.
- For all units within the scope of source, nominal:
  - unit voltage,
  - nominal unit current,
  - unit operation power,
  - nominal unit cos(φ) and
  - apparent nominal unit power.
- Preferred type of reactive power compensation:
  - Synchronous generator,
  - capacitor,
  - inverter,
  - other:________________.
- Total nominal operation power of the source.
- Short circuit current of the unit.
- Unit electric power, for all units.
- Own power of the source consumption.
- Is the insulated unit operation projected apart from parallel one?

3.3.2. Other data

- Address, number of parcel of land,... source.
- Desired point of network connection.
- Desired voltage of network connection.
- Investor's request for the source to serve only for the consumption of facility to which it is connected.
- Is there a request to share the energy with the distribution system operator (for units up to 50 kW)? If YES, the energy and power sharing is planned between ME and distribution system operator.

3.4. Study of connection and establishing project conditions

Study of ME connection to DS (Study, Network analysis) can be done by authorized authority from the field of electrical power (distribution system operator) or other party with references in this field. The costs of study preparation are covered by the ME investor. The study should include all data the investor referred to in the *Request for permit of connection to the network*. Also the study has to consider the current network situation and network development plan in this area. The study can project different connection possibilities for the investor and project designer to choose the most suitable solution for the given situation.

On the basis of the study the *Project conditions for ME connection to the DS* are made and sent to the investor. The annex of project conditions has to be included in the Study.

3.5. Project conditions for connecting ME to the DS

Project conditions for connection ME to the DS (Project conditions) has to include all technical data stated by the investor together with solution of network connection.

Apart from these the project conditions need to include also:

- Characteristics of reactive power compensation, determined by DSO on the basis of the Recommendation and other network features.
- Characteristics of protective installations and values for protection provision at the distribution point (U<, U> f<, f>).
- Permitted flicker coefficients for the wind power stations.
- Permitted currents of higher harmonics for inverter power plants.
- Other operation limits, if there are any.
- Connection scheme permit.
- Energy transformer data for connection on the MV level.
- Permitted equipment features for measurements and conversion via voltage and current transformers.
- All local network features:

- Actual power of short circuit at the ME connection point.
- Maximum permitted power of short circuit at the point of ME connection.
- Maximum expected actual (and maximum permitted) earth fault current of galvanic connected unearthing (356 kV, 10 kV) network to which ME are connected.
- One phase-to-earth fault current of the network (35 kV, 10 kV), earthed via low resistant impedance.
- Period of rest and de-energized pause.
- Maximum generator power of small power plant that could be simultaneously connected to the network.
- Maximum capacitor battery power that can be constantly connected to the network.

On the basis of this, the investor and his authorized project designer complete the *Project and technical documentation for the ME* (Project).

3.6. Format for connection permit

On the basis of *Requests for permit of ME connection to the DS* from the investor with additionally attached documentation and Project, the DSP evaluates the concordance of the Project with the issues Project conditions.

If the Project is in accordance with the Project conditions, then DSO can issue the *Permit for small power plant connection to the distribution network* (Permit).

The permit includes all elements for Project conditions and also:

- Distribution point data.
- Connection point data.
- Measurement point data.
- Current protection data.

4. TECHNICAL RECOMMENDATION FOR THE CONNECTION OF DISTRIBUTED SOURCES IN MONTENEGRO

The basis of technical recommendation for the connection of distributed sources is Technical recommendation num. 16: *GENERAL TECHNICAL PROVISIONS FOR CONNECTION OF SMALL POWER PLANTS TO THE DISTRIBUTION SYSTEM* [10] (TP) which is already applied in Montenegro by the distribution system operator for connection of small power plants to the distribution system of Montenegro.

After the examination of the new TP (year 2011) it is concluded that TP includes many important and good solutions. Therefore, it would be recommended to keep TP however with some changes and amendments. The subjects of TP that need to be changed are corrected and commented upon.

In this section, only the needed changes and modifications of the existing TP are stated.

4.1. Validity and purpose

This TP chapter needs no changes.

4.2. Terms and definitions

2.1 This recommendation uses the terms and definitions according to the Energy Law, Decree on Conditions for Electricity Delivery, SRPS standards N.A0.441:1986 and IEC 62271-200:~~**2003-11**~~[5], as well as technical recommendations.

2.2 Terms are used in the recommendation and have the following meanings:

2.2.25: **Interruption:** interruption of supply (or feed) of electric energy to the distribution system user (voltage at the point of supply is 5 % smaller than nominal distribution network voltage **U < 0.05 *U*n**[6])

[5] Better way of **citing the standard** is without the year since the latest issued standard is thus regarded valid and with it also the newest technical provisions. All standards should be cited only with MEST before the standard denotation but with prior evaluation as MEST standards.

[6] **5 % U_n** is the limit for supply disconnection according to EN 50160. Since EN 50160 is also valid in Montenegro it will be reasonable to adjust that. It is actually unimportant for the DS users whether the voltage drop is 1 % or 5 %, or even 8 % of the nominal voltage. Therefore, the EN 50160 standard governs that the voltage smaller than 5 % of the nominal voltage is regarded as the supply interruption.

2.2.35: **Total Harmonic Distortion factor (THD):** is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency

2.2.36: **Switch in the ME switching installation:** signal switch exclusively monitored by the distribution system operator and is used to disconnect the small power plant from the distribution system. The protection of the switch (exclusively by distribution system operator) is an analogue to the protection of the main protective elements of DS user installations.[7]

4.3. Basic distribution network technical data

This TP chapter needs no changes.

4.4. Basic small power plant technical data

4.3: Nominal frequency value of the output voltage is 50 Hz.
The generator voltage waveform needs to be sinus (IEC 60034-1:~~**2010-02**~~) with form factor (~~**total harmonic distortion**~~[8]) ~~**better than 7%**~~[9] **(THD) better than 5 % under additional condition that it does not cause high THD somewhere else in the network.**

---

[7] **Switch in the ME switching installation** - The switch is the new element in the ME switching installation to which only distribution system operator has the exclusive access. By placing the switch in the position “0” or “OFF” the ME operation conditions on the distribution system are not met and the switching installation has to immediately disconnect ME from DS. By placing the switch in the position "1" or "ON", DSO allows the investor or ME automatics to resynchronize ME in the DS network, if also other protective conditions are met (current, voltage, frequency). If there is the current protection at ME, the switching installation can be arranged for DSO to quit (reset) the current protection in the switching order "1" → "0" → "1". Thus, the investor or ME automatics can resynchronize ME in the DS network, if also other protection criteria (voltage, frequency) are met.

[8] **TOTAL HARMONIC DISTORTION** is used in audio technics. It defines the clarity of audio signal and the presence of audio harmonics in this audio signal. In the electric-energy field THD factors are used for harmonics disturbances in the network or THF (telephoneharmonic) factor for generators.

[9] **THD** or **THF** voltage factor at the generator output of 7 % is regarded as very poor permitted voltage quality, since THD of 8% is the highest permitted THD in the network in general (according to EN 50160). The network plan should reach 60-80% of this limit at the most to provide the reserves for development network. Considering also the disturbances from other consumers and ME in the network, the highest THD of 5 % is recommended.

4.5. Basic technical requirements for small power plant connection to the distribution system

5.1 ME can be connected to DS if it:

- fulfils technical conditions from Points 5.3 to 5.14 of this *Recommendation*;
- includes safety and other conditions for the protection of generators and other ME installations against damages due to DS malfunctions;
- fulfils the conditions given in the connection permit.

Every DI connected to Montenegro DS at any voltage level has to comply with all relevant EU Directives. The compliance with the Directives at LV level for units with nominal power smaller or equal to 16 A per phase is determined with CE marking that is approved by EU Directives. For all other DI on LV level and for all DI on MV level other technical documentation approved by EU Directives can be used instead of CE marking.

5.3 To provide safe connection and parallel operation of ME with DS, ME shall meet the following criteria:

- criterion for permitted voltage deviation (change),
- criterion for short-circuit power,
- criterion for flickers,
- criterion for permitted currents of higher harmonics,
- safe synchronization,
- criterion for maximum permitted injection of DC,
- **criterion for ME reactive power.**

The criterion for short-circuit power is checked only for ME with the installed power higher than 1 MVA.
The attachment of this recommendation provides the examples for evaluation of these criteria.

5.4 *<u>This line should be added:</u>*

Voltage changes are determined only due to potential occurrence of flicker in transient situations (activation, synchronization and full power loss) of generators. The values in the Table correspond to flicker severity $P_{st} = 0.8$ according to standard table for rectangular voltage changes (see IEC/EN 61000-4-15 [15]). <u>For the mere analysis of voltage situations in the network this voltage variations are irrelevant!</u>

5.7 *<u>This line should be added:</u>*

DI with frequency convertors has to be checked also for damaging DI operation on ripple control system or ripple control signal propagation and **PLC system** conditions from the viewpoint of higher harmonics.

5.9 *<u>This line should be added:</u>*

If for the Network analysis study a precise computer network model is used, then calculations using the (10) and (11) equations are not necessary.

5.10 *<u>This line should be added:</u>*
Synchronization is conducted on the generator switch **or / and switching point.**

5.13 At ME connected to DS via inverter the **direct current component** of the delivered current to the distribution network should not exceed 0.5 % of the inverter's nominal power (12). There is an additional condition for the LV network, i.e. the direct injection to the distribution network should not be higher than 1000 mA (12 and 13).

$$I_{DC\,\mathrm{mel}} \leq 0{,}5\ \%\ I_{n\,\mathrm{mel}} \tag{12}$$

$$I_{DC\,\mathrm{mel\,NN}} \leq 1000\ \mathrm{mA} \tag{13}$$

5.14 In terms of **voltage asymmetry in LV network**, ME can be connected with mono-phase (single phase) (L-N) to low voltage network with maximum power not exceeding 3.7 kW[10]. ME powers higher than 3.7 kW are always connected to LV network of DS with three phases. If the permitted ME power is higher than 11 kW, the power asymmetry between any two phases should not exceed 4.6 kW. The project designer is advised to give priority to the variants with smaller number of larger three-phase units, preferably to single phase units. This is the problem namely with photovoltaic ME with inverters. Larger three-phase units more easily maintain the voltage quality within the limits set by this *Recommendation*.

Connections to MV network of DS are always three-phase connections.

[10] **3.7 kW** is the nominal power of 16 A fuses in 230 V network. This is important for the consumer classification and CE marking for all consumers with nominal power smaller or equal to 16 A per phase.

4.6. Basic technical requirements for ME connection installation

6.2 ME connection to DS is single-phase or three-phase connection. ME can be connected with single-phase to the LV network with maximum power up to ~~5 kW~~ **3.7 kW**[11].

6.6 *These corrections should be made:*

Technical characteristics of MV switches (**MEST** IEC 60265):

Technical characteristics of LV switches are defined (**MEST** IEC 947-2~~:1994~~):

Measurement transformers (**MEST** IEC 60044-1):

Technical characteristics of MV transformers (**MEST** IEC 60044-2):

4.7. Technical requirements for points of measurement

7.3 Meters, devices for evaluations and measurement transformers need to:

- be accurate in accordance with metrology requirements;
- have a certificate of type examination by ~~**Directorate of Measures and Precious Metals,**~~[12] **the authorized independent institution** and are regularly tested and tuned (authorization certificate).

[11] **3.7 kW** is a nominal power of 16 A fuses in 230 V network. This is important for the consumer classification and CE mark for all consumers with the same or smaller nominal current than 16 A by phase.

[12] After the ratification of **PECA agreements** (*Protocol to the European agreement on Conformity assessment and Acceptance of industrial products*) with EU this system cannot be configured in this way anymore. Then any institution with the status of examination authority is regarded competent.

4.8. Protection of the small power plant generator and connection line

8.1 *These lines should be added:*

These protections provide the automatic deactivation of the parallel operation with DS at the connection switch.

If ME has the possibility of isolated operation from DS and the reasons for operation protection at the switch point were *U*<, *U*>, *f*< or *f*> *conditions*, than ME is disconnected from DS at the switching point and (on the investor's wish) could start operating separately from DS. After the protection conditions of *U* and *f* are restored for ME operation in DS at the switching point, ME can be resynchronized into DS at the switching point or generator switch, depending on the state of generator(s) in ME.

If the reason for protection operation refers to the electrical current, then the malfunctioning generator has to start deactivation process.

Voltage protection consists of:

- overvoltage protection (U>) with three-phase (or single-phase for single-phase installations) voltage relay of the smallest scope of adjustment (0.9 – 1.2)-Ung, regulated with the smallest time delay of adjustment (0.2 - 3) s;
- undervolatge protection (U<) with three-phase (or single-phase for single-phase installations) voltage relay of the smallest scope of adjustment (1.0 – 0.7)- Ung, regulated with the smallest delay of adjustment (0.2 – 3) s.

8.5 The rule from Point 8.4 does not apply for ME with 30 kW of nominal power used by inverters for electric power production.

8.6 ME with 30 kW nominal power can have frequency protections integrated within the scope of inverter. In this case the connection/disconnection to distribution network can be conducted by the inverter side. Thus the switching element can be placed between the inverter and the network. Its function as automatic connection/disconnection has to be tuned with operation of integrated inverter protections. Apart from automatic function of connection/disconnection the switching element needs to provide also the option of manual connection/disconnection.

8.9 All types of ME need to have the switch in the ME switching installation. This signal switch is exclusively operated by DSO and can provide the disconnection of ME from DS. The switch protection (exclusively in the DSO domain) is an analogue of main installation fuse protection of DS users. DSO uses this switch to disconnect ME from DS. By placing the switch from position "1 (ON)" in the position "0 (OFF)", ME operation parallel with DS is not possible anymore.

8.10 During the operation of current protections at the ME switching point, the ME operation in DS is not possible until DSO does not activate the protection by switching „1“ → „0“ → „1“ (in case of digital protection if it exists) or changes the fuses for this kind of protection.

8.11 It should be noted that after deactivation of the protection or fuse replacement at the switching point, DSO only provides the necessary condition for the investor to reconnect to DS. The investor is held responsible and bares consequences of any reconnections.

8.15 Three-phase generators must to have zero point isolated during the parallel operation with DS. However, when switching to the separate operation, the zero point has to be automatically earthed due to possibility of the detection of I_0 harmful current.

8.16 Standard protection setting at the switching point for all generators in the Table 4.1 and 4.2.

8.17 Table 4.1 applies, if ME has only single-level protection, whereas Table 4.2 applies for ME with the option of two-level protection. The second level of protection in Table 4.2 can be set for any value in the specified zone.

Protection parameters are set to provide ME operation in DS, if voltage and frequency conditions exist. If there are no such conditions, then ME is disconnected from DS and (if there is any interest from the investor) to operate separately in the network until the conditions (voltage and frequency) are met again for ME parallel operation with DS. The standard protection is two-level protection. If ME cannot have two-level protection, but only one-level protection then the protection must be set according to the

Table 4.1. The protection enables ME to stop parallel operation with network in case of damages in parallel lines (not in the ME supply line) or provides quick disconnection of ME from DS in case of ME supply line damages (limit U_n – 15 % ... – 30 %). When there is too high voltage in the system, ME stops parallel operation with DS since this could damage the consumers (limit U_n + 11 % ... + 15 %). When there is increased frequency in the system (impaired part of DS operation) then ME are disconnected from DS at the frequency 51 Hz in order to decrease system frequency. But when the frequency drop occurs in the system (due to impaired part of DS operation or problems in UCTE network) then ME are disconnected from DS at lower frequency of 48 Hz to provide assistance to the system due to operation power insufficiency.

8.18 DSO can require non-standard protection settings at the switching point in special circumstances.

8.18 If DI is to be connected to DS network only to provide safe supply to sensitive consumers and its role is not to supply active power to DS but rather to support the consumers, or to decrease the consumer consumption from DS, such DI can be connected to DS according to **altered connection rules**:

- DI is not compensated for the supplied active power to DS.
- The reactive power characteristics from the *Recommendation* are irrelevant.
- DI has to operate (active power, reactive power, line disturbances and other operation parameters) to fulfil all conditions from consumer connection permit at the connection points in the relevant DS network DS. The responsibility for the determination of DI operation conditions, encompassing all circumstances, fells under the DI project designer.
- DI must not deliver active power to DS. Thus the consumer connected to such network needs to have the installed protection against the reverse power at the decoupling points. This protection needs to be set to maximum 10 % of nominal (applied) power of the consumer at the connection point. The protection operation from the reverse power must not exceed 5 seconds. After protection from return power the DI decoupling unit has to be permanently deactivated with the current protection. In this case the decoupling device can be unblocked only by ODS.

8.19 When DI operates synchronously with DS, its P – f regulator has to be blocked! When DI system protection (U<, U> or f<, f>) activates then (if there exists) the regulator P – f on the DI generator (generators) can be unblocked and a generator(s) can individually supply the consumption within the DI system on owner's wish or if it was so projected. The reactivation in DS is conducted according to the rules for the synchronization of DI with DS from this *Recommendation*. In this case it is advised that during U<, U>, f< or f> protection operation this is conducted at t = 0 to provide easier transfer to isolated DI operation.

Table 4.1: Standard setting of voltage and frequency protection at the ME switching point in case of one-level protection

Parameter	**Longest permitted total protection operation time (s)**	**Settings**
Overvoltage protection	0.2	U_n + 11 %
Undervoltage protection	0.2	U_n – 15 %
Overfrequency protection	0.2	51 Hz
Underfrequency protection	0.2	48 Hz

Table 4.2: Standard setting of voltage and frequency protection at the ME switching point in case of two-level protection

Parameter	**Longest permitted total protection operation time (s)**	**Setting**
Overvoltage protection (2. level)	0.2	U_n + 11 % ... + 15 %
Overvoltage protection (1. level)	1.5	U_n + 11 %
Undervoltage protection (1. level)	1.5	U_n – 15 %
Undervoltage protection (2. level)	0.2	U_n – 15 % ... – 30 %
Overfrequency protection	0.2	51 Hz
Underfrequency protection	0.2	48 Hz

4.9. Compensation of reactive power in ME

9.1 For ME connected to LV network, the ME power factor in relation to DS needs to provide cos φ > 0.95 in the capacitive ~~i~~ or inductive operation regime, without additional toleration. For ME connected to the MV network, ME factor power in relation to DS need to be in accordance with the characteristic shown in the **Figure 13.** If the capacitor batteries need to be installed to provide the required power factor value, the capacity is chosen to prevent any self-excitations of the generators.

9.4 *These lines should be deleted:*

~~Reaktivna snaga potrebna za rad sinhronog generatora bira se u zavisnosti od karaktera opterećenja i veličine pogonske snage, pa je dovoljna konstantna pobuda, ili se koristi automatski regulator faktora snage sa ciljem održavanja napona u Ds u stacionarnom režimu.~~[13]

9.5 ME connected to MV network of DS has to keep the reactive power regime according to the Figures 11 or 12 (blue lines and/or blue areas), depending on ME type. These characteristics need to be kept when the ME operation power exceeds 20 % of ME nominal operation power (P_g ≥ 0,2 P_{ng}). ME nominal operation power need to be min Q_{ng} ≥ 0,5 P_{ng} (cos φ = 0.90). Permitted deviation of the reactive power from the characteristic in every operation point can be up to ± 10 % Q_{ng}. Generators with possible stability problems in capacitive area operation (e.g. synchronous generators), the limit of reactive power can be applied to such value in the voltage area (blue area in the **Figure 13**) that provides stabile generator operation. $U_{mreže}$ is measured voltage in the ME connection point to DS, whereas U_{cg} is agreed voltage in ME connection point. U_{cg} is defined in the study for ME connection on the basis of the calculations of network voltage conditions.

[13] Due to new reactive power regime these types of regulations are not necessary anymore.

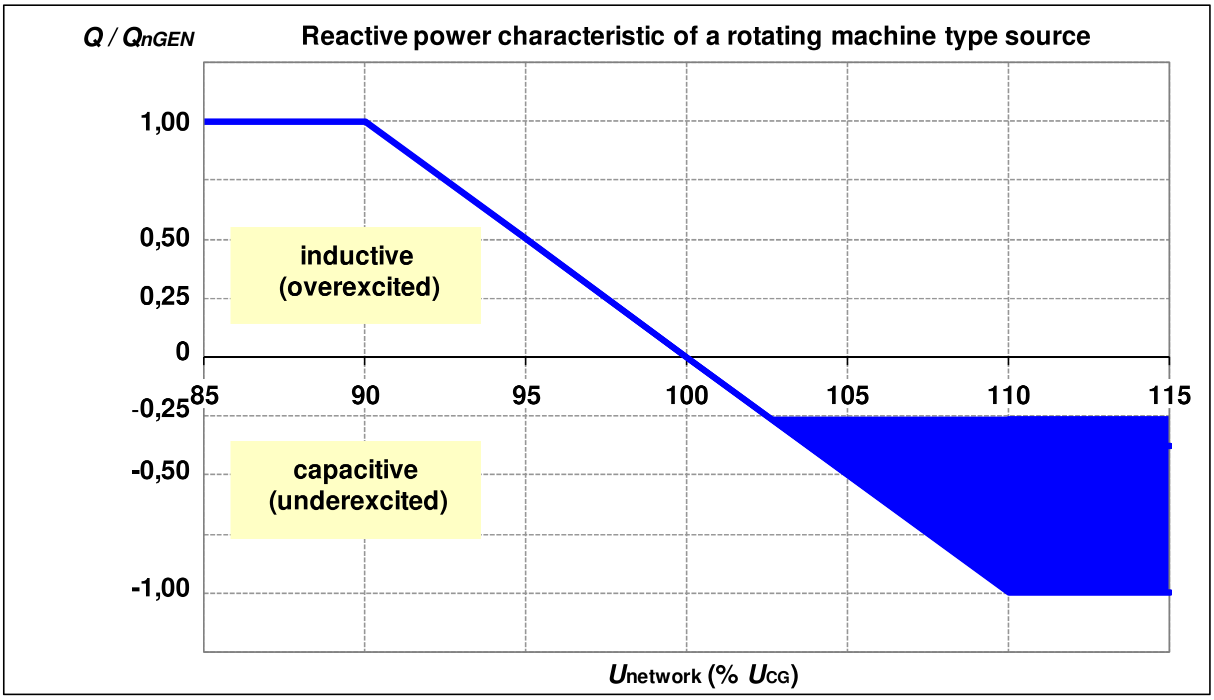


Figure 13: Standard reactive power characteristic of rotating machine source for sources connected to the MV network

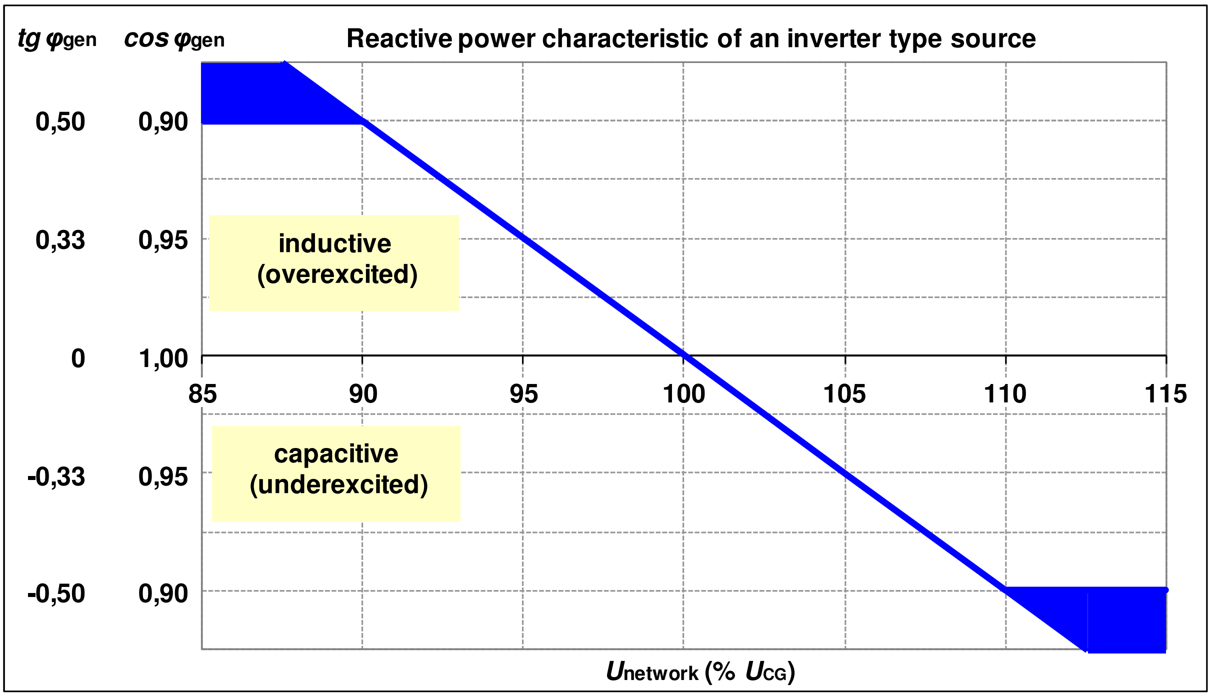


Figure 14: Standard reactive power characteristic of an inverter based source for sources connected to the MV network

4.10. Control and communication with ME

10.7 *These lines should be added:*

ALL ME need to have the switch in the ME switching installation which is exclusively under DSO control and enables DSO to disconnect ME from DS, if needed, or in case ME operation causes problems in the network**.** Switch protection (exclusively in the DSO domain) is an analogue of main fuse protection of DS user installations.

4.11. Procedures and documentation for small power plant connection to the distribution network

11.2.3 *Last bullet should be added:*

Small power plant connection to the distribution network

- After the construction of connection and conducted examinations of technical operation, the facility is connected to the distribution network to run the check and adjustment of the equipment and installations.
- The procedure starts with the written request of the investor with attachments that confirm the operation of the constructed connection.
- As necessary the distributor conducts the controls of the connection and measurement points, and connects the facility to the distribution network and makes the authorized record
- After the conducted examination and adjustment of the installed equipment, managing and protection conditions documented in the record, the power plant is connected to the distribution network.
- DSO issues the necessary guarantee providing ME connection to the network with switch position "1 (ON)". However, the investor is the one who connects his ME to the network by issuing the command for connection and synchronization. In this way DSO cannot be responsible for any damage due to improper ME connection to the network.

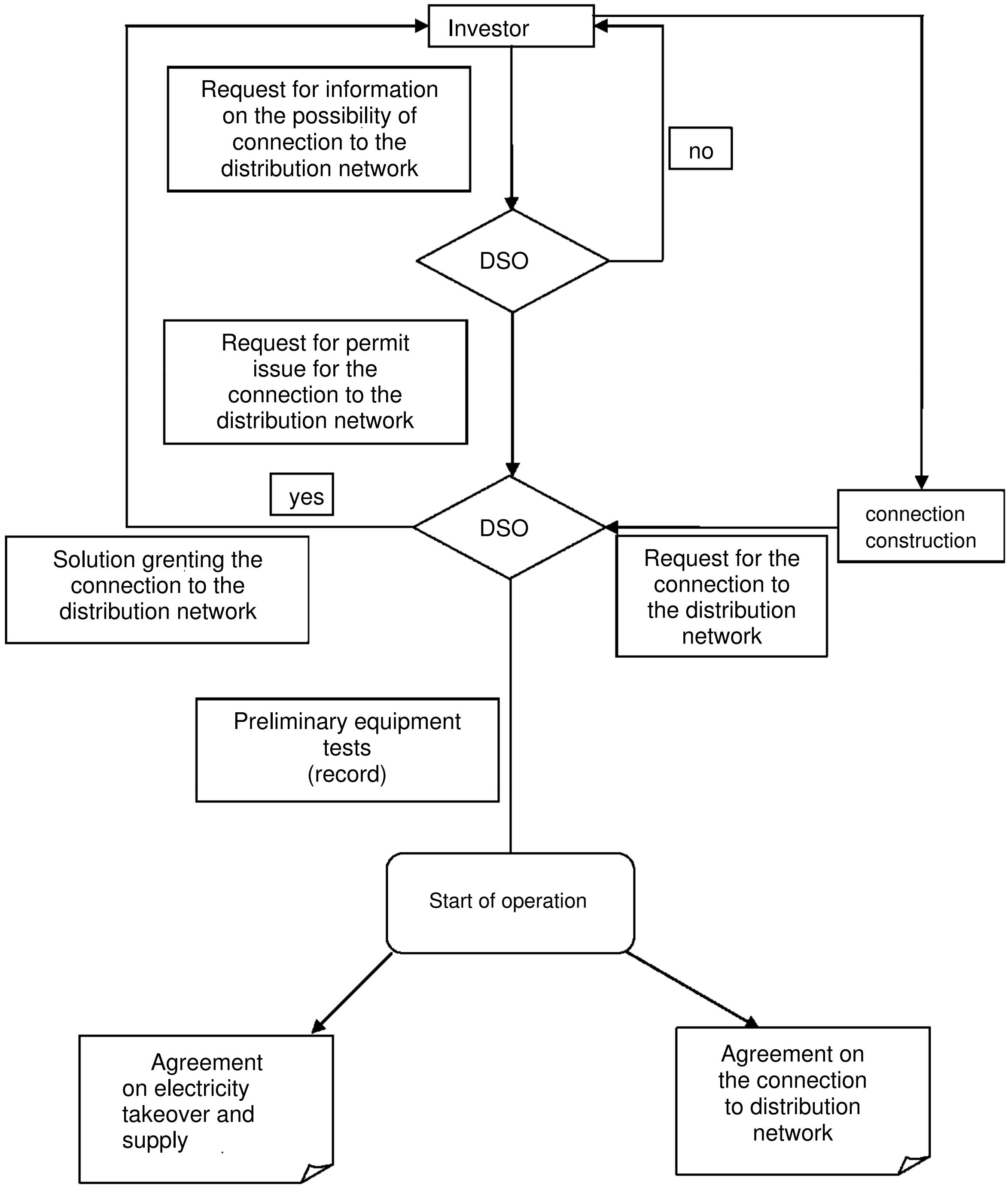


Figure 15: Block diagram of the procedure for connection to the distribution network

5. ANALYSIS OF DISTRIBUTED SOURCE CONNECTION TO THE DISTRIBUTION NETWORK

This chapter shows the complete analyses of distributed source connection to the distribution network of Montenegrin electric power system. Analyses refer to the presented methodology in the third Chapter that defines the required minimum network model and technical options of connection in the most unfavourable situations with reinforcement criteria of the existing network. <u>If possible and suitable, the solutions for distributed source connections are given variantly</u>. In this case also the economic study and classification of variants are conducted. In the continuation, the most important criteria of the presented methodology are summarized acting as the basis for analyses processing.

The general influence of distributed sources on the operation of distribution network is defined and analysed together with the suggested actions for the network operation (voltage regulation, protection adjustment, influence on electric power quality). The opinion is stated about the network points suitable for implementing the projected distributed source measurements (start or end of the connection line).

The sped up integration of distributed sources into distribution network causes difficulties in network operation and management. Integration of remote switches, measurements and advanced information-communication technologies provide better efficiency of network management and thus better reliability in case of network reinforcements. In this context the so called "Smart Grid" technologies are increasingly applied throughout the world.

The influence of various distributed sources connection to the distribution network operation is also explained. There are analyses of small hydroelectric power plants connection on the river Zaslapnica, photovoltaic power plant Čevo and wind power station Birska Gora.

The following Table shows the list of rivers with the projected power output of all power plants analysed in the study. Every river basin (Lim, Komarnica with Piva, Tara and Zeta) are analysed separately in a special subchapter.

All increased outputs are stated with the evaluations of network investments due to the connection of individual distributed sources. The evaluations are given according to standard prices prepared at the EPCG distribution and summarized in the appendix at the end of this Chapter.

Table 5.1: List of rivers with distributed source output power

River	River basin	Installed power [MW]	Municipality
Bistrica	Lim	17	Bijelo Polje
Šekularska	Lim	5	Berane
Trepačka rijeka	Lim	8.3	Berane
Kraštica	Lim	0.8	Berane

Zlorečica	Lim	1.6	Andrijevica
Murinska rijeka	Lim	2.4	Plav
Velička rijeka	Lim	0.3	Plav
Komaraća	Lim	4	Plav
Babinopoljska	Lim	9.5	Plav
Đurička rijeka	Lim	1.4	Plav
Grlja	Lim	3	Plav
Bukovica	Komarnica	3.2	Šavnik
Bijela	Komarnica	1.4	Šavnik
Tušina	Komarnica	6	Šavnik
Vrbnica	Piva	12	Plužine
Bukovica	Tara	0.2	Kolašin
Zaslapnica	Zeta	1	Nikšić

5.1. Summary of technical criteria in the analyses of distributed source connection

Determination of the minimum network model – criterion for determination of the slack node point

In the network node, where the voltage is minimally changed due to distributed source operation, its impact can be negligible. The permitted level of the change is defined by the *Criterion of maximum permitted voltage change Δu_{TM} due to distributed source operation at the point of slack node.* The criterion is described in the methodology section in detail.

Since the network is a radial one, the permitted voltage change Δu_{TM} is the sum of the contributions of the individual distributed sources included in the analysis:

$$\Delta u_{KM} = \sum_i^N \Delta u_{TM_i} < 0{,}005 = \boldsymbol{K_{\Delta U}} \quad - \quad radial\ network \tag{5.1}$$

Criteria for loads and voltage conditions

- **Criteria of permitted loads K_S:**

Lines and transformer loads with maximum DI load and production should not exceed:

- 100 % thermal loads S_{th} for the lines,

$$\boldsymbol{K_{S\_V}}: S_V \leq S_{th} \tag{5.2}$$

- 120% thermal loads for the transformers.

$$\boxed{\boldsymbol{K}_{\mathbf{S\_TR}}:\ \mathrm{S_{TR}} \leq 1{,}2 \cdot \mathrm{S_{th}}} \tag{5.3}$$

- **Criterion of permitted loads in LV network K_{U_NNO}:**

The scope of permitted loads in the LV network:

$$\boxed{\boldsymbol{K}_{\mathbf{U}\_\mathrm{NNO}}:\ 0{,}4\mathrm{kV} \leq U < 0{,}42kV} \tag{5.4}$$

5.2. General DI influence on the distribution network operation

Distributed sources considerably influence the distribution network operation. The most prominent impacts are recorded for:

- voltage changes
- voltage regulation and reactive power compensation
- electric power quality
- protection coordination
- reliability.

5.2.1. Voltage condition changes, voltage regulation and reactive power compensation

Causes of voltage changes

Voltage changes in distribution networks are caused by load oscillations. In the situations with high loads during working days, the voltages are low due to greater voltage drops, whereas in the situations with low loads the voltages are high. Voltage deviations are recorded due to static voltage regulation with transformer tapping adjustment in substations where the voltage is compensated for average load values.

In case of distributed source operation in MV or LV network, the power flow is alternating, causing even more voltage changes in the distribution network. The level of change also depends on the network configuration and power. The management of voltage changes is conducted by voltage regulation or lower impedance through network reinforcement.

In regard to the methodology used in the analyses the voltage changes should be max ± 10 % of nominal voltage, whereas in the LV network this is determined by the Criterion 1.4.

Conversion to 20 kV

In this context, this study suggests that the integration strategy of conversion to 20 kV voltage level is prepared in Montenegro, but with the omission of levels 35 kV and 10 kV. Distribution network also comprises of three voltage levels with 110/20/0.4 kV transformation and active automatic regulation of 20 kV busbars. The general rule is that 35 kV network is converted to 110 kV, 10 kV network to 20 kV.

The integration strategy has to provide answers for several thematic areas that exceed the context of this study. Some of the most important are:

- complete analysis of technical and economic advantages of conversion
- changes of distribution network operation concept (protection coordination, network earthing, influence on energy quality and reliability)
- changes of distribution network planning concept (establishing technical criteria and characteristic network structures, specification of standard network elements)
- conversion dynamics with concrete actions
- specification and standardization of electric power equipment
- priority areas of conversion.

It is evident from the previous experience that the conversion is conducted gradually in the long term, i.e. ten to twenty years or even longer. However, the projected distributed sources analysed in this study have to be connected to the network as soon as possible (in this year or in the following years). That is why the analysis of conversion to 20 kV due to connection of these sources is inconsistent. **However, all the projected solutions for connection and network developments included in the analysis project or permit simple conversion to 20 kV when needed.**

Voltage regulation and reactive power compensation:

The methods of voltage regulation in the distribution network:

- active regulation
  - automatic dynamic power transformer tapping adjustment
  - compensation of reactive power along the distribution network
- passive regulation
  - automatic dynamic power transformer tapping adjustment.

The most basic method of voltage regulation in a distribution network is the adjustment of transformer primary tappings at substations. At the substations with 110 kV/MV transformation the tappings are normally adjusted automatically according to determined voltage. Dynamic tapping adjustment increases (lower voltage on the secondary) or decreases (higher voltage on the secondary) the transformer ratio. In Montenegro, this method is implemented for energy transformers in TS 110/35 kV.

Where the automatic adjustment at the substations is not possible (i.e. TS 35/10 kV and TS 10/0.4 kV), the tappings are constantly set to withhold the voltage within the permitted limits.

During high loads in the distribution network the voltages should be at 35 kV or 10 kV busbars a litter higher due to drops, whereas during low loads somewhat lower. Distributed sources compensate voltage drops or even cause the increase in the opposite direction. **Thus it is necessary to allow active adjustment of determined voltage in the process of network operation management. This adjustment is regulated automatically and adapts to the network situations.**

The analyses of distribution network operation showed that the voltage should be kept within the limits with automatic voltage regulation on 35 kV busbars in TS 110/35 kV:

- **35 kV busbars in TS 110/35 kV above 34.5 kV (low loads) and below 37.5 kV (high loads)**
- **10 kV busbars in TS 35/10 kV above 10.2 kV (high loads) and below 10.6 kV (low loads)**

Node voltage and the balance of reactive power are physically connected. From the viewpoint of distributed source production the inductive reactive power causes voltage increase, whereas the capacitive power decreases the node voltage. In the modern distribution network (Smart Grids) there exists a possibility to withhold the voltage within the limits by inclusion of compensation devices (capacitor banks, reactors) at the characteristic points. The regulation of inductive or capacitive power of individual source in the network operation with distributed sources can be expected in accordance with the Chapter 4.9 provisions of this study.

Due to more efficient use of distribution network, the **network operation analyses** can include a possibility of production or reactive power drainage of distributed source (characteristics in the Chapter 4.9 of this study). There exists a recommendation stating that the **total reactive power in all distributed sources should not exceed 10 % of nominal transformer power S_n with 175 connected sources.**

In the analyses with a great number of distributed sources that include also the network planning **(network development analyses)** it is necessary to establish such a criterion that guarantees reliable network operation in the most demanding conditions with no coordinated voltage regulation by reactive power compensation of all distributed sources in the network section. This is the reason to **project the distributed source operation with cosφ=1**.

The adjustment of the reactive energy over-exchange from the transmission network is mainly provided by activating and deactivating the capacitor banks at the substation. This has a direct influence on voltage value at TS busbars.

5.2.2. Electric power quality

As well as consumers, distributed sources can also cause the electric power quality decrease in the network through their operation. The quality of electric power in the network should be in accordance with MEST EN 50160. To provide this, distributed sources, as well as consumers, should not cause interferences greater than those determined in the **Recommendation** (Chapter 4 of this study), i.e.:

Harmonics:

THD greater than 5 % in accordance with IEC 60034-1, under additional condition that it does not causes too high THD at some other point in the network.

The current of higher harmonics should be in accordance with Point 5.7 and Tables 5.7a and 5.7b of the **Recommendation**.

For DI connected to DS via the inverter, the direct injection component to the distribution network should not exceed 0.5 % of the determined inverter current. The additional condition for LV network is that the direct injection component to the distribution network should not exceed 1000 mA.

DI with frequency convertors has to be checked also for damaging DI operation on ripple control system or ripple control signal propagation and **PLC system** conditions from the viewpoint of higher harmonics.

Flicker and voltage changes:

The highest voltage changes should be in accordance with the Point 5.4 and Table 5.4 of the **Recommendation**.

The permitted long-term flicker P_{lt} of all DI generators in the network should not exceed 0.46.

Synchronization conditions:

Synchronization conditions should be in accordance with the Point 5.10 of the **Recommendation**.

5.2.3. Protection coordination

If a DI is connected to the network, this network should block the APU operation at the feeder to which DI is connected. Thus, DI can be automatically deactivated in case of network damages (according to U or f protection at the decoupling point) before the quick APU can reconnect it to the network. If APU is not blocked, especially at synchronic generators, the damages can occur by shaft breaking.

Single DI operation in the network is not permitted.

The **insulated DI operation** is permitted within the network on the generator side of the decoupling point, if DI structure so allows.

If ME has the possibility of separate operation from DS and the operation protection causes were $U<$, $U>$, $f<$ or $f>$ conditions at the decoupling point, the DI is tapped from DS at this point and can start working separately from DS (if the investor so requires). After the re-established U and f protection conditions for the operation continuation of DI in DS at the decoupling point, according to the investor's requirement, ME can be resynchronized in DS at the decoupling point or generator switch, depending on the state of the generator (generators) in DI.

If the cause of protection operation was a power current, the damaged generator can initiate malfunction stopping.

Over-current protection is a three-phase maximum, time-independent current protection that reacts:

- In current load time delays, exceeding the permitted values of current loads of the connected line (TP-14a) – over-current protection I >;
- Momentarily for close short circuits – short-circuit protection I >>.
- Measuring relays of over-current protection for current rating 5 A and for the smallest range of adjustments are:
- (3 - 9) A for over-current protection I>
- (20 - 50) A for short-circuit protection I>>
- The smallest range of adjustments for over-current time delay protection I > should be (0.2 - 3) s.

Earthing protection is a homopolar protection the performance of which depends on the method of MV network neutral point earthing (TP-6):

- If the neutral point of MV network is earthed through low-resistance impedance, the single-phase maximum time-independent current protection I0 > is applied, with the measuring relay for current rating In = 5 A of the smallest range of adjustment (0.5 – 2.5) A. The protection should react with a minimum time delay of adjustment range (0.2 – 3) s.
- If the neutral point of MV network is separated, the earthing protection depends on the amount of capacitive earthed current of electrically connected network and is implemented towards the point 1.4TP-4a1.

LV protection of the connection line to DI is over-current, via short-circuit (solenoid) and thermal breaker of LV switch, point 6.3.

All types of ME should have a changer in the decoupling ME installation. This is a signal changer that is exclusively monitored by ODS and through which ODS can disconnect ME from DS. Changer protection (exclusively by ODS) is analogue to the protection of main fuse protection system of DS users. ODS applies this changer in cases that ME should be disconnected from DS. By placing the changer from position "1 (ON)" to position "0 (OFF)" the ME cannot operate in parallel with DS.

During current protection operation at the ME decoupling point, the operation of ME on DS is not possible until ODS annuls the protection by switching the changer according to the "1" → "0" → "1" sequence (in case of digital protection, with this possibility) or changes the fuses in case of such protection.

It should be noted that after annulling the protection or change of fuses at the decoupling point, ODS only provides the necessary condition for the investor to reconnect to DS. The responsibility and consequences of the reconnection process are exclusively the investor's.

Three-phase generators operating in parallel with DS should have the zero point insulated. However, in the process of converting to insulated operation, the zero point should be automatically earthed due to the possibility of damage current I_0 detection.

Standard protection adjustment at the decoupling point for all generators is stated in the

Table 4.1 and 8.2.

Table 4.1 is applied, if ME has only one-stage protection, whereas Table 4.2 is used, if ME has the possibility of two-stage protection. In the Table 4.2, the second protection stage can be adjusted to any value in the determined zone.

In special situations, ODS can require a non-standard protection adjustment at the decoupling point.

Automatic restart of DI after the U operation or f protection should not be conducted prior to

- 3 min for rotating machines and
- 20 seconds for inverter systems.

5.2.4. Measurements of the power taken from distributed sources in the distribution network

When connecting a distributed source to the network, the question arises whether the measurements are set at the start or end of the connected line to the network, from the point of distributed sources. The question is important due to cost payment for the losses at the connected line.

If there exists a possibility the distributor uses the connection line for the network development or connection of additional users in the future, measurements are placed at the beginning of the connected line, at the distributed source. Otherwise the measurement can take place at the end in the connection node (TS busbars). Of course, the producer and the distributer can mutually determine these points of measurements.

5.2.5. Network operation reliability

Distributed sources have negative effect on network operation reliability. The biggest problems occur during the voltage changes in the network. Therefore, dispatchers should constantly monitor and adjust the voltage profile in the network. According to the efficient network management it is good to know voltages that occur deeper in the network, below the busbars in the substation. **In this way it is possible to equip distributed sources and some relevant nodes with remotely controlled switches** that measure the voltage and current.

The most important DUP functions:

- they increase the observation of network conditions
- in case of malfunctions they separate the network (short-circuit interruptions) and shorten the time of interruptions at the consumer's points
- transfer a part of load to the neighbouring source (if there is a circular connection)
- they enable the optimum network decoupling according to losses and interruptions

Through the established remote connection between management centres and distributed sources, the dispatcher controls whether the source operates in accordance with U-Q voltage regulation characteristics, governed by the recommendation in the Chapter 4.9.

Especially in networks with sources in a circular configuration, DUP can essentially increase the network operation reliability. **The analysis in the study showed a very poor interconnection of distribution network in the areas with the projected sources**. If possible, the construction of circular connection is projected.

The study of individual cases suggests the establishment of decoupling stations (RS) that are installed in the nodes with several tappings. These tappings become the **feeders from RS and are equipped with complete secondary equipment (protection, remote control, etc.).** Distributed sources are connected directly to RS. **This provides better selectivity and load due to equally distributed sources among the feeders, causing lower impact on network operation.** If the distributed source is connected with its own feeder (line) directly to TS, the installation of standard decoupling system suffices for this line due to complete protection at the source.

5.3. The impact of distributed source type on network connection analysis

In the type of analyses in this study that plan the network development with numerous distributed source connections, the special method needs to be conducted that was presented in the Chapter 3 of this study. The methodology ensures efficient and long-term reliably distribution network operation with gradual connection of all projected distributed sources. These analyses do not include a detailed picture of source operation characteristics, but with the application of implemented criteria they register the most difficult operation statuses in the network.

These are the summarized general facts for planning, established in the methodology, that do not depend on distributed source type:

- **starting points: minimum and maximum loads, confirmed network development**
- **technical criteria (determination of slack node point, permitted loads, permitted voltages)**
- **analysis of energy situations in the most adverse conditions (maximum consumption and minimum production, minimum consumption and maximum production)**
- **operation of distributed sources with cosφ=1.**

A type of distributed source generator is important in case of precise operation analyses of the individual distributed source influence where the flickers, local voltage conditions with reactive power regulation (U – Q characteristics), protection and short-circuit currents and other elements defined in the recommendation of this study are analysed.

The continuation shows the cases of concrete analyses of connections to the network for three different types of generators: hydro and wind generator, and inverter generator:

- Small hydroelectric power plants (mHE) on the River Zaslapnica
- Photovoltaic power plant (FVE) Čevo
- Wind power station (VE) Briska Gora.

5.3.1. Concrete example analysis for the river Zaslapnica

5.3.1.1. Grounds

Information about the power stations

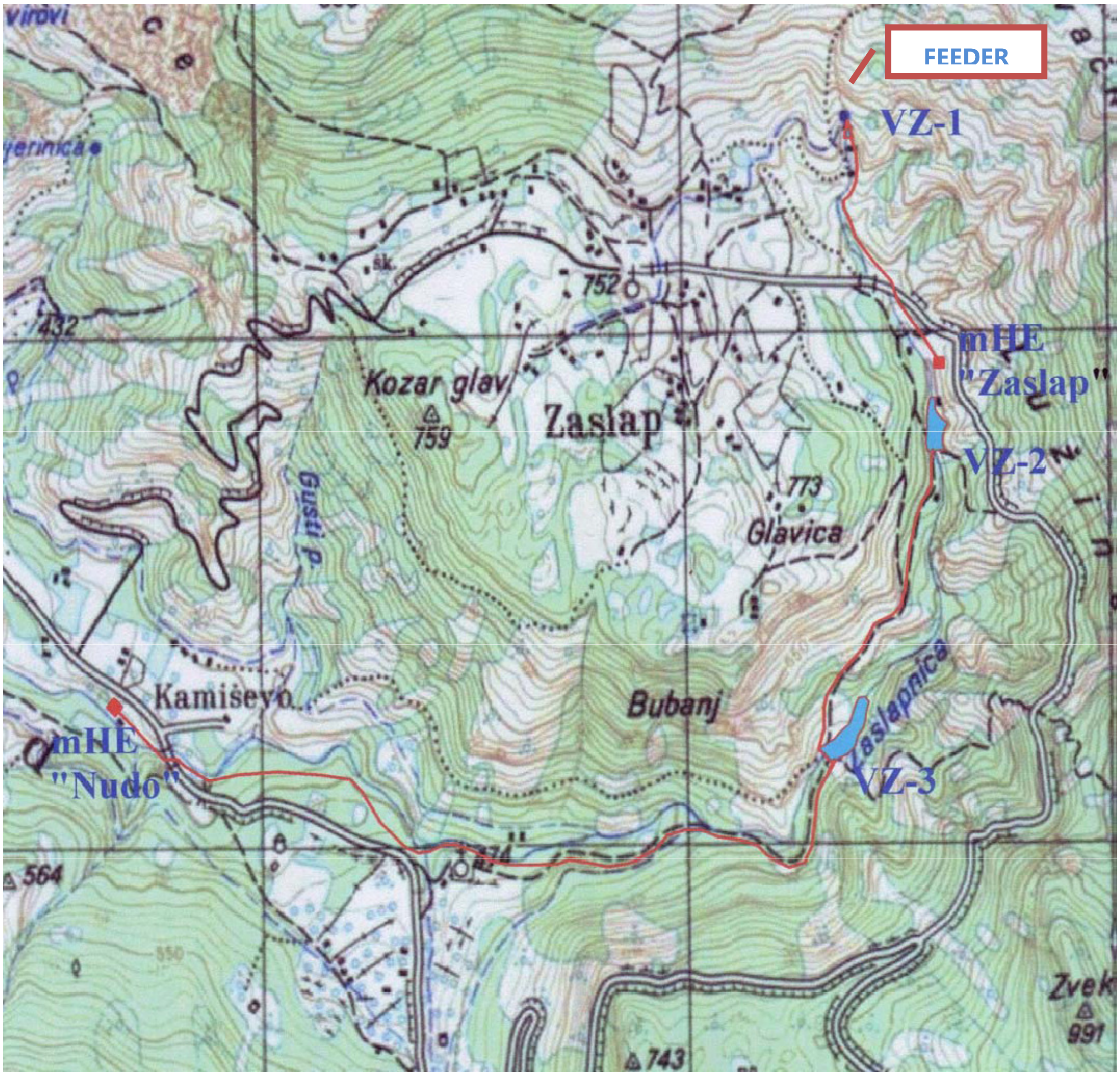


Figure 16: River Zaslapnica – geographical view

The river Zaslapnica rises above the hamlet Zaslap in the south-western part of Montenegro. The first part of the riverbed is steep, falling in the narrow canyon towards the village Nudo. After approximately 6.5 km it merges with the river Sušica and then runs to the river Trebišnjica. The river is a mountain stream.

According to the R1 and R2 study results, the river has the most suitable hydro potential in the first section of 3.7 km. The best solution for exploiting the hydro potential is the construction of the following mHE:

- mHE Zaslap
- mHE Nudo I, II

All important data necessary for the relevant mHE analysis of the influence on the MV distribution network operation are stated in the Table 5.2

Table 5.2: mHE on the river Zaslapnici – basic data

mHE	Q_{inst} (l/s)	H_b (m)	P_{max} **(MW)**	$\cos\phi_n$	generator	Closest SBS 10 kV
Zaslap	270	100	**228**	0.95	synchronous	SBS Zaslap
Nudo I	310	234	**583**	0.95	synchronous	SBS Nudo II
Nudo II	450	141	**511**	0.95	synchronous	SBS Nudo II

The existing distribution network to which mHE on the river Zaslapnica are connected

The power stations will be connected to the MV 10 kV network SBS Vilusi with feeders Petroviči, Velimlje, Trubljela, Grahovo in Vilusi.

Data on SBS Vilusi 110/35/10 kV:

- transformation 110/35 kV
  - 1xTR 110/35 kV:
  - S_{inst} = 10 MVA, U_{n1} = 110 kV, U_{n2} = 36.75 kV
  - automatic voltage regulation at the secondary winding U_{n2} ± 12 ·1,33 %
  - target voltage at the secondary winding: 36,5 kV
- transformation 35/10 kV
  - 1xTR 35/10 kV:
  - S_{inst} = 2.5 MVA, U_{n1} = 36.75 kV, U_{n2} = 10.5 kV
  - manual voltage regulation at the secondary winding U_{n2} ± 2 ·2.5 %
  - target voltage at the secondary winding: 10.5 kV

The geographical view of the 10 kV network SBS Vilusi section with the planned mHE location is shown in the Figure 16. The Zaslapnica River basin powers 10 kV feeder Grahovo, whereas the Vilusi feeder is situated in the vicinity. 10 kV network is a typical countryside network with small volume of consumption with the electrical lines equipped with Al/Fe 35/6 mm^2 conductors. All the feeders are radial and do not allow the option of reserve supply.

The 10 kV SBS Vilusi network does not have any connected distributed sources. According to the available information, the analysed power stations are the only distributed sources connected to the existing network in the medium-term.

Data on feeder loads

The analysis of mHE connection to the distribution network requires the data that is listed in the Table 5.3. This measured data includes the maximum and minimum load from 2011 and the 2015 prognosis.

Table 5.3: Minimum and maximum load – SBS Vilusi

FEEDER	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Grahovo	0.090	0.400	0.097	0.430
Vilusi	0.035	0.100	0.038	0.108
Petrovići	0.075	0.240	0.081	0.258
Velimlje	0.065	0.150	0.070	0.161
Trubljela	0.145	0.400	0.156	0.430
SBS Vilusi	**410**	**1.290**	**442**	**1.387**

Projection of distribution network development

In accordance with the investment plan, the area of SBS Vilusi includes the construction of new SBS 35/10 kV Grahovo with the 35 kV line of 12.5 km from SBS after 2015. The reason is the anticipated increase of consumption in the Grahovo area. The investment will probably not be realized by 2015, therefore the 2015 model analysis has not been yet taken into the account. The second transformer of 35/10 kV, 2.5 MVA will be installed in SBS Vilusi in 2015.

5.3.1.2. Analysis of the power station connection to the network

The power stations are situated near SBS Zaslap and SBS Nudo II that are supplied by SBS Vilusi via the Grahovo feeder. The network with mHE locations is shown in the Figure 17. The Figure shows also the short circuit powers at the nodes of the existing network that are closest to the projected mHE.

Determination of minimum scope of the network model

In the network node, where the voltage is minimally changed due to DI operation, its influence can be negligible. The permitted change limit is defined with the *Criterion on maximum voltage change Δu_{TM} due to DI operation in the slack node point* (**Criterion for defining the slack node point**).

Since the network is a radial one, the permitted voltage change Δu_{TM} is the sum of mHE Zaslapnica and mHE Nudo contribution:

$$\Delta u_{KM} = \sum_{i}^{N} \Delta u_{TM_i} < 0.005 = \boldsymbol{K_{\Delta U}} \quad - \quad radial\ networks$$

The contributions are calculated according to the equations described in the methodology chapter. The calculation bases are the short circuit powers at the SBS busbars and power stations closest to the network points:

- mHE Zaslapnica: $S_{k\_mHE\text{-}Z}$ = 8.11 MVA
- mHE Nudo: $S_{k\_mHE\text{-}N}$ = 7.00 MVA
- 10 kV busbars SBS Vilusi: $S_{k\_SBS\text{-}10}$ = 23.40 MVA
- 35 kV busbars SBS Vilusi: $S_{k\_SBS\text{-}35}$ = 94.90 MVA
- 110 kV busbars SBS Vilusi $S_{k\_SBS\text{-}110}$ = 1154 MVA

Voltage changes along the network from mHE to SBS Vilusi:

- SBS Zaslap: Δu_{TS} = 0,111
- 10 kV busbars SBS Vilusi: Δu_{SBS_10kV} = 0.033
- 35 kV busbars SBS Vilusi: Δu_{SBS_35kV} = 0.008
- 110 kV busbars SBS Vilusi: Δu_{SBS_110kV} **<< 0.005**

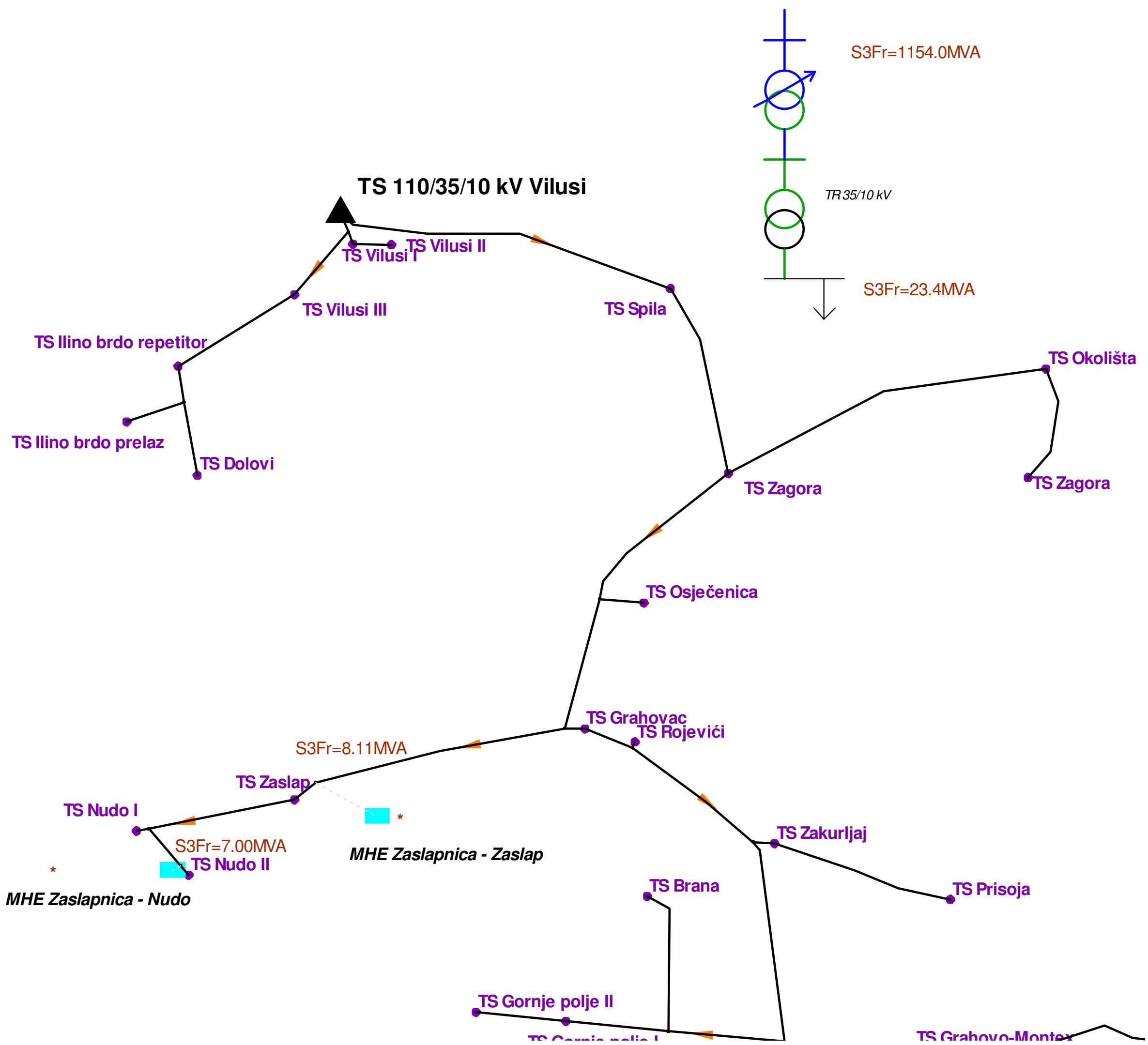


Figure 17: SBS Vilusi network (Vilusi feeder and part of Grahovo feeder) with mHE locations.

The negligible effect of the analysed power stations on the voltage change is achieved only at 110 kV busbars in SBS Vilusi. The network model has to include the 10 kV feeders Grahovo and Vilusi along with transformer 110/35/10 kV in SBS Vilusi for the analysis of the mHE on the river Zaslapnica operation influence.

The network has to be modelled to the LV level of distribution substations with corresponding transformers. Before conducting the distribution transformer analysis, transformer taps have to be adjusted. The simulation of tap adjustment should include:

- Transformer taps are adjusted on days with high loads.
- Estimation of high loads is conducted on the basis of operation hours in the distribution network and peak loads of 10 kV feeders.
- Distribution network in electrical power system of Montenegro has about 5000 operation hours per year. The yearly operation time of the countryside network is lower for about 500 hours.

Conditions before mHE connection to the network

The situations with maximum and minimum loads are analysed. Graphical results of the calculated MV network loads and voltages at LV busbars in TP are shown in the Figure 18 (maximum loads) and Figure 19 (minimum loads).

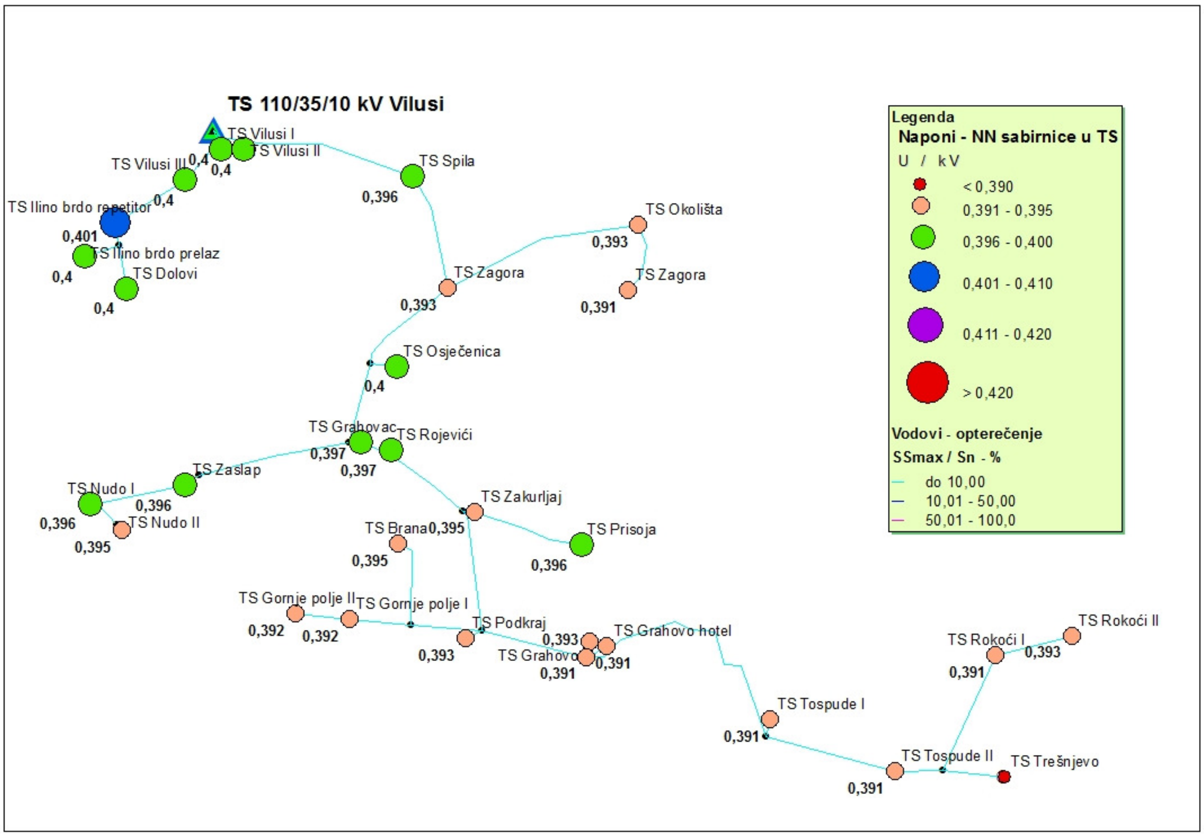


Figure 18: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 without mHE operation.

At low loads the high voltages are recorded in the LV network with the voltages at the individual nodes closing to 0.42 kV.

Operation situation with high loads that show the network load level are not critical. However, the lines are relatively loaded below the permitted thermal limits. Therefore, the following analysis will include only the situations with minimum loads where problems with high voltages arise.

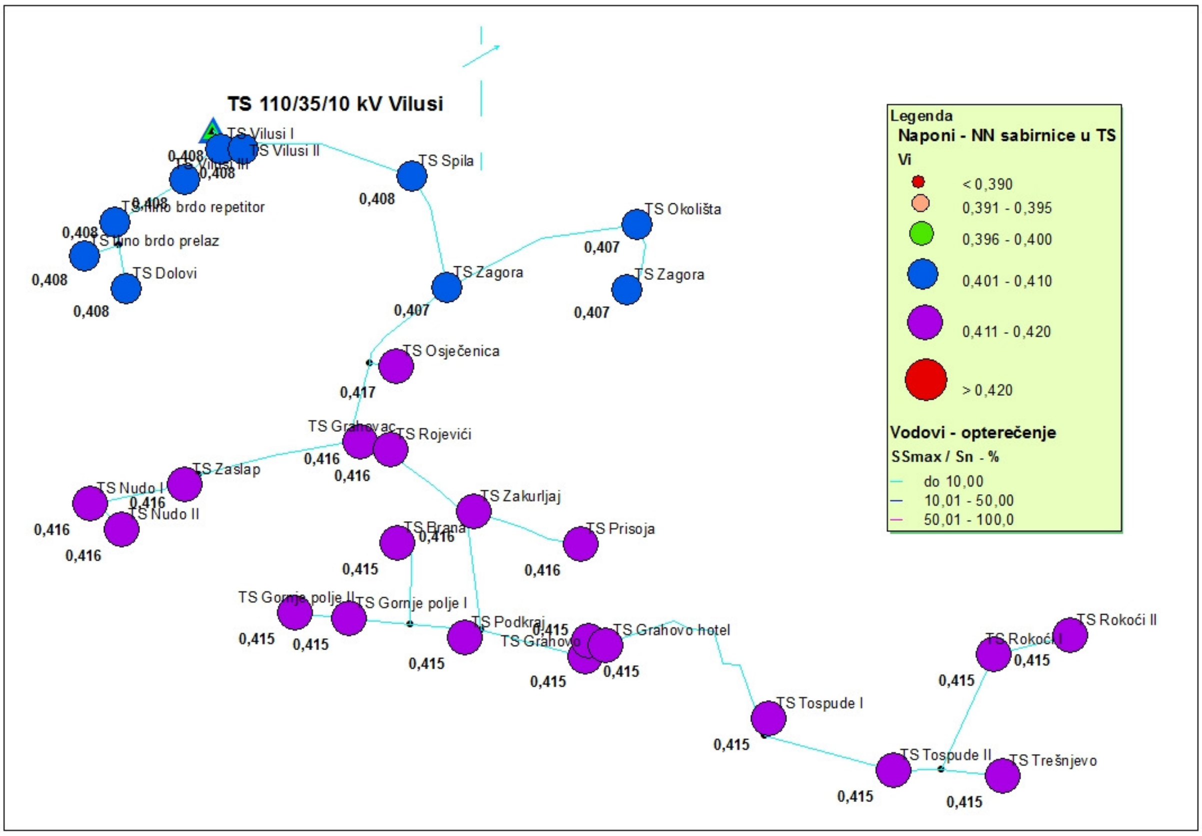


Figure 19: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 without mHE operation.

Connection to the near 10 kV line at the Grahovo feeder

In accordance with the known methodology and criteria, all analysis are conducted for the situations with minimum loads during the mHE operation with the total maximum installed power of 1.318 MW and <u>$\cos\varphi=1$</u>.

The results of analysis for the expected network power conditions in 2011 are shown in the Figure 20 and Figure 21. For the anticipated evacuation of the maximum power of 1.318 MW from mHE the existing network is really too weak because mHE cause the voltage increase in the LV network that exceeds even 0.46 kV. <u>Only up to **0.1 MW** can be safely connected to the existent network.</u>

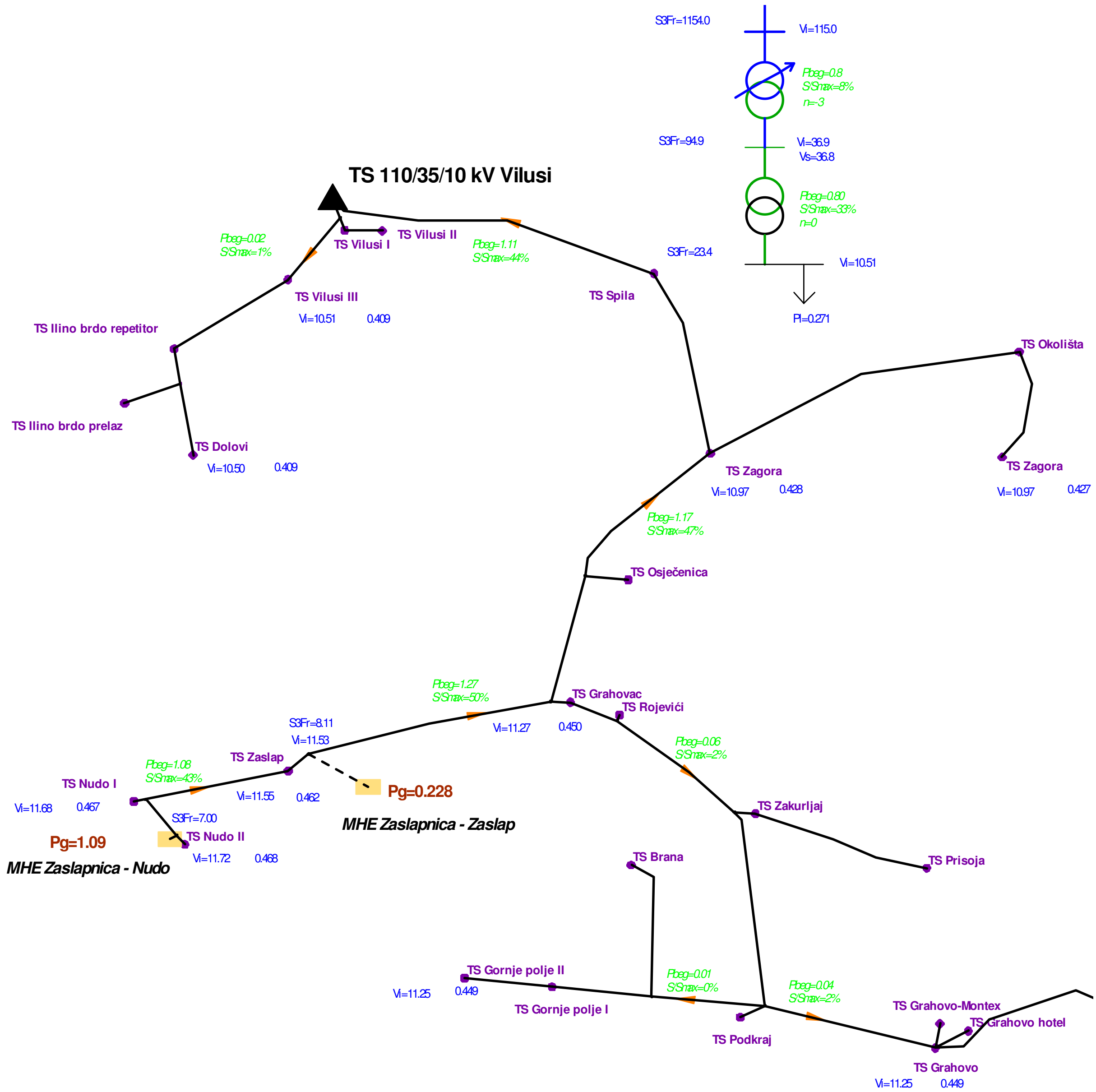


Figure 20: Analysis results of the power conditions – mHE connection to the near 10 kV network, minimum loads 2011.

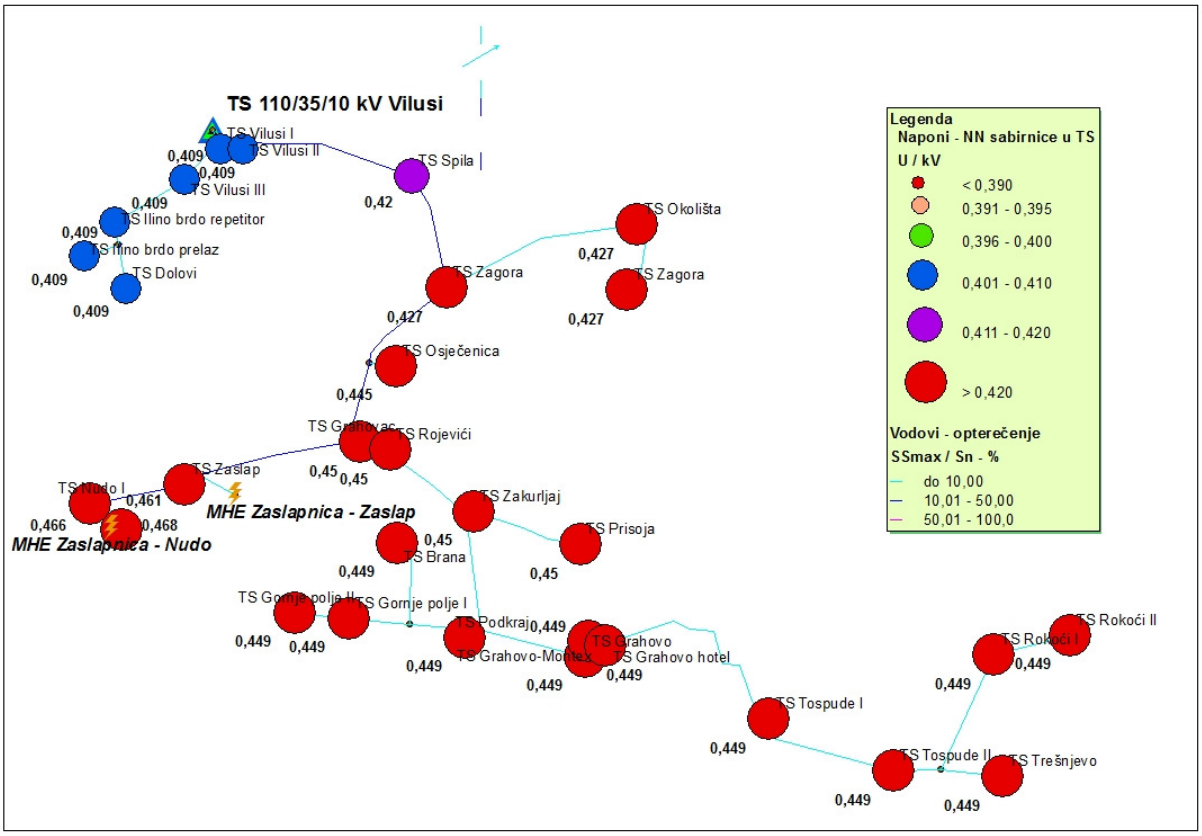


Figure 21: Thematic view of loads in 10 kV network with voltages at LV busbars in TP – mHE connection to the near 10 kV network, minimum loads 2011.

VARIANT A

- **Connection to the 10 kV Vilusi feeder with new Al/Fe 70/12 mm^2 line**
- **Replacement of the existing Al/Fe 35/6 mm^2 with Al/Fe 70/12 mm^2 conductors at the Vilusi feeder**

The Variant shows the mHE connection to the 10 kV Vilusi feeder with new transmission line of the following specifications:

- transmission line Al/Fe 70/12 mm^2,
- total length approx. 6 km
- estimated investment: approx. 330,000 EUR

The existing Al/Fe 35/6 mm^2 conductors have to be replaced with new Al/Fe 70/12 mm^2 conductors in the total length of 3.7 km on the main line (between SBS and SBS Dolovi). The conductor replacement investment is estimated to approx. 15,000 EUR.

The Variant of connecting mHE to the Vilusi feeder is more suitable than the direct connection to the 10 kV SBS Vilusi busbars. The new connection between Zaslap and Dolovi provides the supply of Grahovo feeders in case of malfunctions between SBS Vilusi and SBS Grahovac and Vilusi feeder. In case of emergency overload situation, mHE needs to be disconnected from the network.

An alternative to the transmission line is simply earthed Al 150 mm^2 cable line that has practically the identical results in terms of voltage conditions. Besides, the cable line has lower losses.

Power conditions are shown in the Figure. 22 and Figure 23. Loads and voltage conditions are within the limits defined by the criteria and do not exceed the value of 0.419 kV anywhere in the network.

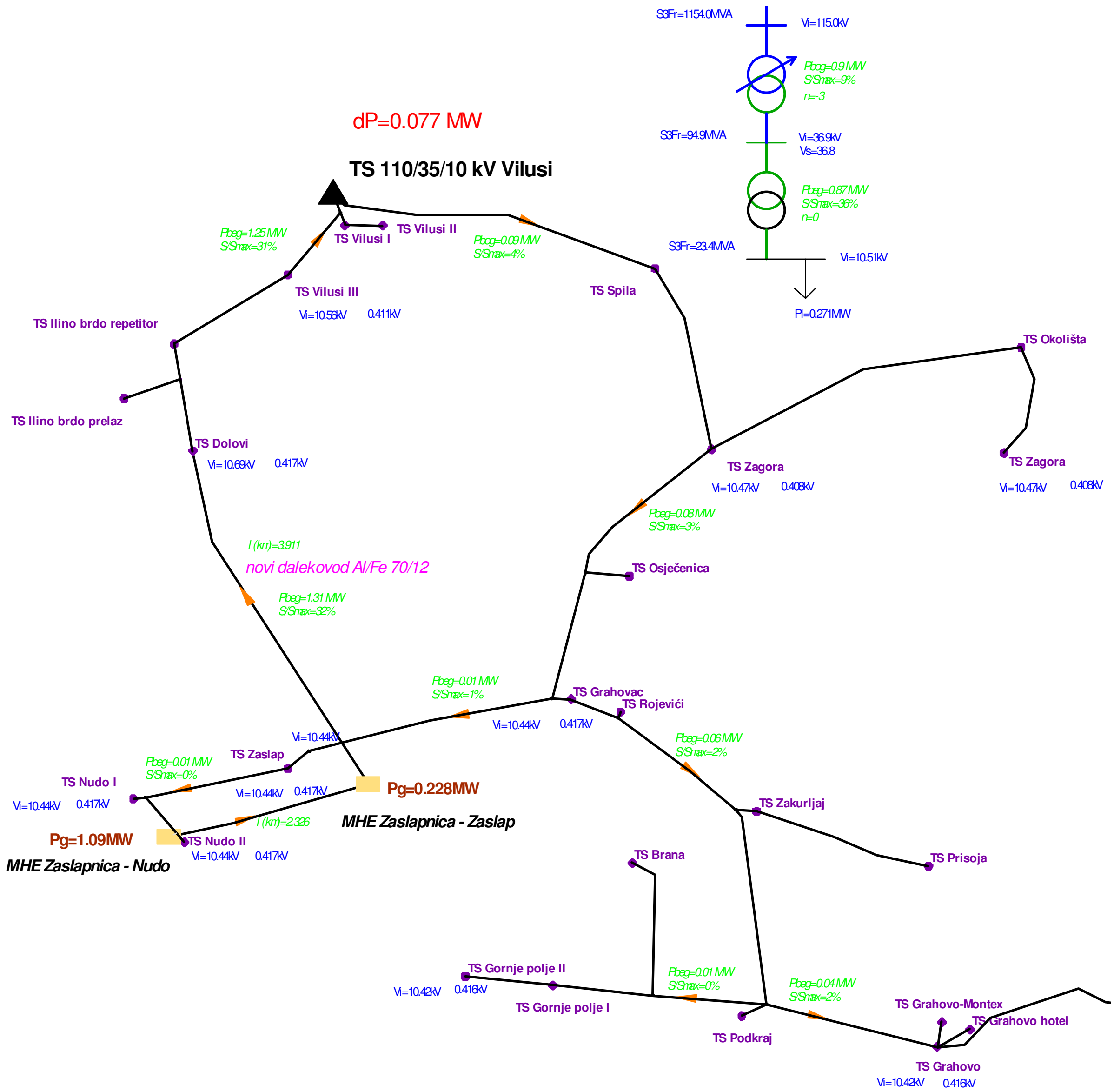


Figure. 22: Analysis results of power conditions – mHE connection to the 10 kV Vilusi feeder with new Al/Fe 70/12 mm^2 transmission line, minimum loads, 2011.

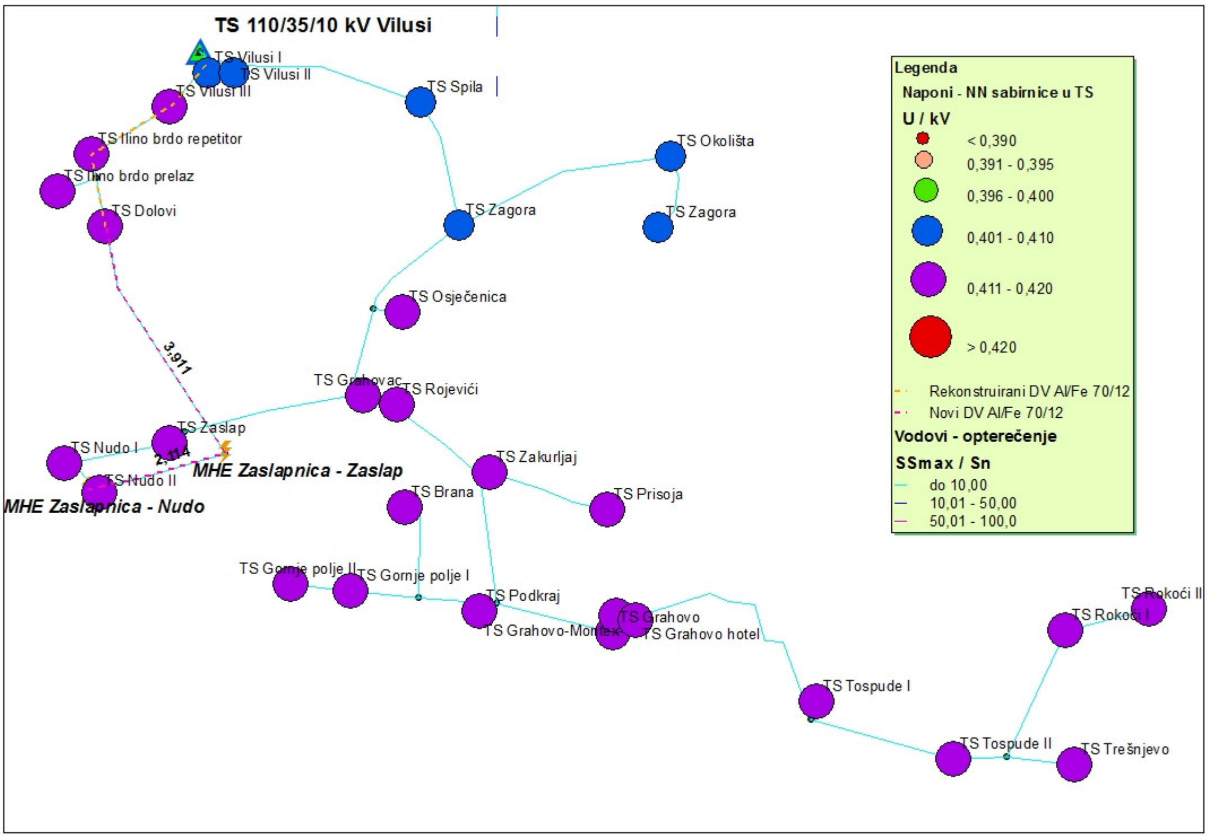


Figure 23: Thematic view of loads in 10 kV network with voltages at LV busbars in TP – connection to new Al/Fe 70/12 mm^2 transmission line, minimum loads, 2011

VARIANT B

- **mHE connection to the new 35 kV feeder Grahovo (Al/Fe 95/15 mm^2 overhead line)**

According to the described variant, mHE are connected to the new section of 35 kV transmission line between Vilusi and Grahovo. The construction of new SBS 35/10 kV Grahovo with new 35 kV transmission line from SBS Vilusi is planned for 2015. The first phase before 2015 can see the construction of the new 35 kV transmission line for the needs of mHE connection to the Zaslapnica tap. Since the transmission line will operate radial in the long-term, the tap connection of mHE to the new transmission line suffices.

Necessary network reinforcements for mHE connection:

- 35 kV overhead line between SBS Vilusi and new SBS Grahovo – a section between SBS Vilusi and a tap in the direction of mHE on Zaslapnica
  - Al/Fe 95/15 mm^2 conductor
  - total length approx. 7 km,
  - estimated investment: approx. 350,000 EUR.
- 35 kV overhead tap between new 35 kV Vilusi overhead line – Grahovo and mHE on Zaslapnica:
  - Al/Fe 95/15 mm^2 conductor
  - total length approx 4.5 km,

– estimated investment: approx 225,000 EUR.

Power conditions for the situations with minimum loads during mHE operation in the network are shown in the Figure 24 and Figure 25. Load and voltage conditions are within the limits defined by the criteria and do not exceed the value of 0.419 kV anywhere in the line.

Figure 24: Analysis results of power conditions – mHE connection to the new 35 kV Grahovo feeder, minimum load, 2011

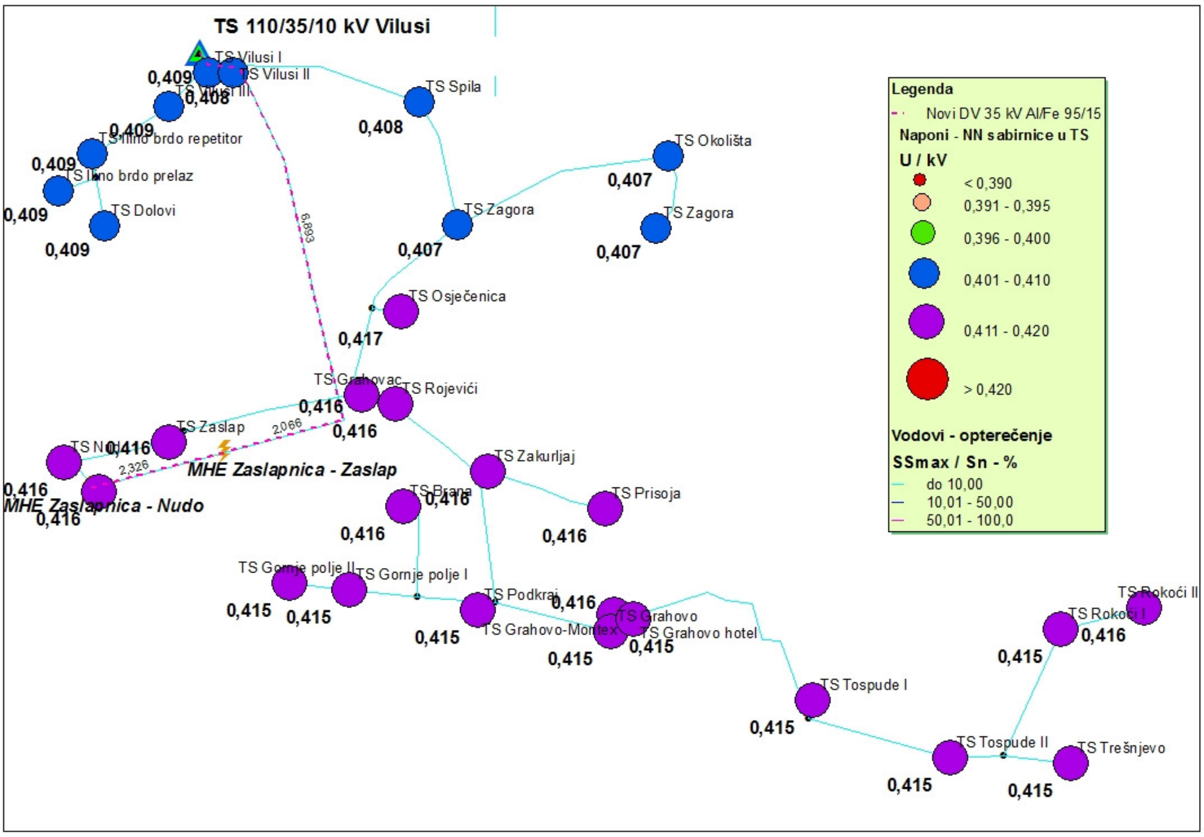


Figure 25: Thematic view of loads in the 10 kV line with voltages at LV busbars in TP – connection to new 35 kV Grahovo feeder, minimum loads, 2011.

5.3.1.3. Summary

The heaviest expected voltage conditions are analysed: maximum loads in the network without mHE operation and minimum loads for full operation power of the projected production. The mHE operation with s cosφ=1 is expected.

Only 0.1 MW of the estimated 1.3 MW can be reliably connected to the existing 10 kV connection on the river Zaslapnica. The main problem of mHE operation in the distribution network is caused by characteristic changes that could bring the characteristic voltage increase exceeding the critical limits of 0.42 kV.

Many of power evacuations that provide distribution network operation with high quality voltage profile can be achieved only with the proper structure reinforcement. The analysis of the recommended network reinforcements includes two versions. Option A refers to the 10 kV network reinforcement, whereas Variant B consists of 35 kV network reinforcements.

2015 analysis has not shown any problem in the network operation. Thus the planned network provides a reliable long-term operation also after 2015. The comparisons of two variants are shown in the Table 3.

Table 5.4: Comparison of mHE connection variants on the river Zaslapnica to the distribution network

mHE – ZASLAPNICA	
Advantages	
VARIANT A – connection to the 10 kV Vilusi feeder	**VARIANT B – connection to the new 35 kV Grahovo feeder**
- low connection costs - better operation reliability of 10 kV network (possibility of oversupply between two feeders) - part of produced power is compensated with environment consumption - solution is not related to other network investments - mHE connection to the network via 10/0, 4 kV transformer is technically (smaller losses) and economically (more inexpensive solution) more suitable solution compared to the connection via transformer 35/0.4 kV)	- smaller voltage oscillations in 10 kV and 0.4 kV network - better operation reliability of the planned mHE - smaller losses in the network (50 kW in average) - more inexpensive solution in case of new 35 kV overhead line construction between Vilusi and Grahovo
Summary of the necessary network reinforcement	
- new overhead line between SBS Dolovi and mHE on the river Zaslapnica (Al/Fe 70/12 mm^2, l=6 km) - replacement of conductors with new Al/Fe 70/12 mm^2 conductors on the main line (Vilusi feeder) between SBS Vilusi and SBS Dolovi (l=3,7 km)	- new section of 35 kV overhead line between SBS Vilusi node and tap in the direction of mHE on the river Zaslapnica (Al/Fe 95/15 mm^2, l=7 km) - new 35 kV overhead line between 35 kV Vilusi – Grahovo overhead line and mHE on the river Zaslapnica (Al/Fe 95/15 mm^2, l=4,5 km)
Investment cost projection	
- 280,000 EUR	- 225,000 EUR (+ 350,000 EUR – part of new 35 kV Vilusi – Grahovo line)

5.3.2. Example of photovoltaic (PV) power plant connection analysis (FVE Čevo)

5.3.2.1. Starting points

Data on the power plant

FVE Čevo with its projected installed power of 1.2 MW is located in the vicinity of the town Čevo with the substation TS 35/10 kV. The geographic location of the projected power plant is shown in the Figure 26.

Figure 26: Location of FVE Čevo

All relevant data needed for the analysis of FVE impact on the operation of MV distribution network are stated in the Table 5.5.

Table 5.5: VFE Čevo – General data

VFE	P_{max} (MW)	$\cos\varphi_n$	generator	closest TS 10 kV
Čevo	**1.2**	1	inverter	TS Donji Kraj

The existing distribution network to which FVE is connected

The power plant will be connected to 10 kV MV network TS Čevo with feeders Bata, Bijele Poljane, Velestovo and Čevo. TS Čevo is supplied by approx. 22 km long 35 kV transmission line from 110/35 kV TS Cetinje, where the voltage is regulated on 35 kV busbars. In the direction of TS Glava Zete the 35 kV transmission line is tapped and serves as a reserve supply.

Data for TS Čevo 35/10 kV:

- <u>Transformation 35/10 kV;</u>
  - 1xTR 35/10 kV

- S_{inst} = 2,5 MVA, U_{n1} = 35 kV, U_{n2} = 10.5 kV
- Manual voltage regulation on the secondary U_{n2}± 2 ·2.5 %
- Short circuit voltage u_k = 5.7 %.

The geographical representation of one part of 10 kV network TS Čevo with projected location is shown in the Figure 27. This is is supplied by 10 kV feeder Bata. In the vicinity there is also the feeder Bijele Poljane. 10 kV network is a typical rural network with low consumption density. The lines are equipped with Al/Fe 35/6 mm^2 conductors. All feeders are radial and without the possibility of reserve supply.

No distributed source is connected to 10 kV network TS Čevo. According to the available data, the analysed power plant is the only distributed source to be connected to the existing network in the medium-term.

Data on the feeder loads

For the needs of the analysis of power plant connection to the distribution network, the Table 5.6 shows measurement data on maximum and minimum loads in 2011 and the prognosis for 2015.

Table 5.6: Minimum and maximum load – TS Čevo

FEEDER	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Bata	0.11	0.33	0.12	0.35
Bijele poljane	0.06	0.18	0.06	0.19
Velestovo	0.05	0.14	0.05	0.15
Čevo	0.09	0.26	0.10	0.28
TS Čevo	**0.31**	**0.91**	**0.33**	**0.97**

The projected development of distribution network

In accordance with the distribution network investment plan, the reconstruction of DV 35 kV Cetinje – Ćevo is projected after 2015 in the area of TS Čevo. The investment is realized to lower the number and duration of losses.

5.3.2.2. Analysis of power plant connection to the network

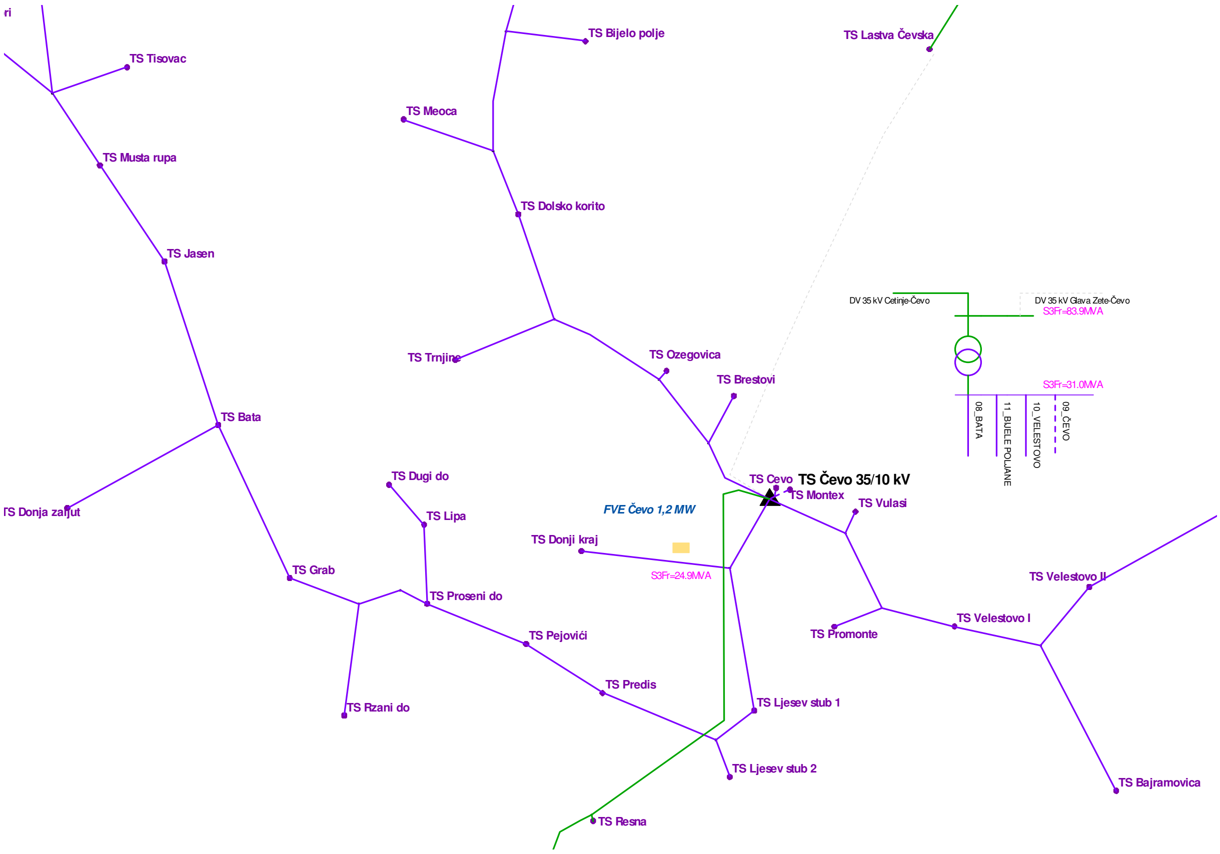


Figure 27: TS Čevo network with FVE location

The power plant is located in the vicinity of the tapping towards TS Donja, where it is supplied from TS Vilusi via feeder Bata. The network with the FVE location is shown in the Figure 27. This figure also shows the short circuit powers in the nodes of the existing network, located the closest to the projected power plant.

Determination of the network model range

Since the network is a radial one, the permitted voltage change Δu_{TM} is calculated according to:

$$\boxed{\Delta u_{KM} = \sum_i^N \Delta u_{TM_i} < 0{,}005 = K_{\Delta U} \quad - \quad \text{radial network}} \qquad 5.1$$

Its contribution is calculated according to equations conducted in the Chapter with the described methodology. The basis for calculation is short circuit power on TS busbars and power plants closest to the network points:

- FVE Čevo: S_{k_FVR} = 24.9 MVA
- 10 kV busbars TS Čevo: $S_{k\_TS\_Cev\text{-}10}$ = 31.0 MVA
- 35 kV busbars TS Čevo: $S_{k\_TS\_Cev\text{-}35}$ = 83.9 MVA
- 35 kV busbars TS Cetinje: $S_{k\_TS\_Cet\text{-}35}$ = 263.2 MVA
- 110 kV busbars TS Cetinje $S_{k\_TS\_Cet\text{-}110}$ = 1542 MVA

Voltage changes along the network from FVE to TS Čevo and TS Cetinje:

- Tapping towards TS Donji kraj: Δu_{mreza_10kV} = 0.029
- 10 kV busbars TS Čevo: $\Delta u_{TS\_Cev\_10kV}$ = 0.023
- 35 kV busbars TS Čevo: $\Delta u_{TS\_Cev\_35kV}$ = 0.008
- 35 kV busbars TS Cetinje: $\Delta u_{TS\_Cet\_35kV}$ **<< 0.005**

Negligible impact of the analysed power plants on the voltage change is achieved only on 35 kV busbars in TS Cetinje. The network model for the analysis of FVE Čevo operation influences should include 10 kV feeders Bata and Bijele Poljane, 35/10 kV transformation in TS Čevo and 35 kV transmission line Čevo – Cetinje with 35 kV busbars in Cetinje.

The network should be modelled to the LV level of distribution substations with the pertaining transformers. Prior to the realization of analyses, the distributed sources should have transformer tappings adjusted. The tappings adjustment simulation should include:

- Transformer tappings are adjusted during high load periods
- The evaluation of high loads is conducted on the basis of operation hours in the distribution network and the highest load of 10 kV feeders
- Distribution network in EES Montenegro has about 5000 operation hours per year; annual operation hour of rural network is lower for about 500 hours.

Conditions prior to FVE connection to the network

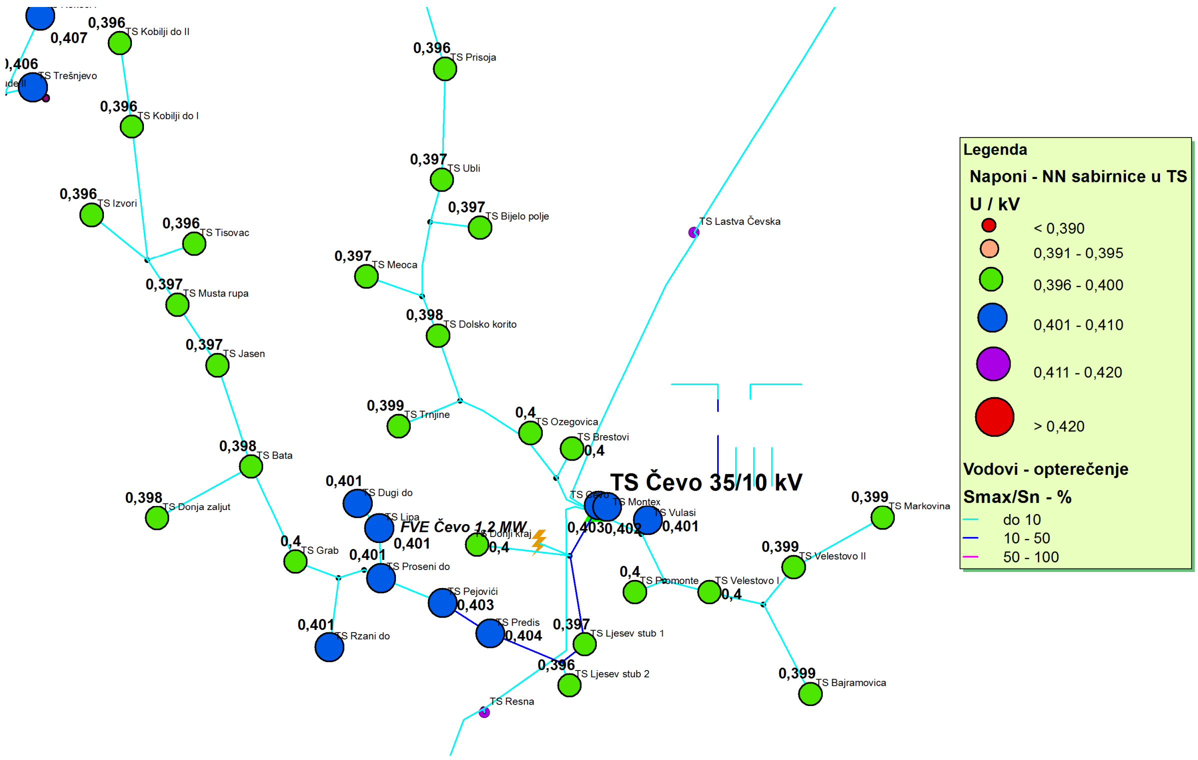


Figure 28: Loads in 10 kV network and voltages on LV busbars TP – maximum loads 2011. Without FVE operation

The situations with maximum and minimum loads are analysed. The graphic results of calculated loads in MV network and voltages at LV busbars in TP are shown in the Figure 28 (maximum loads) and Figure 29 (minimum loads).

Regarding low loads there are recorded high voltages in LV network, with voltages at individual nodes approaching 0.42 kV.

Operation situations with high loads indicating the network load level are not critical. The lines are loaded quite below the permitted thermal limits. That is why the following analyses would include only the situations with minimum loads where there occur difficulties with high voltages.

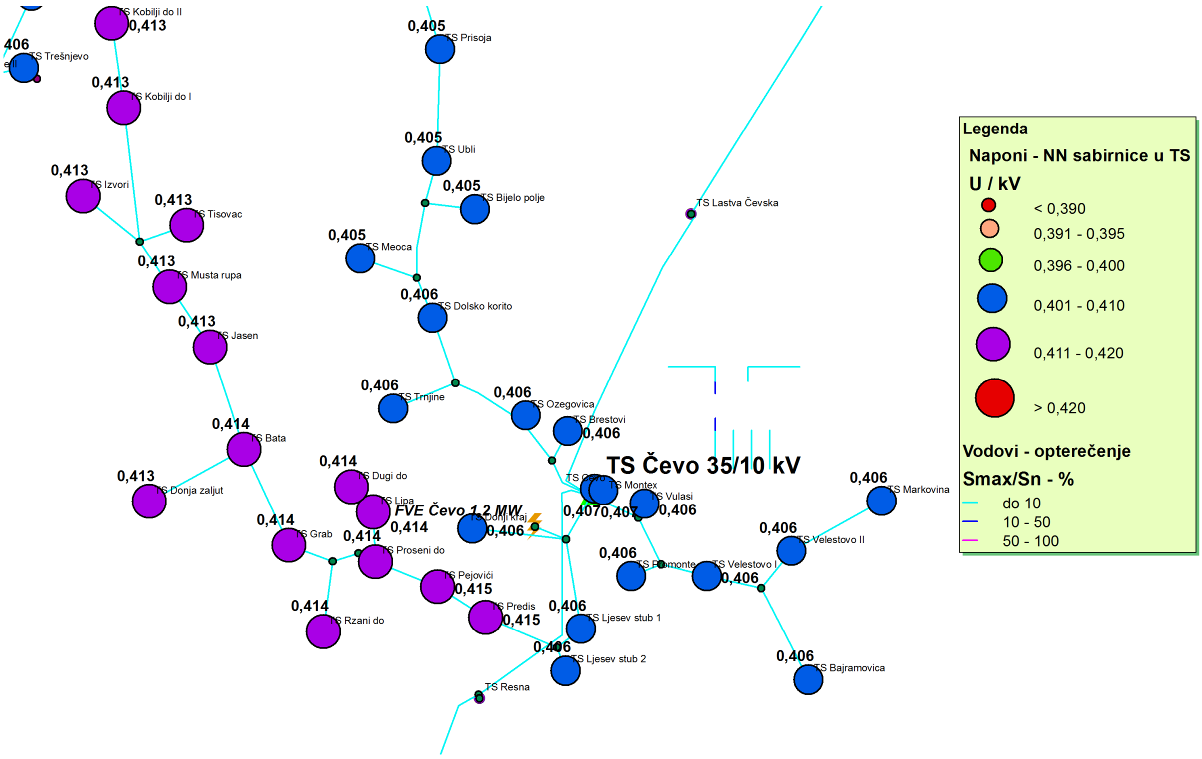


Figure 29: Loads in 10 kV network and voltages on LV busbars TP – minimum loads 2011. Without FVE operation

Evaluation of losses: **0.141 MW**

FVE connection to the network at the proximate 10 kV line at feeder Bata

According to the known methodology and criteria all analyses are conducted for the situations with minimum loads during FVE operation with total maximum installed power 1.2 MW and i cosφ=1.

The analysis results for the expected energy situations in the existing network in 2011 are shown in the Figure 5.4. The existing network is to weak for the expected maximum power evacuation of 1.2 MW from FVE, since FVE cause voltage increase in the LV network somewhat above 0.42 kV (results:Figure 30). Only **0.95 MW** (Figure 31) can be reliably connected to the existing network.

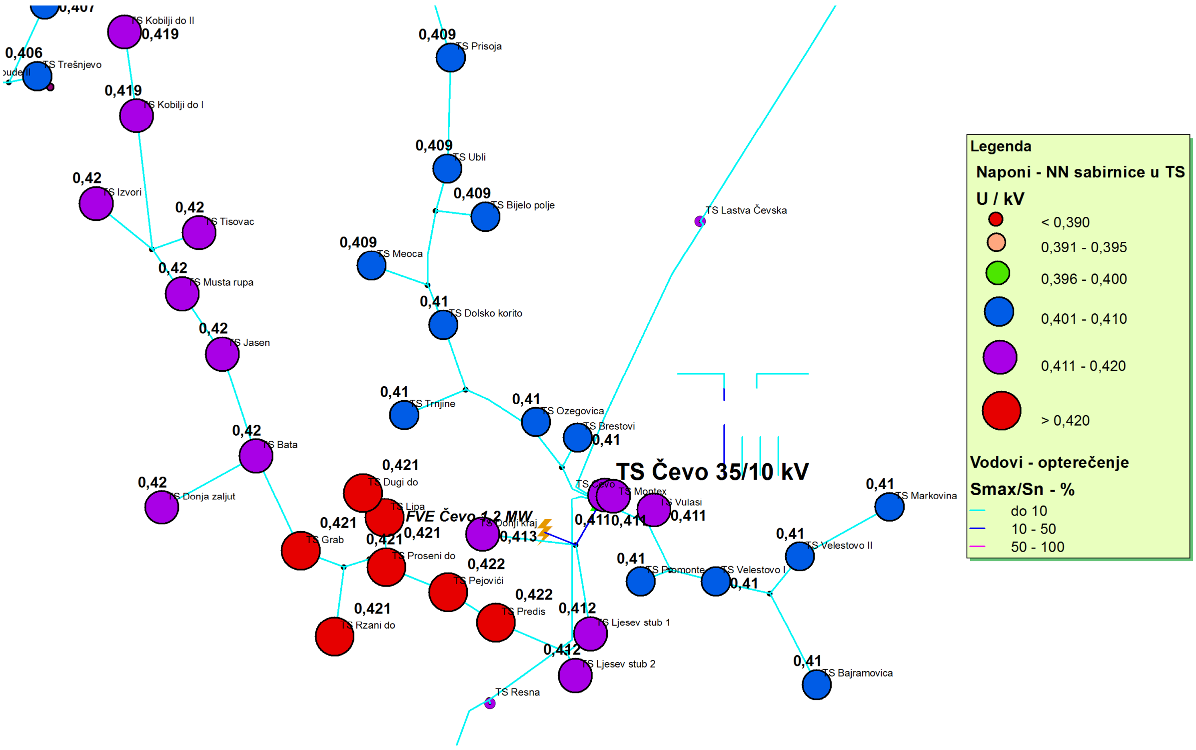


Figure 30: Thematic representation of the load in 10 kV network with voltages at LV busbars in TP – FVE connection to the proximate 10 kV network with the projected maximum power of 1.2 MW, minimum loads 2011.

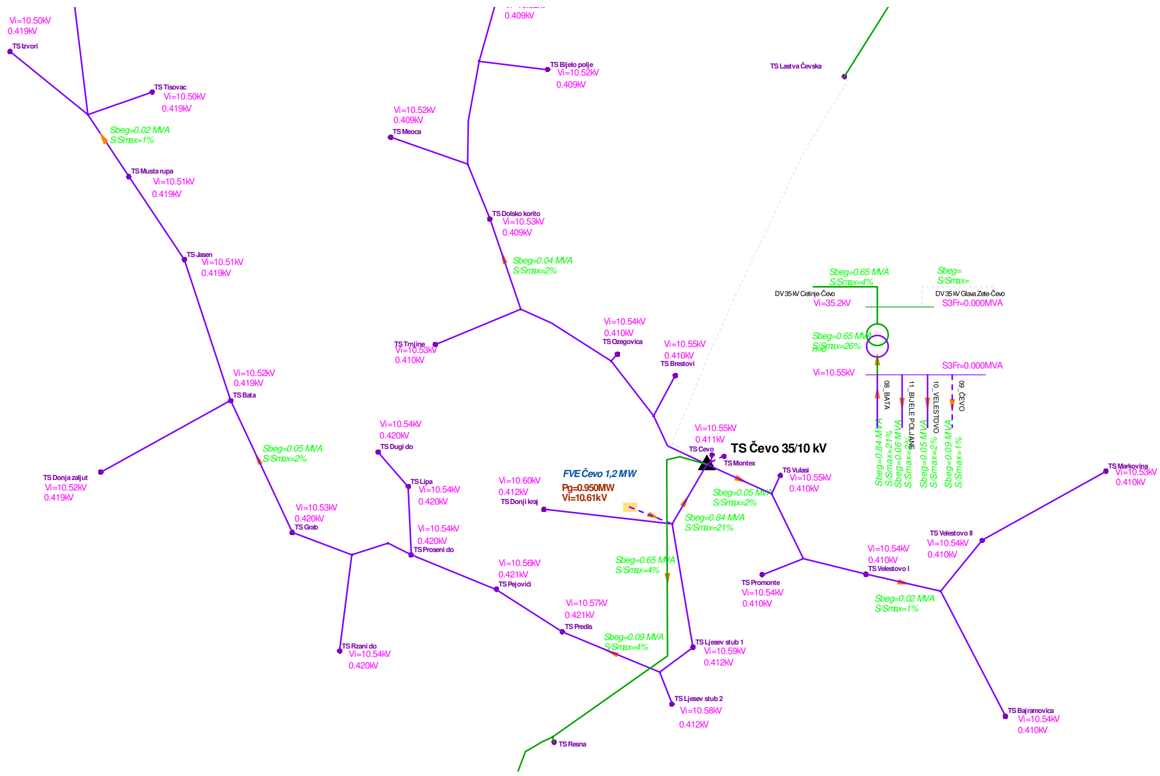


Figure 31: Results of the energy situation analysis – FVE connection with maximum power 0.95 MW to the proximate 10 kV network, minimum loads 2011.

VRIANT A

- **Connection to the existing network on the Bata feeder (tapping towards TS Donji Kraj)**
- **CONDITION: dynamic voltage regulation with the reactive power compensation at FVE**

Due to the fact that this inverter power plant is the only distributed source for the whole TS Čevo area, the decrease of high voltage is projected in the vicinity of the power plant with the dynamic voltage regulation at the power plant inverter.

The regulation is executed by the reactive power regulation defined in the Recommendation (Chapter 4.9) with the characteristics in the Figure 32. This characteristic shows that FVE needs to operate with $\cos\varphi \approx 0.95$ cap in case of high voltages.

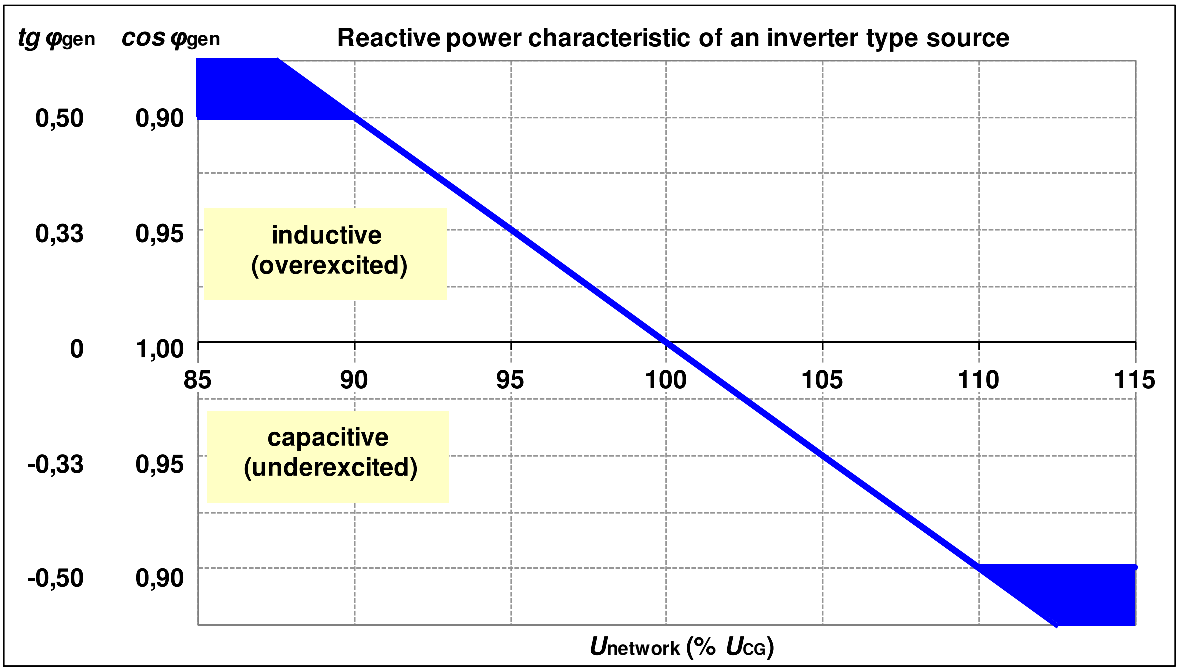


Figure 32: Standard power factor characteristic of inverter ME in relation to DS for ME, which are connected to MV network

If FVE meets the conditions according to the characteristics it can be connected to the existing network (Bata feeder) with the projected installed power 1.2 MW. The connection is executed with the cable Al 150 mm^2 in the length of about 1 km (investment evaluation 40,000 €).

Analysis results for the projected energy situations are shown in the Figure 33 and Figure 34.

Evaluation of losses: **0.145 MW** (by 0.004 MW higher in relation to the situation prior to power plant connection).

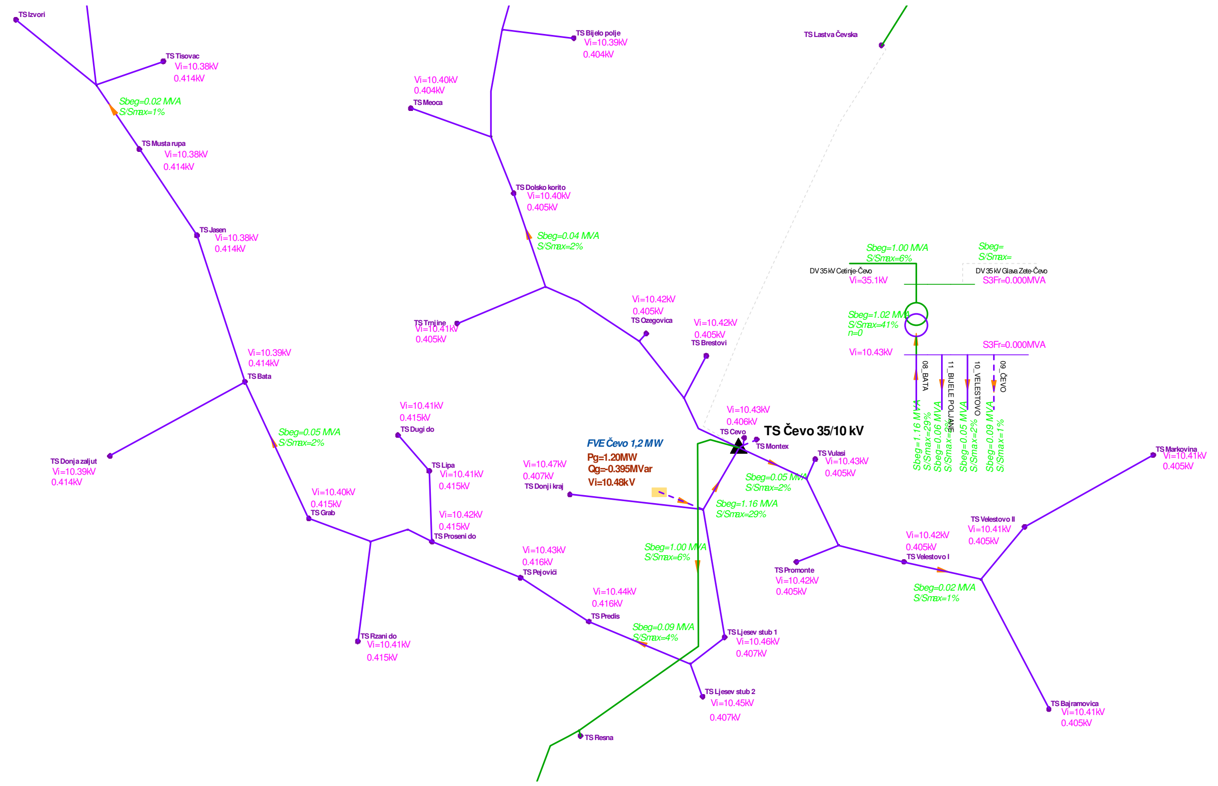


Figure 33: Analysis of energy situation results – FVE connection to FVE on 10 kV Bata feeder with dynamic reactive power compensation at FVE, minimum loads 2011.

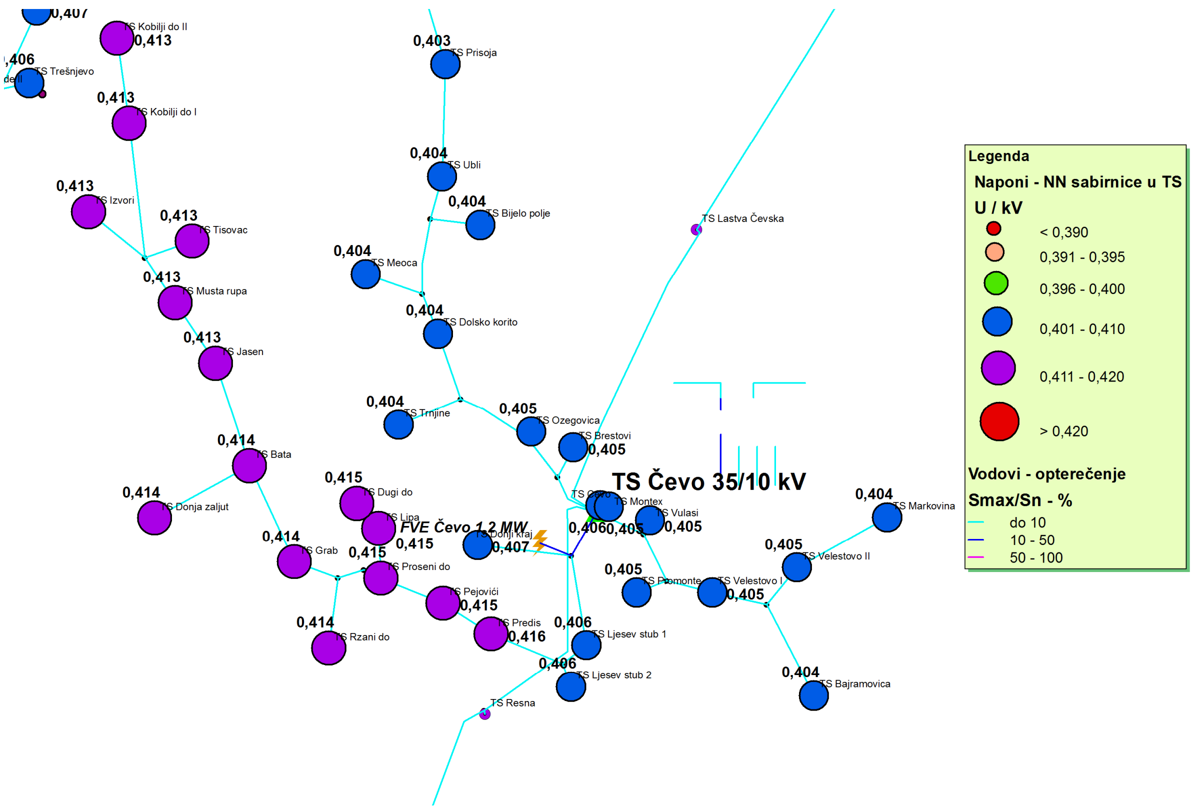


Figure 34: Thematic representation of loads in 10 kV network with voltages at LV busbars in TP – FVE connection to 10 kV Bata feeder with dynamic reactive power compensation at FVE, minimum loads 2011.

VARIANT B

- **Connection to the new 10 kV feeder directly in TS Čevo (cable line Al mm^2) to the existing line at the Bata feeder (tapping towards TS Donji Kraj)**

This variant projects FVE connection directly to 10 kV busbars TS Čevo with new cable feeder. Connection specifications:

- new 10 kV feeder bay in TS Čevo with remotely controlled decoupling installation
- Al 150 mm^2 cable line
- total length approx. 1.5 km
- investment evaluation: cca. 80,000 €.

The connection line for the power plant is clear, without other consumers. Due to protection component at FVE, specified in the Recommendation of this study, the feeder bay suffices with decoupling installation without a switch.

The solution provides very high reliability and low influence on TS Čevo network operation. The interruptions at other feeders due to direct connection do not influence on FVE operation.

Analysis results for the expected energy conditions in this situation are shown in Figure 35 and Figure 36.

Losses evaluation: **0.134 MW** (by 0.007 MW lower in relation to the situation prior to power plant connection, but by 0.011 MW lower compared to the VARIANT A).

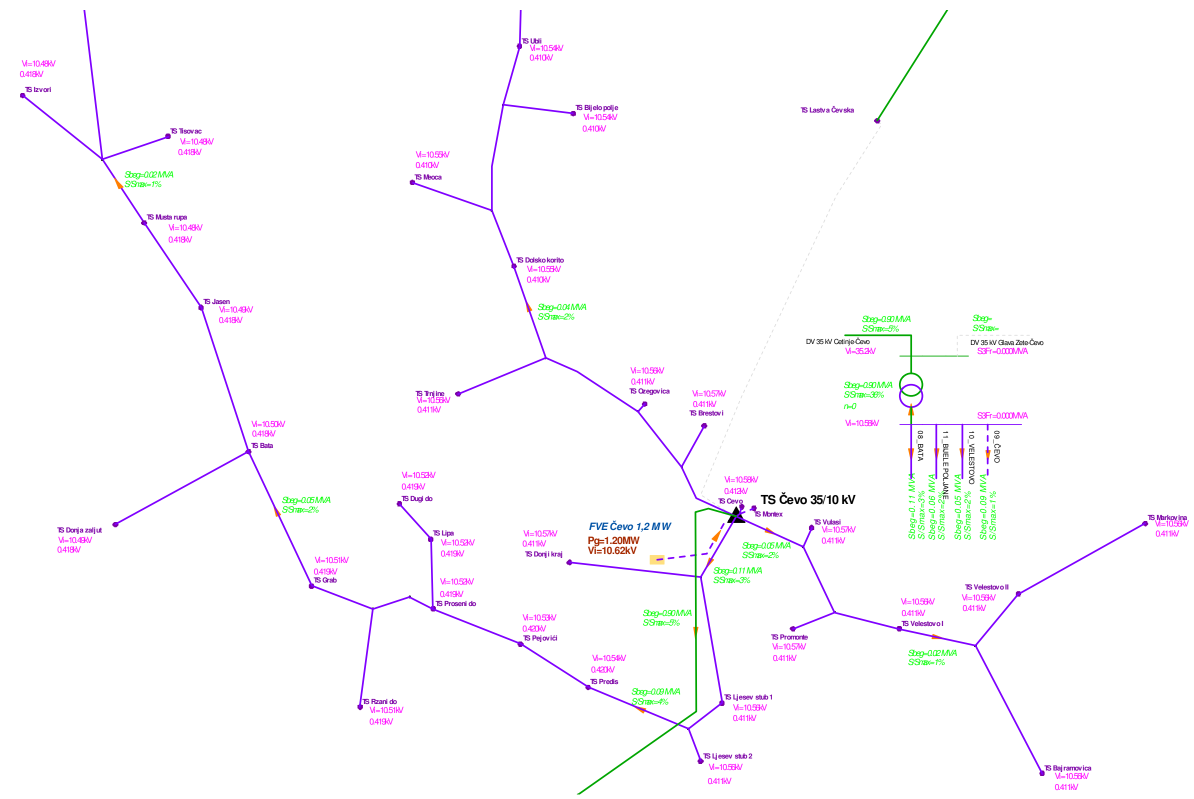


Figure 35: Analysis results of power conditions – FVE connection in TS Čevo 10 kV, minimum loads, 2011.

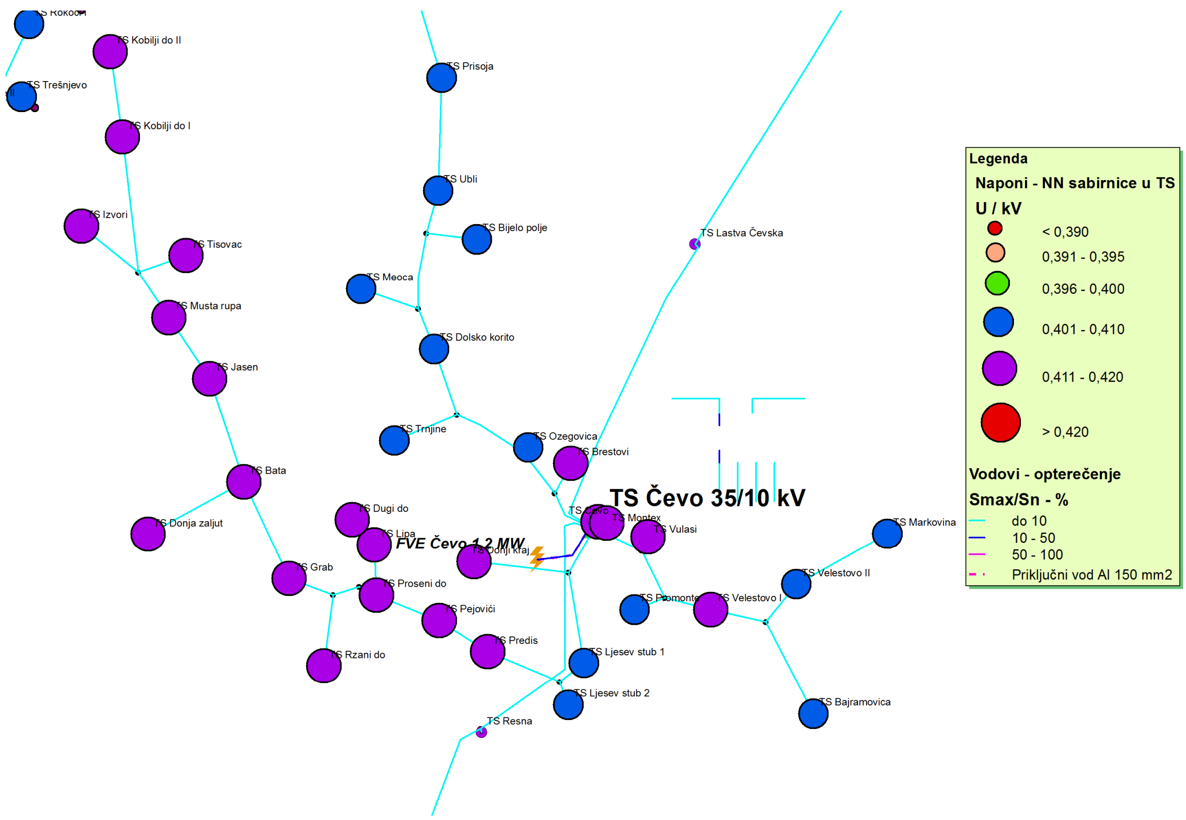


Figure 36: Thematic representation of loads in 10 kV network with voltages at LV busbars in TP – FVE connection to TS Čevo 10 kV busbars, minimum loads 2011.

5.3.2.3. Summary

The most difficult expected operation situations are analysed: maximum load in the network without FVE production and minimum load for full operation of the projected production. The operation of FVE operation with s cosφ=1 is projected.

The maximum 0.95 MW of the projected 1.2 MW can be connected to the existing 10 kV network at the FVE location. The main problem of FVE operation in the network is caused by the great changes that can cause essential voltage increase exceeding the conditions of the 0.42 kV permitted limit.

Full power evacuation that provides reliable distribution network operation with high-quality voltage profile can be established only through voltage regulation at the power plant (reactive power compensation) or through the appropriate system reinforcement. The analysis of the suggested solutions is given in two versions. Variant A refers to the dynamic voltage regulation through the regulatory characteristic stated in the Recommendation, whereas Variant B projects direct connection to TS Čevo 10 kV busbars.

The analysis for 2015 did not show any problems of the network operation. The projected network guarantees a reliable, long-term operation even after 2015. The comparison of two projected variants is given in the Table 5.7.

Table 5.7: Comparison of the variants for FVE connection to the distribution network

FVE Čevo	
Advantages	
VARIANT A – connection to the existing 10 kV network with dynamic voltage regulation at FVE	**VARIANT B – direct connection to TS Čevo 10 kV busbars**
• low connection costs	• lower voltage oscillations in 10 kV and 0.4 kV network • better operation reliability of 10 kV network • low impact of the feeder on TS Čevo network operation • better operation reliability of the projected FVE • smaller losses in the network (in average 11 kW) • low network operation costs
Summary of the projected steps in the network	
• dynamic voltage regulation with the reactive power compensation at FVE • connecting cable line Al 150 mm^2, l =1 km	• new 10 kV feeder bay in TS Čevo with remotely controlled decoupling installation (suitable installation of standard decoupling installation without switch) • connecting cable line Al 150 mm^2, l =1.5 km
Investment cost evaluation	
• 40,000 €	• 70,000 €

5.3.3. Example of wind power station connection analysis (VE Briska Gora)

5.3.3.1. Starting points

Data on power plant

VE Briska Gora with the projected installed power 2 x 2.5 ME is located at the mountain Briska Gora, northeast from Ulcinj. The geographic location of the planned power plant with voltages and substations 35/10 kV in the vicinity is represented in the Figure 37.

Figure 37: Location of VE Briska Gora

Table 5.8: VE Briska Gora – general data

VE	P_{max} (MW)	$\cos\varphi_n$	generator	closest TS 10 kV
Briska Gora	**5**	0,9	inverter	TS D. Briska Gora, TS G. Briska Gora TS Gač

All relevant data needed for the analysis of VE impact on MV distribution network operation are stated in the Table 5.8.

The existing distribution network with the projected VE connection

The power plant will be connected to the distribution network that is supplied from TS 110/35 kV Ulcinj with the regulated voltage at the 35 kV busbars. The following substations are located in the wider area of the power plant: TS Grad, TS Plaža I and II, and TS Vladimir. The Briska Gora area is supplied by 10 kV feeder Gač from TS Grad. The feeder is circularly connected to 10 kV feeders Ada Reč from TS Plaža II, whereas Kodre feeder from TS Vladimir.

Data on TS Ulcinj 110/35 kV:

- transformation 110/30 kV
  - 2xTR 110/35 kV
  - S_{inst} = 2x20 MVA, U_{n1} = 110 kV, U_{n2} = 36.75 kV
  - automatic voltage regulation at the secondary U_{n2}± 10 ·1.5 %
  - the projected voltage at the secondary: 35 kV (low load), 36 kV (high load)

Data on TS Grad 35/10 kV:

- transformation 35/10 kV
  - 2xTR 35/10 kV
  - S_{inst} = 2x8 MVA, U_{n1} = 35 kV, U_{n2} = 10.5 kV
  - manual voltage regulation at the secondary U_{n2}± 2 ·2.5 %
  - short circuit voltage u_k = 6.7 %.

Data on TS Plaža I and II 35/10 kV:

- Transformation 35/10 kV
  - 2xTR 35/10 kV
  - S_{inst} = 2x4 MVA, U_{n1} = 35 kV, U_{n2} = 10.5 kV
  - manual voltage regulation at the secondary U_{n2}± 2 ·2.5 %
  - short circuit voltage u_k = 6.7 %.

Data on TS Vladimir 35/10 kV:

- transformation 35/10 kV;
  - 1xTR 35/10 kV
  - S_{inst} = 1x4 MVA, U_{n1} = 35 kV, U_{n2} = 10.5 kV
  - manual voltage regulation at the secondary U_{n2}± 2 ·2.5 %
  - short circuit voltage u_k = 6.7 %.

The geographical representation of one part of 10 kV network TS Grad, TS Plaža II and TS Vladimir is shown in the Figure 38. This area is supplied by 10 kV Gač feeder circularly connected to the feeders Ada Reč and Kodra. The 10 kV network has the characteristics of rural network type. Due to relatively high consumption and number of tourist facilities the network is well complicated which calls for a good network operation reliability. Main lines are overhead lines with Al/Fe 35/6 mm^2 conductors. Cable and mainly overhead tappings are equipped with Al/Fe 25/4 mm^2 conductors.

The analysed 10 kV network has no single distributed source connected. According to the available data, the analysed power plant represents the only distributed source that is to be connected to the existing network in the medium-term.

Data on feeder loads

For the needs of the analysis of the power plant connection to the distribution network there are measurement data on maximum and minimum loads for 2011 stated in the Table 5.9 along with the 2015 prognosis.

Table 5.9: Minimum and maximum load –VE Briska Gora network

Feeder	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Gač	0.37	1.78	0.39	1.89
other feeders	4.32	14.41	4.58	15.27
TS Grad	**4.69**	**16.19**	**4.97**	**17.16**
Ada Reč	0.47	1.58	0.50	1.67
other feeders	1.58	5.27	1.67	5.58
TS Plaža II	**2.05**	**6.85**	**2.17**	**7.25**
Krute	0.22	0.74	0.23	0.78
other feeders	0.73	2.42	0.77	2.56
TS Vladimir	**0.95**	**3.16**	**1.00**	**3.34**

The projected distribution network development

In accordance with the distribution network investment plan, a reconstruction of TS Grad, TS Plaža I and TS Vladimir is projected for this area after 2015. The investments are realized due to old 35 kV installation and adjustments of TS for remote control (SCADA).

5.3.3.2. Analysis of power plant connection to the network

The power plant is located near the Gač feeder on the location between TS Gornja Briška Gora and TS Donja Briška Gora. Together with VE location the network is shown in the Figure 38. The Figure also shows the short circuit powers in the nodes of the existing network located the closest to the projected power plant.

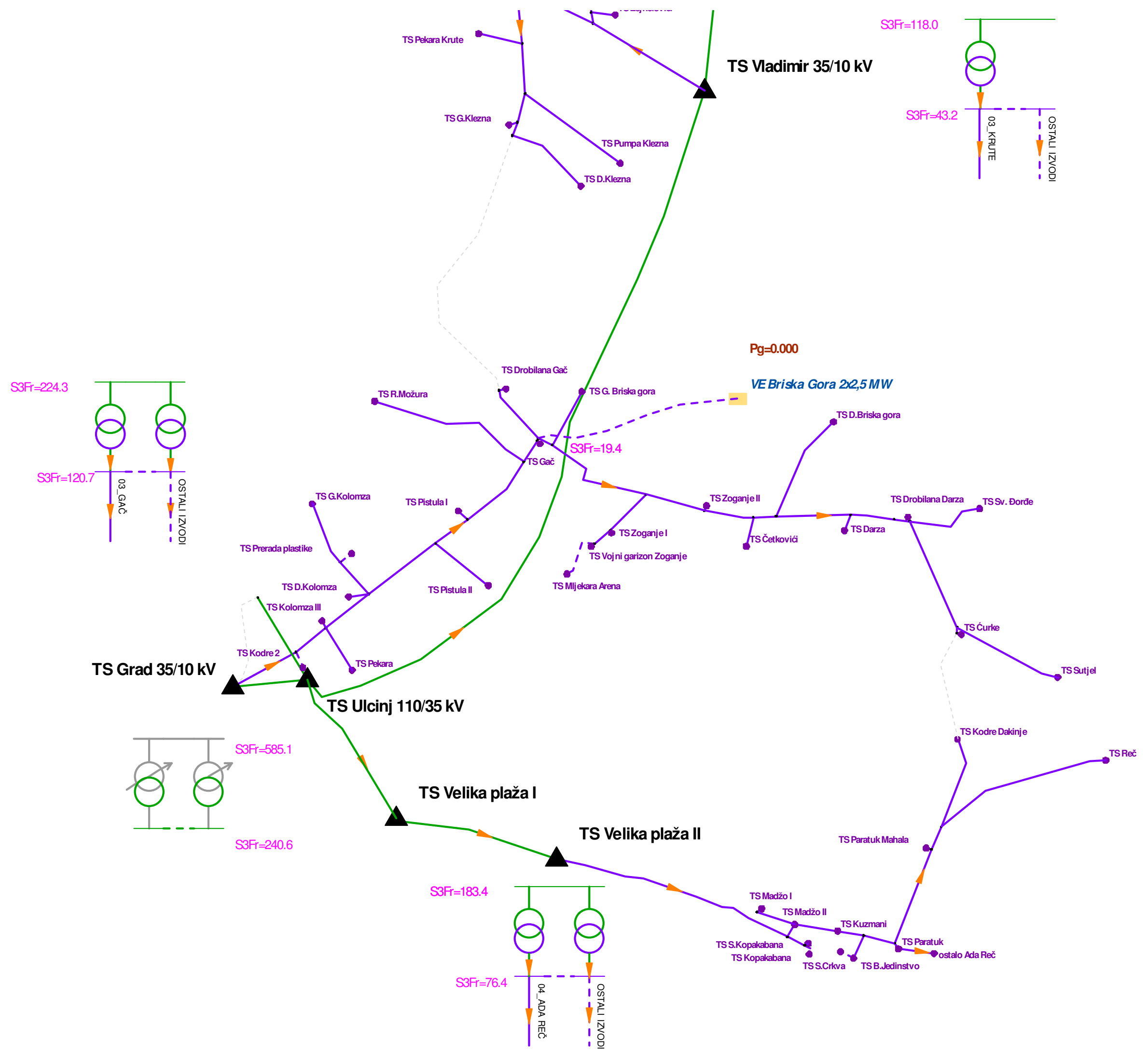


Figure 38: Distribution network at the narrow Birska Gora area with VE location

Determination of minimum network model scale

Since the network is a radial one, the permitted voltage changes Δu_{TM} are calculated according to:

$$\Delta u_{KM} = \sum_i^N \Delta u_{TM_i} < 0{,}005 = K_{\Delta U} \quad - \quad \text{radial network} \qquad 5.1$$

The contribution is calculated according to the equations conducted in the Chapter with the methodology description. The basis for the calculation is short circuit power on TS busbars and power plants of the closest network points:

- VE Briska Gora: S_{k_VR} = 19.4 MVA
- 10 kV busbars TS Grad: $S_{k\_TS\_Grad\text{-}10}$ = 120.7 MVA
- 35 kV busbars TS Grad: $S_{k\_TS\_Grad\text{-}35}$ = 224.3 MVA
- 35 kV busbars TS Ulcinj: $S_{k\_TS\_Ulc\text{-}35}$ = 240.6 MVA
- 110 kV busbars TS Ulcinj $S_{k\_TS\_Ulct\ \text{-}110}$ = 585 MVA

Voltage changes along the network from VE to TS Grad and TS Ulcinj:

- Gač node: Δu_{mreza_10kV} = 0.142

- 10 kV busbars TS Grad: $\Delta u_{TS\_Grad\_10kV} = 0.021$
- 35 kV busbars TS Grad: $\Delta u_{TS\_Grad\_35kV} = 0.011$
- 35 kV busbars TS Ulcinj: $\Delta u_{TS\_Ulc\_35kV} = 0.010$
- 110 kV busbars TS Ulcinj: $\Delta u_{TS\_Ulc\_110kV} \ll \mathbf{0.005}$

The negligible impact of the analysed power plants on the voltage change is achieved only on 110 kV busbras in TS Ulcinj. The network model for the analysis of VE Briska Gora operation impacts should include 10 kV Gač busbars (Bata and Bijele Poljane), 35/10 kV transformation in TS Grad 35 kV network between TS Grad and TS Ulcinj and 110/35 kV transformation in Ulcinj. The model should also include all 10 kV feeders (Ada Reč, Krute) that are circularly connected to the Gač feeder with the pertaining and supply substations and 35 kV network (TS Plaža I and II, TS Vladimir).

The network should be modelled to the LV levels of distribution substations with the pertaining transformers. Before the realization of analyses, the transformer tappings on distribution transformers should be adjusted. The tapping adjustment simulation comprises of:

- transformer tappings are adjusted during high loads;
- evaluation of high loads is conducted on the basis of operation hours in the distribution network and high loads of 10 kV feeders;
- distribution network in EES Montenegro has about 5000 operation hours per year; the annual operation time for rural network is lower for about 500 hours.

Conditions before VE connection to the network

The situations with maximum and minimum loads are analysed. Graphical results of the calculated loads in MV network and voltages at LV busbars in TP are shown in the Figure 39 (maximum loads) and Figure 40 (minimum loads).

High voltages are recorded in LV network during low loads, where the voltages in the individual nodes are approaching 0.42 kV.

Operation situations with high loads that indicate network load level are not critical. The lines are loaded somewhat below the permitted thermal limits. That is why only the situations with minimum loads will be included where the difficulties with high voltages occur.

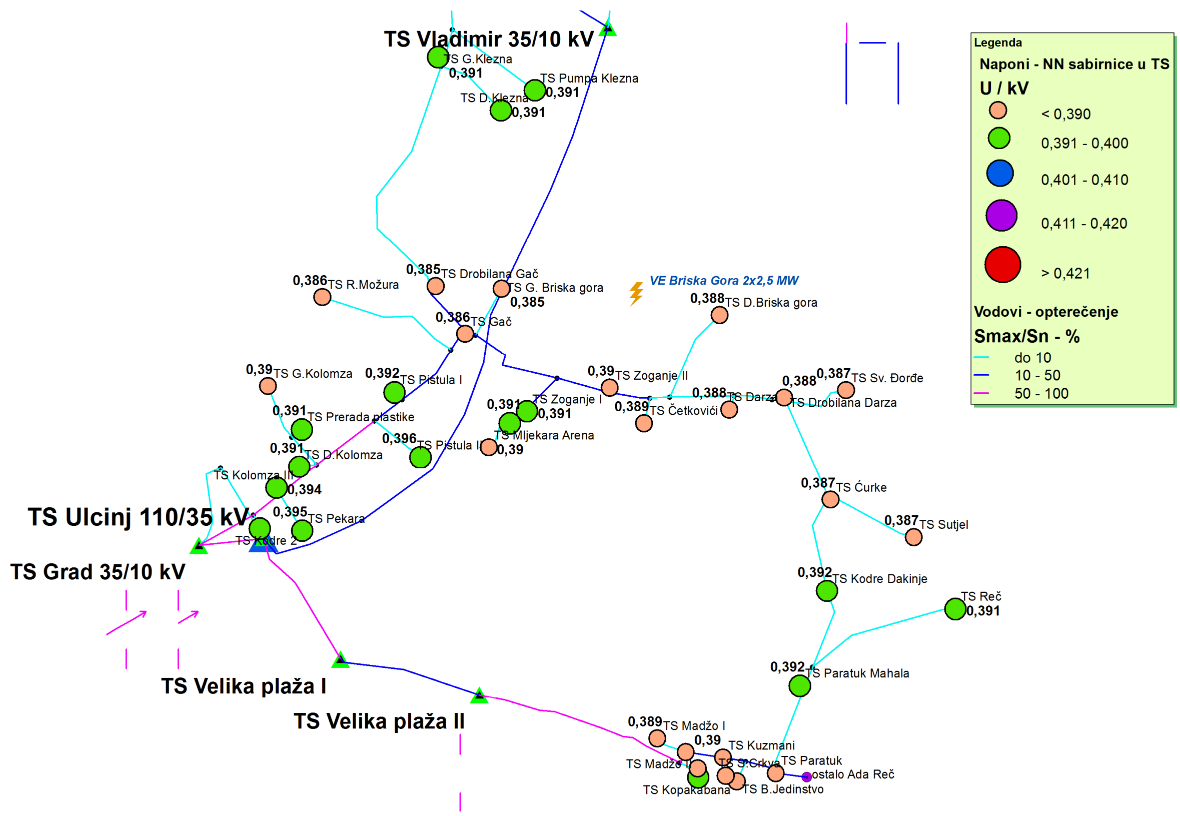


Figure 39: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011. Without VE operation.

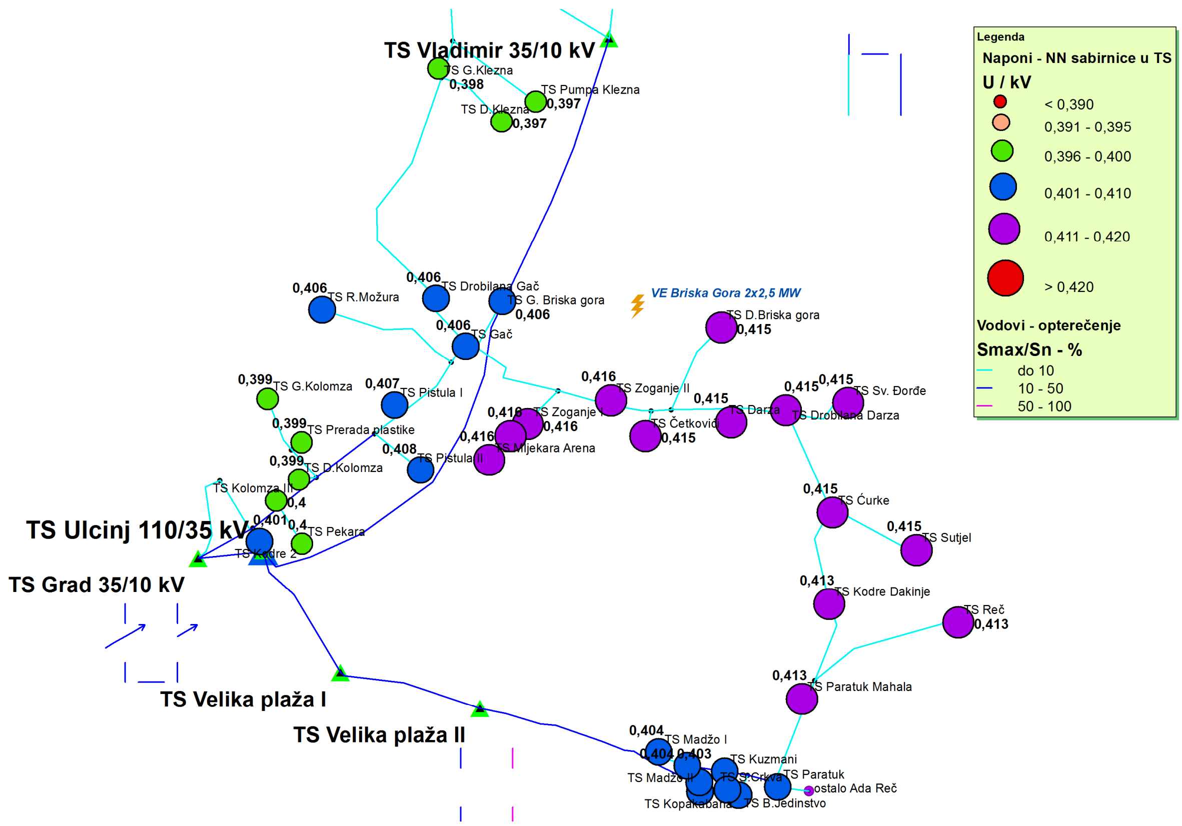


Figure 40: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011. Without FVE operation

Evaluation of losses: **0.943 MW.**

VE connection to the network on the near 10 kV line at Gač feeder

According to the known methodology and criteria, all analyses are conducted for the situations with minimum loads during VE operation with total maximum installed power 5 MW and cosφ=1.

The results of the analysis for the expected power situations in the existing network 2011 are shown in the Figure 41. The existing 10 kV network is too weak for the expected maximum evacuation of 5 MW power because VE cause the voltage increase, well exceeding 0.42 kV in LV network, (results,Figure 41). Maximum **0.2 MW** (Figure 42) can be reliably connected to the existing network.

The conditions are not essentially improved. The dynamic voltage regulation at the power plant inverter is also included. The existing 10 kV network is too weak to evacuate such high power from VE.

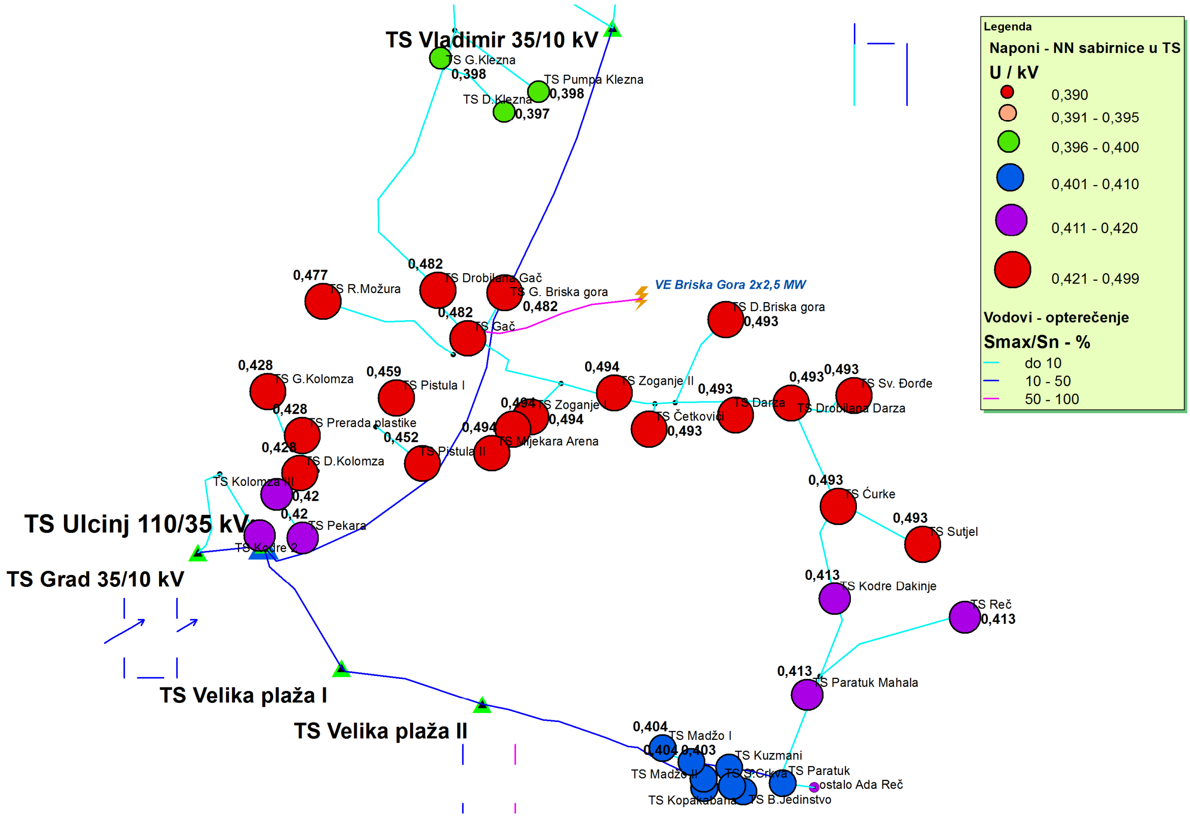


Figure 41: Thematic representation of load in 10 kV network with voltages at LV busbars in TP – VE network with the projected maximum power of 5MW, minimum loads 2011.

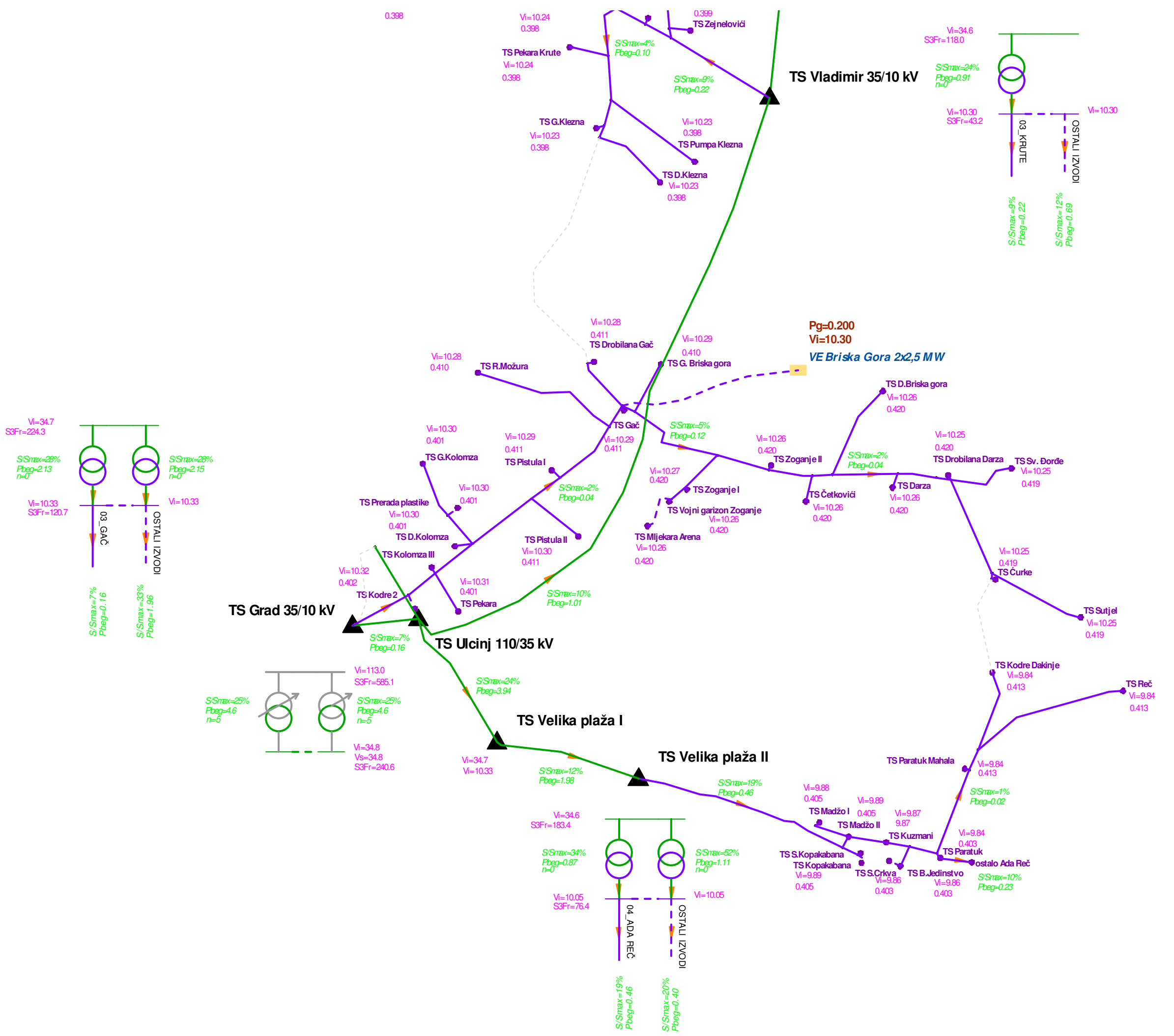


Figure 42: Results of the analysis of power conditions – VE connection with maximum power of 0.2 MW to the proximate 10 kV network, minimum loads 2011.

VARIANT A

- **Connection to the network with new clear 10 kV cable feeder from TS Grad (option TS Plaža I)**

The variant projects the direct VE connection to 10 kV busbras TS Grad with new cable feeder. The option is also directly connected to TS Plaža I or due to permanent increased consumption and lower losses and voltage changes the connection to TS Grad is considered a better option.

Connection specification:

- new 10 kV feeder bay in TS Grad with remotely controlled decoupling installation
- Cu 150 mm^2 cable line
- total length approx. 6 km
- investment evaluation: approx. 290,000 €

The connection line for the power plant remains clear, without other consumers. The decoupling installation with short circuit protection should be installed at the feeder bay. As stated in the beginning of this Chapter, APU should be blocked.

The solution is provided by the reliable network operation with more acceptable source impact on the network. The results of the analysis for the expected conditions in this situation are shown in the Figure 43 and Figure 44.

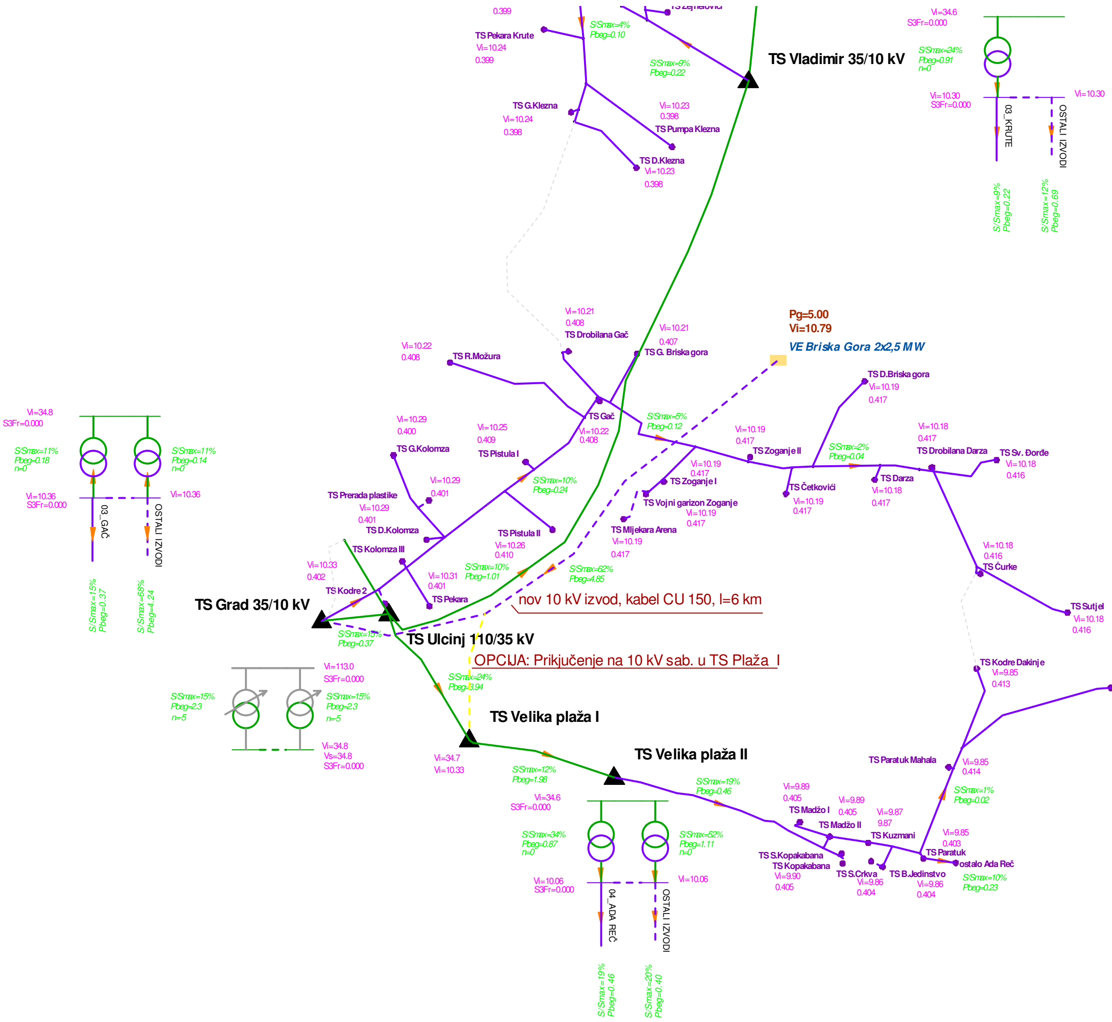


Figure 43: Results of the energy conditions analysis – VE connection with 10 kV cable feeder at busbars to TS Grad (option TS Plaža I), minimum loads, 2011.

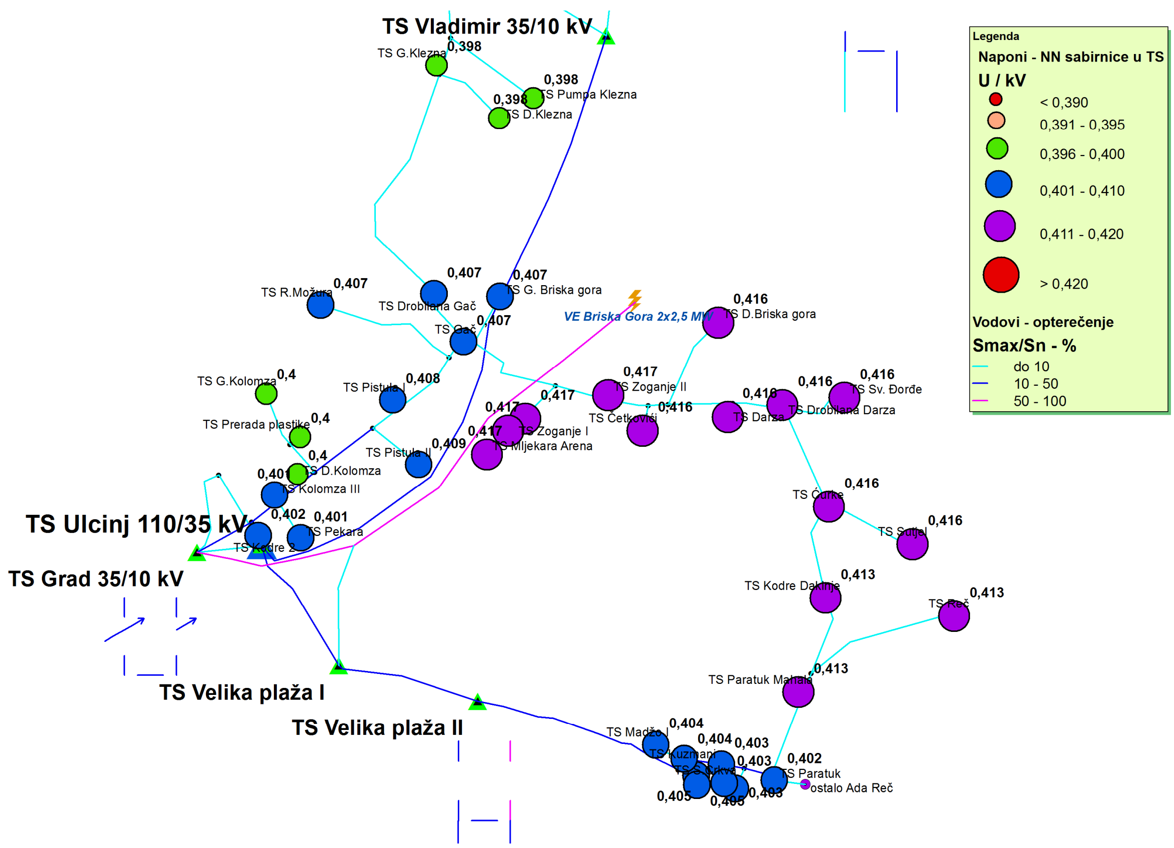


Figure 44: Thematic representation of loads in 10 kV network with voltages at LV busbars in TP – VE connection with 10 kV cable feeder at busbras in TS Grad (option TS Plaža I), minimum loads, 2011.

Evaluation of losses: **1.015 MW** (by 0.072 MW higher in relation to the situation before the power plant connection).

The feeder can be applied for the future network development (supply of new TS, circular connection with neighbouring feeders). The solution is very convenient in case of short-term conversion of 10 kV network at the Ulcinj area to 20 kV voltage level.

VARIANT B

- **Connection to the existing 35 kV transmission line Ulcinj – Vladimir (formation input/output)**

This Variant projects the VE connection to DV 35 kV Ulcinj – Vladimir through the formation input/output. Connection specification:

- New double circuit parallel 35 kV line from VE location to the point of connection to the existing line
  - 2xAl/Fe 70/12 mm^2 conductor
  - length: approx. 2 km
  - cost evaluation: 160,000 €
  - The complete typified protection for installation on 35 kV has to be provided for 35 kV decoupling busbars (cost evaluation 100,000 €).
  - Total investment evaluation: approx. 260,000 €

It is important to establish all typified protection for the 35 kV level due to input/output formation in the 35 kV decoupling installation at the VE location.

The solution provides good evacuation power reliability from VE and the lowest impact of the source on the local distribution network operation.

Results of the analysis for the expected energy conditions in this situation are shown in the Figure 45 and Figure 46.

Losses evaluation: **0.875 MW** (by 0.098 MW lower in relation to the situation before the power plant connection, but by 0,14 MW lower compared to the Variant A).

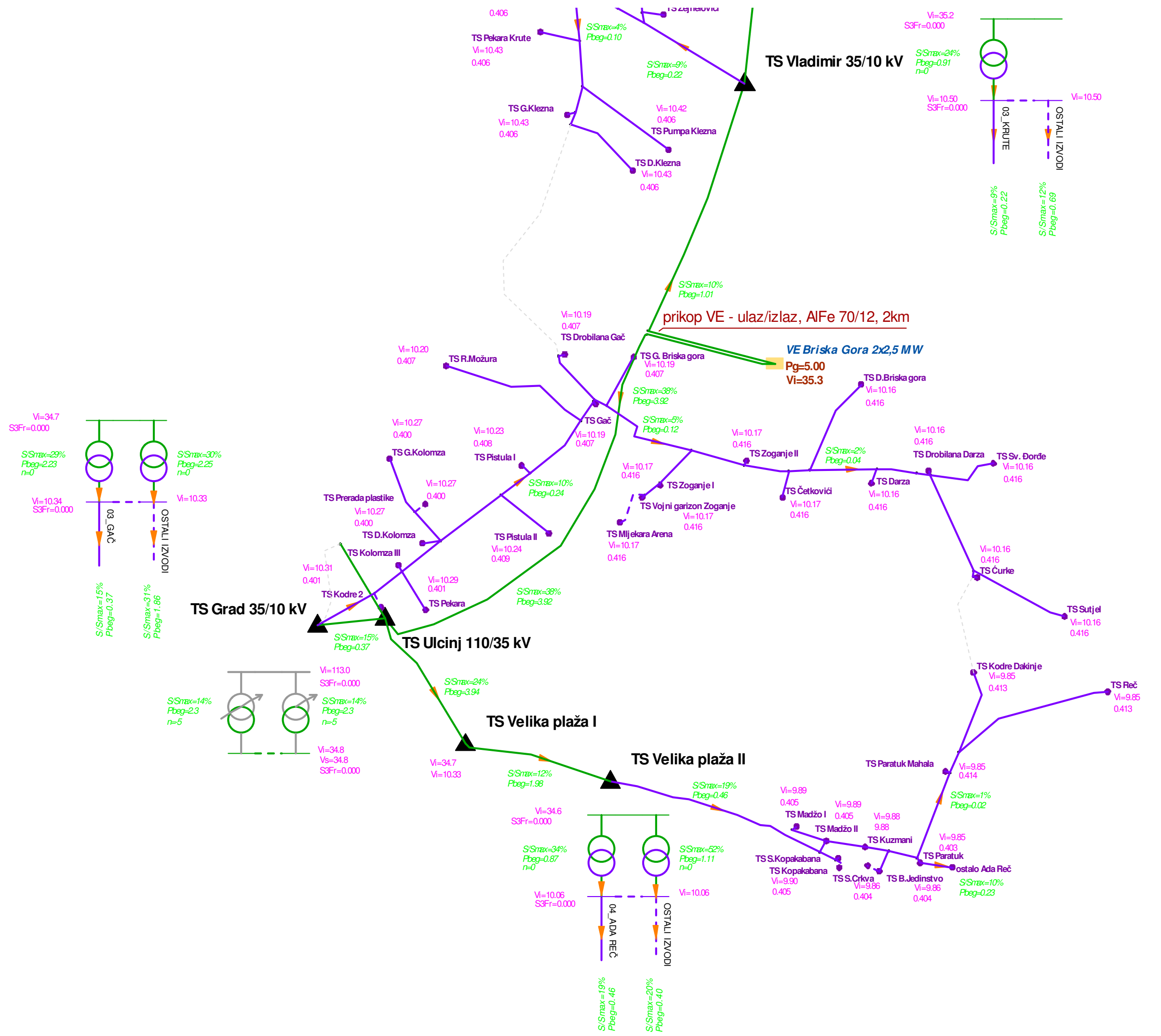


Figure 45: Results of the energy conditions analysis – VE connection to DV 35 kV Ulcinj – Vladimir (formation input/output), minimum loads, 2011.

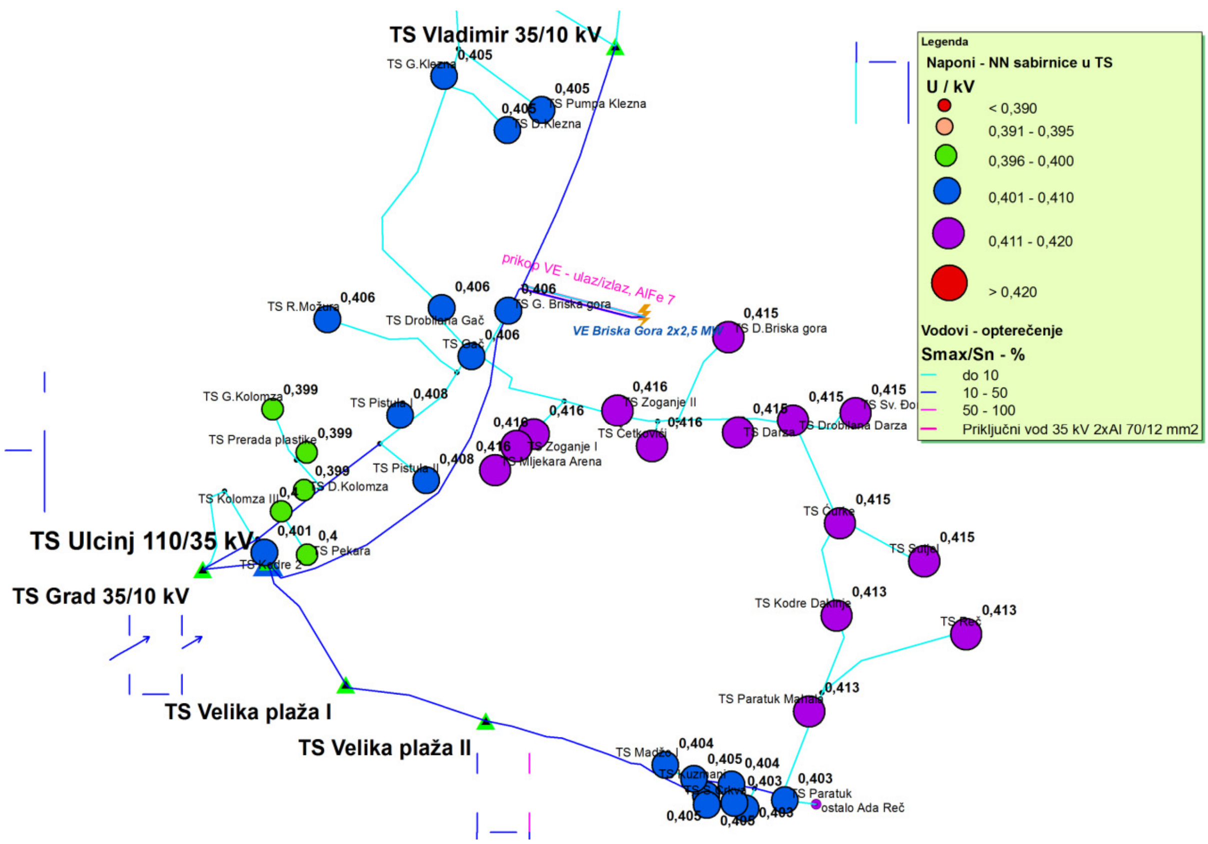


Figure 46: Thematic representation of loads in 10 kV network at LV busbars in TP – VE connection to DV 35 kV Ulcinj – Vladimir (formation input/output), minimum loads 2011.

5.3.3.3. Summary

The most difficult expected operation conditions are analysed: maximum loads in the network without VE production and minimum load for full projected production. The VE operation with cosφ=1 is projected.

Up to 0.2 MW from the projected 5 MW can be reliably connected to the existing 10 kV network at the VE Briska Gora location. The main problem of VE operation in the distribution network is caused by high changes that can essentially cause voltage increase, exceeding the permitted limit of 0.42 kV.

Full power evacuation that provides reliable distribution network operation with quality voltage profile can be achieved only through appropriate system reinforcement. The analysis of the projected network reinforcements is given in two versions. Option A refers to the VE connection with new 10 kV cable feeder to TS Grad, Variant B suggests double circuit 35 kV parallel line construction in the formation input/output in the existing 35 kV line Ulcinj – Vladimir.

The analysis for 2015 did not show any problems of network operation. The projected network can provide reliable, long-term operation also after 2015. The comparison of two presented variants is shown in the Table 5.10.

Table 5.10: Comparison of the variants for VE Briska Gora connection to the distribution network

VE Briska gora	
Advantages	
VARIANT A – connection with new feeder to 10 kV busbars TS Grad	**VARIANT B – connection of 35 kV parallel line Ulcinj – Vladimir (formation input/output)**
• Feeder can be used for the future network development (supply of new TS, circular connection with neighbouring feeders) • Better solution in case of conversion to three-level voltage system 110/20/0.4 kV	• Lower voltage oscillations in 10 kV and 0.4 kV network • Lower connection costs • Better operation reliability of 10 kV network • Low impact of sources on the local distribution network operation • Lower losses in the network (in average 150 kW) • Lower network operation costs
Summary of the steps taken in the network	
• Connecting cable line Cu 150 mm^2, l = 6 km • New 10 kV feeder bay in TS Grad with remotely controlled decoupling installation with short circuit protection	• New double circuit parallel line 35 kV, 2xAlFe 70/12 mm^2, l = 2 km • Connection to the existing 35 kV line in the formation input/output
Investment costs evaluation	
• 290,000 €	• 260,000 €

By comparison of two variants, the VE connection according to Variant B is suggested. The most important reasons are shown in the Table 5.5. To provide very high evacuation power reliability from VE, it will be best to conduct also the Variant A with 10 kV cable feeder that is used as a backup connection in case of losses in 35 kV transmission line between Ulcinj and Vladimir.

5.4. Results of mHE connection to the distribution network – solution for the Lima River basin

5.4.1. Distribution network area with MHE connections

The MHE construction in the Lima River basin area is planned on the following rivers: Bistrica (Bijelo Polje), Bistrica (Berane), the rivers Trepačka, Šekularska, Kraštica, Zlorečica, Murinska, Velička, Komarača, Babinopoljska, Đurička and Grlja.

The main supply nodes for this area are SBS 110/35 kV Riberavine, 2x20 MVA + 1x31.5 MVA, SBS 110/35 kV Berane, 2x20 MVA, and SBS 110/35 kV Andrijevica 1x10 MVA + 1x20 MVA. SBS Nedakusi 35/10 kV, 8MVA + 4 MVA is supplied by SBS 110/35 kV Riberavine with one direct powerful 35 kV (110 kV) transmission line and the other normal 35 kV transmission line via SBS Medanovići. SBS Berane supplies SBS Rudež 35/10 kV, 2x8 MVA, whereas SBS Andrijevica the 35 kV transmission line is constructed in the direction of Plav and Gusinje. In Andrijevici the transformer 35/10 kV, 2x2.5 MVA is situated.

The geographical representation of distribution network with the analysed MHE is given in the Figure 47 and Figure 48.

MHE on the rivers Bistrica (Berane), Šekularska and Trepačka are located in the vicinity of 10 kV Dolac feeder from SBS 35/10 kV Rudež. The area of the river Trepačka is also not far from Trešnjevo feeder from SBS Andrijevica that closes to the Dolac feeder to approximately 1 kilometre. Other MHE are related to the following 10 kV feeders:

- Bistrica (Bijelo Polje): Gubavac feeder from SBS 35/10 kV Nedakusi,
- Krštica: Kralje feeder from SBS 35/10 kV Andrijevica,
- Zlorečica: Konjuhe feeder from SBS 35/10 kV Andrijevica,
- The river Murinska: Murino feeder from SBS 35/10 kV Plav,
- The river Velička: Murino feeder from SBS 35/10 kV Plav,
- Komarača: Meteh feeder from SBS 35/10 kV Plav,
- Babinopoljska: Meteh feeder from SBS 35/10 kV Plav,
- Đurička rijeka: Meteh feeder from SBS 35/10 kV Plav,
- Grlja: Plav feeder from SBS 35/10 kV Gusinje.

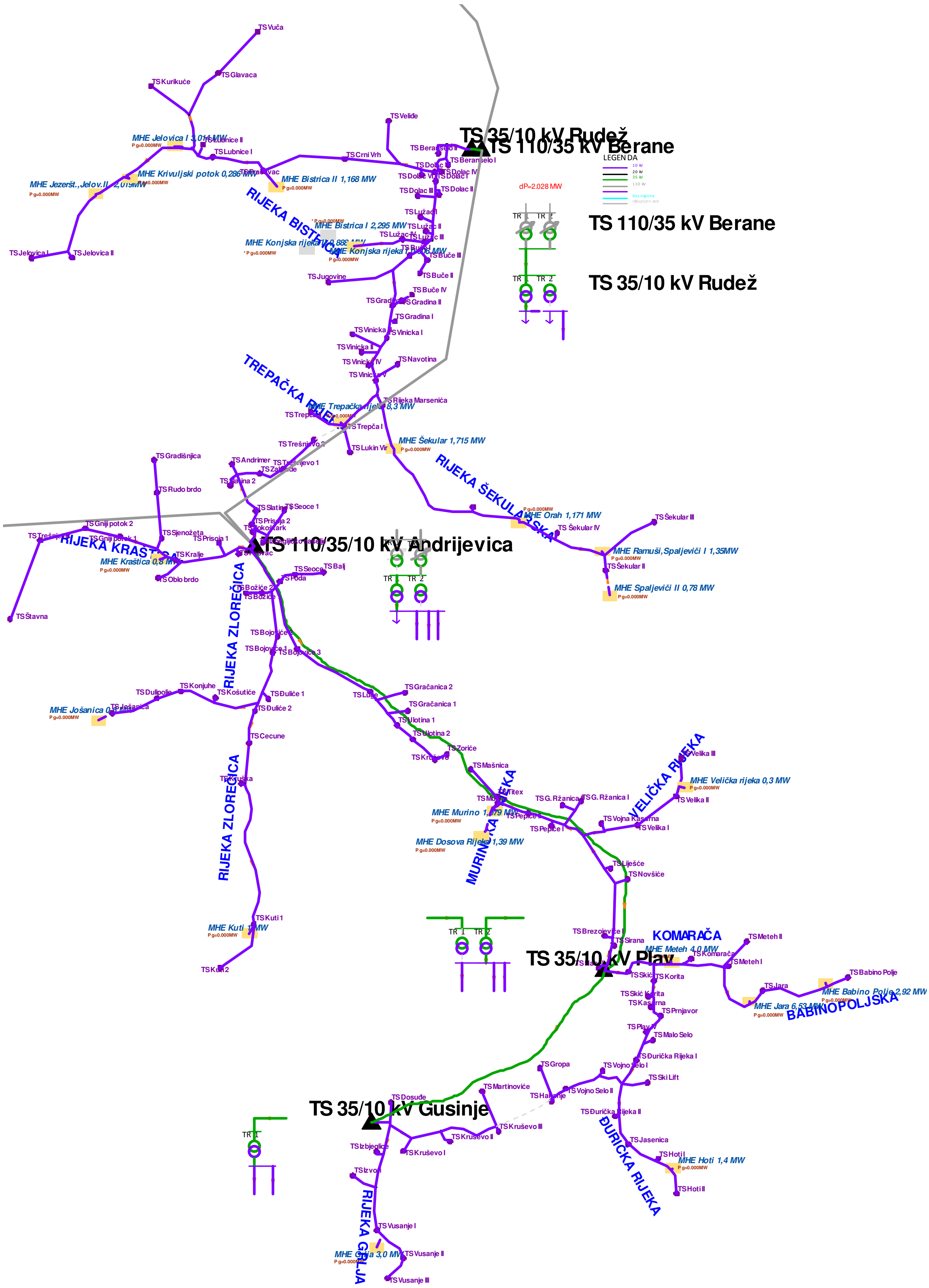


Figure 47: Model of the existing 35 kV and 10 kV distribution network for MHE connection analyses in the Lima River basin – area of Brerano, Andrijevica, Plav and Gusinje.

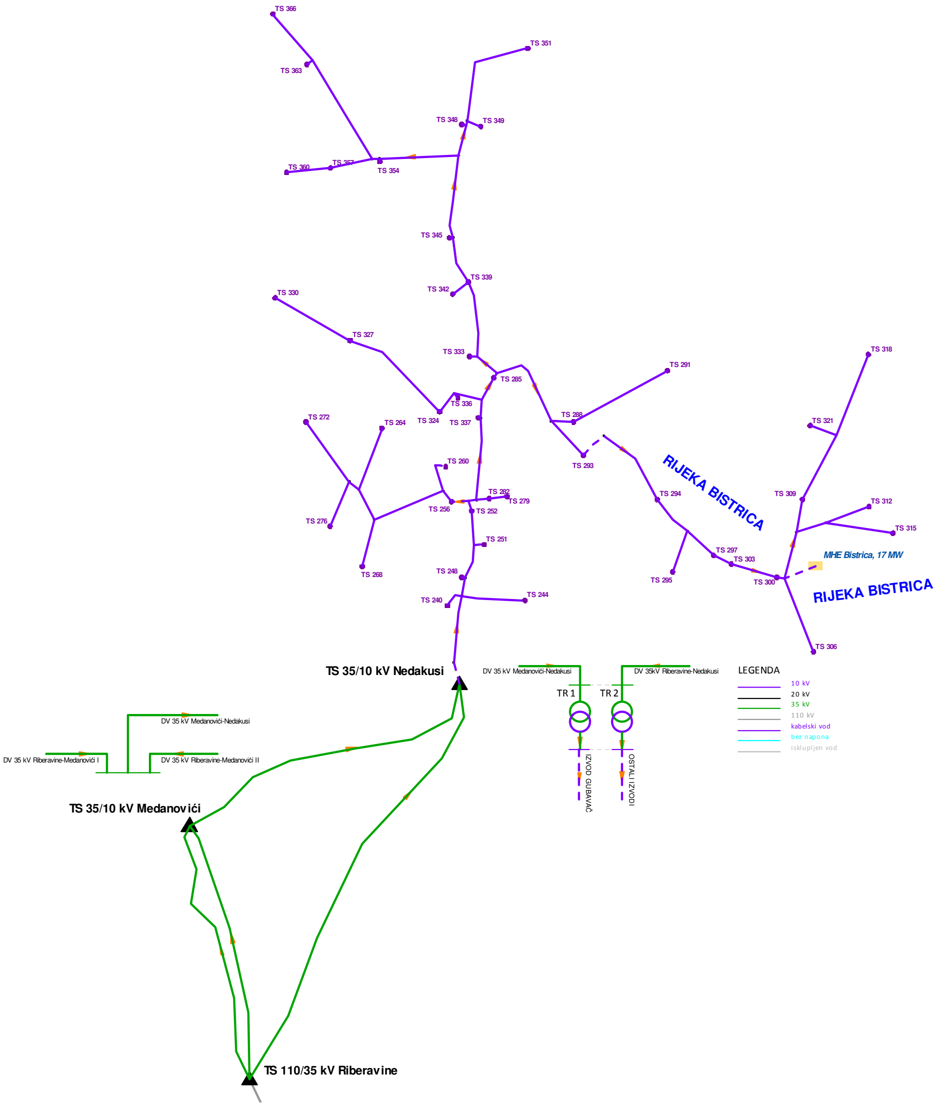


Figure 48: Model of the existing 10 kV network for MHE connection analysis in the Lima River basin – Bijelo Polje area

5.4.2. Network reinforcements before MHE connection to the distribution network

Disburdening the Dolac feeder with new 35/10 kV Lubica feeder from SBS Rudež

Total length of Dolac feeder is more than 70 km. With full feeder load of approximately 3 MW this presents more than 20 % of unacceptable power drops in the existing 10 kV network. High voltage drops in the 10 kV network are thus reflected in considerable voltage changes in the LV network. Before MHE connection to the distribution network the disburdening of Dolac feeder is suggested by constructing new Lubnica feeder to the village Lubnica in the valley of the river Bistrica (Figure 49). Between SBS Rudež and Dolac (on tap towards Crni Vrh and up to Lubnica) the existing overhead line is reconstructed into the double circuit line. Both systems need to have AlFe70/12 mm^2 conductors installed. SBS Beranselo II is connected to the new Lubnice feeder, whereas SBS Beranselo I and SBS Dolac VI remain connected to the Dolac feeder.

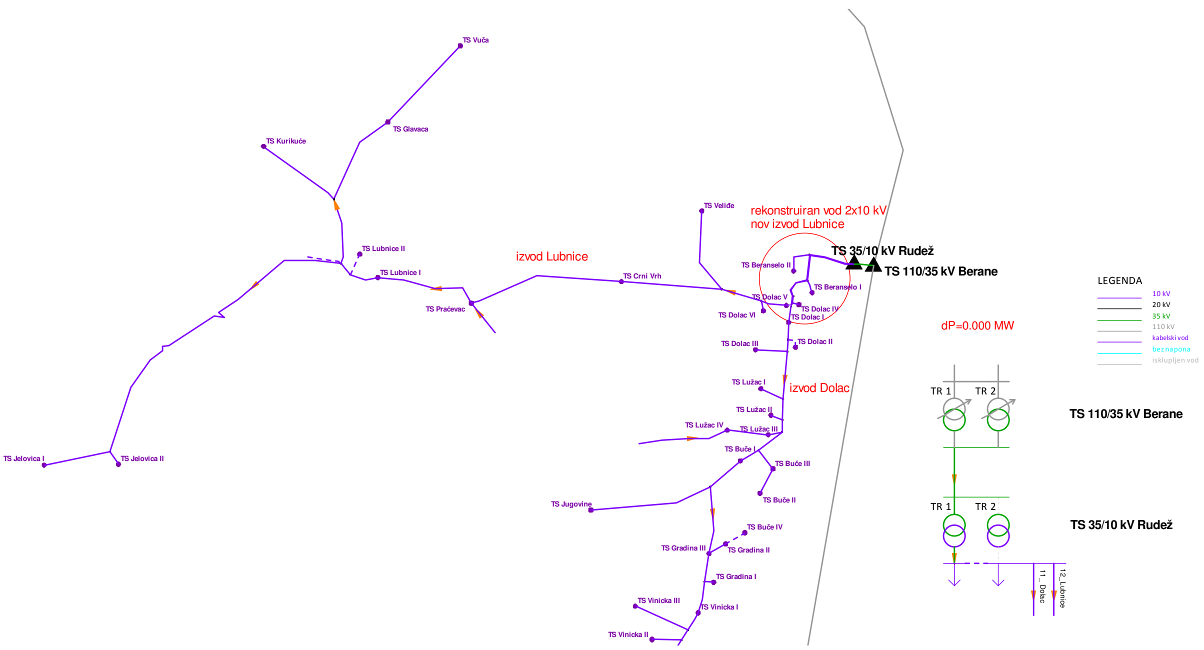


Figure 49: Geographical view of new Lubnica feeder to the village Lubnica and the valley of Bistrica and Jelovica.

Characteristics of the projected reinforcements:

- Reconstruction of 2xAlFe70/12 mm^2 transmission line
- length approx. 2.5 km
- estimated investment: 198,000 EUR

Connection of Dolac feeder (SBS Rudež) and Trešnjevo feeder (SBS Andrijevica)

The construction of this connection provides the transfer of consumption from Šekulara and Trepče to Trešnjevo feeder which is considerably less loaded. In this way the voltage conditions in this area and the remaining Dolac feeder are considerably improved. Thus the reliability of the consumer supply on both feeders is improved. With the construction of new connection the reserve supply is provided in case of malfunctions on one feeder.

Characteristics of the projected connection:

- AlFe70/12 mm2 transmission line

- length approx. 1.5 km
- estimated investment: 82,500 EUR

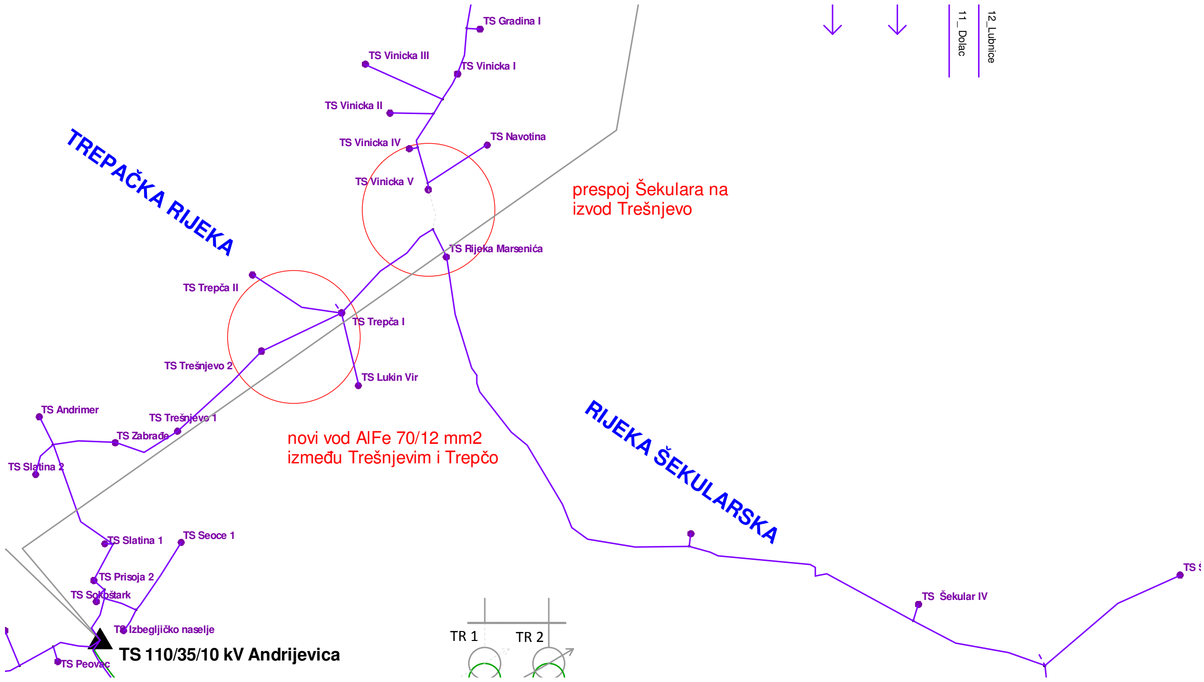


Figure 50: Geographical view of reconnecting the Dolac feeder (Rudež feeder) to the Trešnjevo feeder (SBS Andrijevica).

5.4.3. Needs for 110/35/10 kV transformer and main 35 kV supply lines reinforcement after MHE connection to the distribution network

For the needs of connecting *all* MHE to the analysed rivers, the following main lines and transformers reinforcements have to be implemented:

- **new TR 35/10 kV, 8 MVA in SBS Plav with new 35 kV busbar sector**
  - estimated investment: 100,000 EUR
- **reconstruction of 35 kV Andrijevica – Plav transmission line into the double circuit line**
  - one line system is used for power evacuation from MHE on Babinopoljska via new 35 kV busbar sector in SBS Plav.
  - line is constructed as 110 kV transmission line
  - 2 x Al/Fe150/20 mm^2 conductors
  - length 21 km
  - estimated investment: 2,000,000 EUR

New 110/35 kV, 20 MVA transformer in Andrijevica is used only for power surplus evacuation into the 110 kV network from MHE on the rivers Trepačka, Šekularska and Babinopoljska. Thus the new 35 kV busbar sector has to be built which is connected to single 35 kV transmission line system from SBS Plav (power evacuation from MHE to Babinopoljska). The second transformer is used for consumer supply and evacuation of the remaining power from MHE.

Since the 35 kV transmission line Plav – Gusinje reconstruction is projected the reconstruction should include Al/Fe120/20 mm^2 conductors.

Conditions in the distribution network after the connection of all planned MHE are shown in the Figure 51, Figure 52, Figure 53.

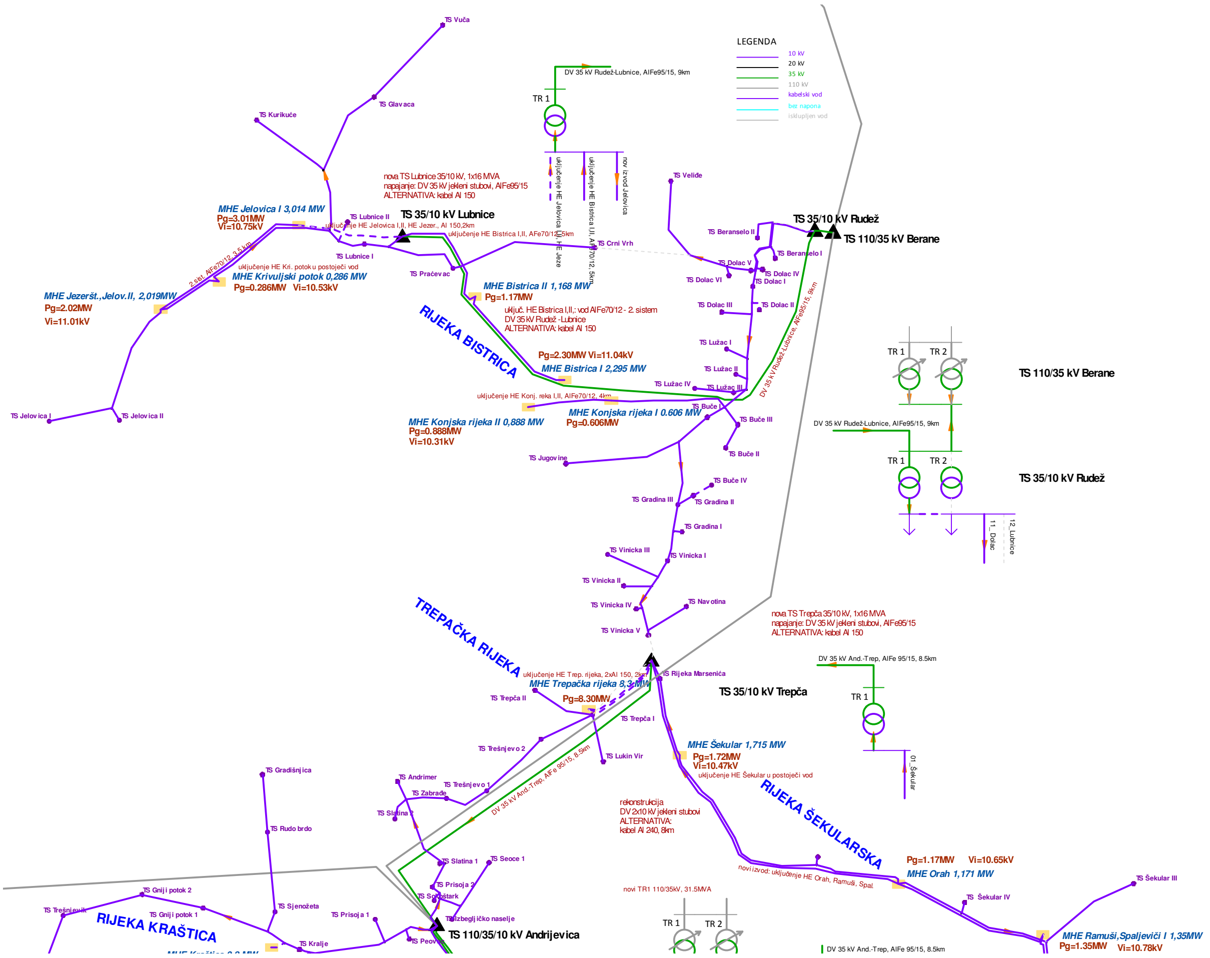


Figure 51: Distribution network configuration after the connection of all planned MHE – Beran and Andrijevica area.

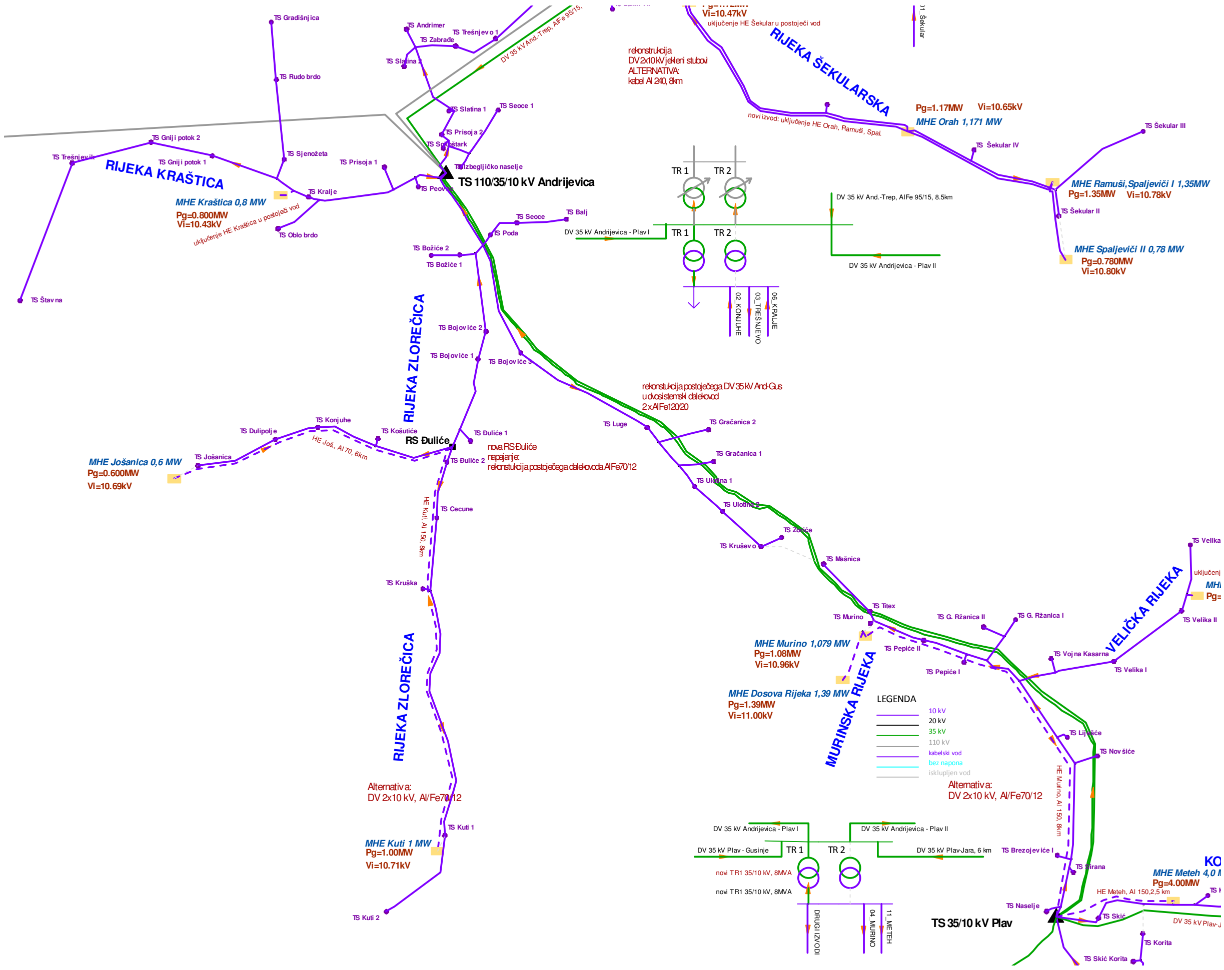


Figure 52: Distribution network configuration after the connection of all planned MHE – Andrijevica and Plav area.

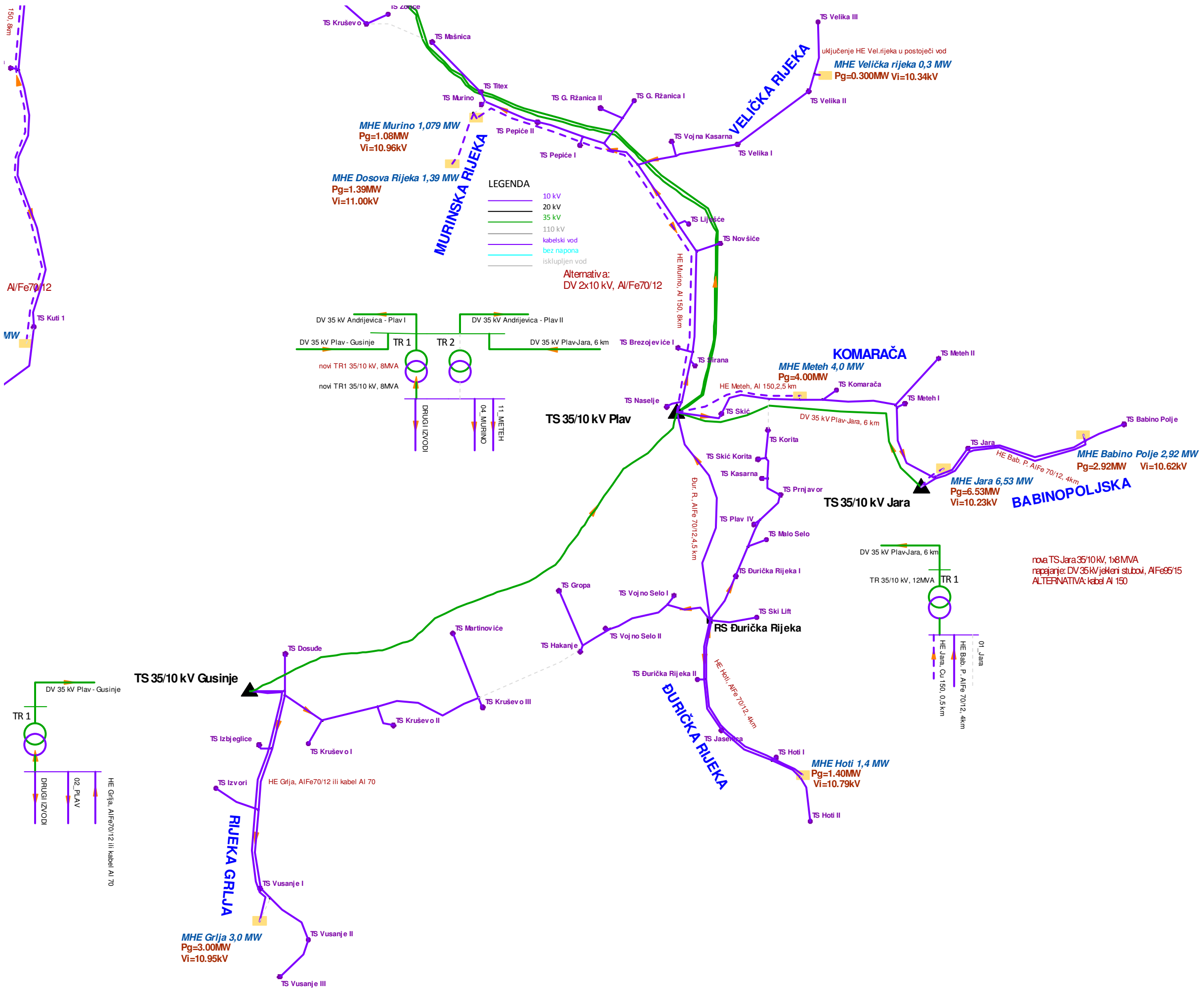


Figure 53: Distribution network configuration after the connection of all planned MHE – Plav and Gusinje.

5.4.4. Necessary distribution network reinforcements for the individual MHE connections

The solutions with analysis of individual MHE connections on the rivers are interpreted in the tables. Here, only main reinforcements of the existing network are summarized for the need of MHE connections on the individual rivers.

Alternative to network reinforcements with overhead AlFe70/12 mm^2 line is a Al 150 mm^2 cable line.

According to the license, the 63 MW of installed power of all MHE is included in the short-term plan in the Lima River basin. The MHE operation will cause great voltage changes in the distribution network, meaning that other loads on 35 kV busbars in SBS 110/35 kV should have actively regulated voltage. The voltage is regulated to provide all SBS 35/10 kV in individual loads the voltage on 10 kV busbars between 10.2 kV and 10.7 kV.

River Bistrica (Bijelo Polje) – total planned installed production 17 MW, Figure 54

- New connection line of 35 (110) kV from SBS Nedakusi, AlFe 150/25 mm2 conductor, length 8 km. The line is constructed as 110 kV line.
- SBS Nedakusi should include an option of switching the power evacuation from MHE directly to SBS Riberavine 110/35 kV (possible reconstruction of 35 kV busbars with at least two sectors).

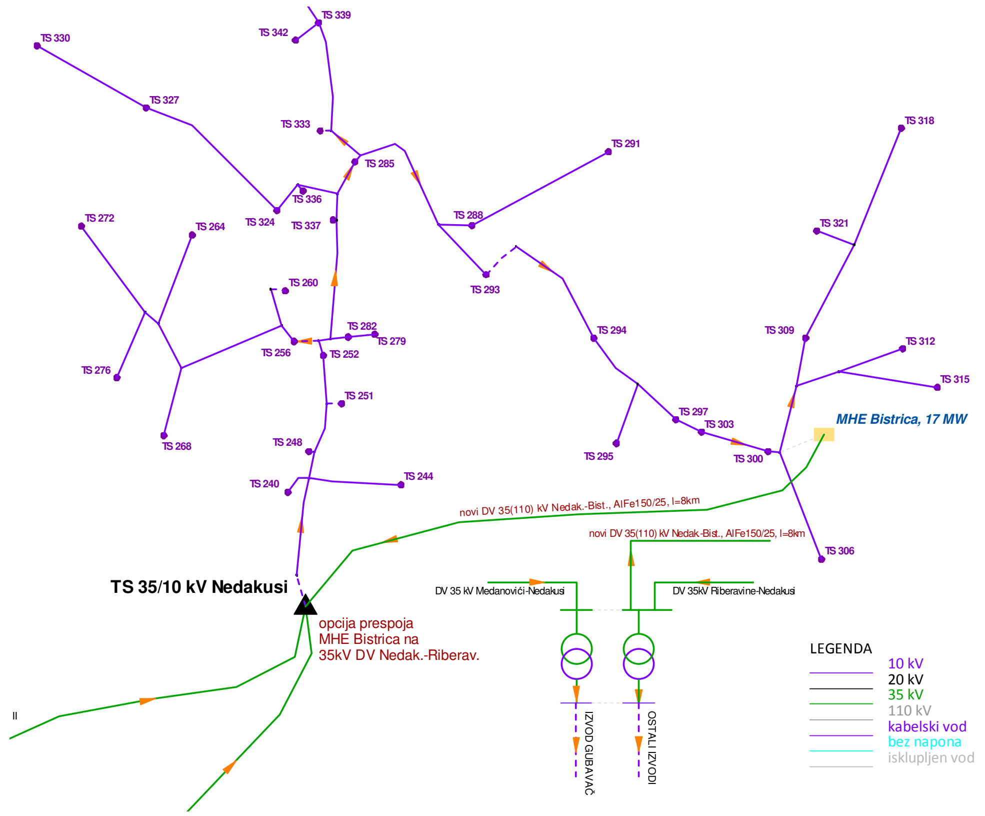


Figure 54: Scheme of MHE connection on the river Bistrica (Bijelo Polje) to the distribution network.

River Bistrica (Berane) – total planned installed production 10.2 MW, Figure 55

- New SBS 35/10 kV Lubnice, 2x8 MVA, three 10 kV feeder bays, one 35 kV feeder bay, two transformer bays (35 kV and 10 kV).
- 35 kV supply line from SBS Rudež (AlFe95/15 mm^2 conductor, length 12 km).
- MHE connection on the rivers Jelovica and Jezerštica via new line from SBS Lubnica (first section: Al 150 mm^2 cable, 2 km; second section: AlFe70/12 mm^2 conductor, 3,5 km).
- MHE connection on the river Bistrica via new feeder from SBS Lubnica (AlFe70/12 mm^2 conductor, 5 km).
- MHE connection on the river Konjska Rijeka to the reconstructed Dolac feeder.
- MHE connection of the river Krivuljski Potok to the existing network (feeder for consumer supply in SBS Lubnica).

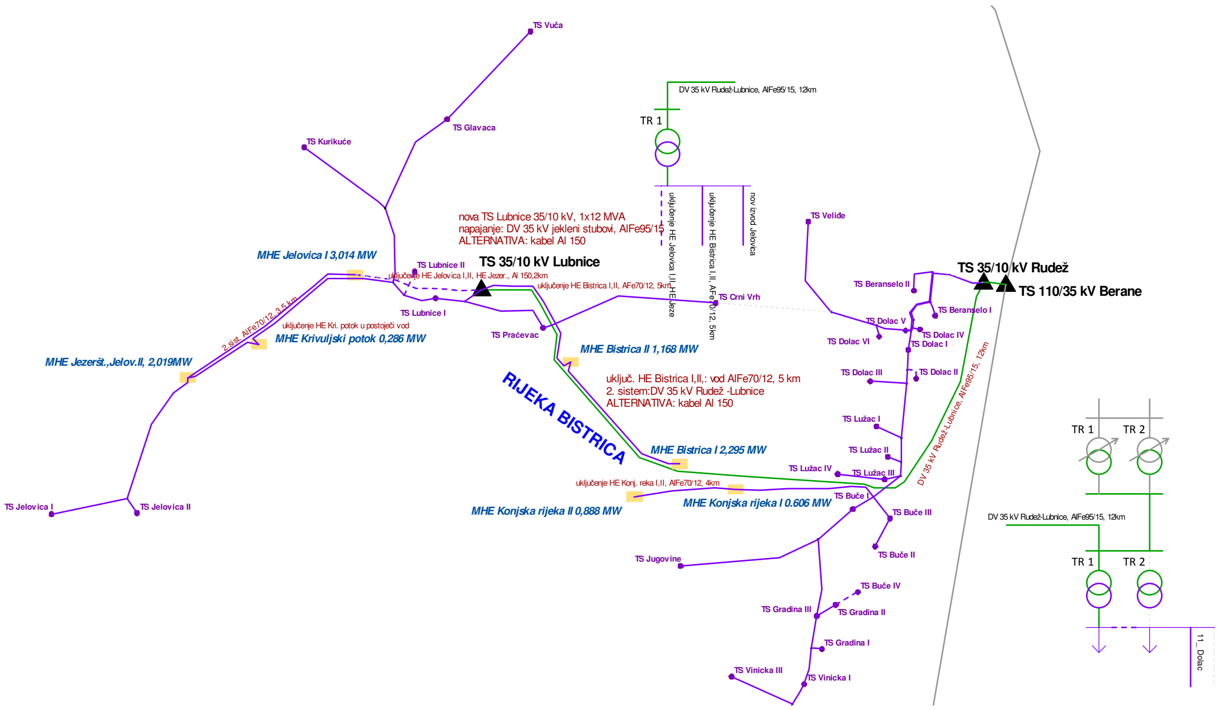


Figure 55: Scheme of MHE connection on the river Bistrica (Berane) to the distribution network.

Rivers Šekularska and Trepačka – total planned installed production 13.3 MW (Šekularska 5.0 MW, Trepačka 8.3 MW), Figure 56

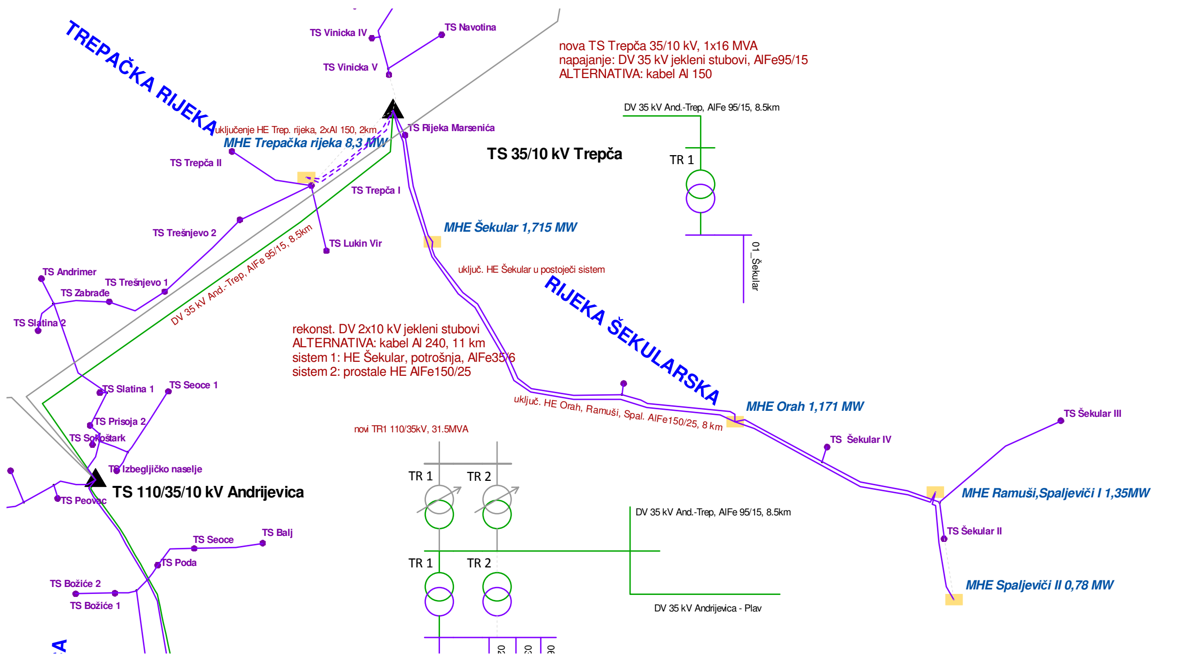


Figure 56: Scheme of MHE connection on the rivers Trepačka and Šekularska to the distribution network.

- New SBS 35/10 kV Trepča, 1x16 MVA (or 2x8 MVA), six 10 kV feeder bays, one 35 kV feeder bay, two transformer bays (35 kV and 10 kV).
- 35 kV supply line from SBS Andrijevica (AlFe95/15 mm^2 conductor, length 8.5 km); the line is connected directly to the 35 kV busbar tap in SBS Andrijevica. One sector with TR 110/35 kV,

20 MVA: power surplus from MHE on the rivers Trepačka and Šekulčarska is evacuated together with production from MHE on the river Babinopoljska. The second sector with TR 110/35 kV, 10 MVA: consumption and evacuation of the power surplus from the remaining MHE.

- MHE connection to the reconstructed double circuit line of the length 11 km (one system with the total consumption and MHE Šekular is equipped with AlFe 35/6 mm^2 conductor, 2nd system with all the remaining MHE is equipped with AlFe 150/25 mm^2 conductor). The alternative to the 2x10 kV reconstruction is the solution with direct connection of MHE Orah, Spaljevići I,II and Ramuši with Al 240 mm^2 cable.
- MHE connection on the river Trepačka with 2 x Al 150 mm^2 cable in SBS Trepča, length 2 km.

River Kraštica – total planned installed production 0.8 MW, Figure 57

- MHE connection of the river Kraštica Potok to the existing network (Kralje feeder in SBS Andrijvica).

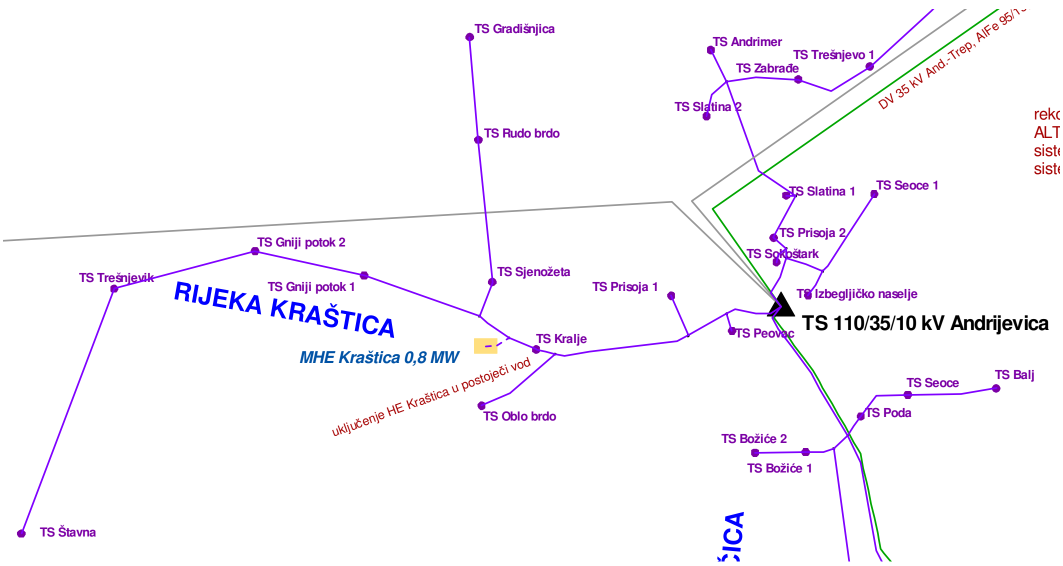


Figure 57: Scheme of MHE connection on the river Kraštica to the distribution network.

River Zlorečica – total planned installed production 1.6 MW, Figure 58

- New switching station SS Đuliće (four feeder bays).
- Reconstruction of SS Đuliće supply line (Konjuhe feeder from SBS Andrijevica) in the AlFe 70/12 mm^2 overhead line of approx. length 6 km.
- MHE Jošanica connection via new feeder from SS Đuliće (Al 70 mm^2 cable, 6 km). Alternative to the cable solution is the reconstruction of the existing line into the double circuit line (1st system with the total consumption is equipped with AlFe 35/6 mm^2 conductor, 2nd system with MHE Jošanica is equipped with AlFe 70/12 mm^2 conductor).
- MHE Kuti connection via new feeder from SS Đuliće (Al 150 mm^2 cable, 8 km). The alternative to the cable solution is the reconstruction of the existing line into the double circuit line (1st system with the total consumption is equipped with AlFe 35/6 mm^2 conductor, 2nd system with MHE Kuti is equipped with AlFe 70/12 mm^2 conductor).

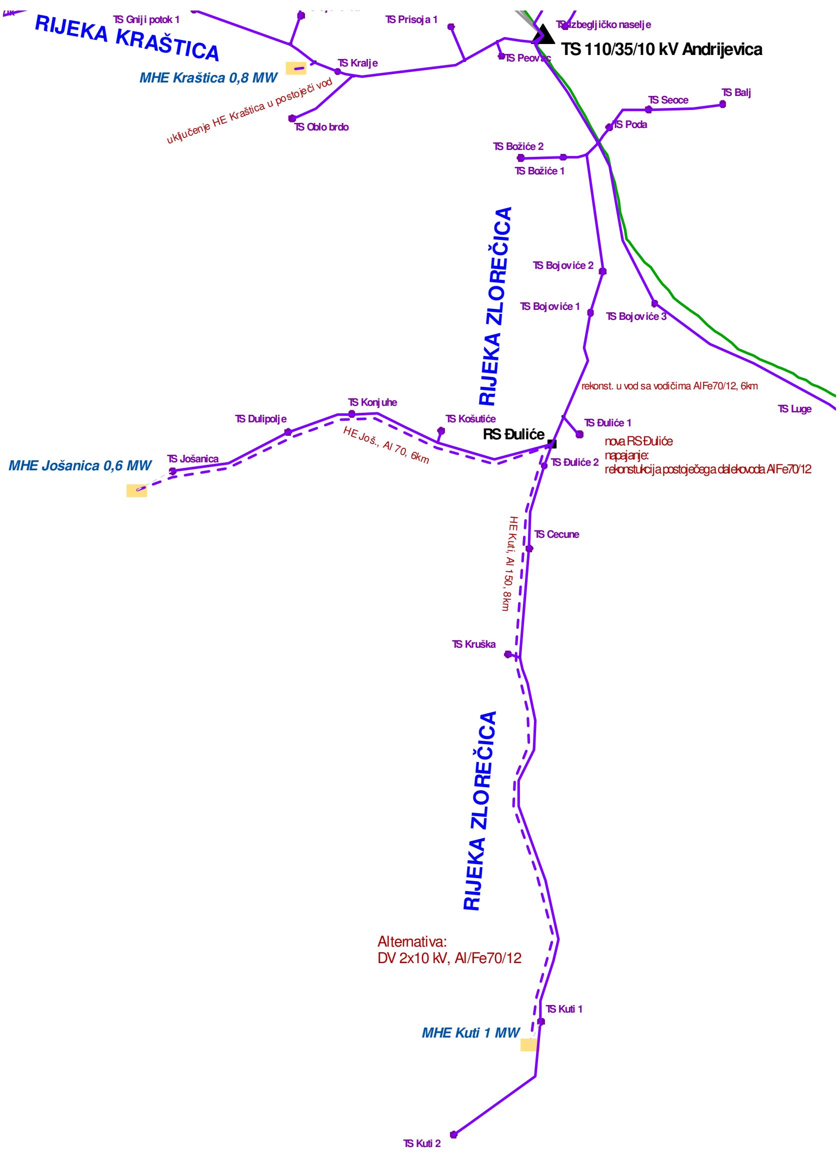


Figure 58: Scheme of MHE connection on the river Zlorečica to the distribution network.

Rivers Murinska, Velička Rijeka and Komarača – total planned installed production 6.8 MW, Figure 59

- MHE Dosova Rijeka and MHE Murino connections on the river Murinska (the amount of installed production 2.5 MW) via new 10 kV feeder directly in SBS 35/10 kV Plav (Al 150 mm^2 cable, 8 km)
- The alternative to the cable solution on the river Murinska is the reconstruction of the existing transmission line in 2x10 kV, 1xAlFe 70/12 mm^2 conductors (MHE) and 1xAlFe 35/6 mm^2 conductors (consumption)
- MHE Velička Rijeka connection to the existing network (Murino feeder in SBS Plav)
- MHE Meteh connection on the river Komarača (the amount of installed production 4.0 MW) via new 10 kV feeder directly in SBS 35/10 kV Plav (Al 150 mm^2 cable 2.5 km)

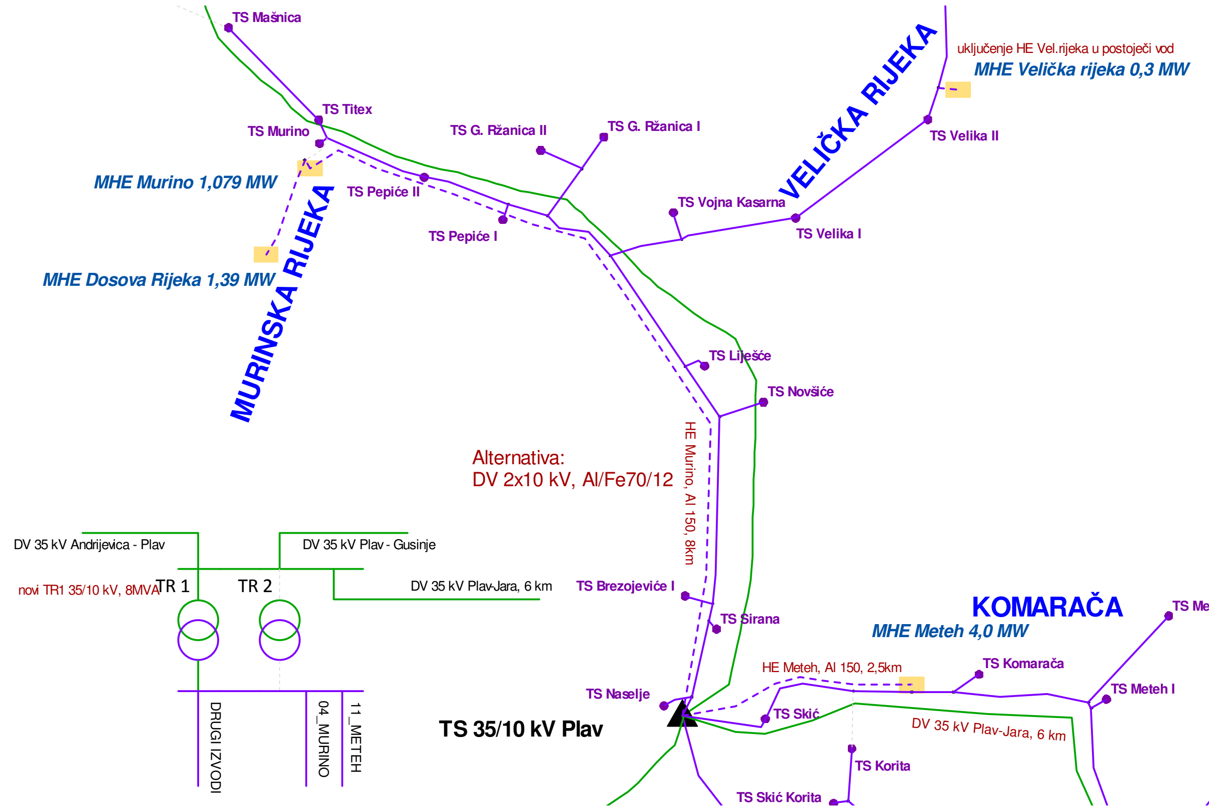


Figure 59: Scheme of MHE connection on the rivers Murinska, Velička Rijeka and Komarača to the distribution network.

River Babinopoljska – total planned installed production 9.45 MW, Figure 60

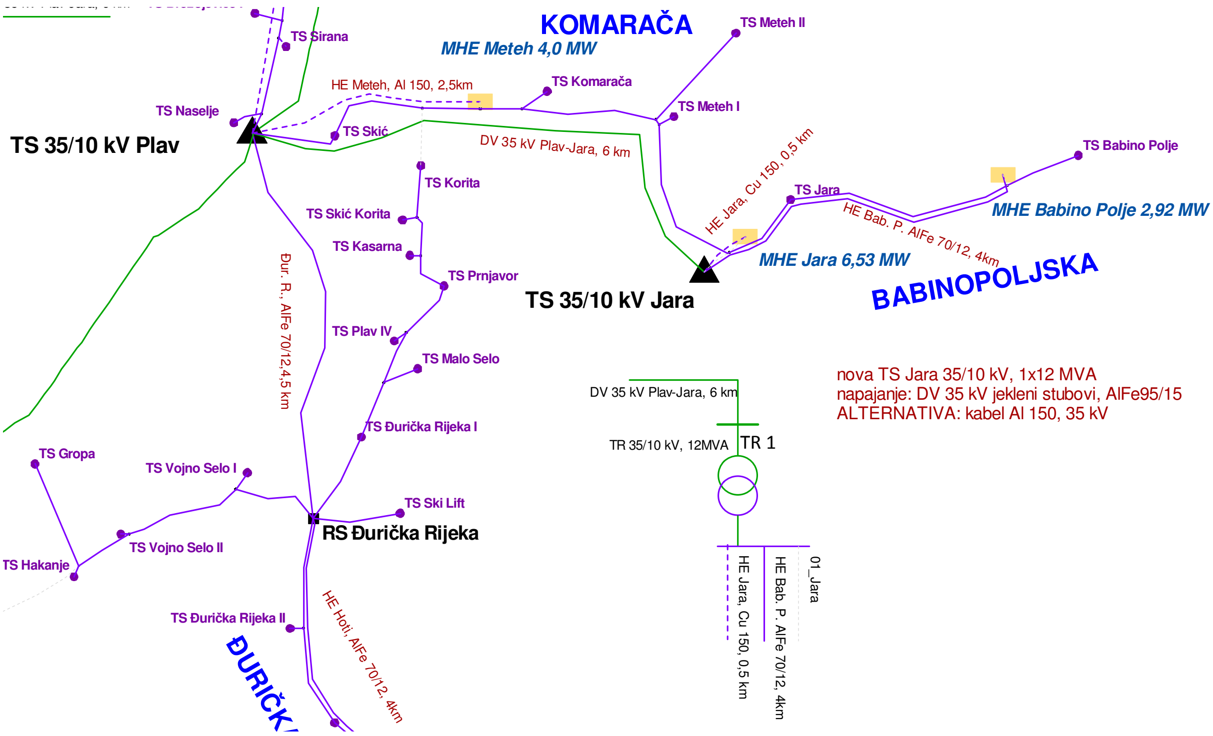
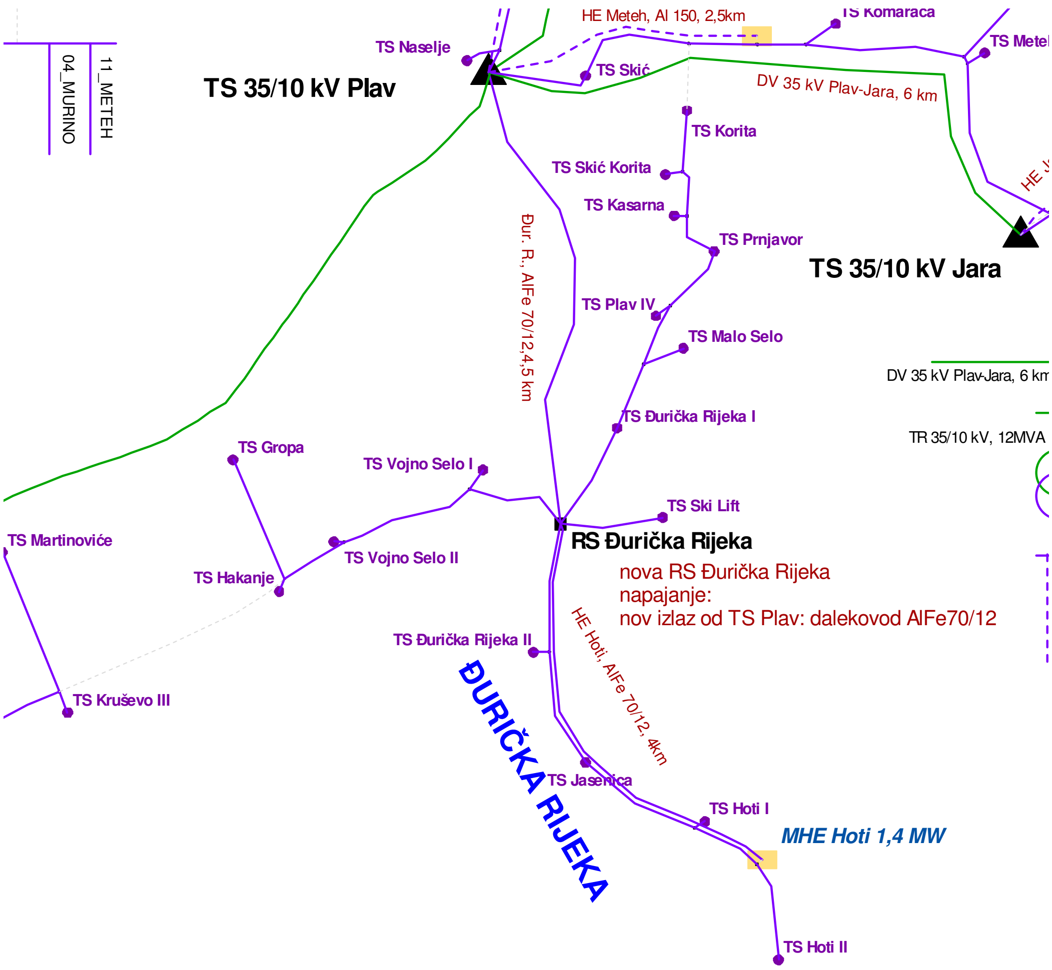


Figure 60: Scheme of MHE connection on the river Babinopoljska to the distribution network.

- **Condition for the connection is reconstructing the 35 kV Andrijevica – Plav transmission line into the double circuit line with AlFe120/20 mm^2 conductor and new 35 kV busbar sector in SBS Plav.**
- New SBS 35/10 kV Jara, 1x8 MVA, three 10 kV feeder bays, one 35 kV feeder bay, one transformer bay (35 kV and 10 kV).
- 35 kV supply line from SBS Plav (AlFe95/15 mm^2 conductor, length 6 km).
- The line is switched to the second system of 35 kV Andrijevica – Plav II transmission line directly on 35 kV busbars in SBS Andrijevica (power surplus is evacuated together with production on the rivers Trepačka and Šekularska via transformer 110/35 kV, 20 MVA to the 110 kV network).
- MHE Babino Polje connection to the reconstructed existing 2x10 kV line of 4 km length (1xAlFe 70/12 mm^2 conductors (MHE) and 1xAlFe 35/6 mm^2 conductors for consumption). The alternative to the reconstruction of 2x10 kV is the solution with the direct MHE connection with Al 150 mm^2 cable.
- MHE Jara connection with Cu 150 mm^2 cable in SBS Jara, length 0.5 km.
- 10 kV feeders from SBS Jara:
  - feeder to MHE Jara
  - feeder to MHE Babino Polje
  - feeder to Meteh (connected to Meteh feeders from SBS Plav)

River Đurička – total planned installed production 1.4 MW, Figure 61

- New switching station SS Đurička Rijeka (six feeder bays).
- SS supply with new10 kV feeder Đurička Rijeka from SBS Plav (AlFe 70/12 mm^2 overhead line, length approx. 4.5 km).
- MHE Hoti connection via feeder from SS Đurička Rijeka. The projected reconstruction of the existing 2x10 kV transmission line, 1xAlFe 70/12 mm^2 conductors (MHE) and 1xAlFe 35/6 mm^2 conductors (consumption). The alternative to the transmission line reconstruction is Al 150 mm^2 cable, length 4 km.
- Feeders from SS Đurička Rijeka:
  - supply connection from SBS Plav
  - feeder to Plav and Prnjavor (connected to Meteh feeders from SBS Plav)
  - feeder to Vojno Selo (connected after Plav feeders from SBS Gusinje)
  - feeder to Hoti
  - feeder Ski lift
  - feeder for MHE Hoti



- Figure 61: Scheme of MHE connection on the river Đurička to the distribution network.

River Grlja – total planned installed production 3.0 MW, Figure 62

- MHE Grlja connection via new 10 kV feeder directly in SBS 35/10 kV Gusinje. The projected reconstruction of the existing 2x10 kV transmission line, 1xAlFe 70/12 mm^2 conductors (MHE) and 1xAlFe 35/6 mm^2 conductors (consumption), length approx. 5 km.
- The alternative includes the cable feeder connection (Al 150 mm^2 cable, 5 km).

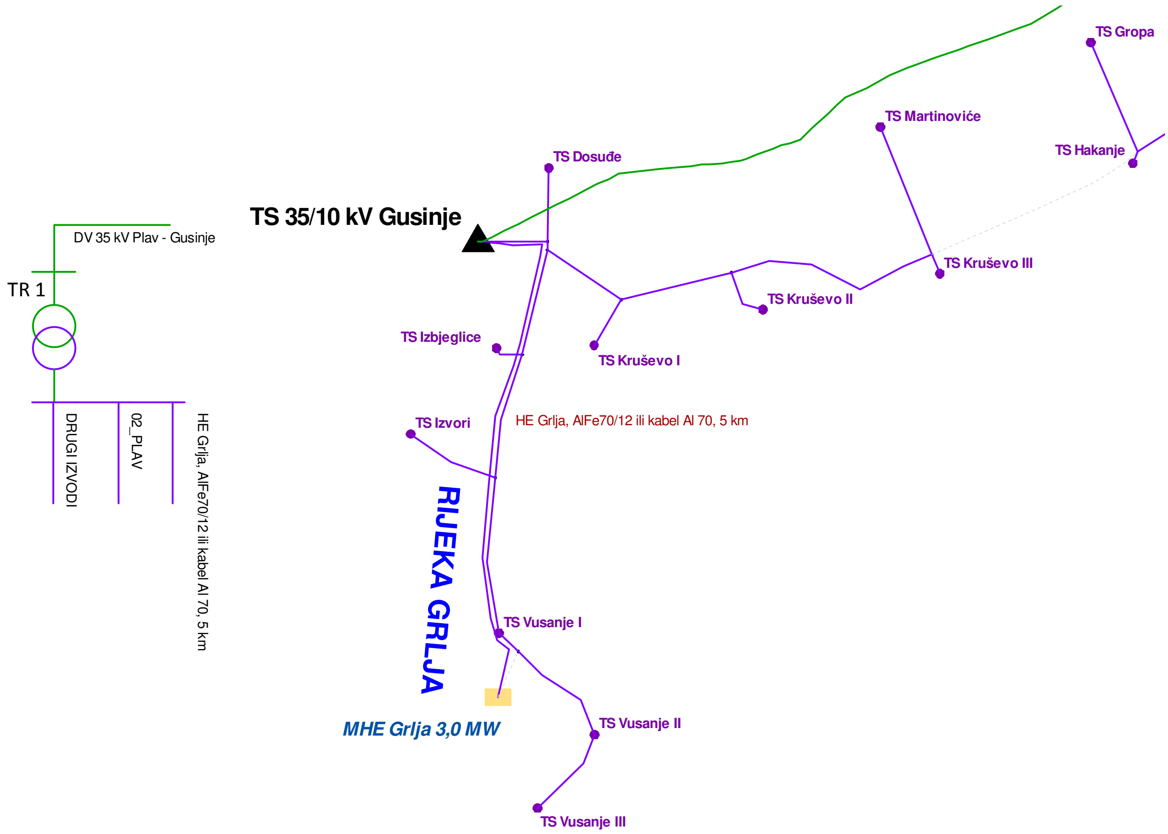


Figure 62: Scheme of MHE connection on the river Grlja to the distribution network.

RIVER BISTRICA (BIJELO POLJE)

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Bistrica	17	SBS 300	7.67
Bisrtrica output	**17**	**Slack node:** 110 kV busbars SBS Riberavine	2775

Min. model of the relevant network:

- SBS Riberavine 110/35 kV
- SBS Nedakusi 35/10 kV
- 10 kV feeder: Gubavač

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Gubavac	0.91	3.36	0.96	3.56
SBS 35/10 kV Nedakusi	**2.87**	**10.1**	**2.95**	**10.7**
SBS 110/35 kV Riberavine	**7.8**	**26**	**8.27**	**27.6**

2.b Relevant data on the projected distribution network development

- Reconstruction of SBS 35/10 kV Nedakusi by 2015 (operation installation)

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	- below permitted limits (min 0.359 kV) - high voltage drops at the Dolac feeder (min voltage approx. 8.71 kV)

Results:

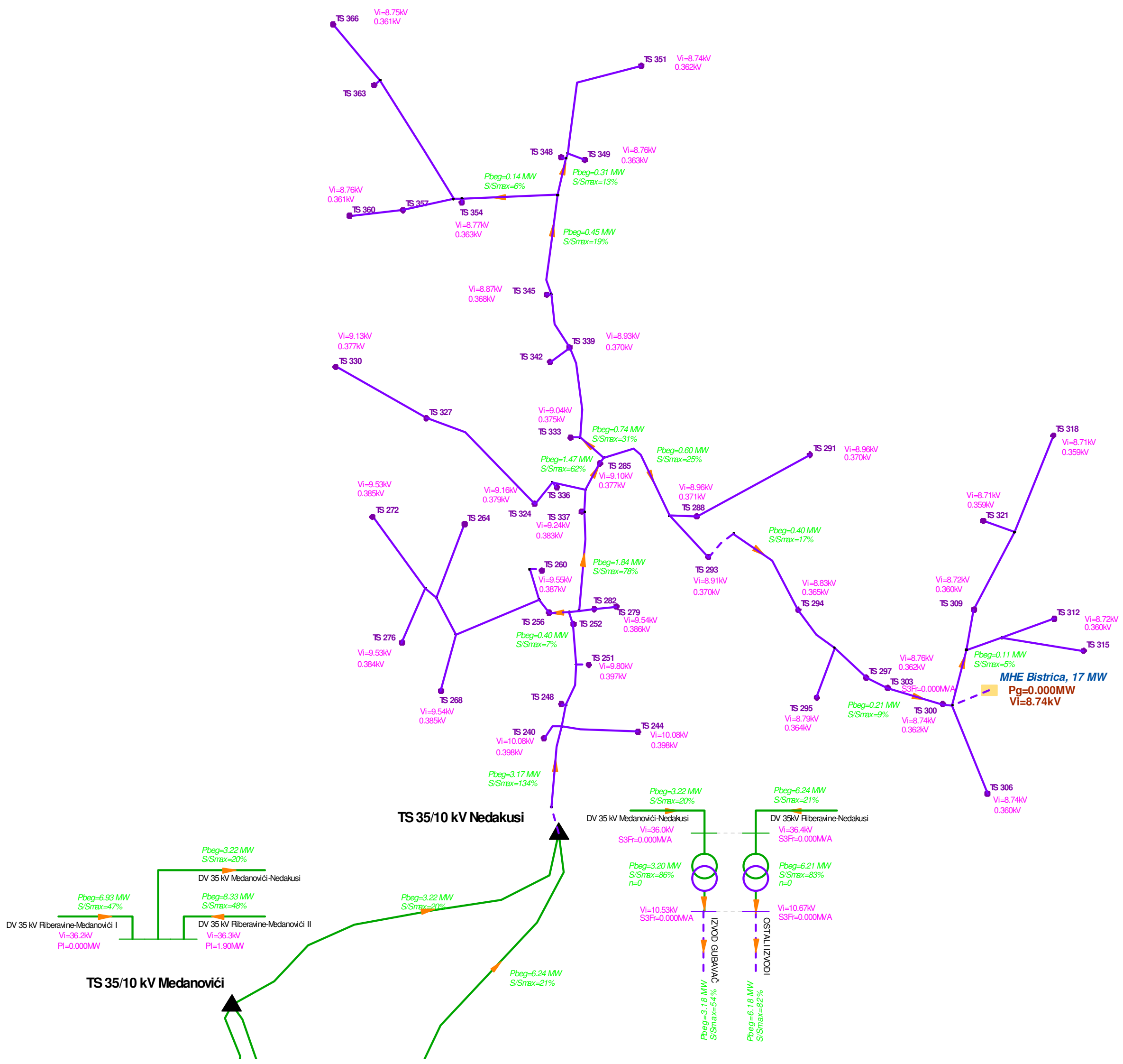


Figure 63: Loads in 10 kV network and loads in LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	- within permitted limits

Results:

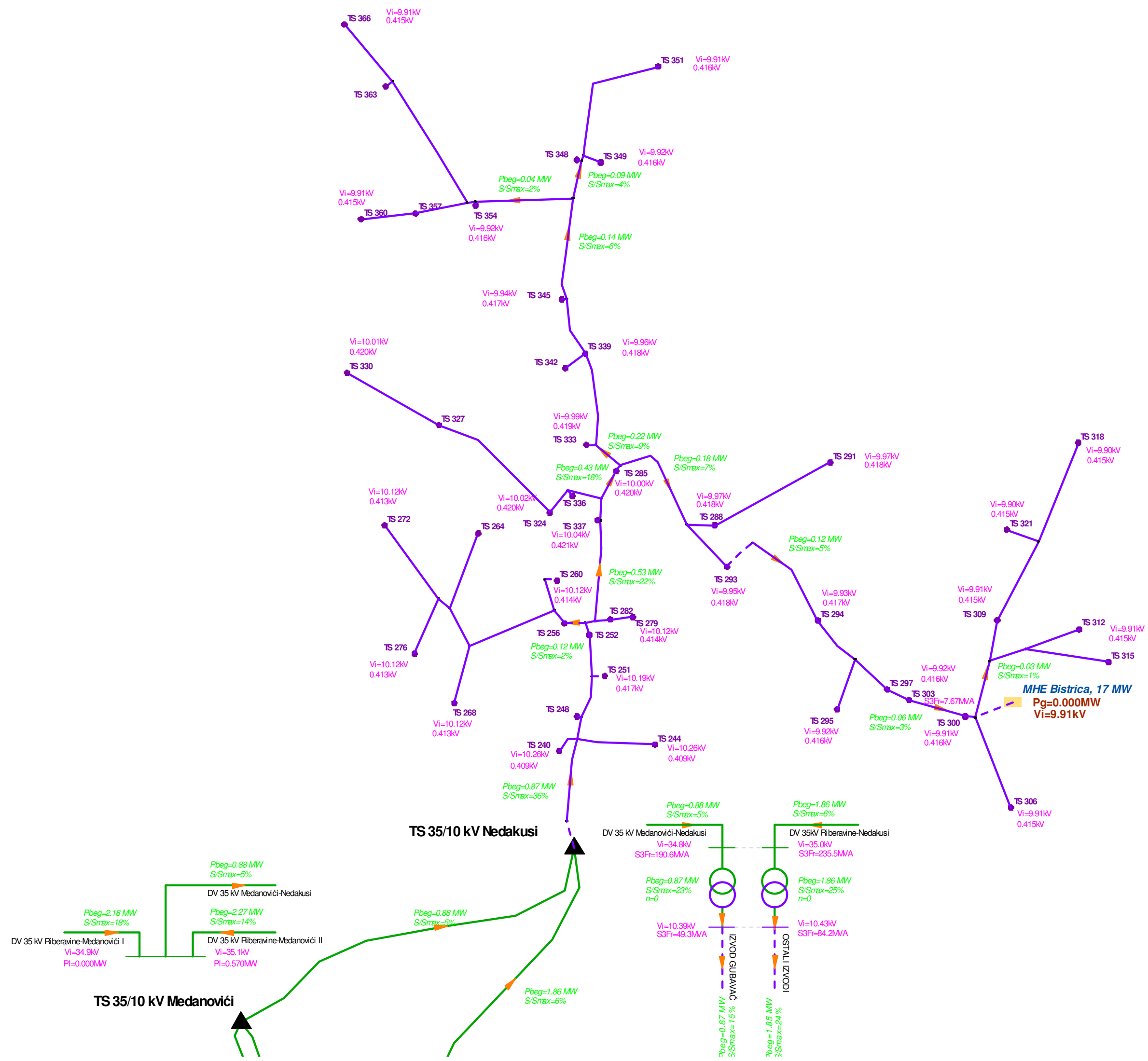


Figure 64: Loads in 10 kV network and loads at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**0.88 MW**	Yearly losses:	**2361.6 MWh**

Necessary network reinforcements before the connection and other results:

- Due to high voltage losses at the Gubavac feeder (higher than 15 %) the reinforcement with new feeders to Bistrica from SBS Nedakusi 35/10 kV is recommended

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.15 MW**

Notes:

- power station with projected characteristics cannot be connected to the existing 10 kV network

Results:

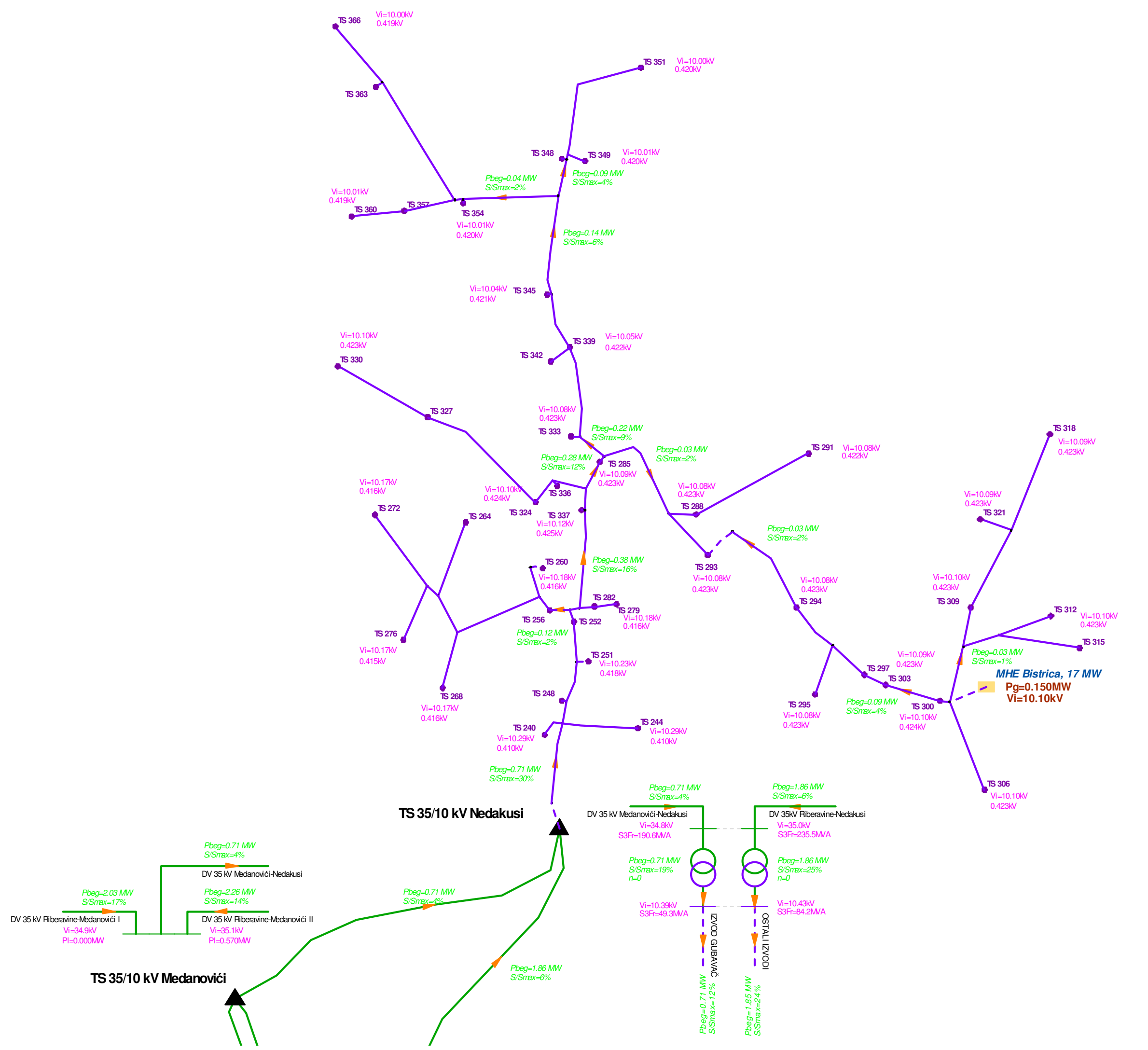


Figure 65: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**0.811 MW**	Yearly losses:	**2176, MWh**

4.b VARIANT A: MHE connection to 35 kV network with overhead line from SBS 35/10 kV Nedakusi

Necessary reinforcements:	Estimated investment in EUR **∑ 1,250,000**
- new connection 35 (110) kV line from SBS Nedakusi (AlFe 150/25 mm^2 conductor, length 8 km) - line is executed as 110 kV line	1,200,000
- in SBS Nedakusi there should be an option to redirect power evacuation from MHE directly to SBS Riberavine 110/35 kV (potential reconstruction of 35 kV busbars with at least two sectors)	50,000

Load conditions after the MHE connection to the network – MHE max load, max production		
Loads and voltages in the network:	Max losses:	Yearly losses:
- small influence of MHE on the LV network - small voltage drops at feeders from 35/10 kV transformers, powered by SBS Medanovići (min 0.350 kV at the end of Gubavac feeder)	**1.267 MW**	**3400.2 MWh**

Results:

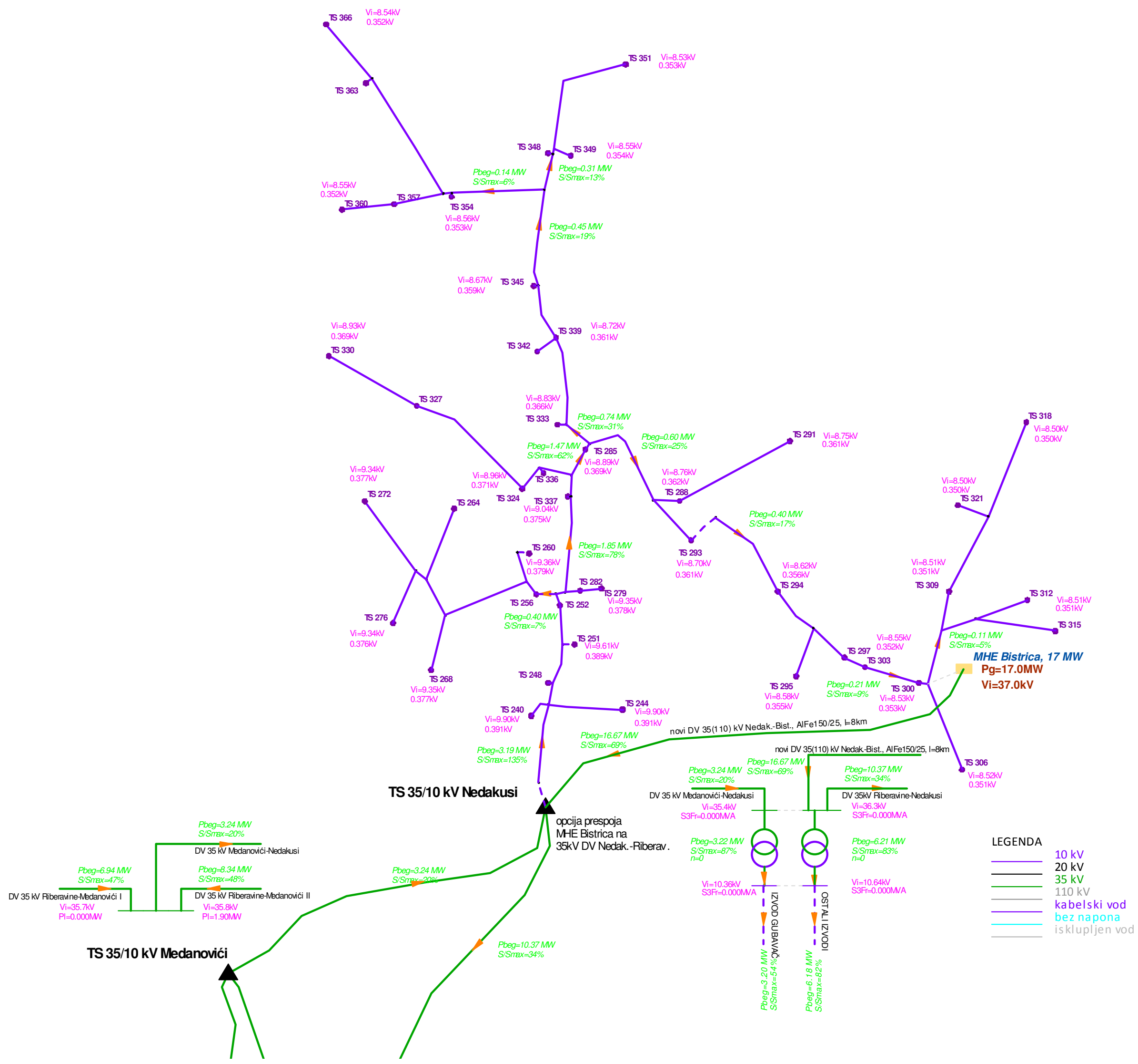


Figure 66: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- small influence of MHE on LV network - within permitted limits (max 0.415 kV)	**0.695 MW**

Results:

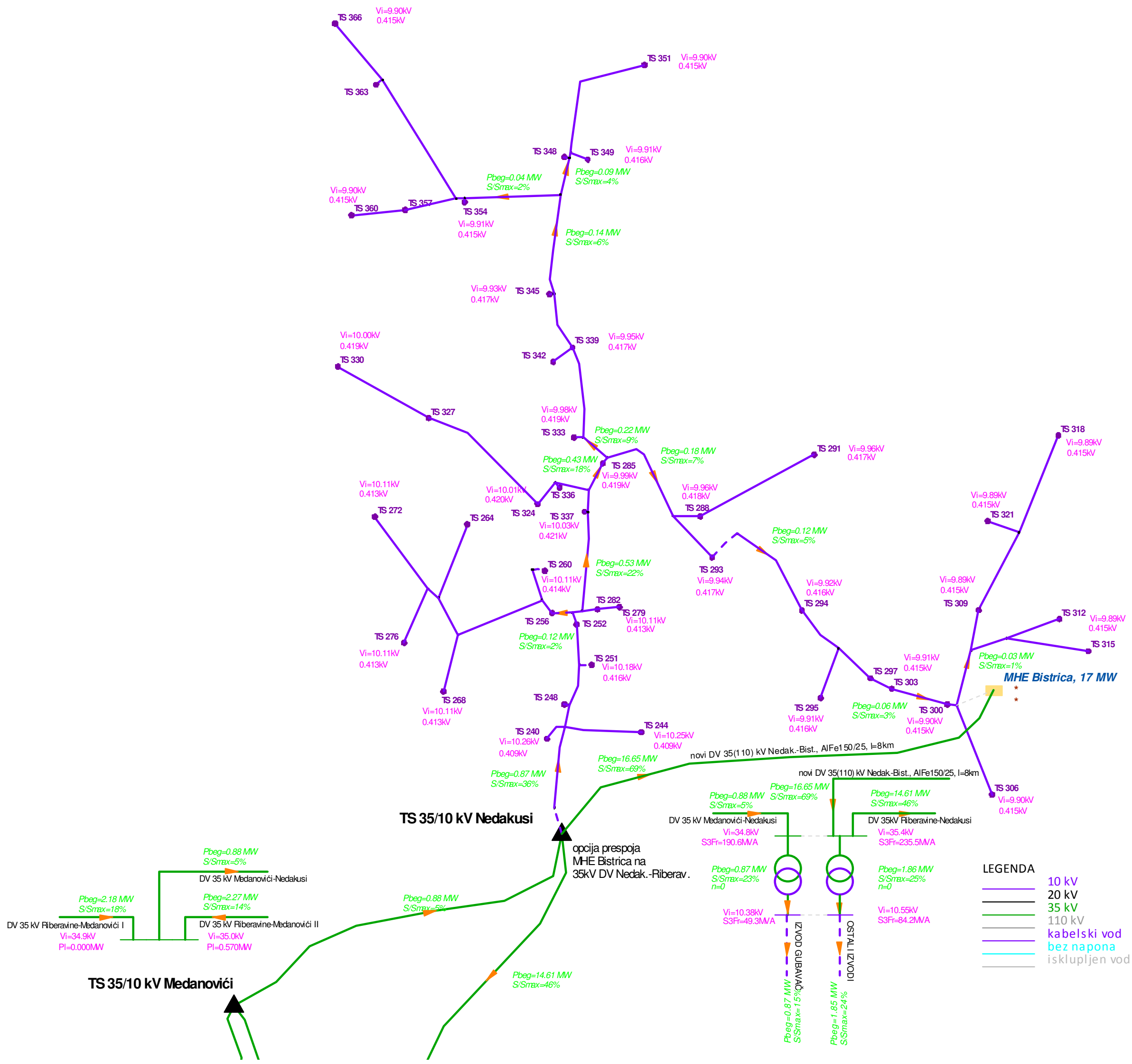


Figure 67: Results of power condition analyses – VARIANT A, min consumption, MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.388 kV, max 0..411 kV)	**1.621 MW**
The same situation as in the situation with maximum consumption before the MHE connection	
Solution advantages	

- **reliable MHE Bistrica connection to 10 kV network is not possible**
- **after excluding 35 kV voltage level, MHE should operate on 110 kV network**
- **option of transmission line reconnection (two sectors of 35 kV busbars in SBS Nedakusi) for power evacuation directly to 110 kV network SBS Riberevine**

5. *RESULTS COMPARISON*

Situation	P_{MHE} [14] (MW)	U_{min} [15] [kV]	U_{max} [16] [kV]	P_{gub} [17] [MW]	ΔP_{gub} [18] [MW]	W_{gub} [19] [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.359	0.420	0.880	**-**	2361.6	**-**	**-**
Connection to existing network	**0.15**	0.371	0.423	0.811	**-0.069**	2176.5	**-185.1**	**-**
VARIANT A	**10.203**	0.359	0.420	1.267	**+0.387**	3400.2	**+1038.6**	**1,250,000**

[14] Power output of all analysed MHE (output before the connection is 0 MW).
[15] Min voltages in LV network (voltages are calculated on the whole network model and occur in situations with high loads at the end of long feeders. Among all analysed SBS, the voltage of that SBS is shown which deviates the most from the nominal voltage).
[16] Max voltages in LV network (voltages are calculated on the whole network model and occur in situations with small loads in the vicinity of SBS 35/10 kV or distribution sources. Among all analysed SBS the voltage of that is shown which deviates the most from the nominal voltage).
[17] Max losses for situation with maximum loads (calculated for the whole network model).
[18] Relative comparison with losses for the situation before MHE connection to the network.
[19] Estimation of yearly losses W_{gub} on the basis of max losses P_{gub} according to the equation:
$W_{gub} = P_{gub} \cdot T_{gub} = P_{gub} \cdot (0.17 + \frac{0{,}83 \cdot T_{pog}}{8760}) \cdot T_{pog}$, T_{pog} are operation hours of distribution network (T_{pog} = 4500 hours)

River BISTRICA (BERANE)

1.Small hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Jezerštica	1.151	SBS Jelovica II	6.41
MHE Jelovica I	3.014	SBS Lubnice II	9.88
MHE Jelovica II	0.795	SBS Jelovica II	6.41
MHE Krivuljski potok	0.286	SBS Lubnice II	9.88
MHE Bistrica I	2.295	SBS Lužac IV	18.4
MHE Bistrica II	1.168	SBS Praćevac	12.9
MHE Konjska rijeka I	0.606	SBS Lužac IV	18.4
MHE Konjska rijeka II	0.888	SBS Lužac IV	18.4
Bisrtrica output	**10.203**	**Slack node:** 110 kV busbars SBS Berane	1215

Min. model of the relevant network:

- SBS Berane 110/35 kV
- SBS Rudež 35/10 kV
- 10 kV feeder: Dolac

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Dolac	0.74	2.46	0.85	2.85
Lubnice	0.18	0.59	0.21	0.68
SBS 35/10 kV Rudež	**2.37**	**7.9**	**2.55**	**8.49**
SBS 110/35 kV Berane	**8.1**	**27**	**8.71**	**29.03**

2.b Relevant data on the projected distribution network development

- this area has no planned reinforcement of the existing network

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	- within permitted limits - high voltage drops at the Dolac feeder (min voltage approx. 9.5 kV)

Results:

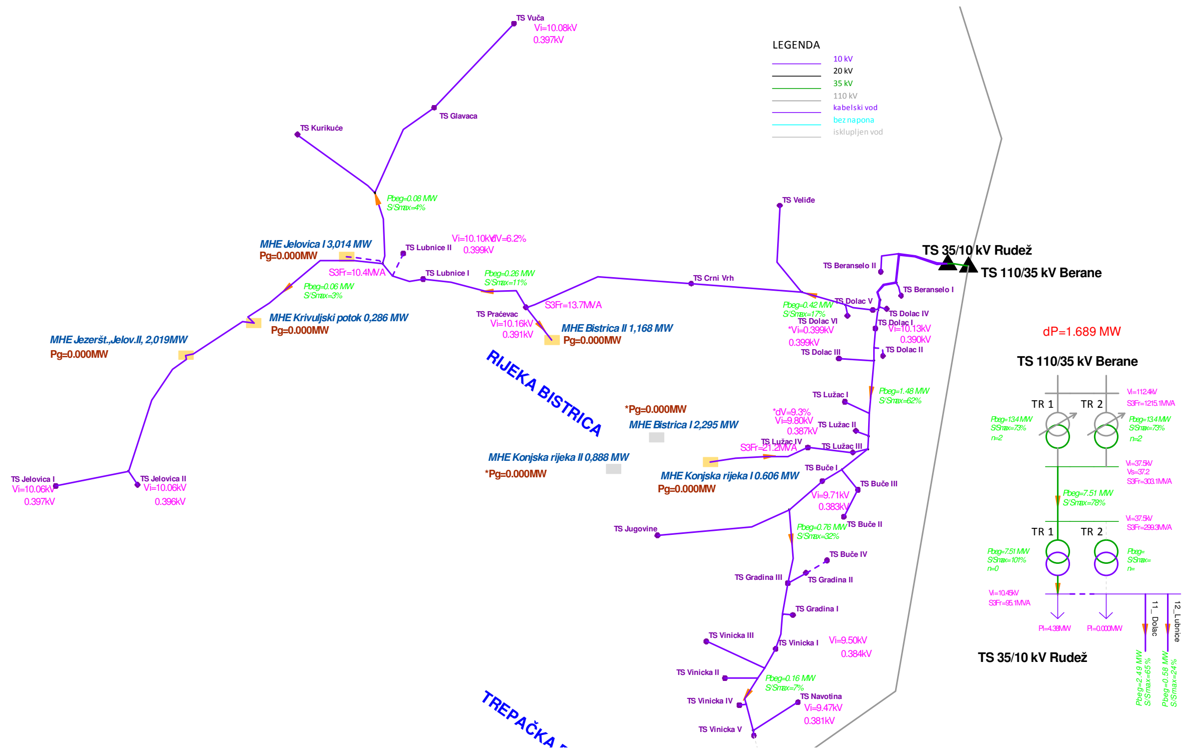


Figure. 68: Loads in 10 kV network and loads in LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	- within permitted limits

Results:

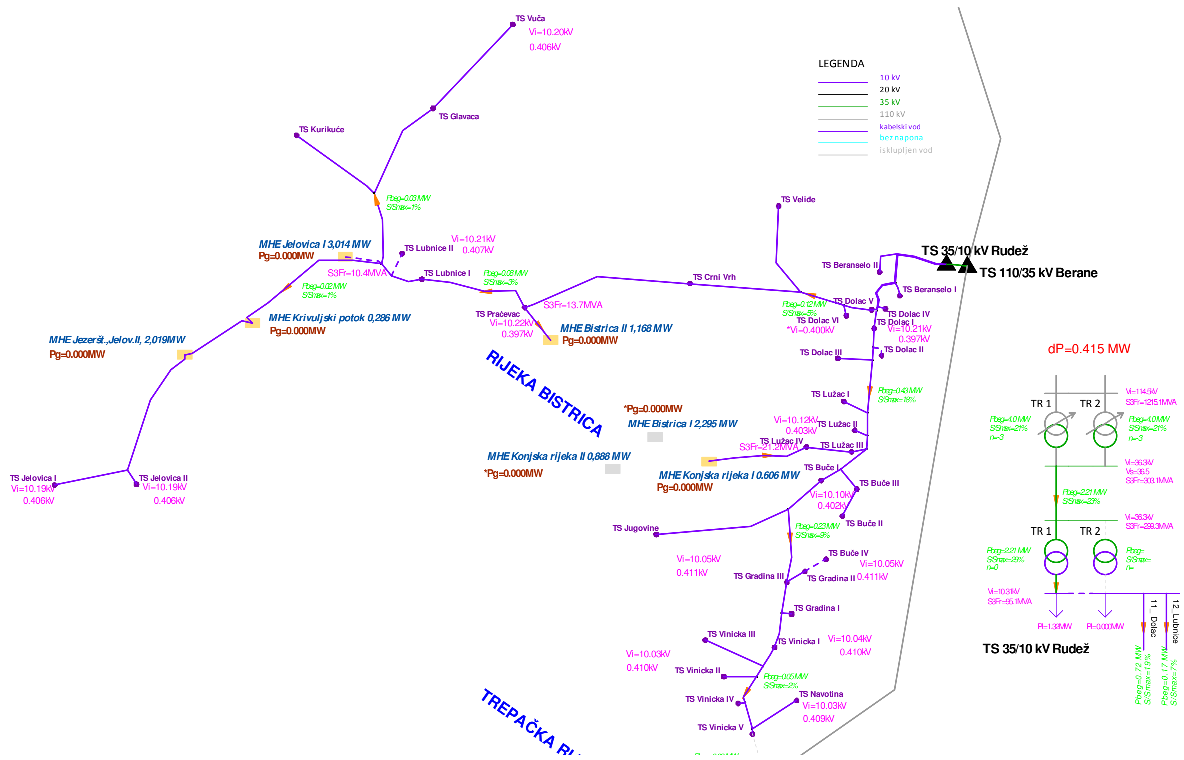


Figure. 69: Loads in 10 kV network and loads at LV busbars TP – minimum loads 2011 in the projected network.

Max losses:	**1.689 MW**	Yearly losses:	**4532.7 MWh**

Necessary network reinforcements before the connection and other results:

- Reinforcement of Dolac feeder with new Lubnica feeders from SBS Rudež 35/10 kV
- Connections of Dolac feeder (SBS Rudež) and Trešnjevo feeder (SBS Andrijevica)

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**1,1 MW**

Notes:

- max 0.3 MW in the area of the rivers Jelovice, Jezerštice and Krivuljsko Potok
- max 0.8 MW in the area of the rivers Bistrica and Konjska Rijeka
- in connections with full power the voltages in LV network increase above 0.420 kV (above 0.5 kV), typical overloads of 10 kV lines

Results:

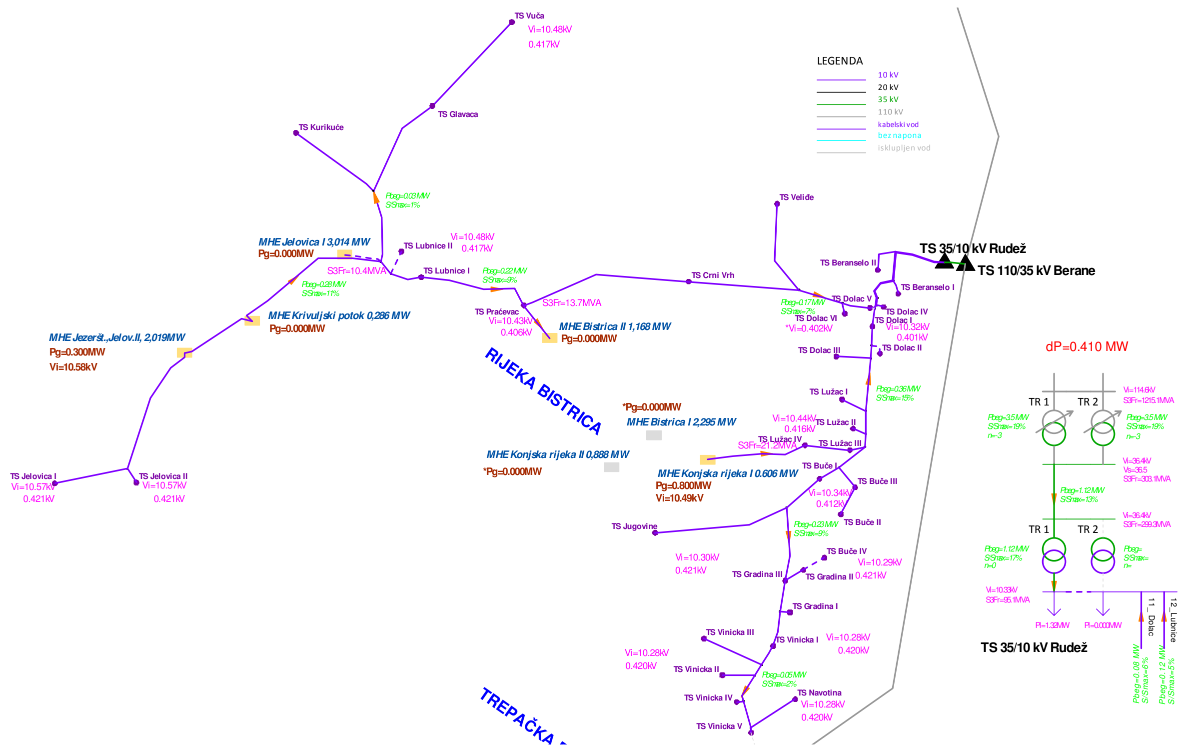


Figure 70: MHE connection to near 10 kV network, minimum loads, 2011.

Max losses:	**1.578 MW**	Yearly losses:	**4234.8 MWh**

4.b VARIANT A: new SBS 35/10 kV Lubnice

Necessary reinforcements:	Estimated investment in EUR **∑ 1,775,000**
MHE connection on the rivers Jelovica, Jezerštica, Krivuljski Potok, Bistrica to SBS	500,000

Lubnice: - New SBS 35/10 kV Lubnice, 1x16 MVA, three 10 kV feeder bays, one 35 kV feeder bay, two transformer bays (35 kV and 10 kV) - 35 kV supply line from SBS Rudež (vodič AlFe95/15 mm^2 conductor, length 12 km) - MHE connection on the rivers Jelovica and Jezerštica to the new feeder from SBS Lubnice (first section: Al 150 mm^2 cable, 2 km, second section: reconstruction of single circuit line into the two circuit AlFe70/12 mm^2 line, 3.5 km) - MHE connection on the river Bistrica to the new feeder from SBS Lubnice (second system on DV 35 kVtransmission line Rudež – Lubnice, AlFe70/12 mm^2 conductor, 5 km) - MHE Krivuljski Potok connection to the existing network (feeder for consumer supply in SBS Lubnice) MHE connection on the Konjska Rijeka to the Dolac feeder: - Connection to Dolac feeder with overhead AlFe70/12 mm^2 line, l= 4 km - Reconstruction of Dolac feeder on the main line between Dolac and Buče into the overhead AlFe70/12 mm^2 line, l= 3.2 km -	700,000 310,000 40,000 5,000 155,000 65,000

Load conditions after the MHE connection to the network – max load, MHE max production		
Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.396 kV, max 0.415 kV)	**1.732 MW**	**4648.1 MWh**

Results:

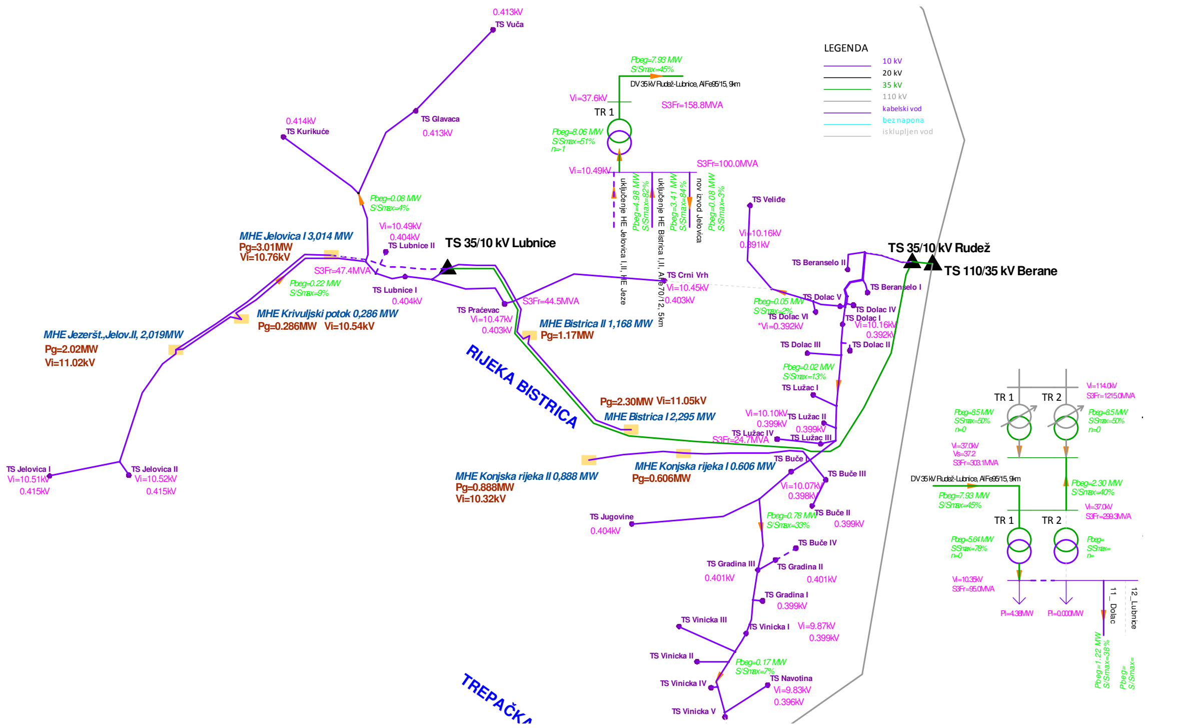


Figure 71: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- small amount above the permitted limits (max 0.423 kV in Buče, min 0.398 in the Lubnica area)	**0,921 MW**

Results:

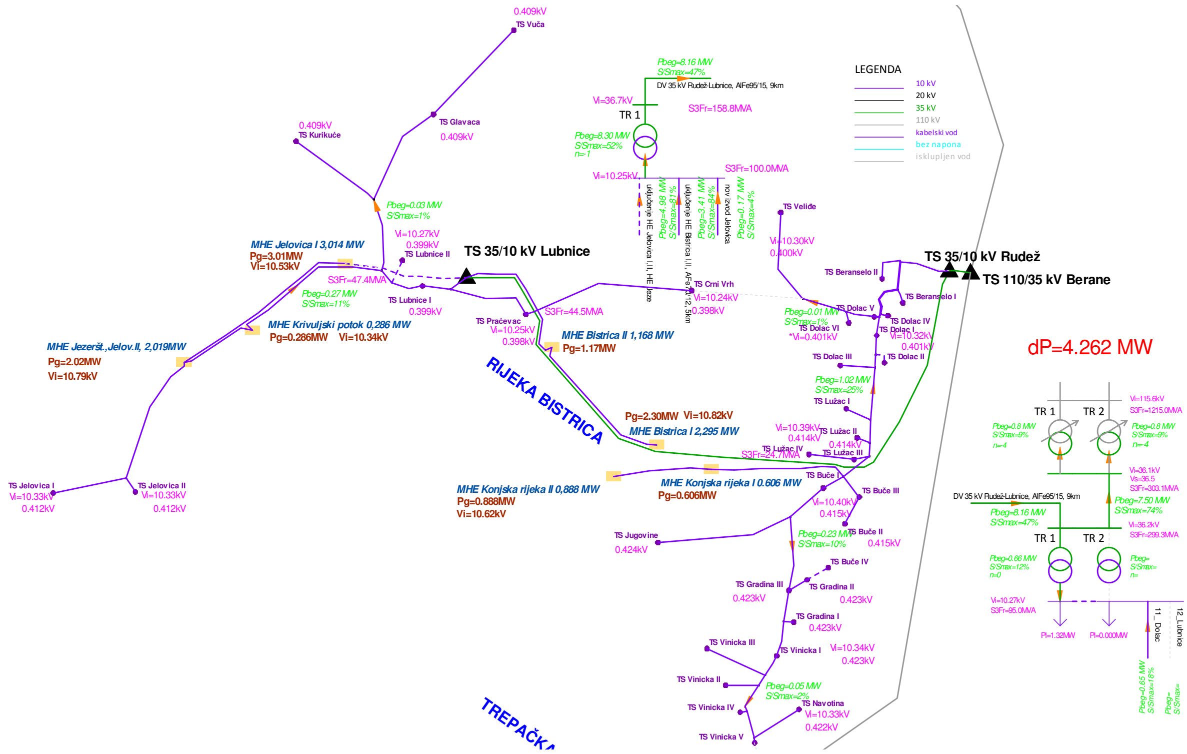


Figure 72: Results of power condition analyses – VARIANT A, min consumption, MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.388 kV, max 0.411 kV)	**1.621 MW**

Results:

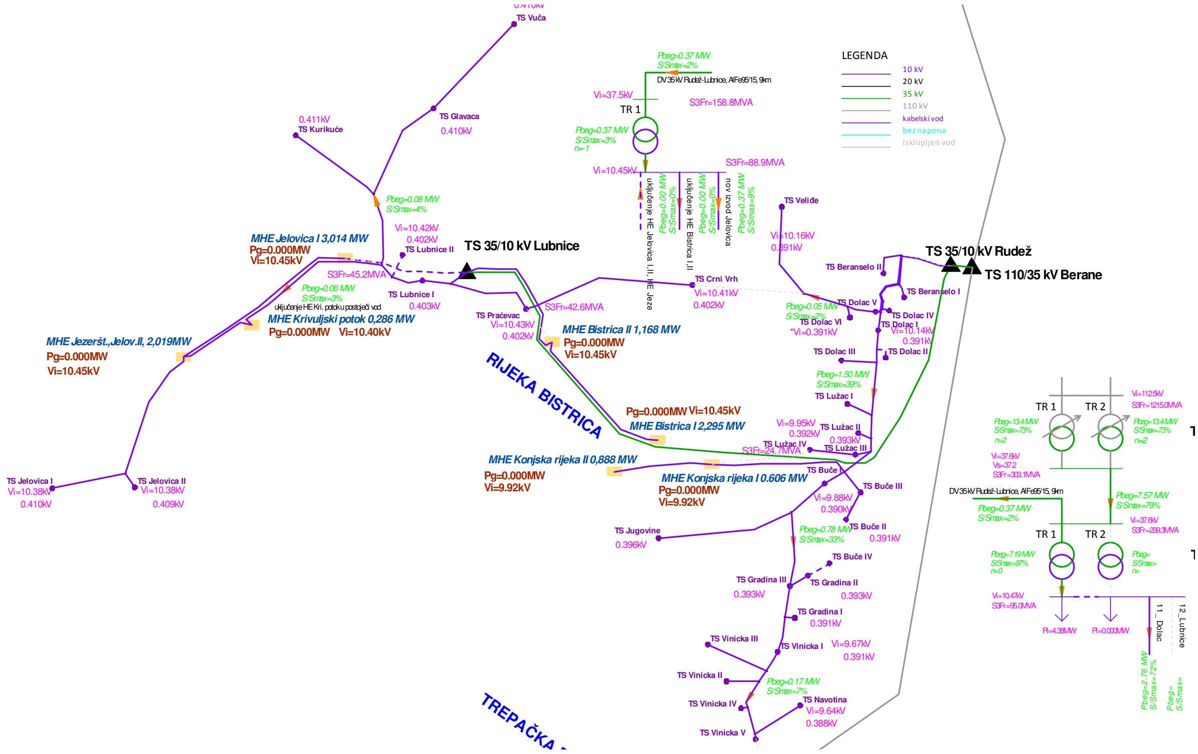


Figure 73: Results of power conditions analyses – VARIANT A, max consumption without MHE production, 2011.

Solution advantages

- good reliability of 35 kV and 10 kV network operation (good voltage conditions, lines are not overloaded, possibility of oversupply between two feeders)
- optimum consumption of the produced power in the area: MHE Krivuljski Potok power is consumed in the Lubnice area, Konjska Rijeka power is consumed at the Dolac feeder.
- Main part of the produced power (approx. 9 MW) is evacuated via SBS 35/10 kV
- MHE operation improves voltage conditions in the areas with the previously low voltages (max loads)
- This solution depends on the active voltage regulation at 35 kV busbars in SBS Berane 110/35 kV:
  - ➢ Situations with high consumption without MHE operation: target voltage at 35 kV busbars: (37.4 – 37.8) kV
  - ➢ Situations with low consumption with MHE operation: target voltage at 35 kV busbars: (36.0 – 36.4) kV

5. RESULTS COMPARISON

Situation	P_{MHE} [20] (MW)	U_{min} [21] [kV]	U_{max} [22] [kV]	P_{gub} [23] [MW]	ΔP_{gub} [24] [MW]	W_{gub} [25] [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.381	0.411	1.689	**-**	4532.7	**-**	**-**
Connection to existing network	**1.1**	0.394	0.421	1.578	**-0.111**	4234.8	**-297.9**	**-**
VARIANT A	**10.203**	0.396	0.423	1.732	**+0.043**	4648.1	**+115.4**	**1,775,000**

[20] Power output of all analysed MHE (output before the connection is 0 MW).
[21] Min voltages in LV network (voltages are calculated on the whole network model and occur in situations with high loads at the end of long feeders. Among all analysed SBS the voltage of that SBS is shown which deviates the most from the nominal voltage).
[22] Max voltages in LV network (voltages are calculated on the whole network model and occur in situations with small loads in the vicinity of SBS 35/10 kV or distribution sources. Among all analysed SBS the voltage of that is shown which deviates the most from the nominal voltage).
[23] Max losses for situation with maximum loads (calculated for the whole network model).
[24] Relative comparison with losses for the situation before MHE connection to the network.
[25] Estimation of yearly losses W_{gub} on the basis of max losses P_{gub} according to the equation:
$W_{gub} = P_{gub} \cdot T_{gub} = P_{gub} \cdot (0.17 + \frac{0.83 \cdot T_{pog}}{8760}) \cdot T_{pog},$ T_{pog} sare operation hours of distribution network (T_{pog} = 4500 hours)

RIVERS ŠEKULARSKA AND TREPAČKA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Šekular	1.715	SBS Rijeka Marsenića	8.93
MHE Orah	1.171	SBS Šekular I, SBS Šekular IV	6.29
MHE Ramuši	0.520	SBS Šekular II	4.95
MHE Spaljevići I	0.848	SBS Šekular II	4.95
MHE Spaljevići II	0.780	SBS Šekular II	4.95
Šekularska output	**5.034**	**Slack node:** 110 kV busbars SBS Andrijevica	969
MHE Trepačka rijeka	8.300	SBS Trepča I	10.5
Trepačka output	**8.3**	**Slack node:** 110 kV busbars SBS Andrijevica	969

Min. model of the relevant network:

- SBS Andrijevica 110/35/10 kV
- 10 kV feeder: Trešnjevo
- due to proximity: SBS Berane 110/35, SBS Rudež 35/10 kV, Dolac feeder

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Dolac	0.74	2.46	0.85	2.85
Lubnice	0.18	0.59	0.21	0.68
SBS 35/10 kV Rudež	**2.37**	**7.9**	**2.55**	**8.49**
SBS 110/35 kV Berane	**8.1**	**27**	**8.71**	**29.03**
Trešnjevo	0.37	1.2	0.39	1.27
SBS 35/10 kV Andrijevica	**1.45**	**4.9**	**1.54**	**5.19**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the loads

- Reconstruction of SBS 35/10 kV Andrijevica by 2015

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network

Max consumption	- within permitted limits	- within permitted limits - high voltage drops in the area of Šekulara (min voltages in MV network approx. 9.5 kV and in LV network approx. 0.375 kV)

Results:

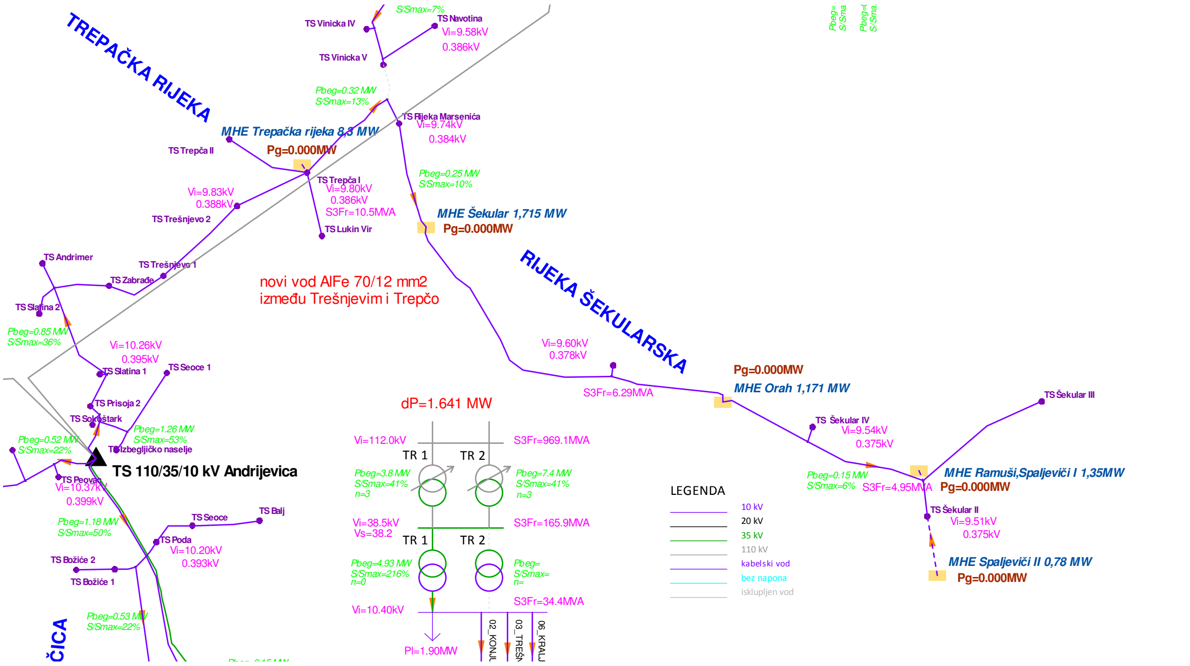


Figure 74: Loads in 10 kV network and loads in LV busbars TP – maximum loads 2011 in the planned network.

Min consumption	- within permitted limits	- within permitted limits

Results:

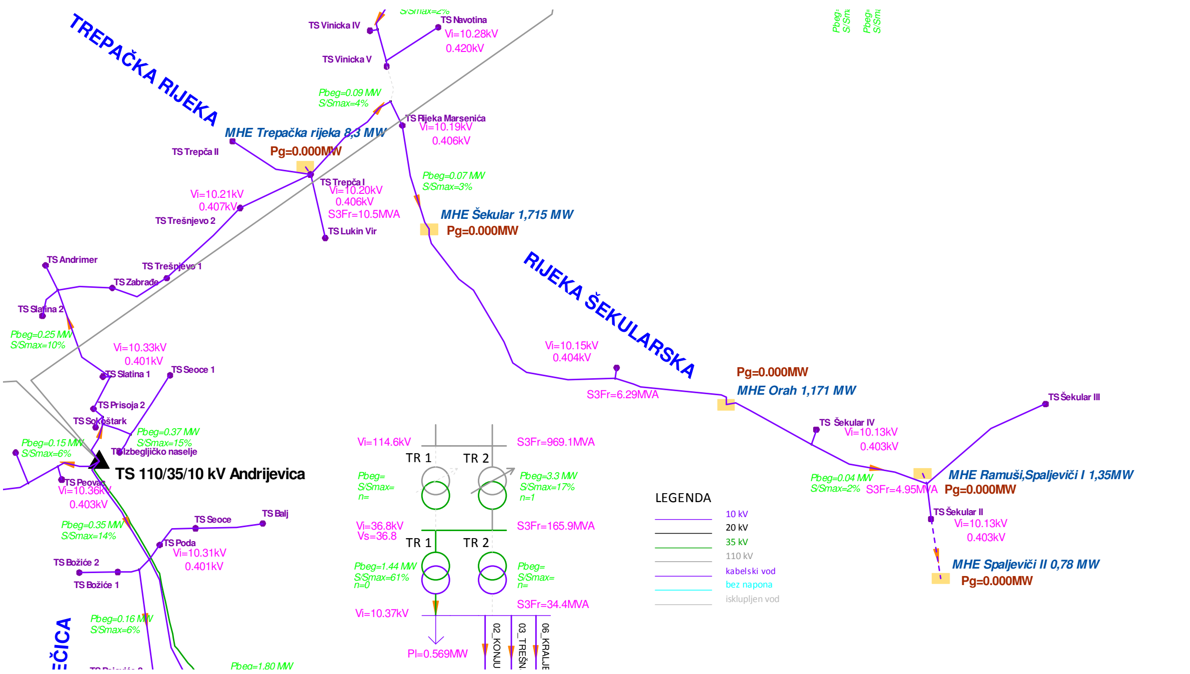


Figure 75: Loads in 10 kV network and loads at LV busbars TP – minimum loads 2011 in the projected network.

Max losses:	**0.410 MW**	Yearly losses:	**1100.3 MWh**

Necessary network reinforcements before the connection and other results:

- Connection of Dolac feeder (SBS Rudež) and Trešnejvo feeder (SBS Andrijevica), a part of consumption at Dolac feeder is redirected to Trešnejvo feeder

Representation: Figure 56

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.6 MW**

Notes:

- max 0.45 MW in the area of MHE Trepačka rijeka (Trepča)
- max 0.15 MW in the area of Šekulara
- In full power connection the voltages in LV network are increased above the criterion 0.420 kV (above 0.5 kV), typical overloads of 10 kV lines

Results:

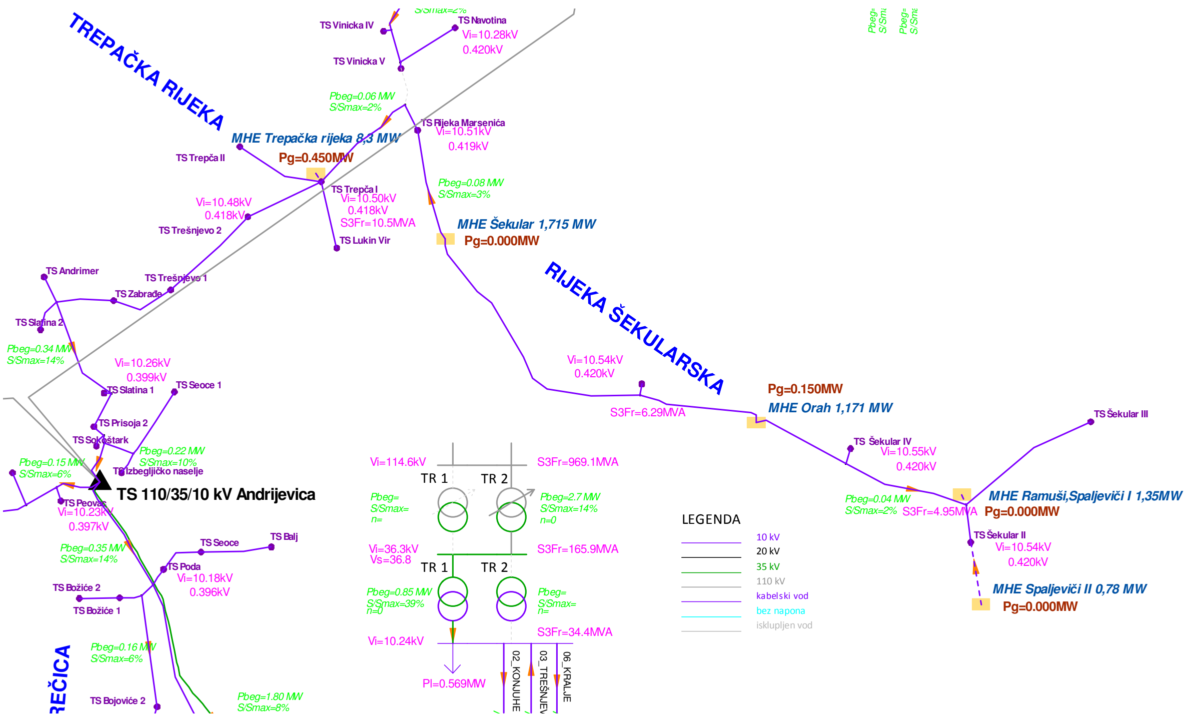


Figure 76: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**1.578 MW**	Yearly losses:	**4234.8 MWh**

4.b VARIANT A: new SBS 35/10 kV Trepča

Necessary reinforcements:	Estimated investment in EUR **∑ 1,760,000**
- New SBS 35/10 kV Trepča, 1x16 MVA, six 10 kV feeder bays, one 35 kV	500,000

feeder bay, two transformer bays (35 kV and 10 kV) - 35 kV supply line from SBS Andrijevica (AlFe95/15 mm^2 conductor, length 8.5 km) line is connected directly to the divided 35 kV busbars in Andrijevica - one sector with TR 110/35 kV, 20 MVA: power surplus from MHE on the rivers Trepačka and Šekulčarska is evacuated together with the MHE production on the river Babinopoljska - Second sector with TR 110/35 kV, 10 MVA: consumption and evacuation of power surplus from the remaining MHE	500,000
MHE connection on the river Šekularska: - Reconstruction of the existing single circuit 10 lV line into the double circuit line, length 11 km, 1. system: MHE Šekulara and the existing consumption (AlFe35/6 mm^2 conductor) 2. system: the remaining MHE (AlFe150/25 mm^2 conductor)	680,000
MHE connection on the river Trepačka: - Connection to the new feeder with the 2 x Al 150 mm^2 cable, length 2 km	80,000

Load conditions after the MHE connection to the network – max load, MHE max production		
Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.394 kV ; max 0.416 kV)	**2.003 MW**	**5375.4 MWh**

Results:

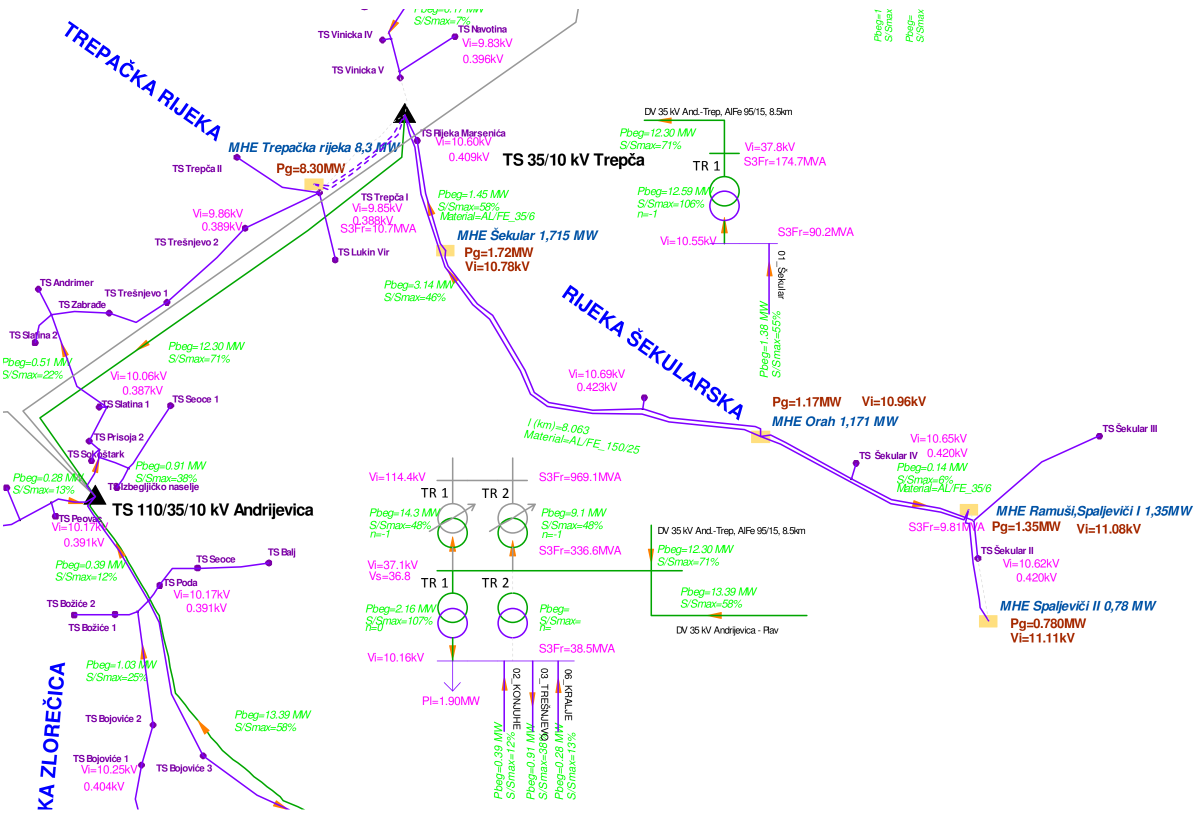


Figure 77: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.403 kV, max 0.421 kV in Šekulara)	**1.110 MW**

Results:

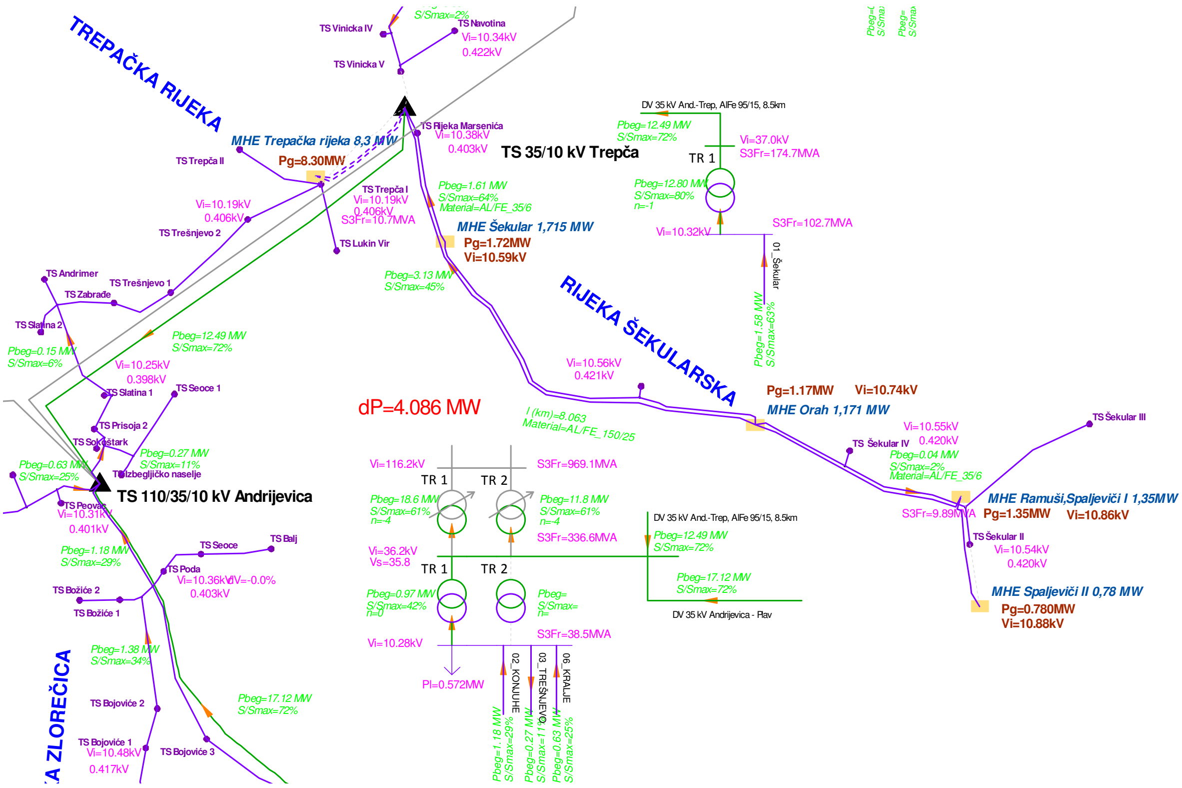


Figure 78: Results of power condition analyses – VARIANT A, min consumption, MHE max production, 2011

Operation conditions after the MHE connection to the network – max consumption, without MHE production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.410 kV, max 0.416 kV)	**1.621 MW**

Results:

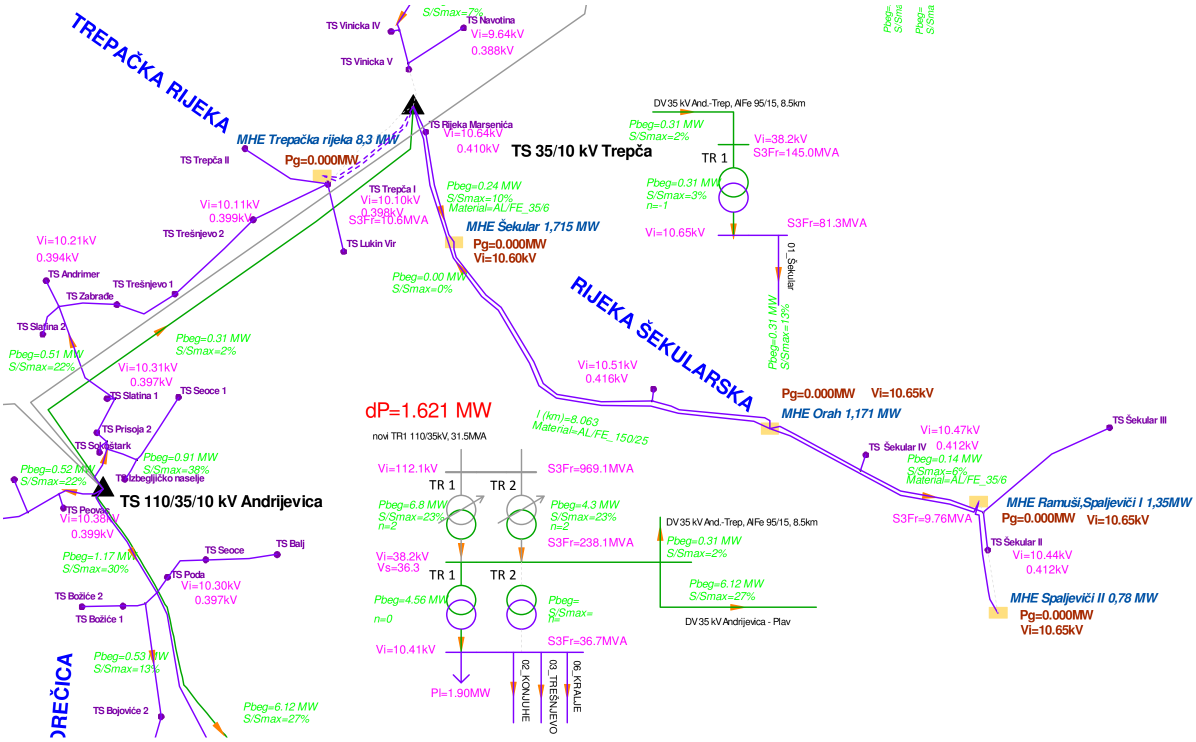


Figure 79: Results of power condition analyses – VARIANT A, max consumption without MHE production, 2011.

Solution advantages
- **good reliability of 35 kV and 10 kV network operation (good voltage conditions, lines are not overloaded, possibility of oversupply between two feeders)** - **since the consumption in the area of Šekulara and Trepča is smaller, the produced power needs to be evacuated into 35 kV and 110 kV network** - **MHE operation improves voltage conditions in the areas with the previously low voltages (Šekular)** - **This solution depends on the active voltage regulation at 35 kV busbars in SBS Andrijevica 110/35 kV:**

- **Situations with high consumption without MHE operation: target voltage at 35 kV busbars: (37.4 – 37.7) kV**
- **Situations with low consumption with MHE operation: target voltage at 35 kV busbars: (35.7 – 36.0) kV**

5. *RESULTS COMPARISON*

Situation	P_{MHE} [26] (MW)	U_{min} [27] [kV]	U_{max} [28] [kV]	P_{gub} [29] [MW]	ΔP_{gub} [30] [MW]	W_{gub} [31] [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.375	0.407	1.689	**-**	4532.7	**-**	**-**
Connection to existing network	**0.6**	0.400	0.420	1.557	**-0.132**	4178.5	**-354.2**	**-**
VARIANT A	**13.334**	0.394	0.421	2.003	**+0.314**	5375.4	**+842.7**	**1,760,000**

[26] Power output of all analysed MHE (output before the connection is 0 MW).
[27] Min voltages in LV network (voltages are calculated on the whole network model and occur in situations with high loads at the end of long feeders. Among all analysed SBS the voltage of that SBS is shown which deviates the most from the nominal voltage).
[28] Max voltages in LV network (voltages are calculated on the whole network model and occur in situations with small loads in the vicinity of SBS 35/10 kV or distribution sources. Among all analysed SBS the voltage of that is shown which deviates the most from the nominal voltage).
[29] Max losses for situation with maximum loads (calculated for the whole network model).
[30] Relative comparison with losses for the situation before MHE connection to the network.
[31] Estimation of yearly losses W_{gub} on the basis of max losses P_{gub} according to the equation:
$W_{gub} = P_{gub} \cdot T_{gub} = P_{gub} \cdot (0.17 + \frac{0.83 \cdot T_{pog}}{8760}) \cdot T_{pog}$, T_{pog} are operation hours of distribution network (T_{pog} = 4500 hours)

KRAŠTICA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Kraštica	0.8	SBS Kralje	21.1
Kraštica output	**8**	**Slack node:** 110 kV busbars SBS Andrijevica	969
Min. model of the relevant network:		- SBS Andrijevica 110/35/10 kV - 10 kV feeder: Kralje	

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Kralje	0.15	0.54	0.16	0.57
SBS 35/10 kV Andrijevica	**1.45**	**4.9**	**1.54**	**5.19**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the projected distribution network development

- Reconstruction of SBS 35/10 kV Andrijevica by 2015

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumpt.	- within permitted limits	- within permitted limits

Results:

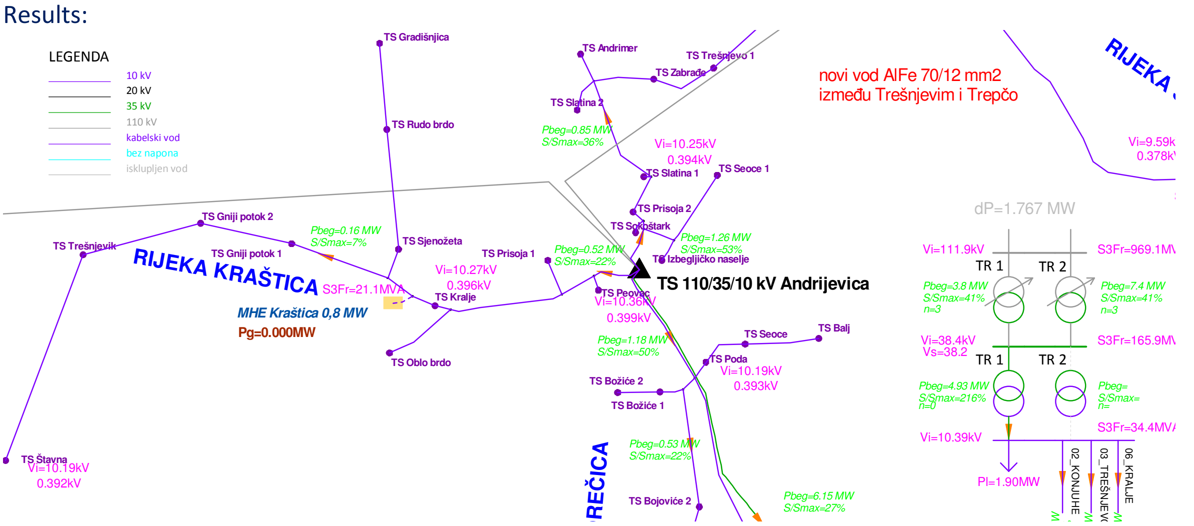


Figure 80: Loads in 10 kV network and loads in LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	- within permitted limits

Results:

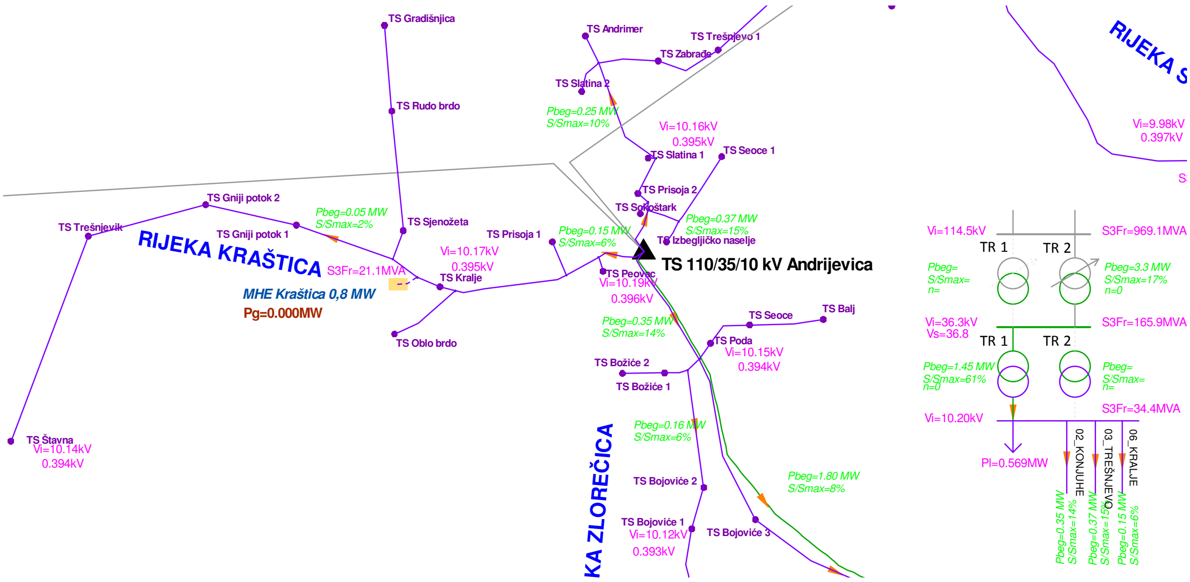


Figure 81: Loads in 10 kV network and voltages at LV busbars in TP – minimum loads in the projected network, 2011.

Max losses:	**1.767 MW**	Yearly losses:	**4742.0 MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.8 MW**

Notes:

- reliable MHE connection to the existing network

Load conditions after the MHE connection to the network – max load, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.391 kV, max 0.394 kV)	**1.571 MW**	**4216.0 MWh**

Results:

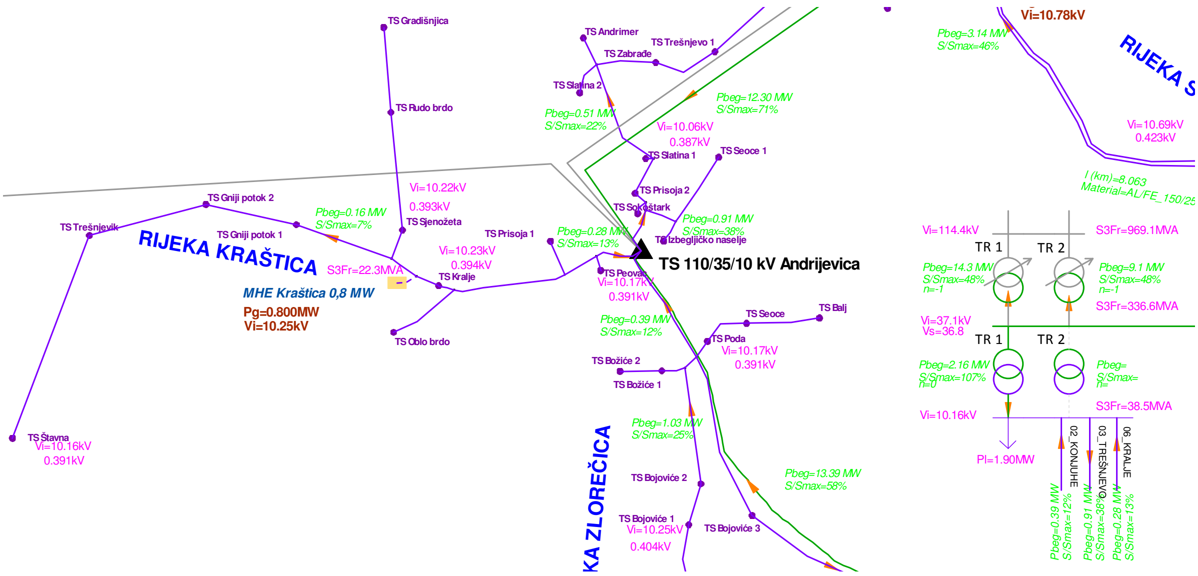


Figure 82: Results of power condition analyses – connection to the existing network, max loads and MHE max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.401 kV, max 0.405 kV)	**0.407 MW**

Results:

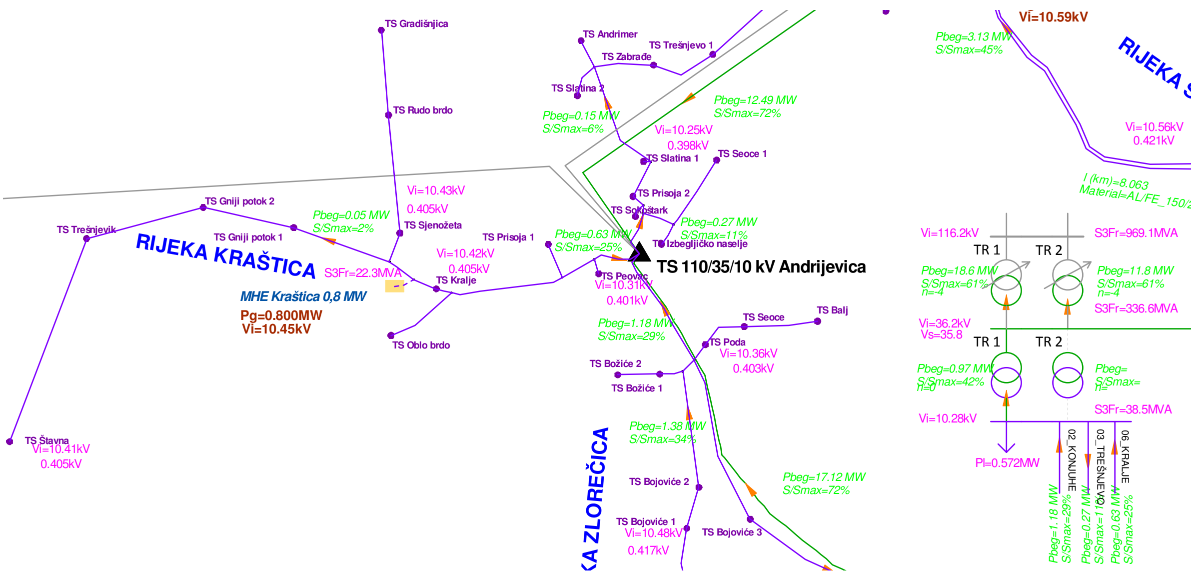


Figure 83: Results of power condition analyses – connection to the existing network, MHE min consumption, max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHe production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.393 kV, max 0.399 kV)	**1.621 MW**

Results:

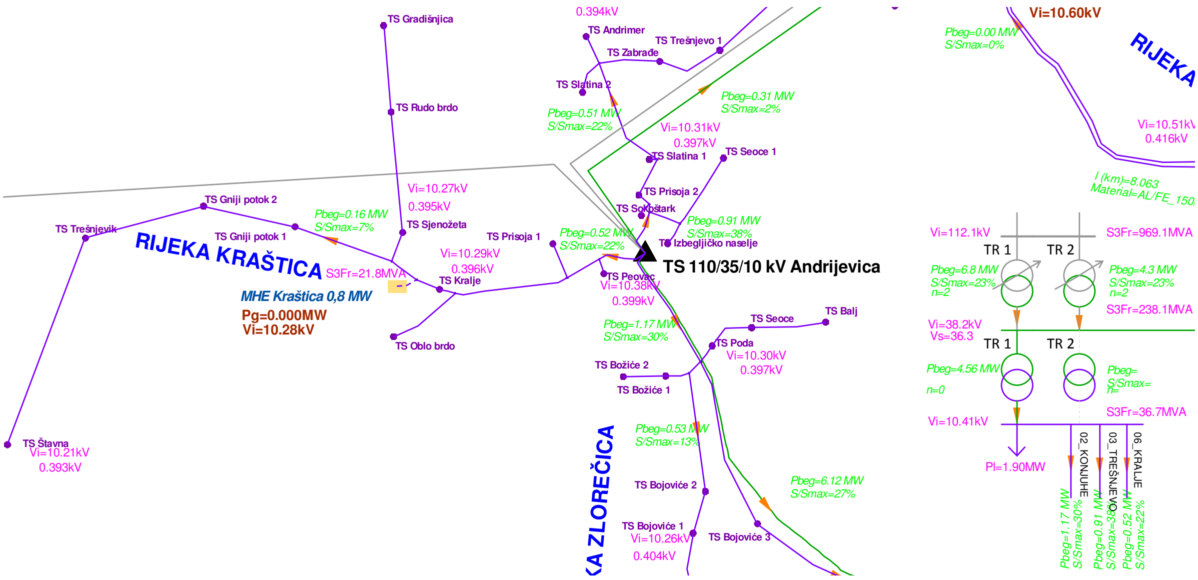


Figure 84: Results of power condition analyses – connection to the existing network, max consumption without MHE production, 2011.

Solution advantages
- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.392	0.400	1.767	-	4742.0	-	-
Connection to existing network	**0.8**	0.391	0.405	1.571	**-0.169**	4216.0	**-526.0**	-

ZLOREČICA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Jošanica	0.6	SBS Jošanica	9.34
MHE Kuti	1.0	SBS Kuti I	9.55
Zlorečica output	**7**	**Slack node:** 110 kV busbars SBS Andrijevica	969

Min. model of the relevant network:

- SBS Andrijevica 110/35/10 kV
- 10 kV feeder: Konjuhe

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Konjuhe	0.36	1.24	0.38	1.31
SBS 35/10 kV Andrijevica	**1.45**	**4.9**	**1.54**	**5.19**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the projected distribution network development

- Reconstruction of SBS 35/10 kV Andrijevica by 2015

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.388 kV, max 0.395 kV)

Results:

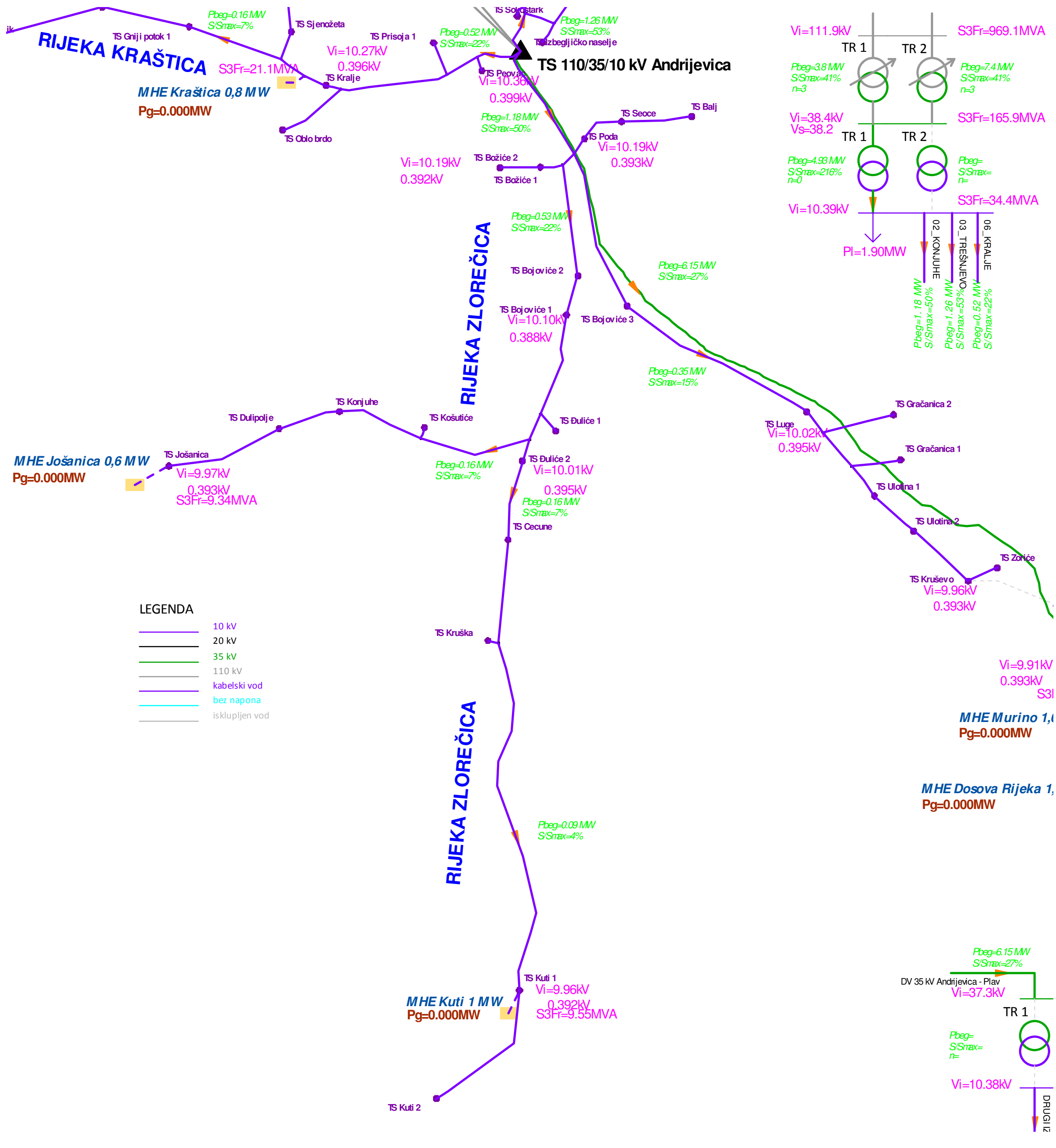


Figure 85: Loads in 10 kV network and voltages at LV busbars in TP – maximum loads 2011 in the existing network.

Min	- within permitted limits	within permitted limits (min 0.394 kV,

consumption		max 0.402 kV)

Results:

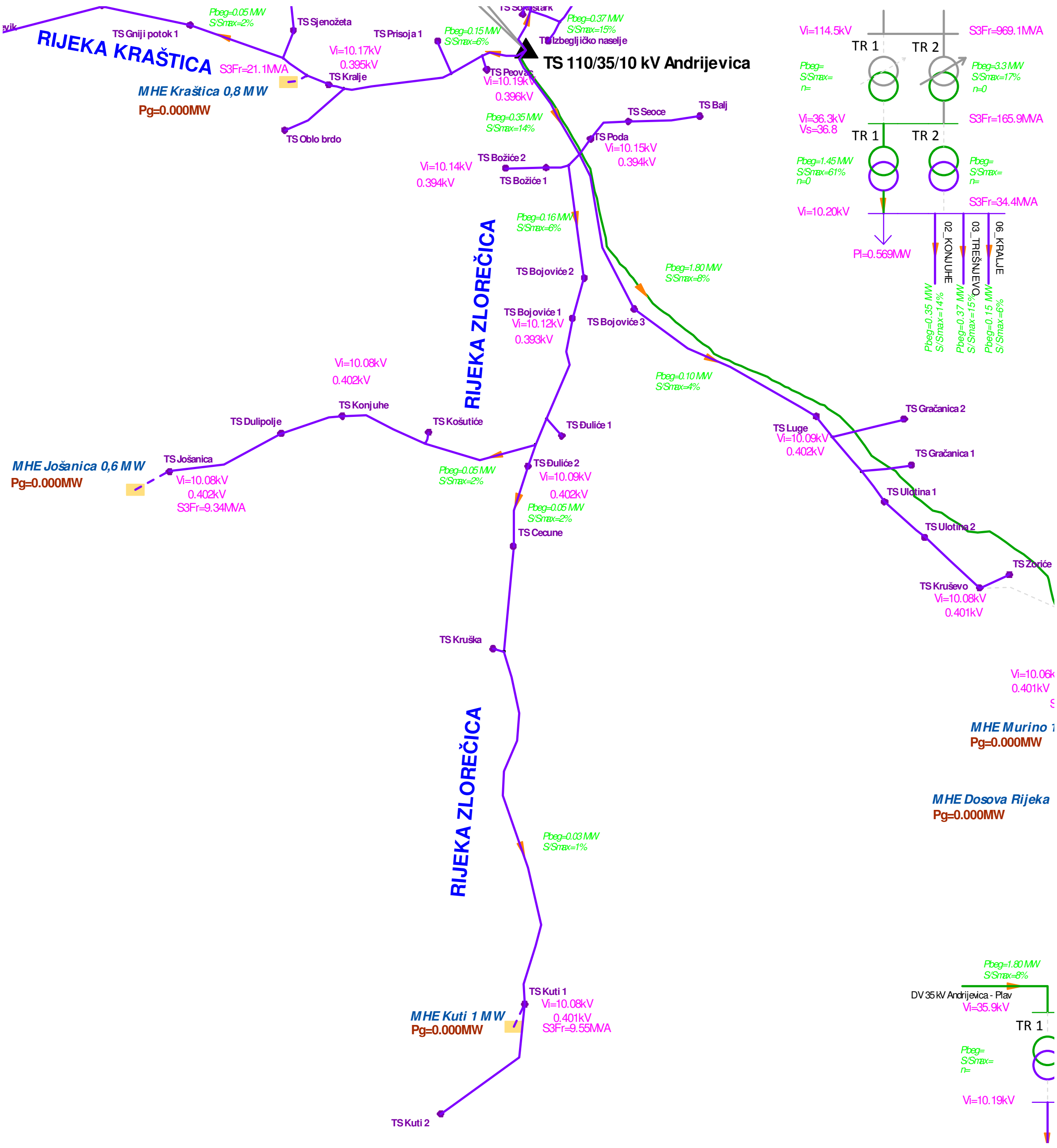


Figure 86: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**1.767 MW**	Yearly losses:	**4742.0 MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.7 MW**

Notes:

- max 0.3 MW from MHE Jošanica
- max 0.4 MW from MHE Kuti
- with full power connections , the LV network voltages increase above the criterion 0.420 kV (above 0.445 kV)

Results:

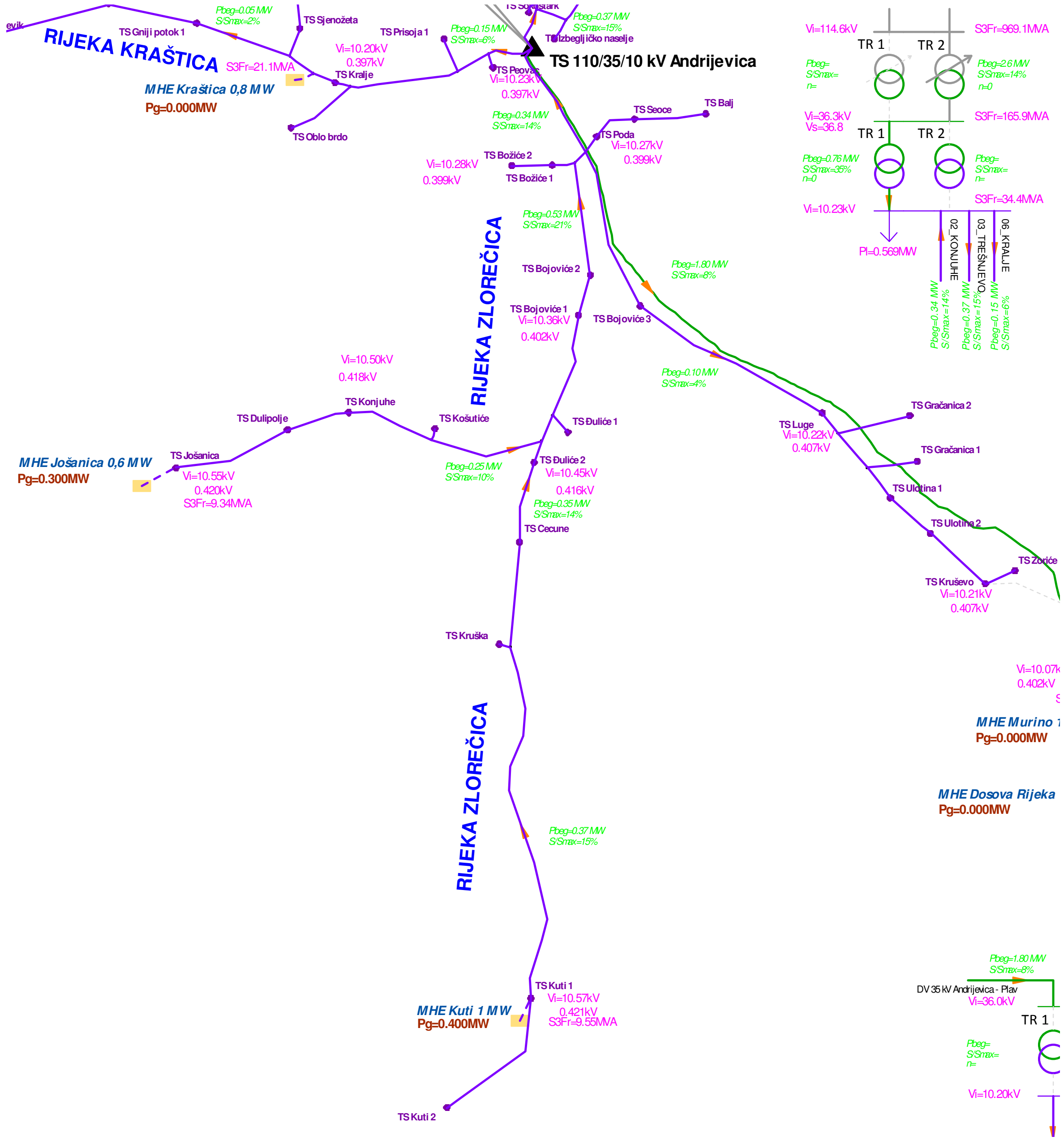


Figure 87: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**1.697 MW**	Yearly losses:	**4554.2 MWh**

4.b VARIANT A: new switching station SS 10 kV Đulića	
Necessary reinforcements:	Estimated investment in EUR **∑ 990,000**
- new switching station SS Dulića (four feeder bays)	250,000
- reconstruction of supply line SS Đulića (Konjuhe feeder from THS Andrijevica) into the overhead AlFe 70/12 mm^2 line of approx. length 6 km	180,000
- MHE Jošanica connection via new feeder from SS Đulića (Al 70mm^2 cable, 6 km)	240,000
- MHE Kuti connection via new feeder from SS Đulića (Al 150 mm^2 cable, 8 km)	320,000

Load conditions after the MHE connection to the network – max load, MHE max production		
Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.391 kV, max 0.406 kV)	**1.707 MW**	**4581.0 MWh**

Results:

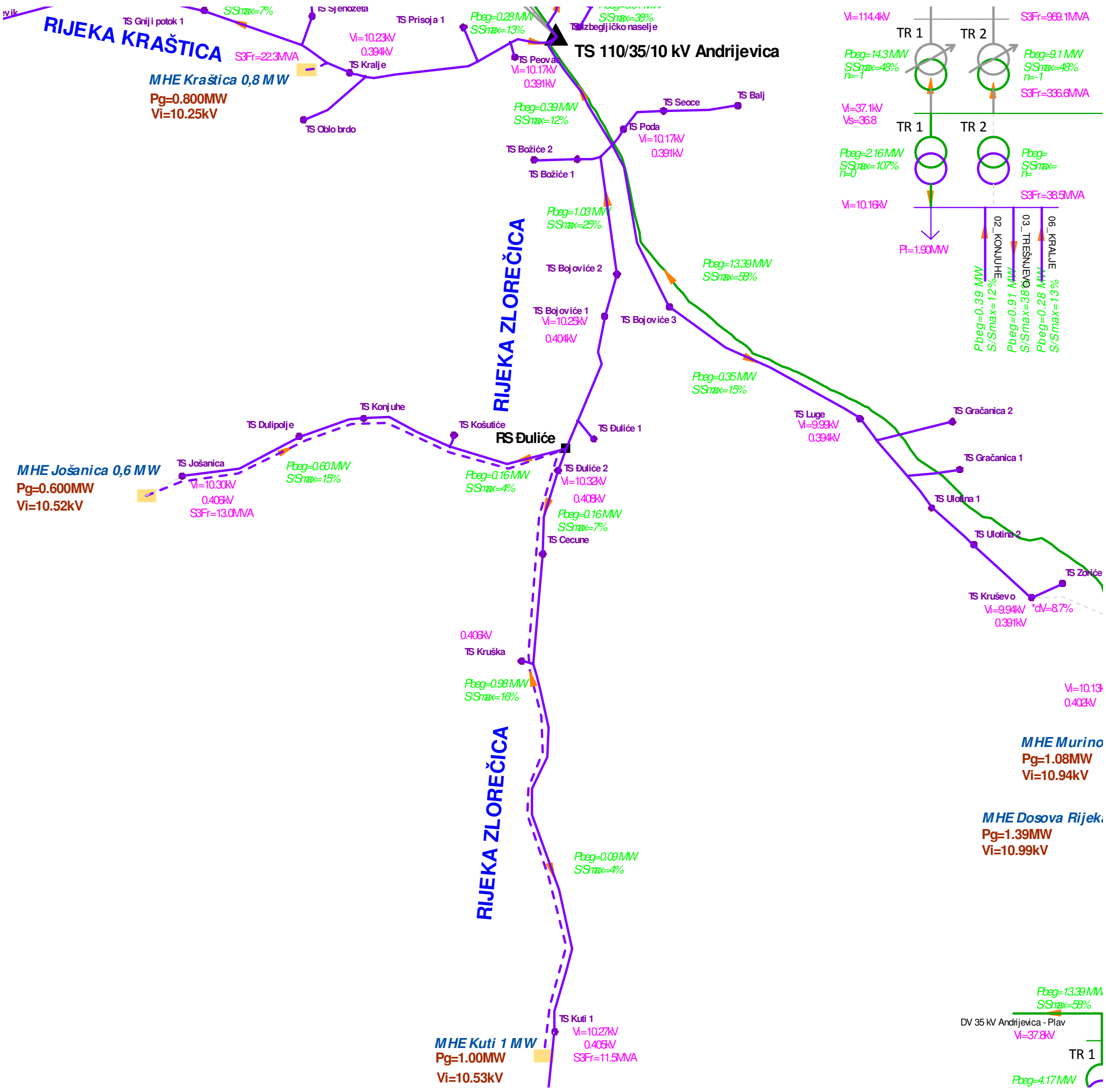


Figure 88: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- small amount above the permitted limits (min 0.403 kV, max 0.423 in the area of Đulića)	**0.453 MW**

Results:

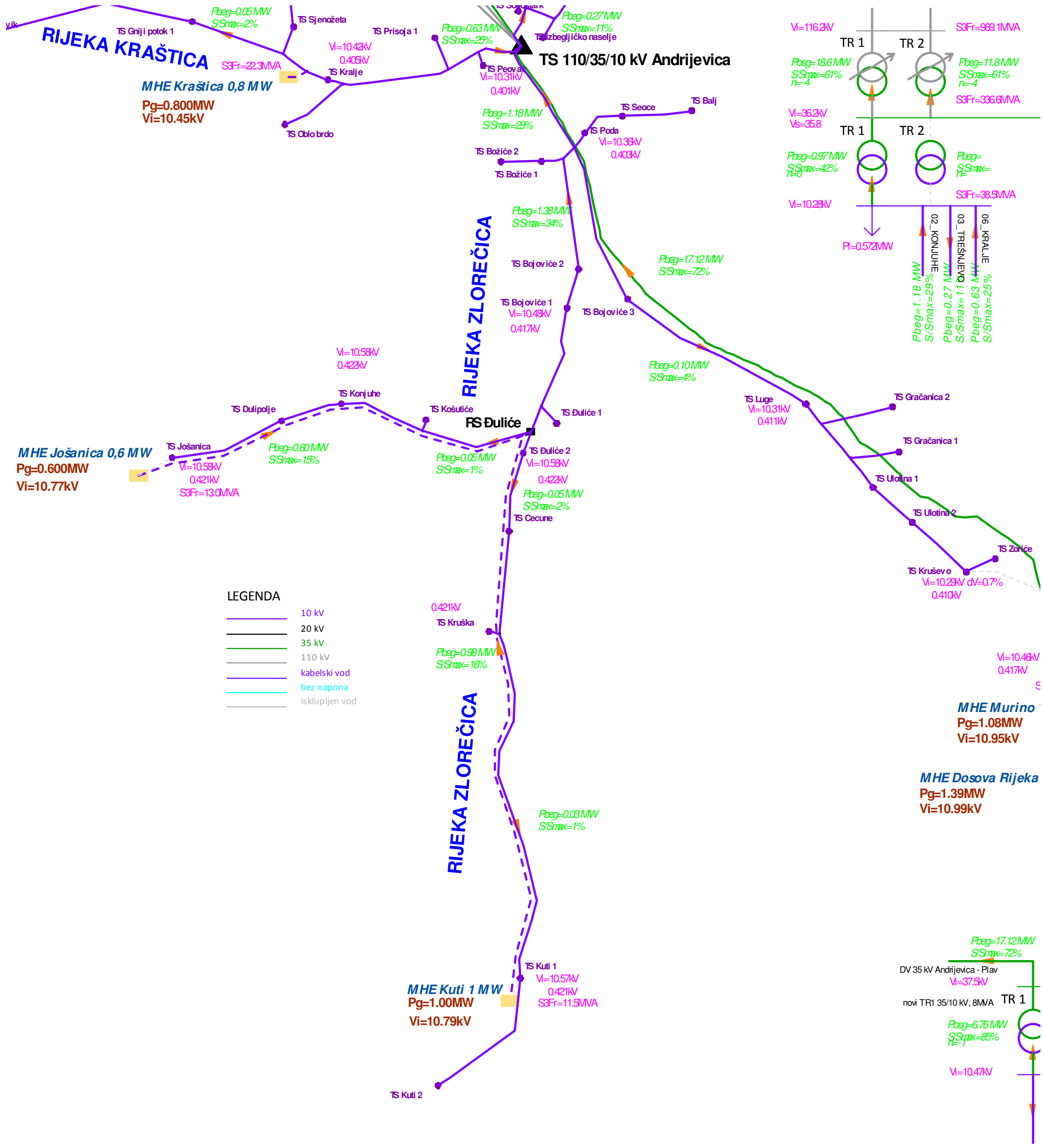


Figure 89: Results of power condition analyses – VARIANT A, min consumption, max MHE production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.389 kV, max 0.396 kV)	**1.634 MW**

Results:

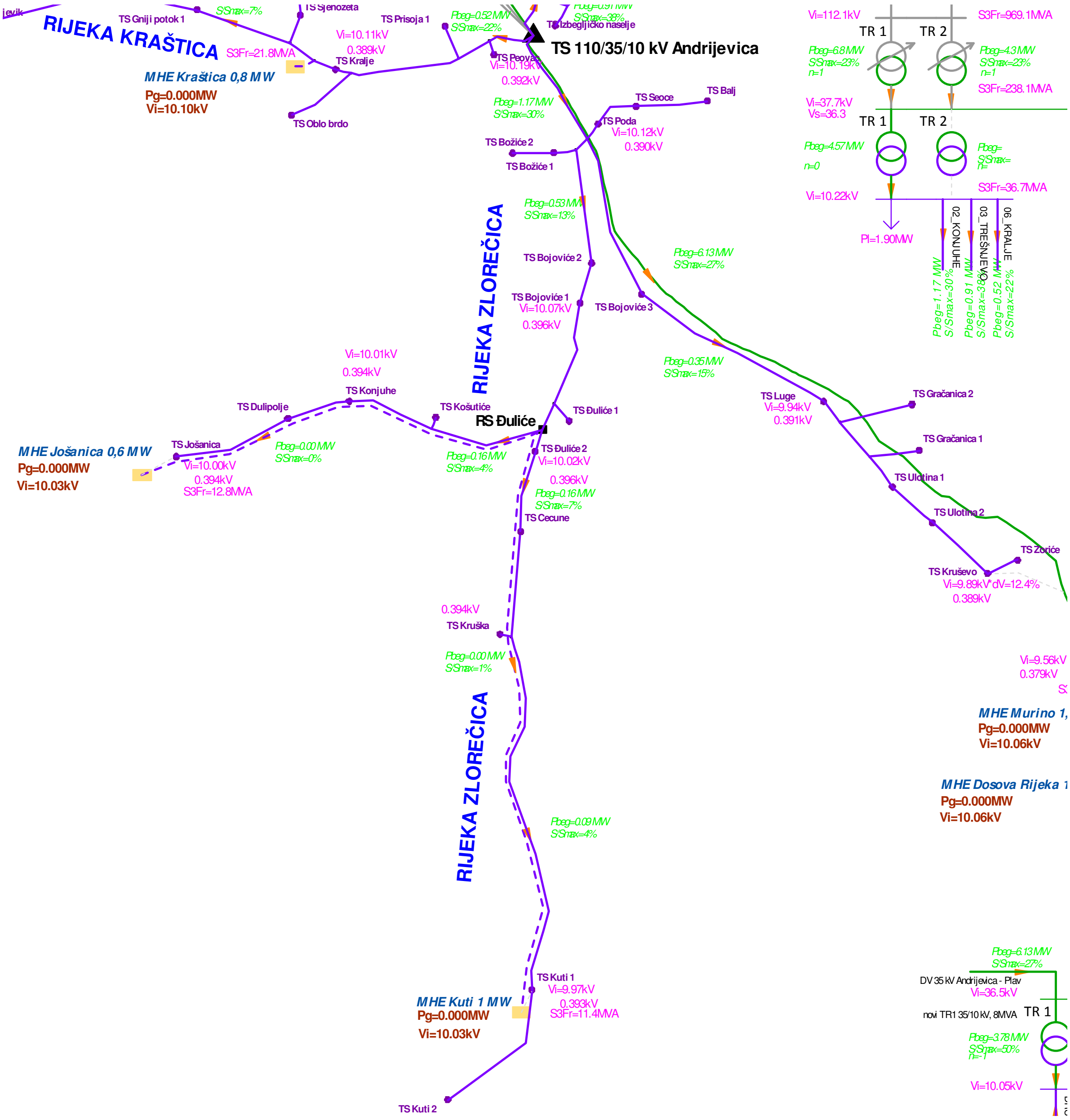


Figure 90: Results of power condition analyses – VARIANT A, MHE max consumption without production, 2011.

Solution advantages
- **switching station improves good reliability of 10 kV network operation (good voltage conditions, less interruptions)**
- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.388	0.402	1.767	**-**	4742.0	**-**	**-**
Connection to existing network	**0.7**	0.399	0.421	1.697	**-0.070**	4554.2	**-187.8**	**-**
VARIANT A	**1.6**	0.391	0.423	1.707	**-0.060**	4581.0	**-161.0**	**990,000**

RIVER MURINSKA RIJEKA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Murino	1.079	SBS Murino	10.9
MHE Dosova Rijeka	1.39	SBS Murino	10.9
Output	**1.119**	**Slack node:** 110 kV busbars SBS Andrijevica	969

Min. model of the relevant network:

- SBS Andrijevica 110/35/10 kV
- SBS Plav 35/10 kV
- 10 kV feeder: Murino

2. Grounds

2.a Relevant data on loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Murino	0.27	0.94	0.29	1.0
SBS 35/10 kV Plav	**1.2**	**4**	**1.27**	**4.24**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the projected distribution network development

- Reconstruction of 35 kV Andrijevica – Plav transmission line by 2015
- Reconstruction of SBS Plav 35/10 kV

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.392 kV, max 0.402 kV)

Results:

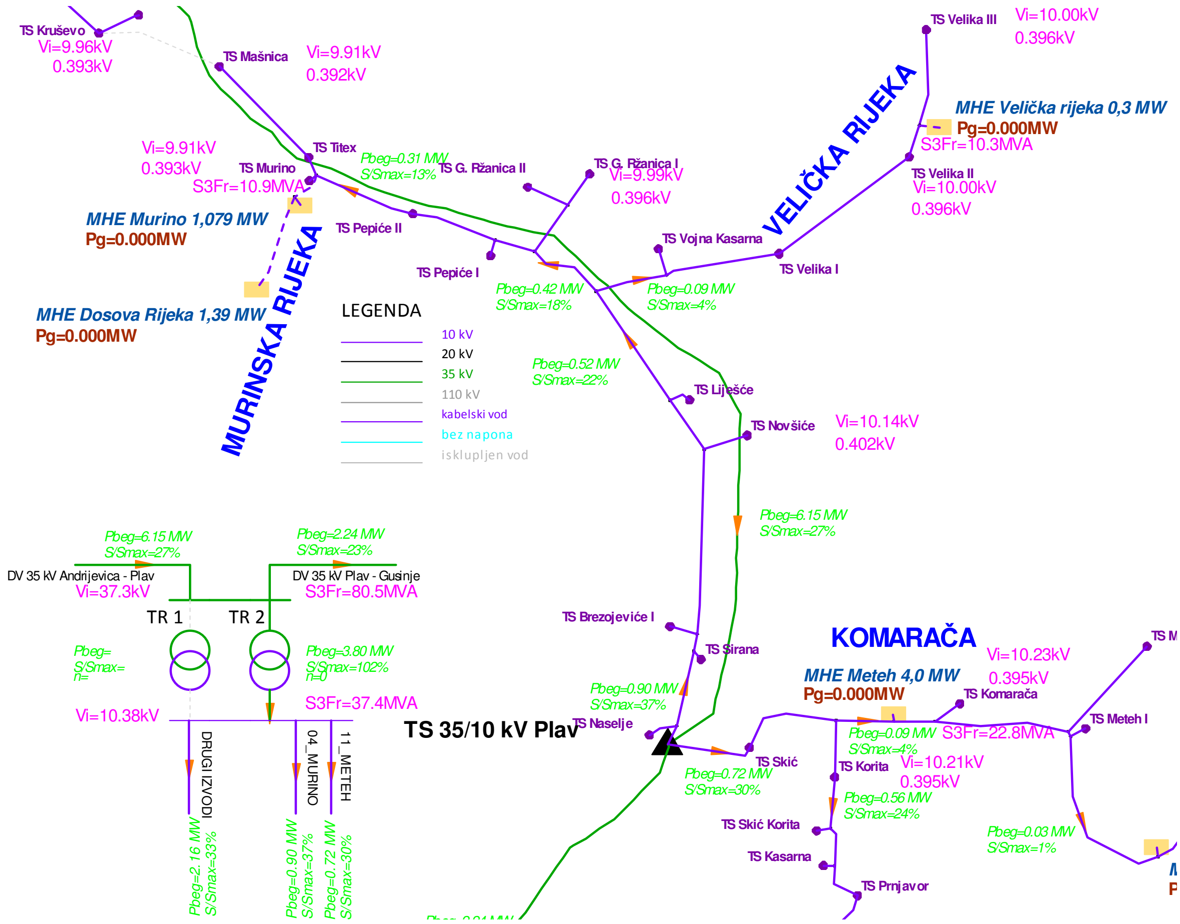


Figure 91: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	within permitted limits (min 0.396 kV, max 0.404 kV)

Results:

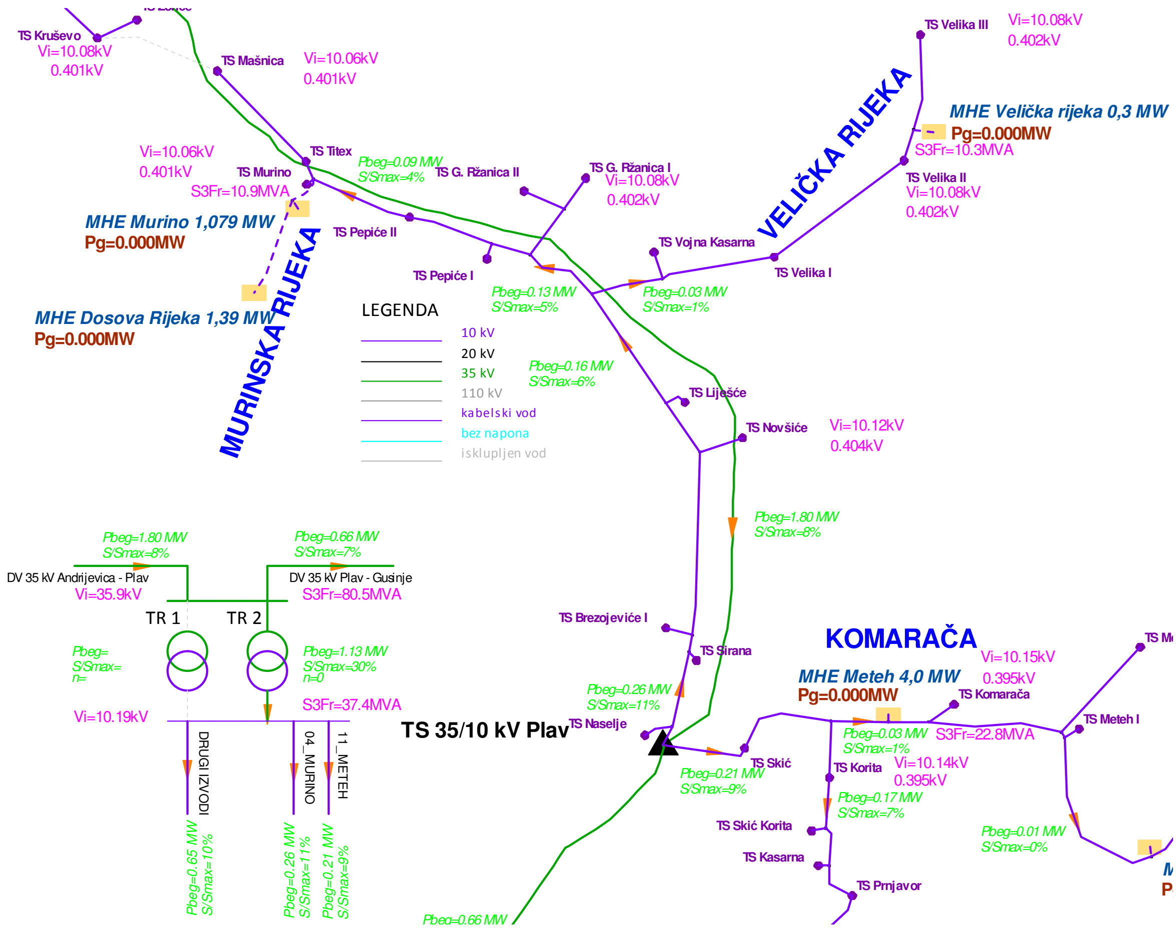


Figure 92: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**2.028 MW**	Yearly losses:	**5442 MWh**

Necessary network reinforcements before the connection and other results:

- none
-

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.4 MW**

Notes:

- with full power connections the LV network voltages increase above the criterion 0.420 kV (above 4.70 kV)

Results:

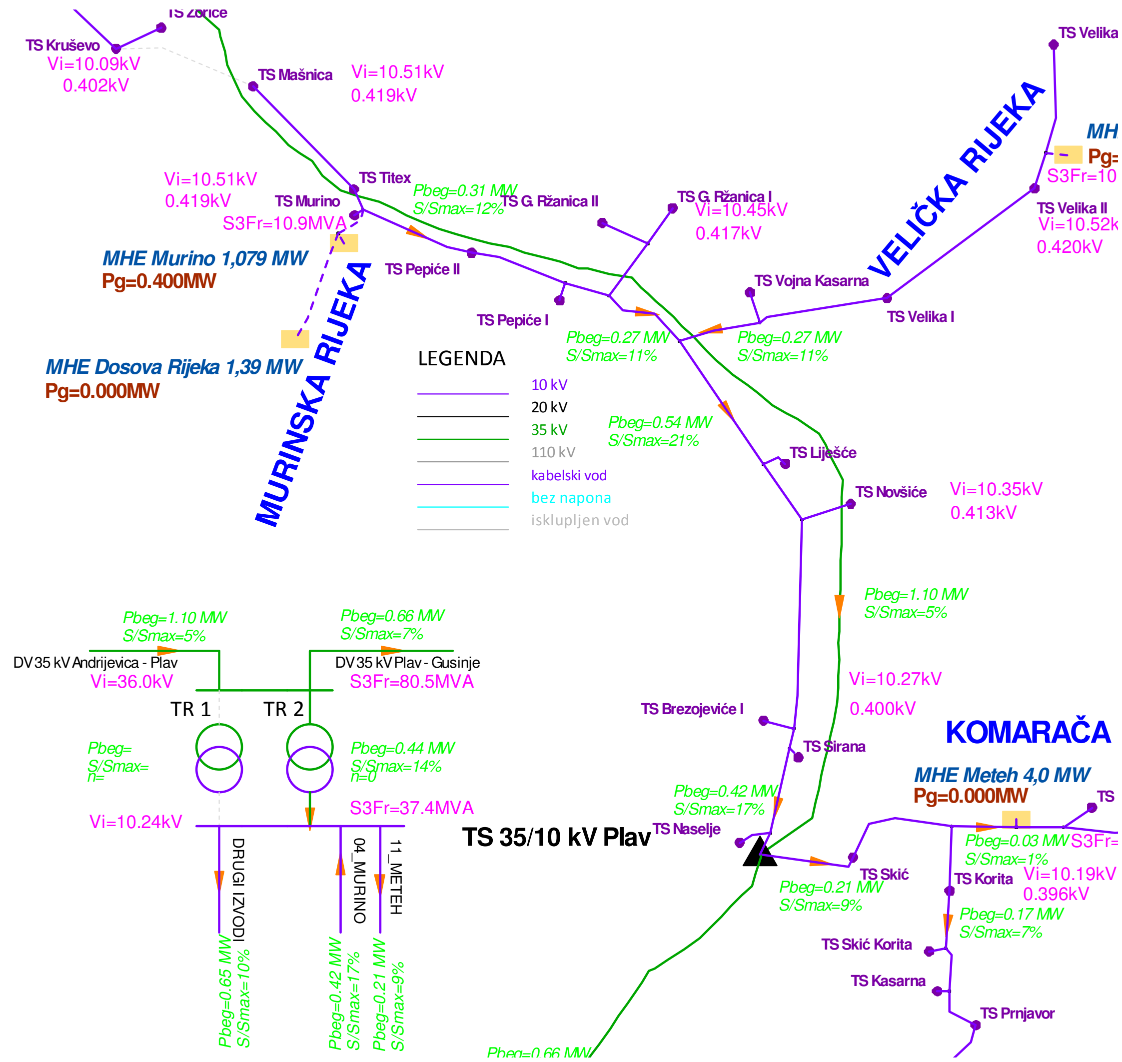


Figure 93: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	1.944 MW	Yearly losses:	5217 MWh

4.b VARIANT A: MHE connection on the river Murinska Rijeka to the new feeder from SBS Plav

Necessary reinforcements:	Estimated investment in EUR ∑ 320,000
- MHE Dosova Rijeka and MHE Murino connection on the river Murinska Rijeka (installed production output of 2.5 MW) via new 10 kV feeder directly to SBS 35/10 kV Plav (Al 150 mm^2 cable, 8 km)	320,000

Load conditions after the MHE connection to the network – max load, MHE max production		
Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.401 kV, max 0.412 kV)	**1.573 MW**	**4221 MWh**

Results:

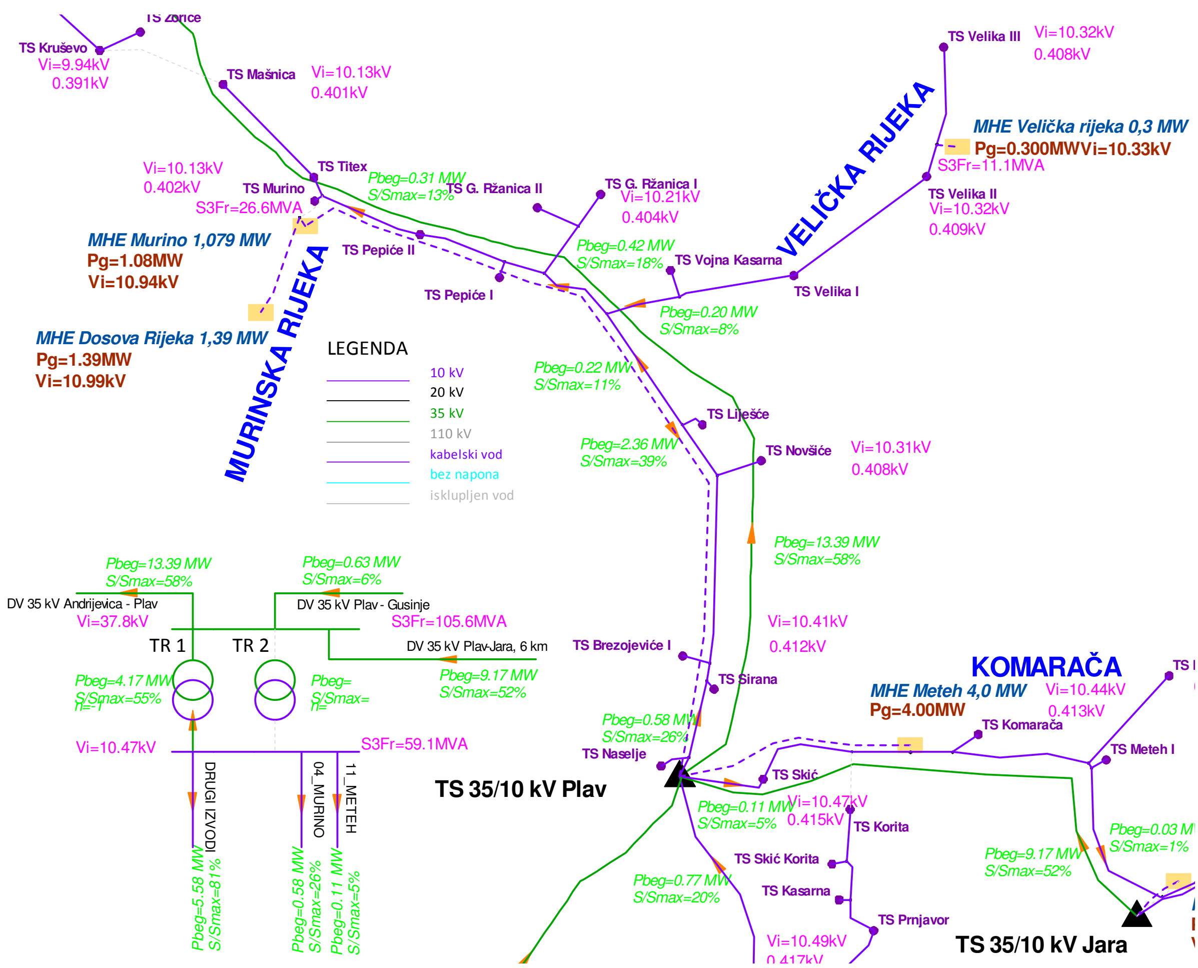


Figure 94: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- small amount above the permitted limits (min 0.408 kV, max 0.422 in the area of the river Velika)	**0.496 MW**

Results:

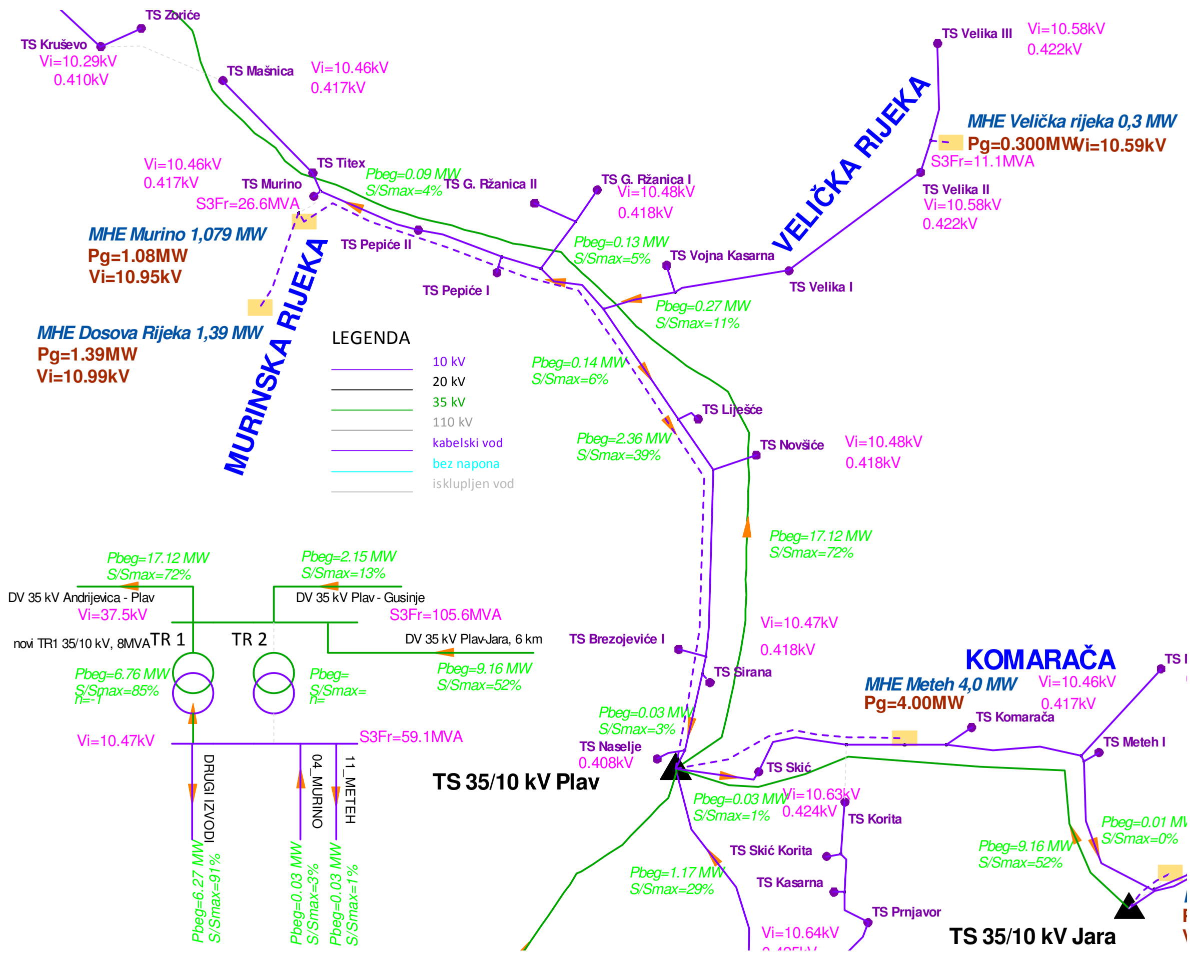


Figure 95: Results of power condition analyses – VARIANT A, min consumption, MHE max production, 2011..

Operation conditions after the MHE connection to the network – max consumption, without MHE production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.385 kV, max 0.401 kV)	**1.621 MW**

Results:

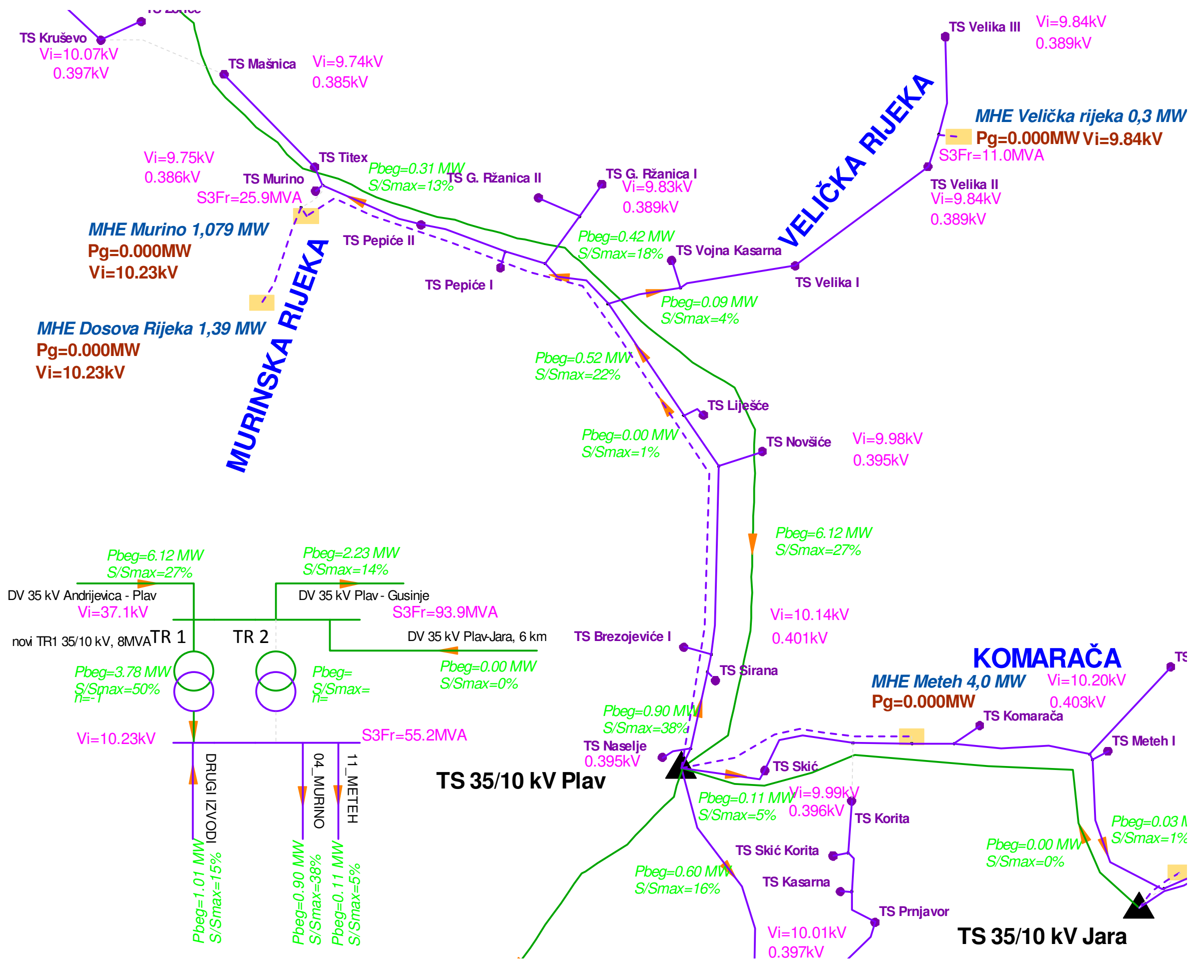


Figure 96: Results of power condition analyses – VARIANT A, max consumption without MHE production, 2011.

Solution advantages
- **MHE operation improves voltage conditions in the areas with previously low voltage** - **Optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.392	0.404	2.028	**-**	5442	**-**	**-**
Connection to existing network	**0.4**	0.403	0.420	1.944	**-0.084**	5217	**-225**	**-**
VARIANT A	**1.6**	0.385	0.422	1.573	**-0.455**	4221	**-1221**	**320,000**

VELIČKA RIJEKA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Velička Rijeka	0.3	SBS Velika II	10.3
Velička Rijeka output	**3**	**Slack node:** 35 kV busbars SBS Plav	80.5

Min. model of the relevant network:

- SBS Plav 35/10 kV
- 10 kV feeder: Murino

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Murino	0.27	0.94	0.29	1.0
SBS 35/10 kV Plav	**1.2**	**4**	**1.27**	**4.24**

2.b Relevant data on the projected distribution network development

- Reconstruction of 35 kV Andrijevica – Plav transmission line by 2015
- Reconstruction of SBS Plav 35/10 kV

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.392 kV, max 0.402 kV)

Results:

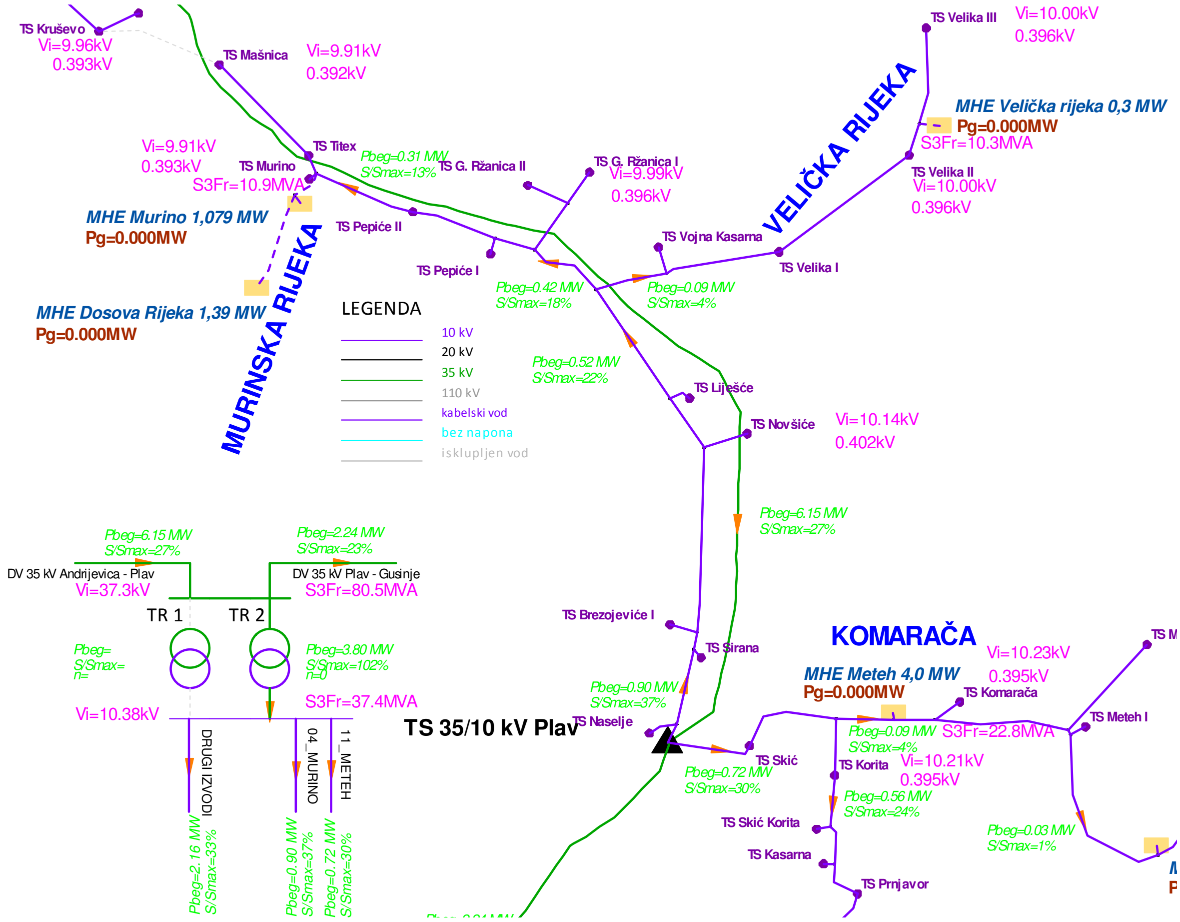


Figure 97: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	within permitted limits (min 0.396 kV, max 0.404 kV)

Results:

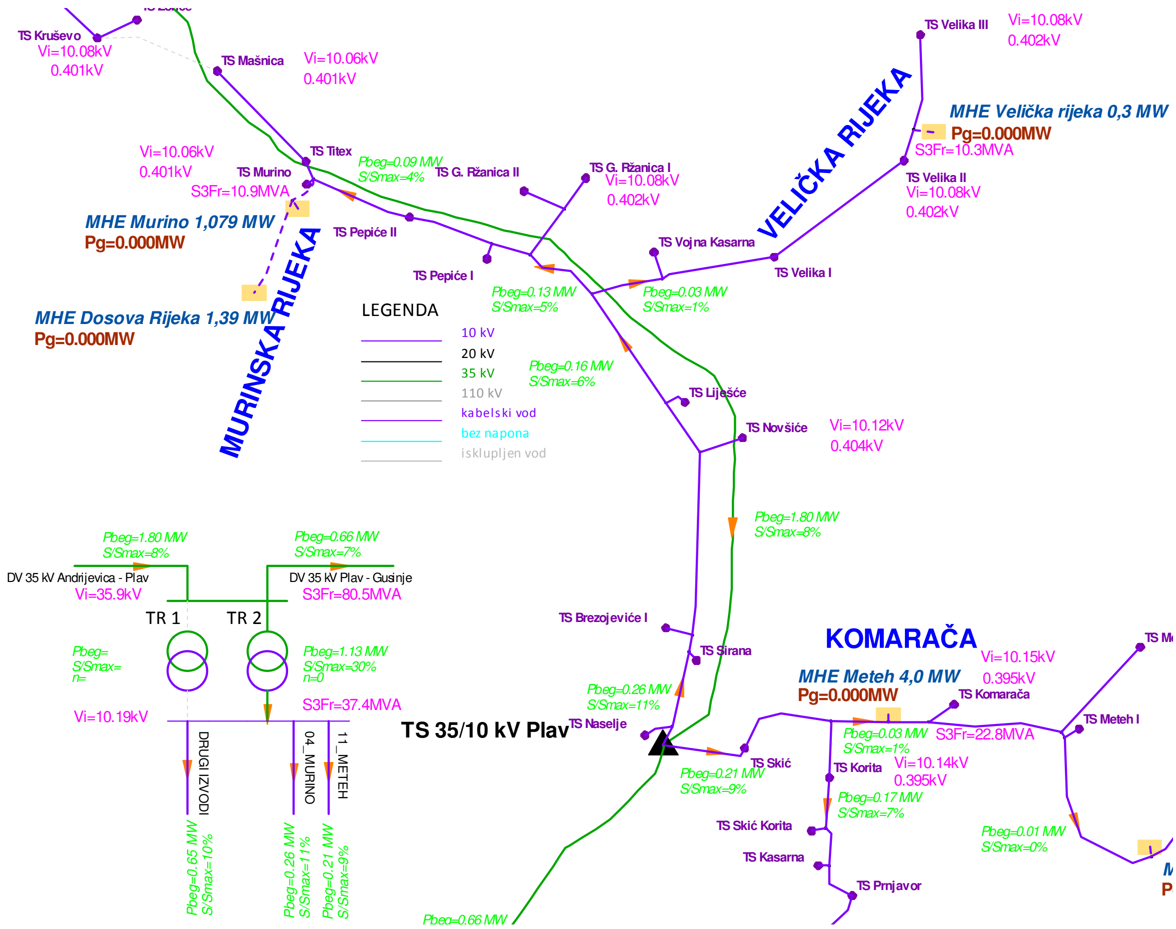


Figure 98: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	2.028 MW	Yearly losses:	5442 MWh

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.3 MW**

Notes:

- reliable MHE connection to the existing network

Load conditions after the MHE connection to the network – max consumption, MHE max production		
Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.401 kV, max 0.412 kV)	**1.967 MW**	**5303 MWh**

Results:

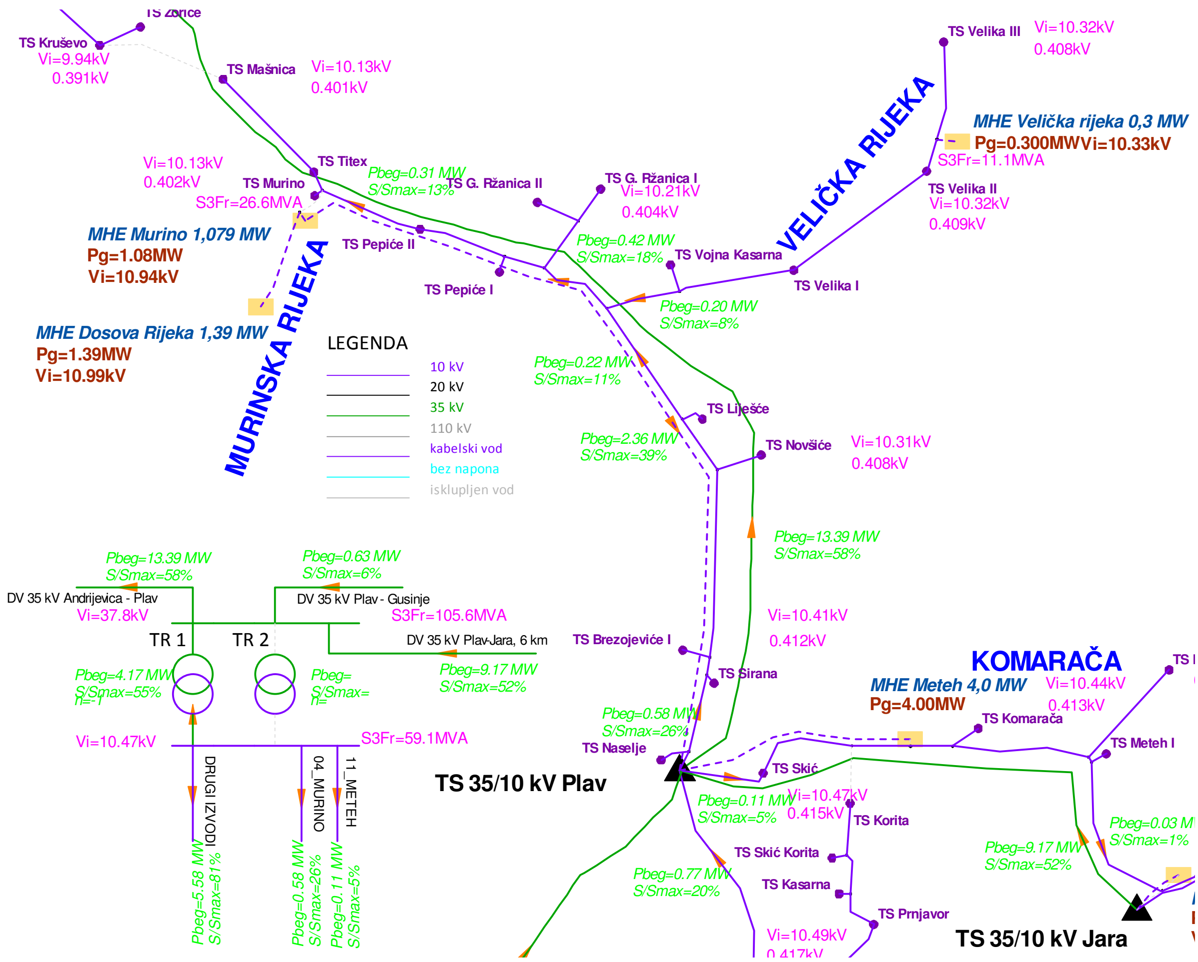


Figure 99: Results of power condition analyses – max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- small amount above the permitted limits (min 0.408 kV, max 0.422 in the area of Velika Rijeka)	**0.433 MW**

Results:

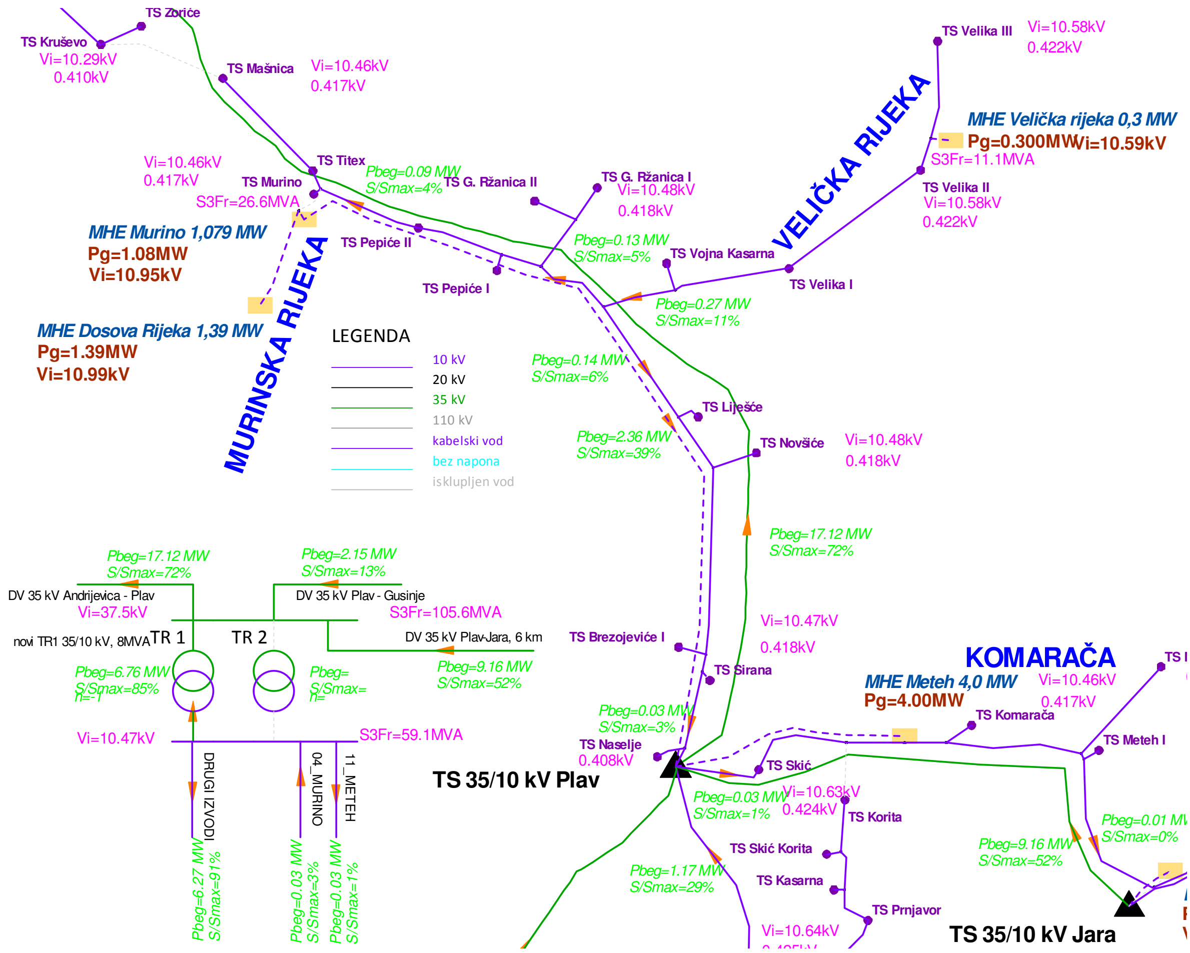


Figure 100: Results of power condition analyses – min consumption and MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.385 kV, max 0.401 kV)	**2.028 MW**

Results:

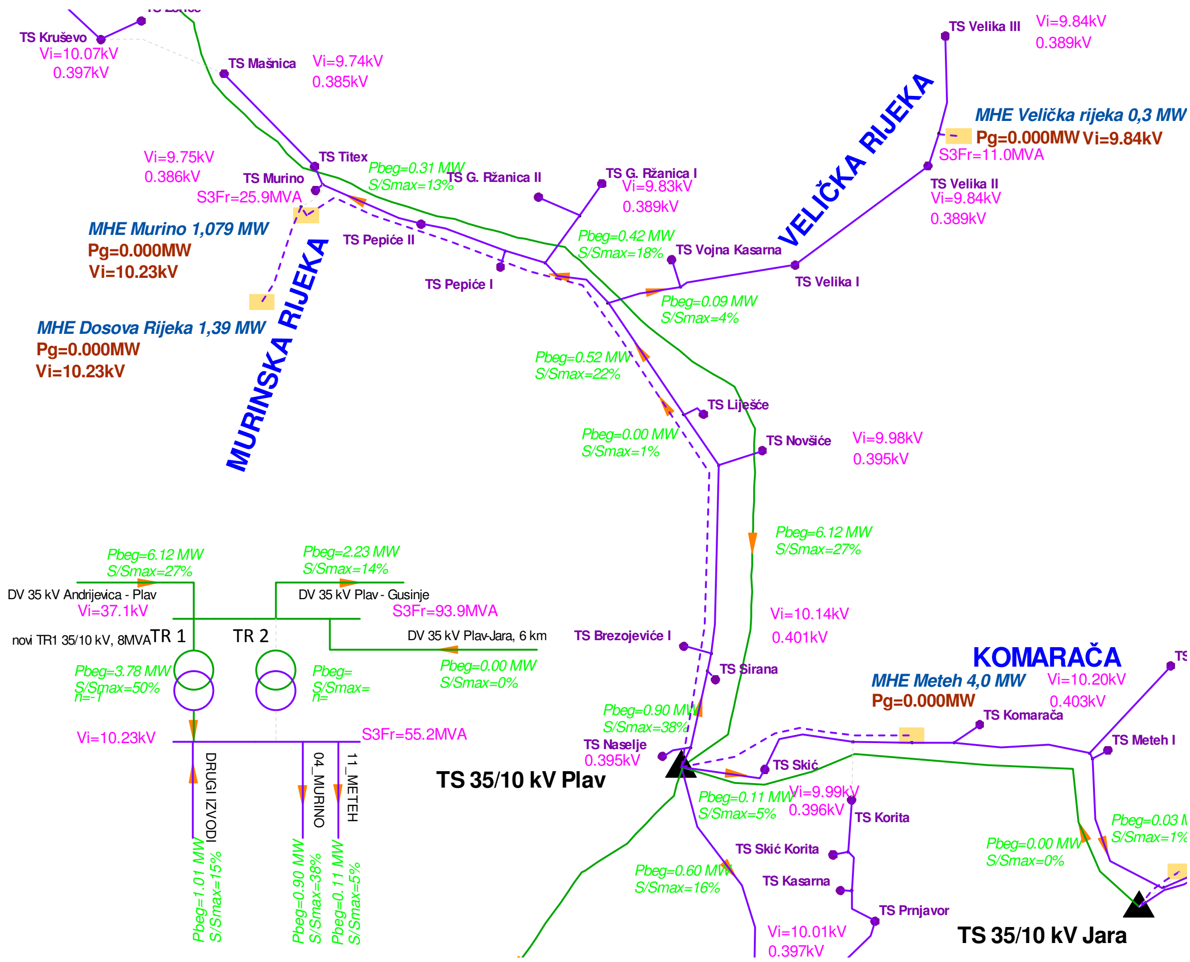


Figure 101: Results of power conditions analyses – max consumption without MHE production, 2011.

Solution advantages

- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR][EUR]
Before connection	**0**	0.392	0.404	2.028	-	5442	-	-
Connection to existing network	**0.3**	0.403	0.427	1.967	**-0.061**	5303	**-139**	-

KOMARAČA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Meteh	4.0	SBS Komarača	22.8
Komarača output	**4**	**Slack node:** 110 kV busbars SBS Andrijevica	969

Min. model of the relevant network:	- SBS Andrijevica 110/35/10 kV - SBS Plav 35/10 kV - 10 kV feeder: Meteh

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Meteh	0.22	0.75	0.23	0.80
SBS 35/10 kV Plav	**1.2**	**4**	**1.27**	**4.24**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the projected distribution network development

- Reconstruction of 35 kV Andrijevica – Plav transmission line by 2015
- Reconstruction of SBS Plav 35/10 kV

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.394 kV, max 0.402 kV)

Results:

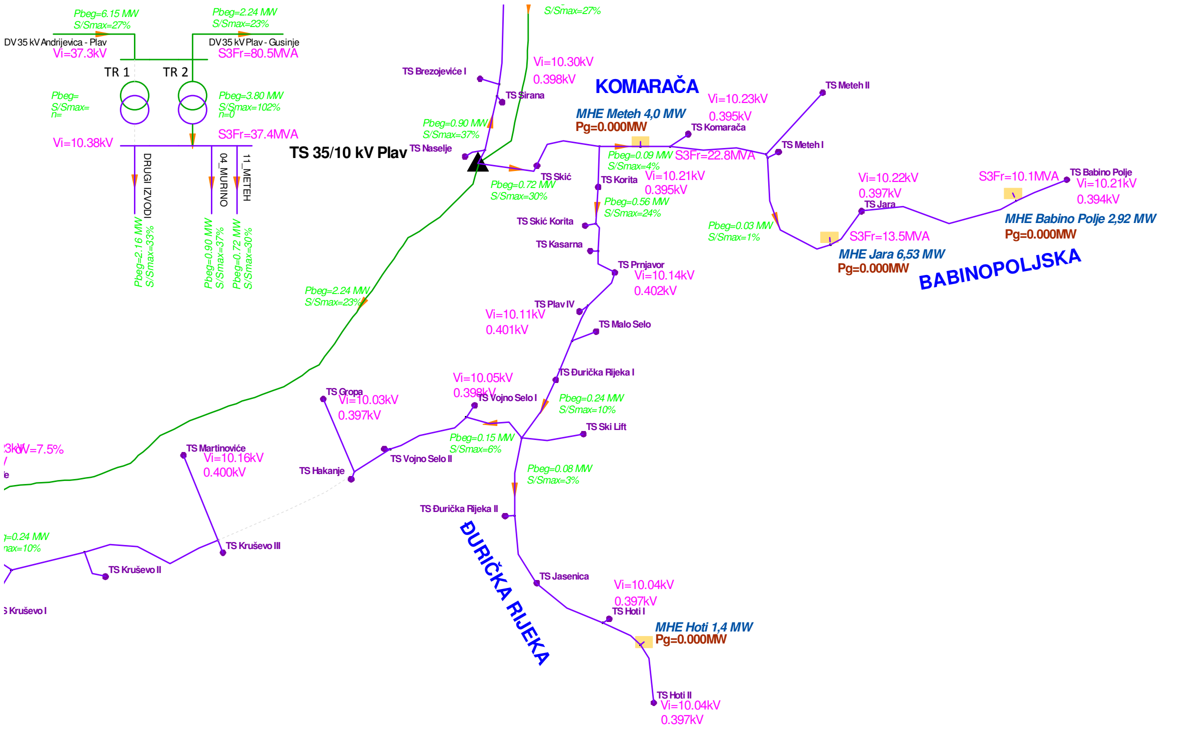


Figure 102: Loads in 10 kV network and voltages in LV busbars TP – maximum loads 2011 in the existing network..

Min consumption	- within permitted limits	- within permitted limits

Results:

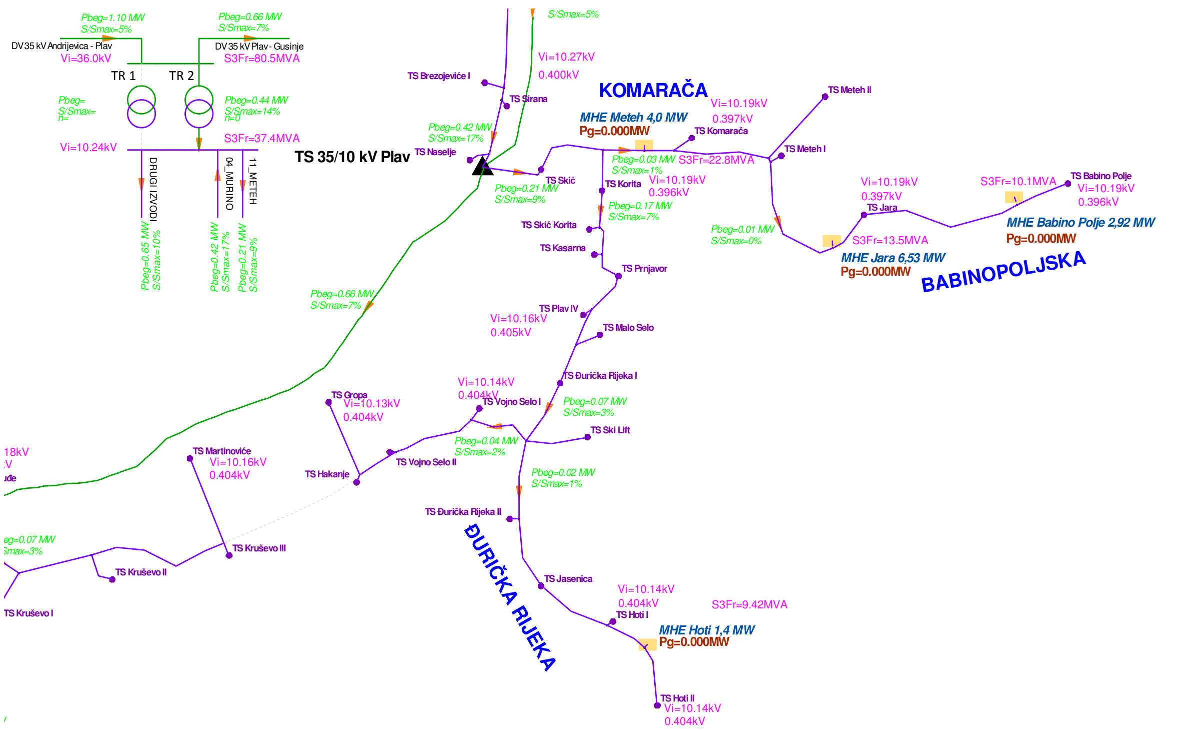


Figure 103: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**2.028 MW**	Yearly losses:	**5442 MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.9 MW**

Notes:

- in the connection with full power, the LV network voltages increase over the criterion 0.420 kV (above 0.46 kV)

Results:

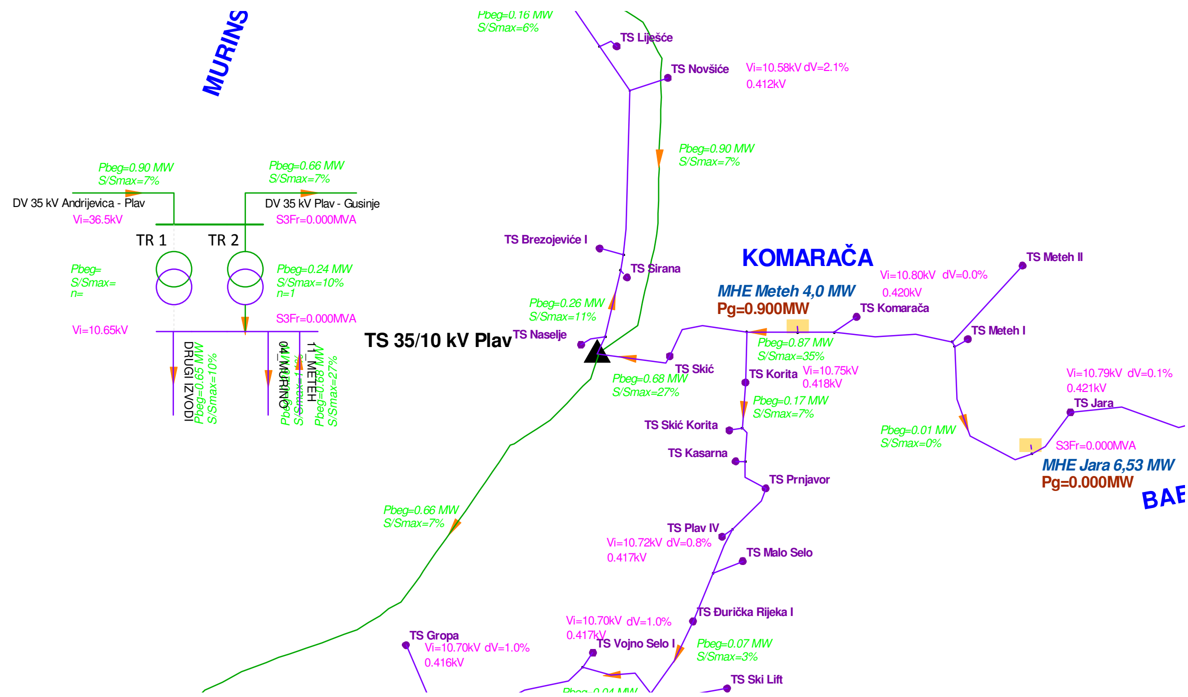


Figure 104: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**1.895 MW**	Yearly losses:	**5085 MWh**

4.b MHE connection to the network - VARIANT A

Necessary reinforcements:	Estimated investment in EUR **∑ 120,000**
- MHE Meteh connection via new 10 kV feeder directly into SBS 35/10 kV Plav (Al 150 mm^2 cable, 2.5 km)	120,000

Load conditions after the MHE connection to the network – max consumption, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.405 kV ; max 0.419 kV)	**1.441 MW**	**3867 MWh**

Results:

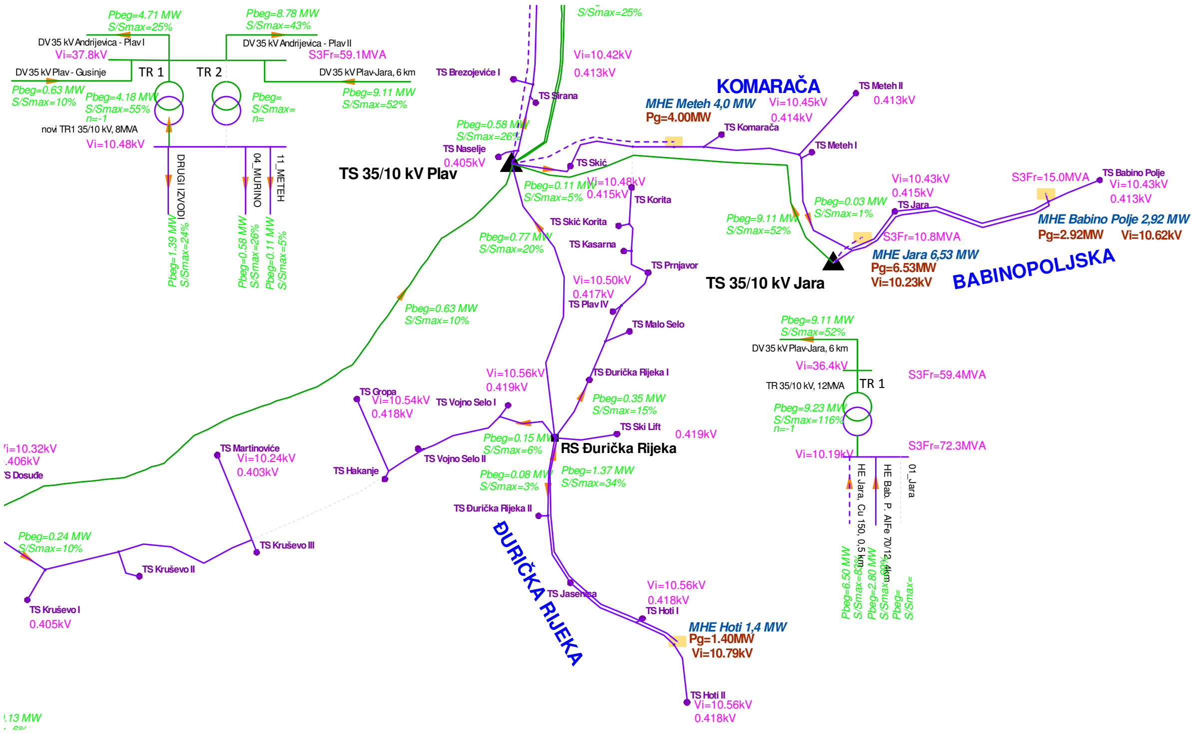


Figure 105: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.409 kV, max 0.417 kV)	**0.476 MW**

Results:

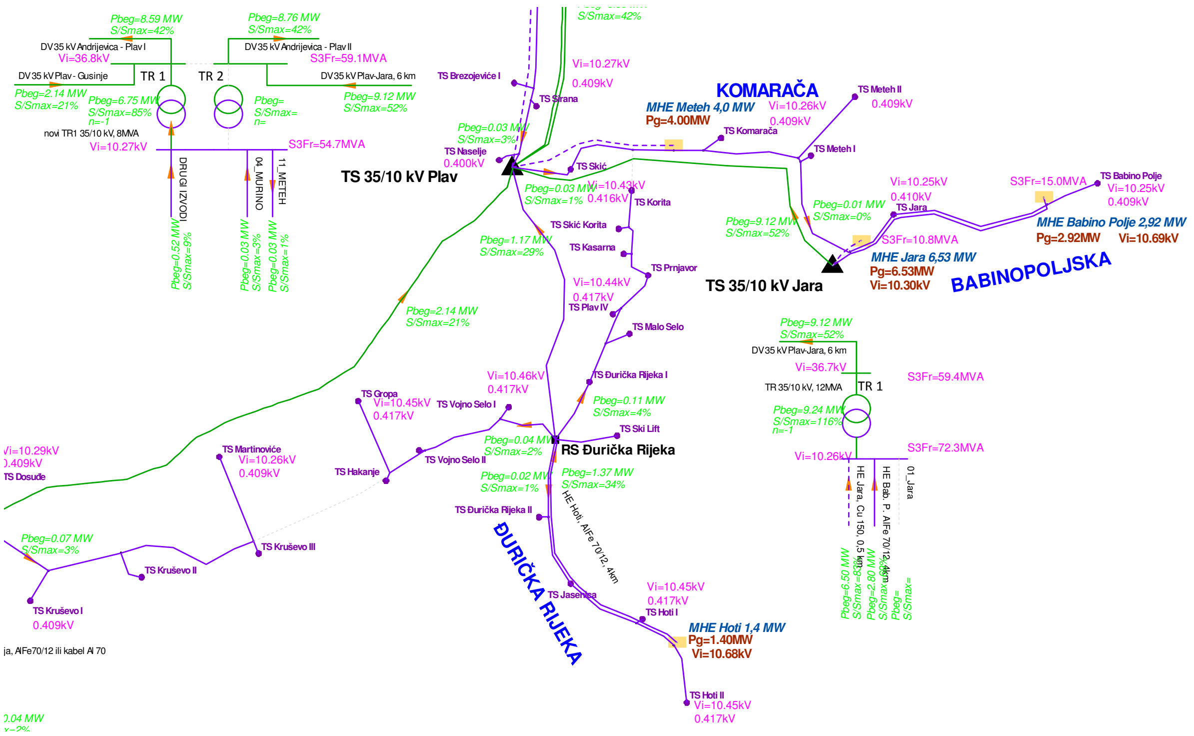


Figure 106: Results of power condition analyses – VARIANT A, min consumption and MHE max production, 2011.

Operation conditions after the MHE connection to the network – MHE max consumption, without production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.398 kV, max 0.407 kV)	**1.621 MW**

Results:

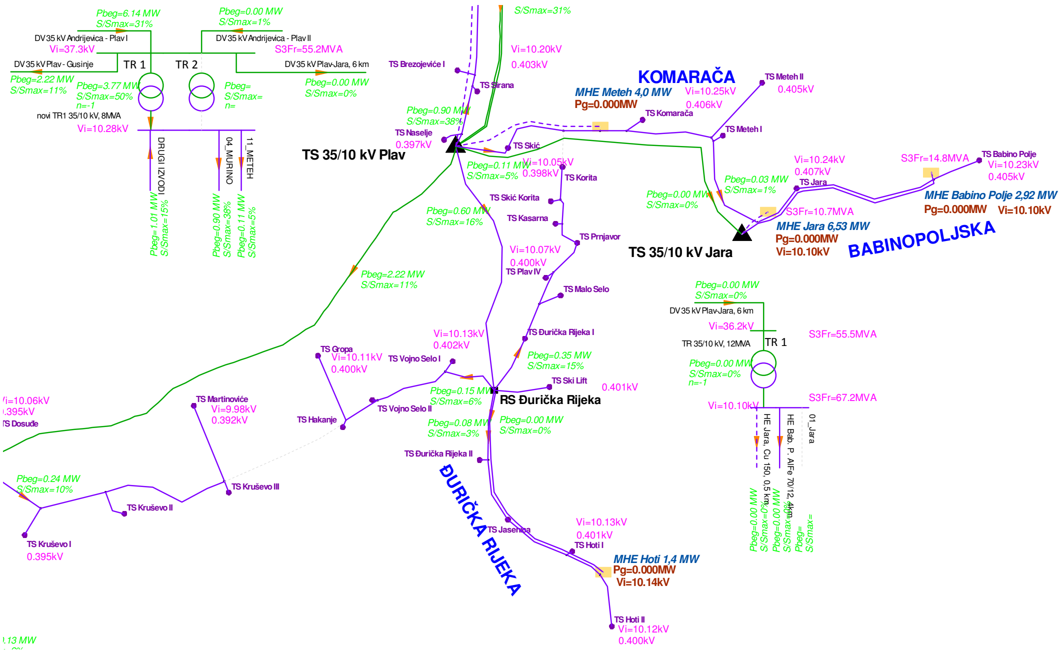


Figure 107: Results of power condition analyses – – VARIANT A, max consumption without MHE production, 2011.

Solution advantages

- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.375	0.407	2.028	**-**	5442	**-**	**-**
Connection to existing network	**0.9**	0.410	0.421	1.895	**-0.133**	5085	**-357**	**-**
VARIANT A	**4**	0.398	0.419	1.441	**-0.587**	3867	**-1575**	**120,000**

BABINOPOLJSKA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Jara	6.53	SBS Jara	13.5
MHE Babino Polje	2.92	SBS Babino Polje	10.1
Babinopoljska output	**9.45**	**Slack node:** 110 kV busbars SBS Andrijevica	969

Min. model of the relevant network:

- SBS Andrijevica 110/35/10 kV
- SBS Plav 35/10 kV
- 10 kV feeder: Meteh

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Meteh	0.22	0.75	0.23	0.80
SBS 35/10 kV Plav	**1.2**	**4**	**1.27**	**4.24**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the projected distribution network development

- Reconstruction of 35 kV Andrijevica – Plav transmission line by 2015
- Reconstruction of SBS Plav 35/10 kV

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.394 kV, max 0.402 kV)

Results:

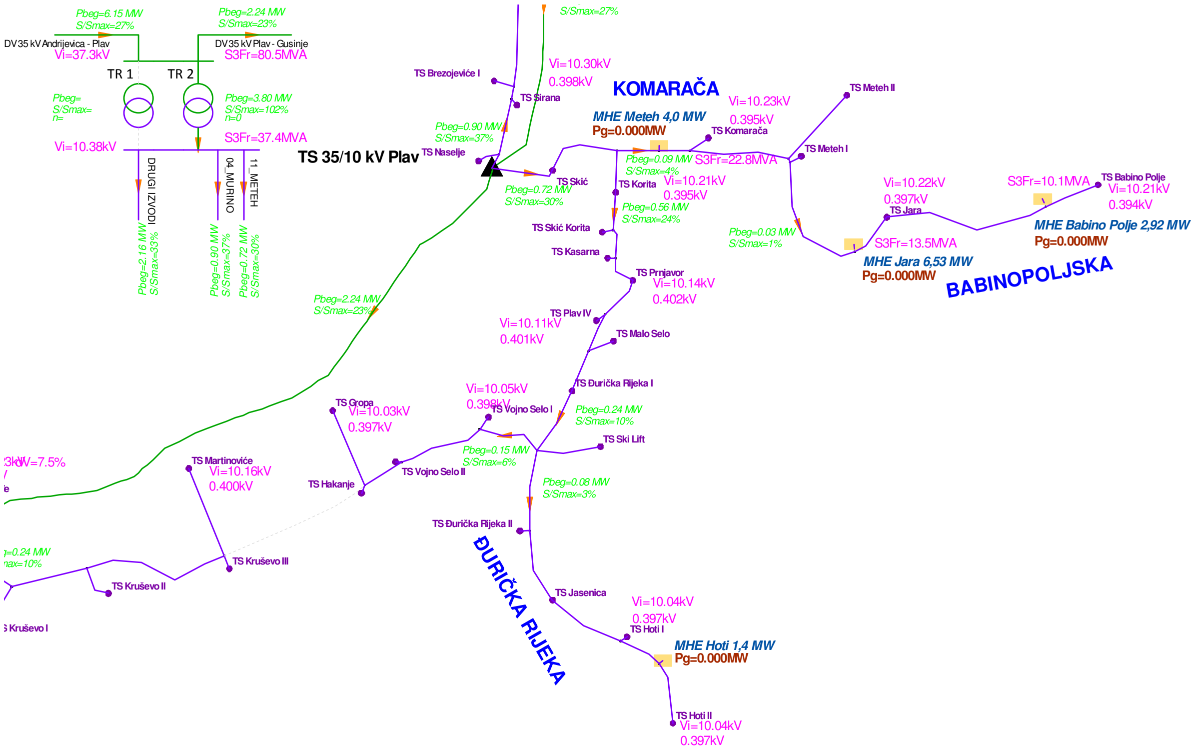


Figure 108: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	- within permitted limits

Results:

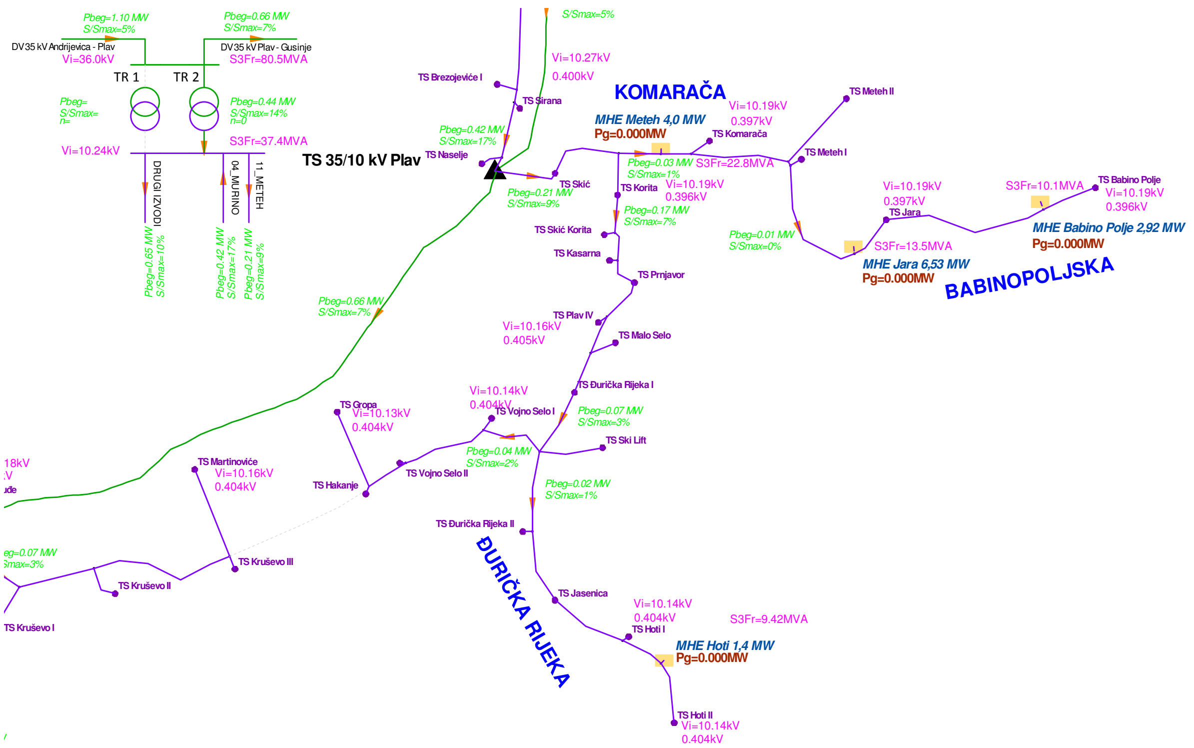


Figure 109: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**2.028 MW**	Yearly losses:	**5442 MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.45 MW**

Notes:

- in connection with full power the LV network voltages are increased above the criterion 0.420 kV (above 0.5 kV), characteristics overloads of 10 kV lines

Results:

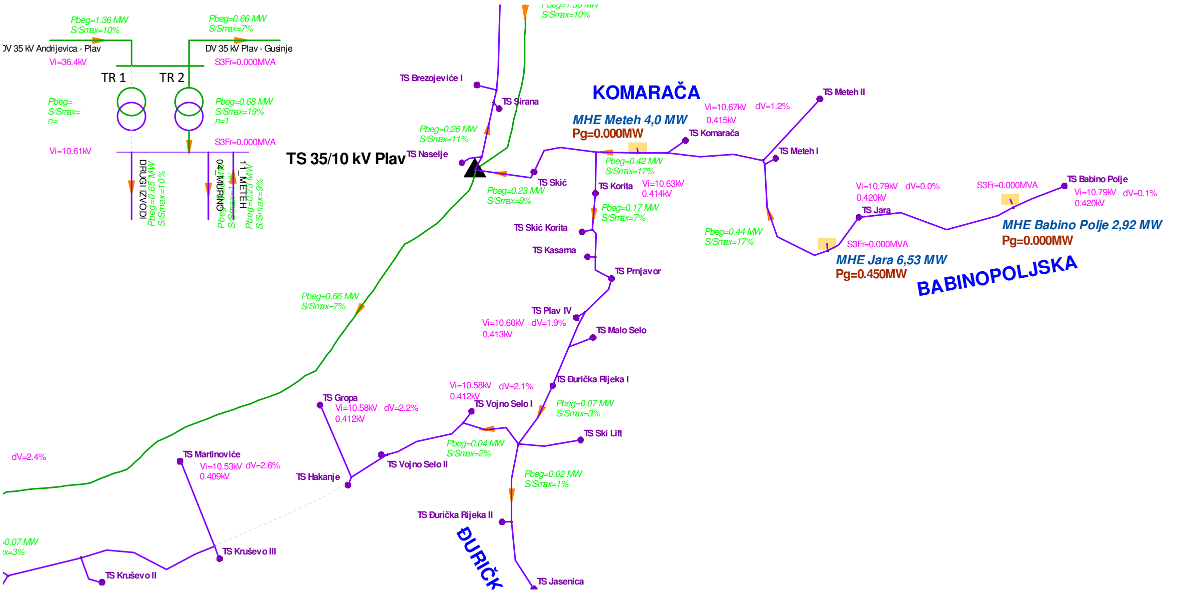


Figure 110: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**1.959 MW**	Yearly losses:	**5257 MWh**

4.b MHE connection to the network – VARIANT A

Necessary reinforcements:	Estimated investment in EUR **∑ 1,080,000**
- **condition for connection is the reconstruction of 35 kV Andrijevica – Plav transmission line into double circuit line with AlFe120/20 mm² conductor and new 35 kV busbars sector in SBS Plav**	
- new SBS 35/10 kV Jara, 1x8 MVA, three 10 kV feeder bays, one 35 kV feeder bay, one transformer bay (35 kV and 10 kV)	450,000
- 35 kV supply line from SBS Plav (AlFe95/15 mm² conductor, length 6 km), line is reconnected to other 35 kV transmission line system na Andrijevica – Plav II directly to 35 kV busbars in SBS Andrijevica (power surplus is evacuated together with production on the rivers Trepačka and Šekularska	350,000

via transformer 110/35 kV, 20 MVA to 110 kV network) - 10 kV feeders form SBS Jara: feeder to MHE Jara, feeder to MHE Babino Polje, feeder to Metehu (connected to Meteh feeders from SBS Plav) - MHE Babino Polje connection to the reconstructed existing 2x10 kV line, 4 km (1xAlFe 70/12 mm^2 conductors (MHE) and 1xAlFe 35/6 mm^2 for consumption) - MHE Jara connection with Cu 150 mm^2 cable to SBS Jara, length 0.5 km	280,000

Operation condition after MHE connection to the network – max consumption, max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.405 kV ; max 0.419 kV)	**1.568 MW**	**4208 MWh**

Results:

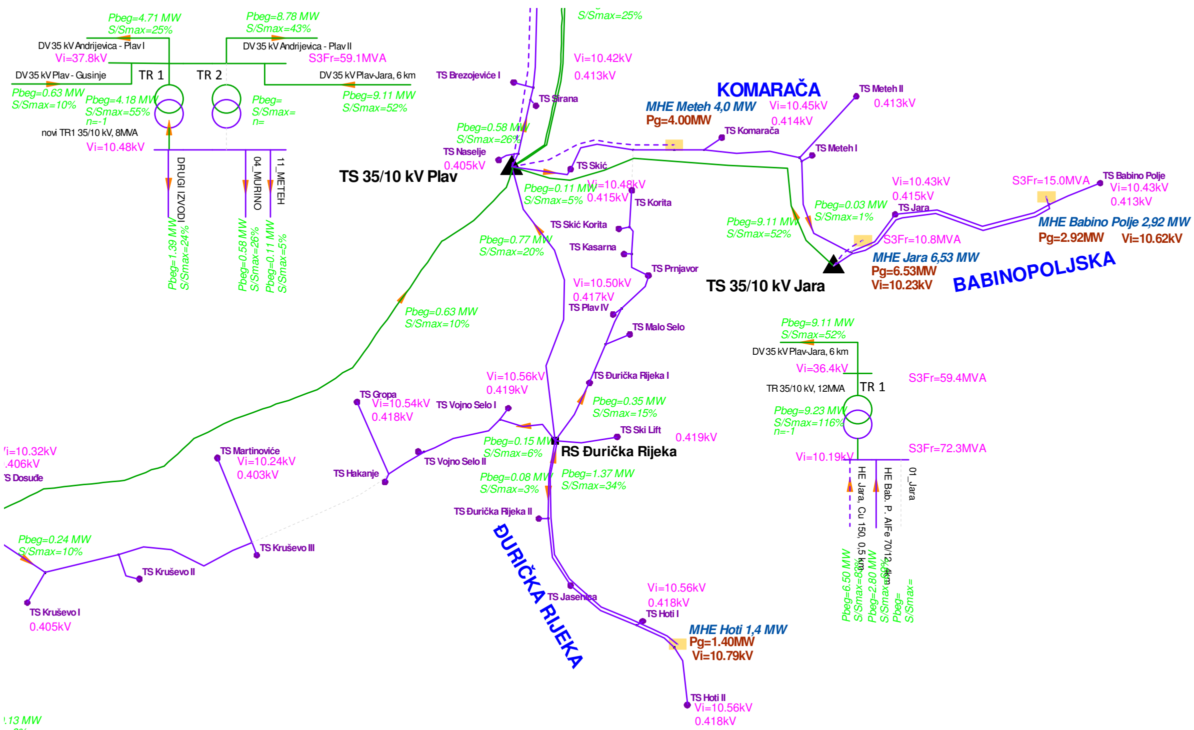


Figure 111: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.409 kV, max 0.417 kV)	**0.806 MW**

Results:

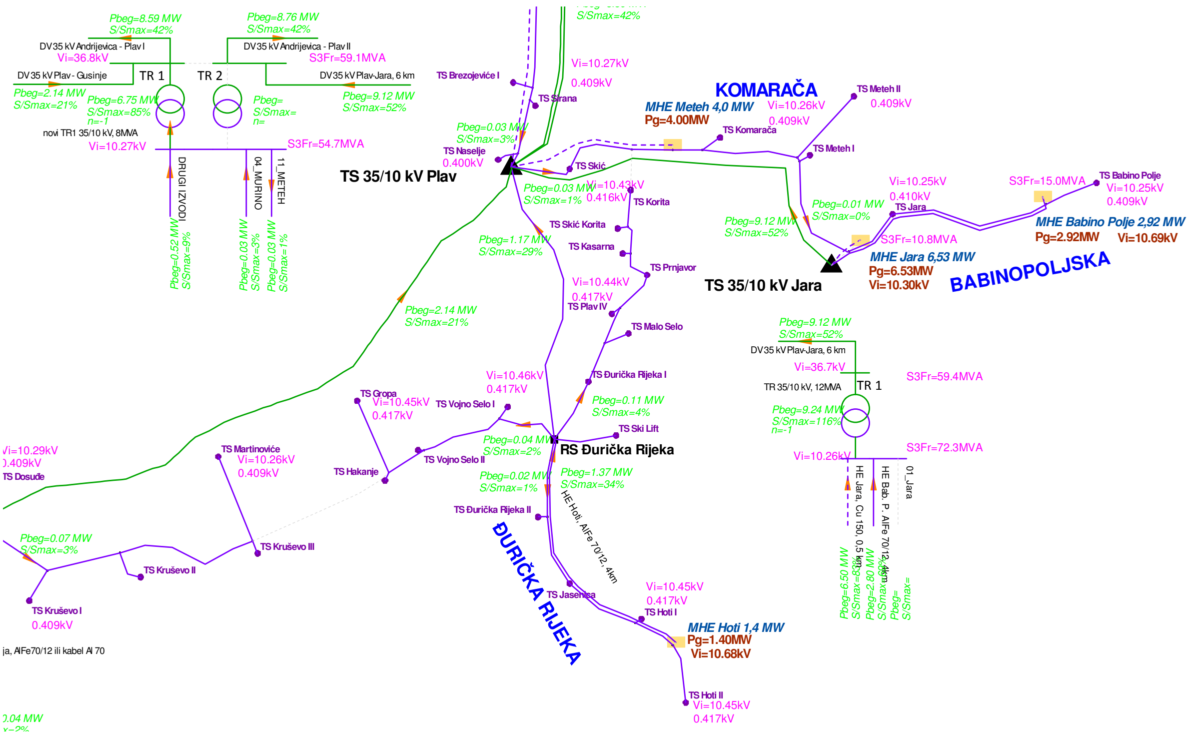


Figure 112: Results of power condition analyses – VARIANT A, MHE min consumption, max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.398 kV, max 0.407 kV)	**1.621 MW**

Results:

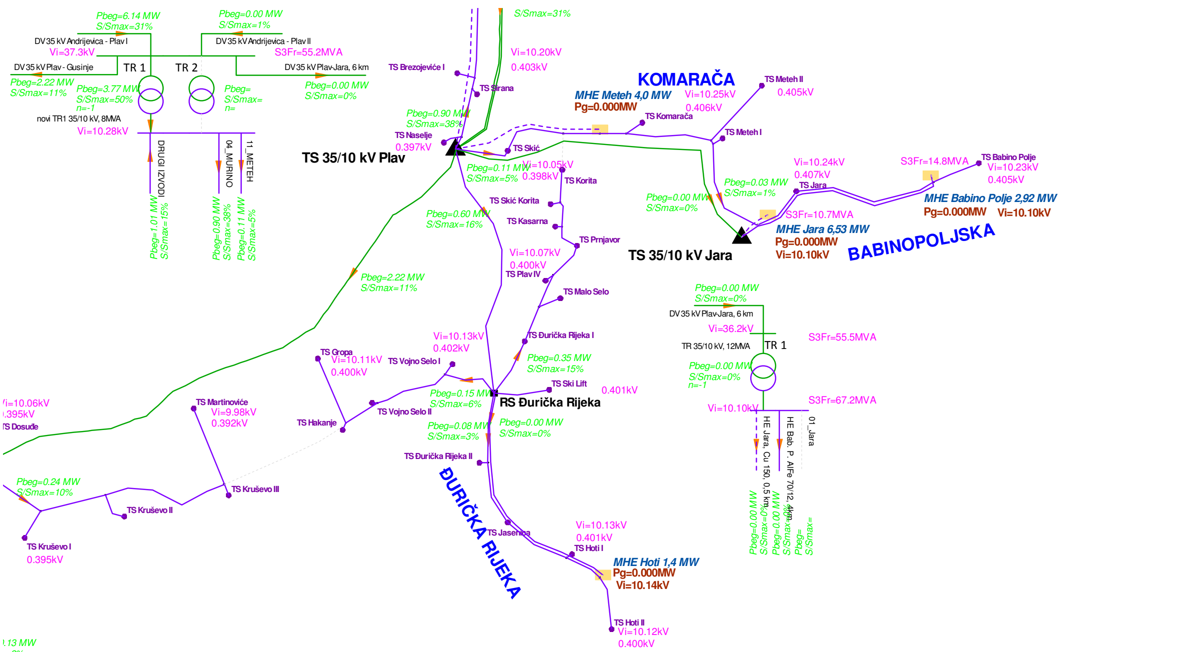


Figure 113: Results of power condition analyses – – VARIANT A, max consumption without MHE production, 2011.

Solution advantages
- **since the production in the area of Plav is smaller (4 MVA), the produced power (total 14.5 MW) needs to be evacuated into 35 kV and 110 kV network** - **MHE operation improves voltage conditions in the areas with previously low voltage** - **This solution is conditioned with active regulation of voltages at 35 kV busbars to SBS Andrijevica 110/35 kV:** ➢ **high consumption situations without MHE operation: target voltage at 35 kV busbars: (37.4 – 37.7) kV** ➢ **low consumption situations with MHE operation: target voltage at 35 kV busbars: (35.7 – 36.0) kV**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.375	0.407	2.028	**-**	5442	**-**	**-**
Connection to existing network	**0.45**	0.410	0.420	1.959	**-0.069**	5257	**-185**	**-**
VARIANT A	**13.334**	0.398	0.419	1.568	**-0.460**	4208	**-1234**	**1,080,000**

RIVER ĐURIČKA RIJEKA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Hoti	1.4	SBS Hoti I	9.42
Đuručka Rijeka output	**1.4**	**Slack node:** 110 kV busbars SBS Andrijevica	969
Min. model of the relevant network:	- SBS Andrijevica 110/35/10 kV - SBS Plav 35/10 kV - 10 kV feeder: Meteh		

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Meteh	0.22	0.75	0.23	0.80
SBS 35/10 kV Plav	**1.2**	**4**	**1.27**	**4.24**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the projected distribution network development

- Reconstruction of 35 kV Andrijevica – Plav transmission line by 2015
- Reconstruction of SBS Plav 35/10 kV

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.394 kV, max 0.402 kV)

Results:

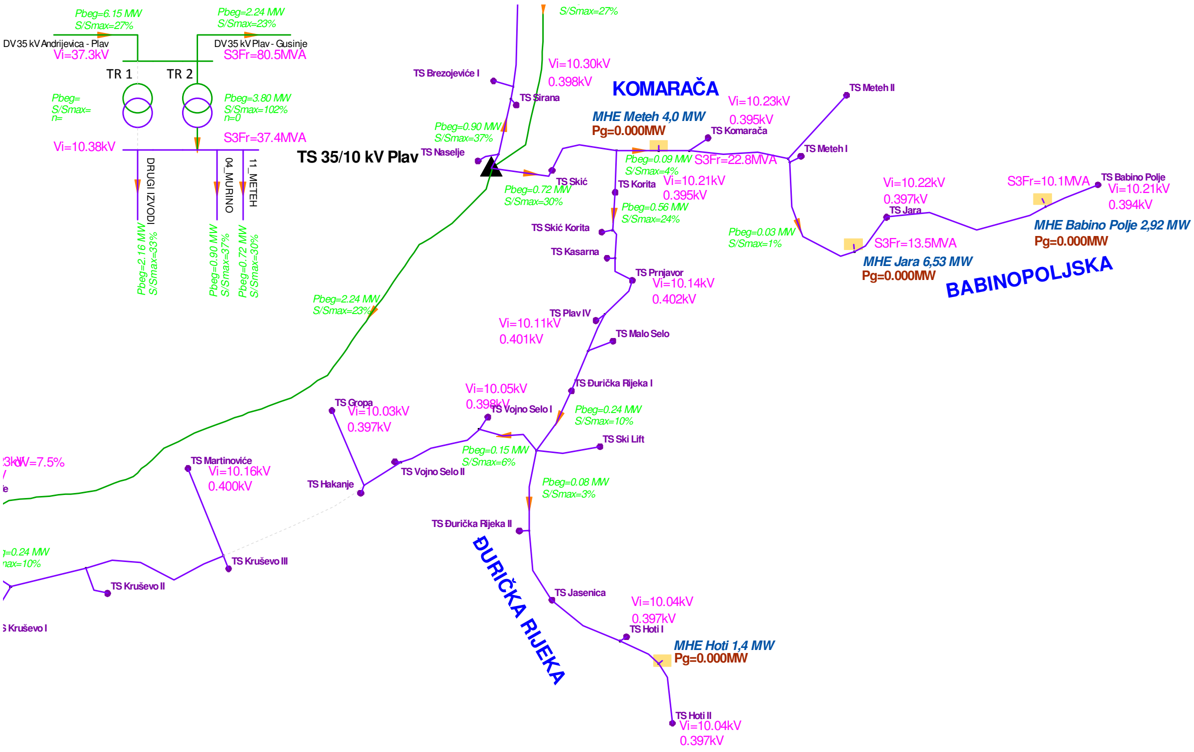


Figure 114: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	- within permitted limits

Results:

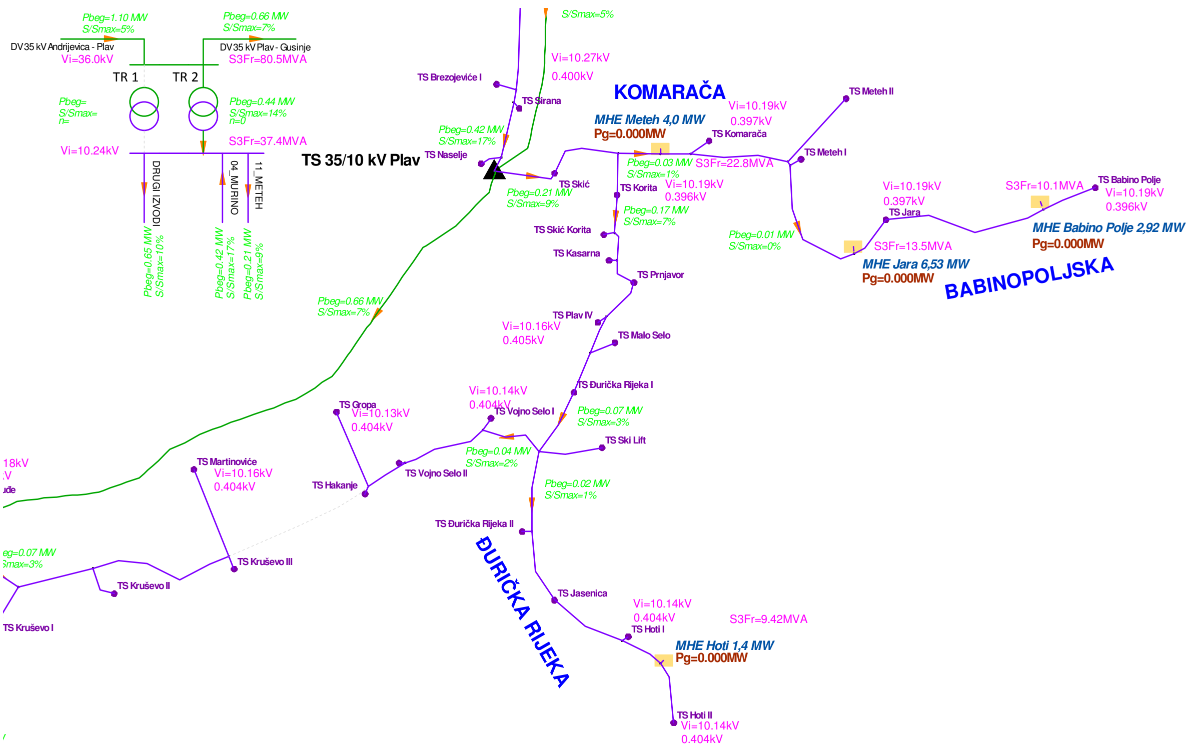


Figure 115: Loads in 10 kV network and voltages at LV busbars in TP – minimum loads 2011 in the existing network.

Max losses:	2.028 MW	Yearly losses:	5442 MWh

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	0.1 MW

Notes:

- in the connection with full power , the LV network voltages are increased above the criterion 0.420 kV (above 0.470 kV)

Results:

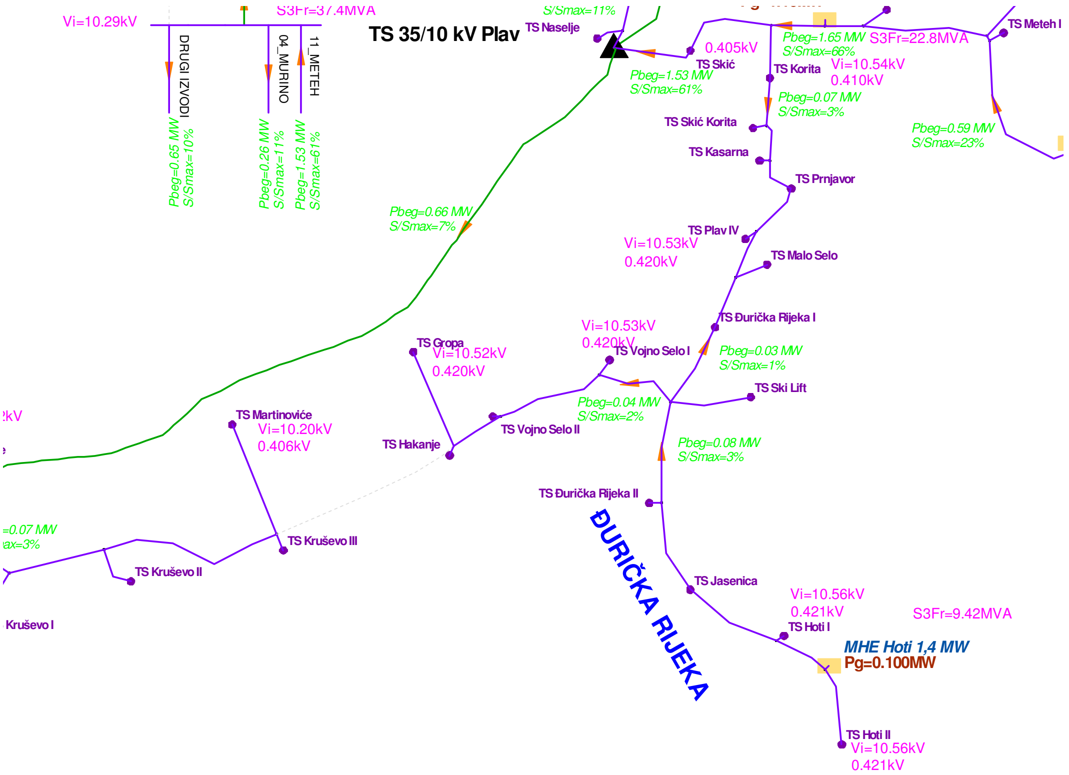


Figure 116: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	2.006 MW	Yearly losses:	5383 MWh

4.b MHE connection to the network – VARIANT A

Necessary reinforcements:	Estimated investment in EUR ∑ 580,000
MHE connection on the river Đurička Rijeka:	
- new switching station SS Đurička Rijeka (six feeder bays)	260,000
- supply of SS with new 10 kV feeder Đurička Rijeka from SBS Plav (overhead AlFe 70/12 mm^2 conductor, approx. length 4.5 km	200,000

- MHE Hoti connection via new feeder from SS Đurička Rijeka – reconstruction of the existing transmission line into the 2x10kV transmission line, 1xAlFe 70/12 mm² (MHE) and 1xAlFe 35/6 mm² conductors (consumption), 4 km	120,000

Load conditions after the MHE connection to the network – max load, max MHE production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.405 kV ; max 0.419 kV)	**1.525 MW**	**4165 MWh**

Results:

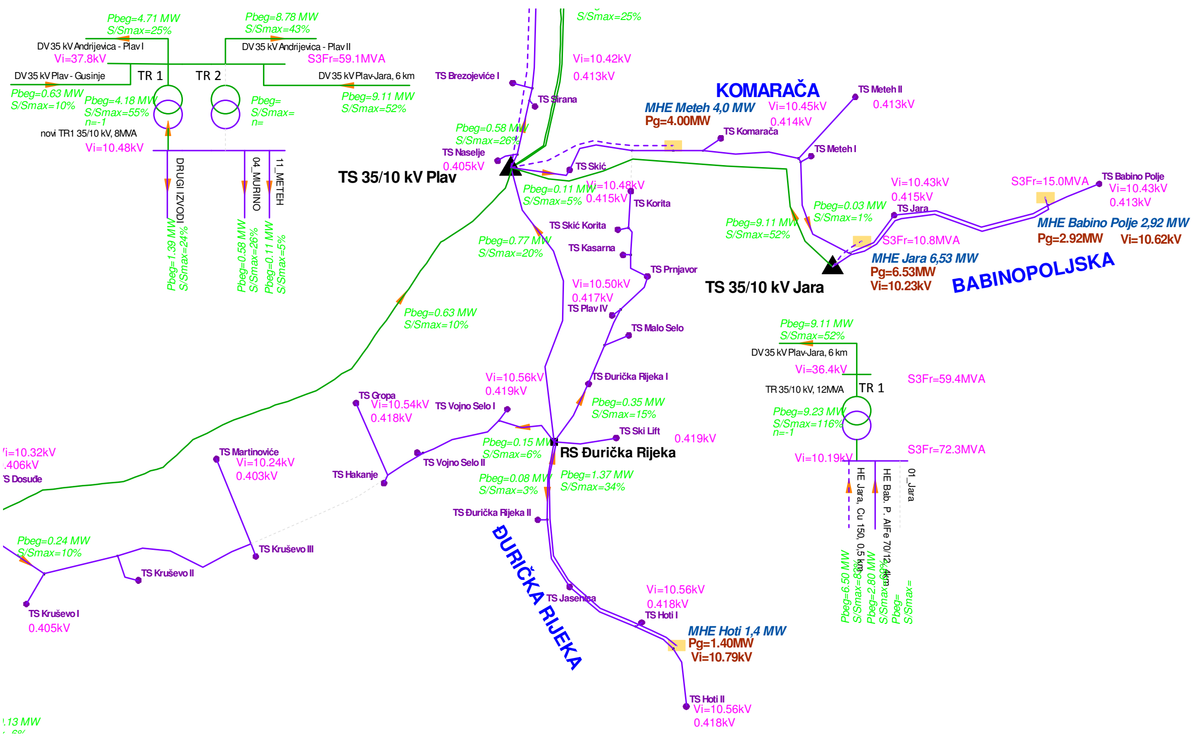


Figure 117: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.409 kV, max 0.417 kV)	**0.438 MW**

Results:

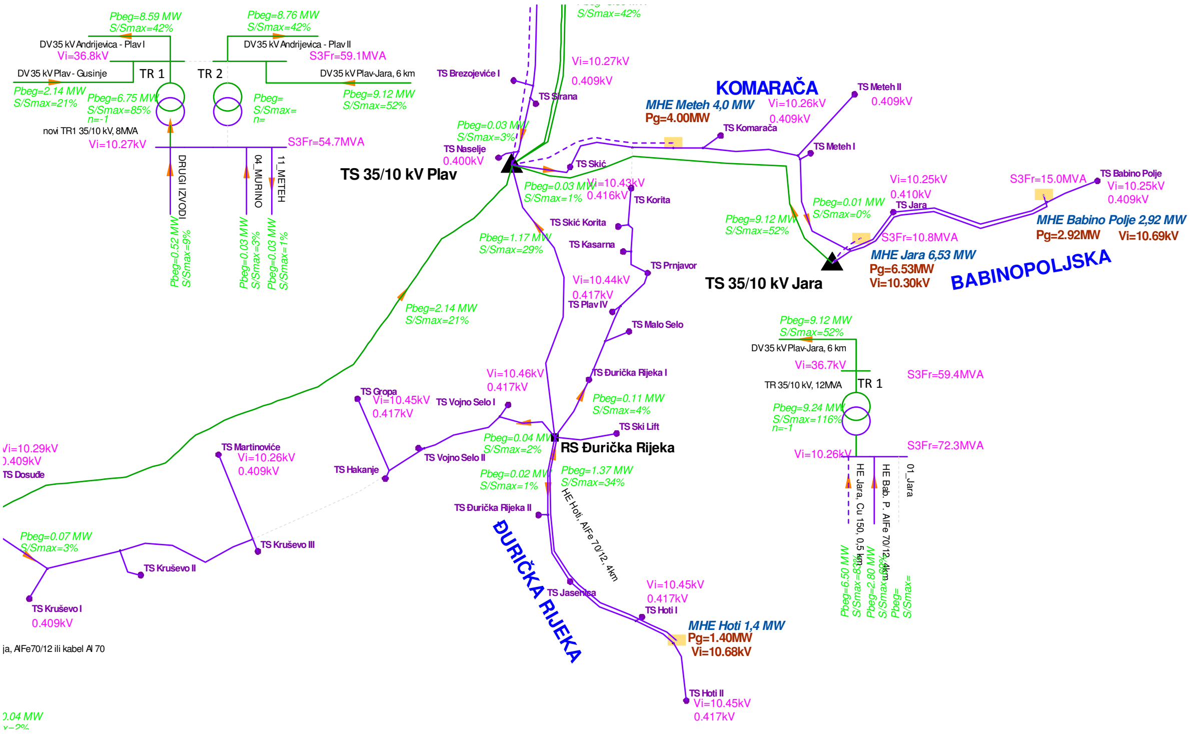


Figure 118: Results of power condition analyses – VARIANT A, min consumption, MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.398 kV, max 0.407 kV)	**1.621 MW**

Results:

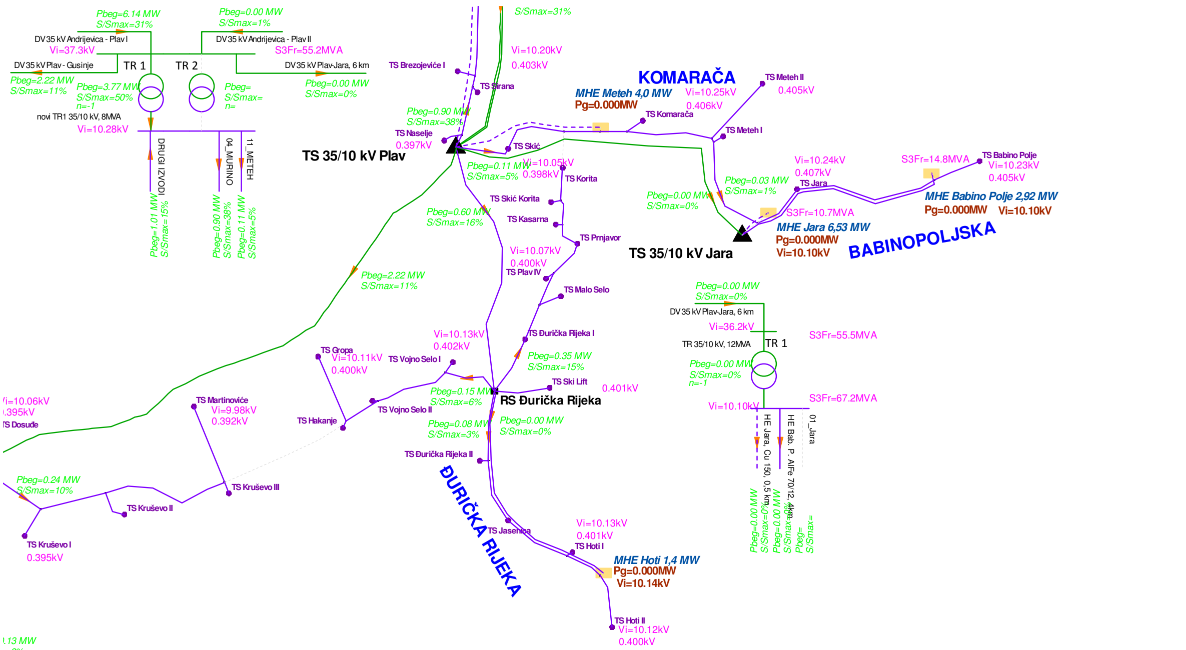


Figure 119: Results of power condition analyses – VARIANT A, MHE max consumption without production, 2011.

Solution advantages

- **good reliability of 10 kV network operation (good voltage conditions, lines are not overloaded, option of oversupply between two feeders)**
- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **Optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR
Before connection	**0**	0.375	0.407	2.028	**-**	5442	**-**	**-**
Connection to existing network	**0.1**	0.410	0.420	2.006	**-0.022**	5383	**-59**	**-**
VARIANT A	**1.4**	0.398	0.419	1.525	**+0.503**	4165	**-1286**	**580,000**

RIVER GRLJA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Grlja	3	SBS Vusanje I	13.7
Grlja output	**3**	**Slack node:** 110 kV busbars SBS Andrijevica	969
Min. model of the relevant network:	- SBS Andrijevica 110/35/10 kV - SBS Gusinje 35/10 kV - 10 kV feeder: Plav		

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Plav	0.17	0.57	0.18	0.60
SBS 35/10 kV Gusinje	**0.69**	**2.34**	**0.73**	**2.48**
SBS 110/35 kV Andrijevica	**3.32**	**11.1**	**3.52**	**11.76**

2.b Relevant data on the projected distribution network development

- Reconstruction of 35 kV Plav – Gusinje transmission line by 2015
- Reconstruction of SBS Gusinje 35/10 kV

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.399 kV, max 0.403 kV)

Results:

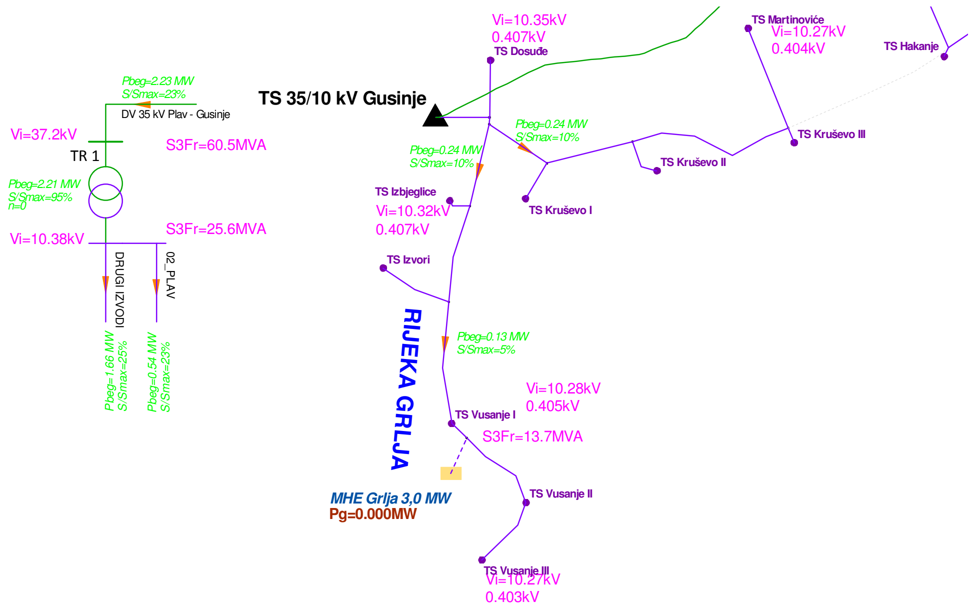


Figure 120: Loads in 10 kV network and voltages at LV busbarsin TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	within permitted limits (min 0.403 kV, max 0.404 kV)

Results:

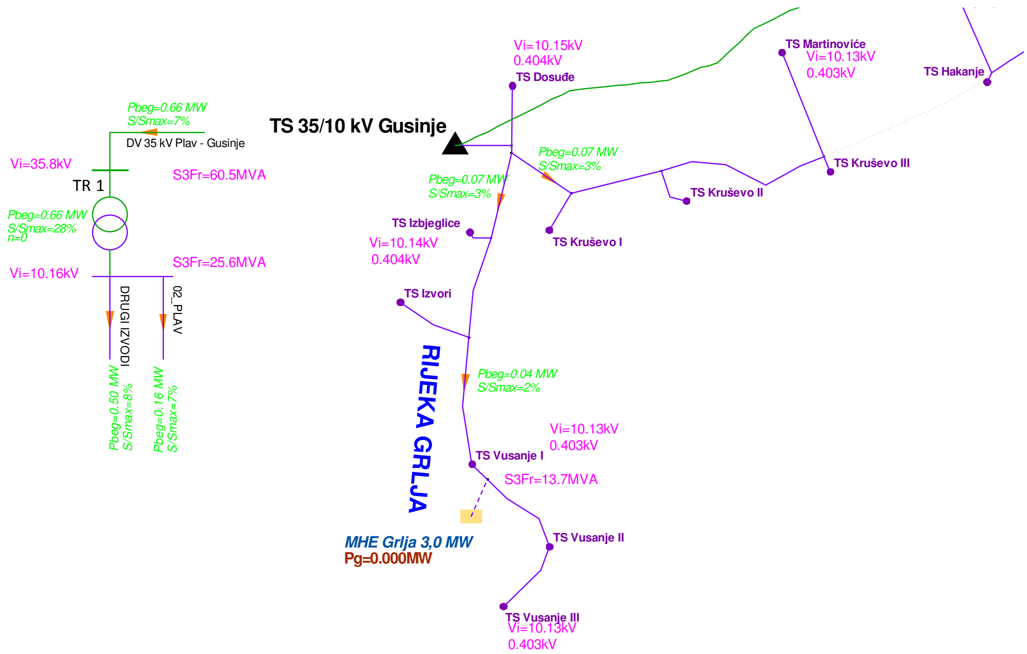


Figure 121: Loads in 10 kV network and loads at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**1.767 MW**	Yearly losses:	**4742,0 MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.85 MW**

Notes:

- in the connection with full power , the LV network voltages are increased above the criterion 0.420 kV (above 0.470 kV)

Results:

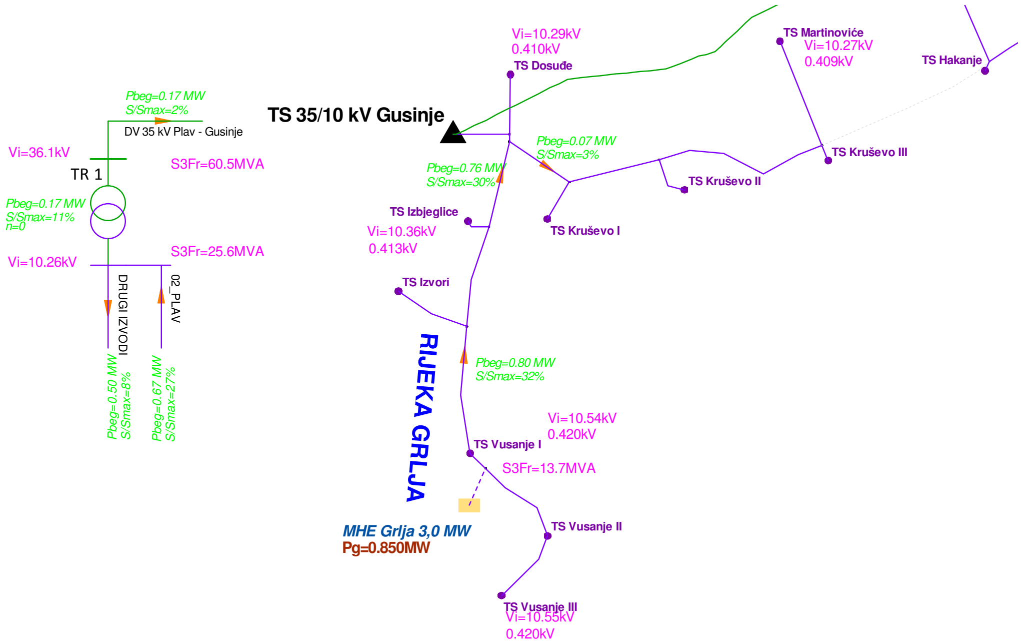


Figure 122: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**1.692 MW**	Yearly losses:	**4540.8 MWh**

4.b VARIANT A: MHE Grlja connection to the new feeder from SBS GUSINJE

Necessary reinforcements:	Estimated investment in EUR **∑ 200,000**
- MHE Grlja connection via new 10 kV feeder directly to SBS 35/10 kV Gusinje, reconstruction of the existing transmission line into 2x10 kV transmission line, 1xAlFe 70/12 mm^2 (MHE) and 1xAlFe 35/6 mm^2 conductors (consumption), approx. length 5 km. - Alternative: connection with cable feeder (Al 150 mm^2 cable, 5 km).	200,000

Load conditions after the MHE connection to the network – max load, max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.402 kV, max 0.406 kV)	**1.610 MW**	**4320.7 MWh**

Results:

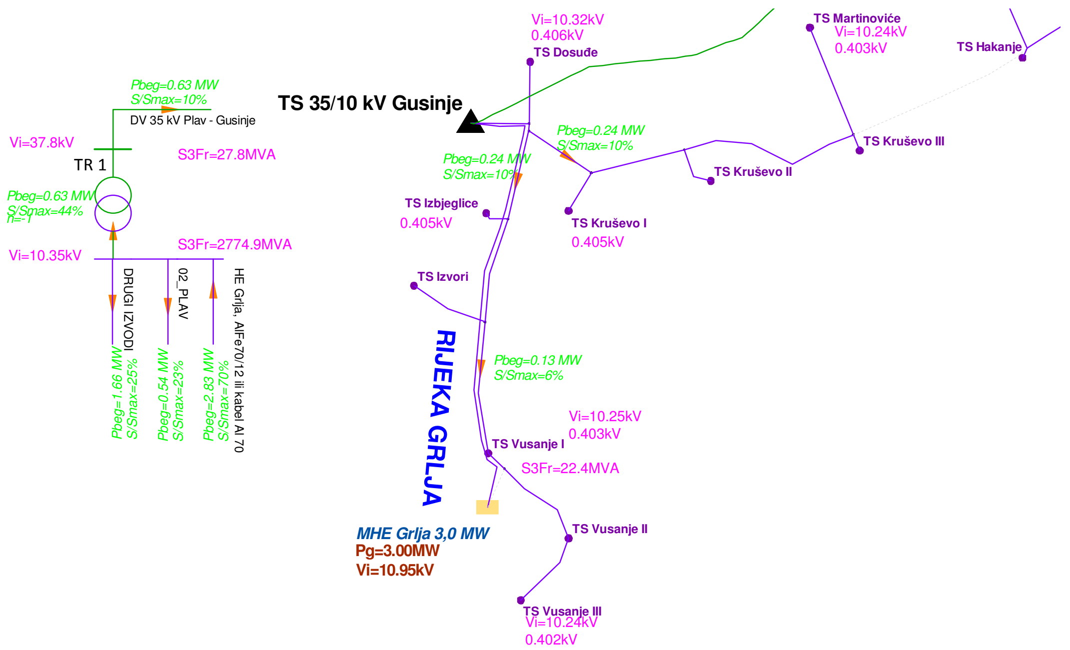


Figure 123: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation condition after MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.408 kV, max 0.410)	**0.645 MW**

Results:

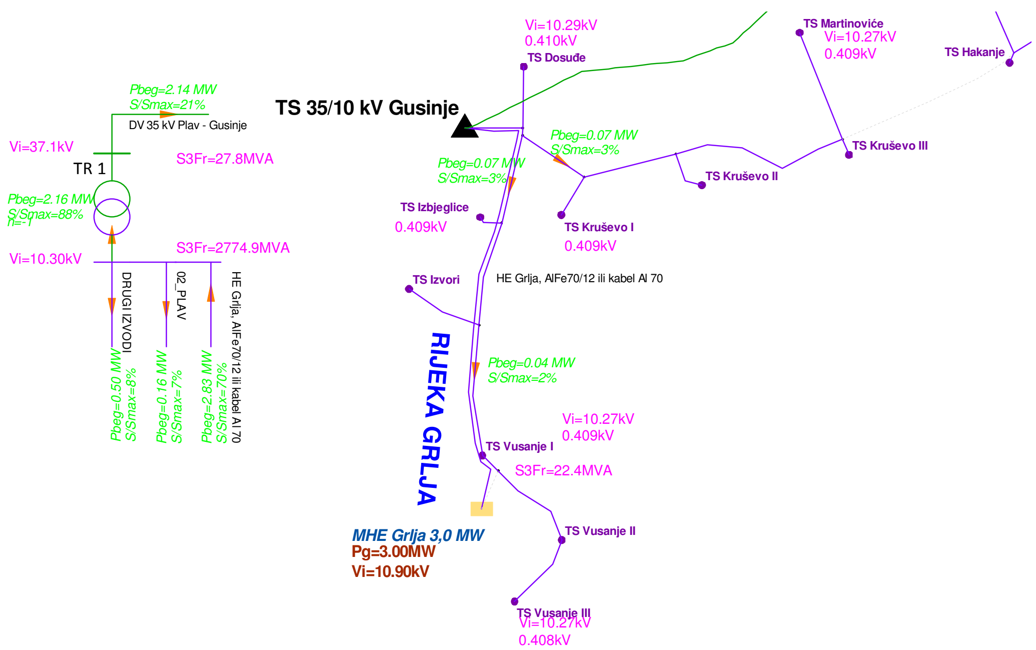


Figure 124: Results of power condition analyses – VARIANT A, min consumption and MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production

Loads and voltages in the network:	Losses:

- within permitted limits (min 0.391 kV, max 0.395 kV)	**1.661 MW**

Results:

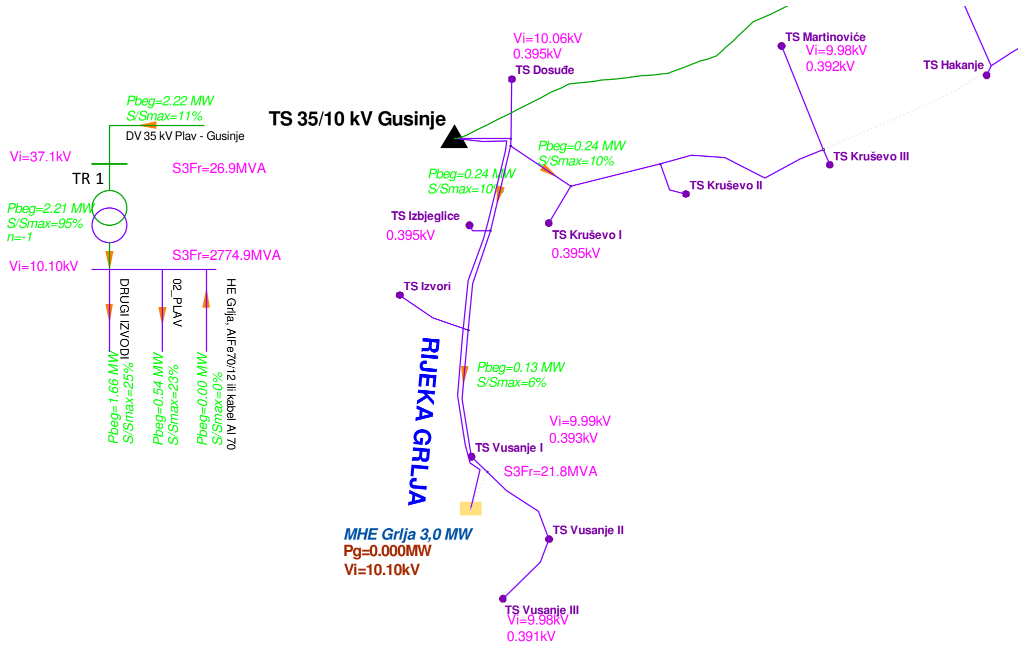


Figure 125: Results of power condition analyses – VARIANT A, max consumption without MHE production.

Solution advantages

- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.392	0.404	1.767	-	4742.0	-	-
Connection to existing network	**0.7**	0.407	0.420	1.692	**-0.075**	4540.8	**-201.2**	-
VARIANT A	**1.6**	0.391	0.410	1.610	**-0.157**	4320.7	**-412.3**	**200,000**

5.5. Results of mhe connection to the distribution network – solutions for the komarnica and piva river basins

5.5.1. Area with the distribution network with MHE connections

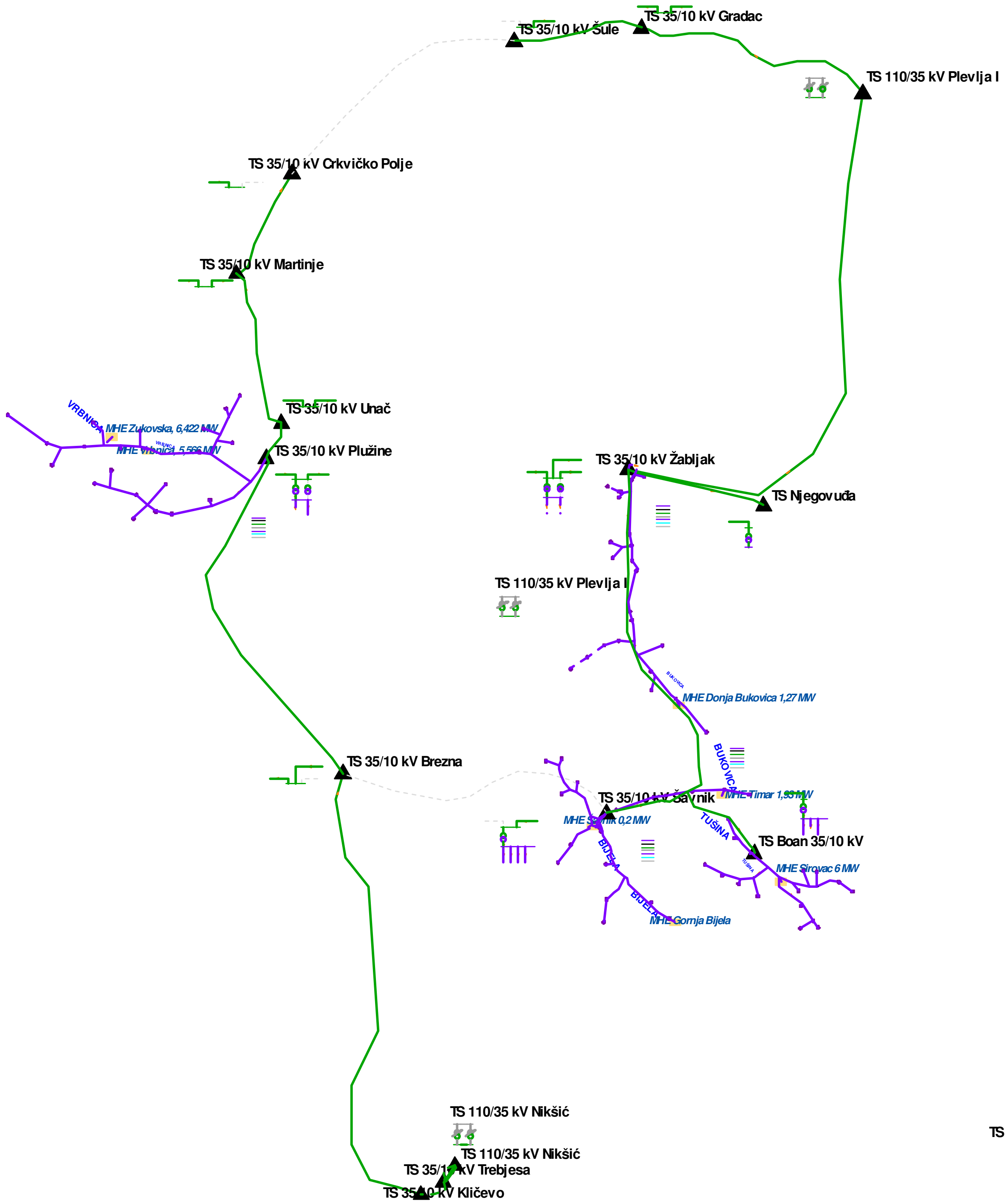


Figure 126: Model of the existing 35 kV and 10 kV distribution network for the analyses of MHE connections in the Komarnica River basin and Pivsko jezero area.

MHE are planned to be constructed in the area of the Komarnica and Piva River basins on the following rivers: Bukovica, Bijela, Tušina and Vrbnica. Total projected output of all planned MHE in this area is 22.6 MW.

Also the construction of wind power stations is projected in this area. They are to be connected to 110 kV network via new 400/100 kV transformer in Brezna. Since these power stations are connected directly to 110 kV transmission line, they do not influence the voltage conditions in the analysed distribution network and are excluded from the analysis models.

The main supply nodes for this area are SBS 110/35 kV Pljevlja 1, 20+40 MVA and SBS 110/35 kV Nikšić, 2x63 MVA. Pljevlja supplies SBS Žabljak 35/10 kV, 2x4 MVA, SBS Boan 35/10 kV, 1 MVA and SBS Šavnik 35/10 kV, 1 MVA. Between Pljevlja and Žabljak there is a new 110 kV transmission line constructed with AlFe 150/25 mm^2 conductor, operating at 35 kV. 35 kV transmission line between Žabljak and Šavnik is equipped with AlFe 50/8 mm^2 conductor. This transmission line supplies power to SBS Boan. Šavnik has guaranteed reserve supply of 35 kV from Brezna. The area of Pivsko Lake is supplied form Nikšić. Between Nikšić and Brezna there is new 110 kV transmission line constructed with AlFe 240/40 mm^2 conductor, operating at 35 kV. From Brezna to SBS Plužine 35/10 kV, 4+2.5 MVA, 35 kV transmission line is equipped with AlFe 70/12 mm^2 conductor. Plužine can be supplied from the other side via transmission line Pljevlje.

The geographical representation of the distribution network with relevant analysed MHE is given in the Figure 126.

5.5.2. Necessary reinforcements of 110/35/10 kV transformation and main 35 kV supply lines after MHE connection to the distribution network

For the needs of connecting <u>all</u> MHE on the analysed rivers in this area, the following reinforcements of main line and transformation needs to be conducted:

- **<u>new TR 35/10 kV, 4 MVA in SBS Šavnik</u>**
  - Peak power evacuation from MHE on the rivers Bukovica and Bijela into the 35 kV network is not possible via the existing transformer with S_n = 1 MVA
  - Estimated investment: 55,000 EUR
- **<u>new TR 35/10 kV, 2.5 MVA in SBS Boan</u>**
  - peak power evacuation from MHE on the rivers Bukovica and Tušina into 35 kV network is not possible via the existing transformer with S_n = 1 MVA
  - estimated investment: 40,000 EUR
- **<u>reconstruction of 110 (35) kV transmission line Brezna – Šavnik – Slatin tap into the double circuit line</u>**
  - reason for this investment lies in the significant voltage changes due to MHE operation. The power production is considerably higher than consumption in this area. Power surplus has to be evacuated into 35 kV network which with the existing loads between Brezna – Šavnika and Žabljaka does not meet the criterion of reliable operation.

- One line system is used for the power evacuation from MHE on the river Tušina directly to SBS Brezno, the remaining sector is used for Šavnik and Boan supply.
- Line is constructed as 110 kV transmission line.
- Total length 23 km.
- 2 x Al/Fe150/20 mm^2 conductors
- Estimated investment: 3,450,000 EUR

- **Reconstruction of 110 (35) kV transmission line Žabljak – Slatin tap**
  - Reason for this investment are similar to the previous reinforcements of 35 kV network between Brezna, Šavnika and node in Saltina.
  - Line is constructed as 110 kV transmission line.
  - Total length 22 km
  - Al/Fe150/20 mm^2 conductors
  - Estimated investment: 2,000,000 EUR

The study plans the gravitation of power from MHE to Brezna. In this node the short-term plan includes 400 /100/ 35 kV installation upgrade of transformer and projects the significant power production by wind power stations. Conditions in the distribution network after the planned MHE connections are shown in the Figure 127 and Figure 128.

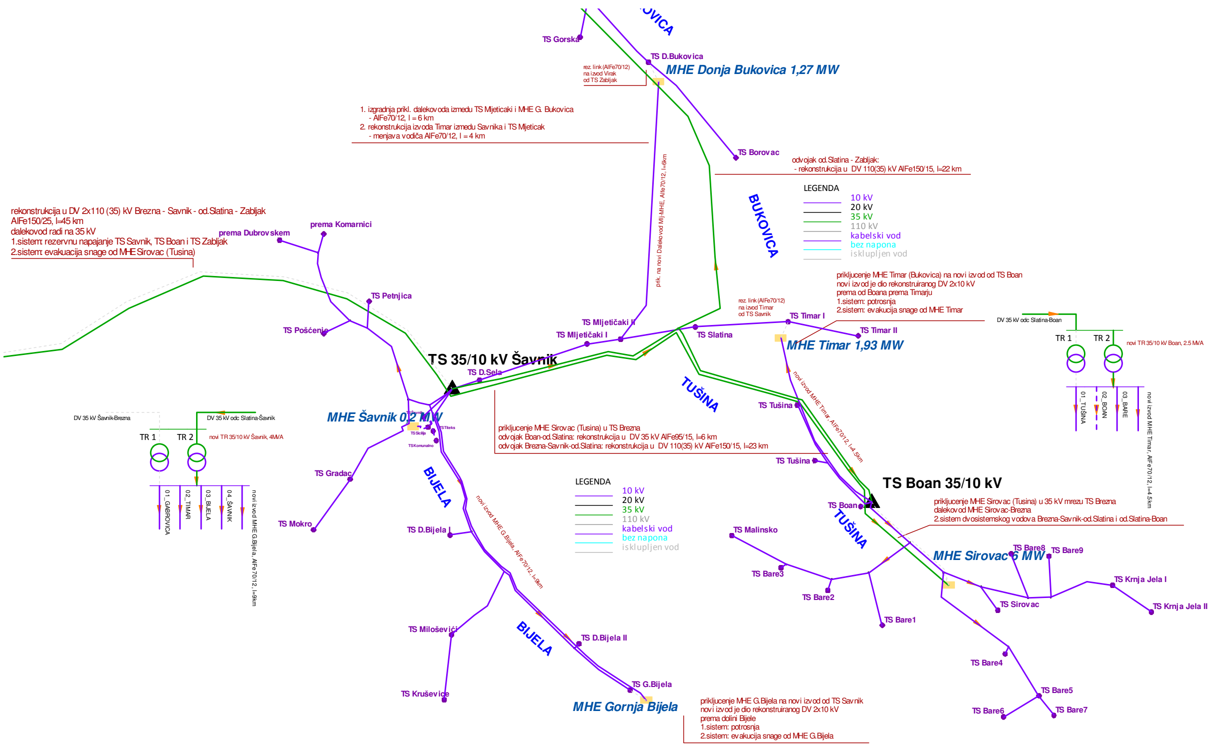


Figure 127: Configuration of distribution network after all planned MHE connections – area of Šavnik and Boan.

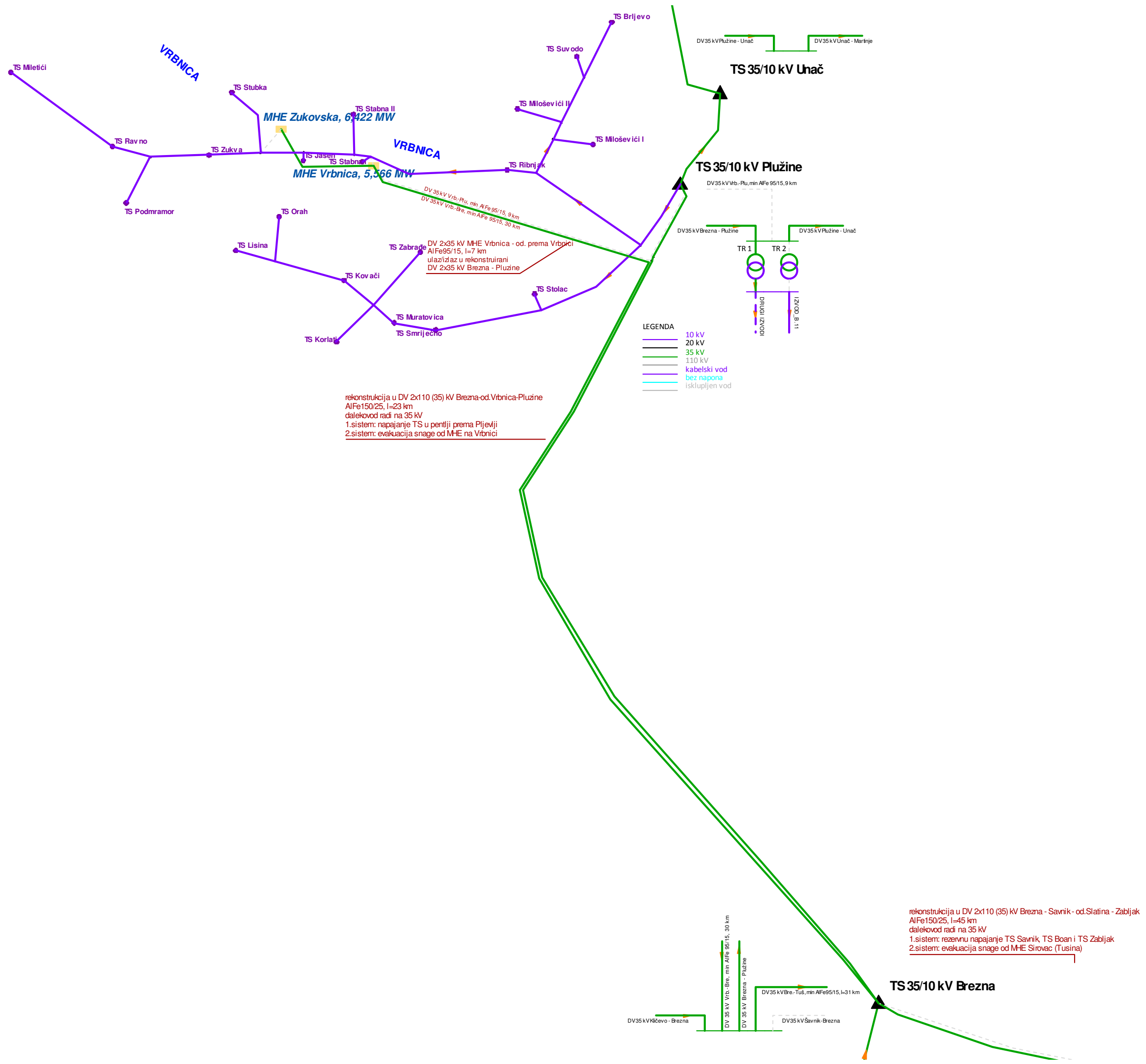


Figure 128: Configuration of distribution network after all planned MHE connections – area of Brezna and Plužin.

If the new SBS 110/35 kV Gvozd is constructed for the needs of wind power stations in the Kronovo area, it is more efficient and operational to connect MHE on the rivers Tušina and Bijela to this substation. In this case it is not necessary to reconstruct 35 kV transmission line between Brezna – Šavnik and Žabljak, whereas in regard to SBS Žabljak the second 35/10 kV transformer installation upgrade with 2.5 MVA suffices. MHE Bijela is connected with new feeder to 10 kV busbars, whereas MHE on the river Tušina are connected to the 35 kV busbars with new transmission line to SBS Gvozd. By connecting MHE to the existing network due to the possibility of supply from the other side, the operation reliability of the distribution network in the area of SBS Šavnik and SBS Boan is improved. In this situation, SBS Šavnik and SBS Boan have improved supply from SBS 110/35/10 kV Brezna, whereas 35 kV transmission line to Žabljak is separated. The geographical image of the solution is shown in the Figure 129.

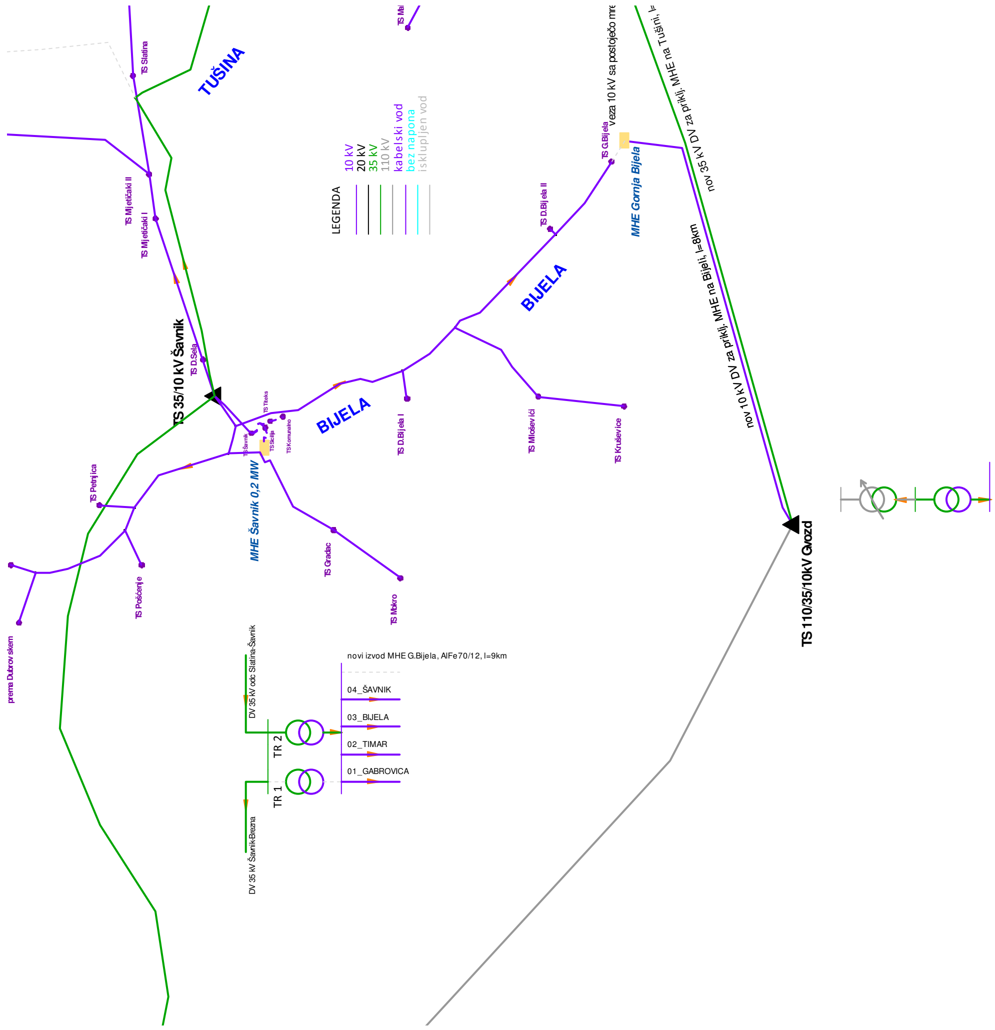


Figure 129: Solution for MHE on the rivers Tušina and Bijela in case of wind power station construction at Kronovo.

5.5.3. Necessary distribution network reinforcements for the connections of individual MHE

The interpretations of solutions with analyses of the individual connected MHE on the rivers are shown in tables. Here, only main network reinforcements are summarized for the needs of MHE connections on the individual rivers..

The alternative to overhead AlFe70/12 mm² conductor of the network is Al 150 mm² cable conductor.

MHE operation will cause significant voltage changes in the distribution network, meaning that it will be necessary to actively regulate voltage at different loads on 35 kV busbars in SBS 110/35 kV. The voltage is regulated to provide all SBS 35/10 kV in individual loads the voltage of 10 kV busbars between 10.2 kV and 10.7 kV.

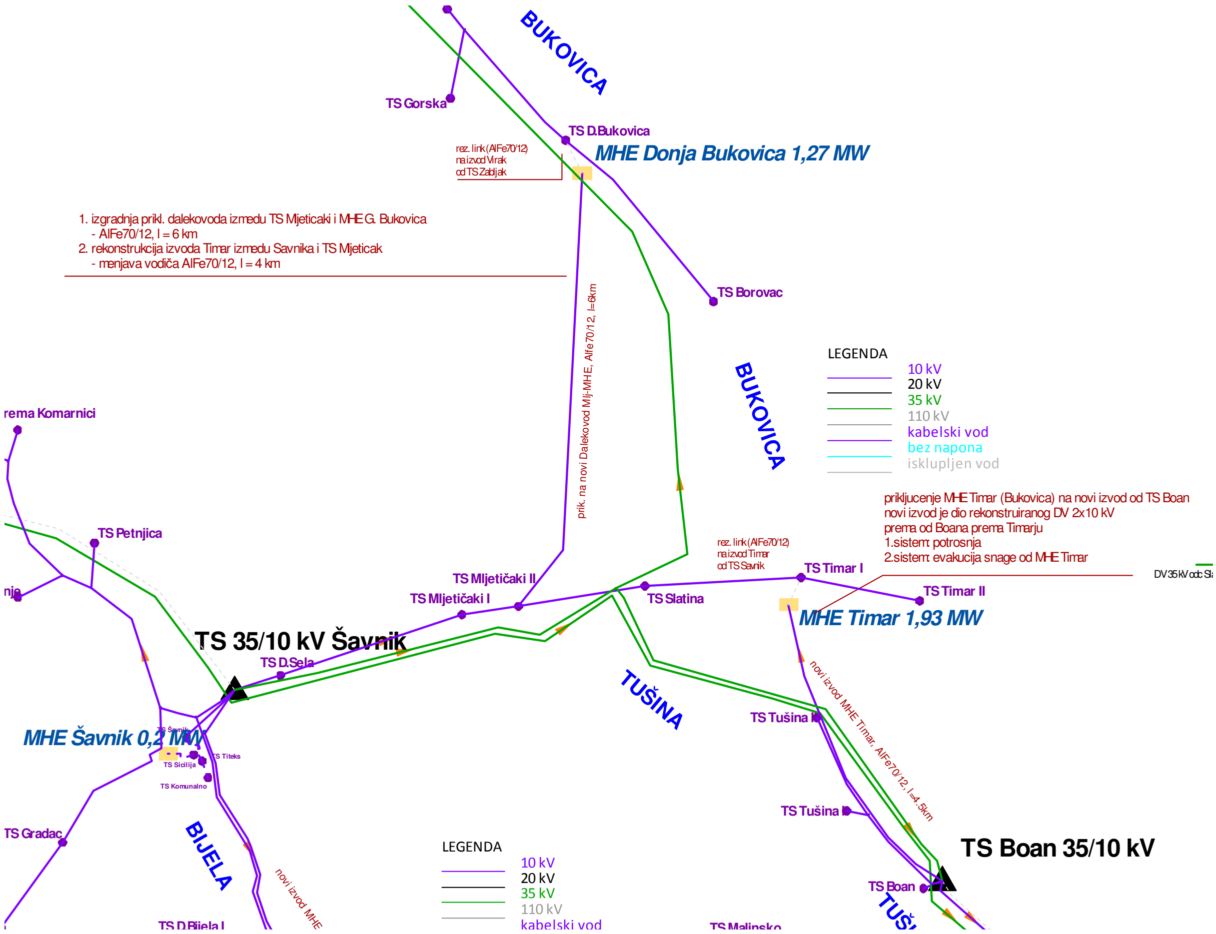


Figure 130: MHE connections on the river Bukovica to the distribution network.

River Bukovica – total planned installed production 3.23 MW, Figure 130

- MHE Timar connection (P_{max} = 1.93 MW) via new feeder from SBS Boan. For this purpose the existing line (Tišina feeder) of 2x10 kV and length 4.5 km (1xAlFe 70/12 mm^2 (MHE) and 1xAlFe 35/6 mm^2 (consumption) conductors) needs to be reconstructed .
- To increase the reliability, the connection between MHE Timar and SVS Timar 1 is constructed on the neighbouring Timar feeder from SBS Šavnik.
- To connected MHE Donja Bukovica (P_{max} = 1,27 MW) the new 4 km transmission line between MHE and SBS Mljitičaki has to be constructed on the Timar feeder from SBS Šavnik (1xAlFe 70/12 mm^2 conductors). Between SBS Šavnik and SBS Mljitičaki 2 the existing transmission line needs to be reconstructed and equipped with AlFe 70/12 mm^2 conductors.
- Also to increase reliability, the connection is established between MHE Donja Bukovica and SBS D. Bukovica on the Virak to SBS Šavnik.

River Tušina – total planned installed production 6 MW, Figure 131

- MHE is connected directly to 35 kV network on 35 kV busbars in SBS Brezno.
- Condition for connection is the reconstruction of the transmission line between Brezna, Šavnik and Žabljak.
- The power station is connected via reconstructed SBS Boan – Slatina tap transmission line of 6 km length (min 2 x AlFe 95/15 mm^2 conductors).

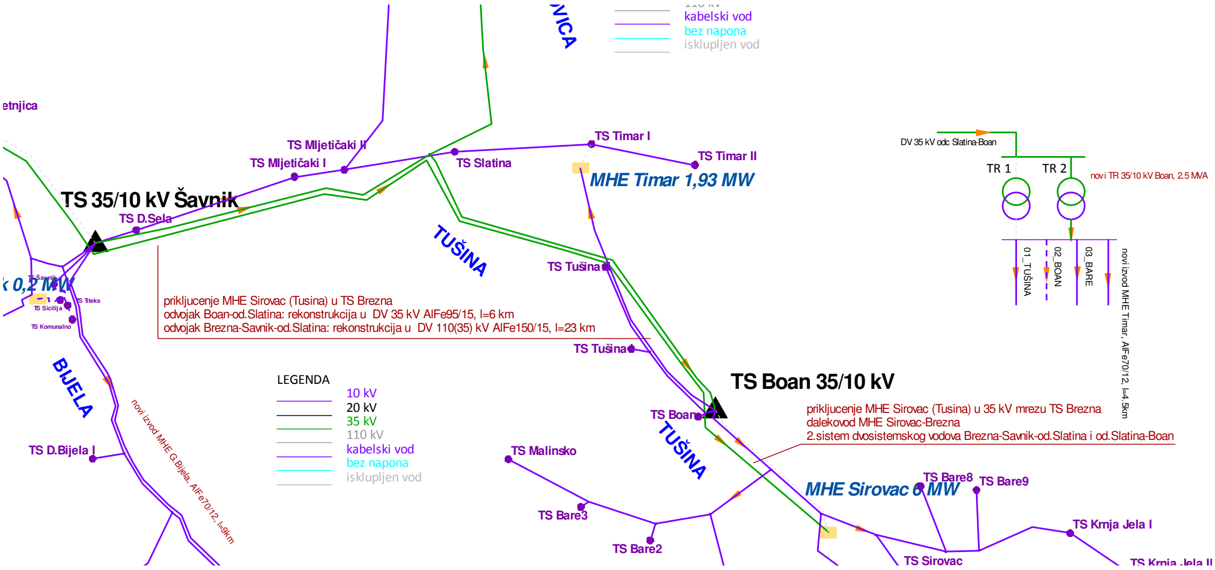


Figure 131: MHE connection on the river Tušina to the distribution network.

- In case of SBS 110/35/10 kV Gvozd construction, MHE is connected via new feeder to 35 kV busbars of this SBS (Figure 129).

River Bijela – total planned installed production 1.4 MW, Figure 132

- MHE Gornja Bijela connection via new feeder from SBS Šavnik. The reconstruction of the existing transmission line into 2x10 kV transmission line is recommended with 1xAlFe 70/12 mm^2 (MHE) and 1xAlFe 35/6 mm^2 (consumption) conductors. The alternative to the transmission line reconstruction is Al 150 mm^2 cable, length 4 km.

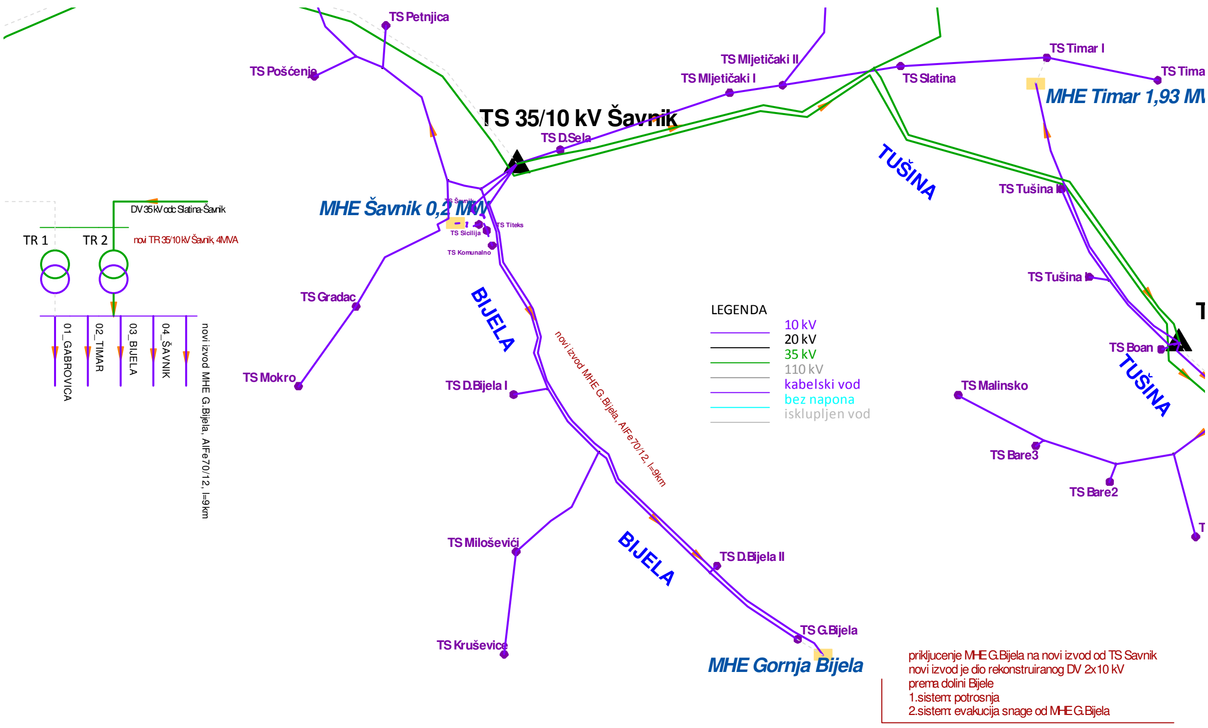


Figure 132: MHE connection on the river Bijela to the distribution network.

- In case of SBS 110/35/10 kV Gvozd construction, MHE is connected via new feeder to 10 kV busbars of this SBS (Figure 129).

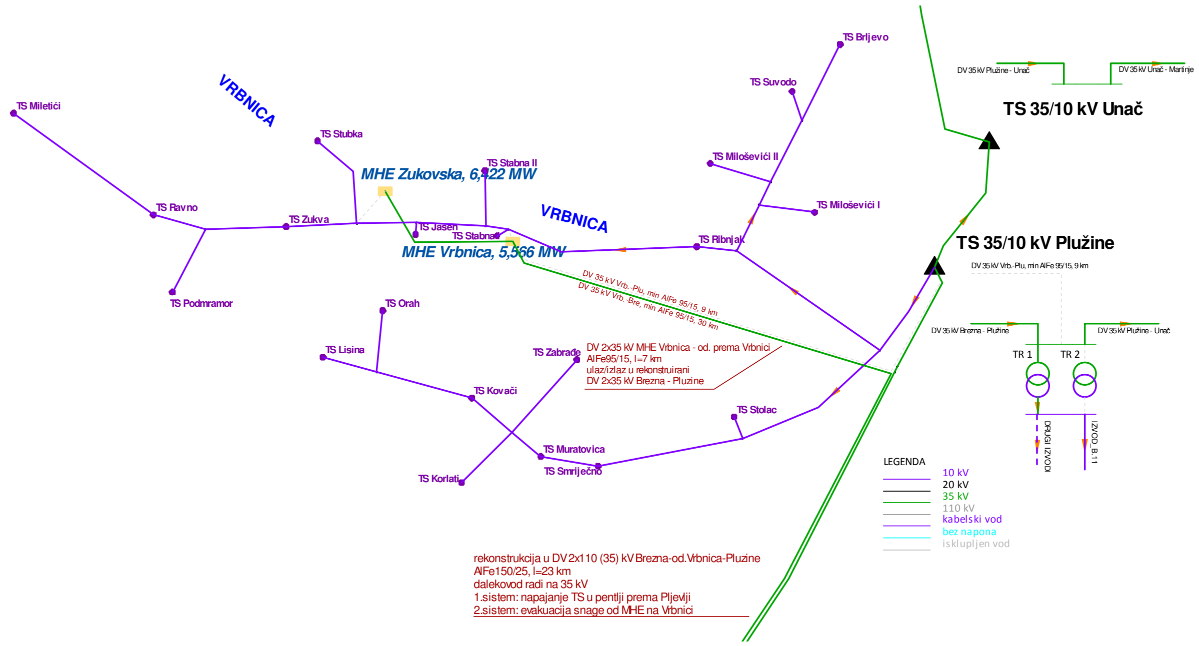


Figure 133: MHE connection on the river Vrbnica to the distribution network.

River Vrbnica – total planned installed production 12 MW, Figure 133

- MHE are connected directly to 35 kV network at 35 kV busbars in SBS Brezna.
- The condition for connection is the transmission line reconstruction between Brezna and Plužina.
- The power station is connected via new double circuit transmission line MHE Vrbnica – Vrbnica tap of 7 km length (min 2 x AlFe 95/15 mm^2 conductors). The type of connection is the input/output into single system of the reconstructed 2x35 kV transmission line Brezna – Plužine.

RIVER BUKOVICA

1. Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Donja Bukovica	1.27	SBS Donja Bukovica	6.18
MHE Timar	1.93	SBS Timar I	7.14
Grlja output	**122**	**Slack node:** 110 kV busbars SBS Plevlja 1	1448
Min. model of the relevant network:		- SBS Plevlja I 110/35/10 kV - SBS Žabljak 35/10 kV, 10 kV feeder: Virak - SBS Šavnik 35/10 kV, 10 kV feeder: Timar - SBS Boan 35/10 kV, 10 kV feeder: Tušina	

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Virak feeder	0.326	1.11	0.345	1.18
SBS 35/10 kV Žabljak	**1.01**	**3.5**	**1.07**	**3.71**
Timar feeder	0.03	0.06	0.03	0.07
SBS 35/10 kV Šavnik	**0.18**	**0.61**	**0.19**	**0.65**
SBS 35/10 kV Boan	**0.12**	**0.41**	**0.13**	**0.43**

2.b Relevant data on the projected distribution network development

- Reconstruction of SBS Žabljak 35/10 kV by 2015
- Reconstruction of SBS Šavnik 35/10 kV by 2015

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	- low voltages in LV network at the Virak feeder from SBS Žabljak - barely within permitted limits (min 0.381 kV, max 0.403 kV)

Results:

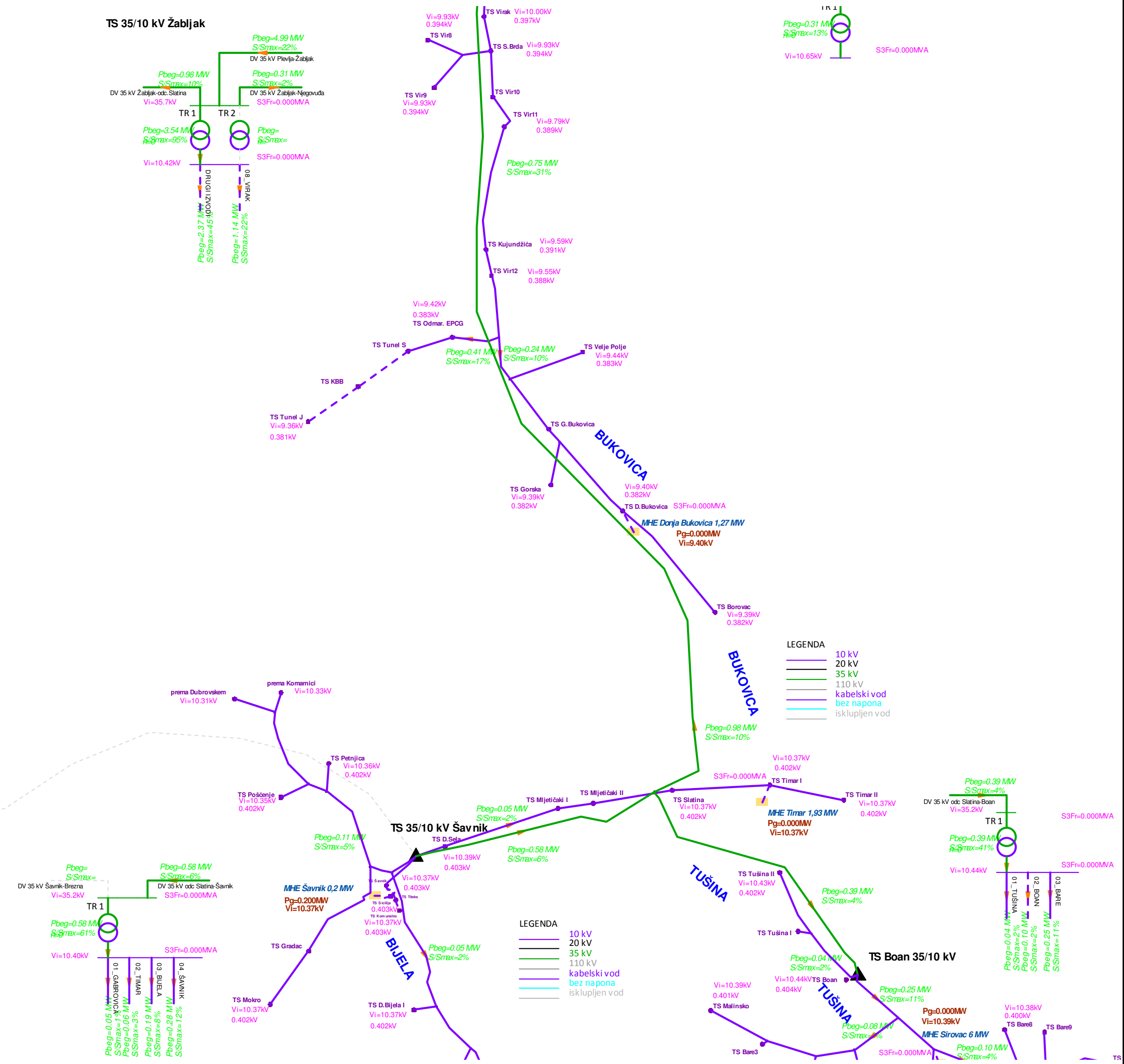


Figure 134: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	within permitted limits (min 0.401 kV, max 0.414 kV)

Results:

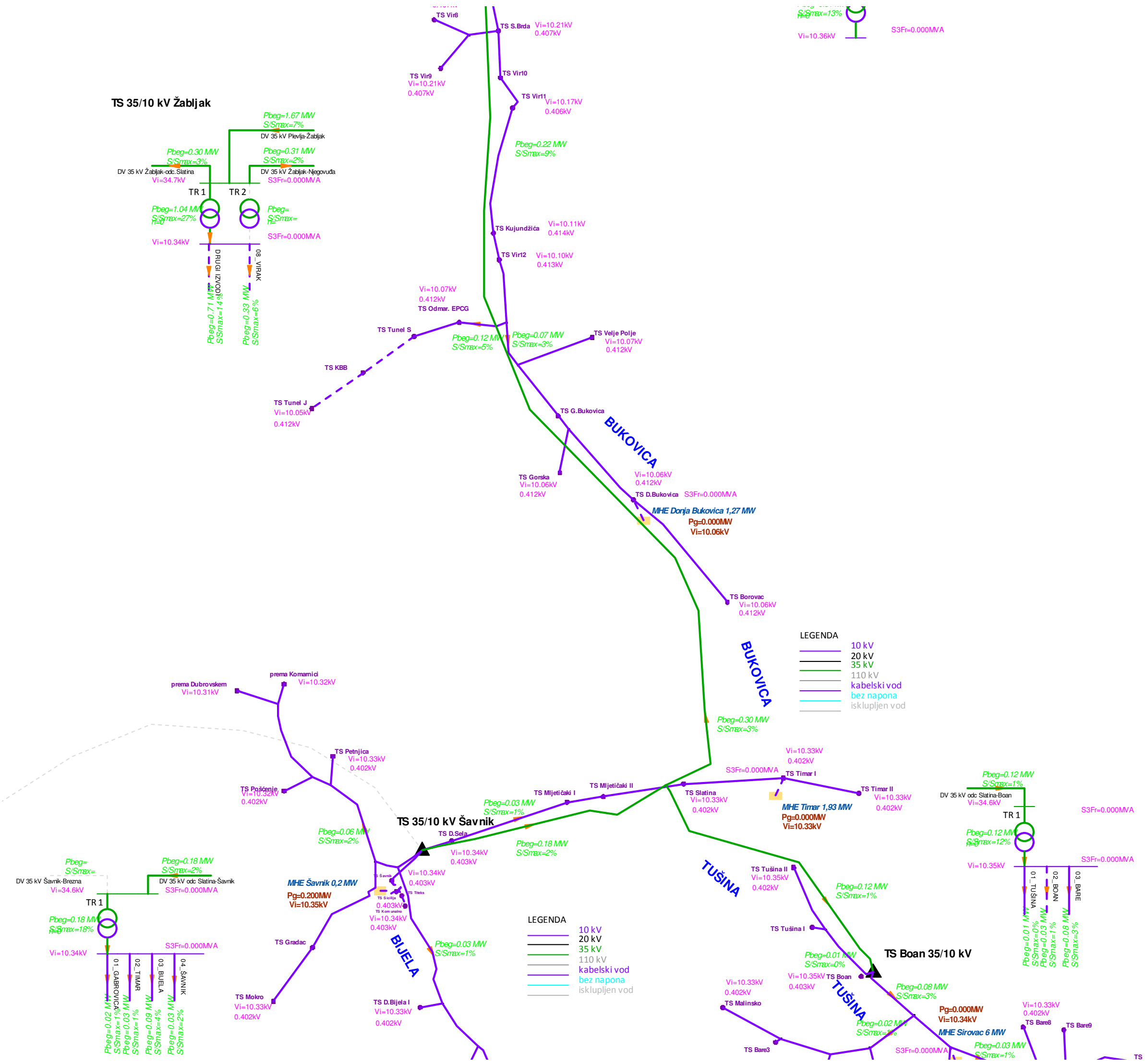


Figure 135: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**4.422 MW**	Yearly losses:	**11867 MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**0.7 MW**

Notes:

- max 0.15 MW from MHE Donja Bukovica
- max 0.55 MW from MHE Timar
- in the connection with full power , the LV network voltages are increased above the criterion 0.420 kV (above 0.470 kV)

Results:

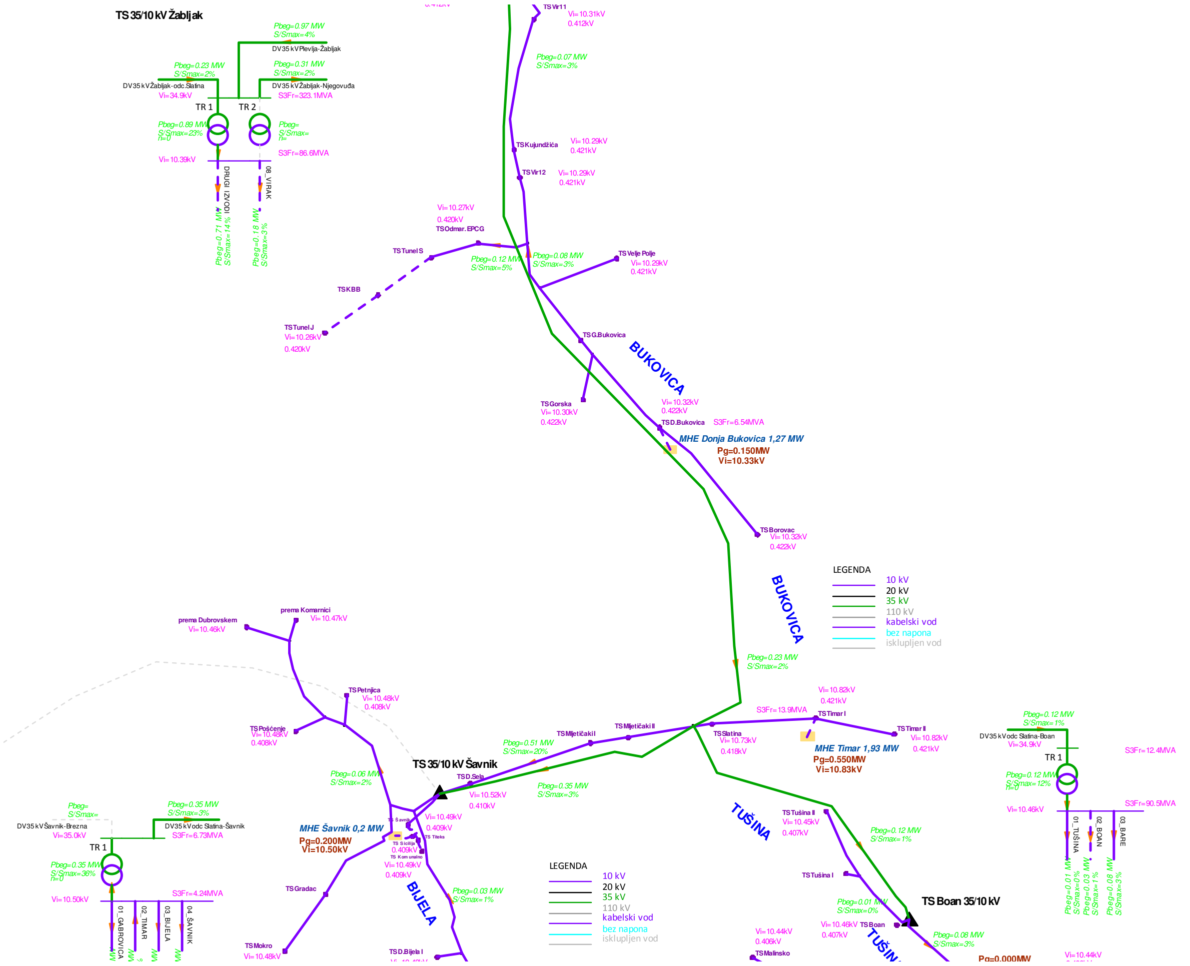


Figure 136: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**4.352 MW**	Yearly losses:	**11679 MWh**

4.b VARIANT A: MHE connection on the river Bukovica to the MV network SBS Šavnik and SBS Boan

Necessary reinforcements:	Estimated investment in EUR **∑ 740,000**
- Reconstruction of SBS 35/10 kV Boan (new transformer 35/10 kV, 2.5 MVA, new 10 kV busbars, one additional feeder bay)	
- Reconstruction of SBS 35/10 kV Šavnik (new transformer 35/10 kV, 4 MVA)	
MHE Timar	
- MHE Timar connection (P_{max} = 1.93 MW) via new feeder from SBS Boan	
- Reconstruction of the exiting line (Tušina feeder) into 2x10 kV of 4.5 km length (1xAlFe 70/12 mm^2 (MHE) and 1xAlFe 35/6 mm^2 (consumption) conductors)	350,000
- Due to better reliability of supply, the connection between MHE Timar and SBS Timar I is recommended (AlFe 70/12 mm^2 transmission line, l=0.5 km)	20,000
MHE Donja Bukovica	200,000

- MHE connection via new 10 kV transmission line between MHE and SBS Mljitičaki 2 at Timar feeder from SBS Šavnik (1xAlFe 70/12 mm^2 conductors, l = 4 km) . - Reconstruction of Timar feeder between SBS Šavnik and SBS Mljitičaki 2 – replacement of the existing conductors with AlFe 70/12 mm^2, l =4 km - Due ro bwtter reliability of supply, the construction of connection is recommended between MHE Donja Bukovica and SBS D. Bukovica (AlFe 70/12 mm^2 transmission line, l=0.5 km)	150,000 20,000

Load conditions after the MHE connection to the network – max consumption, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.410 kV, max 0.417 kV)	**4.383 MW**	**11762 MWh**

Results:

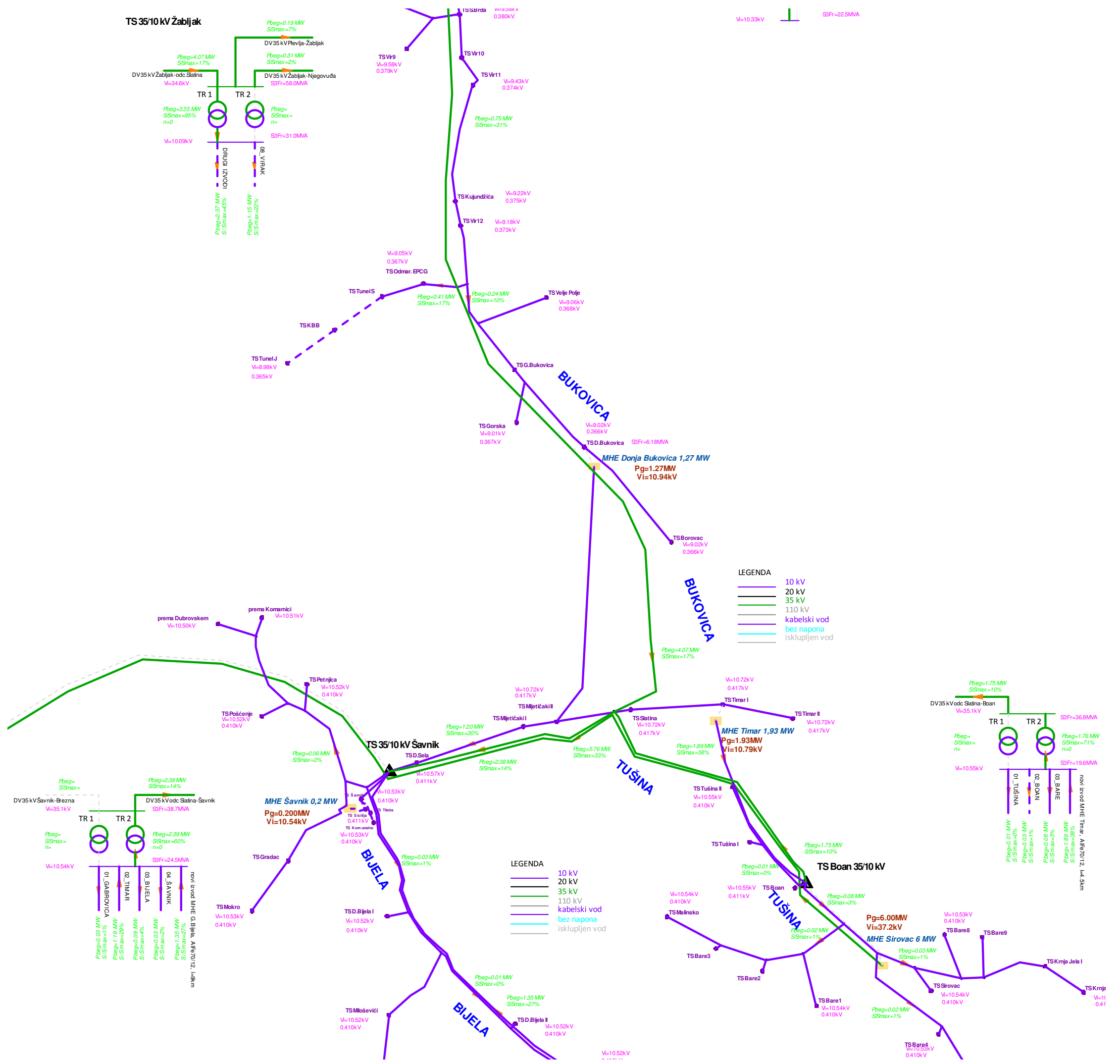


Figure 137: of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Losses:

- within permitted limits (min 0.411 kV, max 0.421)	**0.981 MW**

Results:

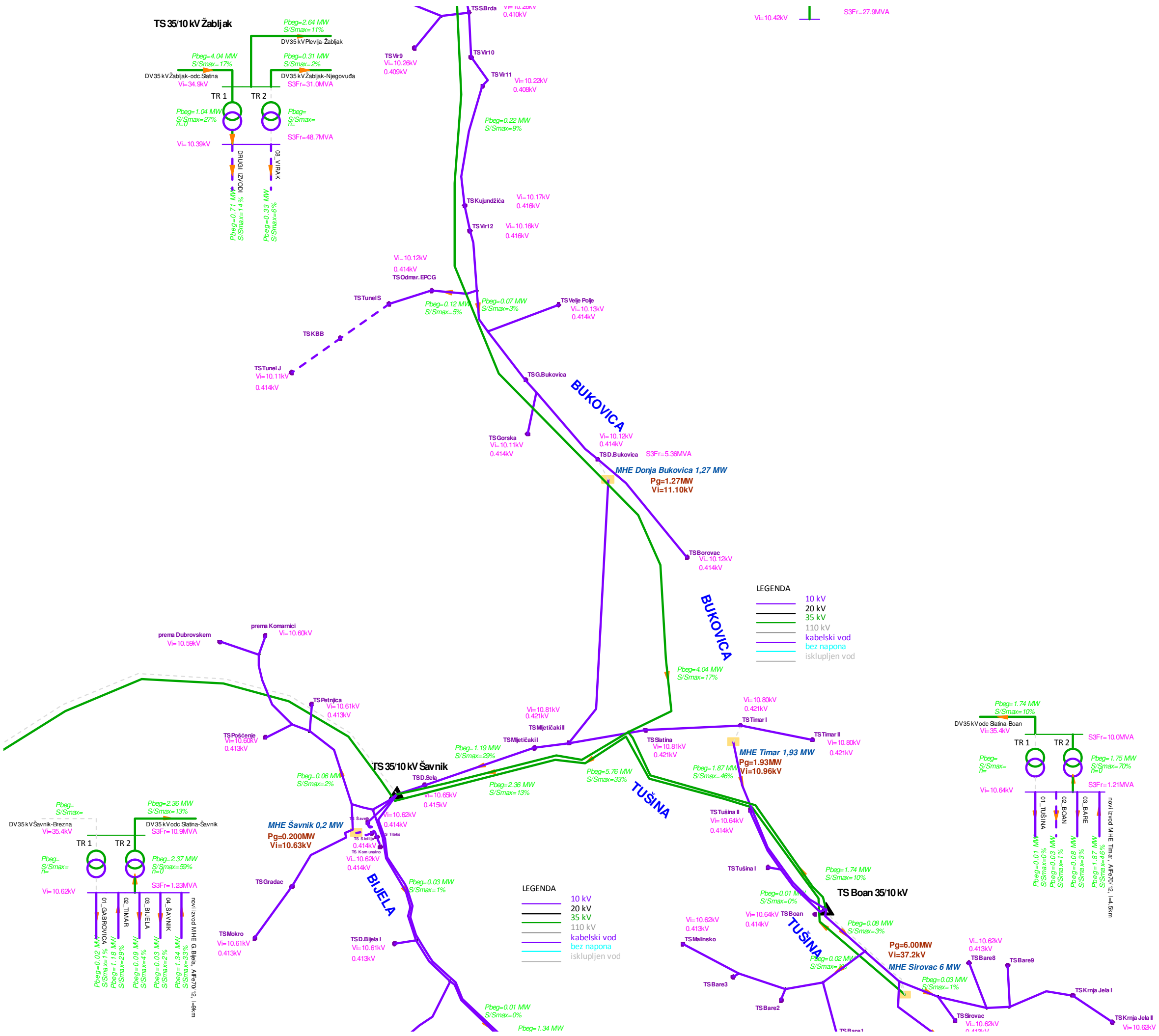


Figure 138: Results of power condition analyses – VARIANT A, min consumption and MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.409 kV, max 0.412 kV)	**4.837 MW**

Results:

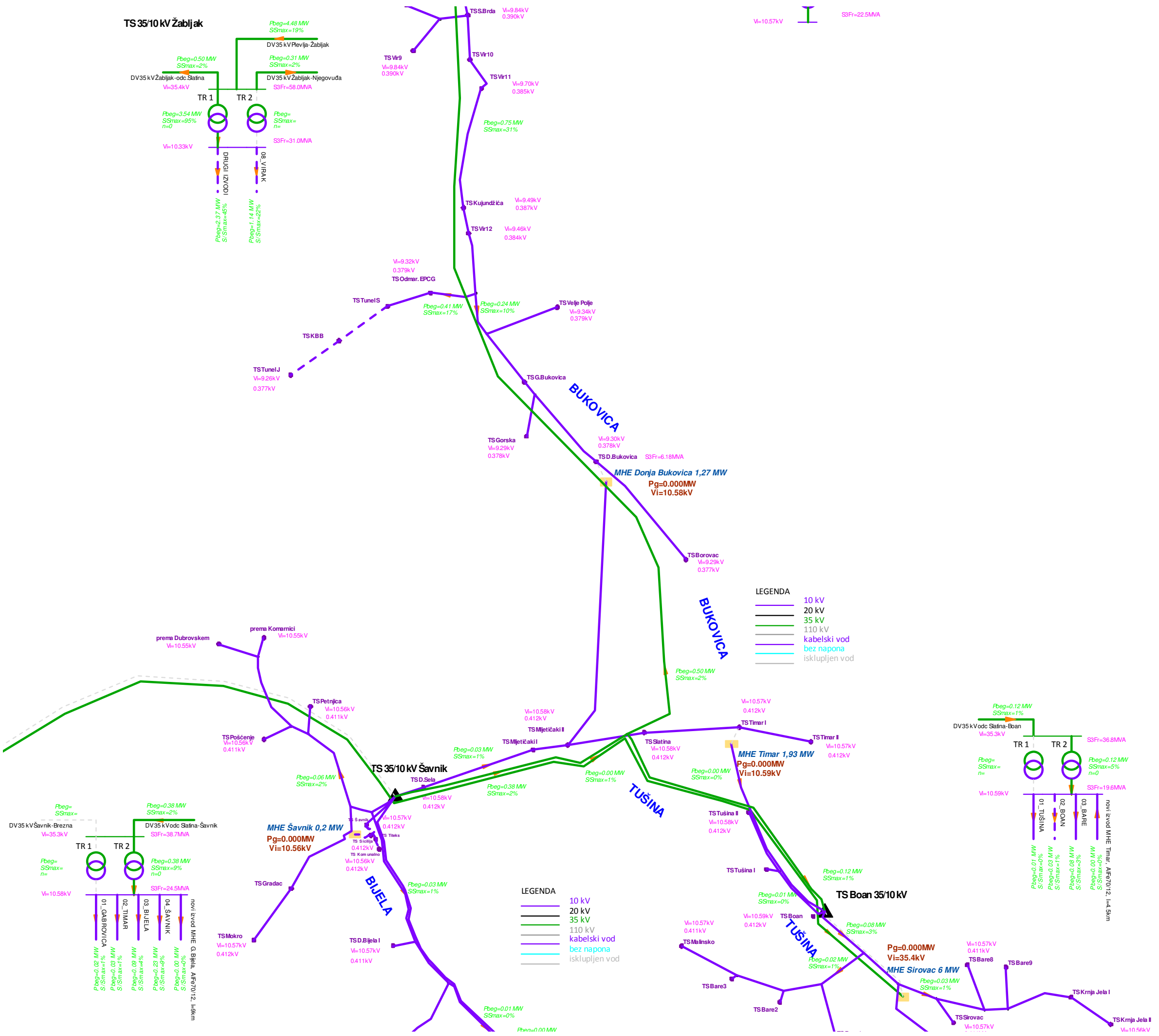


Figure 139: Results of power condition analyses – VARIANT A, MHE max consumption without production, 2011.

Solution advantages

- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **Increased supply reliability for consumers**
- **optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.381	0.414	4.422	**-**	11867	**-**	**-**
Connection to existing network	**0.7**	0.407	0.421	4.352	**-0.070**	11679	**-188**	**-**
VARIANT A	**3.2**	0.410	0.421	4.857	**+0.435**	13035	**+1168**	**740,000**

RIVER TUŠINA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Sirovac	6	SBS Sirovac	9.64
Tušina output	**6**	**Slack node:** 110 kV busbars SBS Plevlja 1	1448
Min. model of the relevant network:	- SBS Plevlja I 110/35/10 kV - SBS Boan 35/10 kV, 10 kV feeder: Bare		

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Bare output	0.08	0.26	0.10	0.32
SBS 35/10 kV Boan	**0.12**	**0.41**	**0.13**	**0.43**

2.b Relevant data on the projected distribution network development

-

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	- within permitted limits (min 0.400 kV, max 0.403kV)

Results:

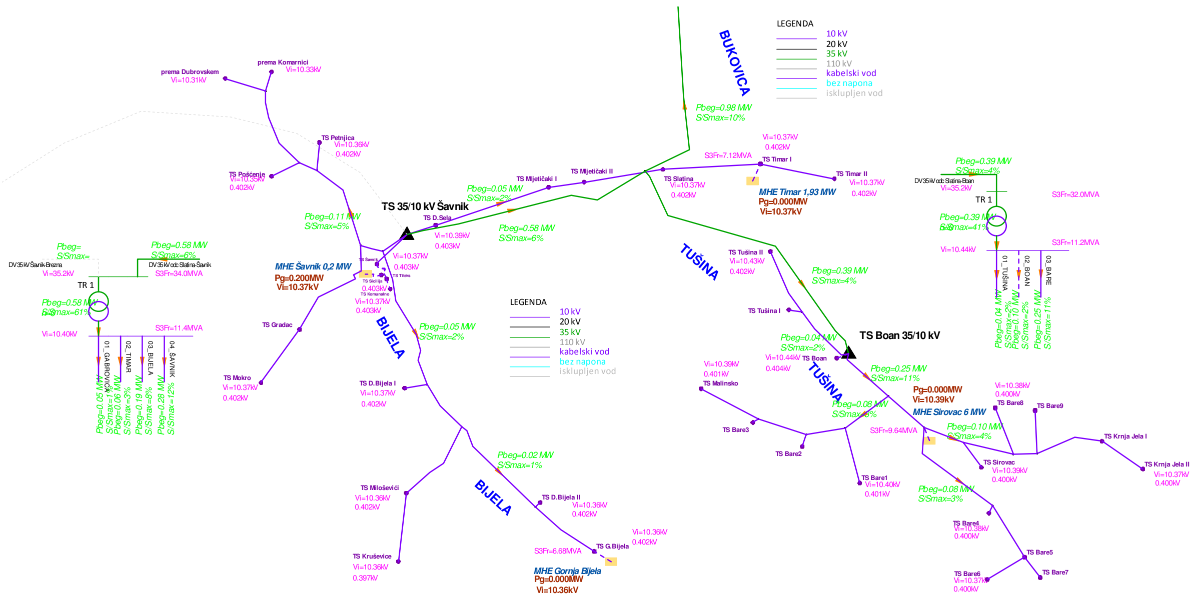


Figure 140: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	- within permitted limits (min 0.400 kV, max 0.403kV)

Results:

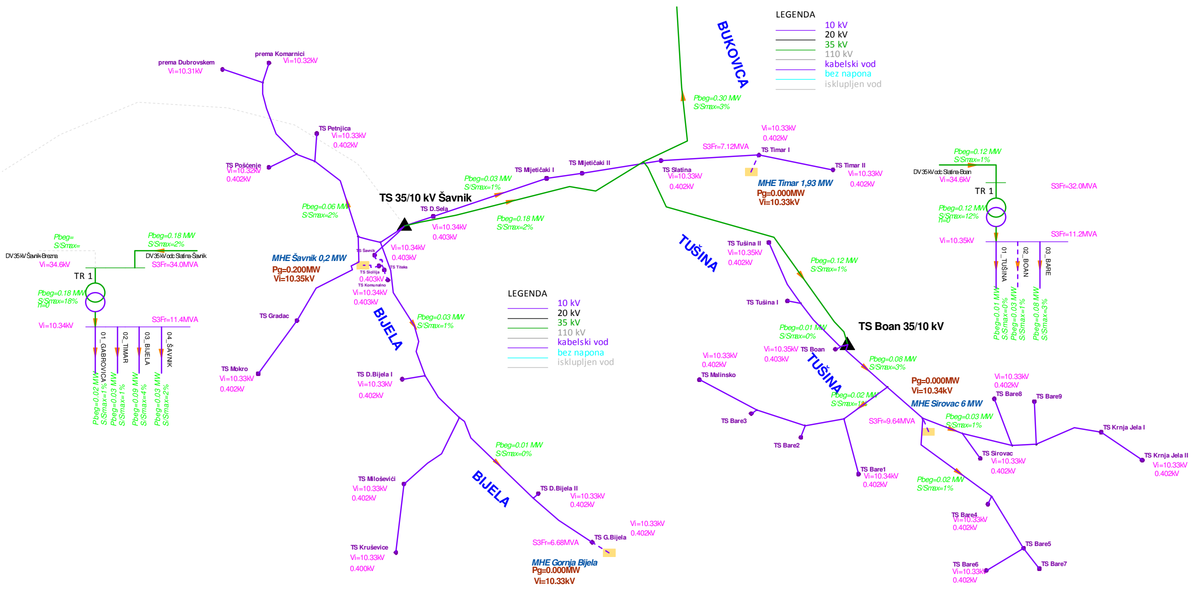


Figure 141: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**4.422 MW**	Yearly losses:	**11867MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	1.1 MW

Notes:

- power station with projected characteristics cannot be connected to the existing 10 kV network

Results:

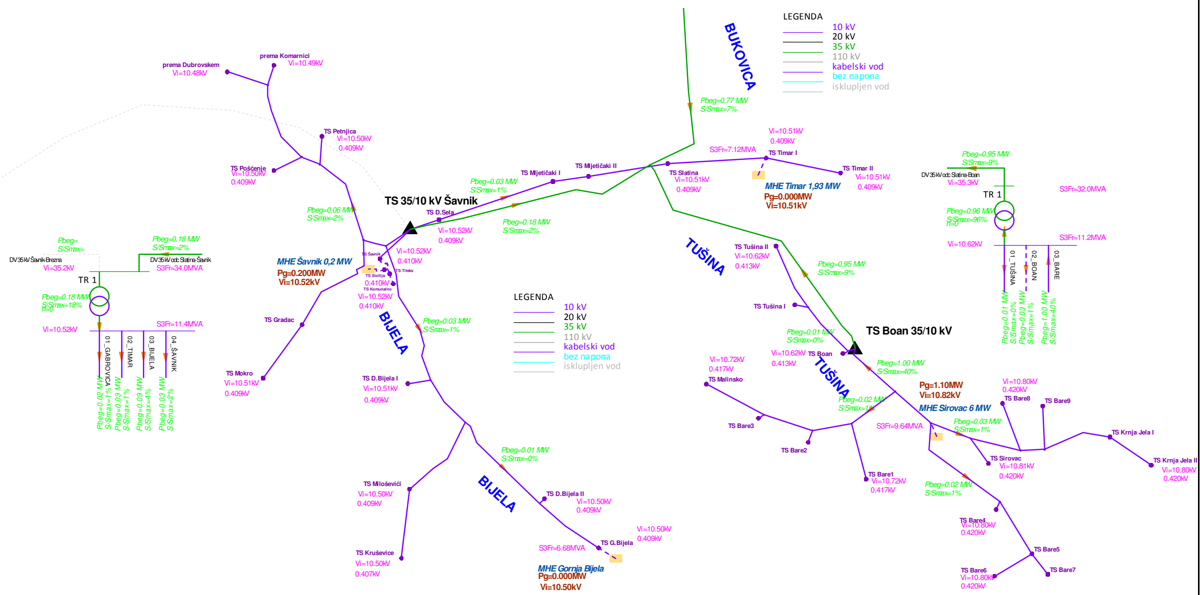


Figure 142: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**4.367 MW**	Yearly losses:	**11720 MWh**

4.b VARIANTA : MHE connection to the 35 kV busbars in SBS Brezna

Necessary reinforcements:	Estimated investment in EUR **∑ 700,000**
- MHE is connected directly to 35 kV busbars in SBS Brezna - **condition: reconstructed 2x35 kV Brezna – Šavnik transmission line – Slatina tapping** - MHE is reconnected to the single system of 2x35 kV Brezna – Šavnik transmission line – Slatina tapping - reconstruction of 2x35 kV Boan - Slatina tapping transmission line into double circuit transmission line with min AlFe 95/15 mm^2, l = 6 km (single system is used for power evacuation from MHE to Brezna, the second system is used for SBS Boan supply)	700,000

Operational conditions after the MHE connection to the network – max consumption, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:

- within permitted limits (approx. 0.411 kV)	**4.427 MW**	**11880 MWh**

Results:

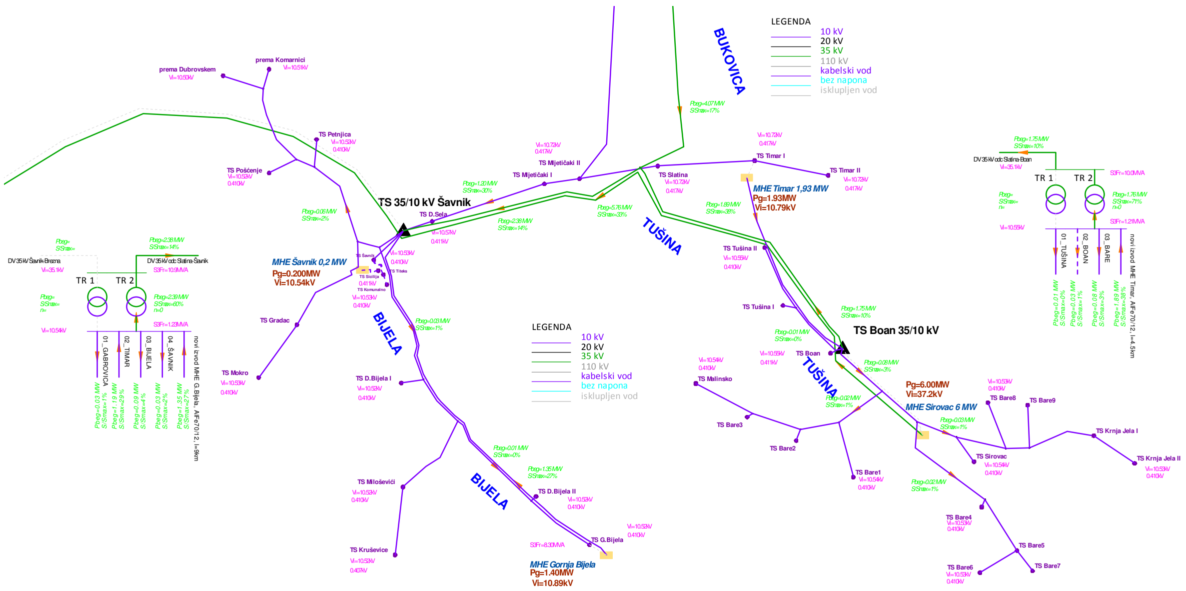


Figure 143: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011..

Operation conditions after MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Losses:
- within permitted limits (approx. 0.413 kV)	**1.113 MW**

Results:

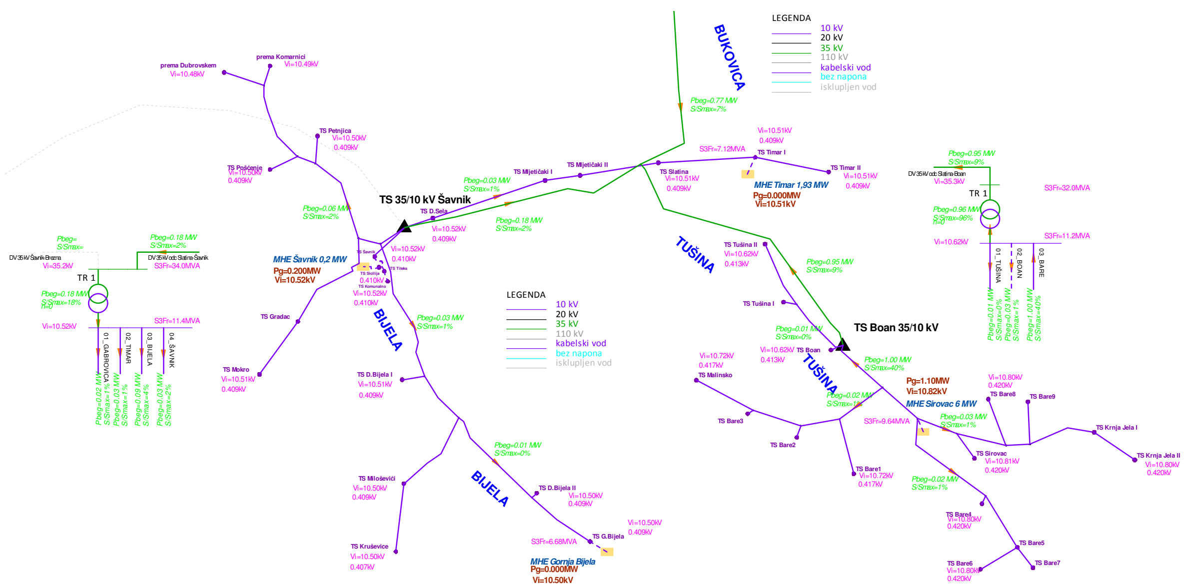


Figure 144: Results of power condition analyses – VARIANT A, min consumption and MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production

Loads and voltages in the network:	Losses:

- within permitted limits (approx. 0.412 kV)	**4.837 MW**

Results:

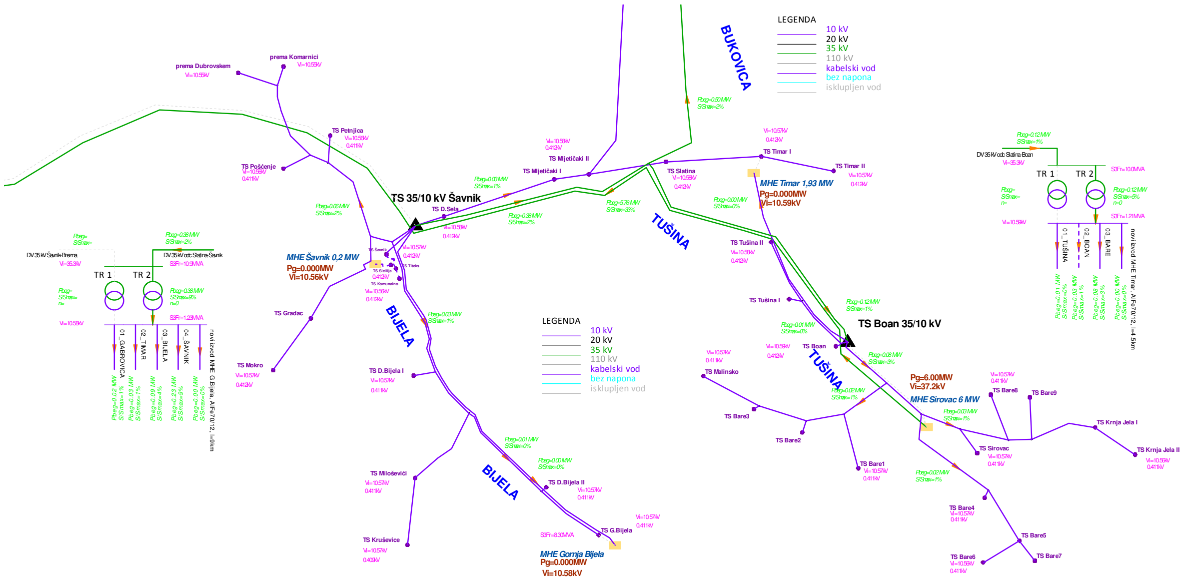


Figure 145: Results of power condition analyses – VARIANT A, max consumption without MHE production, 2011.

Solution advantages

- **reliable MHE Sirovac connection to the 10 kV network is not possible**
- **power evacuation surplus is redirected towards consumption centres (Nikšić)**
- **small MHE influence on LV network**

4.b VARIANT B: MHE connection at 35 kV busbars to new 110/35/10 kV SBS Gvozd

Necessary reinforcements:	Estimated investment in EUR **∑ 940,000**
- MHE is connected with new feeder directly to 35 kV busbars in SBS Gvozd - **condition: constructed SBS Gvozd 110/35/10 kV and 110 kV Brezna- Gvozd (Kronovo) transmission line** - transformer TR 110/35 kV, 20 MVA is installed in SBS Gvozd - from SBS Gvozd to the river Bijela valley the new double circuit 35 kV line is constructed; one system operating 1t 10 kV and serves for MHE connection to the river Bijela outfall, the second system operates at 35 kV and serves for the needs of MHE connection on the river Tušina - the length of double circuit line is approx. 6.5 km - between the rivers Bijela and Tušina the single circuit 35 kV transmission line is constructed in the length of 7 km - 35 kV feeder is equipped with AlFe 95/15 mm^2 conductors	200,000 390,000 350,000

Operational conditions after the MHE connection to the network – max consumption, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:

- within permitted limits	**4.326 MW**	**11610 MWh**

Results:

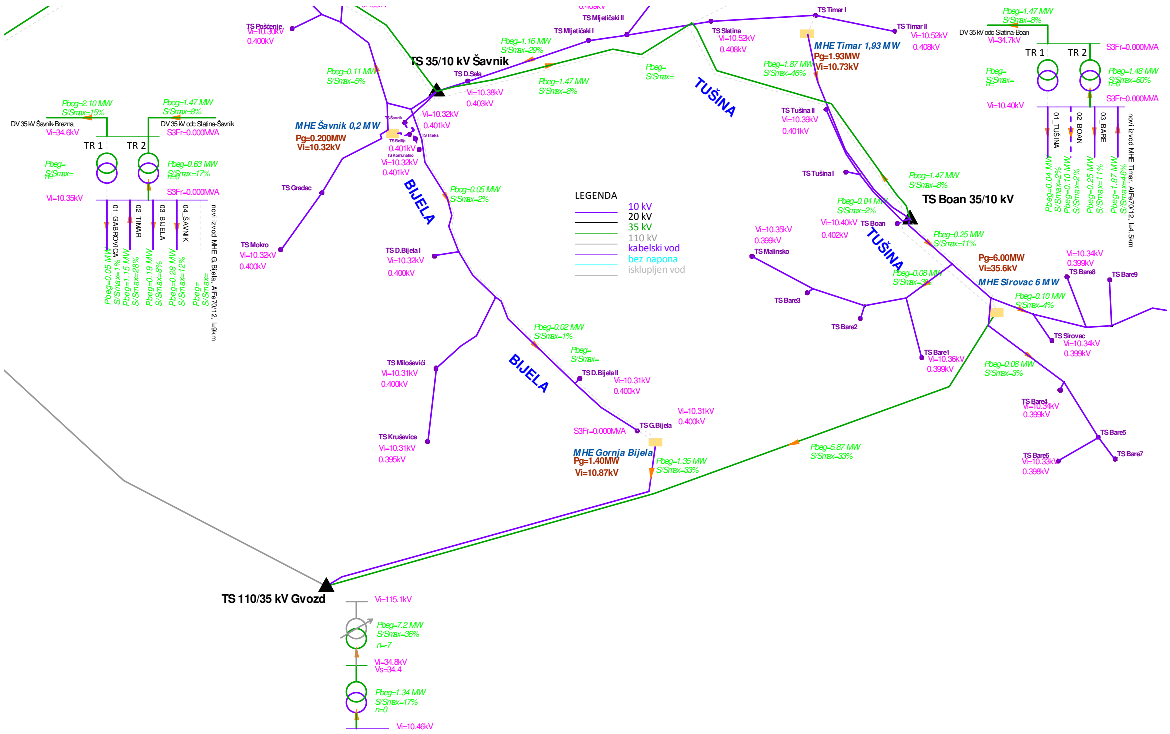


Figure 146: Results of power condition analyses – VARIANT B, max loads and MHE max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- within permitted limits (approx. 0.413 kV)	**0.963 MW**

Results:

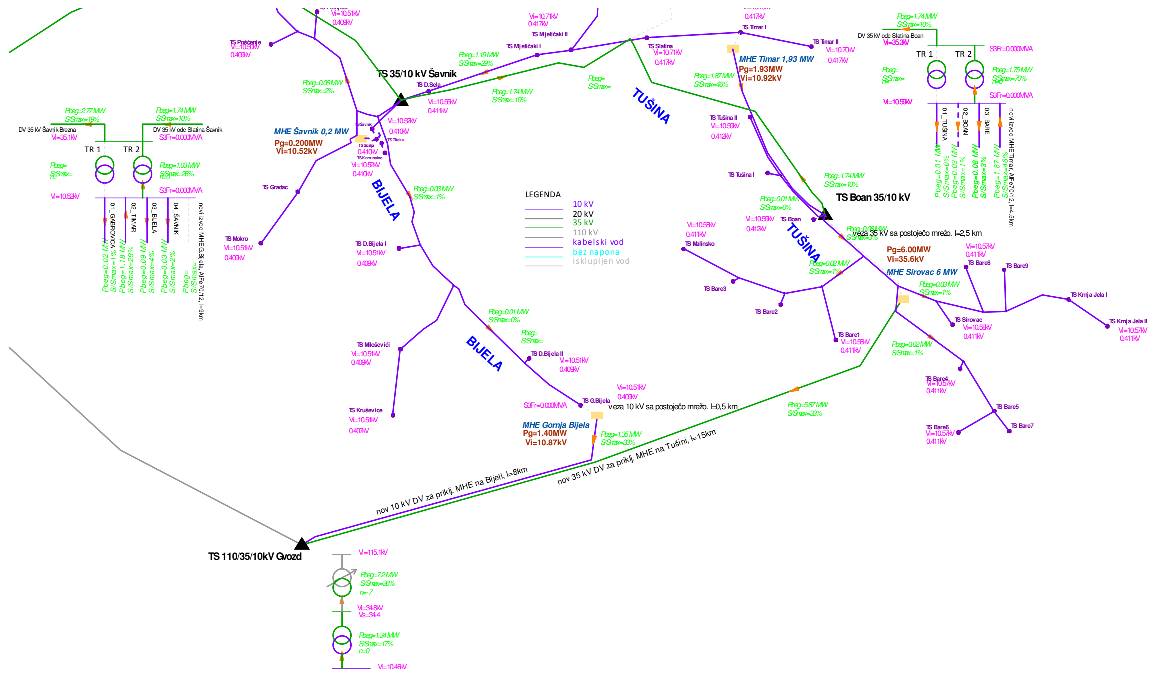


Figure 147: Results of power condition analyses – VARIANT B, min consumption and MHE max production, 2011.

Solution advantages

- **reliable MHE Sirovac connection to the 10 kV network is not possible**
- **produced power is regarded as the surplus and is evacuated to 110 kV network**
- **MHE does not influence the LV network**
- **Connection of 35 kV network between MHE and SBS Boan provides better operation reliability of this network**
- **Solution insufficiency: depends on the wind power station and 110 kV Kronovo network construction**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0,400	0,403	4,422	**-**	11867	**-**	**-**
Connection to existing network	**1,1**	0,410	0,413	4,367	**-0,055**	11720	**-147**	**-**
VARIANT A	**6**	0,359	0,420	4,427	**+0,005**	11880	**+13**	**700,000**
VARIANT B	**6**	none	none	4,326	**-0,096**	11610	**-257**	**940,000**

RIVER BIJELA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Gornja Bijela	1.4	TS Gornja Bijela	6.68
Bijela output	**5**	**Slack node:** 110 kV busbars SBS Plevlja 1	1448

Min. model of the relevant network:

- SBS Plevlja I 110/35/10 kV
- SBS Šavnik 35/10 kV, 10 kV feeder: Bijela

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Bijela feeder	0.09	0.19	0.10	0.20
SBS 35/10 kV Šavnik	**0.18**	**0.61**	**0.19**	**0.65**

2.b Relevant data on the projected distribution network development

- Reconstruction of SBS Šavnik 35/10 kV by 2015

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	within permitted limits (min 0.397 kV, max 0.403 kV)

Results:

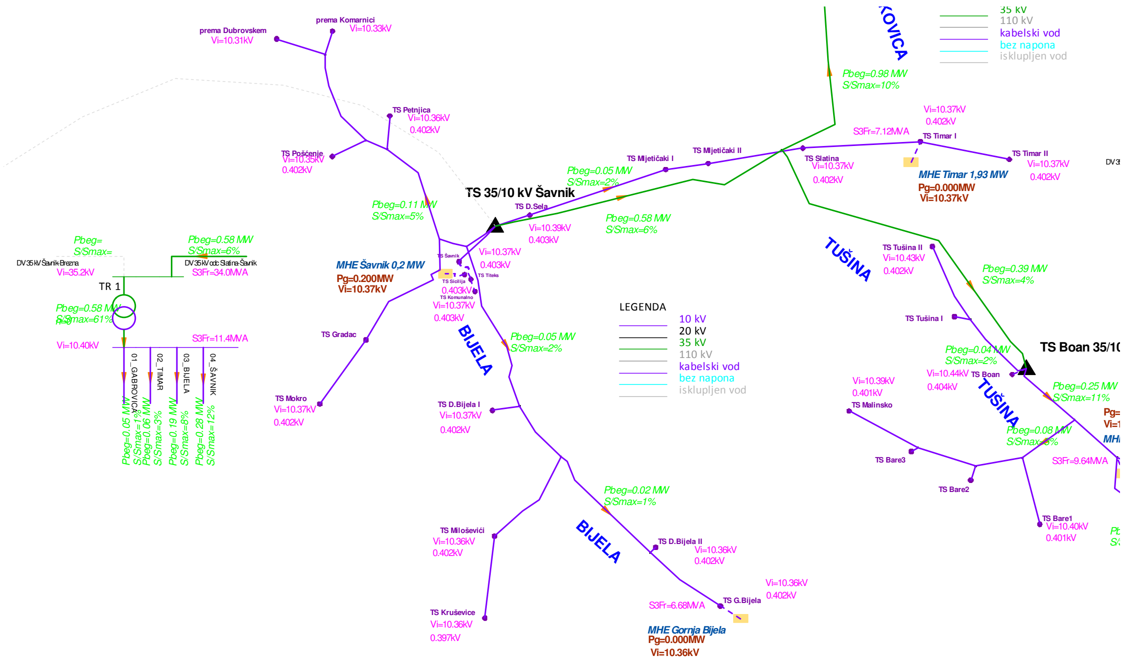


Figure 148: Loads in 10 kV network and voltages at LV busbars TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	within permitted limits (min 0.403 kV, max 0.404 kV)

Results:

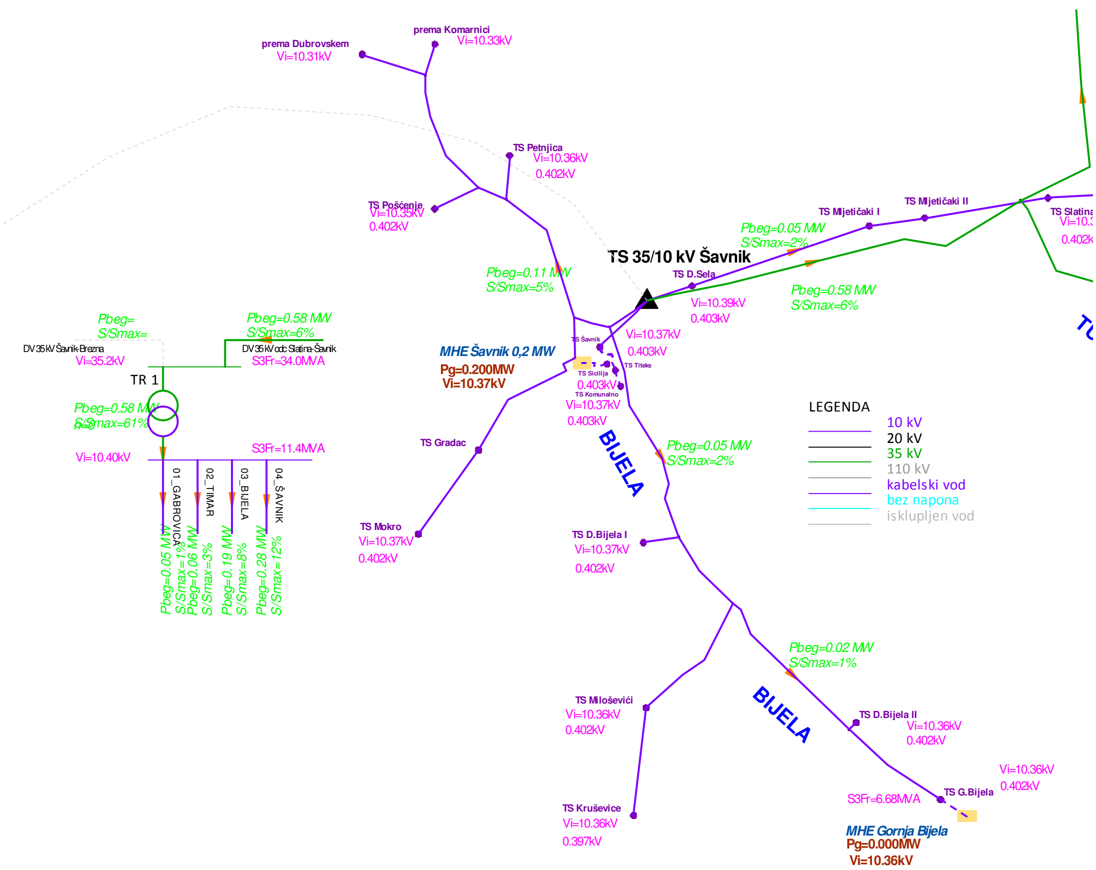


Figure 149: Loads in 10 kV network and voltages at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	4.442 MW	Yearly losses:	11867 MWh

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	0.45 MW

Notes:

- in the connection with full power , the LV network voltages are increased above the criterion 0.420 kV (above 0.470 kV)

Results:

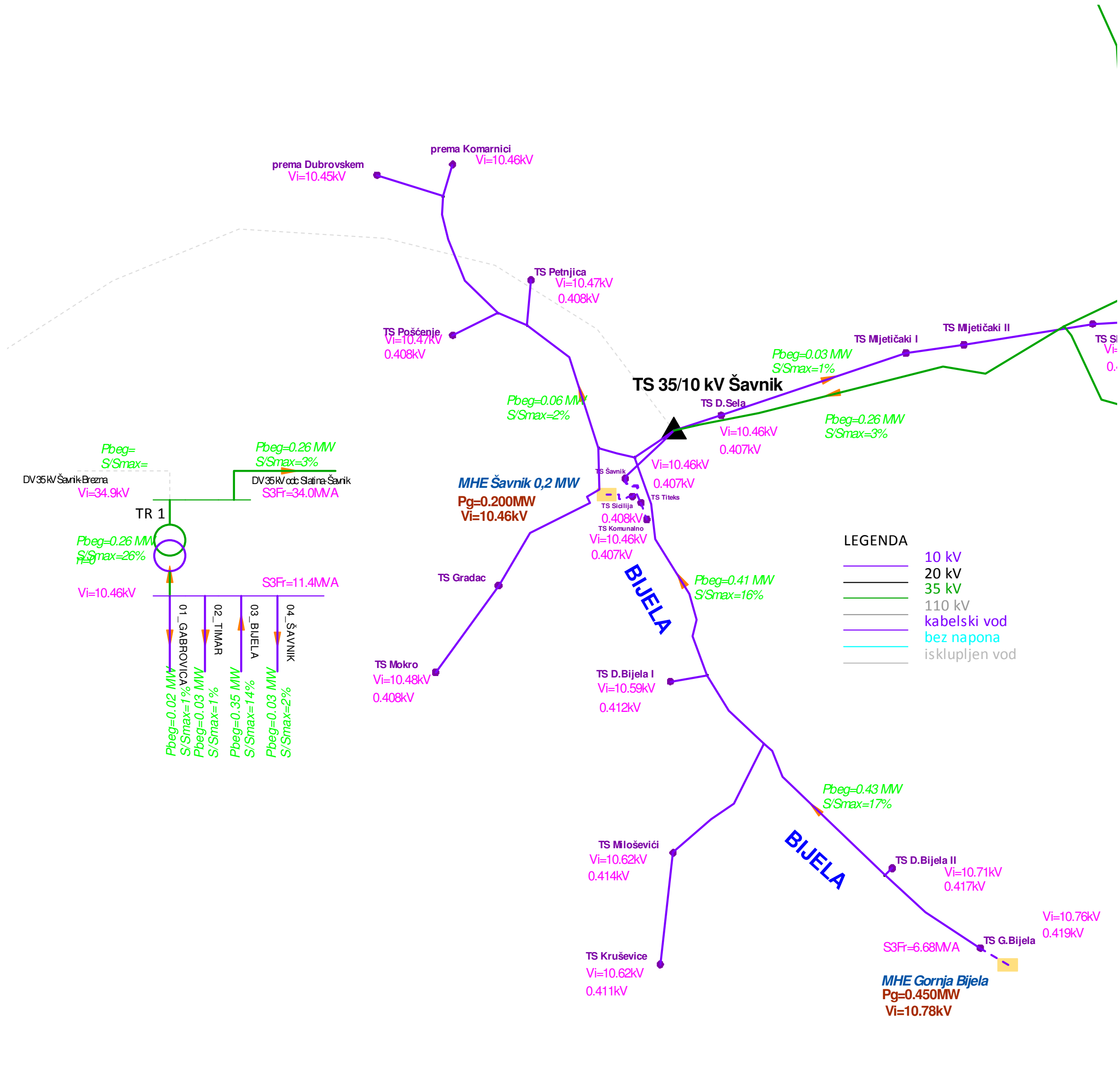


Figure 150: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	4.394 MW	Yearly losses:	11792 MWh

4.b VARIANT A: MHE connection to the new feeder from SBS ŠAVNIK

Necessary reinforcements:	Estimated investment in EUR ∑ 700,000
- Reconstruction of 35/10 kV SBS Šavnik (new transformer 35/10 kV, 4 MVA) - MHE connection via new 10 kV feeder directly to 35/10 kV SBS Šavnik, reconstruction of the existing transmission line between Šavnik and Bijela (Bijela feeder) into 2x10 kV transmission line, 1xAlFe 70/12 mm^2 (MHE) and 1xAlFe 35/6 mm^2 (consumption) conductors, length approx. 9 km. - Alternative: connection with cable feeder (Al 150 mm^2 cable, 9 km).	700,000

Operational conditions after the MHE connection to the network – max consumption, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (approx 410 kV)	**4355 MW**	**11687 MWh**

Results:

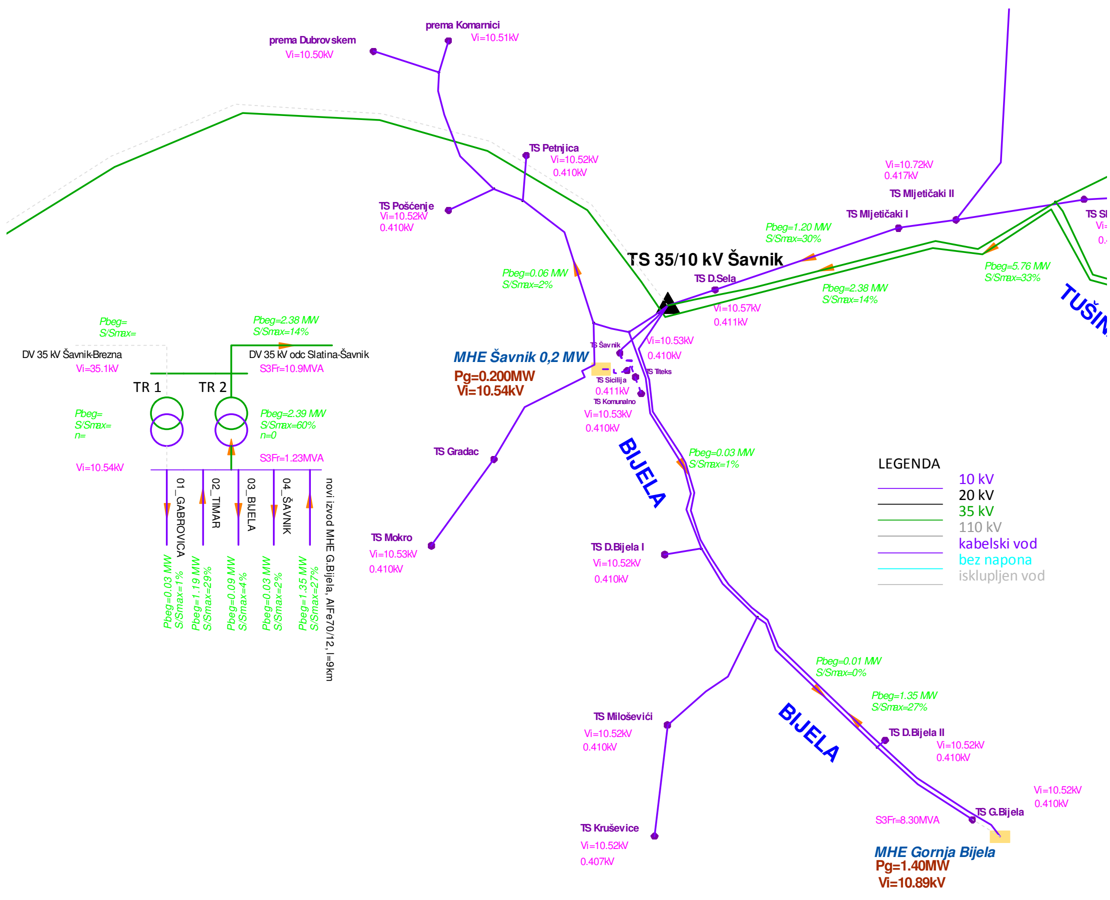


Figure 151: Results of power condition analyses – VARIANT A, max loads and MHE max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.408 kV, max 0.410)	**0.888 MW**

Results:

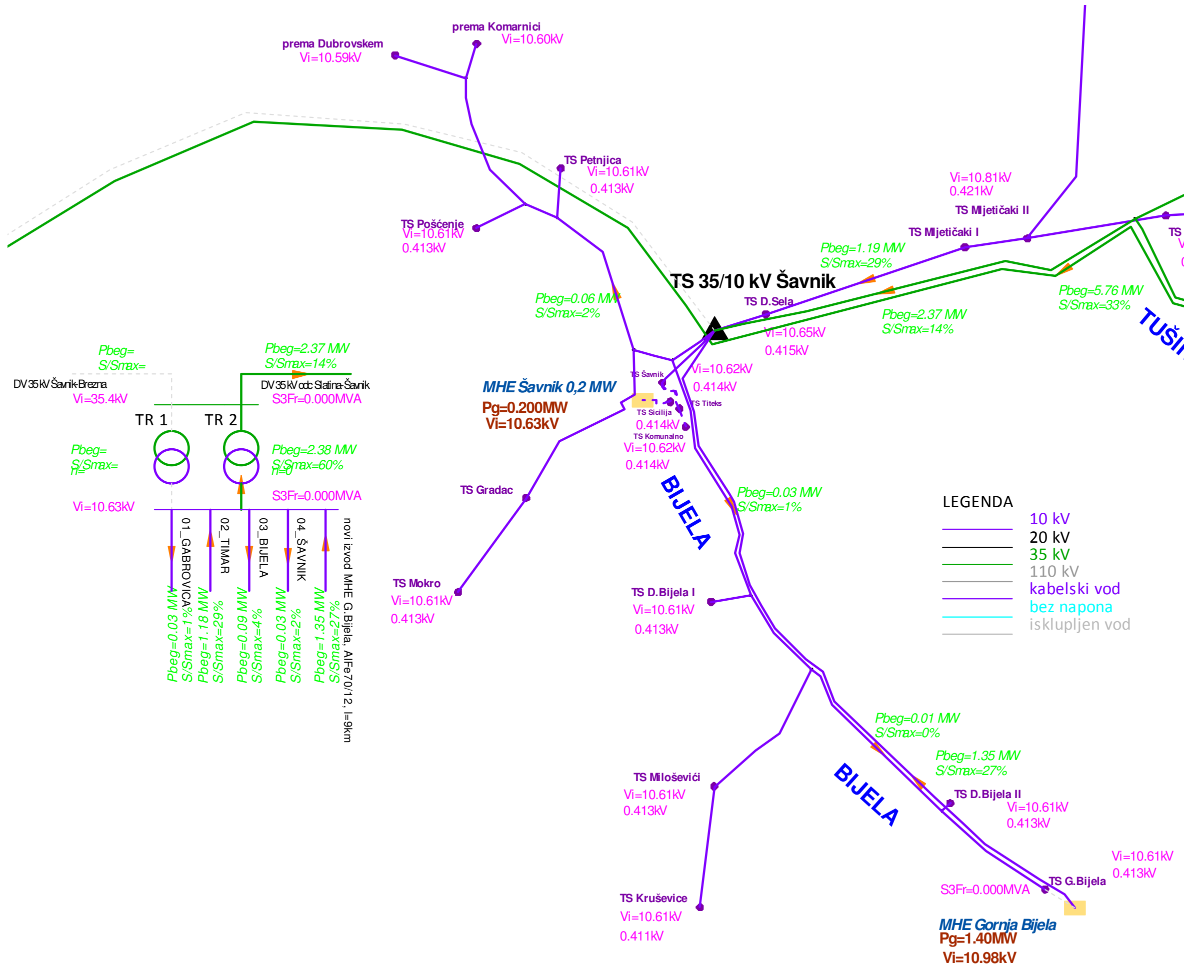


Figure 152: Results of power condition analyses – VARIANT A, min consumption and MHE max production, 2011.

Operation conditions after the MHE connection to the network – MHE max consumption, without production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.391 kV, max 0.395 kV)	**4.373 MW**

Results:

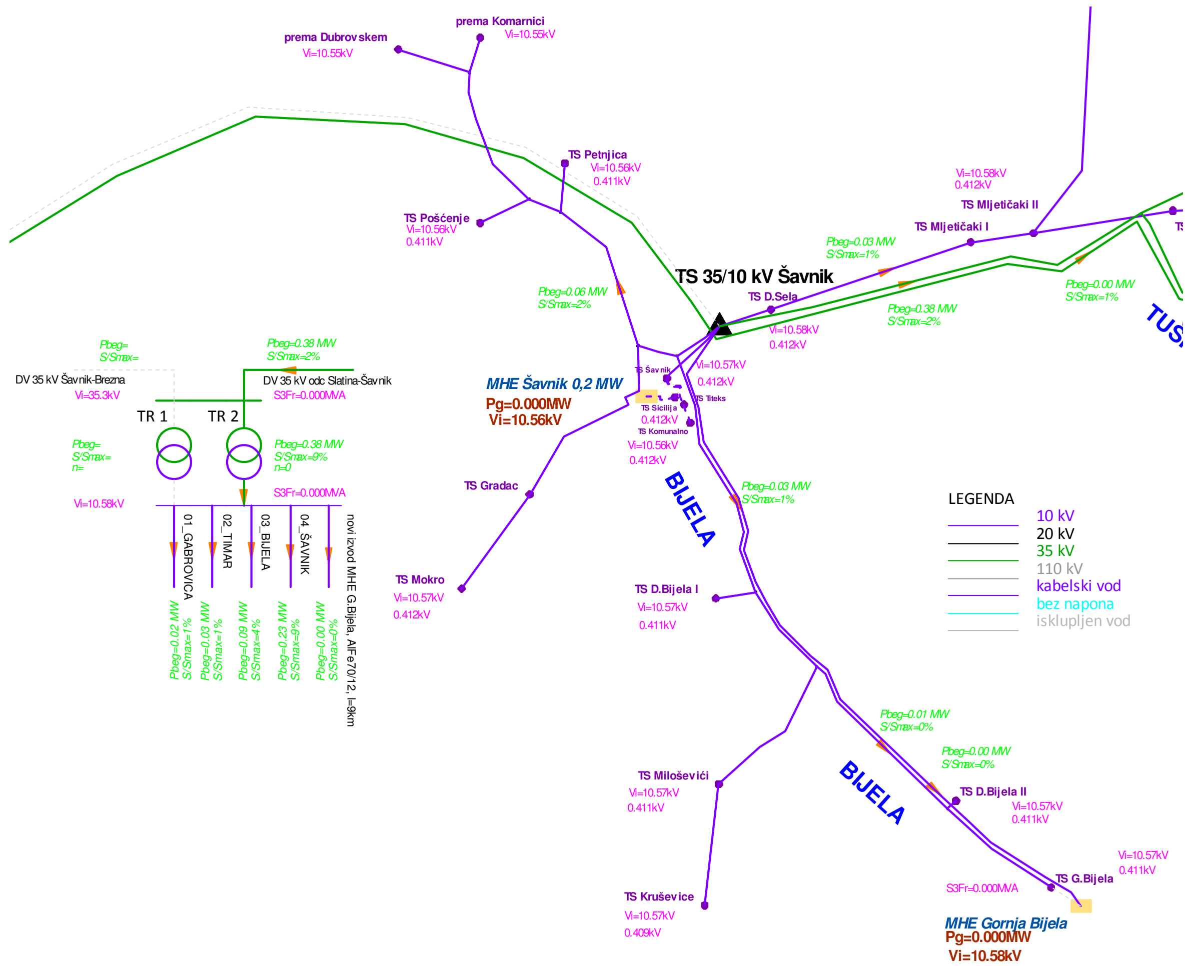


Figure 153: Results of power condition analyses – VARIANT A, max consumption without MHE production.

Solution advantages
- **MHE operation improves voltage conditions in the areas with previously low voltage**   - **optimum consumption of the produced power in the area**

4.b VARIANT B: MHE connection to 10 kV busbars in new SBS Gvozd 110/35/10 kV

Necessary reinforcements:	Estimated investment in EUR **∑ 730,000**
- MHE is connected with new feeder directly to 10 kV busbars in SBS Gvozd - **condition: construction of SBS Gvozd 110/35/10 kV and 110 kV Brezna-Gvozd (Kronovo) transmission line** - Transformer TR 35/10 kV, 2.5 MVA is constructed in SBS Gvozd - Double circuit 35 kV line is constructed from SBS Gvozd to the river Bijela valley, one system operates at 10 kV and serves for the MHE connection in the river Bijela outfall, second system operates at 35 kV and serves for the needs of MHE connection on the river Tušina - Length of double circuit line is approx. 6.5 km	30,000 200,000

- MHE is connected to the double circuit transmission line with 10 kV connected transmission line of approx. 1 km length	350,000
- 10 kV feeder is equipped with AlFe 50/8 mm² conductor	150,000

Operational conditions after the MHE connection to the network – max consumption, max MHE production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits	**4.235 MW**	**11365 MWh**

Results:

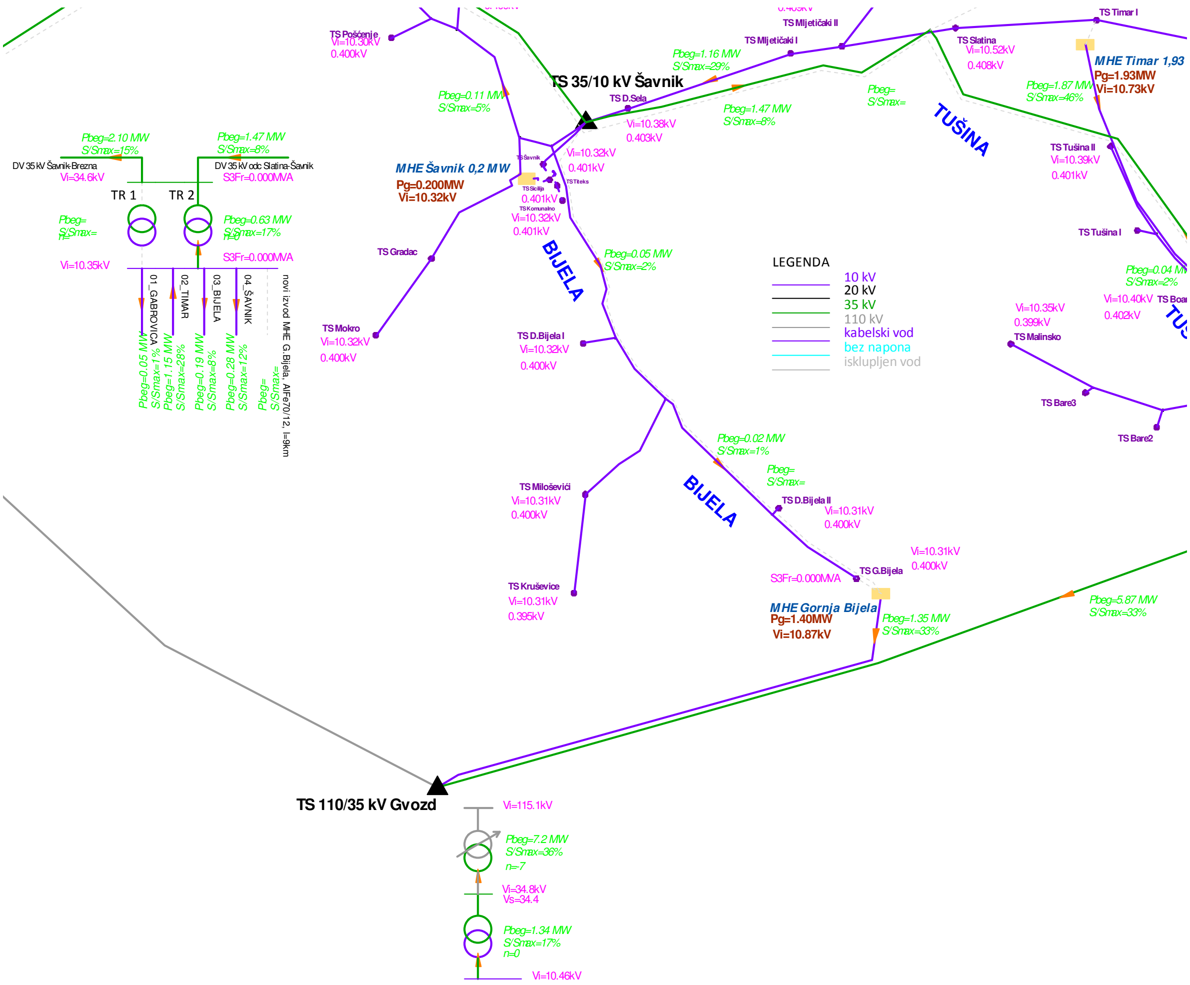


Figure 154: Results of power condition analyses – VARIANT B, max loads and MHE max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Losses:
- within permitted limits (approx. 0.413 kV)	**0.872 MW**

Results:

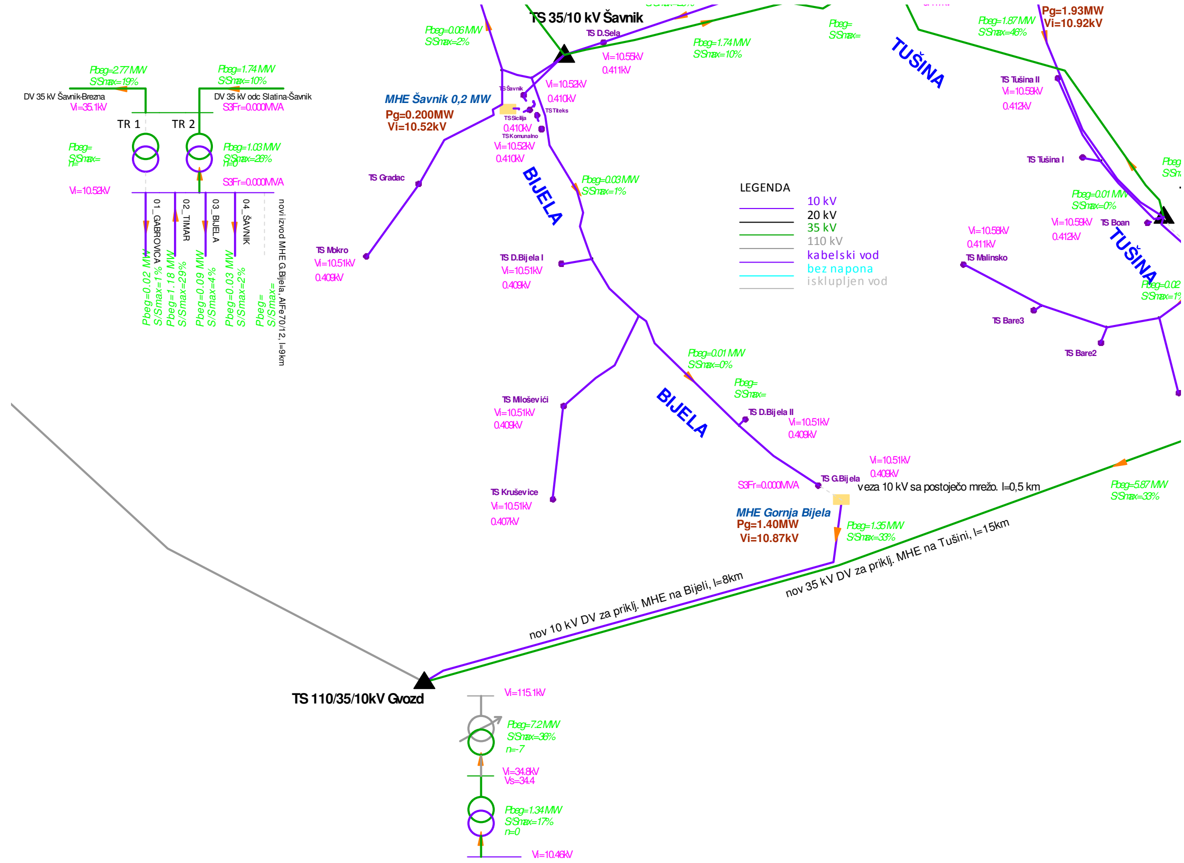


Figure 155: Results of power condition analyses – VARIANT B, min consumption and MHE max production, 2011.

Solution advantages

- **produced power represents the surplus in 10 kV network SBS Šavnik and is to be evacuated in 35 kV and 110 kV network**
- **no MHE influence on LV network**
- **Connection of 10 kV network between MHE and SBS G. Bijela (Bijela feeder from SBS Šavnik) provides better operation reliability of this network**
- **Solution insufficiency: depends on the wind power station and 110 kV Kronovo network construction**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.397	0.404	4.442	**-**	11867	**-**	**-**
Connection to existing network	**0.45**	0.402	0.420	4.394	**-0.048**	11792	**-75**	**-**
VARIANT A	**1.4**	0.391	0.410	4.355	**-0.087**	11687	**-180**	**700,000**
VARIANT B	**1.4**	none	none	4.235	**-0.207**	11365	**-502**	**730,000**

RIVER VRBNICA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Vrbnica	5.566	SBS Stabna	9.57
MHE Zukovska	6.422	SBS Jasen	8.32
Tušina output	**11.988**	**Slack node:** 110 kV busbars SBS Nikšić	2585
Min. model of the relevant network:	- SBS Nikšić 110/35 kV - SBS Plužine 35/10 kV, 10 kV feeder: B.11		

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
B.11 feeder	0.1	0.36	0.11	0.38
SBS 35/10 kV Plužine	**0.6**	**2**	**0.64**	**2.12**

2.b Relevant data on the projected distribution network development

-

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	- barely within permitted limits (min 0.387 kV, max 0.391kV)

Results:

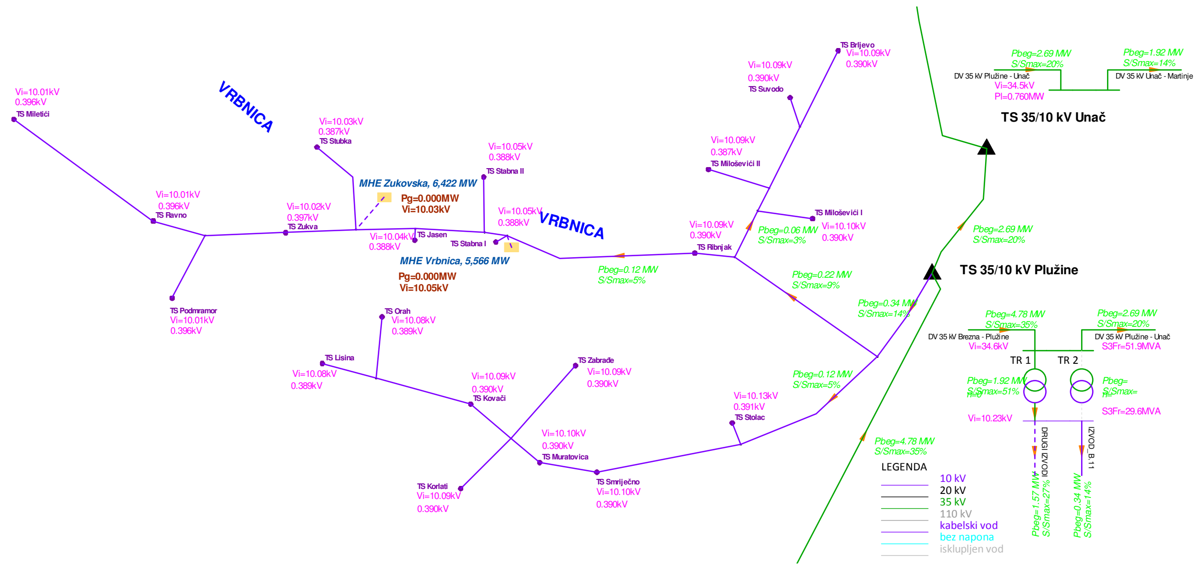


Figure 156: Loads in 10 kV network and voltages at LV busbars in TP – maximum loads 2011 in the existing network.

Min consumption	- within permitted limits	within permitted limits (min 0.402 kV, max 0.412kV)

Results:

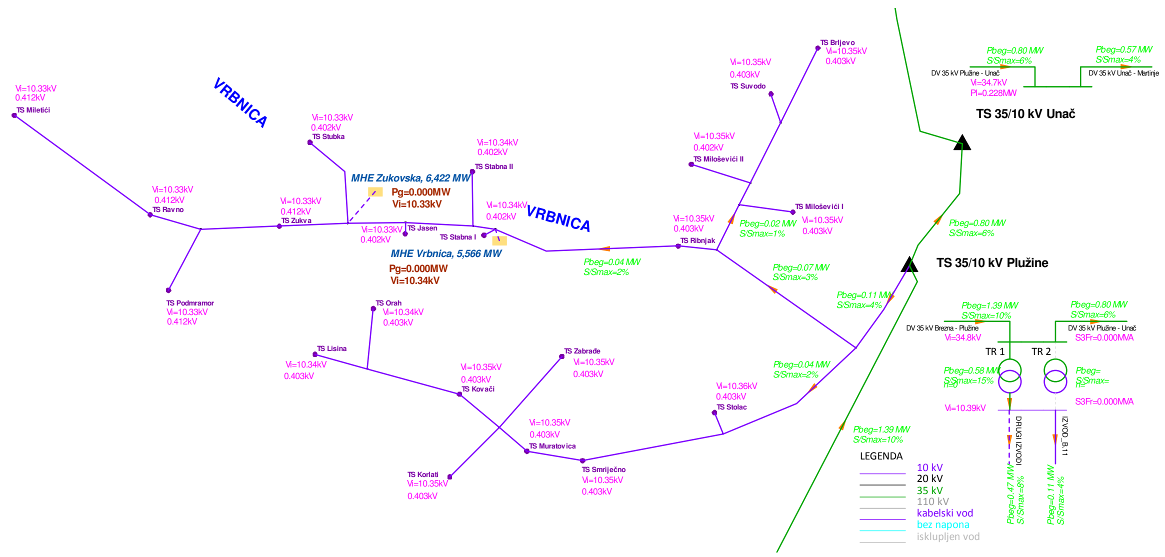


Figure 157: s in 10 kV network and volatges at LV busbars TP – minimum loads 2011 in the existing network.

Max losses:	**4.422 MW**	Yearly losses:	**11867MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	0.3 MW

Notes:

- max 0.15 MW from MHE Vrbnica
- max 0.15 MW from MHE Zukovska
- power plant with projected characteristics cannot be connected to the existing 10 kV network

Results:

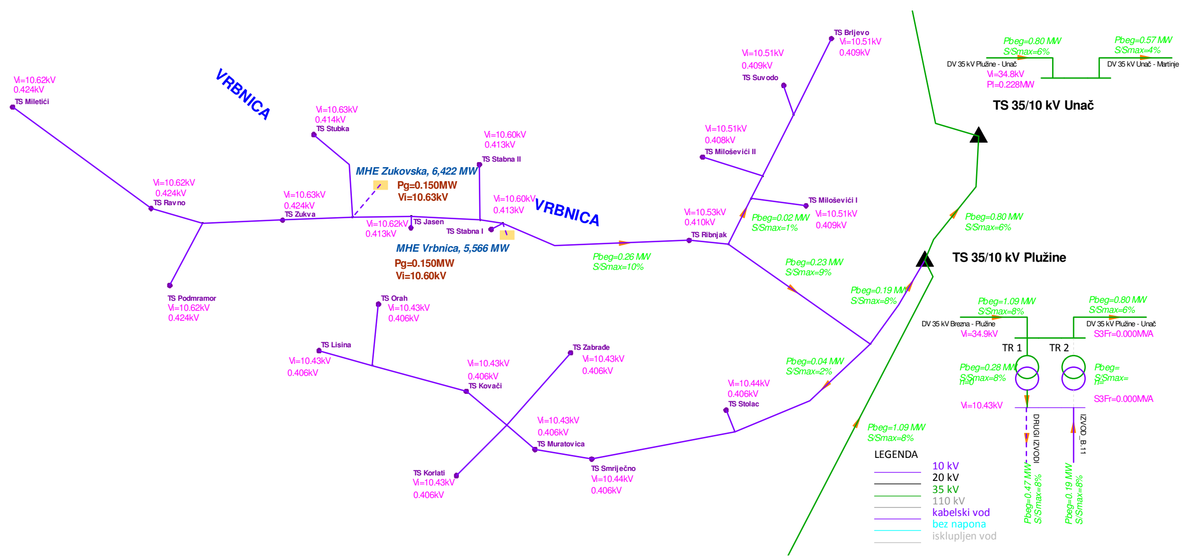


Figure 158: MHE connection to the near 10 kV network, minimum loads, 2011.

Max losses:	**4.378 MW**	Yearly losses:	**11749 MWh**

4.b VARIANT A: MHE connection to 35 kV busbars in SBS Brezna

Necessary reinforcements:	Estimated investment in EUR **∑ 1,000,000**
- MHE is connected directly to 35 kV busbars in SBS Brezna - **Condition: reconstructed 2x35 kV Brezna – Plužine transmission line** 1. system: supplies all SBS TS 35/10 kVin the area Brezna – Plevlja 1 2. system: power evacuation form MHE on the river Vrbinca - for the needs of MHE, the new double circuit connection transmission line is constructed between MHE together with the reconstructed 2x35 kV Brezna – Plužina transmission line(AlFe 95/15 mm^2, l = 9 km) - connection type is input/output for one system of reconstructed 2x35 kV transmission line Brezna – Plužine	1,000,000

Operational conditions after the MHE connection to the network – max consumption, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:

- within permitted limits (min 0.390 kV, max 0.399 kV)	**4.808 MW**	**12903 MWh**

Results:

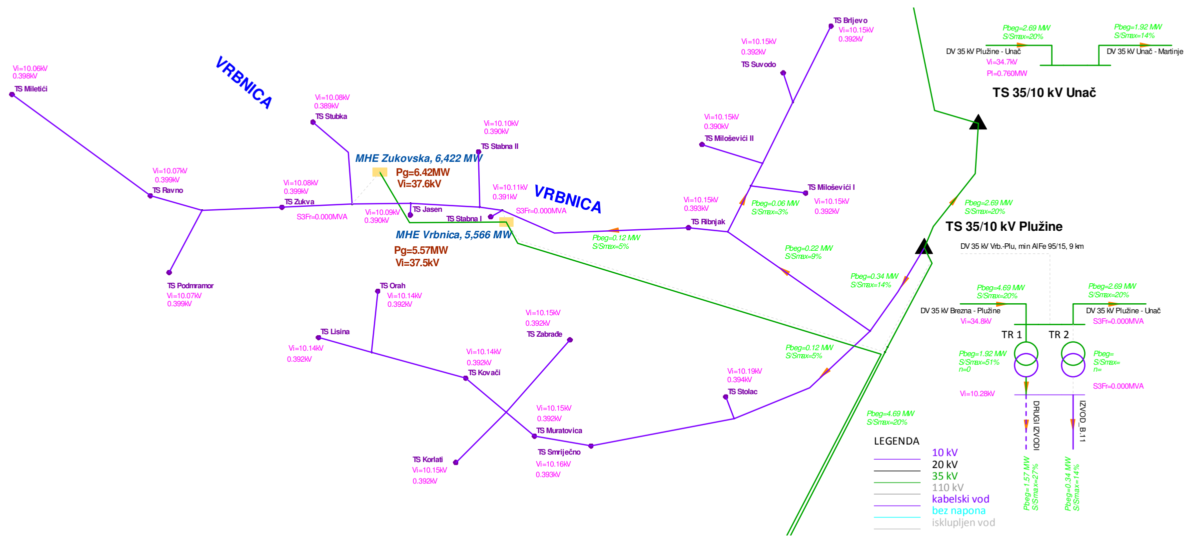


Figure 159: Results of power condition analyses – VARIANT A, MHE max loads and max production, 2011.

Operation conditions after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.410 kV, max 0.420 kV)	**1.743 MW**

Results:

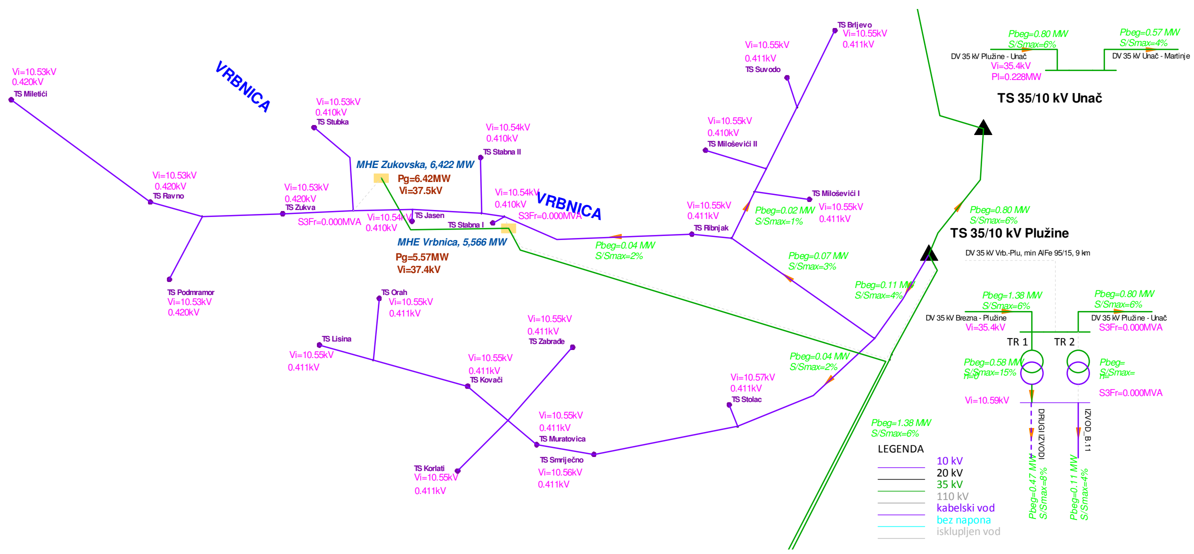


Figure 160: Results of power condition analyses – VARIANT A, min consumption and MHE max production, 2011.

Operation conditions after the MHE connection to the network – max consumption, without MHE production

Loads and voltages in the network:	Losses:
- within permitted limits (min 0.388 kV, max 0.397 kV)	**4.344 MW**

Results:

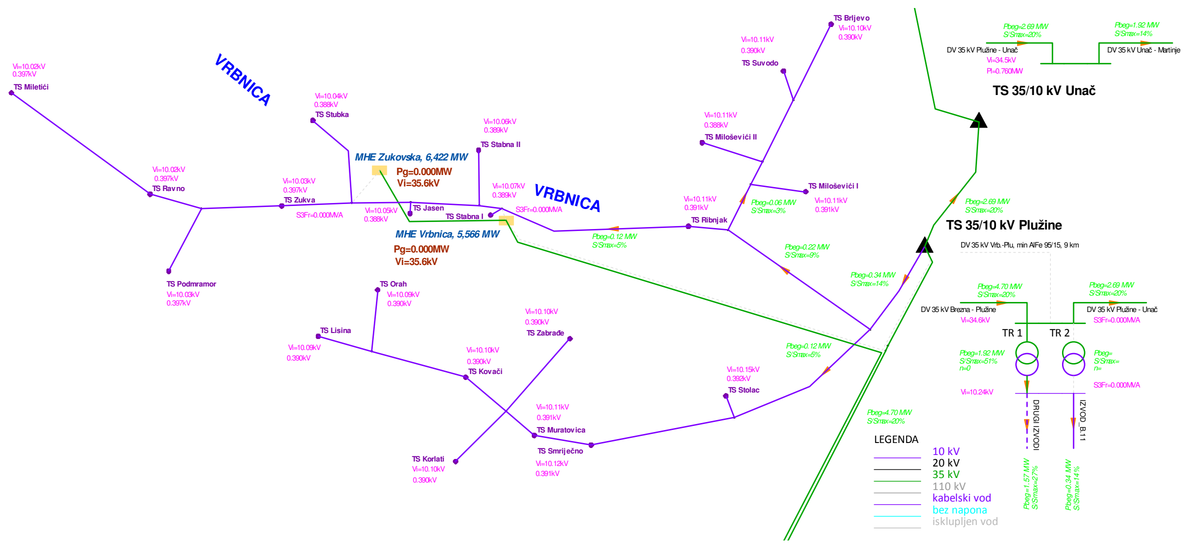


Figure 161: Results of power condition analyses – VARIANT A, max consumption without MHE production, 2011.

Solution advantages

- **reliable MHE connection to 10 kV network is not possible**
- **power surplus is evacuated to the consumption centre (Nikšić)**
- **small MHE influence on the LV network**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.387	0.412	4.422	-	11867	-	-
Connection to existing network	**0.3**	0.398	0.424	4.378	**-0.044**	11749	**-118**	-
VARIANT A	**11.988**	0.390	0.420	4.808	**+0.386**	12903	**+1036**	**1,000,000**

5.6. Results for MHE connection to the distribution network – solutions for Zeta river basin

In the Zeta River basin only the MHE construction on the river Zaslapnica is planned with its total output of 1.4 MW. In the previous chapters the detailed analysis was conducted for this river. Here only the summarized results are shown in the following table.

RIVER ZASLAPNICA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Zaslap	0.288	SBS Zaslap	8.53
MHE Nudo I	0.583	SBS Nudo II	7.29
MHE Nudo II	0.511	SBS Nudo II	7.29
Zaslapnica output	**1.382**	**Slack node:** 110 kV busbars SBS Vilusi	1323
Min. model of the relevant network:	- SBS Vilusi 110/35/10 kV - 10 kV feeder: Grahovo, Vilusi		

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Grahovo	0.090	0.400	0.097	0.430
Vilusi	0.035	0.100	0.038	0.108
SBS 35/10 kV Vilusi	**0.41**	**1.29**	**0.442**	**1.387**

2.b Relevant data on the projected distribution network development

- New SBS 35/10 kV Grahovo (after 2015)
- New 35 kV supply transmission line Vilusi – Grahovo, length 12.5 km (after 2015)
- Transformer 2 35/10 kV, 2.5 MVA in SBS Vilusi (by 2015)

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	- within permitted limits
Results: Figure 162		
Max consumption	- within permitted limits	- within permitted limits - in individual nodes it approaches 0.42 kV
Results: Figure 163		

Max losses:	**0.04 MW**	Yearly losses:	**107.4 MWh**

Necessary network reinforcements before the connection and other results:

- none

Results:

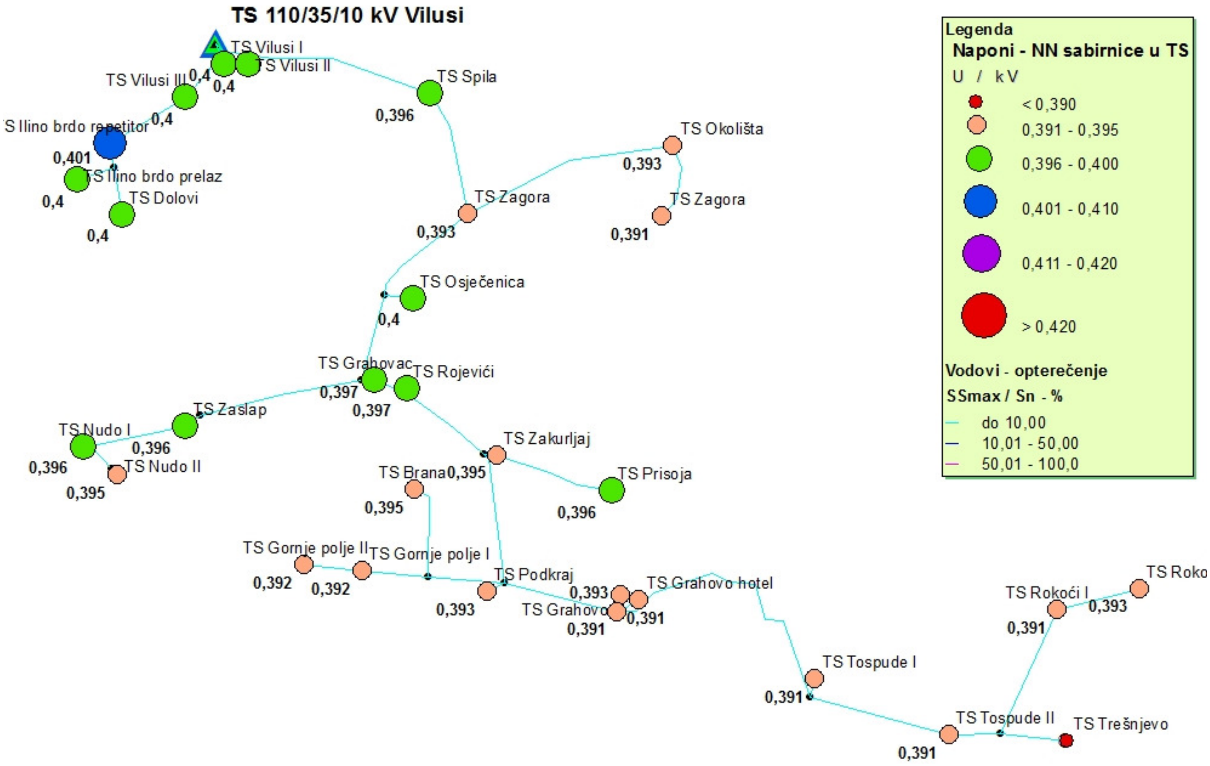


Figure 162: Loads in 10 kV network and voltages at LV busbars TP– max loads 2011 without MHE operation.

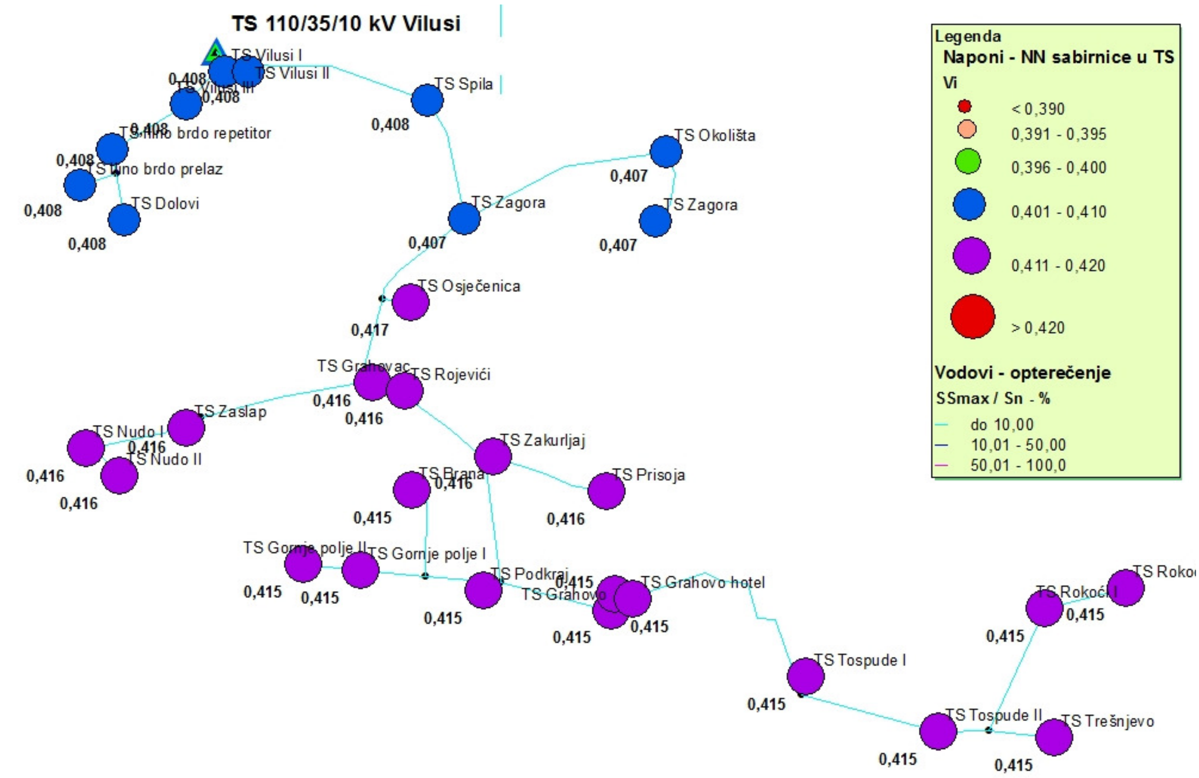


Figure 163: Loads in 10 kV network and voltages at LV busbars in TP – minimum loads 2011 without MHE operation.

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	0.1 MW

Notes:

- in the connection with full power , the LV network voltages are increased above the criterion 0.420 kV (to 0.465 kV),

Results:

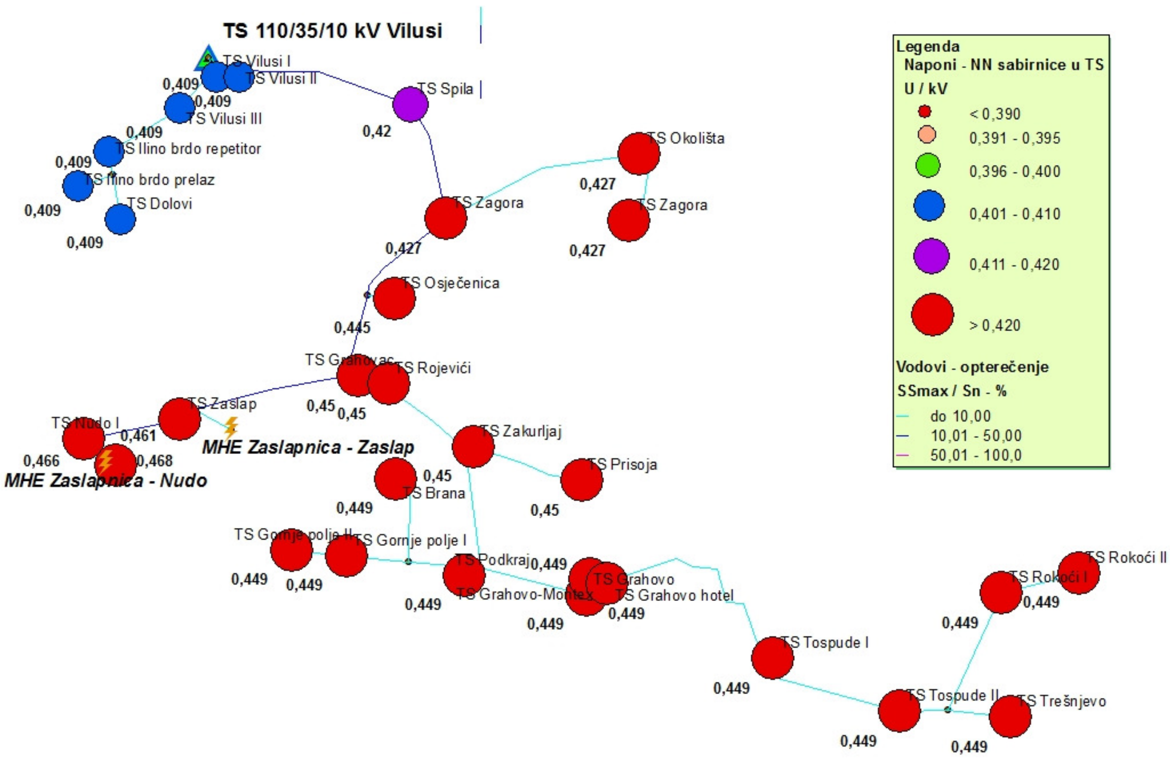


Figure. 164: thematic load scheme in 10 kV network with voltages at LV busbars in TP – MHE connection in the near 10 kV network, minimum loads, 2011.

4.b VAR A: connection to 10 kV network with new AlFe70/12 mm² conductor to Vilusi feeder

Necessary reinforcements:	Estimated investment in EUR ∑ 345,000
- new AlFe 70/12 mm² transmission line between Zaslap and SBS Dolovi, l = 6 km - replacement of the existing AlFe35/6 mm² conductors with new AlFe70/12 mm² conductors between SBS Vilusi and SBS Dolovi	330,000 15,000

Operation conditions with MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits	**0.13 MW**	**348.9 MWh**

Results:

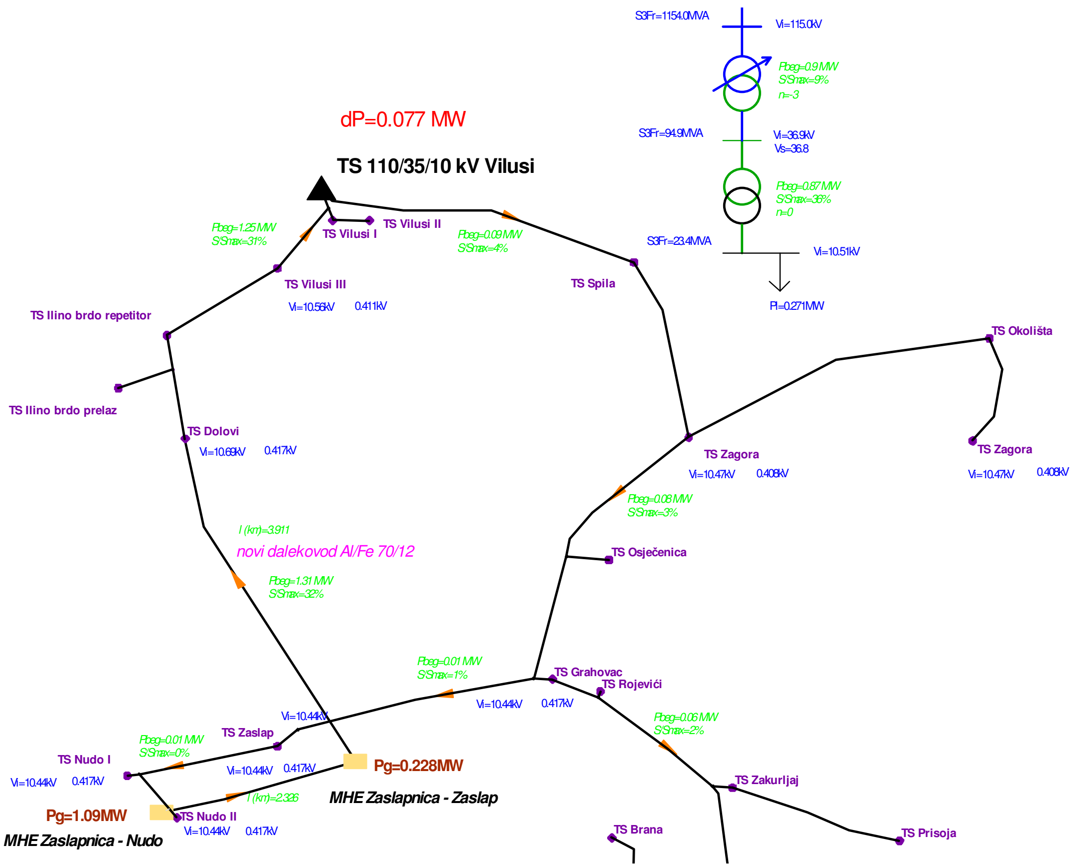


Figure 165: Results of power condition analyses – VARIANT A, min loads, 2011.

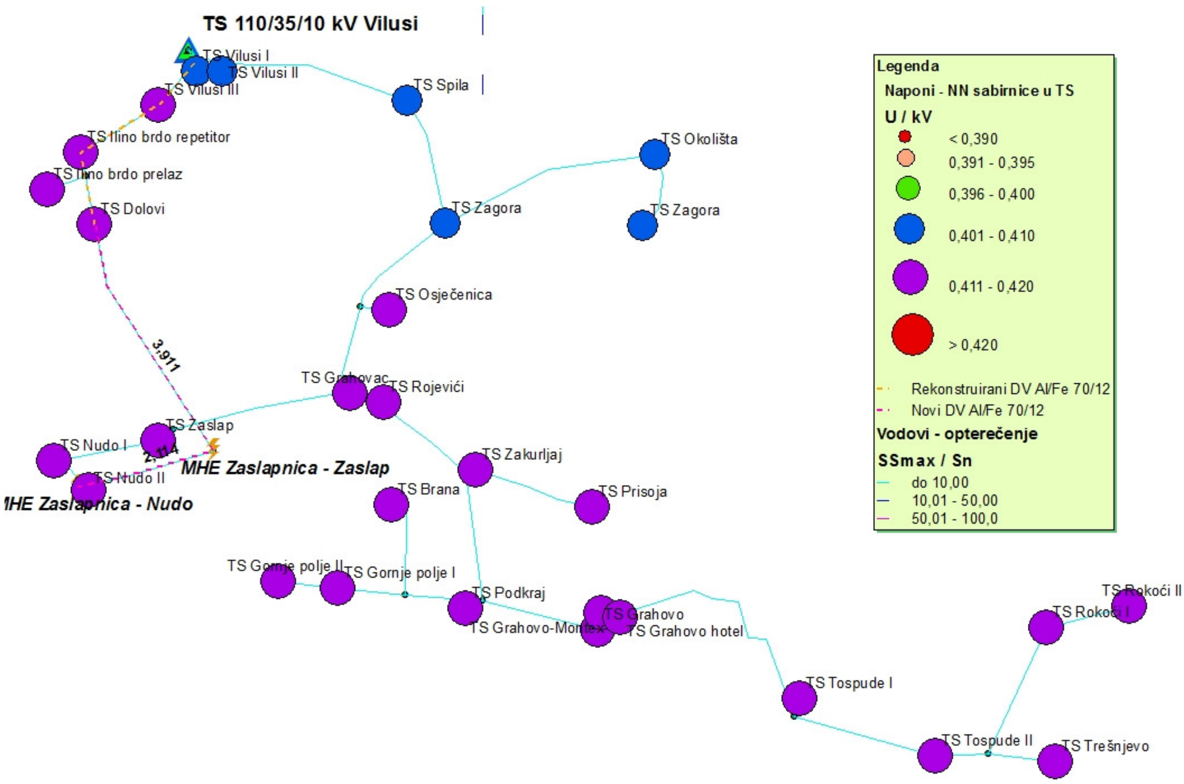


Figure 166: Thematic load scheme in 10 kV network with voltages at LV busbars in TP – VARINAT A, min loads, 2011.

Solution advantages

- **low connection costs**
- **improved operation reliability of 10 kV network (option of reconnection between two feeders)**
- **part of produced power is compensated with environment consumption**
- **solution is not related to other investments to the network**
- **MHE connection to the network via transformer 10/0,4 kV is technically (smaller losses) and economically (more inexpensive solution) better solution compared to connection via transformer 35/0,4 kV)**

4.c VAR B: connection to the new feeder Grahovo 35 kV (overhead AlFe95/15 mm² line)

Necessary reinforcements:	Estimated investment in EUR **∑ 575,000**
- New section of overhead 35 kV line between SBS Vilusi node and tap to MHE on the river Zaslapnica (AlFe95/15 mm^2, l =7 km)	350,000
- New overhead 35 kV line between overhead 35 KV line Vilusi - Grahovo and MHE on the river Zaslapnica (AlFe95/15 mm^2, l =4,5 km)	225,000

Operation conditions with MHE connection to the network – min consumption, max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits	**0.046 MW**	**123.4 MWh**

Results:

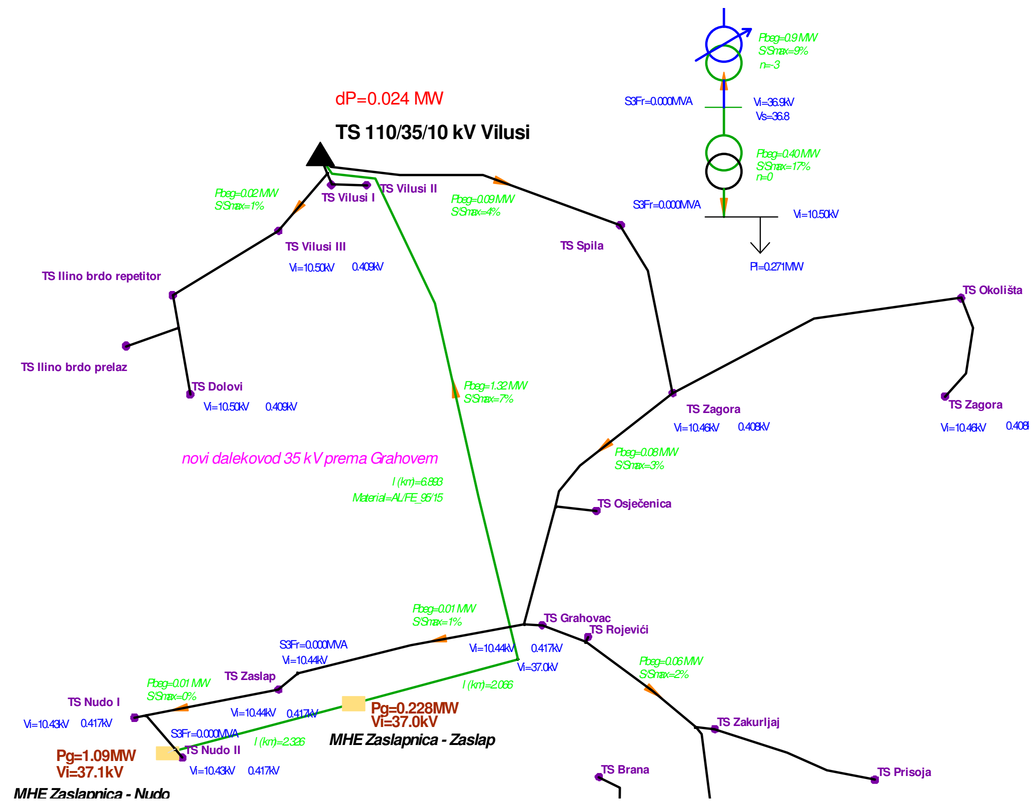


Figure 167: Results of power condition analyses – VARIANT A, min loads , 2011.

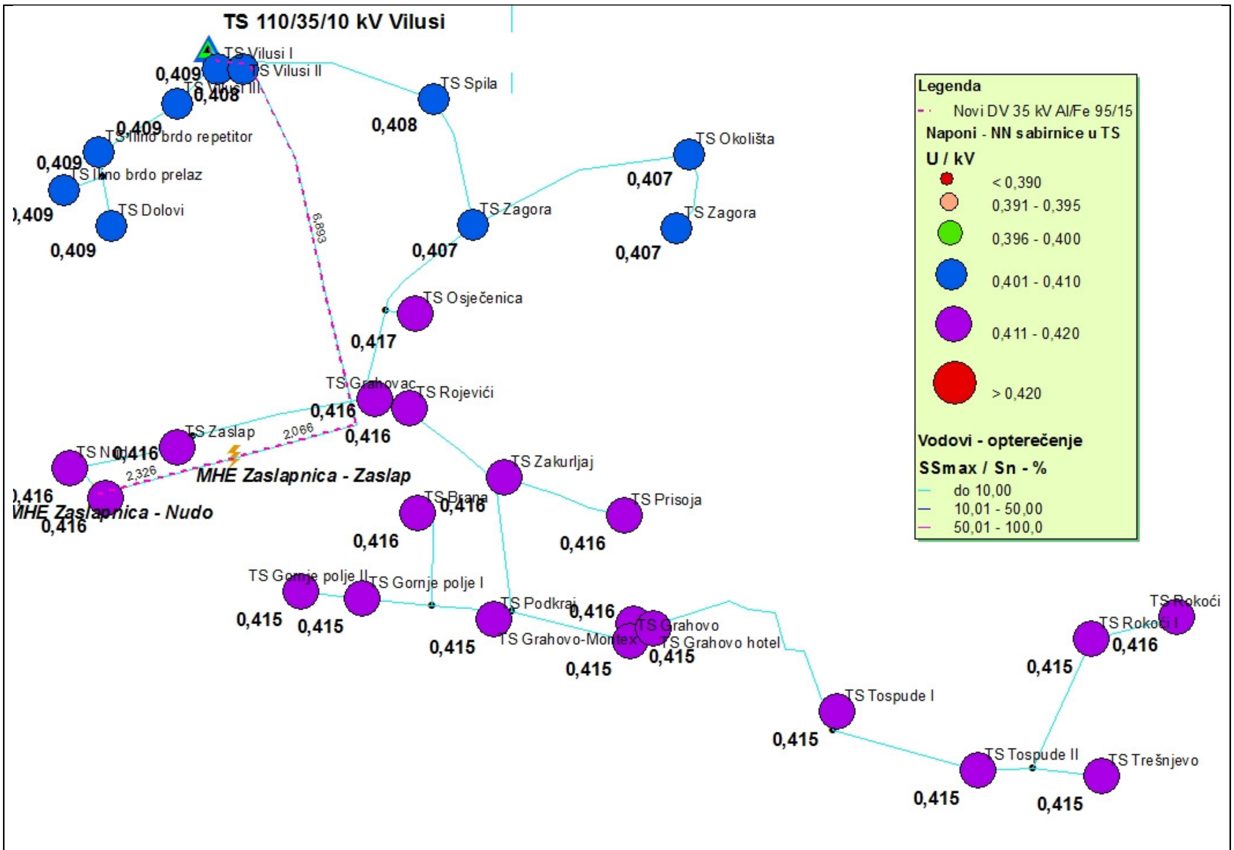


Figure 168: Thematic load scheme in 10 kV network with voltages at LV busbars in TP - connection with new 35 kV feeder Grahovo, min loads, 2011

Solution advantages

- **smaller voltage oscillations in 10 kV and 0.4 kV network**
- **better operation reliability of the planned MHE**
- **smaller network losses (in average 50 kW)**
- **more inexpensive solution in case of constructing new 35 kV overhead line between Vilusi and Grahovo**

5. ***RESULTS COMPARISON***								
Situation	P_{MHE}[32] (MW)	U_{min}[33] [kV]	U_{max}[34] [kV]	P_{gub}[35] [kW]	ΔP_{gub}[36] [kW]	W_{gub}[37] [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.391	0.417	40	**-**	107	-	**-**
Connection to existing network	**0.1**	0.394	0.421	34	**-6**	91	**-16**	**-**
VARIANT A	**1.318**	0.393	0.419	130	**+90**	349	**+242**	**345,000**
VARIANT B	**1.318**	0.390	0.419	46	**+6**	123	**+16**	**575,000**

[32] Power output of all analysed MHE (output before the connection is 0 MW)
[33] Min voltages in LV network (voltages are calculated on the whole network model and occur in situations with high loads at the end of long feeders. Among all analysed SBS the voltage of that SBS is shown which deviates the most from the nominal voltage).
[34] Max voltages in LV network (voltages are calculated on the whole network model and occur in situations with small loads in the vicinity of SBS 35/10 kV or distribution sources. Among all analysed SBS the voltage of that is shown which deviates the most from the nominal voltage).
[35] Max losses for situation with maximum loads (calculated for the whole network model)
[36] Relative comparison with losses for the situation before MHE connection to the network.
[37] Estimation of yearly losses W_{gub} on the basis of max losses P_{gub} according to the equation:
$W_{gub} = P_{gub} \cdot T_{gub} = P_{gub} \cdot (0{,}17 + \frac{0.83 \cdot T_{pog}}{8760}) \cdot T_{pog},$ T_{pog} are operation hours of distribution network (T_{pog} =4500 hours)

5.7. Results for MHE connection to the distribution network - solutions for the river Tara basin

In the Tara River basin only the MHE construction on the river Bukovica is planned with its total output of 0.2 MW. There are no network integration problems expected for MHE with so low power. The results of analysis are shown in the following table.

RIVER BUKOVICA

1.Small Hydroelectric power stations – general information

Name	P_{max} [MW]	Closest SBS	S_k [MVA]
MHE Bukovica	0.2	SBS Water factory	15.6
Bukovica output	**2**	**Slack node:** 10 kV busbars SBS Drijenak	40.8
Min. model of the relevant network:	- SBS Drijenak 35/10 kV, 10 kV busbars - 10 kV feeder: Trebaljevo		

2. Grounds

2.a Relevant data on the loads

SBS, feeders	2011		2015	
	S_{min} [MVA]	S_{max} [MVA]	S_{min} [MVA]	S_{max} [MVA]
Trebaljevo	0.2	0.7	0.21	0.74
SBS 35/10 kV Drijenak	**0.96**	**3.2**	**1.1**	**3.4**

2.b Relevant data on the projected distribution network development

- Reconstruction of SBS 35/10 kV Drijenak by 2015

3. Operation conditions before MHE connection to the network

Critical states	Load	Voltages in LV network
Max consumption	- within permitted limits	- within permitted limits

Results:

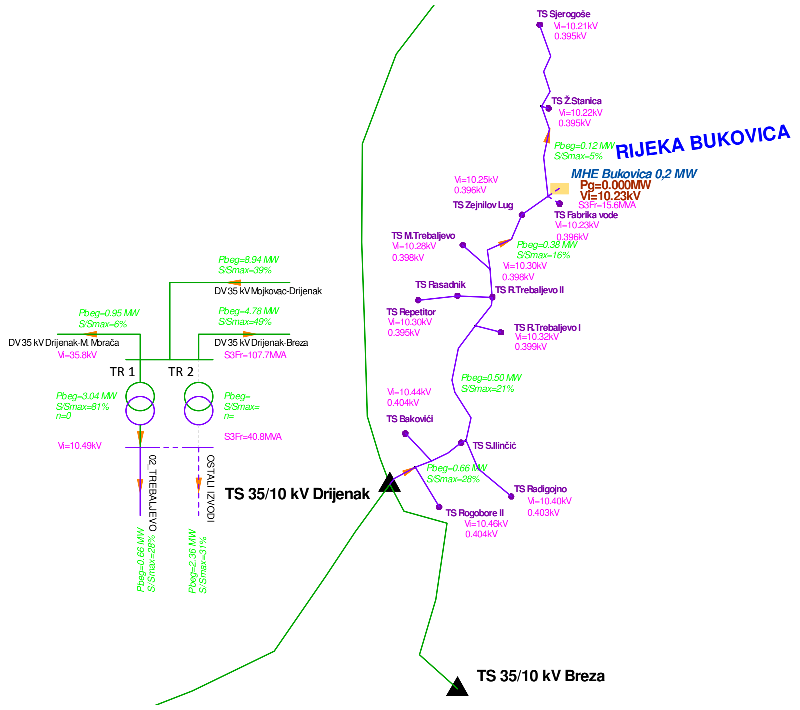


Figure 169: Loads in 10 kV network and voltages at LV busbars in TP – maximum loads 2011 in the existing planned network.

Min consumption	- within permitted limits	- within permitted limits

Results:

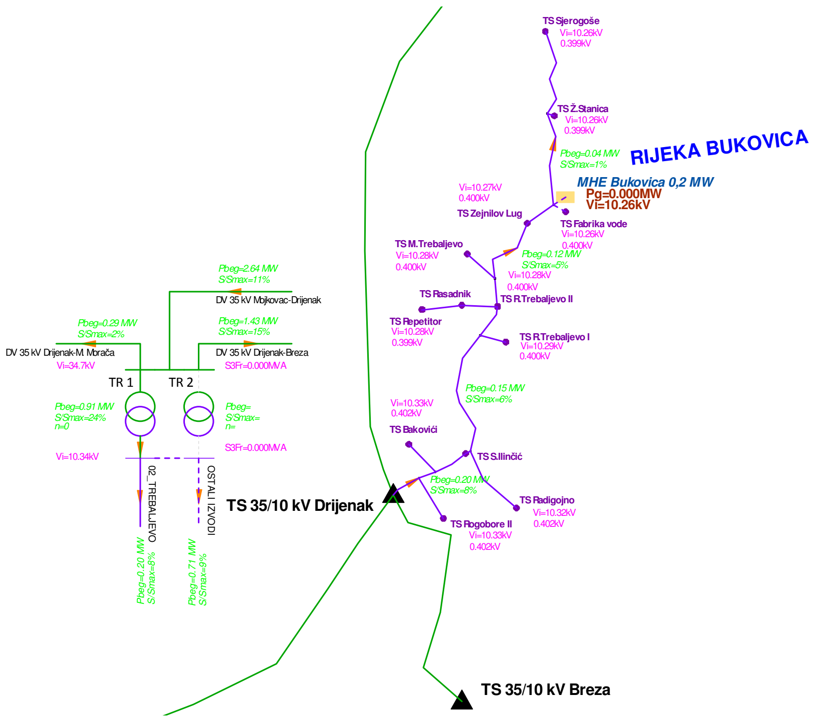


Figure 170: Loads in 10 kV network and loads at LV busbars TP – minimum loads 2011 in the existing planned network
.

Max losses:	**4.378 MW**	Yearly losses:	**11749 MWh**

Necessary network reinforcements before the connection and other results:

- none

4. MHE CONNECTION TO THE NETWORK – SOLUTIONS

4.a Option of reliable connection to the existing network

Max reliable power evacuation from MHE:	**more than 0.2 MW**

Notes:

- reliable MHE connection to the existing network

Operational conditions after the MHE connection to the network – max consumption, MHE max production

Loads and voltages in the network:	Max losses:	Yearly losses:
- within permitted limits (min 0.398 kV, max 0.405 kV)	**4.359 MW**	**11698 MWh**

Results:

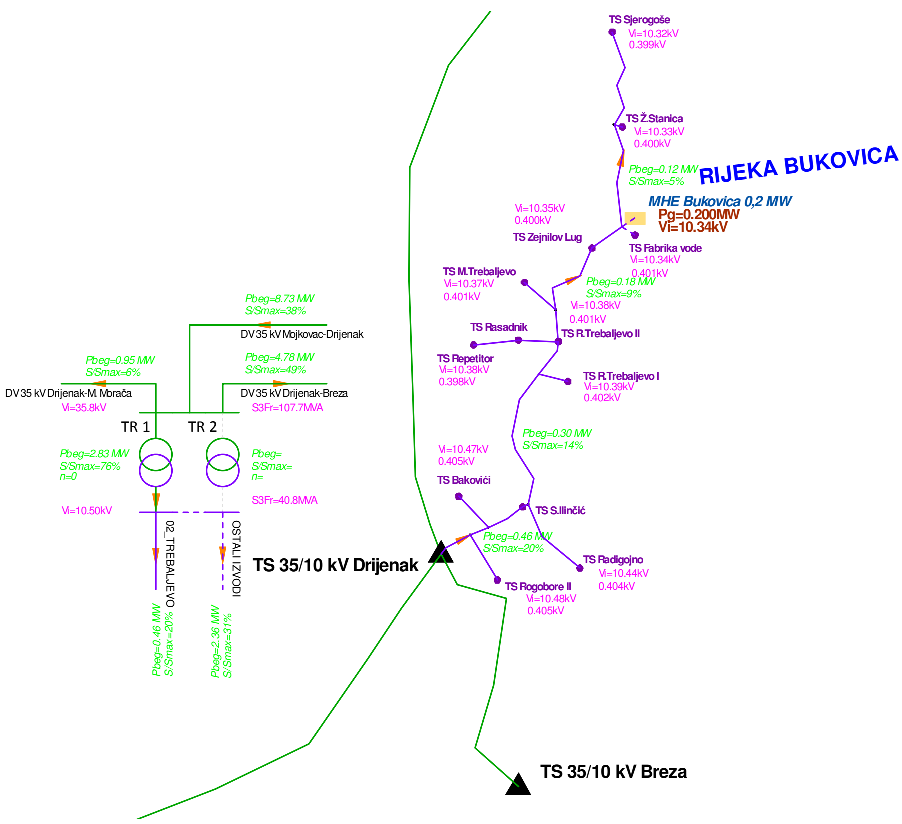


Figure 171: Results of power condition analyses – connection to the existing network, max consumption and MHE max production, 2011

Operation conditions after MHE connection to the network – min consumption, max production	
Loads and voltages in the network:	Losses:
- within permitted limits (min 0.402 kV, max 0.404 kV)	**0.832 MW**

Results:

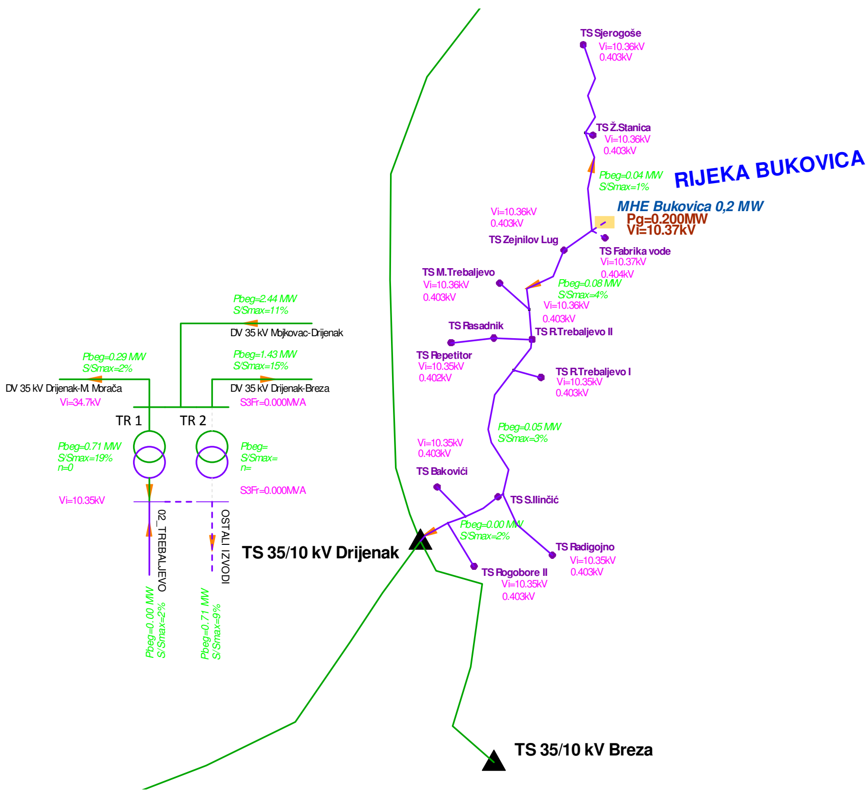


Figure 172: Results of power condition analyses – connection to the existing network, min consumption and MHE max consumption, 2011.

Solution advantages
- **MHE operation improves voltage conditions in the areas with previously low voltage**
- **optimum consumption of the produced power in the area**

5. *RESULTS COMPARISON*

Situation	P_{MHE} (MW)	U_{min} [kV]	U_{max} [kV]	P_{gub} [MW]	ΔP_{gub} [MW]	W_{gub} [MWh]	Δw_{gub} [MWh]	Estimated investment [EUR]
Before connection	**0**	0.395	0.402	4.378	-	11749	-	-
Connection to existing network	**0.2**	0.398	0.405	4.359	**-0.019**	11698	**-51**	-

5.8. Summary of results

The tables show the results of the analyses of MHE connection to the distribution network for all individual rivers. For each river the necessary network reinforcements are given. Also the necessary reinforcements are stated that cause poor operation conditions in the existing network and voltage increases due to operation of all power stations with projected maximum power.

MHE operation will influence on significant voltage changes in the distribution network, meaning that the actively regulated voltage will have different loads at 35 kV busbars in SBS 110/35 kV. The voltage is regulated as to provide all SBS 35/10 k V at individual loads the voltage on 10 kV busbars between 10.2 and 10.7 kV.

Voltage conditions would be significantly improved, if the voltage were automatically regulated at 10 kV busbars in SBS 35/10 kV. **Significantly greater integration with smaller costs would be achieved with gradual integration to 20 kV voltage level with automatic voltage regulation and reconstruction of 35 kV network to 110 kV or 20 kV.**

The Table 5.11 shows the total lengths and number of new/reconstructed lines and substations with average estimated costs of all MHE connections (87.1 MW of installed power) in 10 kV and 35 kV distribution network. Average cost of MHE connection is approx. **220 EUR for one kW of produced power**. Single-pole scheme of 35 kW network with the projected reinforcements is shown in the Figure 171.

Table 5.11: Summary of investments into distribution network due to MHE connection.

		TOTAL LENGTH (km), NUMBER	ESTIMATED INVESTMENT (EUR)
10 kV	lines	109 km	5,120,000
10 kV	switching stations	2	510,000
		total 10 kV	**515,12**
35 kV	lines	116	12,050,000
35 kV	SBS 35/10 kV	3	1,450,000
35 kV	new TR 35/10 kV	3	195,000
		total 35 kV	**13,695,000**
		TOTAL COSTS FOR 87.1 MW MHE CONNECTION TO THE DISTRIBUTION NETWORK	**19,325,000**

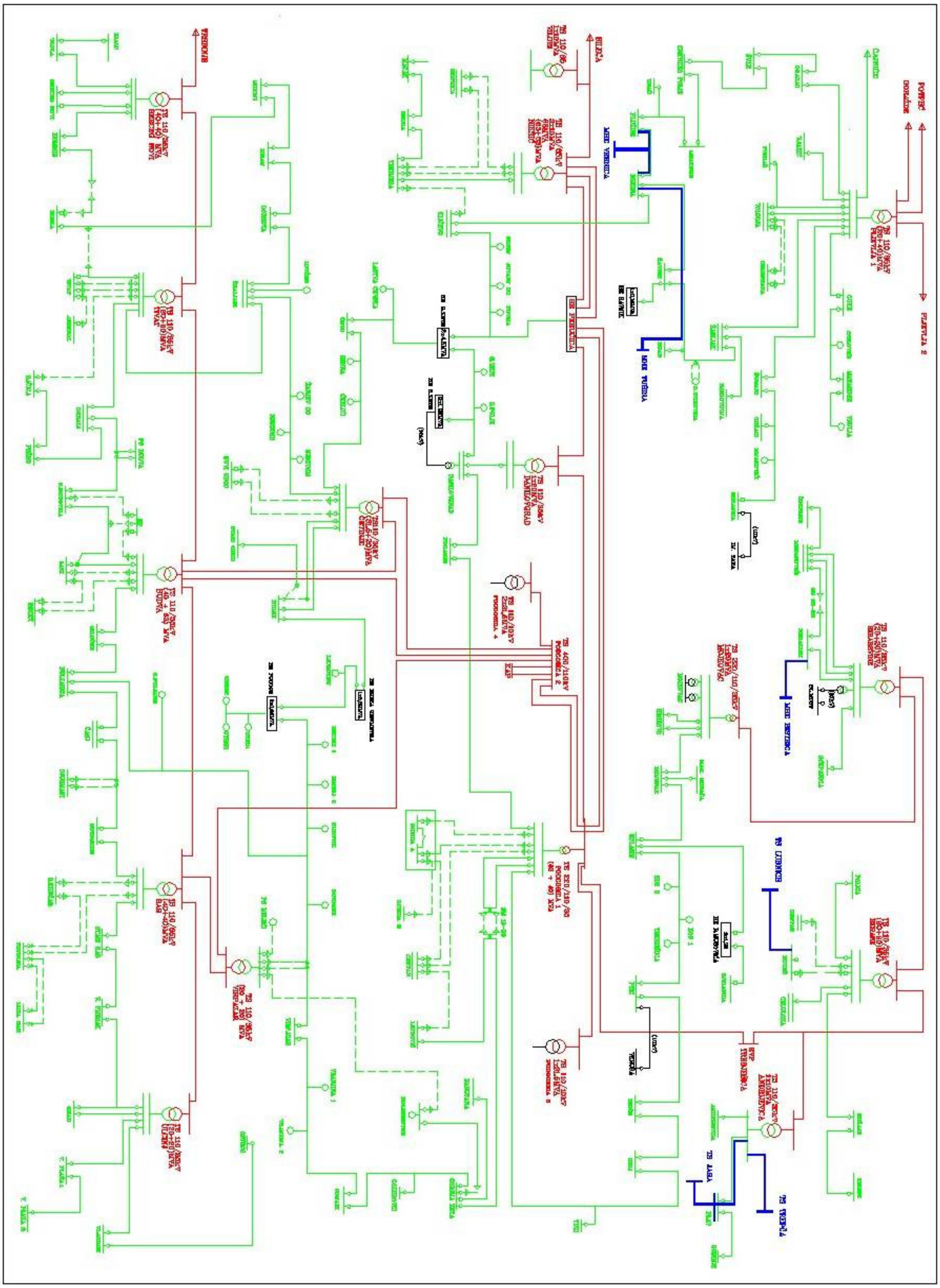


Figure 173: single-pole scheme of 35 kV network after all MHE connection.

5.9. Annex – typical prices

Prices of transformer stations (TS) 110/10(20) kV and 35/10(20) kV:

- construction of urban TS 110/10(20) kV 2×40 MVA: 3 000 000 €
- construction of rural TS 110/10(20) kV 2×20 MVA: 2 200 000 €
- modular construction of rural TS 110/10(20) kV 20 MVA: 1 700 000 €
- construction of simplified TS 110/10(20) kV 1×10 MVA: 960 000 €
- construction of urban TS 110/10(20) kV 2×40 MVA GIS SF_6 type 110 kV: 5 300 000 €
- construction of urban TS 35/10(20) kV 2×8 MVA: 1 000 000 €
- construction of rural TS 35/10(20) kV 2×4 MVA: 850 000 €
- construction of simplified TS 35/10(20) kV 1×4 MVA: 430 000 €
- total reconstruction of TS 35/10 kV, with replacements of all vital TS parts for classical type TS: 410 000 €
- total reconstruction of TS 35/10 kV, with replacements of all vital TS parts with connection black type: 610 000 €
- reconstruction of TS 35/10 kV for power enhancement (reconstruction of transformer foundations): 150 000 €
- replacement of insulators 12 kV on wooden poles for operation at the voltage level 20 kV: 3 300 €/km
- total reconstruction of overhead line 35 kV (without the poles with prolonged lifetime): 25 000 €/km for type Al/Fe 95, and 23 000 €/km for type Al/Fe 50
- line section 110 kV – classic type: 140 000 €
- line section 110 kV - SF_6 type: 500 000 €

Prices of transformer stations 10(20)/0,4 kV without the transformer:

TYPE TS - OPERATION	U_g (kV)	U_d (kV)	PRICE , €
standard pole with equipment (pole 700 kg)	10(20)	0,4	6 500 – 7 000
Constroction and electro-mounting works for pole TS	10(20)	0,4	3 000
Constroction and electro-mounting works for urban TS	10(20)	0,4	6 000
Construction housing for urban TS	10(20)	0,4	5 000 – 8 500

Prices of power transformers:

U_g (kV)	U_d (kV)	S (kVA)	WEIGHT (kg)	PRICE, €
110	10(20)	10 000	27 800	170 000
110	10(20)	16 000	33 000	203 500

U_g (kV)	U_d (kV)	*S* (kVA)	WEIGHT (kg)	PRICE, €
110	10(20)	20 000	41 400	220 000
110	10(20)	31 500	53 000	250 000
110	10(20)	40 000	59 500	283 000
110	10(20)	63 000	75 000	425 000
35	10	1 600	4 320	22 500
35	10	2 500	6 600	26 000
35	10	4 000	9 200	38 000
35	10	8 000	13 500	63 000
35	10	16 000	29 000	120 000
35	10(20)	1 600	4 320	24 000
35	10(20)	2 500	5 800	27 500
35	10(20)	4 000	9 200	38 500
35	10(20)	8 000	13 500	70 000
35	10(20)	16 000	29 500	127 000
20	10	2 500	4 200	28 000
20	10	4 000	9 100	39 000
20	10	8 000	13 200	71 500
10	0,4	30	260	1 600
10	0,4	50	370	1 975
10	0,4	100	500	2 500
10	0,4	160	750	3 075
10	0,4	250	1 040	4 050
10	0,4	400	1 320	5 150
10	0,4	630	1 820	6 850
10	0,4	1 000	2 620	9 600
20	0,4	30	300	1 750
20	0,4	50	430	2 200
20	0,4	100	665	2 250
20	0,4	160	850	3 400
20	0,4	250	1 127	4 425
20	0,4	400	1 405	5 650
20	0,4	630	1 900	7 600
20	0,4	1 000	2 800	10 425
10(20)	0,4	30	310	2 075
10(20)	0,4	50	440	2 600
10(20)	0,4	100	646	3 300

U_g (kV)	U_d (kV)	*S* (kVA)	WEIGHT (kg)	PRICE, €
10(20)	0,4	160	900	4 050
10(20)	0,4	250	1 155	5 300
10(20)	0,4	400	1 485	6 800
10(20)	0,4	630	1 800	9 050
10(20)	0,4	1 000	2 792	12 500

Prices for line construction:

LINE TYPE	*U*n (kV)	PRICE (€/km)	
		EASY TERRAIN	HARD TERRAIN
Overhead line, one circuit	110	75 000	95 000
Overhead line, double circuit	110	120 000	150 000
Cable line (1000 Al)	110	500 000	600 000
Overhead line, one circuit, 3x120 Al/Fe, with protection line	35	55 000	65 000
Overhead line, one circuit, 3x120 Al/Fe, without protection line	35	45 000	55 000
Overhead line, double circuit, 3x120 Al/Fe, with protection line	35	91 000	106 500
Overhead line, double circuit, 3x120 Al/Fe, without protection line	35	79 000	96 500
Rural cable line (185 Al)	35	50 000	60 000
Overhead line, one circuit, 3x95 Al/Fe	20	38 500	48 500
Overhead line, one circuit, 3x120 Al/Fe	20	42 500	52 500
Overhead line, one circuit, 3x150 Al/Fe	20	48 500	57 500
Overhead line, double circuit, 3x95 Al/Fe	20	65 500	83 000
Overhead line, double circuit, 3x120 Al/Fe	20	74 500	92 000
Overhead line, double circuit, 3x150 Al/Fe	20	83 000	100 500
Overhead line, one circuit, 3x50 Al/Fe, concrete poles or poles with concrete foundations	20	20 000	25 000

LINE TYPE	*U*n (kV)	PRICE (€/km)	
		EASY TERRAIN	HARD TERRAIN
Cable line (150 Al), rural	20	40 000	50 000
Cable line (150 Al), urban	20	50 000	75 000
Overhead line (SKS 70 Al), concrete poles or poles with concrete foundations	0,4	20 000	25 000
Cable line (150 Al)	0,4	30 000	40 000

For 10 kV lines with regard to the 20 kV lines of the same characteristics, the lines differ only in one insulator per line. Taking into consideration standard distances between poles, the line price differs (is lower than for 20 kV lines) for approx. 1000 EUR or 2 % to 4 %. Price difference is significantly lower than price variation because of the terrain type and is thus neglected.

6. PREPARATION OF NETWORK ANALYSIS IN PSS®SINCAL

6.1. Qualification for the integration of distributed sources

To apply these instructions it is considered that a person possesses basic skills needed for the general operation with the PSS®SINCAL program. In this case, the process will start with the preparation of data base (lines, transformers), followed by the design of the network model and finally the representation of various analyses to evaluate the situation of electric parameters in the relevant simulation network.

To actually prepare the simulation network model for later simulations, the following elements have to be determined:

- data on installation elements applied in the network (element base);
- interrelations among these elements (network topology);
- load output in modelled substations (load).

Figure 174 Scheme shows the process to be applied for the preparation of simulation network model.

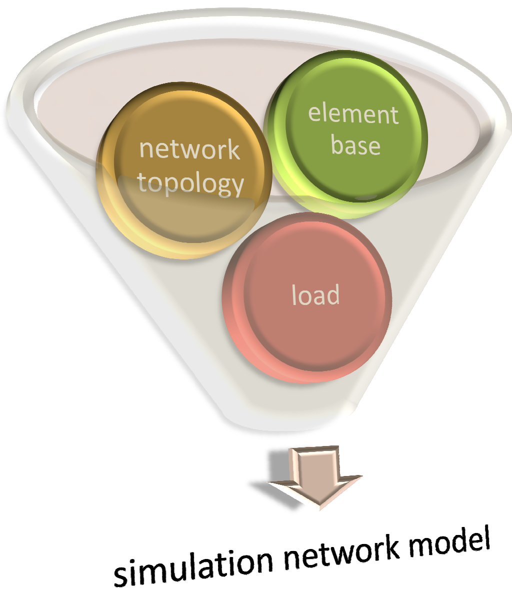


Figure 174: Schematic representation of the procedures for the preparation of simulation network model

6.2. PREPARATION OF SIMULATION NETWORK model

6.2.1. Element base

Each network consists of electric-power elements that in their topologic interrelation build the network. The behaviour of these elements is described with various parameters that differ according to the type of element (line, generator, transformer, etc.) and their nominal data (installed power, nominal voltage, etc.). In attempt to create good possibilities for efficient control of element statuses in the already prepared simulation model and also for quicker preparation of such model, the local element base preparation is recommended. This should include all typical transformers, lines, cables, generators, and other potential elements. It should consist of as many elements as possible. The more the base is complete the lesser the possibility of errors (typing) and the quicker the element type replacement in the process of network planning.

To enter the data go to *Insert>Standard Type>choose element*. The form opens to select the base (preferably local) and enter the required parameters. It should be emphasized that the amount of the required data depends on previously checked calculation methods in *Calculate>Methods*. It is evident that the quantity of the required data is increased by the number of checks. After all required elements are inserted there follows the next step in the process of simulation network model preparation.

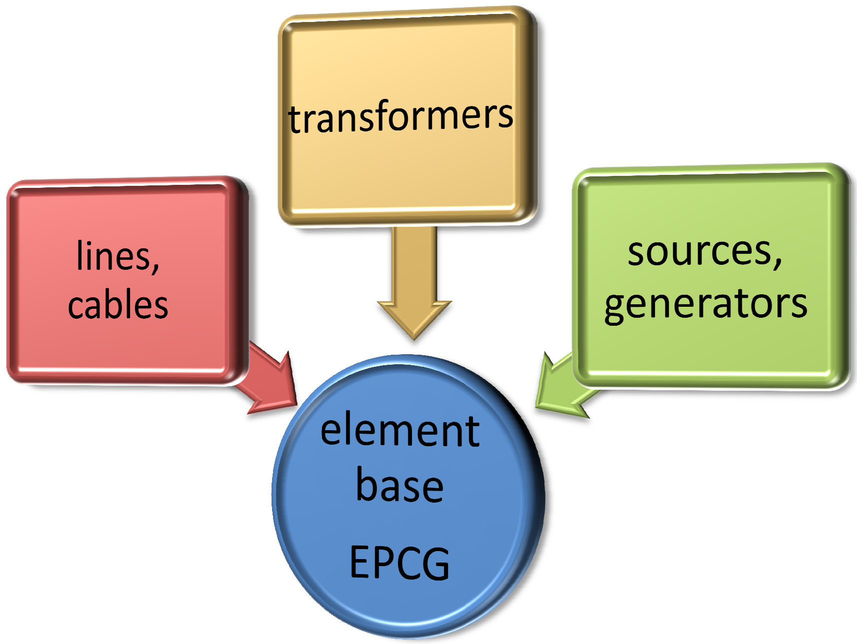


Figure 175: schematic presentation of electric-power element base

Since the main point of each base is to provide the application of its data to several users at the same time, it is reasonable to create a local EPCG base. This base is created at the accessible location, accessed via PSS®SINCAL.

6.2.2. Network topology

Electric-power network is made of electric-power elements which are interrelated. These relations are described by the so called network topology. The single-pole network scheme is used for engineer practice. The topological distribution of elements in PSS®SINCAL is conducted:

- geographically,
- schematically.

The advantage of preparing the network in geographical method is in automatic calculations of line lengths, good representation of the situation, and analysis statuses. The basis for the geographical method is the topographic map with the determined ratio, upon which the lines, sources and substations are drawn. Before the actual drawing starts, the required voltage levels need to be created with their operation and nominal voltage defined. Furthermore, the attention must be paid when drawing transformers and their actual voltage level. It should be noted that the transformer in PSS®SINCAL are always drawn from the high voltage node to the low voltage node, otherwise the problems might arise in the later simulations.

After the network drawings are finished, apart from the geographical image also the schematic method is possible. This view offers better topological insight into the situation. It should be noted that the replacement of any data in any view effects the data in all other views.

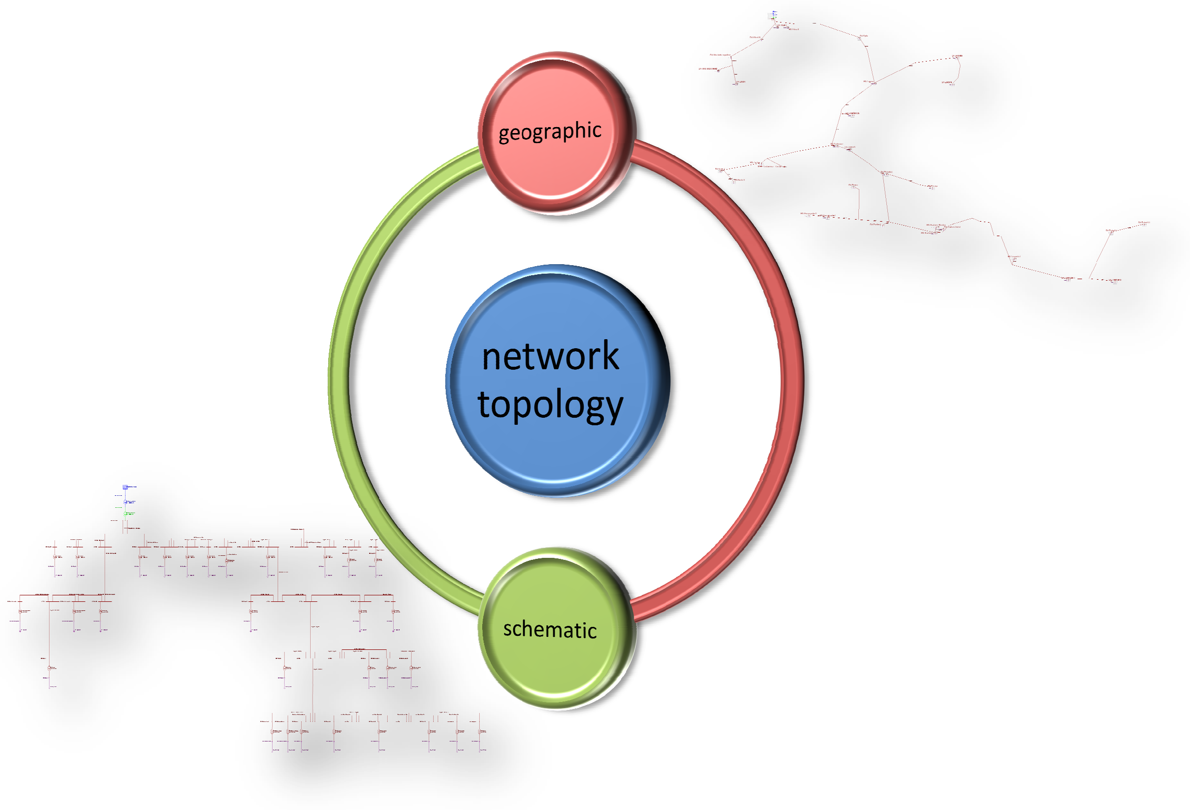


Figure 176: possible topological representation of simulation network model

6.2.3. Load

The main reason for the preparation of electric-power networks is to satisfy the electric-power consumerism. This consumerism, loading the network, varies during the day, week, month and year. Therefore it is hard to denote it only with one number. To conduct the target analyses of distributed sources connection, the network load limits suffice; minimum and maximum load. Thus, two network variants are created; MIN and MAX. Both are subordinated to the *Basic variant*. The *Base variant* is superior to all other variants and represents the unison of all subvariants.

The *Base variant* includes the configuration of all maximum loads, giving them the manipulation factor for each individual feeder. Then the MIN load variant follows and all global manipulation factors are configured for all loads on all feeders. Thus the simulation network model is prepared with the maximum (Max load) and minimum (MIN load) load.

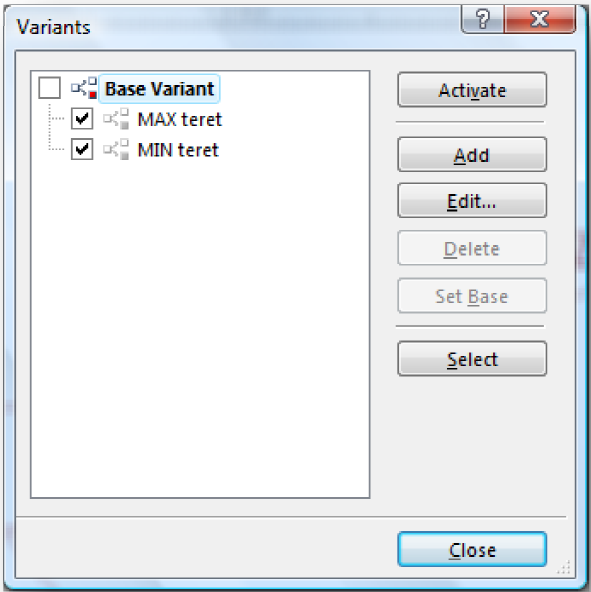


Figure 177: presentation of the created variants in pss®SINCAL, i.e. subordinated base variants

6.3. Network Analysis

The concept of network analysis comprises the realization of various simulations, in this case Load Flow, in order to selectively represent the relevant results in the studied network nodes. This analysis of distributed sources connection includes the following variants:

- maximum load without distributed sources (***MAX load – without HE***)
- maximum load with distributed sources operation (***MAX load – with HE***)
- minimum load with distributed sources operation (***MIN load – with HE***)

6.3.1. Situation analysis before and after the distributed source connection

Now the Load Flow simulation can be carried out. First the global parameters are configured for the simulation calculation found at *Calculate>Settings>Load flow*. Then the simulation calculation can be conducted. The amount of results in the current view is controlled with various filters at *View>Annotiaton and filter*. This filter form provides a powerful tool for showing the calculated values in various colours that are predefined for the scope of the presented results. Furthermore, even more complex calculation in colours can be applied at *Tools>ISO Area*.

At this point it should be emphasized that the regulation of transformers with this actual option has to be determined first. PSS®SINCAL enables the automatic regulation of transformer taps but only with the checked window in *Calculate>Calculation settings>Enable controllers*. The taps are adjusted and inserted into the fixed state, since MV/LV transformers do not have automatic regulation. In regard to this detail the manual monitoring and voltage control in the corresponding nods can proceed.

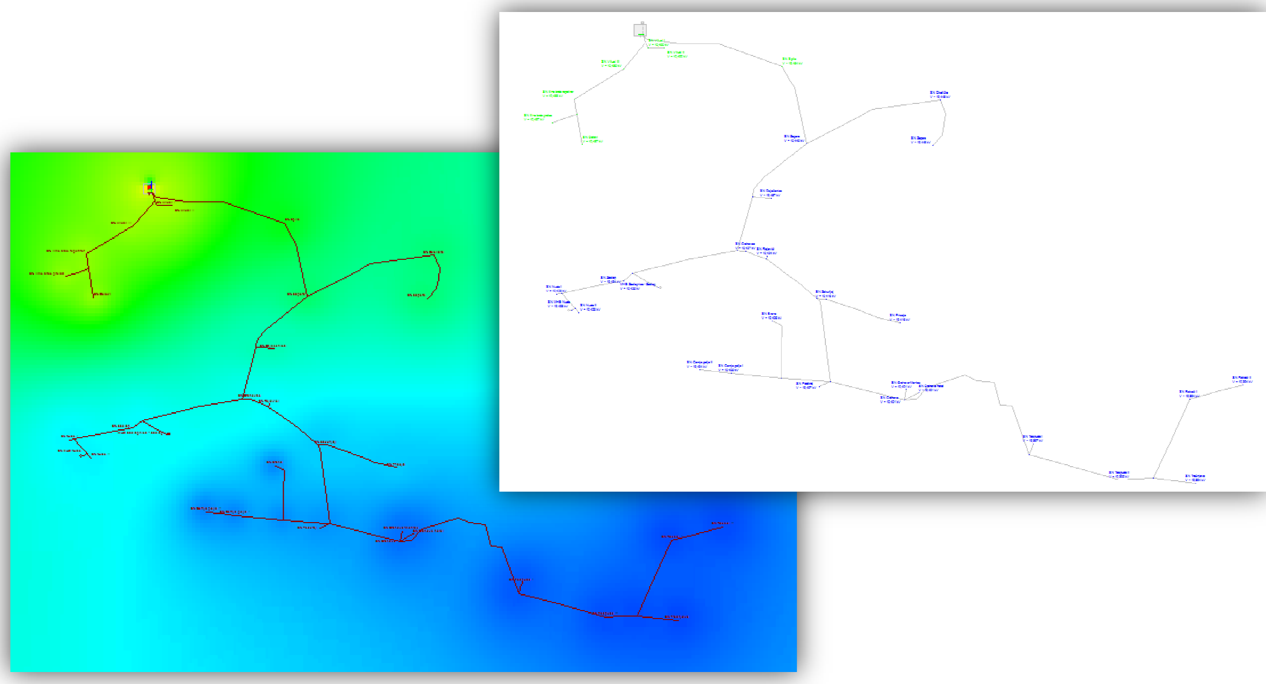


Figure 178: Possible views of voltage level in network nodes

The most representative results can be viewed and analysed in the table view, accessed by the F9 key. Here, there are various results for currently conducted calculations of corresponding network situation. All results can be copied to other programs (Excel) where further analysis can be performed or this data used for result collection of different network variants.

First, the Load Flow analysis calculation will be realized for the situation without any additional distributed sources. During the analysis the voltage change and output in MV and LV network are shown in relation to the network load situation and distributed source connections. The situation with maximum load is calculated. Then the variant MAX load is applied to create two different sub-variants in terms of the presence of distributed sources. The simulation is started in the variant MAX load – without HE. The results are automatically saved in variant memory to provide the next step of variant MAX load – with *HE*. Thus the line load situation, voltage situation, and influence of distributed sources on the mentioned parameters are established. The situation example for the variant MAX load – without HE, shows that the voltage in LV nodes is from 391 V to 420 V. In the situation with connected HE, the LV node voltages are form 391 V to 449 V. This is shown in the graph.

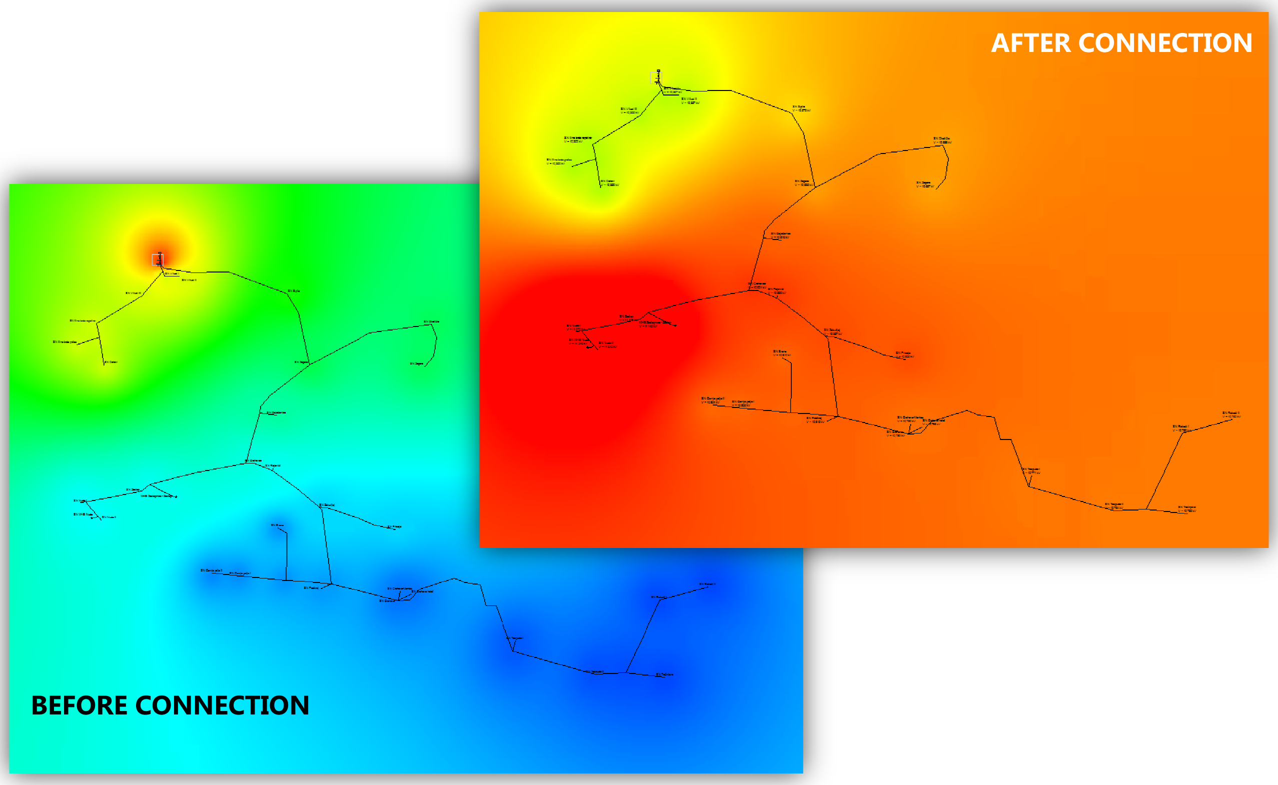


Figure 179: Graph of network voltage before and after distributed sources connection

It is evident that the voltages are too high in the situation with activated distributed sources. The results of line loads show that the highest line load is almost 50 % of its nominal capacity. The above mentioned parameters can be also directly compared between variants. By applying *View>Annotiaton and filter* the selection of desired parameters for comparison is done. The parameter is selected and then with the right click the desired view is selected. Now the variant selection follows where the variants to be compared are checked. In this way, the fast overview over variant situations is provided.

In general, also the graphical comparison of voltage profile along the feeder can be applied. First a group has to be created on which the voltage profile will be monitored. To carry out the comparison between the variants it is recommended to create the nominal group in the Base variant. In the Base variant the elements along the feeder with relevant voltage profile are selected. This can be done manually (by clicking and holding Shift) or automatically in Network Browser. Go to *View>Network browser* to select *Calculate routes* or directly to *Tools>Calculate routes*. Then the window *Lines* is selected, we click the button *Calculate* and determine the starting and final node in new window to select the elements. E.g. *Vilusi 10 kV* (start node) and *MV Nudo II* (end node) is selected. The button OK is clicked and the Route one is calculated. Then Select button is right clicked. Now the lines between the chosen nodes are selected. With the lines still selected we go to *Insert>Network element group* and create new group and define the *Voltage curve* type. Now all is prepared to run the graphical length comparison along the feeders with various variants.

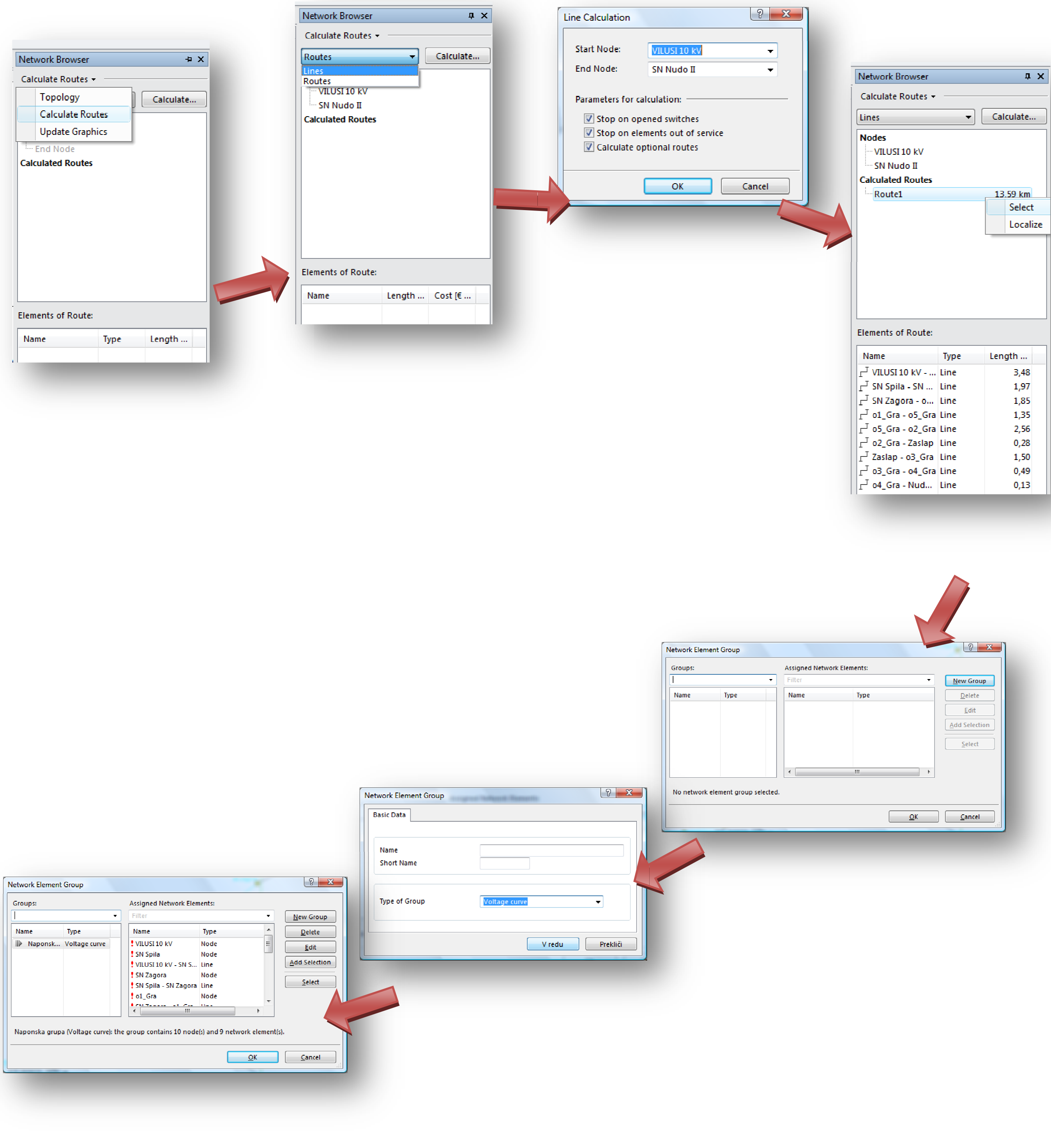
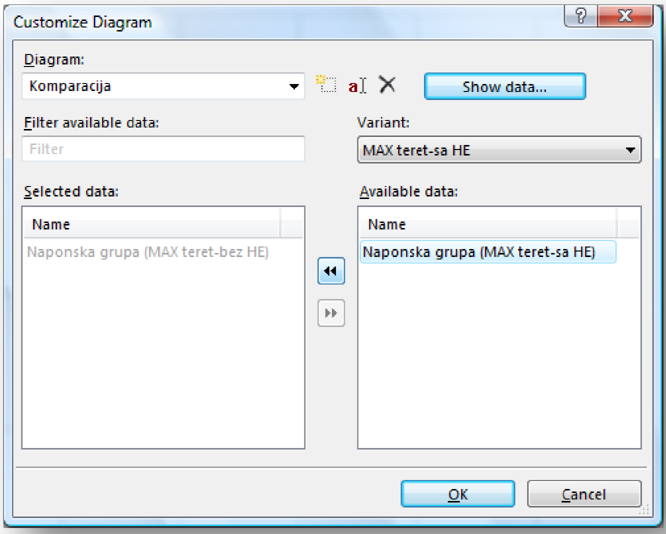


Figure 180: Process of creating the voltage group in pss®sincal

Now, the variants are selected to be compared. For each of them the Load Flow calculation is run. Go to *View>Diagram view* and in the window (left) select previously created *Voltage curve* groups. By clicking the right button we select *Customize diagram* and create a new diagram. In the column variants we select them and add from the window *Available data* to the window *Selected data*. Now we can clearly see the influence of the added distributed sources on the voltage situation in 10 kV network. We go to the variant *MAX load - without HE* and *MAX load - with HE* to create Load Flow calculations. According to the described process the diagram of voltage profile along the selected feeder is created.



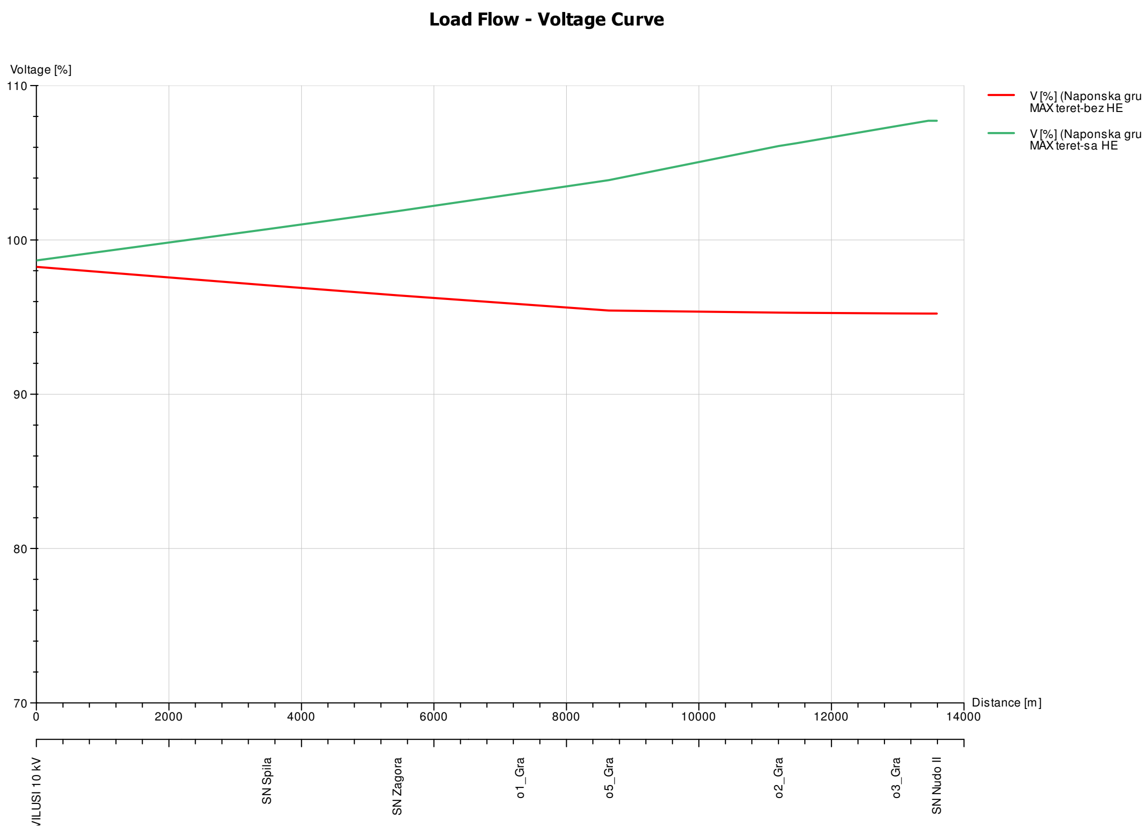


Figure 181: Perparation of comparison diagram of the voltage group in PSS®SINCAL

This Figure clearly shows the influence of distributed sources on the voltage profile in the network. By selecting other data in Show data (right click on the graph) the view of voltage profile in the phase voltage relation, power relation or the feeder length and even the situation of line loads can be easily changed. In all cases the abscissa shows the absolute length of the relevant lines with the node locations, whereas the ordinate displays the output of the selected data category.

Also the situation in the least favourable situation with minimum load and connected distributed sources (variant MIN load – with HE). Voltages in this example with LV nodes are increased even to 465 V.

Now the proper measures need to be taken for the situation reestablishment in the network and provision of normal operation situation with connected distributed sources.

6.3.2. Network analysis after the realized rehabilitation

Due to problems during the connection of distributed sources, manifested in the excessive voltages in our case, the necessary measures need to be taken to rehabilitate the existing situation. The network reinforcement is opted for. In this way the new sources are connected to the Dalovi feeder and simultaneously to the direct line to RTS Vilusi with reinforced AL/Fe 70/12 conductor. Now the series of simulations can be conducted and their results analysed.

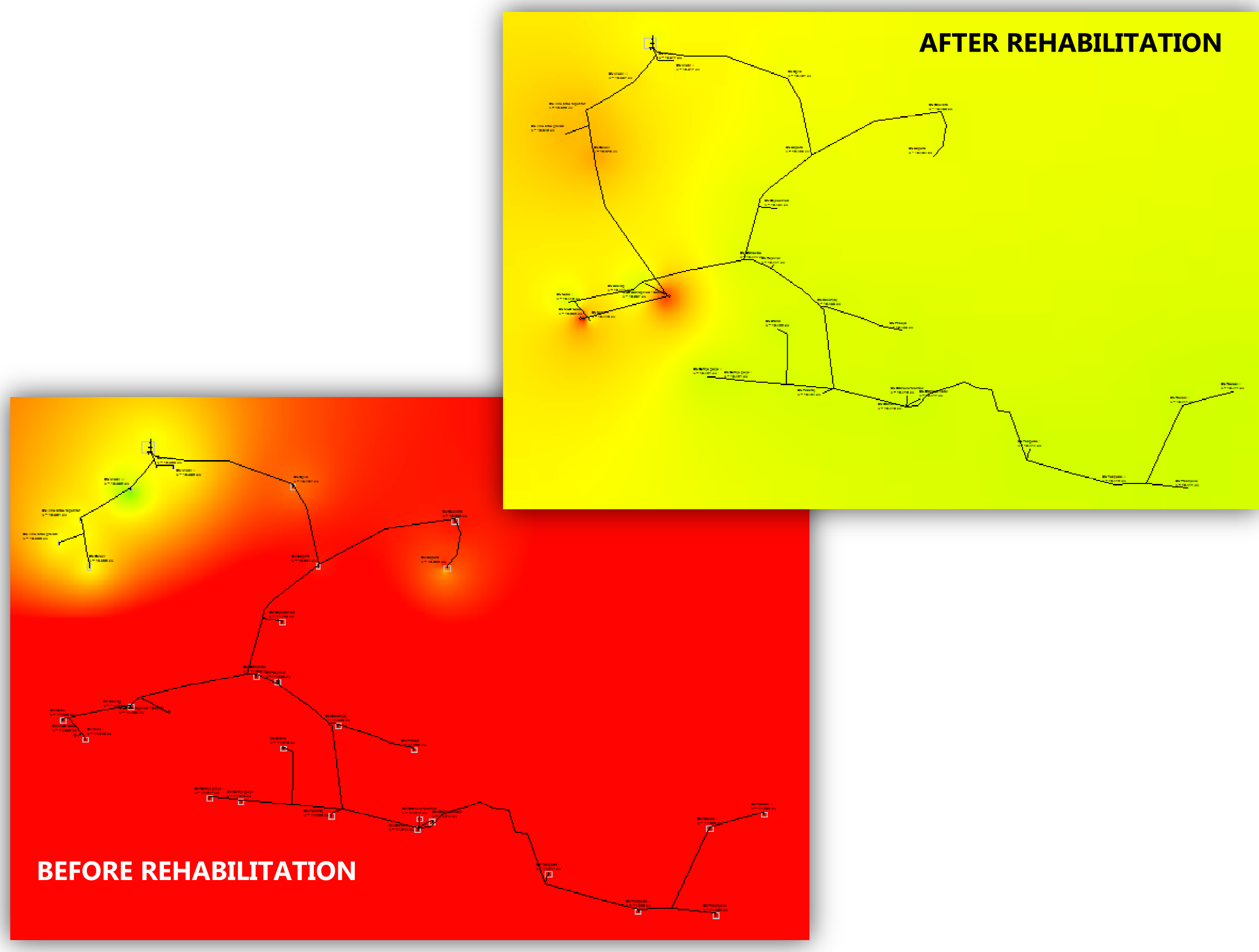


Figure 182: Voltage situation before the conducted rehabilitation of the network with connected distributed sources

Also the approaches can be applied to establish the power limits for the connection to the existing network. Thus, the distributed sources (generators) need to be replaced by negative load. By negative

load the power is returned and the voltage in near nodes monitored. The result of this is a graph that shows the node responsiveness on the injected power increase.

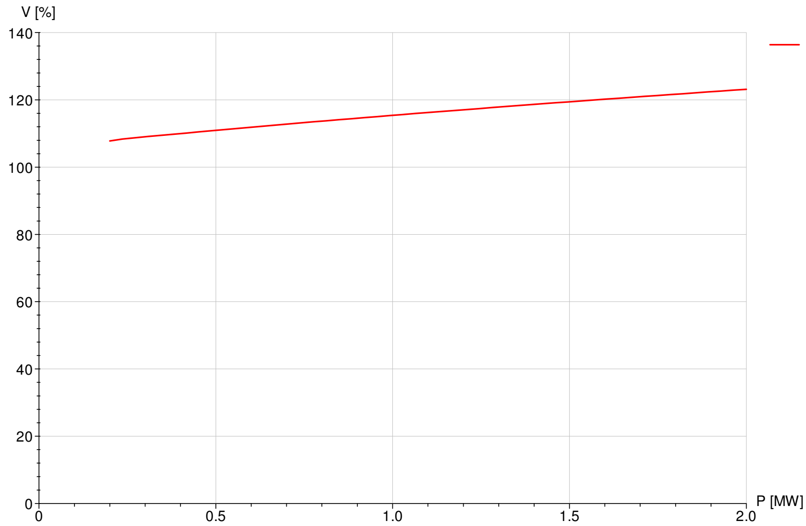


Figure 183: Node responsiveness on injected power increase

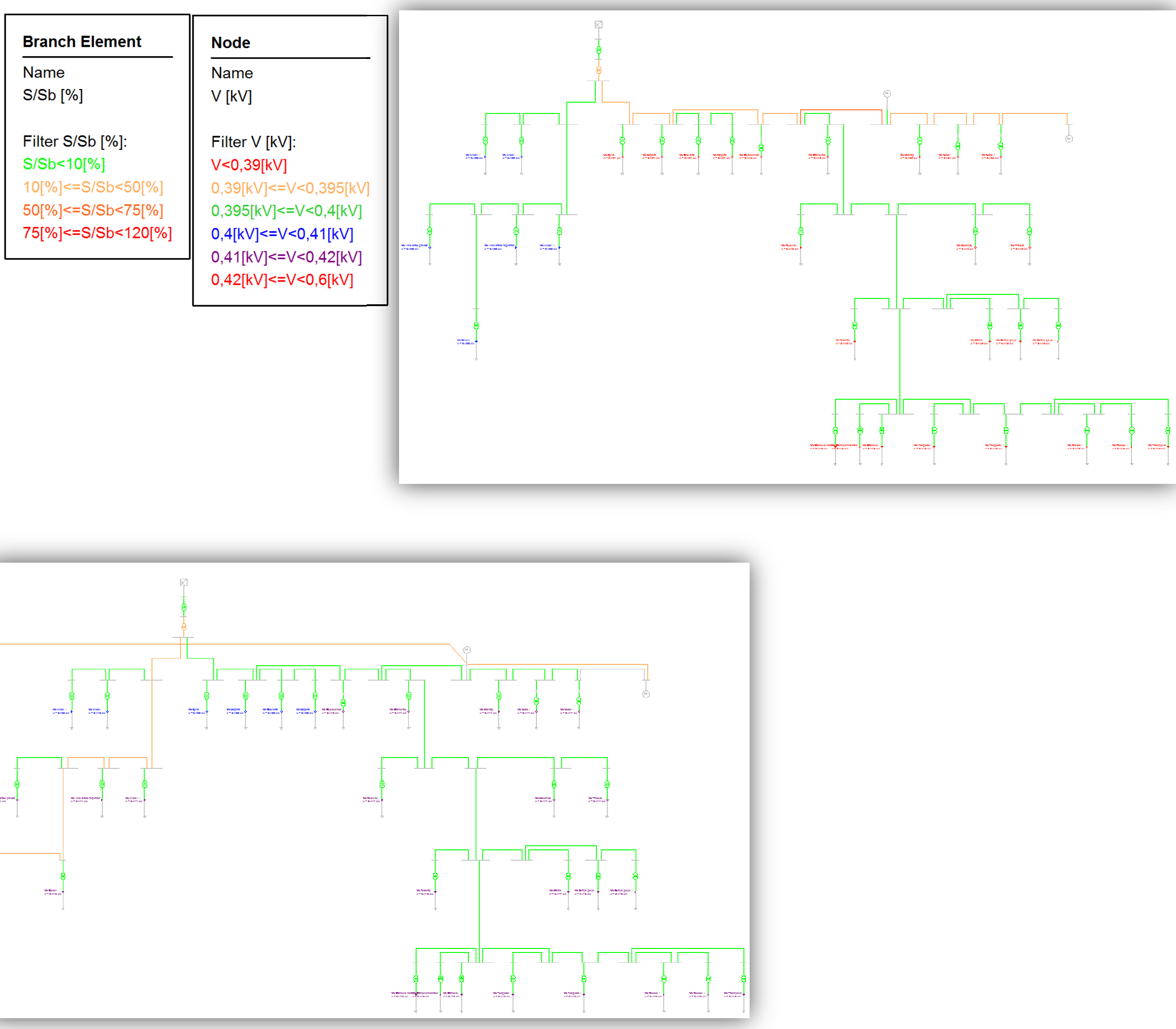


Figure 184: example of voltage in LV network after the conducted rehabilitation

The method of representation and the quality of the analysed PSS®SINCAL data mainly depends on the engineer who runs and operates the simulations and his desired analysis scope.

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