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INTEGRATION OF SMALL HYDROPOWER PLANT WITH THE GRID, MODELLING USING PSS SINCAL SOFTWARE

MASTER'S THESIS DISSERTATION

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ABSTRACT

This thesis studies the use of hydroelectric energy, as an energy source to produce electricity, and to inject this energy to the distribution line. This type of power plant takes advantage of the potential energy of water and converts it into mechanical and finally electrical energy. Moreover, hydropower plant is a predictable source of energy, so the available power can be known.

For this project, a study will be carried out on a small hydroelectric plant, which will be connected to an existing medium voltage distribution network. Hydropower plants are divided into two main parts, which are the generator and the transformer, thus both part are sizing and analysing in the system.

A response study is carry out after the connection of the hydroelectric power plant, to check that there are no technical problems and that this energy source can be perfectly integrated in parallel with the power supply to the network.

The PSS SINCAL software was used for this purpose, and the short-circuit and load flow simulations were carried out.

In addition, compliance with the regulations of the Polish Grid Code has been taken into account.

KEY WORDS: hydroelectrical, PSS SINCAL, short-circuit, load flow, network model analysis

1. INTRODUCTION. PURPOSE AND SCOPE OF THE STUDY

The objective of this project is to define and test the conditions for connecting a hydropower plant to a 20kV grid connected to the 110kV high voltage grid, demonstrating its impact on the operation of the grid.

The impact analysis of the connection of a hydroelectric plant, for different output powers, will be carried out in order to evaluate the effect that several plant sizes would have on the network.

The report includes calculations of two types of calculations:

1. load flow (LF)
2. short current (SC).

LF gives the power and currents in network branches in normal and alert operation condition. It enables defines possibilities of transport power by the network by defining load current in branches and their displacement from full load currents. It enables also checking whether the voltage level on the 20kV side of the stations is correct – do not exceed the limit values in nodes of the network.

Short circuit calculations gives values of currents in nodes and branches of network in cases of faults. There is possibility to check whether the increase in current resulting from the connection of the hydroelectric plant to the network will not cause local overloads in the line sections, in order to determine the safety of the installed equipment.

In general, requirements for the scope of the study have been checked.

In other words, the intention is to check most important requirements deciding about possibility of implementation of a renewable resource with the electricity network of medium voltage (20 kV)

For the realization of the project, that is to say for the analysis of the system, PSS SINCAL software will be used. It will be the main working tool.

2. SOFTWARE PSS SINCAL

PSS SINCAL is a simulation software for analysis and planning of all network types.

Through its modular design, PSS SINCAL is highly flexible and customizable. It offers a wide variety of analysis functions for the planning, design and operation of power systems, allowing you to simulate and study: power quality, frequency stability, distributed generation interconnection, protection coordination, restoration of supply, economic driven design decisions, and more.

For this project the program module of interest is PSS SINCAL modules for electrical network planning. Supporting all network types from the lowest to the highest voltage levels with balanced and unbalanced network models, PSS SINCAL offers you a various range of capabilities from short-term to long-term planning tasks, fault analysis, reliability, harmonic response, protection coordination, stability (RMS), electromagnetic transient (EMT) studies, and more.

3. TECHNICAL REQUIREMENTS FOR THE OPERATION

3.1. VOLTAGE QUALITY CRITERIA

The parallel operation of the power system with a hydroelectric power plant is characterized by significant and continuous variability in the condition of the system, associated with a possible change in the active power generated, depending on how this new energy is managed. The change of the generated power is transferred to the change of the voltage value at the switch-on location. The effect of connecting a hydroelectric power plant to the grid is a static voltage change (voltage rise) at a given node of the power system.

For generation units connected to the distribution network, voltage changes must be within a declared range in the Grid Code.

The voltage and frequency values are given above and are quasi-stationary, with a gradient of change at frequencies and voltages also defined in the Grid Code.

Connecting the generating unit to the mains may cause short transient states of the supply voltage. The magnitude of the dynamic voltage changes depends on the type of power plant and the level of short-circuit power at the switching point. The question of dynamic voltage changes is mainly related to wind farms.

The plant must be equipped in such a way as to ensure that the voltage conditions specified in the regulations and the stability of the cooperation with the system are maintained. It should be capable of adjusting the power factor and/or voltage at the connection point.

3.2. GRID CODE

A grid code is a technical specification which defines the parameters that must be met by an installation connected to a public electric grid to ensure safe, secure and economic proper functioning of the electric system. The grid code is specified by an authority responsible for the system integrity and network operation. Its elaboration usually implicates network operators (distribution or transmission system operators), representatives of users and, to an extent varying between countries, the regulating body.

Contents of a grid code vary according to the transmission company's requirements. Typically, a grid code will specify the required behaviour of a connected generator during system disturbances. These include voltage regulation, power factor limits and reactive power supply, response to a system fault (short-circuit), response to frequency changes on the grid, and requirement to "ride through" short interruptions of the connection.

3.3. IMPLEMENTATION OF EUROPEAN NETWORK CODES

European GRID CODES (GC)[1]

The European GC are a set of regulations adopted by the European Union, through a comitology process, to be published and applied directly, but not in all cases immediately, in the EU Member States.

The need to draft the European GC was identified during the development of the 3rd legislative package for the constitution of an internal market for gas and electricity in the European Union. This legislation established specific drafting roles for the GC for the following entities: the European Commission (EC[2]) to initiate the development and adoption of the GC; the Agency for the Cooperation of Energy Regulators (ACER) to develop the framework guidelines and recommend the adoption of the GC to the EC; and the European Network of Transmission System Operators for Electricity (ENTSOE[3]) to draft the GC.

As defined in Regulation EC No. 714/2009, European GC contribute to the harmonisation, integration and efficiency of the European electricity market. Each GC is a key factor in the competitiveness of the internal energy market and in achieving the EU's energy objectives.

The European GC conferences cover three main areas:

- Network connection. They set requirements for electricity production facilities, power consumption and distribution facilities, and HVDC transmission facilities that are connected to the electricity system.
- System Operation. With the increasing interconnectivity between the electrical systems of the different European countries and the different individual practices of each TSO to ensure the security of the system and guarantee of supply in real time, a set of regulations is established constituting a common guideline for the operation of these systems.
- Markets. They lay the foundations for the creation of the internal electricity market in the field of capacity calculation and allocation on a long-term, daily and intraday basis and in the functioning of the electricity balance markets.

To elaborate this project, the necessary grid code area to consider is the first one, network connection characteristics.[4]

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[1] https://www.esios.ree.es/es/pagina/codigos-de-red

[2] http://www.iec.ch/

[3] *ENTSOE. (2016). Parameters of non-exhaustive requirements.*

[4] http://www.ree.es/es/actividades/operacion-del-sistema-electrico/procedimientos-de-operacion

National Grid Codes tend to be more exhaustive and specific than continental Grid Codes.

3.4. GRID CODE IN POLAND

In Poland there to basic sets of requirements treated about connection of generation units to the grid. First set describe requirements for transmission network of highest voltages220 kV and more. This set is publish by Polish Power Grid Company (PPGC) (Polskie Sieci Energetyczne SA) which is the operator (manage) the transmission system. This set of requirements is based on the European Transmission System Operators (ETSO) issues.

Second group of requirements is publishing by distributions companies. These requirements are destined to distribution networks and partially based on PGC issue.

Basic requirement for connection of generation units to distribution network

1. For asynchronous generators, which start as the engine, requirements are like for engines. For generators with pulled-out power up to 100 kVA connected to the distribution low voltage grid LV, starting current should not exceed 60 A. For other generation units starting currents should be limited to the values which prevent negative influence on the distribution network.
2. For synchronous generators the synchronizer is needed which enables came into operation with following requirements of synchronisation:
   a) difference of voltages – $\Delta U < \pm 10$ % Un,
   b) difference of frequency – $\Delta f < \pm 0{,}5$ Hz,
   c) phase displacement angle – $\Delta\varphi < \pm 10°$,

3. Nominal frequency is 50 Hz with tolerate displacement from the range -0,5Hz do +0,5 Hz, in 99,5% of week time.
4. For generators connected do distributed network, in each week, 95% from the 10-minute averages of root-mean-square voltage values should be in the range ±5% of nominal voltage or declare voltage (in LV declare and nominal voltages are equal).
5. For places of connection in distribution network of nominal values 110 kV, MV and LV, contents of each harmonics in relation to basic harmonic should not exceed 0,5 %.

6. THD coefficient (which takes all harmonics up to 40) of voltage distortion should not exceed:
   a) 1,5 % - for place of connection in the network of nominal voltage not greater than 110 kV and greater than 30 kV,
   b) 3,0 % - for place of connection in the network of nominal voltage not greater than 30 kV and greater than 1 kV,
   c) 5,0 % - for place of connection in the network of nominal voltage not greater than 1 kV.

7. In the normal operation mode of distribution network, in each week, index of long term light flicker Plt caused by voltage fluctuation, by 95 % of time should fulfil requirement: $Plt \leq 0,6$.
8. This requirement is also fulfilled for cases, when:
   - for generation units connected to MV network supplied from buses of 110/MV station:

$$\frac{S_{rA}}{S_{kV}} x100\% < 2\sqrt{N} \qquad \text{Eq. 1}$$

   - for generation units connected to LV network

$$\frac{S_{rA}}{S_{kV}} x100\% < \frac{3\%}{k} \qquad \text{Eq. 2}$$

where:

S_{rA} – pull-out power of generation unit,

SkV – short circuit capacity in the place of connection of generation unit,

N – number of thyristor converters of similar nominal power cooperated with generation unit,

k – coefficient equal:

1 – for synchronous generators,

2 – for asynchronous generators which are put in service at 95 % ÷ 105 % of synchronous speed,

Ia/Ir - for asynchronous generators, which are put in operation like a engine,

8 – for cases, where starting current is not known,

Ia – starting current,

Ir – nominal continuous current.

4. SYSTEM DESCRIPTION

4.1. GENERAL DESCRIPTION

The potential for hydroelectric systems depends on the availability of suitable water flow where the resource exists, but in any case, it can provide cheap, dean, reliable electricity. Hydroelectric plants convert the kinetic energy of a waterfall into electric energy. The power available in a flow of water depends on the vertical distance the water falls and the volume of the flow of water. The water drives a turbine, and its rotation movement is transferred through a shaft to an electric generator. A hydroelectric installation alters its natural environment. The impact on the environment must therefore be evaluated during planning of the project to avoid problems such as noise or damage to ecosystems.[5]

4.1.1. SMALL HYDROPOWER IN EU-27

As a backbone for renewable energy production in Europe hydropower has a key role in meeting both the 2020 renewable energy targets as well as the greenhouse gas reduction targets. Small Hydropower generates 41 000 GWh of electricity and accounts to over 13 000 MW1 of installed capacity in EU-27 which is enough to supply electricity for over 12 million households. This contributes to annual avoidance of CO^2 by 29 million tonnes, which translates into annual avoided CO^2 cost of about 377 million euros.

Hydropower is very dependent on a country’s geography. This is demonstrated by the fact that over 90 % of installed small hydropower capacity is concentrated in six-member states of the EU-27. These leading six countries are Italy on the top, followed by France, Spain, Germany,

Austria and Sweden. In addition, Switzerland and Norway have a high SHP capacity, while the largest capacities in the new member states are in Bulgaria, the Czech Republic, Poland and Romania.

The potential for small hydropower in Europe both from upgrading and from building new schemes is considerable accounting up to 10,000 MW or 38,0002 GWh annually. This potential is defined as additional or remaining economically feasible potential where the environmental constraints have been taken into account. The total potential in EU-27, which includes existing plans and potential, accounts to 68,4003 GWh annually. The largest potential among the MS can unsurprisingly be found in Austria, France, Italy, Poland and Romania that already have high electricity generation from SHPs. It is also worth noting that Norway, Switzerland and Turkey have high remaining potentials.

With the increased global electricity demand, urgent need to cut down greenhouse gases and fight against climate change and environmental degradation from fossil fuel use, there is an increasing interest in developing SHP. Indeed, this considerable, yet untapped SHP potential can make a significant contribution to future energy needs in Europe and globally and to contribute to EU’s goal to make the transition to a low-carbon economy by 2050.

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[5] Integration of distributed resources in power systems, Robert Lis, Marian Sobierajski

4.1.2. OVERVIEW SPAIN

In the report obtained of (Unied Nations Industrial Development organization, 2016)[6] it is possible to have an overview of small hydropower plant in Spain. Spain has a total installed capacity of 180.299 MW (by 2015), of which 19% corresponds to hydropower. The distribution of the energy sources providing electricity is shown in the following graph:

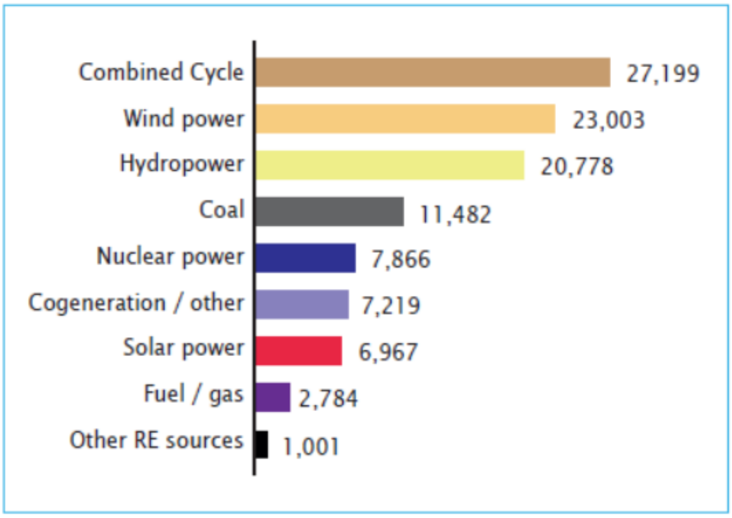

Figure 1. Installed electricity capacity in Spain by source (MW)[7]

For small hydropower (SHP), in Spain there is an installed capacity of 2.104 MW from 1.901 plants. Most of them are located in the north of Spain, in the region

ns where the larger number of river basins with more hydropower resources are located.

SHP plants, due to the favourable administrative and legal framework, have considerably increased their capacity since the early 1990s.

From 1998 to 2014, the number of SHP plants and installed capacity has increased by 62.6 %. The SHP plants

have an important impact on the Spanish economy. In 2013, the SHP industry contributed EUR 518 million (US$571 million) to the national GDP.

The total theoretical hydropower potential in Spain is 162,000 GWh/year, the technically feasible potential is 61,000 GWh/year and the economically feasible potential is 37,000 GWh/year. The SHP potential generation has been estimated at 7,500 GWh/year.

The resurgence of the SHP sector was due to the Government's support of the producers of renewable energy. The Electricity Sector Law (54/1997) set a special regulation for sources of renewable energy with an installed capacity lower than 50 MW. But, the Spanish economic crisis, alongside the increase of tariffs, has led to the adoption of a series of contentious measures against renewable energy, as they were seen as the cause of this increase.

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[6] *World Small Hydropower Development Report, Unied Nations Industrial Development organization*

[7] https://www.ieee.org/

Later, the new Electricity Sector Law (24/2013) was issued. The law foresees the possibility in certain exceptional cases, to establish retributive regimes in order to promote the production of renewable energy.

There is currently no regulation published concerning the residual flow. A recommendation could be made in the sense that this flow should be variable during the year, to enable a better adjustment to the differences of the natural hydrological regime and to the spawning seasons.

There are some barriers to small hydropower development, although SHP has played an important role in electricity generation in the country, SHP development, particularly since the tariff deficit, currently faces several barriers:

- Some potential hydropower sites have not been studied in detail, thus, there is a lack of knowledge regarding their actual potential.
- In order to use water for hydropower purposes, licences need to be issued which requires an environmental authorization approval; the excessive waiting time to get approvals slows the development of potential projects.
- Difficulties in renewing the water concession periods of the current hydropower plants. This could lead to the abandonment of some existing SHP plants.
- The administrative process to get a licence is complex, even for small projects.
- There are obstacles in the procedure of getting authorization from regional and local organs.

HYDROELECTRIC GENERATOR

Diagram of a hydroelectric generator can be like follow:

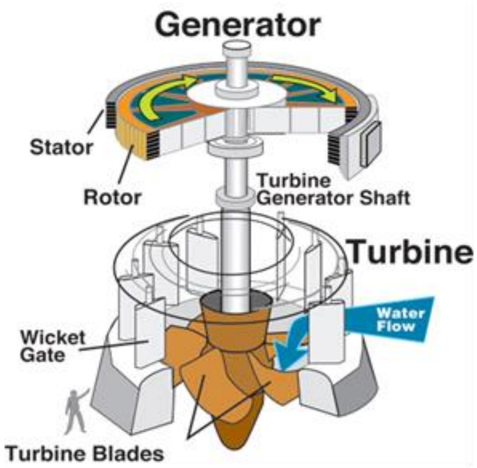

Figure 2. Diagram of hydroelectric generator

Water flow impinges on turbine blades, which converts the kinetic energy of the working fluid, in this case water, into rotational motion of the turbine shaft.

This shaft is connected in the same plane to the generator shaft, that is to say the generator turns at the same time, and converts mechanical energy into electrical energy

Hydroelectric Power Generation Efficiency

Hydroelectric power generation is by far the most efficient method of large scale electric power generation. Energy flows are concentrated and can be controlled. The conversion process captures kinetic energy and converts it directly into electric energy. There are no inefficient intermediate thermodynamic or chemical processes and no heat losses. The overall efficiency can never be 100% however since extracting 100% of the flowing water's kinetic energy means the flow would have to stop.

The conversion efficiency of a hydroelectric power plant depends mainly on the type of water turbine employed and can be as high as 95% for large installations. Smaller plants with output powers less than 5 MW may have efficiencies between 80 and 85 %. It is however difficult to extract power from low flow rates.[8]

SUPPLY WITH GENERATORS

In order to analyse the electrical connection system, first of all, it is necessary to know the process that follows the power from generation to final consumption.

Like general overview, the process that electric energy follow, from generator to the consumers consists of some steps.

First, the hydroelectric generator generates high current, low voltage alternating current, which is then passed on to a transformer that converts it into high or medium voltage, suitable for transport over long distances with minimum losses. In this case it is converted to medium voltage, as the generator is located close to the medium voltage line and the consumption areas.

Later, in the consumer station, a new transformer transforms it into a low voltage current for direct application to domestic and industrial receivers.

4.2. SYSTEM ANALYSED

The complete electrical distribution system to be analysed, chosen to integrate a hydroelectric power plant, is as shown in the Figure 3, represented schematically with arrows and symbols in the programme SINCAL.

It’s composed of the electric grid like main supply, connected to a substation HV/MV to convert high voltage of 110 kV in medium voltage of 20 kV, and after that going to many points of consumers. In which a new MV/LV transformation is required. In this case, the transformation is carried out from medium voltage to low voltage, in order to be able to supply electricity to the final consumers.

In the middle it can be show a source, that it would be represent generator of hydropower plant, which can be connected or disconnected in the system for compare different scenarios.

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[8] http://www.mpoweruk.com/hydro_power.htm

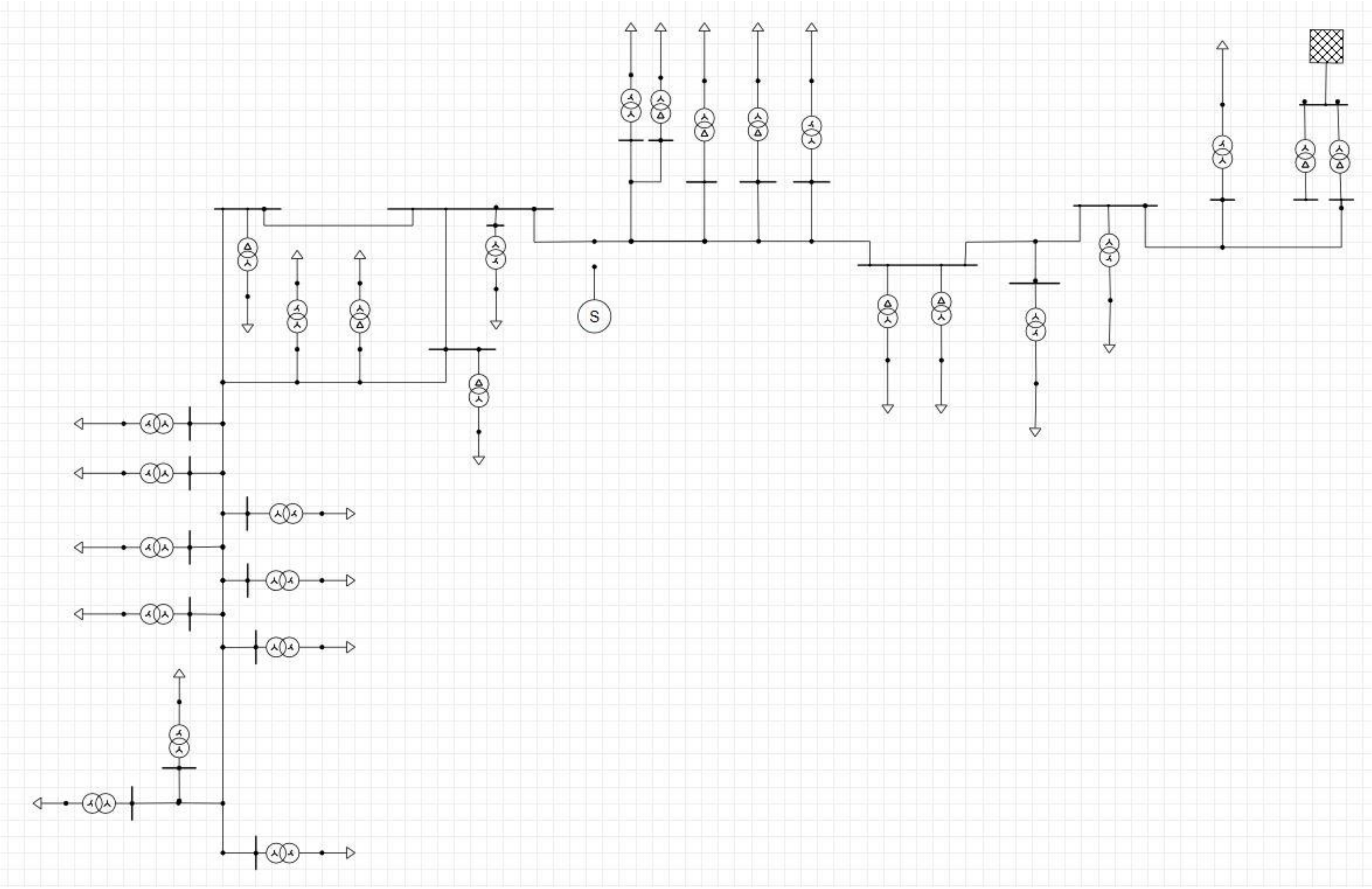


Figure 3. Diagram of the whole distribution network

The system can be divided in different kind of components, like this:

- TRANSFORMERS (HV/MV and MV/LV)
- LOADS
- LINES
- BUSES
- HYDROPOWER PLANT / GENERATOR

Furthermore, it's important to remark that the network is distributed in different levels of voltage in function of the installation site, and this is an important definition concept.

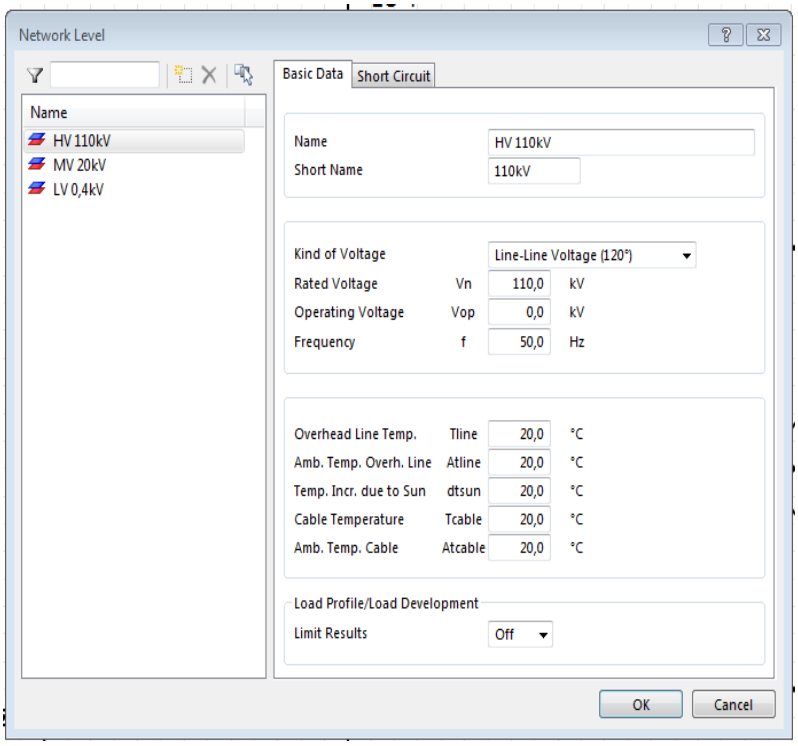
4.2.1. NETWORK LEVELS

In every energy transmission and distribution system it is necessary to have different levels of network, making the transition from one level to another in the transformer stations.

In this case, the system is divided into 3 levels, that can be named and divided as follows:

- High voltage (HV): 110kV, this is the level at which the grid power supply is connected to the system. Which comes from the general electricity transmission network of the country.
- Medium voltage (MV): 20kV, is the distribution network of this system, from the transformation in the main substation to each of the low voltage transformers. But also, the generator of hydropower plant is connected in this level of voltage.
- Low voltage (LV): 400V, this is the level of distribution to each of the final consumption.
- Low voltage for hydrogenator: 500V, the generator of the hydropower plant produces electricity with a voltage of 500V.

Differents levels are defined in SINCAL with characteristics like follow:



HV 110kV
MV 20kV
LV 0,4kV

Name: HV 110kV
Short Name: 110kV
Kind of Voltage: Line-Line Voltage (120°)
Rated Voltage Vn 110,0 kV
Operating Voltage Vop 0,0 kV
Frequency f 50,0 Hz
Overhead Line Temp. Tline 20,0 °C
Amb. Temp. Overh. Line Atline 20,0 °C
Temp. Incr. due to Sun dtsun 20,0 °C
Cable Temperature Tcable 20,0 °C
Amb. Temp. Cable Atcable 20,0 °C
Load Profile/Load Development
Limit Results: Off

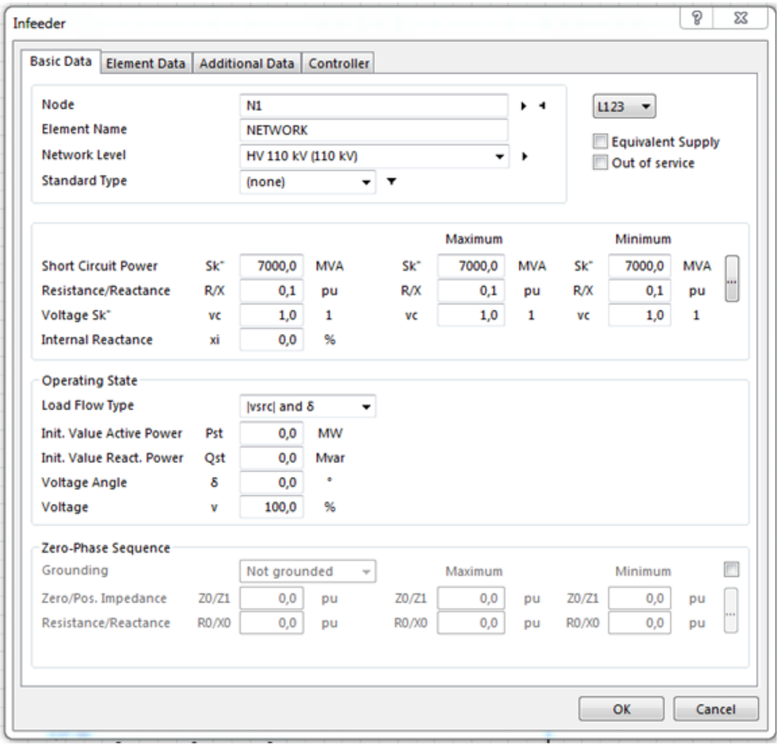
Figure 4. Network levels defined in SINCAL

4.2.2. BUS

It is a rigid electrical conductor, located in substations in order to serve as a connector for two or more electrical circuits, which is essential in that network model. It can represent substation in the case of single-bus station.

There are different buses, differentiated for each voltage level. For this raison, the different levels of buses are the same that network levels:

- High voltage (HV): 110kV
- Medium voltage (MV): 20kV
- Low voltage (LV): 400V
- Low voltage for hydrogenator: 500V



Node: N1
Element Name: NETWORK
Network Level: HV 110 kV (110 kV)
Standard Type: (none)
L123
☐ Equivalent Supply
☐ Out of service

				Maximum			Minimum	
Short Circuit Power	Sk"	7000,0	MVA	Sk"	7000,0	MVA	Sk"	7000,0	MVA
Resistance/Reactance	R/X	0,1	pu	R/X	0,1	pu	R/X	0,1	pu
Voltage Sk"	vc	1,0	1	vc	1,0	1	vc	1,0	1
Internal Reactance	xi	0,0	%						

Operating State

Load Flow Type		|vsrc| and δ	
Init. Value Active Power	Pst	0,0	MW
Init. Value React. Power	Qst	0,0	Mvar
Voltage Angle	δ	0,0	°
Voltage	v	100,0	%

Zero-Phase Sequence

				Maximum			Minimum		
Grounding		Not grounded							☐
Zero/Pos. Impedance	Z0/Z1	0,0	pu	Z0/Z1	0,0	pu	Z0/Z1	0,0	pu
Resistance/Reactance	R0/X0	0,0	pu	R0/X0	0,0	pu	R0/X0	0,0	pu

Figure 5. Infeeder properties in SINCAL

4.2.3. TRANSFORMER

There are three levels of transformation, one of them is for change from high to medium voltage (from 110kV to 20kV), other is the change from medium to low voltage (from 20kV to 400V), and the last one, is the transformation used in the hydropower plant, for pass from low voltage (500V) to medium voltage (20kV).

- For the change from high level to medium level there is only two transformers, only one of them is operative for connect with the whole system and the other is a support or reservation system.
  It is a two-winding transformer, of the vector group YND11, the most common for power transformers. This kind of transformer means that the high voltage connection is star, neutral is brought out, and medium voltage connection is delta. Moreover, the number 11 mean that MV lead the HV by 30 degrees. The next picture is the scheme of the winding connection, on the left side high-voltage winding (H), and in the right side low-voltage winding (X):

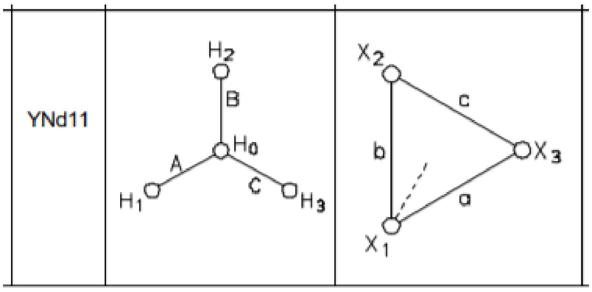
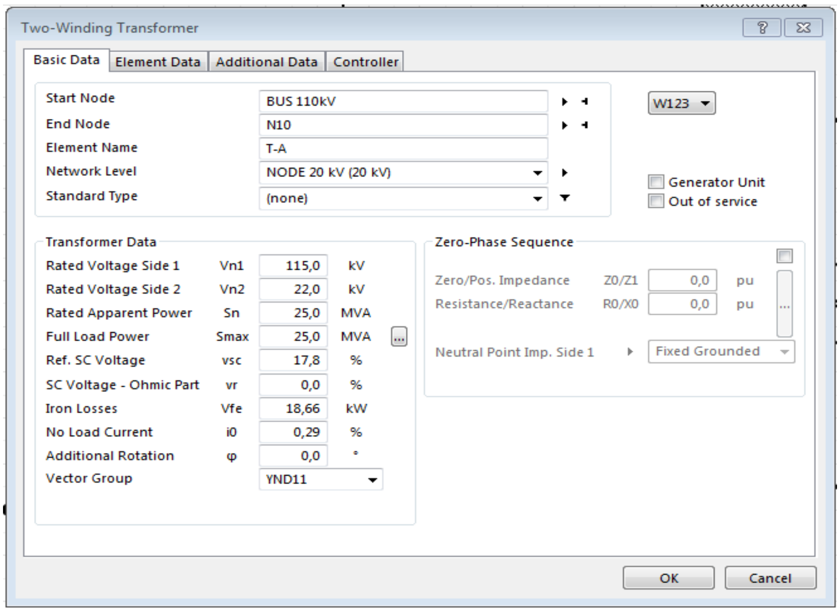


Figure 6. Scheme of the winding connection YND11

It can have observed characteristics of this transformer in the next picture, with data introduced in SINCAL:


Two-Winding Transformer

Basic Data | Element Data | Additional Data | Controller

Start Node: BUS 110kV
End Node: N10
Element Name: T-A
Network Level: NODE 20 kV (20 kV)
Standard Type: (none)

W123
☐ Generator Unit
☐ Out of service

Transformer Data

Rated Voltage Side 1	Vn1	115,0	kV
Rated Voltage Side 2	Vn2	22,0	kV
Rated Apparent Power	Sn	25,0	MVA
Full Load Power	Smax	25,0	MVA
Ref. SC Voltage	vsc	17,8	%
SC Voltage - Ohmic Part	vr	0,0	%
Iron Losses	Vfe	18,66	kW
No Load Current	i0	0,29	%
Additional Rotation	φ	0,0	°
Vector Group		YND11	

Zero-Phase Sequence ☐

Zero/Pos. Impedance	Z0/Z1	0,0	pu
Resistance/Reactance	R0/X0	0,0	pu
Neutral Point Imp. Side 1		Fixed Grounded	

Figure 7. High-medium transformer, characteristics SINCAL

- For medium to low voltage switching, there are 10 transformers, and two different kinds of them:
    - With vector group YZN5: This is normally used or distribution transformer up to 250MVA for local distribution system. And this vector means that the high voltage connection (in this case medium voltage) is star, low voltage connection is zig-zag and there are not accessible neutral on wye winding. In addition, the second winding is out of phase 150° of the first one. It can be shown represented schematically like this:

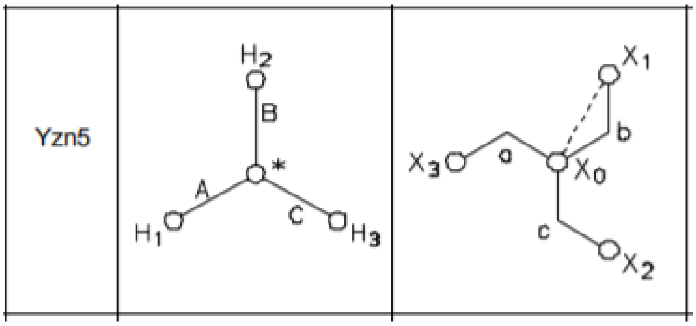
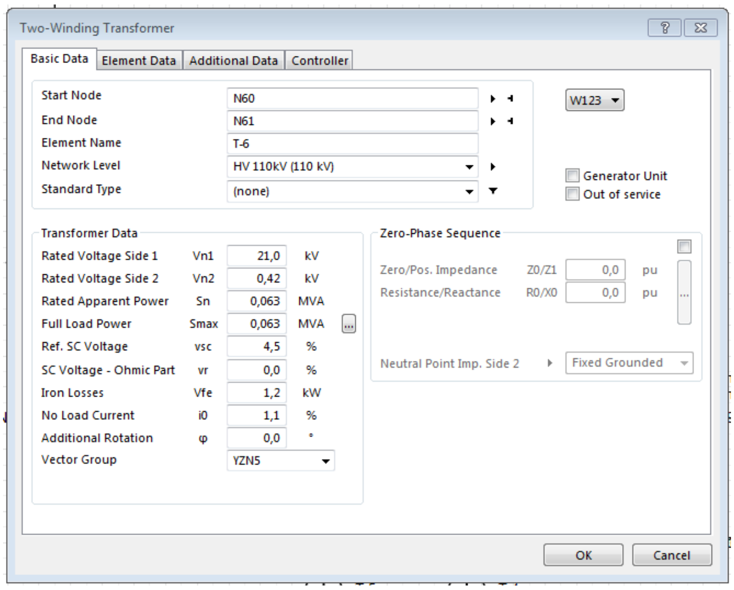


Figure 8. Scheme of the winding connection YZN5

This is an example of one of them with the data introduced in SINCAL:



Start Node: N60
End Node: N61
Element Name: T-6
Network Level: HV 110kV (110 kV)
Standard Type: (none)
☐ Generator Unit
☐ Out of service

Transformer Data

Rated Voltage Side 1	Vn1	21,0	kV
Rated Voltage Side 2	Vn2	0,42	kV
Rated Apparent Power	Sn	0,063	MVA
Full Load Power	Smax	0,063	MVA
Ref. SC Voltage	vsc	4,5	%
SC Voltage - Ohmic Part	vr	0,0	%
Iron Losses	Vfe	1,2	kW
No Load Current	i0	1,1	%
Additional Rotation	φ	0,0	°
Vector Group		YZN5	

Zero-Phase Sequence ☐

Zero/Pos. Impedance	Z0/Z1	0,0	pu
Resistance/Reactance	R0/X0	0,0	pu

Neutral Point Imp. Side 2: Fixed Grounded

Figure 9. Medium-Low transformer YZN5, characteristics SINCAL

- With vector group DYN5: This is also very common in local distribution system. This kind of vector consist of, the primary side (medium side) is connected like delta, the second (low voltage) is connected in star, and neutral accessible on wye winding. Moreover, it have phase displacement of 150° lag. The scheme for dis distribution is the following:

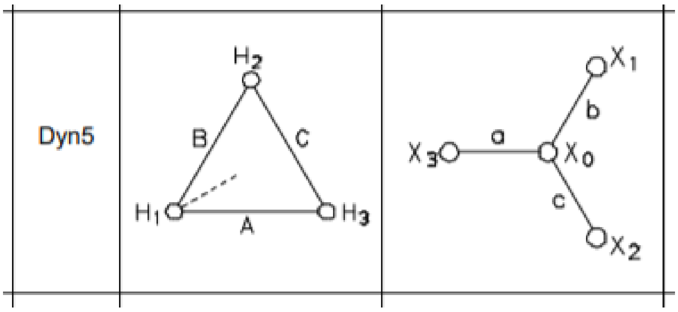
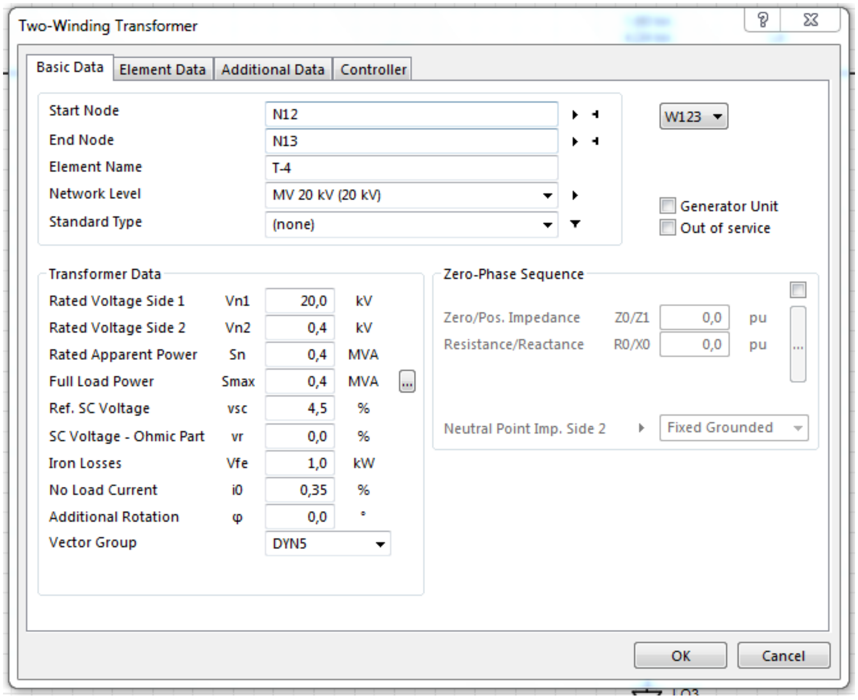


Figure 10. Scheme of the winding connection DYN5

One example of this transformer in SINCAL could be the next:



Start Node: N12
End Node: N13
Element Name: T-4
Network Level: MV 20 kV (20 kV)
Standard Type: (none)
☐ Generator Unit
☐ Out of service

Transformer Data

Rated Voltage Side 1	Vn1	20,0	kV
Rated Voltage Side 2	Vn2	0,4	kV
Rated Apparent Power	Sn	0,4	MVA
Full Load Power	Smax	0,4	MVA
Ref. SC Voltage	vsc	4,5	%
SC Voltage - Ohmic Part	vr	0,0	%
Iron Losses	Vfe	1,0	kW
No Load Current	i0	0,35	%
Additional Rotation	φ	0,0	°
Vector Group		DYN5	

Zero-Phase Sequence

Zero/Pos. Impedance	Z0/Z1	0,0	pu
Resistance/Reactance	R0/X0	0,0	pu

Neutral Point Imp. Side 2: Fixed Grounded

Figure 11. Medium-Low transformer DYN5, characteristics SINCAL

4.2.4. LOADS

The system consists of 10 loads, with different demand of active power each one.

These loads are part of an urban nucleus, divided in several areas of consumption. The supply of electricity in loads is made at low voltage, specifically at 400V, because the use of this electricity is normal houses, so it is used in direct application to domestic and industrial receivers, which required low voltage current.

Another necessary value to know is the power factor, which is estimated for all of them as 0.95, which is usually the typical value in these cases.

In the next table are shown the demand of each of them:

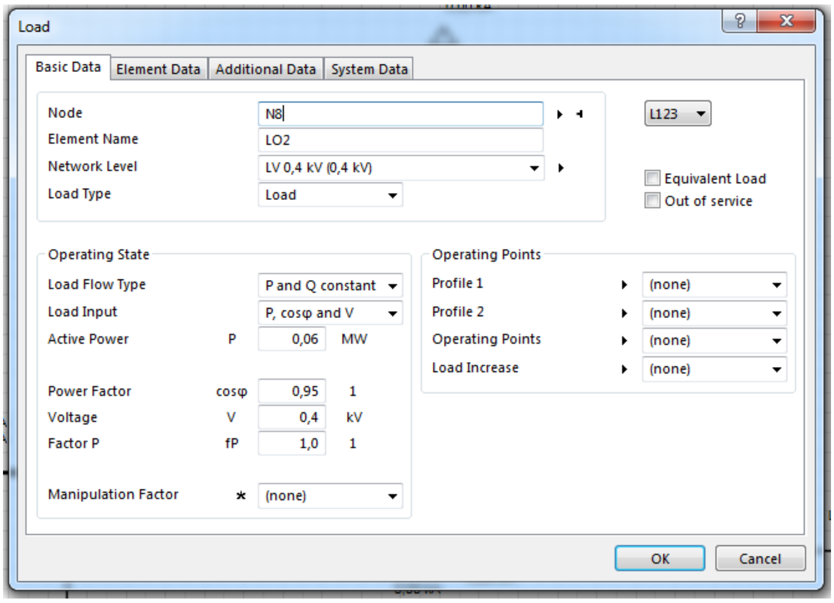
Table 1. Demands of loads

Nº LOAD	DEMAND (kW)
LOAD 1	60
LOAD 2	60
LOAD 3	60
LOAD 4	240
LOAD 5	240
LOAD 6	40
LOAD 7	150

LOAD 8	150
LOAD 9	240
LOAD 10	160
TOTAL LOAD	1400

As we can see, total load demanded by the system is 1,40 MW.

In the next picture, it possible show one example of parameters introduced for each load:



Node: N8
Element Name: LO2
Network Level: LV 0,4 kV (0,4 kV)
Load Type: Load
L123
☐ Equivalent Load
☐ Out of service

Operating State
Load Flow Type: P and Q constant
Load Input: P, cosφ and V
Active Power P: 0,06 MW
Power Factor cosφ: 0,95 1
Voltage V: 0,4 kV
Factor P fP: 1,0 1
Manipulation Factor *: (none)

Operating Points
Profile 1: (none)
Profile 2: (none)
Operating Points: (none)
Load Increase: (none)

Figure 12. Parameters of loads in SINCAL

With ISO visualization mode that offer the software it’s possible to see the distribution of loads and the mayor sources of consumption, as follow:

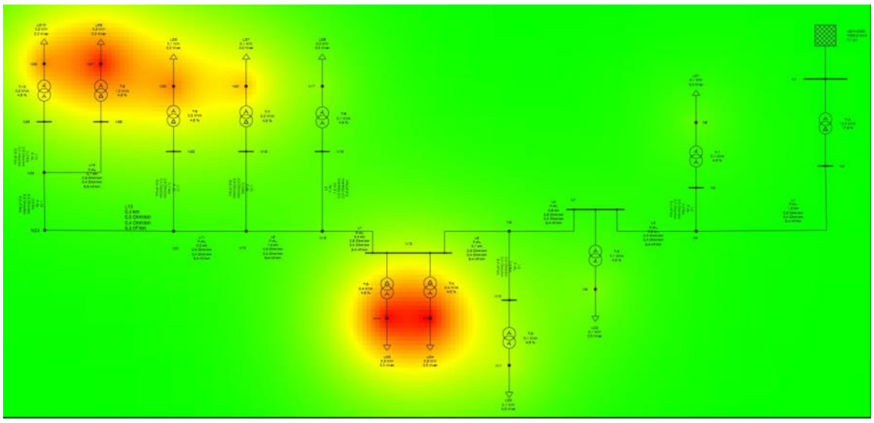


Figure 13. ISO visualization of the system

As shown in the picture, loads 4,5, 9 and 10 are the ones with the highest power consumption. Therefore, we will have to pay more attention to these points.

4.3. SYSTEM MODELLING

4.3.1. GRID-CONNECTED DISTRIBUTION SYSTEM

To model and simulate the system, the PSS SINCAL tool was used, as mentioned above.

The whole system is represented as follows:

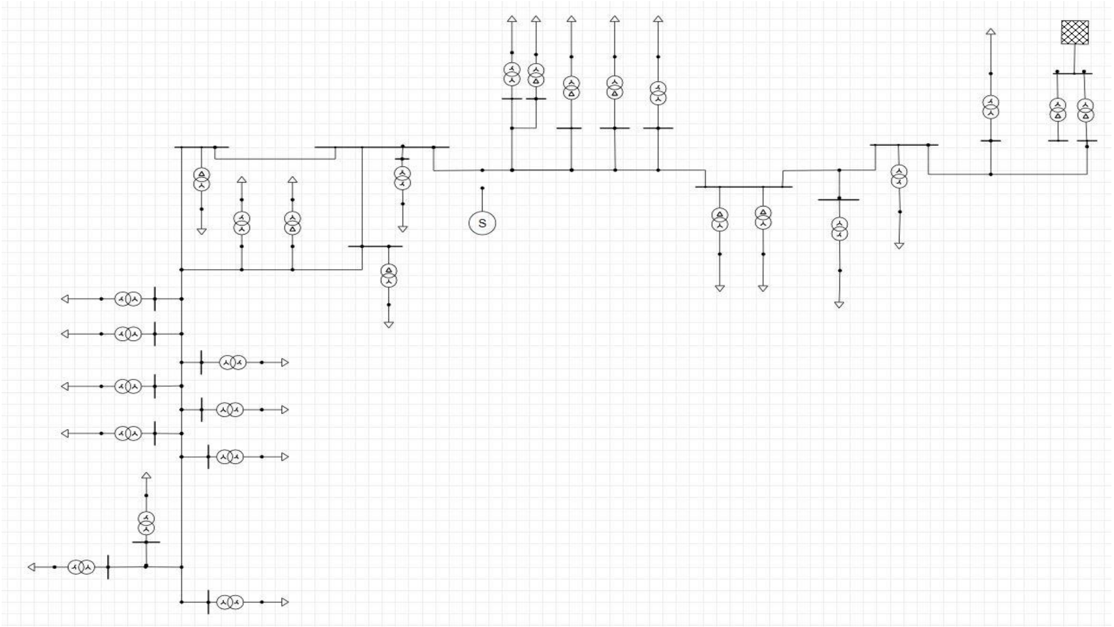


Figure 14. Diagram of the whole distribution network

Here there are one Infeeder, that is the main grid of high voltage, which supply electricity to 25 loads of low voltage, with their respective transformers for achieve the nominal voltage to use in each part of the system.

But, due to the limitations of the SINCAL software, the system could not be simulated completely, due to excess the limit of model nodes in educational version, so the system was reduced until it was possible to perform the simulation, to be able to work with it.

Finally, the system that it going to be studied is as shown in the follow picture:

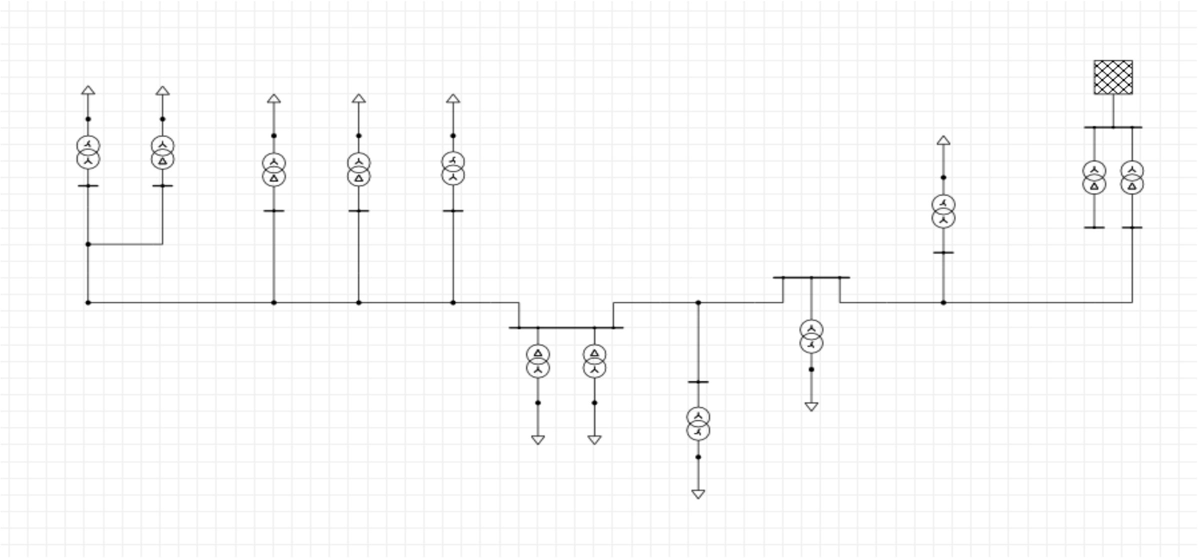


Figure 15. Diagram of the simplified distribution network

In this scenario, the grid is supplying energy to 10 loads, with their corresponding transformers.

This has been the first situation to simulate, to check the knowledge of the system connected only with the network supply, before connecting the generator. However, other change has to be made, as the software was giving problems with the backup transformer, in parallel with the main one, it had to be removed for simulation. But, this is not a problem or a change in the results because in the normal situation this second transformer is inactive.

So, the study will be carried out with the following simplification, as it shown in the **¡Error! No se encuentra el origen de la referencia.**, showing also input data of characteristics of the components.

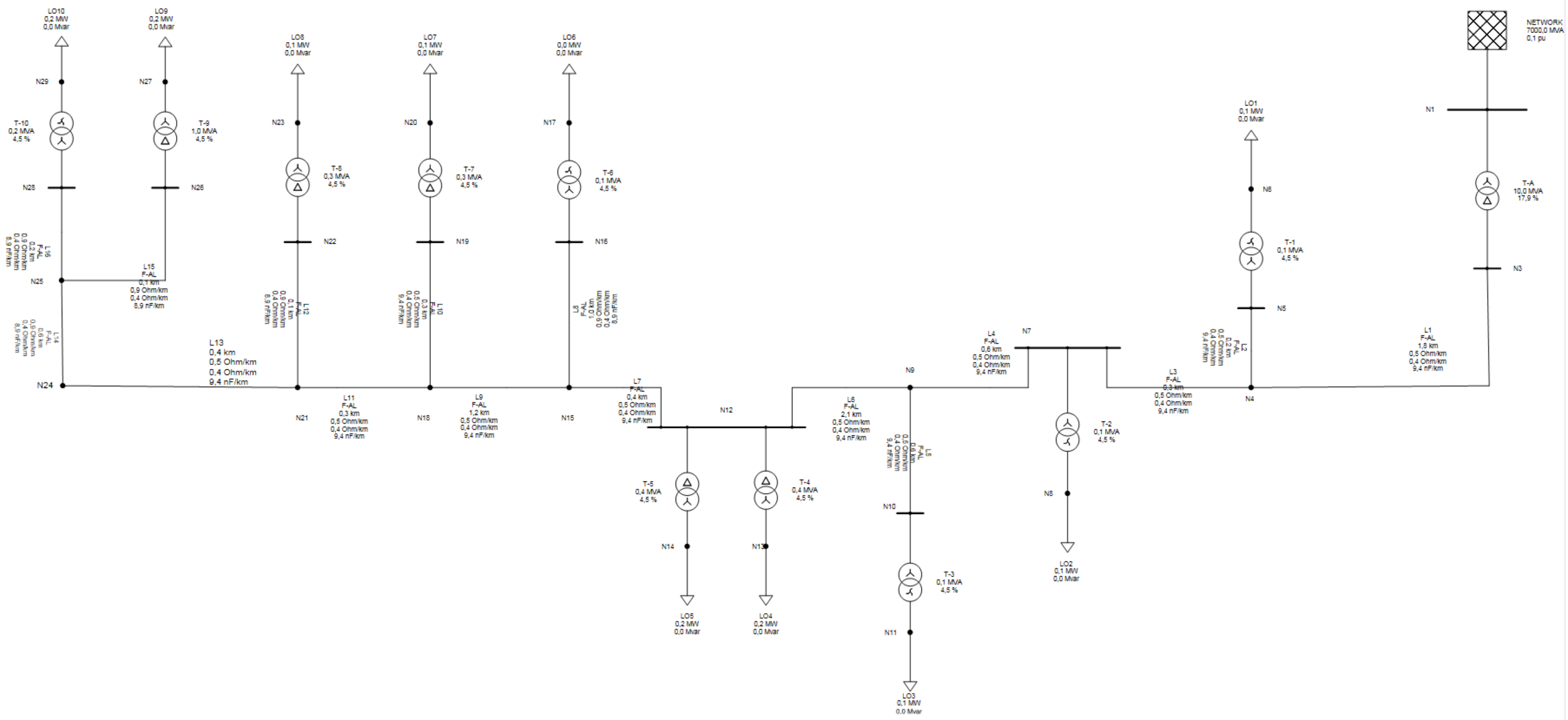


Figure 16. Diagram of the second simplification of the distribution network

Secondly, considering the connection of the hydropower plant in one extreme of the line, the system looks like follows:

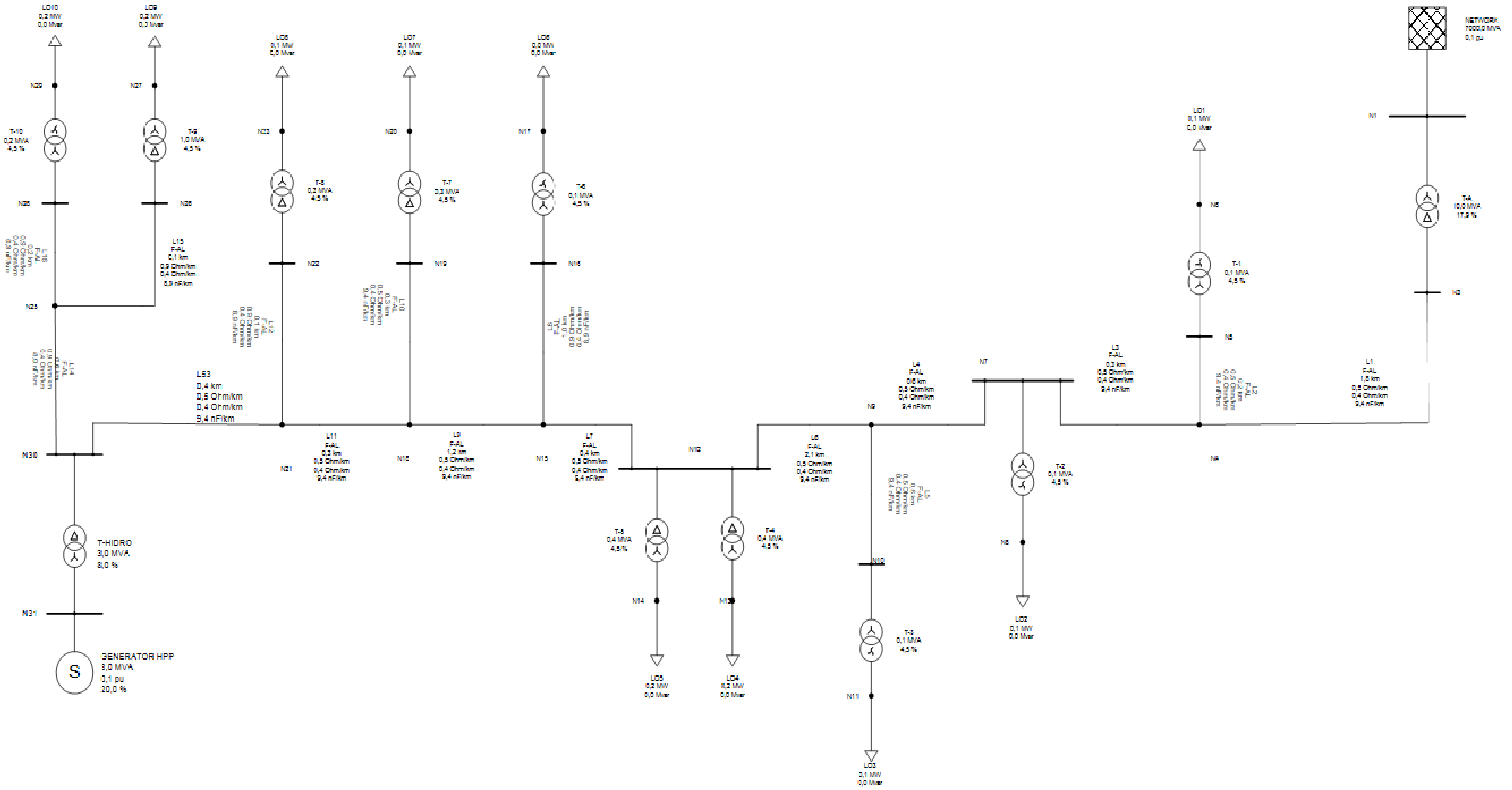


Figure 17. Diagram of the distribution network with SHPP

For both scenarios, other change was made in the main transformer. Since the system has been split in half, the main transformer is oversized, so it would be convenient to put one in the system's size. It has been proven that this happens when a transformer with less power is installed, in this case it has been selected a power of 10 MVA.

Here are shown the difference results of load flow simulated with both size of transformer, transformer of 10 MW at left, and transformer of 25 at the right side

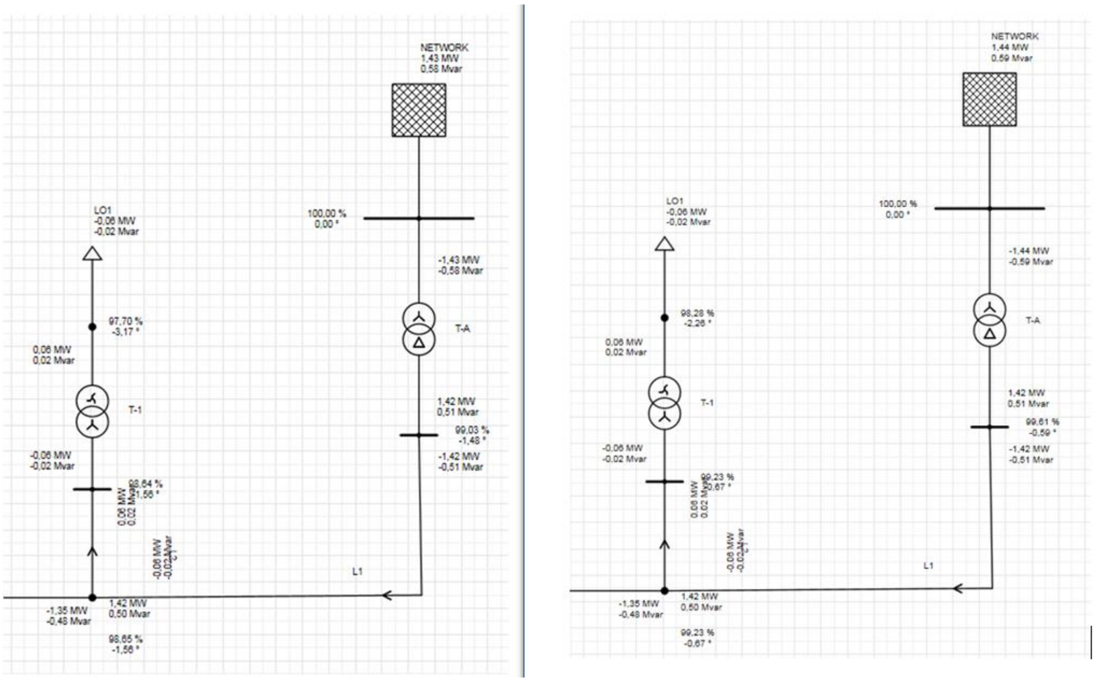


Figure 18. Comparison between two powers for the transformer

The result has been positive, because in this way there is a little drop in the power output required to be supplied by the electrical grid, in addition to a reduction of reactive power in the exit of the grid. This reduction is worthwhile, besides the fact that the transformer would be cheaper than the bigger one. That is to say, that finally the main transformer will have a power of 10MVA.

4.3.2. IMPLEMENTATION HYDROPOWER PLANT

GENERATOR

Most of hydroelectric installations utilize salient pole synchronous generators.

This kind of machines are employed because the hydraulic turbine in the hydroelectric plants operates at low speeds compared to steam plants, for example, therefore generators in hydro plant requires large number of field poles to produce the rated frequency.

Rotor of synchronous generator requires salient poles is mechanically best suited for low-speed applications.

This is an example about the scheme for the connection of generator to the grid:

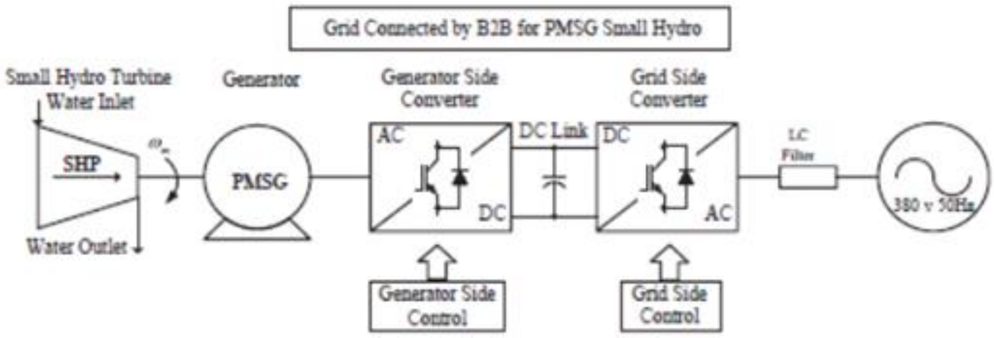


Fig.1. PMSG Grid connected diagram

Figure 19. Connection diagram of generator of an Small Hydro Power Plant

First, the turbine transmits the movement to the generator, which generates the electricity. After that, two converters are placed, one to control the characteristics of the generator and the other to control the network characteristics. Once the control has been carried out, it is transformed to a higher or lower voltage, depending on the case, and injected into the grid.

The used generator will cover powers between 100W and 3000W, which is the power range to be studied. It will depend on the chosen generating power.

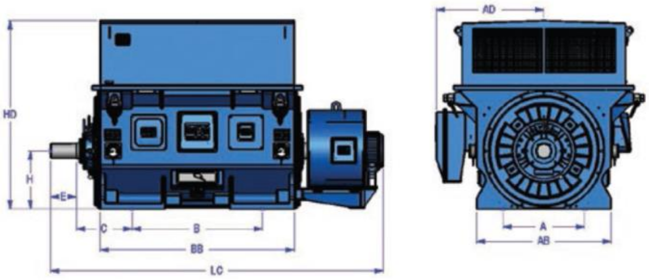


Figure 20. Picture of generator

The generator it will be the model GH10 Line of the brand WEG. Which has the following characteristics introduced in the software, changing the power as required[9].

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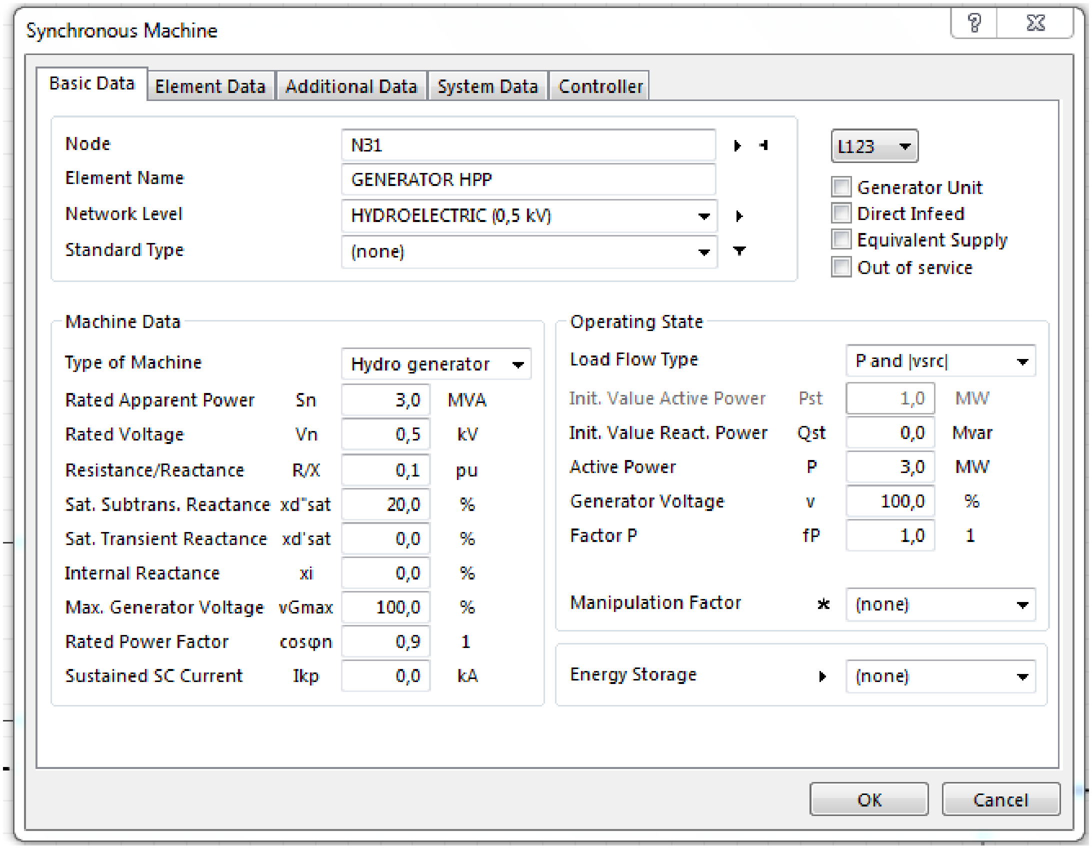
[9] www.weg.net



Node	N31
Element Name	GENERATOR HPP
Network Level	HYDROELECTRIC (0,5 kV)
Standard Type	(none)

L123

☐ Generator Unit
☐ Direct Infeed
☐ Equivalent Supply
☐ Out of service

Machine Data

Type of Machine		Hydro generator	
Rated Apparent Power	Sn	3,0	MVA
Rated Voltage	Vn	0,5	kV
Resistance/Reactance	R/X	0,1	pu
Sat. Subtrans. Reactance	xd"sat	20,0	%
Sat. Transient Reactance	xd'sat	0,0	%
Internal Reactance	xi	0,0	%
Max. Generator Voltage	vGmax	100,0	%
Rated Power Factor	cosφn	0,9	1
Sustained SC Current	Ikp	0,0	kA

Operating State

Load Flow Type		P and |vsrc|	
Init. Value Active Power	Pst	1,0	MW
Init. Value React. Power	Qst	0,0	Mvar
Active Power	P	3,0	MW
Generator Voltage	v	100,0	%
Factor P	fP	1,0	1
Manipulation Factor		(none)	
Energy Storage		(none)	

Figure 21. Characteristics generator in SINCAL

TRANSFORMER

Transformer for generator for hydropower plant has been sized for a wide range of power, between 100kW until 3.000kW, in order to make comparations and analysis of the system with different magnitudes of power.

The more typical kind of transformer use for this end is the one with vector YD11. This is a transformer consisting of a high voltage star winding and a low voltage delta winding in advance of 30 degrees. This transformer has not accessible neutral on wye winding.

The scheme of the winding connection, vector representation and visual diagram can be shown like follow:

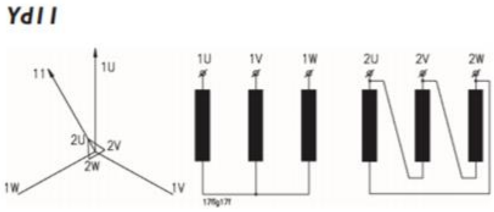


Figure 22. Scheme of the winding connection YD11

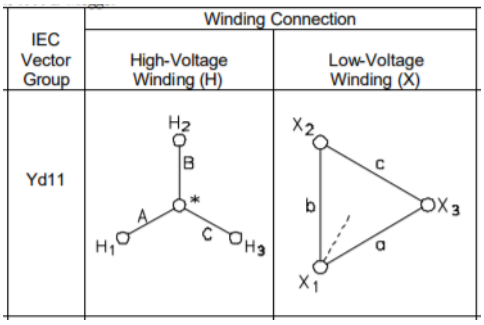
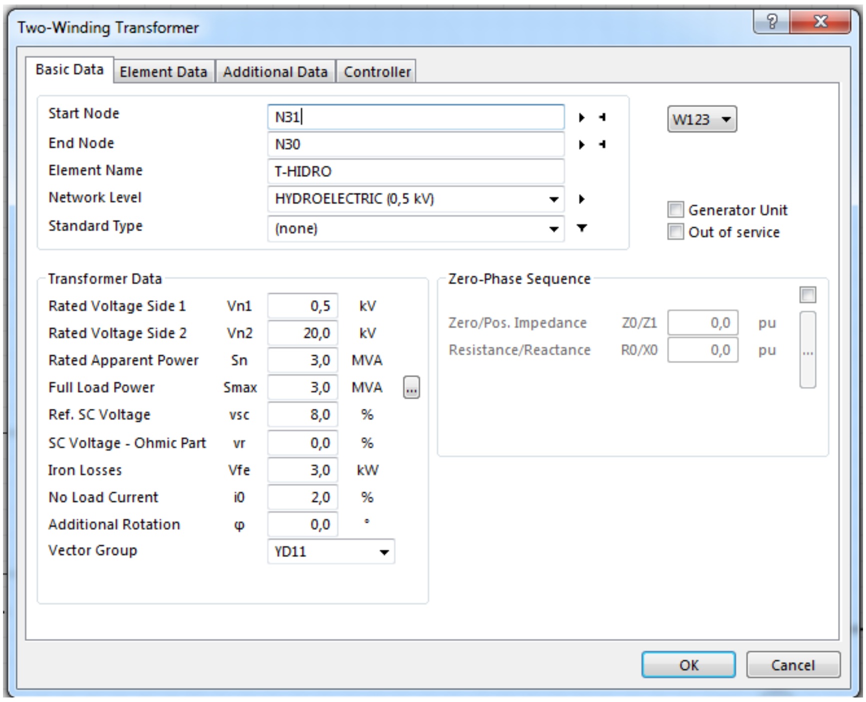


Figure 23. Winding connection of main transformer YD11

The transformer used is a dry transformer of the brand CRT. The characteristics introduced in the software are the followings:



Start Node: N31
End Node: N30
Element Name: T-HIDRO
Network Level: HYDROELECTRIC (0,5 kV)
Standard Type: (none)
W123
☐ Generator Unit
☐ Out of service

Transformer Data

Rated Voltage Side 1	Vn1	0,5	kV
Rated Voltage Side 2	Vn2	20,0	kV
Rated Apparent Power	Sn	3,0	MVA
Full Load Power	Smax	3,0	MVA
Ref. SC Voltage	vsc	8,0	%
SC Voltage - Ohmic Part	vr	0,0	%
Iron Losses	Vfe	3,0	kW
No Load Current	i0	2,0	%
Additional Rotation	φ	0,0	°
Vector Group		YD11	

Zero-Phase Sequence ☐

Zero/Pos. Impedance	Z0/Z1	0,0	pu
Resistance/Reactance	R0/X0	0,0	pu

Figure 24. Characteristics of main transformer in SINCAL

BUS

To perform the connection between the hydroelectric power plant to grid, it’s also necessary a medium voltage bus of 20kV.

5. SIMULATION LOAD FLOW AND SHORT CIRCUIT

In order to know the knowledge of the system with and without hydrogenator, and with different scenarios, it’s very useful realize study of load flow and short circuit. With these two analysis it would be possible compare several scenarios, to find critical or difficult points of the system and check the correct knowledge of the distribution line.

5.1. LOAD FLOW

The process that SINCAL follow for calculation of load flow is the method of Newton-Raphson. It is based on a non-linear model of the system, is a method that can be applied to meshed or radial networks, it has a solid mathematical foundation and fast convergence because it incorporates information from the first derivative during the iterative process.

The results that can be obtain after simulation are:

- For nodes:
    - Percentage of voltage deviating from nominal voltage (V/Vn)
    - Additional voltage angle in reference to angle of the rated V of the winding (°)
- For branches:
    - Active power that circulates along that stretch of line (MW)
    - Reactive power that runs along the corresponding line section (Mvar)

5.1.1. SIMPLE NETWORK

The first simulation is for the base case, that is to say the network system only connected to the power supply unit, without taking in account the generator of hydropower plant. In this way, it would be possible to check the knowledge of the system under normal conditions.

The results obtained are plotted in the next picture, showing for each node and branch results in the Figure 25.

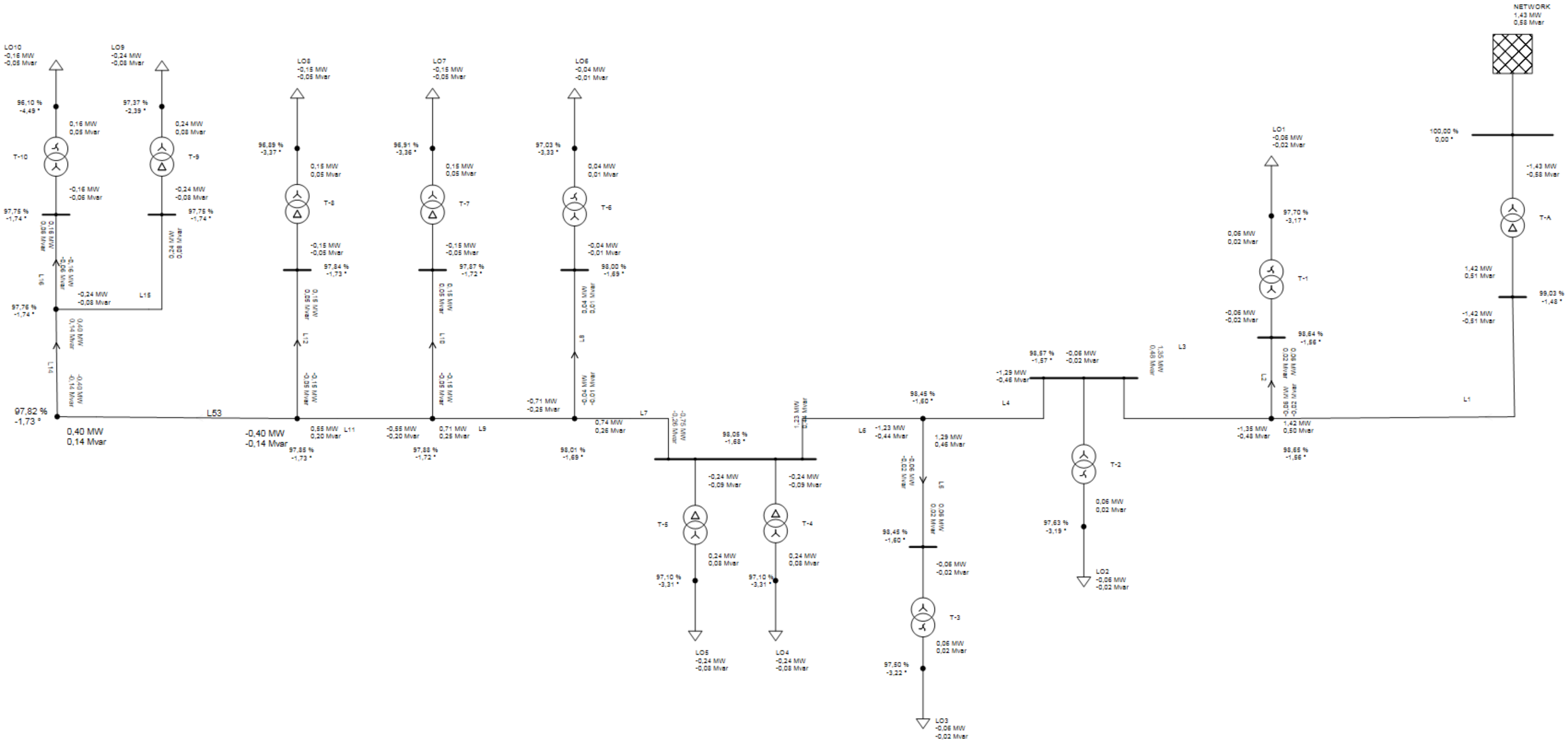


Figure 25. Results of the load flow calculation – simple network

It can be shown in a better way percentage of voltage in the next table:

Table 2. Node Voltage/Rated Node Voltage in the base case

NETWORK LEVEL **0,4 kV**

NODE		N11	N13	N14	N17	N20	N23	N27	N29	N6	N8
V/Vn (%)	GRID	97,49	97,09	97,09	97,02	96,91	96,88	97,37	96,09	97,69	97,62

NETWORK LEVEL **20kV**

NODE		N10	N12	N15	N16	N18	N19	N21	N22	N24
V/Vn (%)	GRID	98,44	98,05	98,01	98,00	97,87	97,86	97,84	97,84	97,82

NETWORK LEVEL **20kV**

NODE		N25	N26	N28	N3	N4	N5	N30	N7	N9
V/Vn (%)	GRID	97,755	97,747	97,748	99,027	98,646	98,644	97,821	98,574	98,452

The percentage of the deviation of voltage in the first node is 100%, because it is just the exit of the grid feeder. After that, at medium voltage this percentage slowly decreases, from 99 to 97.80 % at the last node. This is a good result, as the deviation is small and does not exceed the limit value imposed in the Grid Code, in which this value is said to be between 90 and 110%. In low voltage the values are slightly lower, in the order of 96 and 97, but still good values within the limits.

About the voltage, is logically 0 in the high voltage zone. In the medium voltage zone, the values are increasing from 1.48 to 1.74, which are low, which means that there is no problem. And at low voltage this value is around 3%, higher than at medium voltage, but still within the limits.

The active power at the power supply output is 1.43MW and the reactive power is 0.58Mvar. Being the power demanded by the system 1.40MW means that there are some losses of 0.03MW. Which is normal, but there's still not much loss.

Moreover, the rest of power in the system are properly distributed, all loads are supplied with the required power.

5.1.2. NETWORK WITH GENERATOR – 0,1 MW

After install the generator system, with its corresponding transformer, the system is simulated starting with a small value of generator power, which is 0,1MW.

The result of this simulation can be shown in the image below, due to the dimensions of the image, only the left side is shown (where the generator is placed):

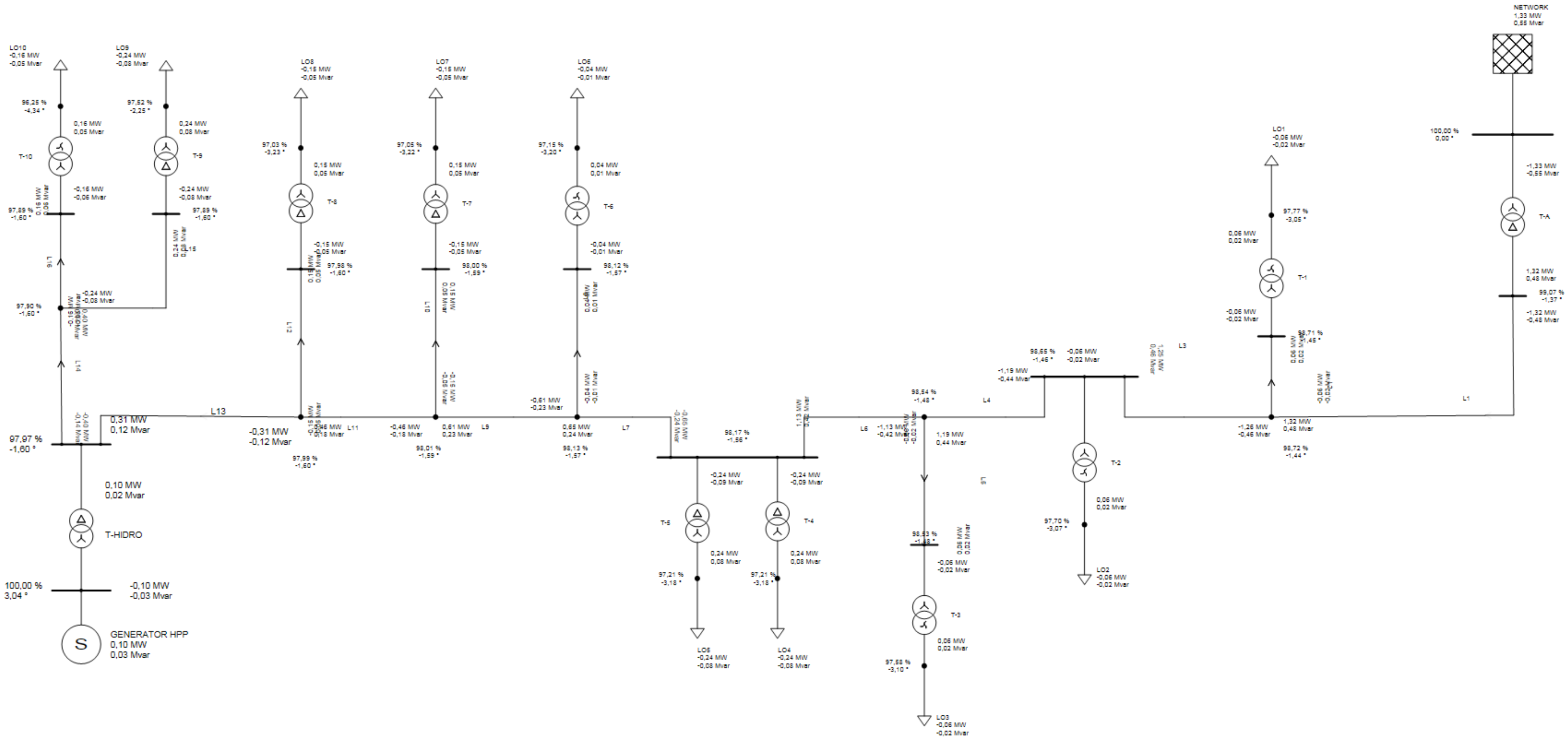


Figure 26. Results of the load flow calculation – generator 0,1MW

In this case the network is supplying 1,33MW to the system because the generator of hydropower plant is supplying 0,1MW, that in total this amount would summarize 1,43MW. As in the base case, the grid supply 0,03MW more that the demand.

The generator is very small, so its contribution to the system is almost negligible.

5.1.3. NETWORK WITH GENERATOR – 0,5 MW

In this case, the contribution of hydropower plant is going to be higher, 0,5MW will be the power of supply.

The results are shown in the Figure 27.

The supply covers up to the first two loads and parts of the third one, which takes more weight off the grid.

By means of this generator the grid must supply only 0.92 MW, in this case it is obtained that also generates 0.48 Mvar.

5.1.4. NETWORK WITH GENERATOR – 1 MW

Increasing the generator power to 1MW the values in Figure 28 are obtained.

In this solution, the generator is supplying power to more loads, and the main feeder of the grid have to provide only 0,42MW, it supplies 0,02MW more that the required power due to losses.

5.1.5. NETWORK WITH GENERATOR – 3 MW

With a higher power in the generator a different solution is obtained in Figure 29.

In this case, the hydroelectric power plant would be larger, so much so that it covers the demand required by the loads and there is still plenty of power left over, which could be supplied to the grid if it were able to sell it.

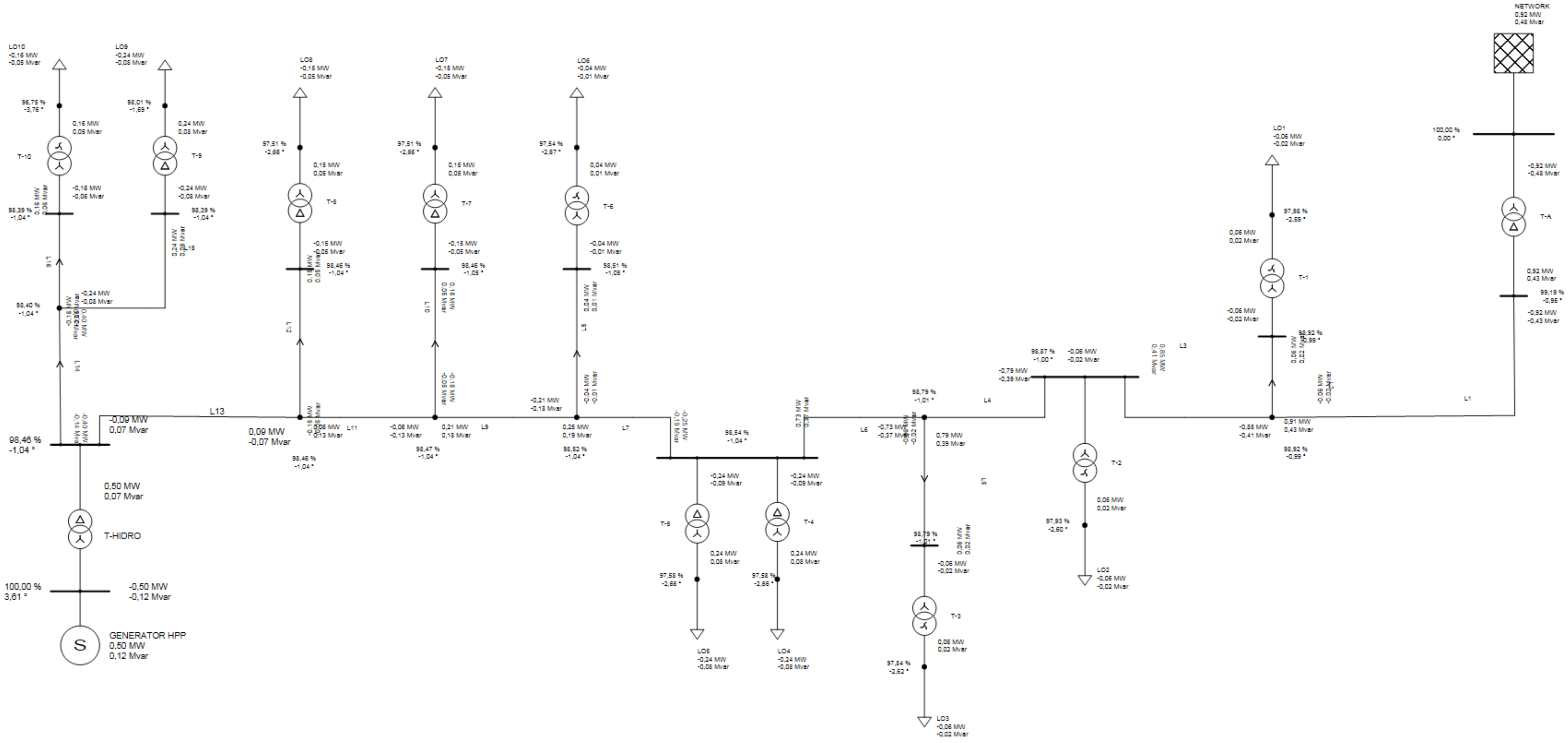


Figure 27. Results of the load flow calculation – generator 0,5MW

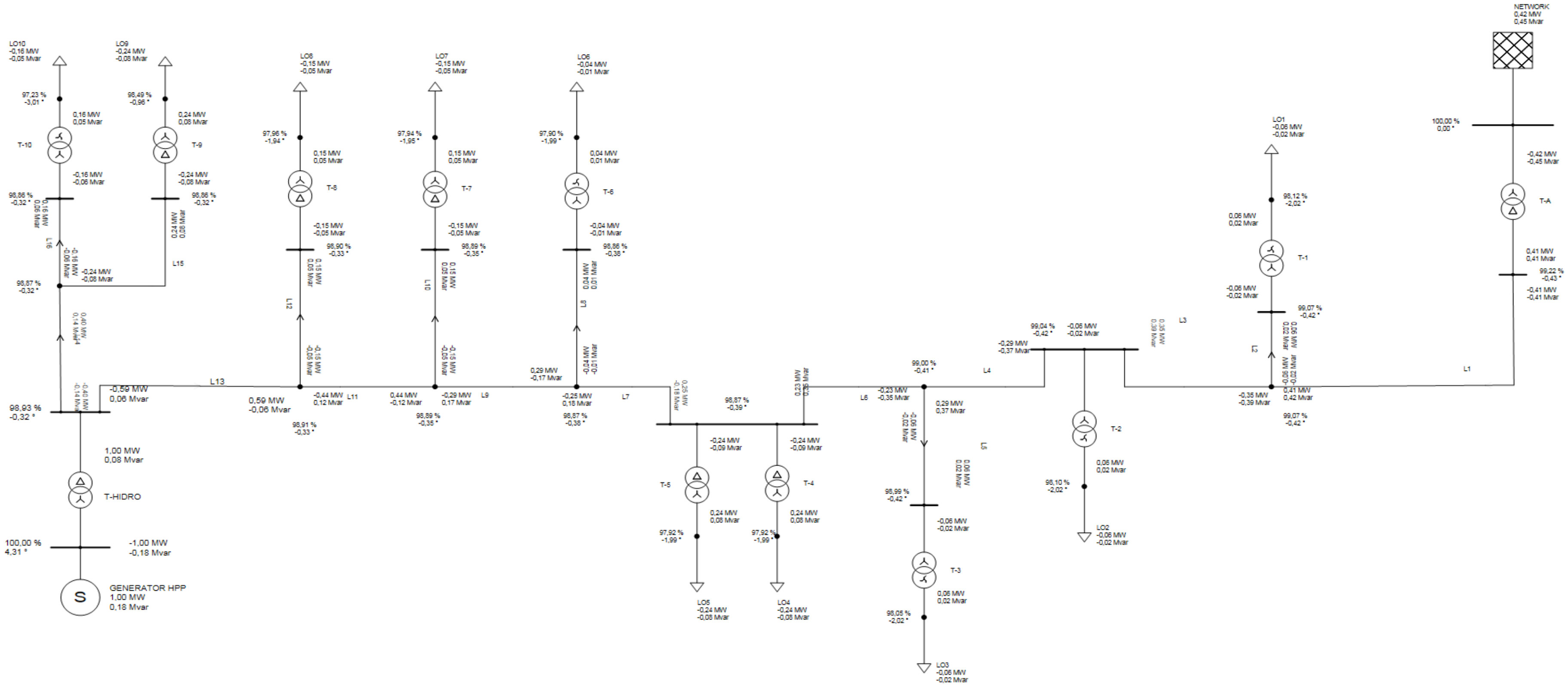


Figure 28. Results of the load flow calculation – generator 1MW

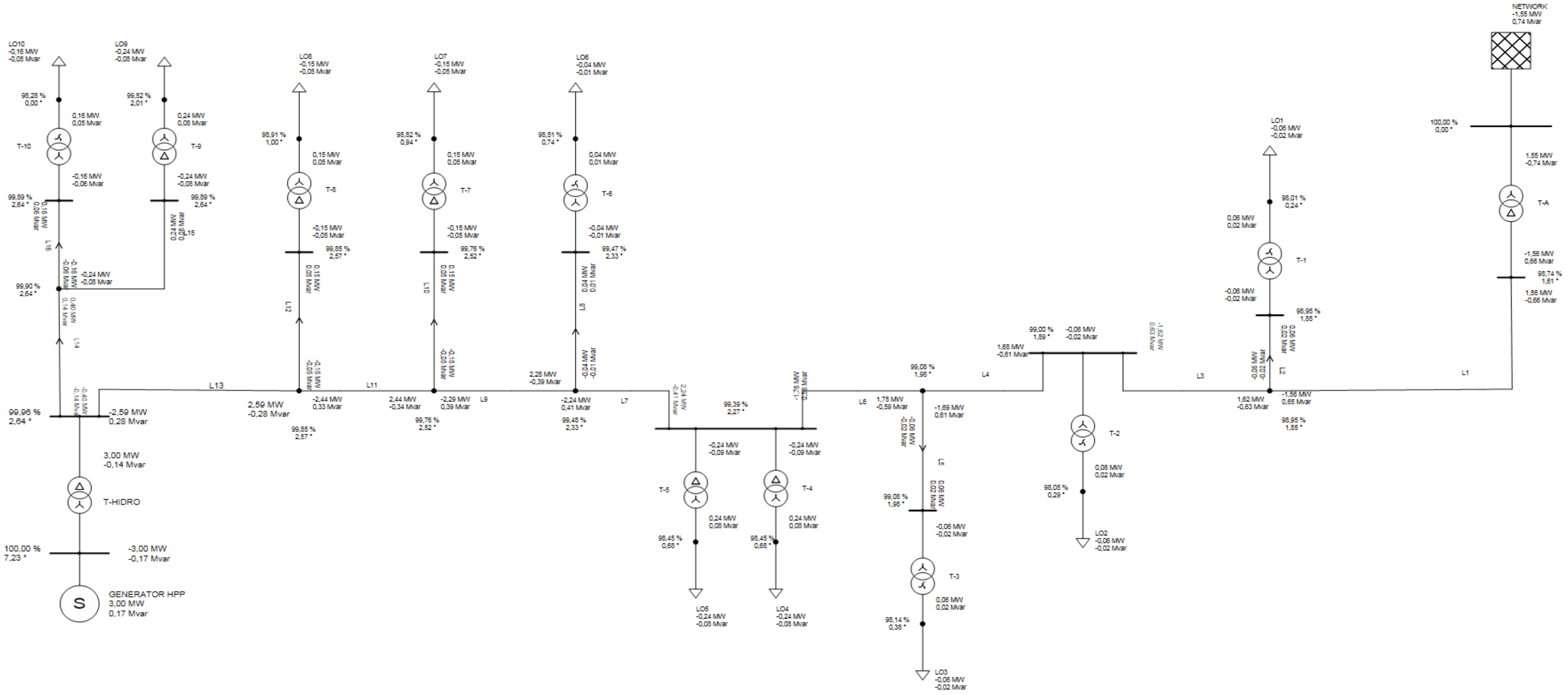


Figure 29. Results of the load flow calculation – generator 3MW

5.2. SHORT CIRCUIT:

The analysis made was 3-phase short circuit, and it is calculated by SINCAL according to VDE 0102/2016.

Simplified VDE calculations leave out all the line capacities and non-motoric positive-phase-sequence shunt impedances such as consumers or power capacities.

The following illustration shows the short circuit current curve[10]:

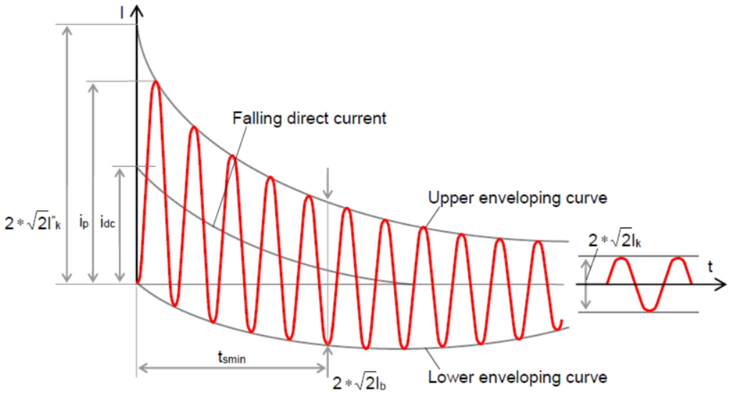


Figure 30. Short circuit current curve[11]

There are two output intensities displayed like results in the simulation, which are the initial symmetrical short circuit current (Ik’’) and peak short circuit current (Ip), but for the analysis is going to focus on Ik’’.

PSS SINCAL calculates the phase voltages φ_{kL1}, φ_{kL2}, φ_{kL3} using the transformation formulas for the symmetric components "L1, L2, L3 system".

$$\varphi_{kL1} = \varphi_{k1} + \varphi_{k2} + \varphi_{k0} \qquad \text{Eq. 3}$$

$$\varphi_{kL2} = a^2\varphi_{k1} + \varphi_{k2} + \varphi_{k0} \qquad \text{Eq. 4}$$

$$\varphi_{kL3} = a\varphi_{k1} + a^2\varphi_{k2} + \varphi_{k0} \qquad \text{Eq. 5}$$

Where,

φ_{k1}, positive-phase-sequence voltage vector

φ_{k2}, negative-phase-sequence voltage vector

φ_{k0}, zero-phase-sequence voltage vector

φ_{kL1}, L1-phase voltage vector
φ_{kL2}, L2-phase voltage vector
φ_{kL3}, L3-phase voltage vector

---

[10] *Document short-circuit, helps to PSS SINCAL software*

$a = e^{j\frac{2\pi}{3}}$, 120° rotation

The network currents are calculated from the differences in charge at the nodes and from the impedance between the nodes.

For simulations with component data only the positive-phase sequence data is required.

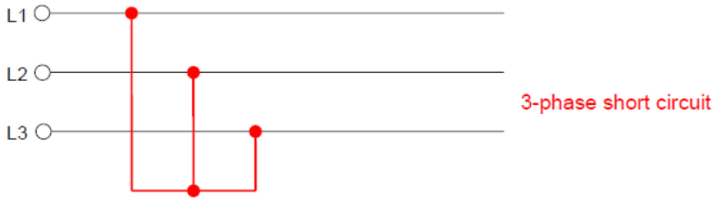


Figure 31. Scheme position 3-phase short circuit calculation

5.2.1. SIMPLE NETWORK

As in the load flow calculation, for the short circuit mode the first simulation is performed for the base case, this mean simulate the first system with the grid supplying electricity to the loads, without hydrogenator. Hence, it can be shown firstly the reference data of short circuit current that then them will be used for comparing different scenarios of generators.

The first simulation is for the base case, the network system only connected to the power supply unit, without taking in account the generator of hydropower plant. In this way, it would be possible to check the knowledge of the system under normal conditions.

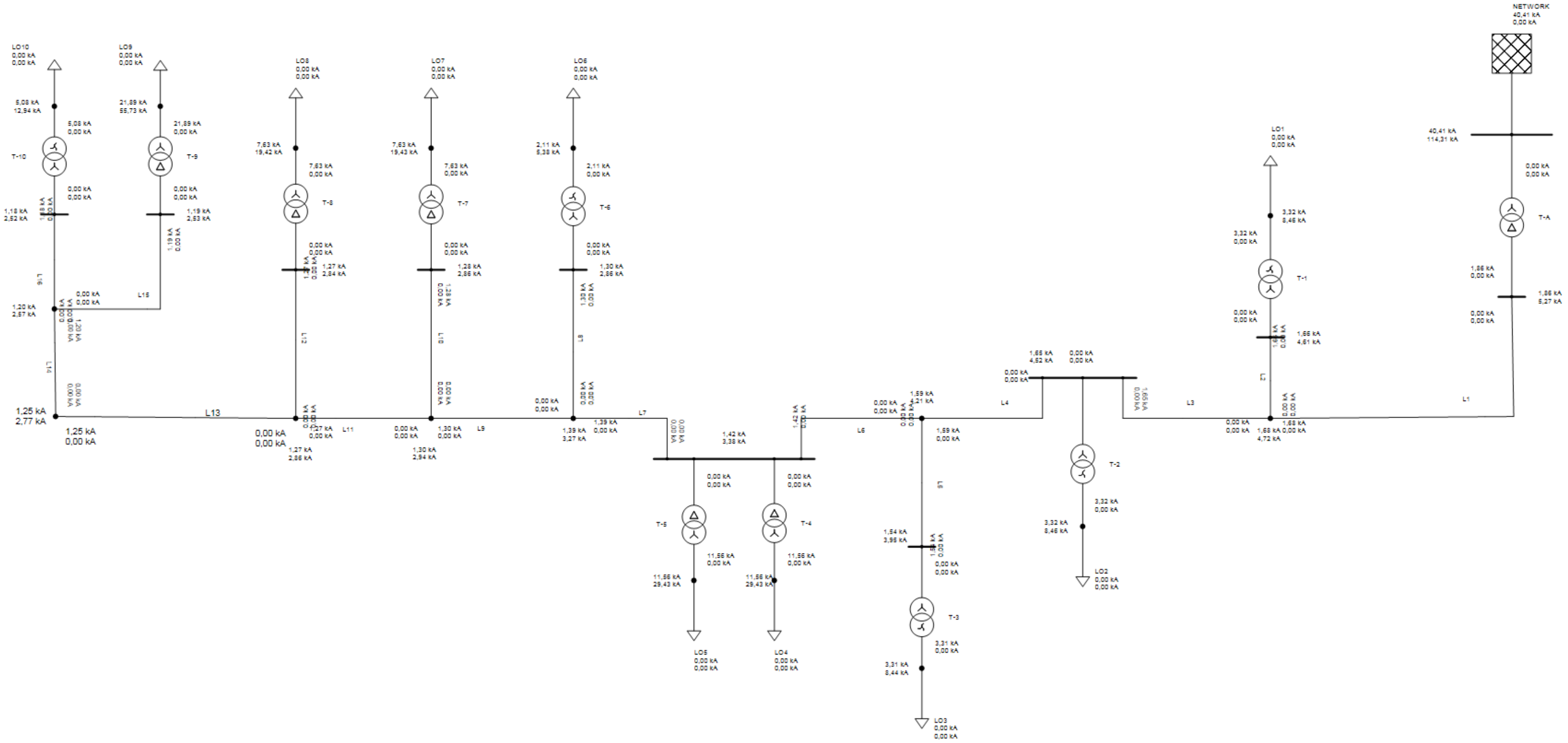


Figure 32. Results of the short-circuit calculation – generator 0,1MW

It can be shown more clearly short-circuit current for each point of the installation:

Table 3. Short-circuit current in the base case

NETWORK LEVEL	**0,4 kV**									
NODE	N11	N13	N14	N17	N20	N23	N27	N29	N6	N8
Ik''	3,314	11,56	11,56	2,114	7,632	7,628	21,893	5,083	3,323	3,322

NETWORK LEVEL	**20kV**								
NODE	N10	N12	N15	N16	N18	N19	N21	N22	N24
Ik''	1,543	1,415	1,386	1,296	1,297	1,276	1,275	1,269	1,248

NETWORK LEVEL	**20kV**							
NODE	N25	N26	N28	N3	N4	N5	N7	N9
Ik''	1,198	1,187	1,187	1,864	1,684	1,665	1,651	1,593

Firstly, as can be seen at the main output, at high voltage, the short-circuit current is 40,41kA, it is a very high value, but it is normal in this part of installation at very high power, but this mean that this part of the system requires significant protections.

In medium voltage, short-circuit current are low values, around 1,3kA, the maximum short-circuit value is the one at the origin of the line, as it moves away from that point the currents are getting smaller, until 1,18kA.

In low voltage, short circuit current is more variable, the value is between 3,31kA and 21,89kA, depending on the power supplied to the loads.

5.2.2. NETWORK WITH GENERATOR – 0,1 MW

After connecting the generator with a low power, it has been obtained these results to the software, like show the Figure 33.

In the picture, it’s possible to see a very low short-circuit current in the generator and a bigger but also low circuit at the output to the generator and to the transformer.

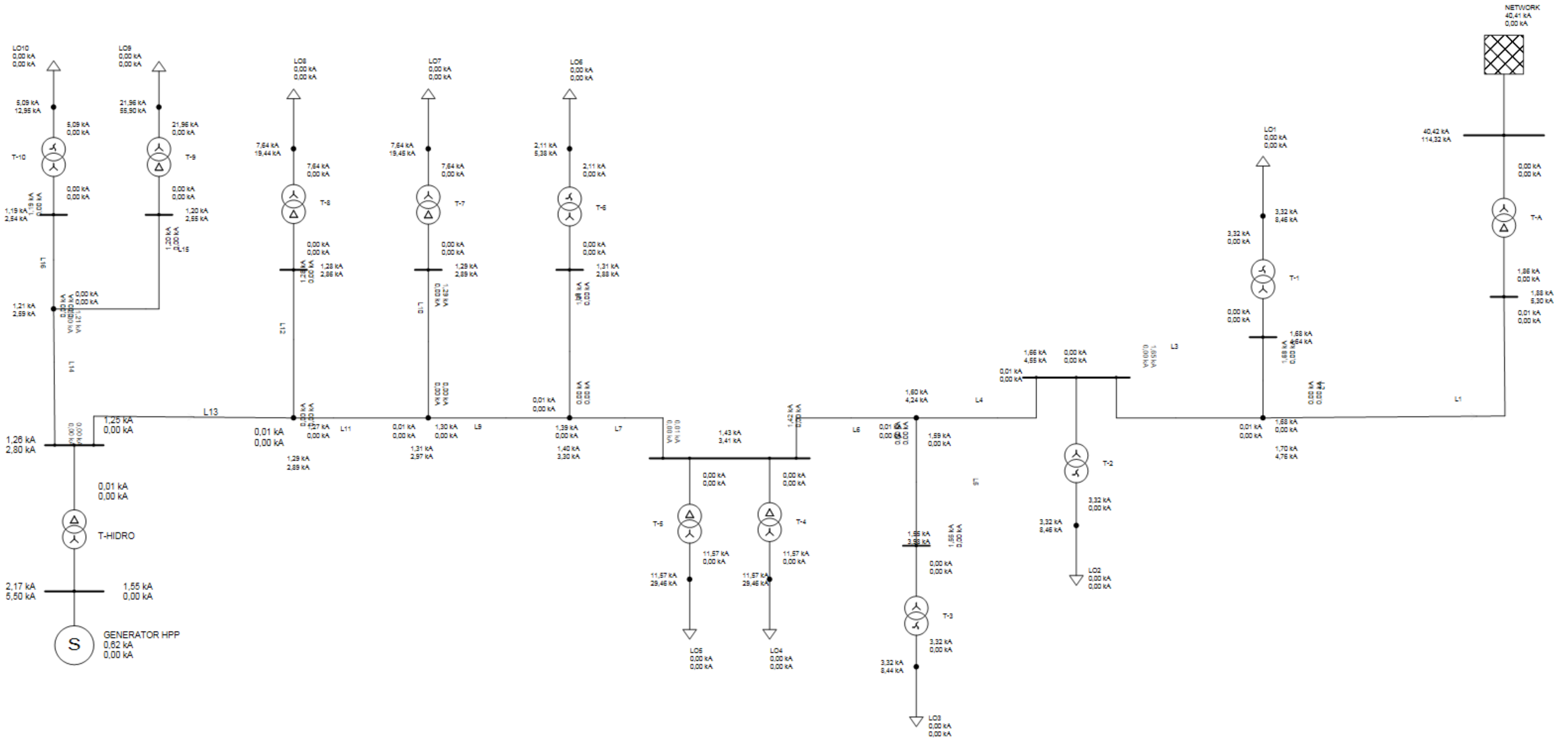


Figure 33. Results of the short-circuit calculation – generator 0,5MW

)

5.2.3. NETWORK WITH GENERATOR – 0,5 MW

Results after power increase to 0,5MW are plotted like on figure 35.

Short circuit currents are more or less stable in the network and increase slightly in the part of the power plant.

5.2.4. NETWORK WITH GENERATOR – 1 MW

With an installed power of 1MW results are in Figure 35

Values of short circuit current are stable respect the base case, before connecting generator, and with other powers of connection.

5.2.5. NETWORK WITH GENERATOR – 3 MW

After last simulation, with a power bigger that the required for the system, the results of short-circuit currents are as on Figure 36.

Values remain stables, except in the hydropower plant, which is bigger because of the power of generator is bigger, and it would need more protection.

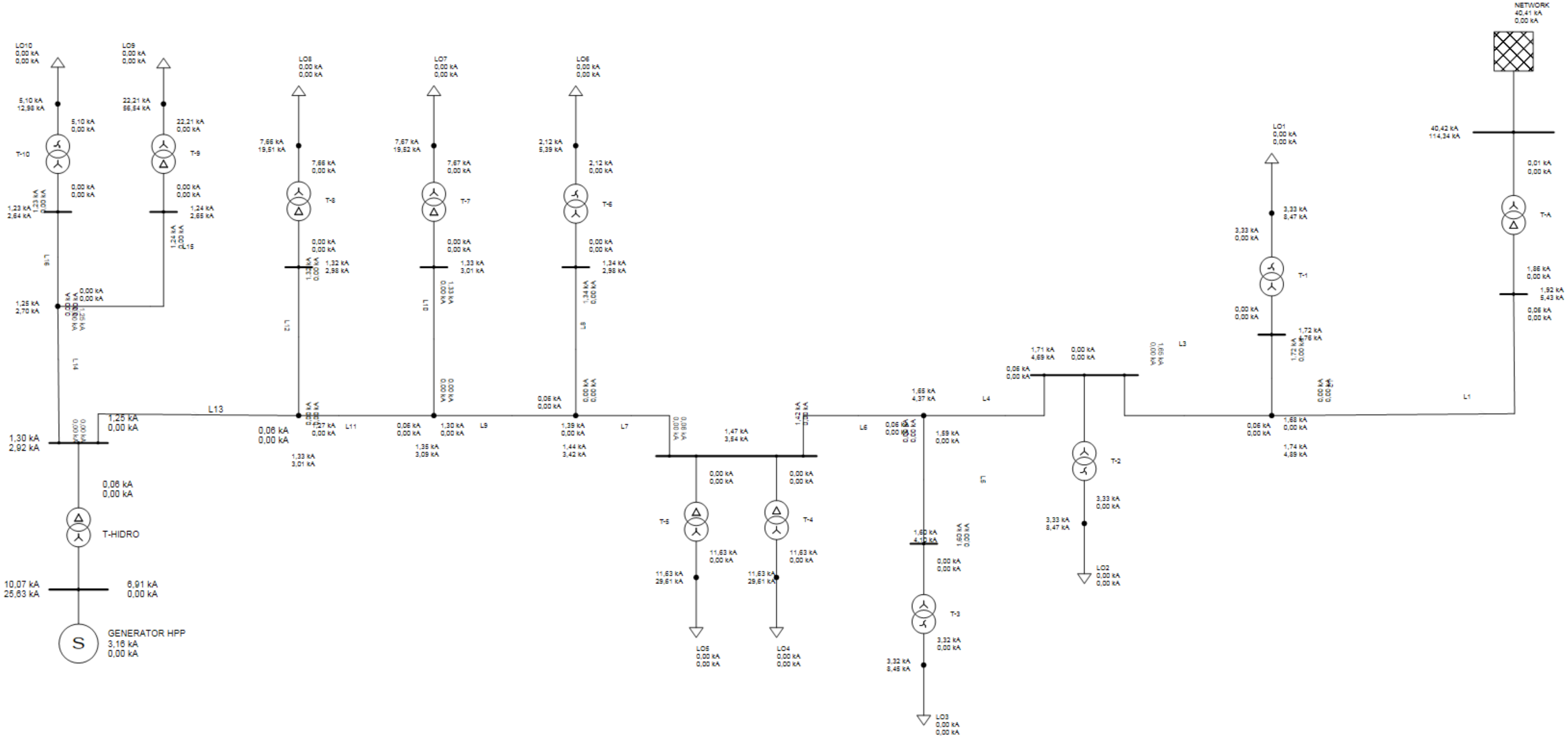


Figure 34. Results of the short-circuit calculation – generator 1MW

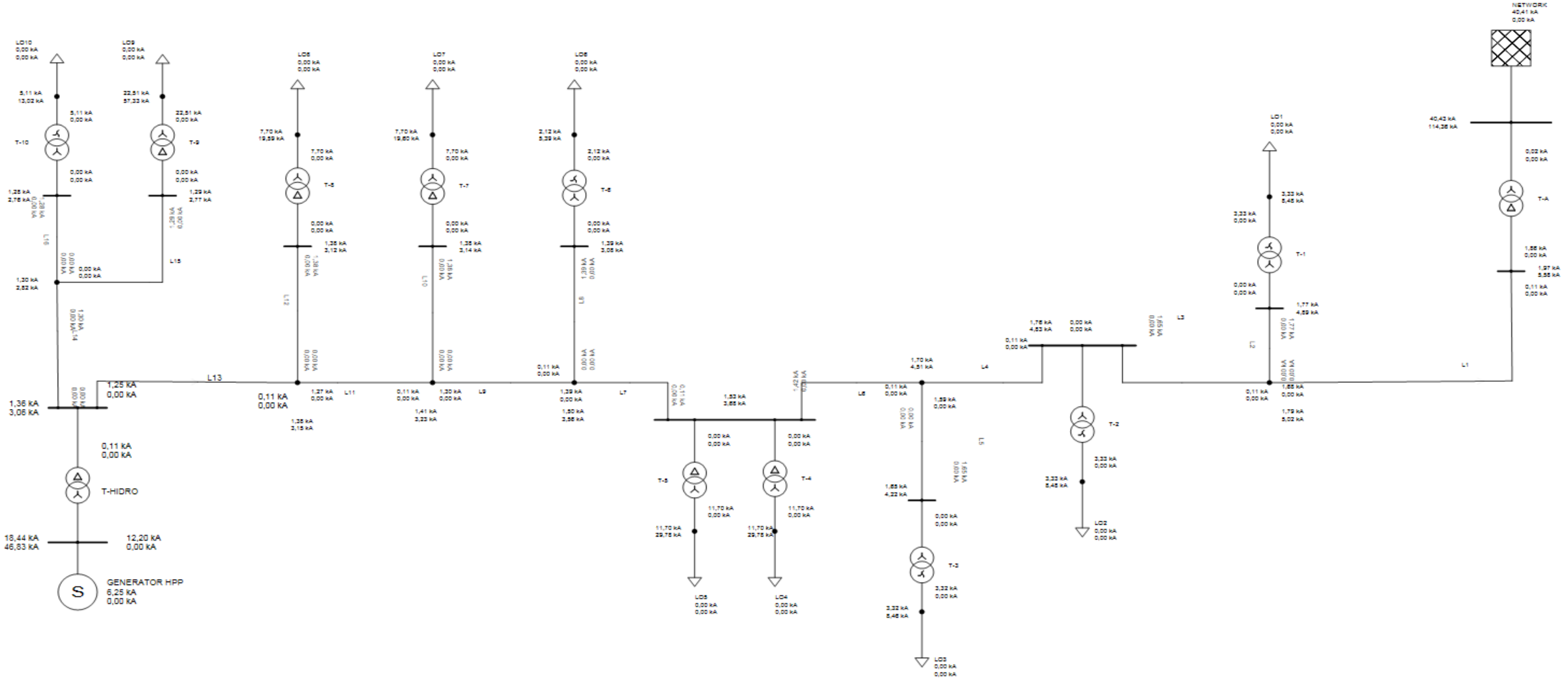


Figure 35. Results of the short-circuit calculation – generator 1MW

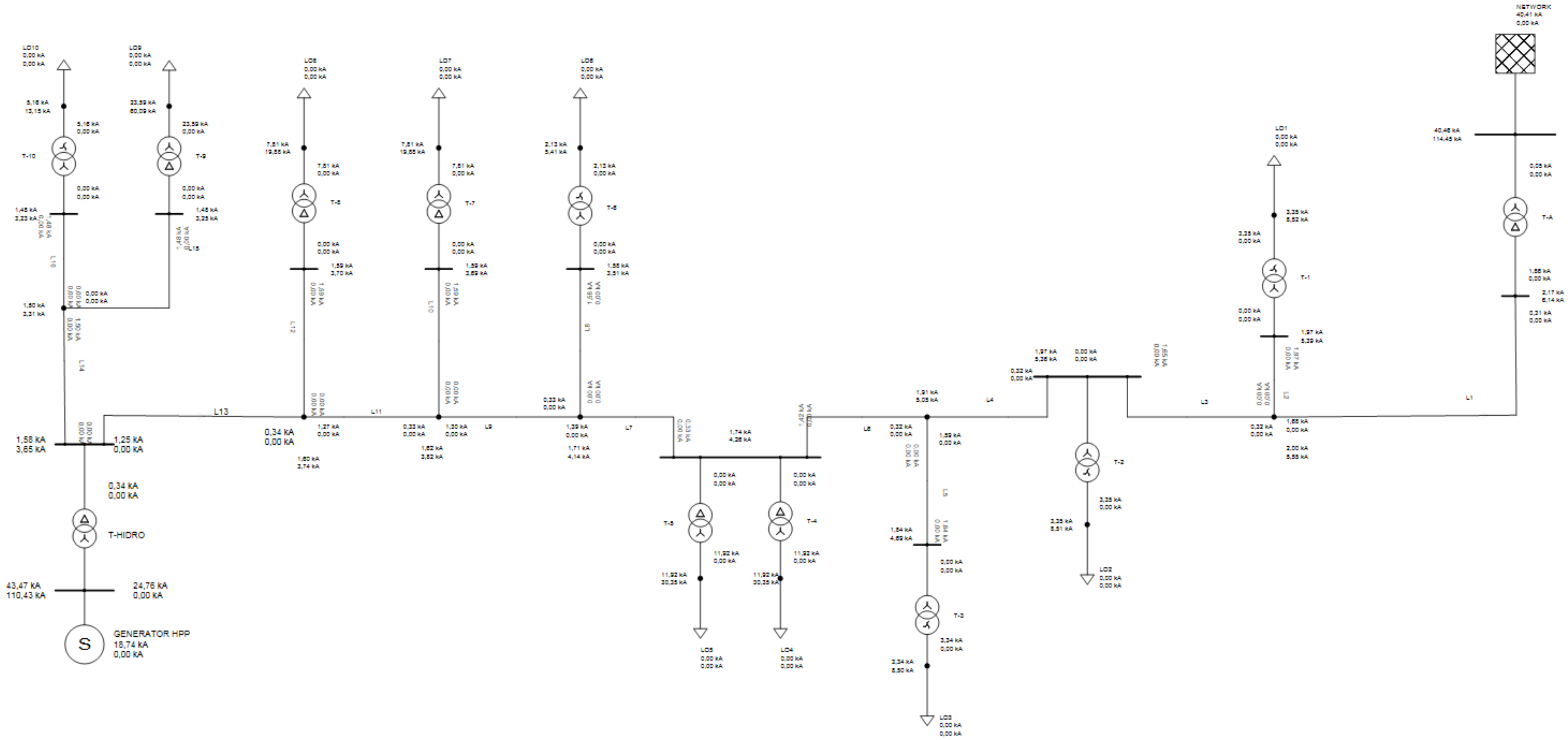


Figure 36. Results of the short-circuit calculation – generator 3MW

5.3. ANALYSIS AND COMMENTS

The comparations between base case and the system after connecting the small hydropower plant, will be analysed for the different cases of installed power, previously observed.

5.3.1. LOAD FLOW

After all the simulations you can see the comparison of all of them. Firstly, the percentage of the voltage respect the rate voltage is compared for each node, before and after connecting the hydropower plant, as can be seen in the following table.

Table 4. Summary of V/Vn (%) of load flow calculation

NETWORK LEVEL	**NODE**	**V/Vn (%)**				
		ONLY NETWORK	GRID + GENERATOR (0,1MW)	GRID + GENERATOR (0,5MW)	GRID + GENERATOR (1MW)	GRID + GENERATOR (3MW)
0,4 kV	N11	97,50	97,58	97,84	98,05	97,58
	N13	97,10	97,21	97,58	97,92	97,21
	N14	97,10	97,21	97,58	97,92	97,21
	N17	97,03	97,15	97,54	97,90	97,15
	N20	96,91	97,05	97,51	97,94	97,05
	N23	96,89	97,03	97,51	97,96	97,03
	N27	97,37	97,52	98,02	98,49	97,52
	N29	96,10	96,25	96,75	97,23	96,25
	N6	97,70	97,77	97,98	98,12	97,77
	N8	97,63	97,70	97,93	98,10	97,70
20kV	N10	98,45	98,53	98,79	98,99	98,53
	N12	98,06	98,17	98,54	98,87	98,17
	N15	98,01	98,13	98,52	98,87	98,13
	N16	98,00	98,12	98,51	98,86	98,12
	N18	97,88	98,01	98,47	98,89	98,01
	N19	97,87	98,00	98,46	98,89	98,00
	N21	97,85	97,99	98,46	98,91	97,99
	N22	97,84	97,98	98,46	98,91	97,98
	N24	97,82	97,97	98,46	98,93	97,97
	N25	97,76	97,90	98,40	98,87	97,90
	N26	97,75	97,98	98,39	98,86	97,89
	N28	97,75	97,89	98,39	98,86	97,89
	N3	99,03	99,07	99,19	99,22	99,07
	N4	98,65	98,72	98,92	99,07	98,72
	N5	98,64	98,71	98,92	99,07	98,71
	N7	98,57	98,65	98,88	99,04	98,65
	N9	98,45	98,54	98,79	99,00	98,54
110kV	N1	100,00	100,00	100,00	100,00	100,00
0,5kV	N31		100,00	100,00	100,00	100,00

As it can observe, the deviation of the voltage is very similar with and without generator, it’s a little higher after connecting generator than in the base case without it. This mean that the voltage is more closed to the rate voltage with it, which is positive for the system. Moreover, installing more power capacity in the generator, it is able to provide more electricity to the system, which requires less mains supply. So, at the moment install the generator, and more capacity have a little positive aspect referring to voltage rate.

For a better understanding of these values are represented in the following chart:

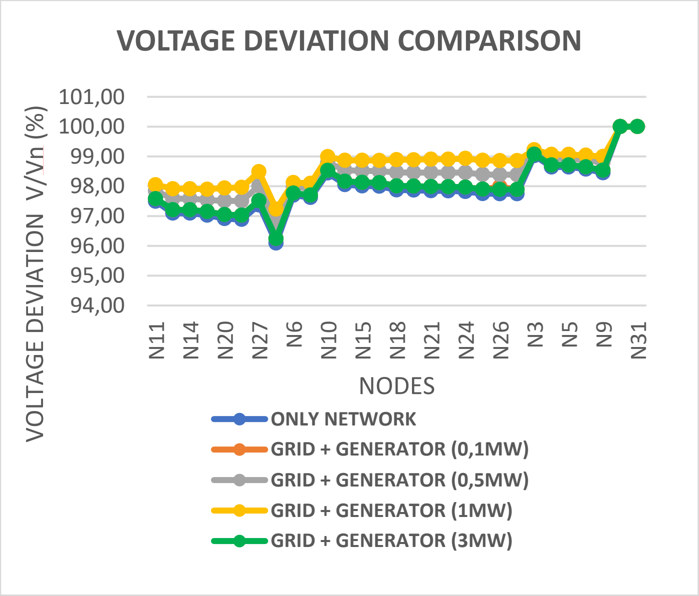


Figure 37. Graph voltage deviation (V/Vn) comparison

It can be seen, the values are similar in all cases, but they are higher and closer to 100% in the case of connecting the 1 MW generator to the grid. So, as far as node voltages are concerned, this would be the best solution. In addition, this, and the rest of the cases studied, are within the voltage range admitted by the grid code, which is 10% with respect to the nominal voltage.

Besides that, analysing voltage deviation angle, as can be shown in the reports in the ANNEX **8.1**, in nodes this value is slightly lower after installing the generators that in the base case, which is good for the system, to have smaller deviation from the rate base. Moreover, with higher installed power, lower is the angle.

5.3.2. SHORT CIRCUIT

It’s interesting to compare the short circuit currents in the nodes, before and after installing the generator, we can see that comparison below in the Table 5.Table 5. Summary of Ik" (kA) of short circuit calculation

Table 5. Summary of Ik'' (kA) of short circuit calculation

NETWORK LEVEL	**NODE**	**Ik'' (kA)**				
		ONLY NETWORK	GRID + GENERATOR (0,1MW)	GRID + GENERATOR (0,5MW)	GRID + GENERATOR (1MW)	GRID + GENERATOR (3MW)
0,4 kV	N11	3,31	3,32	3,32	3,32	3,34
	N13	11,56	11,57	11,63	11,70	11,92
	N14	11,56	11,57	11,63	11,70	11,92
	N17	2,11	2,12	2,11	2,12	2,13
	N20	7,63	7,64	7,67	7,70	7,81
	N23	7,63	7,64	7,66	7,70	7,81
	N27	21,89	21,96	22,21	22,51	23,59
	N29	5,08	5,09	5,10	5,11	5,17
	N6	3,32	3,32	3,33	3,33	3,35
	N8	3,32	3,32	3,33	3,33	3,35
20kV	N10	1,54	1,55	1,60	1,65	1,84
	N12	1,42	1,43	1,47	1,53	1,74
	N15	1,39	1,40	1,44	1,50	1,71
	N16	1,30	1,31	1,34	1,39	1,58
	N18	1,30	1,31	1,35	1,41	1,62
	N19	1,28	1,29	1,33	1,38	1,59
	N21	1,28	1,29	1,33	1,38	1,60
	N22	1,27	1,21	1,32	1,38	1,59
	N24	1,25	1,26	1,30	1,36	1,58
	N25	1,20	1,21	1,25	1,30	1,50
	N26	1,19	1,20	1,24	1,29	1,48
	N28	1,19	1,19	1,23	1,28	1,05
	N3	1,86	1,88	1,92	1,27	2,17
	N4	1,68	1,70	1,74	1,79	2,00
	N5	1,67	1,68	1,72	1,77	1,97
	N7	1,65	1,66	1,71	1,76	1,97
	N9	1,59	1,60	1,65	1,70	1,91
110kV	N1	40,42	40,42	40,42	40,43	40,46
0,5kV	N31		2,18	10,03	18,44	43,48

As a general review, the values of short-circuit are similar in low voltage depending on capacity of loads and are very closed in all nodes in medium voltage between them. In high voltage the value is very high, so the necessary protection must be more powerful. In other side, the current of generator is higher when output power is higher.

But, the more important thing is that the system behaves the same with and without connecting the generator.

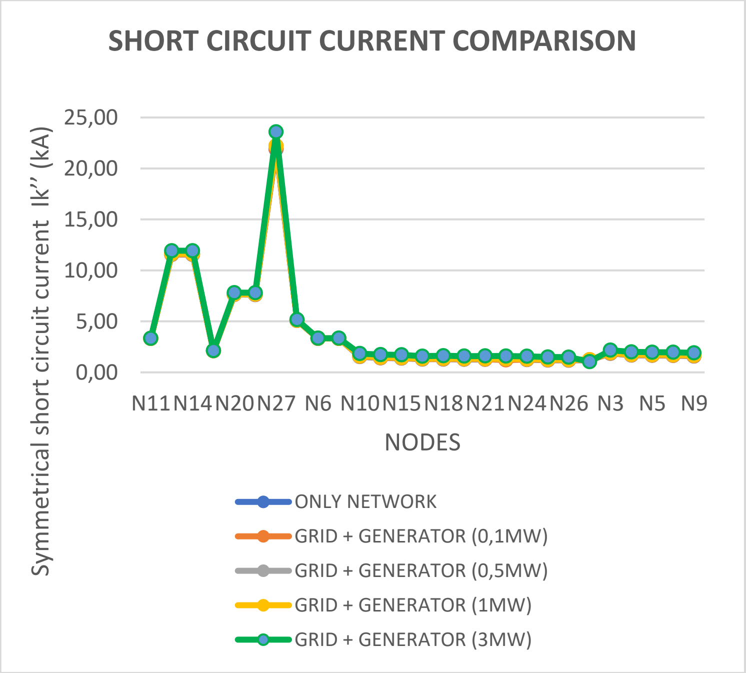


Figure 38. Graph short circuit current comparison

The graph shows that the data are almost the same in all scenarios. The short circuit study is not affected by the installation or not of a hydroelectric plant.

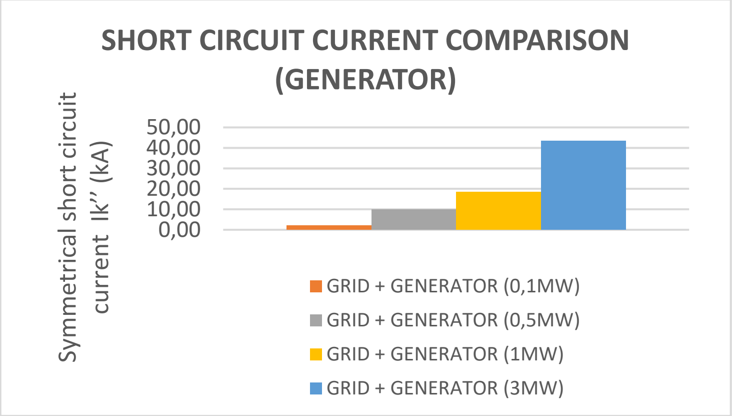


Figure 39. Graph short circuit current generator

In the generator, the short-circuit current is changing when the power is raising, because when there is more output power the system require more protection. This is the only limitation in order to install the generator according to short-circuit current limits.

It should be considered that in order to have the most restrictive case, the highest short-circuit current should be taken into account in order to design the protections. In case a generator is installed with the option to use more or less power as appropriate.

5.3.3. ALTERNATIVE

After these analysis, it is concluded that the best option could be to install 1MW of hydroelectric power, but it is necessary to go further. It can be analysed this case by placing the hydroelectric plant elsewhere on the grid and see how the grid system responds.

Assuming that there is a water resource on the other side of the distribution network, the generator and transformer of the hydroelectric power plant are located as follows:

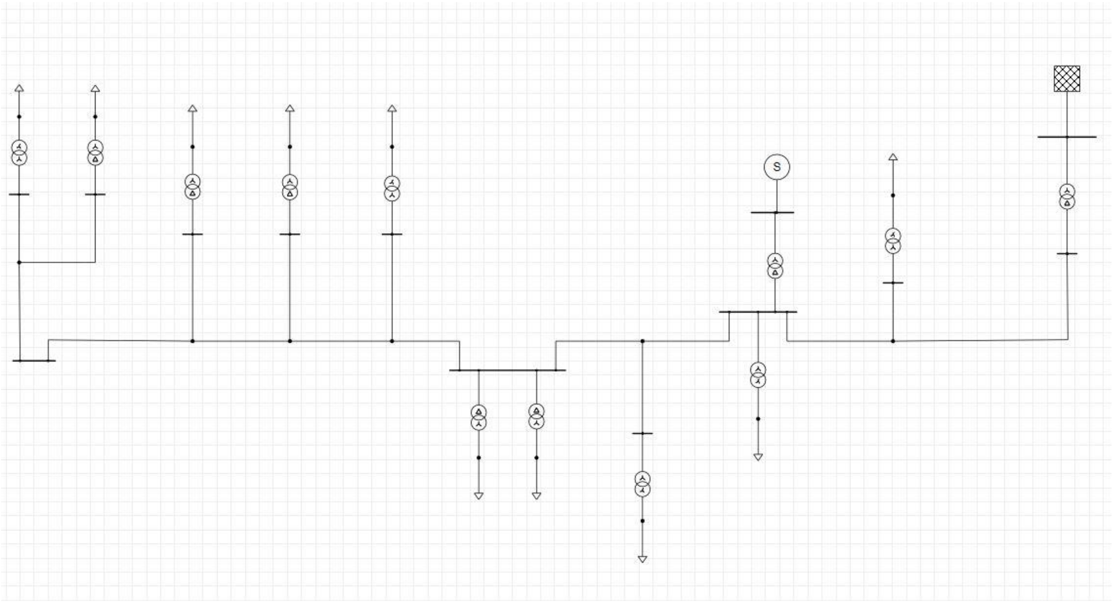


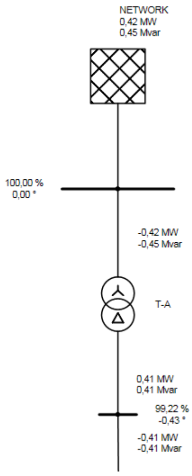
Figure 40. Scheme of the system placed SHPP to an alternative side

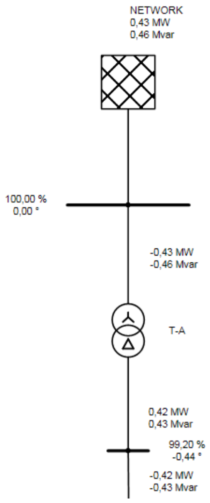
For this system, the simulations for the calculation of short circuit and load flows have been performed again.

LOAD FLOW:

After simulation it is possible to have some comparisons of voltage with the previous scenario.

First of all, this following picture show the case of the generator installed at the end of the line (at left) and the generator in the middle involves the result at the right side:





The picture show that the grid needs to supply less power if the generator is placed at the end of the line, but the difference is quite small. This mean that, although for little difference it would be better to install it at the end of the line, if the renewable source were halfway down the line it wouldn't matter.

It’s useful also to compare de deviation of voltage like follow:

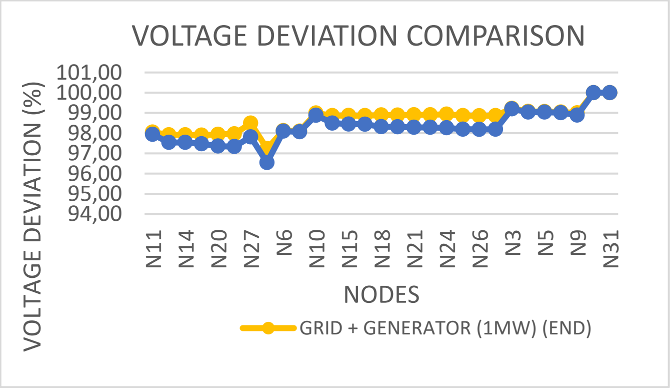


Figure 41. Voltage deviation (V/Vn) comparison - alternative

The conclusion of this graph is that the first case (by placing the generator at the end) is better option for a small difference than the second one (placing the generator in the middle of the system), because the deviation of the voltage with respect to the nominal voltage is lower in this case.

SHORT-CIRCUIT:

After comparing the short-circuit currents of both cases it can be seen that they hardly change at all:

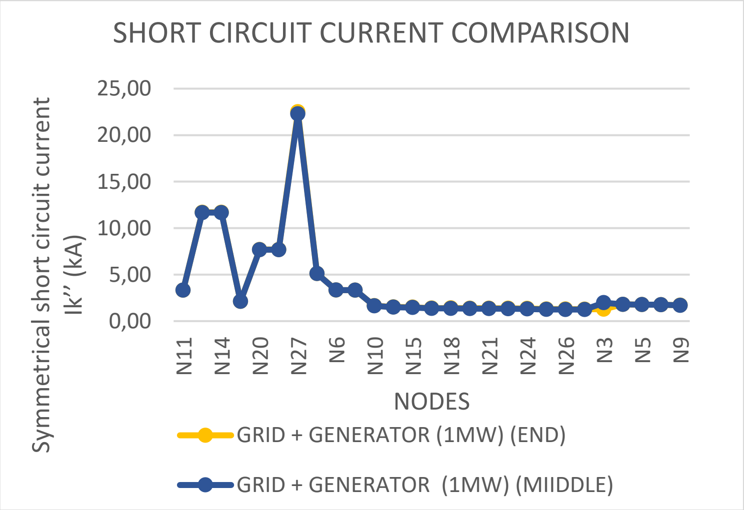


Figure 42. Short circuit current Ik''(kA) comparison – alternative

It doesn't affect the position of the hydropower plant for the knowledge of the system.

5.3.4. FINAL MODEL

The more effective solution is the choosing of connect the small hydropower plant at the extreme of the line with a capacity of 1MW. This is assuming that the hydroelectric capacity available can provide this capacity. Otherwise, with another installed power, as previously it have seen, the system would work perfectly.

About this better solution, on the one hand, this is the option where the voltage at the nodes is closer to nominal voltage, which is more positive for the operation of the line. And the rest of the parameters, like the voltage angle, are also stable in this way.

On the other hand, providing 1MW to the system, the grid supply only 0,4 MW. So, the hydropower plant has a contribution of 71% of the power.

In order to see the change between the line before and after connecting the generator, the following tables are useful tools.

By means of load flow calculation, by means of results in the software the following tables (Table 6 and Table 7) are made like a summary of current in lines and voltages in nodes, in order to compare both scenarios.

Table 6. Current in lines, before-after connection

NETWORK LEVEL	NODE 1	NODE 2	ELEMENT	TYPE	BEFORE CONNECT. SHPP		AFTER CONNECT. SHPP		LINE LOAD DIFFERENTIAL	
					I (kA)	I/Ib (%)	I (kA)	I/Ib (%)	ΔI (kA)	ΔI (%)
110	N1	N3	T-A	Transf.	0,01	15,41	0,03	6,16	-0,02	9,25
20	N3	N1	T-A	Transf.	0,04	15,07	0,02	5,84	0,03	9,23
0,4	N11	N10	T-3	Transf.	0,09	63,16	0,09	63,16	0,00	0,00
20	N10	N11	T-3	Transf.	0,02	64,23	0,00	64,23	0,02	0,00

0,4	N13	N12	T-4	Transf.	0,38	63,16	0,37	63,16	0,00	0,00
20	N12	N13	T-4	Transf.	0,01	64,08	0,01	64,08	0,00	0,01
0,4	N14	N12	T-5	Transf.	0,38	63,16	0,37	63,16	0,00	0,00
20	N12	N14	T-5	Transf.	0,01	64,08	0,01	64,08	0,00	0,01
0,4	N17	N16	T-6	Transf.	0,06	63,16	0,06	63,16	0,00	0,00
20	N16	N17	T-6	Transf.	0,00	64,75	0,00	64,75	0,00	-0,01
0,4	N20	N19	T-7	Transf.	0,24	63,16	0,23	63,16	0,00	0,00
20	N19	N20	T-7	Transf.	0,05	64,14	0,01	64,14	0,05	0,01
0,4	N23	N22	T-8	Transf.	0,24	63,16	0,23	63,16	0,00	0,00
20	N22	N23	T-8	Transf.	0,01	64,14	0,01	64,14	0,00	0,01
0,4	N27	N26	T-9	Transf.	0,37	25,26	0,37	25,26	0,00	0,00
20	N26	N27	T-9	Transf.	0,01	25,69	0,01	25,69	0,00	-0,01
0,4	N29	N28	T-10	Transf.	0,25	105,26	0,25	105,26	0,00	0,00
20	N28	N29	T-10	Transf.	0,01	107,35	0,01	107,31	0,00	0,04
0,4	N6	N5	T-1	Transf.	0,09	63,16	0,09	63,16	0,00	0,00
20	N5	N6	T-1	Transf.	0,00	64,23	0,00	64,23	0,00	0,00
0,4	N8	N7	T-2	Transf.	0,09	63,16	0,09	63,16	0,00	0,00
20	N7	N8	T-2	Transf.	0,00	64,23	0,00	64,23	0,00	0,00
20	N10	N9	L5	Line	0,00	0,74	0,00	0,73	0,00	0,01
20	N9	N10	L5	Line	0,00	0,74	0,00	0,73	0,00	0,00
20	N12	N15	L7	Line	0,02	9,13	0,01	3,55	0,01	5,57
20	N12	N9	L6	Line	0,04	15,04	0,01	4,84	0,03	10,21
20	N9	N12	L6	Line	0,04	15,03	0,01	4,81	0,03	10,22
20	N15	N16	L8	Line	0,00	0,70	0,00	0,70	0,00	0,01
20	N15	N18	L9	Line	0,02	8,66	0,01	3,84	0,01	4,82
20	N18	N15	L9	Line	0,02	8,67	0,01	3,85	0,01	4,81
20	N15	N12	L7	Line	0,02	9,13	0,01	3,56	0,01	5,57
20	N16	N15	L8	Line	0,00	0,71	0,00	0,70	0,00	0,01
20	N18	N19	L10	Line	0,01	1,85	0,01	1,83	0,00	0,02
20	N19	N18	L10	Line	0,01	1,86	0,01	1,84	0,00	0,02
20	N18	N21	L28	Line	0,02	6,81	0,01	5,23	0,00	1,58
20	N21	N18	L28	Line	0,02	6,81	0,01	5,23	0,00	1,58
20	N21	N24	L13	Line	0,01	4,96	0,02	6,83	0,00	-1,87
20	N24	N21	L13	Line	0,01	4,96	0,02	6,83	0,00	-1,87
20	N21	N22	L12	Line	0,01	2,78	0,01	2,75	0,00	0,03
20	N22	N21	L12	Line	0,01	2,78	0,01	2,75	0,00	0,03
20	N24	N25	L14	Line	0,01	7,44	0,01	7,36	0,00	0,08
20	N25	N24	L14	Line	0,01	7,44	0,01	7,36	0,00	0,08
20	N25	N26	L15	Line	0,01	4,46	0,01	4,41	0,00	0,05
20	N26	N25	L15	Line	0,01	4,46	0,01	4,41	0,00	0,05
20	N25	N28	L16	Line	0,01	2,98	0,01	2,95	0,00	0,04
20	N28	N25	L16	Line	0,01	2,98	0,01	2,95	0,00	0,04
20	N4	N5	L2	Line	0,00	0,74	0,00	0,73	0,00	0,00
20	N5	N4	L2	Line	0,00	0,74	0,00	0,73	0,00	0,00
20	N4	N7	L3	Line	0,04	16,50	0,02	6,03	0,03	10,47
20	N7	N4	L3	Line	0,04	16,51	0,02	6,04	0,03	10,47

20	N4	N3	L1	Line	0,04	17,24	0,02	6,69	0,03	10,56
20	N3	N4	L1	Line	0,04	17,23	0,02	6,67	0,03	10,56
20	N7	N9	L4	Line	0,04	15,77	0,01	5,41	0,03	10,36
20	N9	N7	L4	Line	0,04	15,77	0,01	5,41	0,03	10,36

Table 7. Voltage in nodes (V/Vn), before-after connection

NETWORK LEVEL	**NODE**	**BEFORE CONNECTION SHPP**	**AFTER CONNECTION SHPP**	**DELTA V**
		V/Vn (%)	V/Vn (%)	Δ(V/Vn) (%)
0,4 kV	N11	97,50	98,05	0,55
	N13	97,10	97,92	0,82
	N14	97,10	97,92	0,82
	N17	97,03	97,90	0,87
	N20	96,91	97,94	1,03
	N23	96,89	97,96	1,07
	N27	97,37	98,49	1,12
	N29	96,10	97,23	1,13
	N6	97,70	98,12	0,43
	N8	97,63	98,10	0,47
20kV	N10	98,45	98,99	0,54
	N12	98,06	98,87	0,81
	N15	98,01	98,87	0,86
	N16	98,00	98,86	0,86
	N18	97,88	98,89	1,02
	N19	97,87	98,89	1,02
	N21	97,85	98,91	1,06
	N22	97,84	98,91	1,06
	N24	97,82	98,93	1,11
	N25	97,76	98,87	1,11
	N26	97,75	98,86	1,11
	N28	97,75	98,86	1,11
	N3	99,03	99,22	0,20
	N4	98,65	99,07	0,42
	N5	98,64	99,07	0,42
	N7	98,57	99,04	0,47
	N9	98,45	99,00	0,54
110kV	N1	100	100,00	0,00

Both tables show that the voltage and current differential is small, it affects certain currents more than certain voltages, but even so it is an almost negligible change.

With short circuit calculation, it is possible to show the next table:

Table 8. Voltage in nodes (V/Vn), before-after connection

NETWORK LEVEL	NODE	BEFORE CONNECTION SHPP	AFTER CONNECTION SHPP	DELTA Ik''	
		Ik'' (kA)	Ik'' (kA)	ΔIk'' (kA)	ΔIk'' (%)
0,4 kV	N11	3,31	3,32	0,01	0,00
	N13	11,56	11,70	0,14	0,01
	N14	11,56	11,70	0,14	0,01
	N17	2,11	2,12	0,01	0,00
	N20	7,63	7,70	0,07	0,01
	N23	7,63	7,70	0,07	0,01
	N27	21,89	22,51	0,62	0,03
	N29	5,08	5,11	0,03	0,01
	N6	3,32	3,33	0,01	0,00
	N8	3,32	3,33	0,01	0,00
20kV	N10	1,54	1,65	0,10	0,06
	N12	1,42	1,53	0,11	0,07
	N15	1,39	1,50	0,11	0,07
	N16	1,30	1,39	0,10	0,07
	N18	1,30	1,41	0,11	0,08
	N19	1,28	1,38	0,11	0,08
	N21	1,28	1,38	0,11	0,08
	N22	1,27	1,38	0,11	0,08
	N24	1,25	1,36	0,11	0,08
	N25	1,20	1,30	0,10	0,08
	N26	1,19	1,29	0,10	0,08
	N28	1,19	1,28	0,10	0,07
	N3	1,86	1,97	0,11	0,06
	N4	1,68	1,79	0,11	0,06
	N5	1,67	1,77	0,11	0,06
	N7	1,65	1,76	0,11	0,06
	N9	1,59	1,70	0,11	0,06
110kV	N1	40,42	40,43	0,02	0,00

As the table show, the change of short-circuit currents are even more negligible that previous currents and voltage.

It is necessary also, to check the following condition set by the network code:

- for generation units connected to LV network:

$$\frac{S_{rA}}{S_{kV}} x100\% < \frac{3\%}{k} \qquad \text{Eq. 6}$$

where:

S_{rA} – pull-out power of generation unit,

SkV – short circuit capacity in the place of connection of generation unit,

k = 1 for synchronous generators,

For this particular case, the value of power of generation unit is 1MVA, and the short circuit capacity in the place of connection is 47,002 MVA, thus the operation is like follow:

$$\frac{1\ MVA}{47{,}002\ MVA} * 100 = 2{,}3\% < 3\% \qquad \textit{Eq. 7}$$

The restriction given by $\frac{S_{rA}}{S_{kV}} x100\% < \frac{3\%}{k}$ Eq. 6 is fulfilled, and therefore complies with the grid code.

6. CONCLUSIONS

After simulating several short circuit and load flow calculations, for several different situations, it can be concluded that there is no problem in connecting a small hydropower plant, with the wide range of installing generation capacities from 0.1 to 3MW, and the connection could probably be done with an even wider range. The system responds correctly to the installation of the hydroelectric power plant

If it would be possible to choose, the best option is to install 1MW of installed capacity of a small hydropower plant at the end of the line. With little difference with the rest of the cases. The image below shows the system mentioned, with the input data:

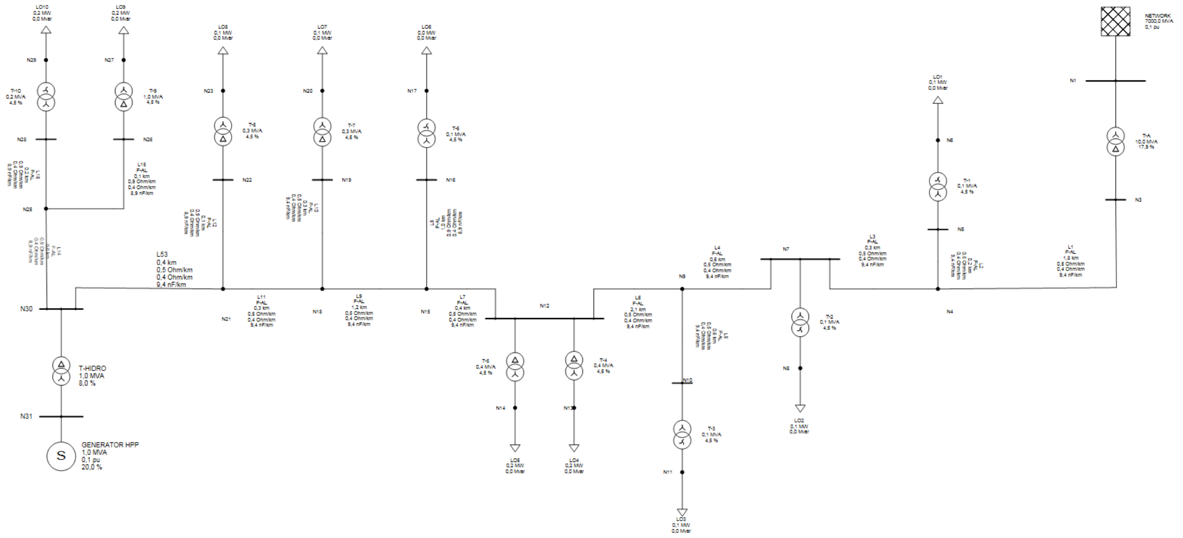


Figure 43. Diagram of the final system analysed

Taking into account this installation, it mean that the contribution of SHPP to the system is (71%) of the demand, requiring little supply from the network, which mean lower cost of electricity production and bigger renewable contribution.

Compared to the rest of cases of study this option causes less voltage deviation in its nodes.

Study of short-circuit and load flow have been positives, that the values are not outside the limits and don't vary greatly from case to case. So, it isn't a technical problem to adapt the power of a renewable resource to the grid.

Grid Code of Poland is also correctly implemented in the system, taking into account their limitations.

7. LITETARUTE

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8. APPENDICES

8.1. REPORT OF LOAD FLOW AND SHORT CIRCUIT CALCULATIONS-NETWORK WITH GENERATOR – 1 MW

8.2. CATALOGUES

8.2.1. CATALOGUE GENERATOR

8.2.2. CATALOGUE TRANSFORMER

8. APPENDICES

8.1. REPORT OF LOAD FLOW AND SHORT CIRCUIT CALCULATIONS-NETWORK WITH GENERATOR – 1 MW

Content

Input Data

Nodes

Ik"max	Maximum Admissible Short Circuit Current
ipmax	Maximum Admissible Peak Short Circuit Current
vll	Voltage Lower Limit
vul	Voltage Upper Limit
Vref	Voltage Target Value

Network Level: HV 110 kV (110,00 kV)

Name	Short Name	Node Type	Ik"max [kA]	ipmax [kA]	vll [%]	vul [%]	Vref [kV]
N1	N1	Node	0,000	0,000	0,000	0,000	0,000

Network Level: HYDROELECTRIC (0,50 kV)

Name	Short Name	Node Type	Ik"max [kA]	ipmax [kA]	vll [%]	vul [%]	Vref [kV]
N31	N31	Node	0,000	0,000	0,000	0,000	0,000

Network Level: LV 0,4 kV (0,40 kV)

Name	Short Name	Node Type	Ik"max [kA]	ipmax [kA]	vll [%]	vul [%]	Vref [kV]
N11	N11	Node	0,000	0,000	0,000	0,000	0,000
N13	N13	Node	0,000	0,000	0,000	0,000	0,000
N14	N14	Node	0,000	0,000	0,000	0,000	0,000
N17	N17	Node	0,000	0,000	0,000	0,000	0,000
N20	N20	Node	0,000	0,000	0,000	0,000	0,000
N23	N23	Node	0,000	0,000	0,000	0,000	0,000
N27	N27	Node	0,000	0,000	0,000	0,000	0,000
N29	N29	Node	0,000	0,000	0,000	0,000	0,000
N6	N6	Node	0,000	0,000	0,000	0,000	0,000
N8	N8	Node	0,000	0,000	0,000	0,000	0,000

Network Level: MV 20 kV (20,00 kV)

Name	Short Name	Node Type	Ik"max [kA]	ipmax [kA]	vll [%]	vul [%]	Vref [kV]
N10	N10	Node	0,000	0,000	0,000	0,000	0,000
N12	N12	Node	0,000	0,000	0,000	0,000	0,000
N15	N15	Node	0,000	0,000	0,000	0,000	0,000
N16	N16	Node	0,000	0,000	0,000	0,000	0,000
N18	N18	Node	0,000	0,000	0,000	0,000	0,000
N19	N19	Node	0,000	0,000	0,000	0,000	0,000
N21	N21	Node	0,000	0,000	0,000	0,000	0,000
N22	N22	Node	0,000	0,000	0,000	0,000	0,000
N25	N25	Node	0,000	0,000	0,000	0,000	0,000
N26	N26	Node	0,000	0,000	0,000	0,000	0,000
N28	N28	Node	0,000	0,000	0,000	0,000	0,000
N3	N3	Node	0,000	0,000	0,000	0,000	0,000
N30	N30	Node	0,000	0,000	0,000	0,000	0,000
N4	N4	Node	0,000	0,000	0,000	0,000	0,000
N5	N5	Node	0,000	0,000	0,000	0,000	0,000
N7	N7	Node	0,000	0,000	0,000	0,000	0,000
N9	N9	Node	0,000	0,000	0,000	0,000	0,000

Network Elements

Ti	Establishment Date
Ts	Shutdown Date

Network Level: HV 110 kV (110,00 kV)

Name	Short Name	Network Element Type	OP State	Ti	Ts
NETWORK	NETWORK	Infeeder	On		
T-A	T-A	Two-Winding Transformer	On		

Network Level: HYDROELECTRIC (0,50 kV)

Name	Short Name	Network Element Type	OP State	Ti	Ts
GENERATOR HPP	N31	Synchronous Machine	On		
T-HIDRO	2T46	Two-Winding Transformer	On		

Network Level: LV 0,4 kV (0,40 kV)

Name	Short Name	Network Element Type	OP State	Ti	Ts
LO1	LO1	Load	On		
LO10	LO10	Load	On		
LO2	LO2	Load	On		
LO3	LO3	Load	On		
LO4	LO4	Load	On		
LO5	LO5	Load	On		
LO6	LO6	Load	On		
LO7	LO7	Load	On		
LO8	LO8	Load	On		
LO9	LO9	Load	On		

Network Level: MV 20 kV (20,00 kV)

Name	Short Name	Network Element Type	OP State	Ti	Ts
L1	L1	Line	On		
L10	L10	Line	On		
L11	L28	Line	On		
L12	L6	Line	On		
L13	L13	Line	On		
L14	L14	Line	On		
L15	L15	Line	On		
L16	L16	Line	On		
L2	L2	Line	On		
L3	L3	Line	On		
L4	L4	Line	On		
L5	L5	Line	On		
L6	L6	Line	On		
L7	L7	Line	On		
L8	L8	Line	On		
L9	L9	Line	On		
T-1	T-1	Two-Winding Transformer	On		
T-10	T-10	Two-Winding Transformer	On		
T-2	T-2	Two-Winding Transformer	On		
T-3	T-3	Two-Winding Transformer	On		
T-4	T-4	Two-Winding Transformer	On		
T-5	T-5	Two-Winding Transformer	On		

Network Level: MV 20 kV (20,00 kV)

Name	Short Name	Network Element Type	OP State	Ti	Ts
T-6	T-6	Two-Winding Transformer	On		
T-7	T-7	Two-Winding Transformer	On		
T-8	T-8	Two-Winding Transformer	On		
T-9	T-9	Two-Winding Transformer	On		

Lines

l	Length
r	Resistance
x	Reactance
c	Capacitance
va	Leakage Losses to Ground
Vn	Rated Voltage
p	Number of Parallel Systems
Ith	Thermal Limit Current
I1s	Admissible Short Circuit Power (1 Second)

Network Level: MV 20 kV (20,00 kV)

Start Node	End Node	Name	Line Type	l [km]	r [Ohm/km]	x [Ohm/km]	c [nF/km]	va [kW/km]	Vn [kV]	p	Ith [kA]	I1s [kA]
N3	N4	L1	Overhead line	1,770	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N19	N18	L10	Overhead line	0,315	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N18	N21	L28	Overhead line	0,340	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N21	N22	L6	Overhead line	0,063	0,886	0,407	8,940	0,000	20,000	1,000	0,170	2,450
N21	N30	L13	Overhead line	0,411	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N30	N25	L14	Overhead line	0,620	0,886	0,407	8,940	0,000	20,000	1,000	0,170	2,450
N25	N26	L15	Overhead line	0,132	0,886	0,407	8,940	0,000	20,000	1,000	0,170	2,450
N25	N28	L16	Overhead line	0,170	0,886	0,407	8,940	0,000	20,000	1,000	0,170	2,450
N5	N4	L2	Overhead line	0,202	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N4	N7	L3	Overhead line	0,350	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N7	N9	L4	Overhead line	0,620	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N9	N10	L5	Overhead line	0,560	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N9	N12	L6	Overhead line	2,115	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N15	N12	L7	Overhead line	0,390	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900
N15	N16	L8	Overhead line	0,973	0,886	0,407	8,940	0,000	20,000	1,000	0,170	2,450
N15	N18	L9	Overhead line	1,245	0,463	0,386	9,450	0,000	20,000	1,000	0,255	4,900

Results

Power Data

Base Data

View Date	-	**Determine Rating**	Base rating
Load Data Date	-	**Voltage Unbalance**	V2/V1
Use Load Data	Base Data	**Diagram Creation**	Completely
Frequency	50,00 Hz	**Controller Adjustment**	Discrete
Reference Power	0,00 MVA	**Reference Voltage**	0,00 kV

Zero Sequence Data

Mode Zero-Phase Impedance	Input data
Act. Part Lock Imp.	10000,00 Ohm
Imag. Part Lock Imp.	0,00 Ohm

Load Flow

Load Flow Procedure	Newton-Raphson	**Flat Start**	Yes
Store Results	Completely	**Load Flow Change**	On
Extended Calculations	None	**Pre-Calculate**	No
Imped. Load Conversion	No	**Enable Controllers**	Yes
Max. Number of Iterations	200	**Island Operation**	Yes
Voltage Limit Load Reduction	80,00 %	**LF Speed Factor**	1,00 1
Power Accuracy	1,00 %	**Min. Power Accuracy**	0,00 MVA
Mesh Accuracy	0,01 %	**Node Accuracy**	0,01 %
Voltage Lower Limit	90,00 %	**Voltage Upper Limit**	110,00 %
Element Utilization Limit	100,00 %	**Line Utilization Limit**	95,00 %

Extended Settings for Controlling

Activate Transformer Tap Changer	On	**Activate Generator Controlling**	Yes
Activate Shunt Tap Changer	No	**Activate Area Interchange**	On
Acitvate Load Shedding	Yes	**Activate Redistribute Power**	No

Load Profile

Start Time	0,00 h
Duration	24,00 h
Time Step	0,25 h

Load Development

Start Date	-
End Date	-

Node Results Line-Line Voltage

V	Node Voltage
φV	Angle - Slack Voltage
P	Active Power
Q	Reactive Power
S	Apparent Power
V/Vref	Voltage/Reference Voltage
V/Vn	Node Voltage/Rated Node Voltage

Network Level: HV 110 kV (110,00 kV)

Node	**V [kV]**	**φV [°]**	**P [MW]**	**Q [Mvar]**	**S [MVA]**	**V/Vref [%]**	**V/Vn [%]**	**V/Vn 100%**
N1	110,000	0,000	0,421	0,449	0,616	0,000	100,000	

Network Level: HYDROELECTRIC (0,50 kV)

Node	**V [kV]**	**φV [°]**	**P [MW]**	**Q [Mvar]**	**S [MVA]**	**V/Vref [%]**	**V/Vn [%]**	**V/Vn 100%**
N31	0,500	4,312	1,000	0,184	1,017	0,000	100,000	

Network Level: LV 0,4 kV (0,40 kV)

Node	**V [kV]**	**φV [°]**	**P [MW]**	**Q [Mvar]**	**S [MVA]**	**V/Vref [%]**	**V/Vn [%]**	**V/Vn 100%**
N11	0,392	-2,016	-0,060	-0,020	0,063	0,000	98,048	
N13	0,392	-1,992	-0,240	-0,079	0,253	0,000	97,916	
N14	0,392	-1,992	-0,240	-0,079	0,253	0,000	97,916	
N17	0,392	-1,990	-0,038	-0,012	0,040	0,000	97,899	
N20	0,392	-1,950	-0,150	-0,049	0,158	0,000	97,941	
N23	0,392	-1,937	-0,150	-0,049	0,158	0,000	97,960	
N27	0,394	-0,963	-0,240	-0,079	0,253	0,000	98,489	
N29	0,389	-3,010	-0,160	-0,053	0,168	0,000	97,231	
N6	0,392	-2,021	-0,060	-0,020	0,063	0,000	98,123	
N8	0,392	-2,019	-0,060	-0,020	0,063	0,000	98,097	

Network Level: MV 20 kV (20,00 kV)

Node	V [kV]	φV [°]	P [MW]	Q [Mvar]	S [MVA]	V/Vref [%]	V/Vn [%]	V/Vn 100%
N10	19,798	-0,415	0,000	0,000	0,000	0,000	98,991	
N12	19,773	-0,391	0,000	0,000	0,000	0,000	98,867	
N15	19,774	-0,381	0,000	0,000	0,000	0,000	98,871	
N16	19,772	-0,381	0,000	0,000	0,000	0,000	98,862	
N18	19,779	-0,346	0,000	0,000	0,000	0,000	98,893	
N19	19,777	-0,347	0,000	0,000	0,000	0,000	98,886	
N21	19,781	-0,335	0,000	0,000	0,000	0,000	98,907	
N22	19,781	-0,335	0,000	0,000	0,000	0,000	98,905	
N25	19,774	-0,323	0,000	0,000	0,000	0,000	98,868	
N26	19,772	-0,323	0,000	0,000	0,000	0,000	98,860	
N28	19,772	-0,323	0,000	0,000	0,000	0,000	98,861	
N3	19,845	-0,431	0,000	0,000	0,000	0,000	99,224	
N30	19,787	-0,319	0,000	0,000	0,000	0,000	98,933	
N4	19,814	-0,422	0,000	0,000	0,000	0,000	99,068	
N5	19,813	-0,422	0,000	0,000	0,000	0,000	99,066	
N7	19,808	-0,420	0,000	0,000	0,000	0,000	99,040	
N9	19,799	-0,414	0,000	0,000	0,000	0,000	98,996	

Branch Results

V	Node Voltage
V/Vn	Node Voltage/Rated Node Voltage
φV	Angle - Slack Voltage
P	Active Power
Q	Reactive Power
S	Apparent Power
cosφ	Power Factor
I	Current
I/Ib	Base Rating

Network Level: HV 110 kV (110,00 kV)

Node	V [kV]	V/Vn [%]	φV [°]	Nb. Node	Element	P [MW]	Q [Mvar]	S [MVA]	cosφ	I [kA]	I/Ib [%]
N1	110,000	100,000	0,000								
	Two-Winding Transformer			N3	T-A	-0,421	-0,449	0,616	0,684	0,003	6,157
	Infeeder				NETWORK	0,421	0,449	0,616	0,684	0,003	0,000

Network Level: HYDROELECTRIC (0,50 kV)

Node	V [kV]	V/Vn [%]	φV [°]	Nb. Node	Element	P [MW]	Q [Mvar]	S [MVA]	cosφ	I [kA]	I/Ib [%]
N31	0,500	100,000	4,312								
	Synchronous Machine				N31	1,000	0,184	1,017	0,984	1,174	101,672
	Two-Winding Transformer			N30	2T46	-1,000	-0,184	1,017	0,984	1,174	101,672

Network Level: LV 0,4 kV (0,40 kV)

Node	V [kV]	V/Vn [%]	φV [°]	Nb. Node	Element	P [MW]	Q [Mvar]	S [MVA]	cosφ	I [kA]	I/Ib [%]
N11	0,392	98,048	-2,016								
	Load				LO3	-0,060	-0,020	0,063	0,950	0,093	0,000
	Two-Winding Transformer			N10	T-3	0,060	0,020	0,063	0,950	0,093	63,158
N13	0,392	97,916	-1,992								
	Load				LO4	-0,240	-0,079	0,253	0,950	0,372	0,000
	Two-Winding Transformer			N12	T-4	0,240	0,079	0,253	0,950	0,372	63,158
N14	0,392	97,916	-1,992								
	Load				LO5	-0,240	-0,079	0,253	0,950	0,372	0,000

Network Level: LV 0,4 kV (0,40 kV)

Node	V [kV]	V/Vn [%]	φV [°]	Nb. Node	Element	P [MW]	Q [Mvar]	S [MVA]	cosφ	I [kA]	I/Ib [%]
	Two-Winding Transformer			N12	T-5	0,240	0,079	0,253	0,950	0,372	63,158
N17	0,392	97,899	-1,990								
	Load				LO6	-0,038	-0,012	0,040	0,950	0,059	0,000
	Two-Winding Transformer			N16	T-6	0,038	0,012	0,040	0,950	0,059	63,158
N20	0,392	97,941	-1,950								
	Load				LO7	-0,150	-0,049	0,158	0,950	0,233	0,000
	Two-Winding Transformer			N19	T-7	0,150	0,049	0,158	0,950	0,233	63,158
N23	0,392	97,960	-1,937								
	Load				LO8	-0,150	-0,049	0,158	0,950	0,233	0,000
	Two-Winding Transformer			N22	T-8	0,150	0,049	0,158	0,950	0,233	63,158
N27	0,394	98,489	-0,963								
	Two-Winding Transformer			N26	T-9	0,240	0,079	0,253	0,950	0,370	25,263
	Load				LO9	-0,240	-0,079	0,253	0,950	0,370	0,000
N29	0,389	97,231	-3,010								
	Load				LO10	-0,160	-0,053	0,168	0,950	0,250	0,000
	Two-Winding Transformer			N28	T-10	0,160	0,053	0,168	0,950	0,250	105,263
N6	0,392	98,123	-2,021								
	Load				LO1	-0,060	-0,020	0,063	0,950	0,093	0,000
	Two-Winding Transformer			N5	T-1	0,060	0,020	0,063	0,950	0,093	63,158
N8	0,392	98,097	-2,019								
	Load				LO2	-0,060	-0,020	0,063	0,950	0,093	0,000
	Two-Winding Transformer			N7	T-2	0,060	0,020	0,063	0,950	0,093	63,158

Network Level: MV 20 kV (20,00 kV)

Node	V [kV]	V/Vn [%]	φV [°]	Nb. Node	Element	P [MW]	Q [Mvar]	S [MVA]	cosφ	I [kA]	I/Ib [%]
N10	19,798	98,991	-0,415								
	Line			N9	L5	0,060	0,022	0,064	0,942	0,002	0,734
	Two-Winding Transformer			N11	T-3	-0,060	-0,022	0,064	0,942	0,002	64,227
N12	19,773	98,867	-0,391								
	Two-Winding Transformer			N13	T-4	-0,241	-0,087	0,256	0,940	0,007	64,079
	Two-Winding Transformer			N14	T-5	-0,241	-0,087	0,256	0,940	0,007	64,079
	Line			N15	L7	0,253	-0,180	0,310	-0,814	0,009	3,553
	Line			N9	L6	0,229	0,355	0,423	0,543	0,012	4,838
N15	19,774	98,871	-0,381								

Network Level: MV 20 kV (20,00 kV)

Node	V [kV]	V/Vn [%]	φV [°]	Nb. Node	Element	P [MW]	Q [Mvar]	S [MVA]	cosφ	I [kA]	I/Ib [%]
	Line			N16	L8	-0,038	-0,013	0,040	0,947	0,001	0,695
	Line			N18	L9	0,291	-0,168	0,336	-0,867	0,010	3,844
	Line			N12	L7	-0,253	0,181	0,311	-0,814	0,009	3,556
N16	19,772	98,862	-0,381								
	Line			N15	L8	0,038	0,014	0,041	0,938	0,001	0,701
	Two-Winding Transformer			N17	T-6	-0,038	-0,014	0,041	0,938	0,001	64,751
N18	19,779	98,893	-0,346								
	Line			N19	L10	-0,151	-0,054	0,160	0,942	0,005	1,834
	Line			N21	L28	0,442	-0,115	0,457	-0,968	0,013	5,230
	Line			N15	L9	-0,291	0,169	0,337	-0,865	0,010	3,853
N19	19,777	98,886	-0,347								
	Line			N18	L10	0,151	0,054	0,160	0,942	0,005	1,836
	Two-Winding Transformer			N20	T-7	-0,151	-0,054	0,160	0,942	0,005	64,135
N21	19,781	98,907	-0,335								
	Line			N22	L6	-0,151	-0,054	0,160	0,942	0,005	2,752
	Line			N18	L28	-0,442	0,116	0,457	-0,968	0,013	5,231
	Line			N30	L13	0,593	-0,062	0,596	-0,995	0,017	6,826
N22	19,781	98,905	-0,335								
	Line			N21	L6	0,151	0,054	0,160	0,942	0,005	2,753
	Two-Winding Transformer			N23	T-8	-0,151	-0,054	0,160	0,942	0,005	64,135
N25	19,774	98,868	-0,323								
	Line			N26	L15	-0,243	-0,084	0,257	0,946	0,008	4,412
	Line			N28	L16	-0,160	-0,061	0,172	0,935	0,005	2,948
	Line			N30	L14	0,403	0,144	0,428	0,942	0,013	7,359
N26	19,772	98,860	-0,323								
	Line			N25	L15	0,243	0,084	0,257	0,946	0,008	4,413
	Two-Winding Transformer			N27	T-9	-0,243	-0,084	0,257	0,946	0,008	25,692
N28	19,772	98,861	-0,323								
	Line			N25	L16	0,160	0,061	0,172	0,935	0,005	2,949
	Two-Winding Transformer			N29	T-10	-0,160	-0,061	0,172	0,935	0,005	107,313
N3	19,845	99,224	-0,431								
	Line			N4	L1	-0,412	-0,414	0,584	0,705	0,017	6,668
	Two-Winding Transformer			N1	T-A	0,412	0,414	0,584	0,705	0,017	5,844
N30	19,787	98,933	-0,319								
	Line			N25	L14	-0,404	-0,144	0,429	0,942	0,013	7,355
	Two-Winding Transformer			N31	2T46	0,997	0,082	1,000	0,997	0,029	100,039
	Line			N21	L13	-0,593	0,062	0,597	-0,995	0,017	6,826

Network Level: MV 20 kV (20,00 kV)

Node	V [kV]	V/Vn [%]	φV [°]	Nb. Node	Element	P [MW]	Q [Mvar]	S [MVA]	cosφ	I [kA]	I/Ib [%]
N4	19,814	99,068	-0,422								
	Line			N5	L2	-0,060	-0,021	0,064	0,943	0,002	0,733
	Line			N7	L3	-0,351	-0,394	0,528	0,665	0,015	6,033
	Line			N3	L1	0,411	0,416	0,585	0,703	0,017	6,685
N5	19,813	99,066	-0,422								
	Line			N4	L2	0,060	0,022	0,064	0,942	0,002	0,734
	Two-Winding Transformer			N6	T-1	-0,060	-0,022	0,064	0,942	0,002	64,227
N7	19,808	99,040	-0,420								
	Two-Winding Transformer			N8	T-2	-0,060	-0,022	0,064	0,942	0,002	64,227
	Line			N9	L4	-0,290	-0,373	0,473	0,614	0,014	5,405
	Line			N4	L3	0,351	0,395	0,528	0,664	0,015	6,037
N9	19,799	98,996	-0,414								
	Line			N10	L5	-0,060	-0,021	0,064	0,945	0,002	0,732
	Line			N12	L6	-0,230	-0,353	0,421	0,546	0,012	4,814
	Line			N7	L4	0,290	0,374	0,473	0,613	0,014	5,411

3-Phase Node Results

Vsc	Driving Voltage
ts	Switch Delay
Sk"	Initial Short Circuit Alternating Power
Ik"	Initial Short Circuit Current
φIk"	Angle - Initial Short Circuit Current
R/X Ik"	Initial Ratio X/R
Idc	Direct Current at Switch Delay
Ikmin	Minimum Sustained Short Circuit Current
Sa	Tripping Power
Ib	Breaking Short Circuit Current
ip	Peak Short Circuit Current
Zr	Impedance Real
Zi	Impedance Imaginary
Za	Impedance Absolute
Sk"/Sk"max	Utilization Initial Short Circuit Power

Network Level: HV 110 kV (110,00 kV)

Node Name	Vsc [kV]	ts [s]	Sk" [MVA]	Ik" [kA]	φIk" [°]	R/X Ik"	Idc [kA]	Ikmin [kA]	Sa [MVA]	Ib [kA]	ip [kA]	Zr [Ohm]	Zi [Ohm]	Za [Ohm]	Sk"/Sk"max [%]
N1	121,000	0,100	7703,580	40,433	-84,290	0,100	2,471	36,745	7703,220	40,431	114,362	0,172	1,719	1,728	0,000

Network Level: HYDROELECTRIC (0,50 kV)

Node Name	Vsc [kV]	ts [s]	Sk" [MVA]	Ik" [kA]	φIk" [°]	R/X Ik"	Idc [kA]	Ikmin [kA]	Sa [MVA]	Ib [kA]	ip [kA]	Zr [Ohm]	Zi [Ohm]	Za [Ohm]	Sk"/Sk"max [%]
N31	0,550	0,100	15,972	18,443	-85,011	0,087	1,680	11,609	14,607	16,866	46,828	0,001	0,017	0,017	0,000

Network Level: LV 0,4 kV (0,40 kV)

Node Name	Vsc [kV]	ts [s]	Sk" [MVA]	Ik" [kA]	φIk" [°]	R/X Ik"	Idc [kA]	Ikmin [kA]	Sa [MVA]	Ib [kA]	ip [kA]	Zr [Ohm]	Zi [Ohm]	Za [Ohm]	Sk"/Sk"max [%]
N11	0,420	0,100	2,302	3,323	-89,555	0,008	3,683	3,001	2,302	3,323	8,460	0,001	0,073	0,073	0,000
N13	0,420	0,100	8,103	11,696	-87,802	0,038	4,952	10,486	8,103	11,696	29,775	0,001	0,021	0,021	0,000
N14	0,420	0,100	8,103	11,696	-87,802	0,038	4,952	10,486	8,103	11,696	29,775	0,001	0,021	0,021	0,000
N17	0,420	0,100	1,468	2,119	-89,399	0,010	2,155	1,914	1,468	2,119	5,393	0,001	0,114	0,114	0,000
N20	0,420	0,100	5,334	7,698	-87,992	0,035	3,619	6,917	5,334	7,698	19,599	0,001	0,031	0,031	0,000
N23	0,420	0,100	5,332	7,696	-87,966	0,036	3,565	6,914	5,332	7,696	19,594	0,001	0,031	0,032	0,000

Network Level: LV 0,4 kV (0,40 kV)

Node Name	**Vsc [kV]**	**ts [s]**	**Sk" [MVA]**	**Ik" [kA]**	**φIk" [°]**	**R/X Ik"**	**Idc [kA]**	**Ikmin [kA]**	**Sa [MVA]**	**Ib [kA]**	**ip [kA]**	**Zr [Ohm]**	**Zi [Ohm]**	**Za [Ohm]**	**Sk"/Sk"max [%]**
N27	0,420	0,100	15,597	22,512	-82,401	0,133	0,482	19,840	15,597	22,512	57,326	0,001	0,011	0,011	0,000
N29	0,420	0,100	3,543	5,114	-88,262	0,030	2,788	4,604	3,543	5,114	13,019	0,001	0,047	0,047	0,000
N6	0,420	0,100	2,308	3,332	-89,729	0,005	4,062	3,009	2,308	3,332	8,481	0,000	0,073	0,073	0,000
N8	0,420	0,100	2,308	3,331	-89,714	0,005	4,028	3,008	2,308	3,331	8,480	0,000	0,073	0,073	0,000

Network Level: MV 20 kV (20,00 kV)

Node Name	**Vsc [kV]**	**ts [s]**	**Sk" [MVA]**	**Ik" [kA]**	**φIk" [°]**	**R/X Ik"**	**Idc [kA]**	**Ikmin [kA]**	**Sa [MVA]**	**Ib [kA]**	**ip [kA]**	**Zr [Ohm]**	**Zi [Ohm]**	**Za [Ohm]**	**Sk"/Sk"max [%]**
N10	22,000	0,100	57,037	1,647	-79,426	0,187	0,007	1,415	56,634	1,635	4,219	1,416	7,583	7,714	0,000
N12	22,000	0,100	52,832	1,525	-76,188	0,246	0,001	1,291	52,372	1,512	3,684	1,988	8,087	8,328	0,000
N15	22,000	0,100	51,800	1,495	-75,417	0,260	0,001	1,262	51,339	1,482	3,564	2,139	8,221	8,494	0,000
N16	22,000	0,100	48,224	1,392	-70,799	0,348	0,000	1,166	47,863	1,382	3,083	3,001	8,617	9,124	0,000
N18	22,000	0,100	48,715	1,406	-73,184	0,302	0,000	1,175	48,252	1,393	3,231	2,613	8,646	9,032	0,000
N19	22,000	0,100	47,872	1,382	-72,533	0,315	0,000	1,154	47,435	1,369	3,143	2,759	8,767	9,191	0,000
N21	22,000	0,100	47,926	1,384	-72,629	0,313	0,000	1,153	47,462	1,370	3,151	2,741	8,762	9,181	0,000
N22	22,000	0,100	47,713	1,377	-72,348	0,318	0,000	1,148	47,256	1,364	3,123	2,796	8,788	9,222	0,000
N25	22,000	0,100	44,984	1,299	-69,385	0,376	0,000	1,074	44,582	1,287	2,818	3,444	9,155	9,781	0,000
N26	22,000	0,100	44,565	1,286	-68,859	0,387	0,000	1,063	44,176	1,275	2,771	3,561	9,209	9,873	0,000
N28	22,000	0,100	44,445	1,283	-68,710	0,390	0,000	1,060	44,059	1,272	2,758	3,595	9,224	9,900	0,000
N3	22,000	0,100	68,348	1,973	-89,642	0,006	2,293	1,721	67,911	1,960	5,578	0,040	6,438	6,438	0,000
N30	22,000	0,100	47,002	1,357	-71,989	0,325	0,000	1,128	46,537	1,343	3,060	2,895	8,903	9,361	0,000
N4	22,000	0,100	62,153	1,794	-83,785	0,109	0,083	1,553	61,704	1,781	5,025	0,766	7,038	7,079	0,000
N5	22,000	0,100	61,389	1,772	-83,110	0,121	0,056	1,533	60,959	1,760	4,892	0,860	7,116	7,167	0,000
N7	22,000	0,100	60,994	1,761	-82,770	0,127	0,046	1,520	60,543	1,748	4,825	0,908	7,157	7,214	0,000
N9	22,000	0,100	59,001	1,703	-81,078	0,157	0,017	1,465	58,548	1,690	4,508	1,157	7,367	7,457	0,000

8.2. CATALOGUES

8.2.1. CATALOGUE GENERATOR

GH10 and GH11 Lines

The GH10 and GH11 line is an optimized hydrogenerator line aiming at high performance and cost reduction. They are suitable where there is no requirement of high inertia and the hydraulic loads are supported by the turbine bearings.

Range of Application

The GH10 and GH11 lines can be supplied with the following technical data:

- Output range: 500 kVA to 11,500 kVA
- Number of poles: 4 to 18
- Rated voltage: 400 V to 11,000 V for 50 Hz
  480 V to 13,800 V for 60 Hz

Note: other voltages upon request.

GH10 Line

Power ranges were established for the development of the GH10 line, each one corresponding to one hydrogenerator and providing the respective reference code. Table 1 shows the full application range of the GH10 line.

GH10					
Code	Output range (kVA)	400 V / 50 Hz	480 V / 60 Hz	3,300 V / 50 Hz	4,160 V / 60 Hz
A	≤500	●	●	●	●
B	>500≤1,000	●	●	●	●
C	>1,000≤1,400	●	●	●	●
D	>1,400 ≤1,600	●	●	●	●
E	>1,600 ≤1,800	●	●	●	●
F	>1,800 ≤2,000	●	●	●	●
G	>2,000 ≤2,250	●	●	●	●
H	>2,250 ≤2,500	●	●	●	●
I	>2,500 ≤2,800	●	●	●	●
J	>2,800 ≤3,150	●	●	●	●
K	>3,150 ≤3,550	●	●	●	●
L	>3,550 ≤4,000	●	●	●	●
M	>4,000 ≤4,500		●		●

Table 1 - Application range of the GH10 line

GH11 Line

Power ranges were established for the development of the GH11 line, each one corresponding to one hydrogenerator and providing the respective reference code. Table 2 shows the full application range of the GH11 line.

GH11									
Code	Output range (kVA)	400 V / 50 Hz	480 V / 60 Hz	3,300 V / 50 Hz	4,160 V / 60 Hz	6,300 V / 50 Hz	6,600 V / 60 Hz	11,000 V / 50 Hz	13,800 V / 60 Hz
C	>1,000≤1,400	●	●	●	●	●	●		
D	>1,400≤1,600	●	●	●	●	●	●		
E	>1,600≤1,800	●	●	●	●	●	●		
F	>1,800≤2,000	●	●	●	●	●	●		
G	>2,000≤2,250		●	●	●	●	●		
H	>2,250≤2,500		●	●	●	●	●		
I	>2,500≤2,800			●	●	●	●		
J	>2,800≤3,150			●	●	●	●		
K	>3,150≤3,550			●	●	●	●		
L	>3,550≤4,000			●	●	●	●		
M	>4,000≤4,500			●	●	●	●		
N	>4,500≤5,000			●	●	●	●		
O	>5,000≤5,600			●	●	●	●		
P	>5,600≤6,300			●	●	●	●		
Q	>6,300≤7,100							●	●
R	>7,100≤8,000							●	●
S	>8,000≤9,000							●	●
T	>9,000≤10,000							●	●
U	>10,000≤11,200							●	●

Table 2 - Application range of the GH11 line

GH10 and GH11 Lines

Types of Reference Hydrogenerators of the GH10 Line - 50 Hz

	Output range code						
Poles/rpm	A	B	C	D	E	F	G
4/1,500	45A04	50B04	50C04	56D04	56E04	63F04	63G04
6/1,000	50A06	50B06	56C06	63D06	63E06	63F06	-
8/750	56A08	56B08	63C08	63D08	-	-	-
10/600	56A10	63B10	63C10	-	-	-	-
12/500	63A12	63B12	-	-	-	-	-
14/429	63A14	-	-	-	-	-	-

Types of Reference Hydrogenerators of the GH10 Line - 60 Hz

	Output range code							
Poles/rpm	A	B	C	D	E	F	G	H
4/1,800	-	45B04	50C04	50D04	56E04	56F04	63G04	63H04
6/1,200	45A06	50B06	50C06	56D06	63E06	63F06	63G06	-
8/900	50A08	56B08	56C08	63D08	63E08	-	-	-
10/720	50A10	56B10	63C10	63D10	-	-	-	-
12/600	56A12	63B12	63C12	-	-	-	-	-
14/514	63A14	63B14	-	-	-	-	-	-
16/450	63A16	-	-	-	-	-	-	-

Types of Reference Hydrogenerators of the GH11 Line - 50 Hz

	Output range code																	
Poles/rpm	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
8/750	-	-	-	-	-	-	63I08	63J08	63K08	07L08	07M08	07N08	07O08	08P08	08Q08	09R08	09S08	09T08
10/600	-	-	-	-	63G10	63H10	63I10	07J10	07K10	07L10	07M10	08N10	08O10	08P10	09Q10	09R10	09S10	10T10
12/500	-	63D12	63E12	63F12	07G12	07H12	07I12	07J12	08K12	08L12	08M12	08N12	09O12	09P12	09Q12	10R12	10S12	10T12
14/429	63C14	63D14	07E14	07F14	07G14	07H14	07I14	08J14	08K14	08L14	08M14	09N14	09O14	09P14	10Q14	10R14	10S14	-
16/375	07C16	07D16	07E16	07F16	08G16	08H16	08I16	08J16	08K16	09L16	09M16	09N16	09O16	10P16	10Q16	-	-	-
18/333	07C18	07D18	07E18	08F18	08G18	08H18	08I18	09J18	09K18	09L18	09M18	10N18	10O18	10P18	-	-	-	-

Types of Reference Hydrogenerators of the GH11 Line - 60 Hz

	Output range code																		
Poles/rpm	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
8/900	-	-	-	-	-	-	-	63J08	63K08	63L08	07M08	07N08	07O08	07P08	08Q08	08R08	09S08	09T08	09U08
10/720	-	-	-	-	-	-	63I10	63J10	63K10	07L10	07M10	07N10	08O10	08P10	09Q10	09R10	09S10	09T10	10U10
12/600	-	-	-	63F12	63G12	63H12	07I12	07J12	07K12	07L12	08M12	08N12	08O12	08P12	09Q12	09R12	10S12	10T12	10U12
14/514	63C14	63D14	63E14	07F14	07G14	07H14	07I14	07J14	08K14	08L14	08M14	08N14	09O14	09P14	10Q14	10R14	10S14	10T14	-
16/450	63C16	63D16	07E16	07F16	07G16	07H16	08I16	08J16	08K16	08L16	08M16	09N16	09O16	09P16	10Q16	10R16	-	-	-
18/400	07C18	07D18	07E18	07F18	07G18	08H18	08I18	08J18	08K18	09L18	09M18	09N18	10O18	10P18	10Q18	-	-	-	-

8.2.2. CATALOGUE TRANSFORMER

Dane techniczne

Klasa izolacji 24 kV

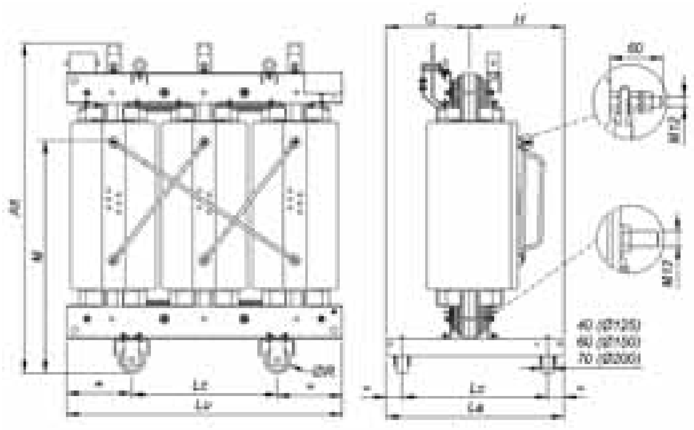
Normy	CEI 14-4 e 14-8 - IEC 60076-11 - CENELEC HD 538.1		
Moc znamionowa (kVA)	100÷3150		
Częstotliwość (Hz)	50		
Napięcie pierwotne (kV)	20-21	klasa izolacji	24 kV BIL 95/125 kV
Napięcia wtórne (V)	400-410-420	klasa izolacji	1,1 kV
Odczepy, strona wysokonapięciowa	±2x2,5%		
Grupa połączeń	Dyn5		
Klasa systemu izolacji	F/F		
Temperatura przegrzania	100/100 K		
Klasa	E2-C2-F1 Certyfikat CESI N. 98/11 908		
Tolerancje	Zgodnie z IEC		
Uwagi	Dane dotyczą przekładni 20/0,4 kV; dla innych przekładni mogą się nieco różnić. Wartości Lpa mierzone w odległości ok. 1 m, zgodnie z IEC 60076-10. Rozmiar i waga zintegrowanej obudowy, strona 135 BIL 125 na specjalne zamówienie za dopłatą		

kVA	Nr ref.	U pier	U wtór	Uk%	Po	Pk (W)		I_0 %	Poziom dźwięku	Poziom mocy akustycznej	Waga
		kV	V		(W)	120°	75°		L_{PA}	L_{WA}	kg
500	EH4RBGBB	20	400	4	1300	6400	5700	1,1	49	61	1640
500	EH4RAGBB	20	400	6	1050	6700	5960	1,1	49	61	1500
500	EH4NBGBB	20	400	4	1580	6400	5700	1,2	56	69	1640
500	EH4NAGBB	20	400	6	1350	6700	5960	1,2	56	69	1500
500	EH4DAGBB	20	400	6	1650	6700	5960	1,2	56	70	1550
500	EH4SAGBB	20	400	6	1900	6700	5960	1,5	56	70	1650
630	EI4RBGBB	20	400	4	1600	6900	6150	1	50	62	2000
630	EI4RAGBB	20	400	6	1250	7800	6940	1	50	62	1800
630	EI4NBGBB	20	400	4	1950	6900	6150	1,1	56	70	2000
630	EI4NAGBB	20	400	6	1650	7800	6940	1,1	56	70	1800
630	EI4DAGBB	20	400	6	1900	7800	6940	1,2	57	71	1800
630	EI4SAGBB	20	400	6	2300	7800	6940	1,4	57	71	1950
800	EJ4RAGBB	20	400	6	1450	9400	8370	0,9	52	64	2100
800	EJ4NAGBB	20	400	6	1850	9300	8290	1	58	71	2100
800	EJ4DAGBB	20	400	6	2200	9400	8370	1,1	58	72	2150
800	EJ4SAGBB	20	400	6	2600	9400	8370	1,3	58	72	2350
1000	EK4RAGBB	20	400	6	1800	11000	9800	0,8	53	65	2500
1000	EK4NAGBB	20	400	6	2200	10800	9630	0,9	59	73	2500
1000	EK4DAGBB	20	400	6	2650	11000	9800	1	59	73	2550
1000	EK4SAGBB	20	400	6	3100	11000	9800	1,2	59	73	2800
1250	EL4RAGBB	20	400	6	2100	13000	11600	0,7	55	67	2900
1250	EL4NAGBB	20	400	6	2600	12800	11430	0,8	60	74	2900
1250	EL4DAGBB	20	400	6	3100	13400	11800	1	60	74	3000
1250	EL4SAGBB	20	400	6	3550	13400	11800	1,1	60	74	3250

Wszystkie dane mogą się zmieniać w dowolnym czasie ze względu na optymalizację produkcji.

Dane techniczne

Klasa izolacji 24 kV



Połączenie
do zacisków HV

Zaciski LV strona 134

Śruba uziemiająca

Najważniejsze wymiary. Wymiary do projektowania należy odczytać z rysunków konstrukcyjnych.

kVA	Nr ref.	Uk%	Długość (mm)	Szerok (mm)	Wysok. (mm)	LC (mm)	ØR (mm)	G (mm)	H (mm)	M (mm)	Waga (kg)
500	EH4RBGBB	4	1450	750	1610	670	125	345	405	980	1640
500	EH4RAGBB	6	1500	750	1560	670	125	345	405	960	1500
500	EH4NBGBB	4	1450	750	1610	670	125	345	405	980	1640
500	EH4NAGBB	6	1500	750	1560	670	125	345	405	960	1500
500	EH4DAGBB	6	1500	750	1570	670	125	345	405	960	1550
500	EH4SAGBB	6	1500	750	1570	670	125	345	405	960	1650
630	EI4RBGBB	4	1500	850	1690	670	150	395	455	1100	2000
630	EI4RAGBB	6	1500	850	1650	670	150	395	455	1080	1800
630	EI4NBGBB	4	1500	850	1690	670	150	395	455	1100	2000
630	EI4NAGBB	6	1500	850	1650	670	150	395	455	1080	1800
630	EI4DAGBB	6	1500	850	1700	670	150	395	455	1090	1800
630	EI4SAGBB	6	1500	850	1700	670	150	395	455	1090	1950
800	EJ4RAGBB	6	1550	850	1810	670	150	395	455	1200	2100
800	EJ4NAGBB	6	1550	850	1810	670	150	395	455	1200	2100
800	EJ4DAGBB	6	1550	850	1850	670	150	395	455	1300	2150
800	EJ4SAGBB	6	1550	850	1850	670	150	395	455	1300	2350
1000	EK4RAGBB	6	1650	1000	1890	820	150	470	530	1310	2500
1000	EK4NAGBB	6	1650	1000	1890	820	150	470	530	1310	2500
1000	EK4DAGBB	6	1650	1000	1930	820	150	470	530	1300	2550
1000	EK4SAGBB	6	1650	1000	1930	820	150	470	530	1300	2800
1250	EL4RAGBB	6	1650	1000	2030	820	150	470	530	1370	2900
1250	EL4NAGBB	6	1650	1000	2030	820	150	470	530	1370	2900
1250	EL4DAGBB	6	1650	1000	2070	820	150	470	530	1460	3000
1250	EL4SAGBB	6	1650	1000	2070	820	150	470	530	1460	3250

Wszystkie dane mogą się zmieniać w dowolnym czasie ze względu na optymalizację produkcji.