Connecting a Group of Small Hydropower Plants on the Side of Neretvica River to a Medium Voltage Distribution Grid

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Abstract. Since Bosnia and Herzegovina is a country famous for its river flows there has been an expansion of constructing small hydropower plants (SHP) where the whole process includes projecting, gaining concessions and building. 'JP Elektroprivreda' has a plan for constructing 15 small hydropower plants on the side of Neretvica. The construction is planned throughout three phases. This paper discusses the issues of connecting small hydropower plants of the planned first phase to a medium voltage distribution grid, and effects it has on the distributive grid. The already mentioned hydropower plants are to be connected to an existing 35 kV voltage grid, although the strategical commitment of JP Elektroprivreda was to leave this voltage level back. The main focuses of this paper are the models of calculating the power flow, the losses of the voltage, the short circuit calculations, and the evaluation of the effect of connecting a SHP group on the existing 35 kV distributive grid. All the calculations are made using the professional software PowerCAD. Results of analysis are showing meaningful impact of SHP group connecting to an existing distributive grid, which are mostly seen voltage changes and increases in grid loses. The parameters that are important for the work of this project stayed in the allowed domain after the simulation of the SHP group has been done.

1 Introduction

The early 90s were characterised by the excessive grow of the usage of renewable energy sources. The main condition for this growth was the technological development, strictly speaking, in the field of the energetical electronics. The mentioned growth presented challenges for using that knowledge in the distributive as well as in the general electro energetical system. The medium and the low voltage grids gained a new philosophy of planning, projecting and exploiting. The distributive electro energetic system is made of a distributive electro energetic grid, consumers of the electrical

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energy and the distributive sources (generators) that are connected to this grid. By connecting the distributive industry the network becomes active, which means the power flow in the distributive network isn't going in one way anymore which could lead to serious negative effects, such as huge losses, the fluctuation of the voltage and frequency outside the proposed domain, etc. Because of that it is very important to make an effective control of the distributive industry, especially with many distributive generators on board. Distributive generators are low power generators, connected directly to the distributive grid, and using as a main source of energy the renewable sources [1]. By saying renewable energy it is mean the energy subtracted from the natural renewable processes, such as: geothermal energy, biomass energy, solar energy, the energy of small water flows and the wind energy. While the world has gone mad for the producement of energy using windmills and solar panels, Bosnia and Herzegovina is known for the development of small hydropower plants, because of the unused water potentials it has. The small hydropower plant is a plant that transforms the energy of the small water flows into electrical. The output power of such a plant varies between 10 kW and 10 MW. This type of plants has no significant environmental effects and has great advantages at the same time (reducing the emission of greenhouse gases, small area needed, small costs, has positive social effects-employment, etc.). The usage of SHP is gaining popularity of the scientific and the technical society in the last couple of years. Thus, the paper [2] is focusing on the identification of the behaviour of a group of synchronous generators connected to a medium voltage grid while applying some noise, using the real system of six synchronous SHP generators. This work [3] discusses the issues of connecting three SHP on a distributive grid in the location of Vakuf municipality and the various voltage effects of such a connection. Beside connecting SHP on a medium voltage grid, they can also be connected to a low voltage distributive grid. The issues of making such a connection are discussed in the paper [4]. The most important aspect of connecting the SHP is the economical one. Thus, paper [5] contains a techno-economical analysis of connecting small hydropower plants on a distributive grid. Connecting distributive sources lead to reorganising the power flows in the distributive network, thus leading to changes in the amount of losses of the active energy. In the paper [6] is the methodology of calculations of the annual losses of active energy in the distributive grid in the occasions of a connected distributive source, where it starts from the known slopes of load and producement.

2 Small Hydropower Plants on the Side of Neretvica River

In the municipality of Konjic, on the side of Neretvica river, there is a plan to build 15 small hydropower plants throughout three phases. All of the 15 small hydropower plants are derivatebly flowable-pressurable, and the overall installed power is to be 24.5 MW, with annual producment of 99.9 GWh. The whole project is valued at 103 million BAM, and its financed by JP EPBiH and EBRD credit foundation. The planned realisation of the project is given in the table: (Table 1)

Table 1. Planned realisation of the project of SHP on the side of Neretvica river

Phase	Small hydropower plants	Overall installed power (MW)	Time framework
IA	SHP Srijanski most	6.4	Jan–Dec 2017
	SHP Gorovnik ušće		
IB	SHP Crna Rijeka	3	Jun 2017–Jun 2018
	SHP Gorovnik		
II	SHP Podhum 1	7,9	Jan–Dec 2018
	SHP Podhum 2		
	SHP Donji Obalj		
	SHP Poželavka		
	SHP Mala Neretvica–ušće		
III	SHP Obaščica	7,2	Jan–Dec 2019
	SHP Duboki potok 2		
	SHP Ruste		
	SHP Plavuzi		
	SHP Prolaz		
	SHP Duboki potok 1		

3 The Regulative Demands and Models

The technical recommendation for the connection and the plant of distributive generators was approven by JP Elektroprivreda BiH on 11.8.2016 (registered as TP-17) [7]. The technical recommendation TP-17 regulates the conditions for the connection and the plant of distributive producing units on the electro distributive system of the JP Elektroprivreda BiH d.d. Sarajevo (JP EP BiH). The maximum allowed voltage deviations from the steady states nominal values in the distribution system are:

- $\Delta u_m = \pm 10\%$ for medium voltage network (35, 20, 10 kV).
- $\Delta u_m = +5$ and -10% for the low voltage (0.4 kV) network.

The generators used for the small hydropower plants can be synchronous or asynchronous. They can also be sources with electronic transformators with output voltage of 50 Hz. The most used are the synchronous generators, their main characteristic is their behaviour in short circuits. The synchronous generator will in the case of short circuting provide the breakpoint with energy until the protection is activated because of an independent motive and thus will deepen the current of the break. One of the main elements that effect the power of the short circuit is the characteristic value of the reactance of the short circuit. This reactance depends on the conditions in which the distributive generator is working and it can be subtransient, transient or permanent. Those three values differ in the synchronous generators. The connection of the distributive generator can't allow the power of the three phase fault to grow above the value which the equipment is designed for in the EDS. Based on [7] every node in the analysed network has to please the given condition:

$$S_{k3} = \sqrt{3}U_n I_{k3} = \sqrt{3}U_n \frac{cU_n}{\sqrt{3}Z_d} \leq S_{k3Max} \tag{1}$$

where:

Zd (Ω)	is the impedance of the direct flow of the network from the source (TS and DG) to the break point.
Ik3 (A)	the current of the three phase short circuit.
Sk3Max (MVA)	the maximum allowed power of the three phase short circuit in the distributive circuit.
C	the voltage factor (c = 1.1 according to IEC 60909).

In the distributive networks the following values of the maximum allowed powers of the three phase short circuits are given:

- 0.4 kV grid: 18 MVA in a cabel grid and 11 MVA in an overground grid.
- 10 kV grid: 250 MVA.
- 20 kV grid: 500 MVA.
- 35 kV grid: 750 MVA.

The energetic analysis is made using the professional PowerCAD software tool. The PowerCAD is a package made for the calculation of power flows and short circuits with a graphical representation and a database. Its main characteristic is the fast numerical analysis of the transformable, distributive and industrial grids and plants. It has four modules:

- Graphical module
- Calculating voltages and power flows module
- Calculation short and underground grids module
- Communication with the database module.

There are no significant network size limits since the applied technique is with a rarely filled matrices, thus it can be analyzed grids with several thousand nodes even on computers with relatively small memory size. The whole software is C++ program language based and the network is made completely using graphical interface. Every element of the network can be defined as active or inactive, which helps the user in a fast analysis of various on/off conditions.

4 Simulation

4.1 Model Description

This paper analyses the Jablanica and Konjic grids and the connection of small hydropower plants on the side of Neretvica river according to the first phase. SHP are connected to a 35 kV voltage level on TS 35/10 kV Buturović polje (2.5 MVA), and the first phase is consisted of connecting the powerplants in the following order:

1. SHP Gorovnik ušće
2. SHP Gorovnik
3. SHP Sirjanski most
4. SHP Crna rijeka.

The statical analysis of the connection of the mentioned SHP is done in PowerCAD, and the grid par that is being discussed is given in the picture (Fig. 1).

As seen above, SHP Podhum 2 is not in the plant since its connection is not planned in the first phase, which is simulated with disconnecting the transformators connected

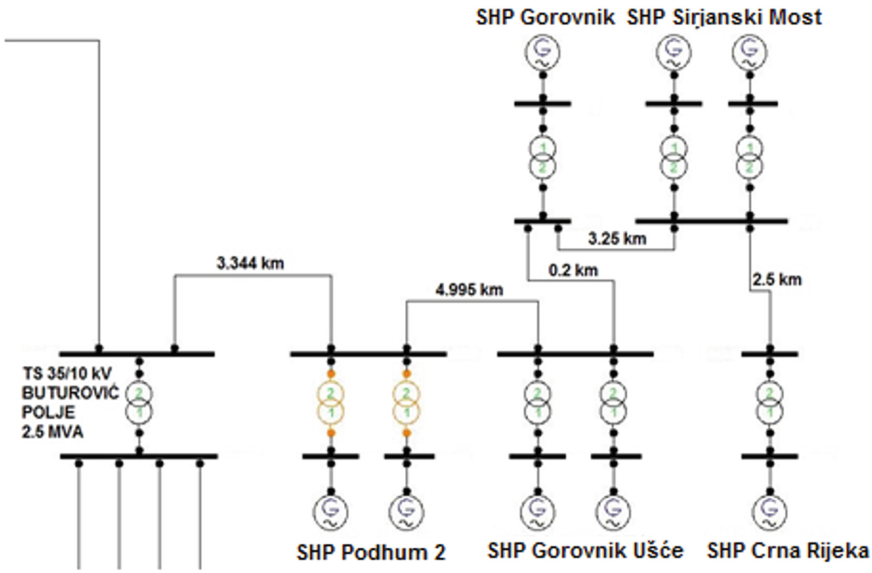

Fig. 1. Part of considered model scheme

with that SHP (the orange is for deactivated transformators). The first analysis is made when no SHP is connected to the grid, after that they were connected gradually in the order given above. The current load for connection line Buturović Polje-Podhum 2 is tracked as well as the voltage changes on the 35 kV voltage level source, the overall losses on the 35 kV voltage level source and the change in power of the three phase faults on the 35 kV buses which (using transformators) are connected to the mentioned SHP and on which the analysis of the mentioned parameters is being made. To obtain the values of the mentioned parameters two types of calculation were made in PowerCAD: power flow calculation and short circuits calculation. The power flow calculations is done for two cases: minimum (according to [8] its about 30% of the maximum load) and the maximum load. This calculation gave the values of the voltages and the losses of active power, while the informations about powers of the three phase faults are obtained by calculating the short circuit. For the power flow calculations only the values of the overall installed power of the SHP is needed, which are given in the table. (Table 2)

Table 2. Overall installed power od the SHP from first phase

SHP	Overall installed power (MVA)
Gorovnik ušće	3.427
Gorovnik	0.859
Sirjanski most	3.03
Crna rijeka	2.113

As mentioned above, very important parameter in the short circuit case is the reactance of the generator. Having that in mind, in the calculation of the short circuit (which is defining the power change of the three phase fault) with activating certain SHP, beside the overall installed power of SHP, values of the subtransient (xd''), inverse (xi) and zero (x0) reactance are also needed, as well as the values of the ohmical resistance of the statoric winding (R). Those informations are given in the table (Table 3).

Table 3. Values of reactanses and ohmicah resistances of SHP from first phase [9]

SHP	Subtransient reactanse x_d'' (%)	Inverse reactanse x_i (%)	Zero reactanse x_0 (%)	Ohmic resistance of statoric winding R (%)	Number of generators
Gorovnik ušće	10	12	6	5	2
Gorovnik	12	10	5	2	1
Sirjanski most	12	10	5	1.2	2
Crna rijeka	8	10	5	4	1

It is important to mention that all SHP work with a power factor of one ($\cos \varphi = 1$) since this is the most demanding regime that the distributive generators work on. This means that there is no reactive energy transfer with the grid.

4.2 The Effect of SHP on Load Current and Voltage Profiles

The change of the current load in connecting line Buturović Polje-mHe Pohum 2 which was used for the connecting of the discussed SHP with grid and in the dependence of the number of the connected SHP for for minimum and maximum grid load is shown in the picture (Fig. 2).

The change of the overall network load (min or max) does not affect the change of the current load of the analysed connecting line because discussed SHP are located

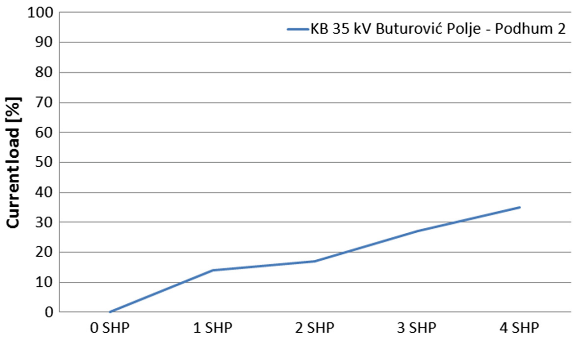

Fig. 2. Current load of connecting line Buturović Polje—Podhum 2 in dependance of number of connected SHP

where there is no electrical energy consumers. The current load given in the previous picture is given in the percentages depending on the maximum allowed current value which can flow through the connecting line, which is 450A (obtained using Power-CAD). Analyzing the picture above, it can be deduced that the current load won't be above 40% of the maximum allowed, which means that the current overflow protection won't be triggered to deactivate the discussed connecting line. The voltage changes to 35 kV on the buses that are connected to the small hydropower plants and depending on the number of the connected SHP and in the minimum and maximum grid load, are shown on the pictures (Figs. 3 and 4).

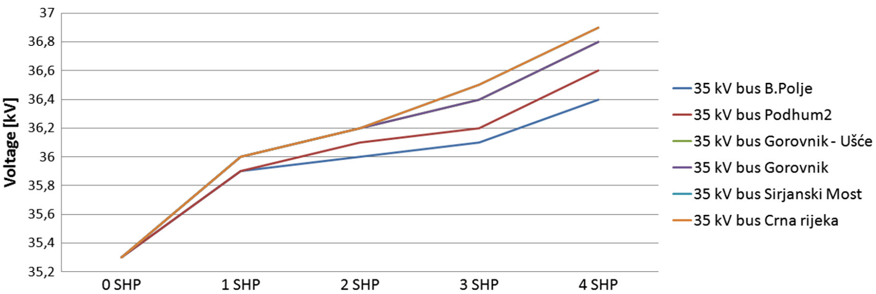

Fig. 3. Voltage changes to 35 kV on the buses that are connected to the SHP in dependance of the numer of connected SHP, in the minimum grid load (max. consumation)

Analyzing the obtained results it can be deduced that the voltage on the discussed buses has the least values when there is no SHP connected, and it rises with the gradual connecting of the SHP. The reason behind that is that the SHP deliver an amount of active power to the network where one part of it goes to the consumers and the other one which does not go to the consumers effects on the rise of voltage on the buses. As long as the number of SHP increases the active power delivered is higher and so the

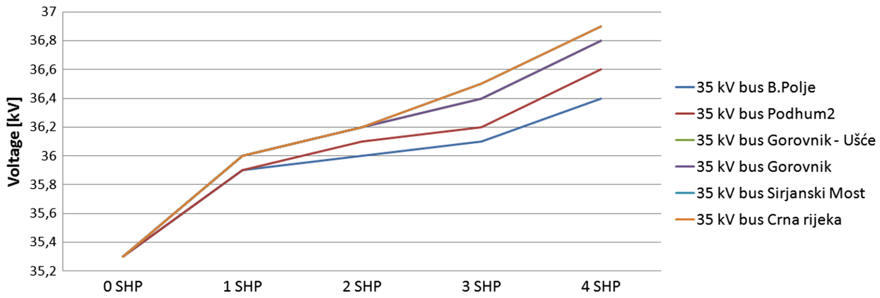

Fig. 4. Voltage changes to 35 kV on the buses that are connected to the SHP in dependance of the numer of connected SHP, in the maximum grid load (min. consumation)

voltage on the buses is also higher which is visible in the previous pictures. In case of a overflow value of the voltage, some of the generators needs to be transfered into the underexcited regime to reduce the values of the voltage. In EES BiH the generators rarely work in underexcited conditions since that could lead to the overheating of the stators, and that problem also needs to be discussed. It is very important for the criteriums set in the TP-17 to be satisfied, which means that the voltage deviation has to be inside the ±10% for medium voltage (SN) network. Since the mentioned buses are at 35 kV that means that the changes may occur in between 31.5 and 38.5 kV. The pictures shown above clearly shows that the voltages don't violate the conditions given and are all inside the bandwidth that is already mentioned, which means that neither one of the SHP is in the underexcited state. It can also be deduced that the change of the load does not affect majorly the voltage change on the buses, because the SHP are located on an unique location where there is no electrical energy consuming.

4.3 The Effect of SHP on the Active Power Losses

The analysis of the losses of the electrical power is very important when planning and exploiting the distributive network. The overall active power losses on a 35 kV voltage level, with minimum and maximum grid load, are given in the picture (Fig. 5).

All SHP have power factor of 1, which means that there is no reactive power transfer with the grid. It can be deduced from the pictures that overall active power losses on 35 kV voltage level rises with connecting of SHP. The reason behind that is that the overall producing exceeds the needs of the consumers and thus the part of electrical energy which is not used for the consumers increases overall active power losses. Effect of network loads on the overall active power losses also can be seen. With minimum network load, in other words, with maximum electrical energy consumation, the losses are less than in the case of maximum load, or in other words said, the minimum consumation of the electrical energy. The reason behind that is that with maximum consumation of the electrical energy, part of unused electrical energy that produces the losses is smaller than in the case of minimum electrical energy consumation. As it can be seen on picture below, connecting of considered small hydropower plants causes significant increases of active power losses on 35 kV voltage level,

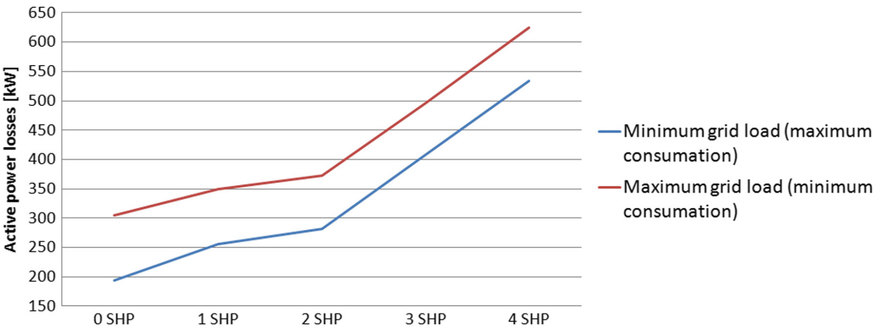

Fig. 5. The overall active power losses on a 35 kV voltage level (cosφ = 1 of all SHP)

which indicates bad influences on the whole EES. In order to decrease mentioned losses, SHP in considered area are being connected in various ways, and analysis for each of them have been made. Analysis results showed that, no matter which way of connecting SHPs is chosen, active power losses can't be affected so much. So it can be concluded that problem is electrical energy which has been produced in considered SHPs, and is being transferred to distant consumers, having in mind that the are where these SHPs are located, doesn't have an electrical energy consumers. According to that, in order to reduce active power losses, connection of specified numbers of consumers at a place where SHPs are located, is needed. In that way, biggest part of electrical energy produced in considered SHPs would be consumed locally, while the part being transferred to distant consumers would decrease.

4.4 The Effect of SHP on the Power of a Three Phase Fault

The connection of distributive generator of the small hydropower plants can't lead to rise in the power of a three phase fault above the values of the technical design of the equipment in the electro distributive system. The change of the power of a three phase fault on a 35 kV bus Buturović Polje which connects all small hydropower plants on the side of Neretvica river, as well as the change on 35 kV buses that are connected to the each SHP, depending on their connection, is shown in the picture (Fig. 6).

As it can be seen in the previous picture, the rise of the power of a three phase fault is obvious with the connection of the SHP. With that, the power of a three phase fault has greater value as the SHP approaches the 35 kV bus Buturović Polje. Also it can be seen that there is no moment in which the power of a three phase fault, no matter how many small hydropower plants are connected, won't exceed the value of cca 175 MVA. Since the technical recommendation for the connection and the plant of distributive generators (TP-17) allows maximally the power of a three phase fault value of 750 MVA at a 35 kV voltage level, than it can be deduced that the conditions set for the power of a three phase fault are met. That means that the SHPs in the case of a break won't produce break currents that have huge values, in other words said, the influence of SHPs in the case of break is negligible [8].

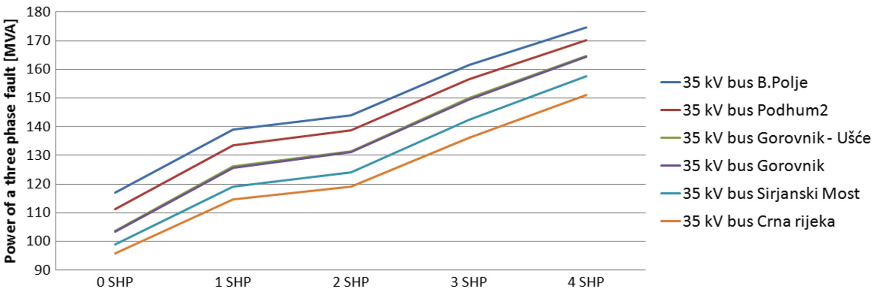

Fig. 6. Changes of the power of a three phase fault in dependance of number of connected SHP

5 Conclusion

The paper discussed connecting small hydropower plants on the side of Neretvica rive, which are planned in the first phase of the construction, and those are: Gorovnik ušće, Gorovnik, Sirjanski most and Crna Rijeka. Various effects of changes in the distributive grid are discussed when the small hydropower plants are connected to the 35 kV voltage level. Beside the many positive effects, the connection of SHP on the Neretvica river effects the quality of the electrical energy, rising the voltage on the buses, rising the losses of active energy, the power of a three phase fault, etc. However, throughout the analysis it has been deduced that the considered changes which are caused by connecting the SHP are in the bandwidth defined within the technical recommendation TP-17. Only problem in considered connecting is significant increase of active power losses. In order to lower mentioned losses, and to do connecting of considered SHPs on 35 kV voltage level effectively, connection of specified number of consumers in considered area is needed.

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