THE ISSUE OF ASYMMETRY IN LOW VOLTAGE NETWORK WITH DISTRIBUTED GENERATION

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ABSTRACT

The issue of asymmetry in a low voltage network gets a new dimension with integration of distributed generation, especially within weak LV networks. The relative importance of power plant relative to the local network leads to changes in a power flow from the source to the parent network. This phenomenon raises several questions, like technical problems: issues of energy loss and a permitted increase in voltage asymmetry. The question is to what extent to tolerate the asymmetry in low voltage network, where the utilization factor is not predictable - especially with mostly mono phase network users (customers). Furthermore, if such an asymmetry becomes a problem only with the appearance of distributed source, can a symmetrical source be considered as a source of asymmetry.

INTRODUCTION

This paper discusses the asymmetry in the low voltage network with distributed generation. The aim is to show the impact of the solar power plant on current-voltage conditions in non symmetric low voltage network and its impact on losses.

One of the goals of this paper is to analyze the phenomenon which was not present in the low voltage network before the integration of distributed generation. In the case of a significant asymmetry in the network, one special phenomenon could appear. During the day there is a period in which the production in one phase is greater than the load of that phase, while in other phases it is not a case. Therefore, in that phase energy flows in reverse (from power plant towards the substation), while in the other two phases energy flows as usual: from the substation towards the power plant. It is a phenomenon of different power flow directions at single phases of the same low-voltage feeder.

The intention of this paper is to evaluate the importance of this phenomenon, to recognize its consequences and to suggest corrective measures for prevention and correction of the observed effect.

ASYMMETRY IN THE LOW VOLTAGE NETWORK

Asymmetry in the low voltage network represents the uneven load distribution in phases. This is usually the result of customers asymmetry, non symmetric load distribution in customer’s installation and uneven coincidence factor of loads connected to different phases.

However, the most prominent asymmetry comes as a result of connection of single-phased customers, unevenly distributed in phases, creating a situation in network that all of the three phases are unevenly loaded. The consequences of this unbalanced loads are unbalanced voltages.This problem gets even more exposed if there is a power plant integrated in such an asymmetrically loaded network, because the power plant increases voltage in the network.

Generally, power plant as a symmetric source symmetrically increases the voltage in the network, therefore the existing asymmetry in the network is retained, only the voltage is higher.

This can be affected in two ways. Firstly, an impact on customers in terms of voltage increase in single phase over 10 % Un, which causes operational difficulties and even causes damage to the user's appliances with consequences that are difficult, if not impossible to prove. On the other hand, the voltage in the power plant increases and could reach the level, theoretically, that will cause outage of the power plant (disconnection from the network) because of the overvoltage protection activation. In this paper, the real case of low voltage network with the solar power plant is analyzed, whereby all calculations were made in "Neplan" software in 4P modul.

NETWORK MODEL DESCRIPTION

The actual example of a typical low voltage network is analyzed (Figure 1): low voltage line connected to substation TS 10/0.4 kV, 250 kVA, overhead main line made of self supported insulated cable type X00/0 (3x70+71,5) mm2, total length of 1004 m, with underground cable branches made of cable type PP00-A4x50 mm2 total length of 422 m.

The customers are relatively uniformly distributed along the main line, but they are asymmetrically distributed over the phases. The solar power plant is connected to the node number 7 by underground cable type XP00-A 4x35 mm2, a length of 40 m.

The solar power plant is symmetrical three phase generator with connected power of 30 kW.

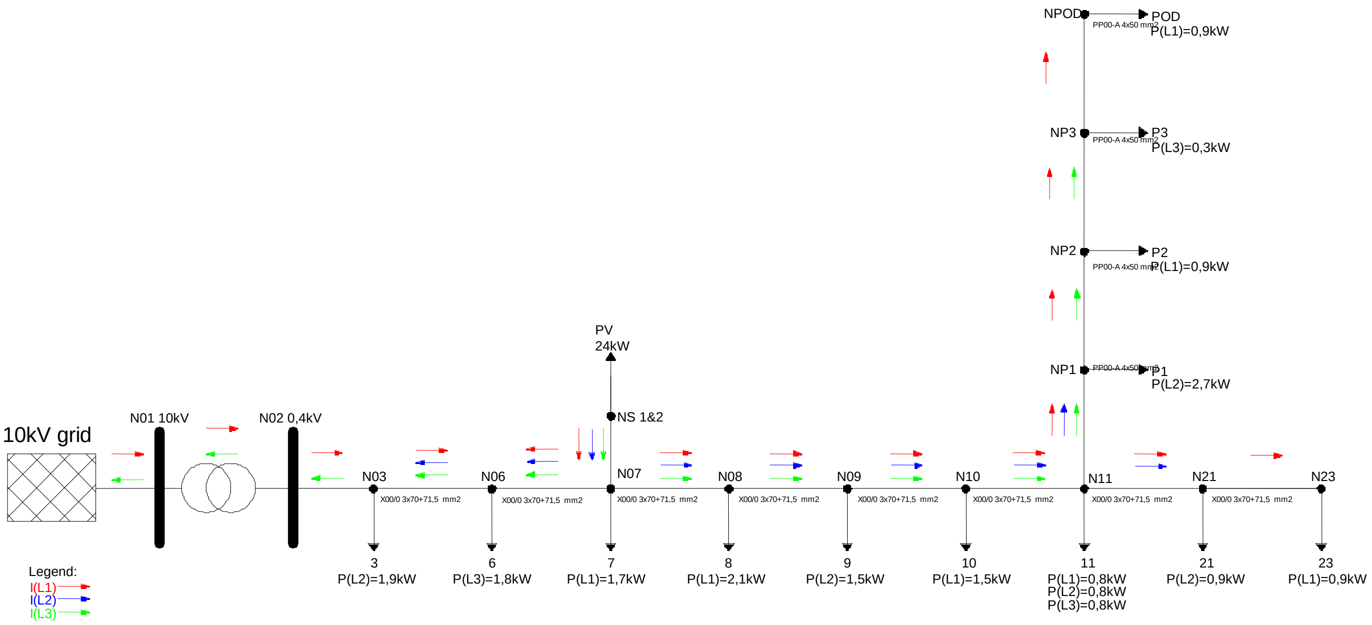

Figure 1. Model of analyzed actual low voltage network

Figure 2 shows pronounced load unbalance. Phase L3 (blue in Figure 2) is the least loaded all day long, while the remaining two phases are relatively evenly loaded, mostly more than double than the L3 phase.

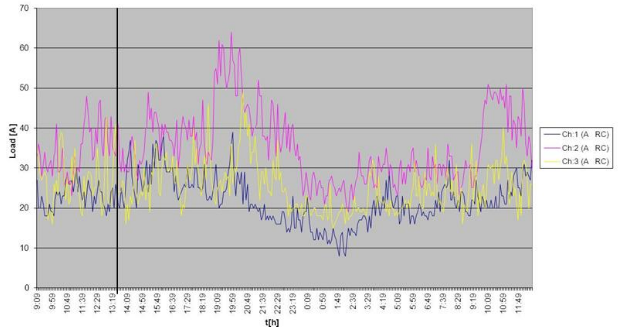

Figure 2. Measured daily load of LW line without solar power plant, measured in substation 10/0,4 kV

Based on the measured values (Figure 2), daily load diagram for each phase of the line is made:

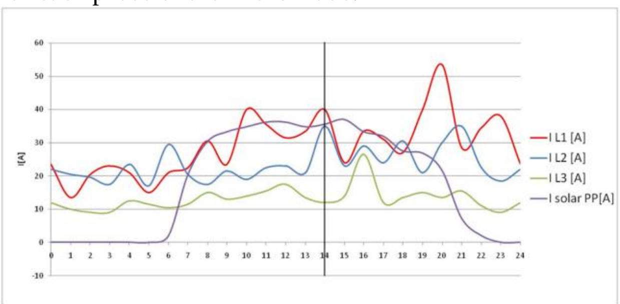

Figure 3. Daily diagram of consumption of line by phases, and daily diagram of symmetrical 3-phase solar power plant production

The daily load diagram of line by phases (Figure 3), made by superimposing daily consumption diagram with daily power plant production diagram (symmetrical three-phased source) moment analyzed in this paper is marked with a line in Fig. 3 (at 14h). This paper analyzes the actual situation in the network at that moment. By overlaying the diagram of line consumption with the diagram of power plant production at the observed moment, asymmetry is obvious: the consumption in phase L1 is higher than the power plant's production, the consumption in phase L2 is equal to the power plant's production, while the consumption in phase L3 is lower than power plant's production.

Thus, in the observed moment from the substation's bus position, the direction of energy flow in phases L1 and L3 is opposite. In the L2 phase the production of the power plant is approximately equal to the consumption of consumers, so the energy flow on the bus is approximately equal to zero.

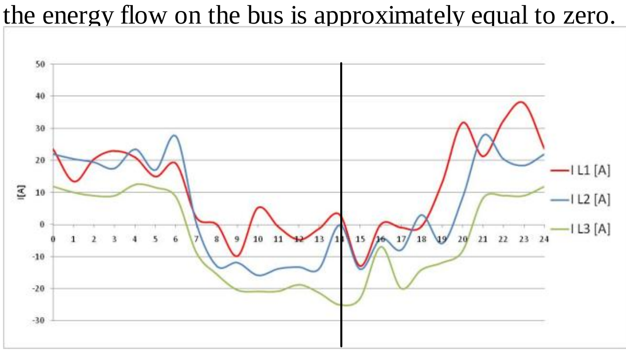

Figure 4. Aggregate diagram of consumption and production

The direction of energy in the phase L1 is from substation to the power plant, while in the phase L3 the direction is reversed. From the power plant towards the end of a line, direction of energy flow is, as expected, stable in all three phases and usual – from the supply substation to the end of line, because the power flow from power plant down the line is determined only by the consumers and not by the power plant. The diagram of line daily load (Figure 4 and 5) is made by superimposing of diagram of daily consumption of one or two power generating units.

Figures 3 and 4 show that in the periods in which the amount of production approaches to the current consumption, the change in the energy direction in the line appears. Because of existing asymmetry in consumption, the equalization of production and consumption in all phases doesn't occur simultaneously. Therefore, the change of energy flow firstly occurs in the phase in which production overcomes consumption (the phase with the lowest consumption), while in the other two phases the change in the energy flow has not yet occurred. The time interval in which this phenomenon occurs will depend on the relative amount of production and consumption in asymmetrically loaded phases.

A model with a symmetrical distribution of consumption in the line is made for a competent assessment of the significance of asymmetry. In the case of symmetry, the consumption is equally distributed on every phase, while in the case of asymmetry it is distributed as is shown in Table 1.

Table 1. Asymmetrical consumption distribution in the line

Node	Phase	P consumption [kW]
N 03	L2	1,9
N 06	L3	1,8
N 07	L1	1,7
N 08	L1	2,1
N 09	L2	1,5
N 10	L1	1,5
N 11	L1	0,8
	L2	0,8
	L3	0,8
N 21	L2	0,9
N 23	L1	0,9
N P1	L2	2,7
N P2	L1	0,9
N P3	L3	0,3
N Pod	L1	0,9

The data in Table 1 shows, although the load in the network is low, asymmetry is obvious, and the majority of consumers (customers) is distributed on phases L1 and L2. That gives us the foundation for simulating the conditions in the network, with symmetrical or asymmetrical consumers, and the situation with and without power plant.

NETWORK ANALYSIS

For a more detailed analysis, the model with asymmetric loads (Table 1) at the observed moment (Figure 3) is chosen. Production of power plant is as always symmetrical. The following cases are considered:

- Asymmetrically loaded network without the power plant
- Asymmetrically loaded network with the power plant
- Symmetrically loaded network without the power plant
- Symmetrically loaded network with the power plant

Asymmetrically loaded network

The case with all of the customers asymmetrically distributed on the network (Table 1) is analyzed.

Energy flows from the power plant to the substation. Thus, in all three phases, the energy flows from the power plant to the end consumers and from the power plant to the 10 kV network. In this case, the problem of change of direction of energy flow in one phase occurs, and there is the problem of voltage drop increase due to the problem of unbalanced load.

The results of the calculations are shown in the voltage line profile diagram (Figure 2).

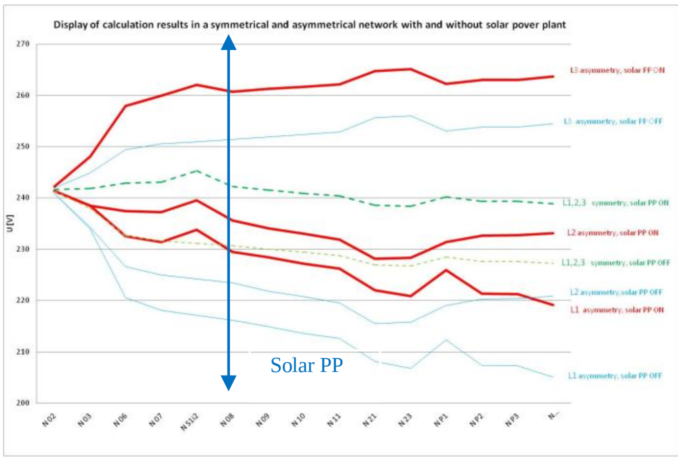

Figure 5. Voltage profile of asymmetrically loaded line with and without solar power plant

By analysis of the results for the L1 and L2 phases, the estimated trend of voltage drop along the line is obtained. These phases are the most loaded, taking the asymmetry into account.

Node N S1i2 presents a power plant and it is clearly visible that it boosts the voltage so much, that in case of asymmetry in phases L1 and L2, the voltage at the node on which the power plant is connected is higher than the voltage along the line, but not higher than the voltage at the transformer buses, because the total energy consumption is greater than the energy that solar power plant injects into the network.

The results in phase L3 are completely different. The voltage at power plant's connection node (N S1i2) is greater than the voltage on 0,4 kV buses in the substation. The production of the power plant in phase L3 is greater than the consumption of consumers, so the surplus energy flows through the substation to the 10 kV network.

This are unnatural conditions for the transformer at the substation, because the phase L1 has a different energy flow direction than the phase L3. On the other hand, at the phase L3 the voltage at the end of the line is higher than the voltage at the power plant, which is a quite different situation than in phases L1 and L2.

The consequence is further increased asymmetry, because while the reduction of voltage in two phases appears, there is the voltage increase in the third phase. This problem gets more pronounced with the greater asymmetry.

It is obvious that problem of voltage increase at the end of the line due to an asymmetry has existed before the power plant integration. However, at that time the problem was recognized only as voltage drop along the line and only consumers felt it. Before the 4-pole calculations of low voltage network were not carried out, the effect of voltage increase towards the end of the line due to an asymmetry was not noticed, and the phenomenon was treated as a „slightly lower voltage drop“ along the line on a certain phase because of asymmetrical consumers.
By integrating a power plant to asymmetrically loaded network, in this case solar power plant, due to the voltage increase that is always caused by power plant, at the end of the line the voltage rises even further, which makes this problem even more pronounced. Therefore, the consumers at the end nodes suffer due to a poor voltage conditions.The impact of the power plant in asymmetrical network is beneficial only for lines in which the consumption exceeds the production, because the increasing voltage due to a power plant decreases relatively large voltage drop over the line, making the voltage conditions better. However, the negative impact of power plant is significantly more problematic, because the increasing voltage towards the end of the line might exceed the upper permissible limit of network supply voltage.
This phenomenon should be taken into account when determining the maximum allowable voltage at the point of delivery of energy in the network, because it is obvious that in an asymmetrically loaded network it should be required that power plants activate overvoltage protection at voltage levels lower than 1,1 Un, in order to the voltage at the end of the line does not exceed allowed 1,1 Un due to the negative impact of the power plant.

CONCLUSION

The paper shows that integration of symmetrical power plant to an asymmetrically loaded low voltage line has a negative impact to losses and voltage situation.
Special phenomenon is analyzed: due to a consumption asymmetry in the line, influenced by the symmetrical energy production, the energy does not flow in the same direction in each phase of the same line. Therefore, at the end of the line the voltage is lower in the phase with the dominant consumption (as expected), while, at the same time, in phase with the dominant production voltage is higher.
Therefore, measurements of asymmetry in low voltage line should be obligatory as a routine analysis prior to power plant connection, and, if asymmetry is intolerable, load balancing procedures should be implemented.
During the trial period of power plant's operation, it's necessary to measure the voltage at the end of the line fed by the power plant to obtain reliable and complete insight in order to determine the power plant's influence on voltage is within the legal limits [1].
Finally, asymmetry in the low voltage network is a serious issue that should not be neglected. The consequences of ignoring the problem of asymmetry can be calculated, measured and evaluated financially through the network losses increase. Contrary, the procedures for the reduction of asymmetry are simple and, in long terms, represent a negligible cost.

LITERATURE

[1] 2006, “The grid code”, Croatia, Official Gazette no.36
[2] E_NEP_Elec, Neplan manual