Evaluation of the impact of photovoltaic systems on the power quality in electrical grids – preliminary study

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Abstract. This paper deals with an analysis of the threats and adequate counter-measures connected with the impact of photovoltaic systems on low voltage grids characteristics. The growing interest in photovoltaic systems use is to be analysed from the perspective, that electrical energy distributed in industrial grids meets the relevant quality requirements in accordance with strictly defined standards.

1. Introduction

Solar energy can be produced by using photovoltaic (PV) systems, whose importance in the global demand for electricity is intensifying [1,2]. This increase is mainly due to the fact that energy is obtained without noise, pollution, and in most cases, maintenance-free. However, it should be remembered that the electricity produced meets the relevant quality requirements that are necessary for the proper operation of the equipment. An appropriate power quality in case of PV installations cooperating with industrial electrical grid is threatened by primary factors like changes of the solar radiation power, as well as secondary factors, mainly provoked by the use of the power inverters.

Following the introduction, the rest of this paper is structured in this way: Section 2 shortly describes the cooperation principles of PV systems with and their impact on low voltage power grids, Section 3 presents the selected aspects of assessment of the power quality in the PV systems, and the last Section 4 is the conclusion of the study.

2. Cooperation of PV systems with and their impact on low voltage (LV) power grids

PV systems are most often coupled with power grids through the use of power inverters, which generate higher voltage/current harmonics, injected at various buses, lines and transformers [3,4]. The power of the inverter should be selected according to the power of the PV generator. The general rule is that the power of the generator should be in the range of 0,8-1,25 of the inverter's power [5]. The inverter automatically synchronizes with the power grid and in the event of a failure has an electronic system that will disconnect it from the network, preventing further distribution of electricity produced.

The recommended practice [6] contains guidance regarding equipment and functions necessary to ensure compatible operations of PV systems that are connected in parallel with electric utility.

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The impact of PV systems on LV power grids is initially observed as:
- level of difficulty in balancing the power of the National Power System (NPS),
- changes in the power quality parameters.

In figure 1, the configuration of PV system connection to industrial network based on [7] is shown.

3. Assessment of the power quality in the electrical grid cooperating with the PV system
In order to assess, the selected real cases of changes in the parameters of the quality of electricity in the power grid cooperating with the solar system are analysed.

3.1. Fluctuations in the power generated by PV dependent on changing weather conditions
The large fluctuations of power obtained from solar energy dependent on atmospheric conditions have been confirmed by research presented by a group of scientists [7], where a 30 kWp PV system connected to the power grid was tested. The variation of the output power within two adjacent days (see figure 2.a,b) and over the month (see figure 2.c) were measured.

Presented results show, that daily power changes mainly occur closely to midday and may reach a value of 25 kW or about 8 kW in sunny or cloudy day, respectively, with relatively high probability of the occurring monthly power changes.

3.2. Power balancing in the NPS
In a situation where the participation of photovoltaics is small, the issue of the impact on the stability of the power grid is negligible (part of micro-installation is equipped with energy storage and power inverters working independently). With its increased share, the solution could be the extension of the pumped storage power plant used to stabilize the NPS [8]. The principle of this solution is presented in figure 3.

3.3. The impact of PV systems on changes in power quality parameters and stability of the energy systems

Figure 1. The configuration of PV system connection to industrial network; PCC – Point of Common Coupling; INV – power inverter

Figure 2. Volatility of power generated by PV over days: a) sunny day, b) cloudy day and c) over a month [7]

Figure 3. The reaction of the energy store to changes in frequency in the network [8]
When demand on electrical power rises, the energy storage system instantly begins discharging, and frequency drop is controlled. Also when demand declines, frequency rise is controlled by battery charging. More and more common use of the energy storage is evidenced by recent investments carried out by countries such as the United Kingdom [9], Israel [10] and Germany [11]. The disadvantage of this system is the price, which prompts us to analyze the cost-effectiveness of the entire solution of these storage systems.

3.3.1. Impact on voltage changes and stability of the power system
To assess the impact of large-scale PV generation on the stability of the energy system, the researchers [12] tested the impact of PV generation on the elimination of the problem of under-voltage in the grid. Voltage instability is related to the imbalance of reactive power. To reduce the above phenomenon, it is necessary to reduce the losses of reactive power in the transmission system or introduce additional sources of reactive power generation. In the tested case [12], the phenomenon of under-voltage appeared in one of the three power rails. For this purpose, PV system (50 MWp and alternatively 100 MWp systems) was connected to the second power rail (SL2; see figure 4.a). Changes in the voltage were checked and the voltage indicator without connected PVs was also taken into account for comparison (see figure 4.b) (bus voltage in relation to its nominal value). The results showed that the problem of under-voltage was solved. What's more, the voltage on the other two buses has also increased due to the connection of solar systems to the power grid.

![Figure 4](image_url)

**Figure 4.** Influence of PGV on electrical network: a) industrial power system with 3 rails, b) the effect of photovoltaic generation on the increase of the supply voltage, based on [12]; SL – Static Load

3.3.2. Impact on harmonic distortion
Problems of PV systems from the perspective of harmonics are included in their deformations after adding this system to the network and the impact of changing weather conditions on the rated output current PV. The PV output current at the PCC connection point (see figure 1) is directly proportional to the power transmitted to the power grid. The dominant harmonics [12], which were focused during the study are: the third, fifth, seventh, ninth and thirteenth. Harmonics of higher orders were also recorded, however their impact was considered to be negligible. In figure 5, it can be observed that during the solar period, subsequent harmonics were proportional to the basic current component.

![Figure 5](image_url)

**Figure 5.** Parameter changes in the PV system during the day: a) radiation level and output power, b) the current harmonics, c) the waveform of the basic current and THD voltage distortions [13]
During the sunrise and sunset there were significant third order harmonic jumps, amounting to 40-50% of the fundamental harmonic amplitude. The profile of voltage harmonics is not related to the size of solar radiation. The THD of voltage was in the range of 1-1.75% while the PV installation was in operation. The conclusion is that the occurring distortions do not have a significant impact on the deterioration of the quality parameters of the power system.

4. Final conclusions
This preliminary study covers some selected threats and preventive measures. As a result, it is possible to draw conclusions presented below.

- The problem of PV generation variability can be reduced by using, among others, power regulation and storage systems by accumulating the surplus and using it in an energy deficit case. In the analyzed examples, frequency deviations were within specific standards, but the phenomenon was reduced by using a battery-based energy storage system.
- Additionally, it was noted, that a problem of under-voltage in the grid can be solved by adding the PV sources to the system, improving at the same time a stability of the analyses grid.
- Analysed studies on the impact of PV systems on harmonics of currents and voltages revealed the occurrence of the problem, however, groups of scientists said that these impacts have no significant impact on the change in the quality of electricity in the electricity grid.

The presented subject covers many more interesting phenomena, but they cannot be discussed in a limited volume of the paper. The results of the aforementioned analyses may be useful in further research in the subject of PV and the PQ in the electrical power grid.

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