Contribution of PV Power Plants to Flicker Severity in Power Distribution Grids

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Abstract—This paper presents some results of an extended power quality investigation based on complex measurements in the substations of the local distribution grids having a photovoltaic system interconnected to. To track practical considerations about the propagation of the electromagnetic disturbances in the studied grid, all information on PV units operation were collected and analyzed, for different operation grid’s configurations. The results of the experimental investigation proved that the presence of the grid-connected PV system cause power quality problems, but its responsibility could be split with other former connected consumers depending on the network topology.

Keywords—Distribution grids, power quality, monitoring, grid-connected PV power plant, power quality, flicker.

I. INTRODUCTION

The actual impact of the power quality (named here PQ) on the power systems’ operation covers issues as lost production, equipments’ failures or additional costs of operation and investment.

Since more utilities are aware that a proper evaluation of PQ level is necessary for their service, they agree with their users under contracts to provide a specified PQ level, especially in the presence of the grid-connected renewable energy sources. On the other hand, the increasingly number of sensitive customer loads alongside the renewable generation ask nowadays for a more proper, unitary and honest manner to define and evaluate PQ by the power companies and their customers, too.

Therefore a set of right parameters, limits and procedures should be defined for evaluating the PQ product and service, as well as for establishing right responsibilities for the grid’s users that mainly help the power grid users in keeping the compatibility between their loads and the quality of grids’ electricity [1, 2].

The PQ level in the transmission and distribution grids must be verified periodically at the strategic or suspicious buses: e.g. boundaries between grids, area with numerous customer complaints regarding the quality of the supplied power or renewable energy grid-connected sources [1, 2]. For this purpose, some PQ performance targets should be selected so that the contractual agreements between grid’s operators and their users to be concluded.

In these circumstances, the renewable energy sources, especially PV systems, have become more significant sources of energy in the national power system. Nonetheless, the connection of large PV systems to utility grids may cause several operational problems for distribution networks, as well as for the quality of the power delivered by these ones. The severity of these problems directly depends on the percentage of PV penetration, the geographical location of the installation, as well as the network topology [3, 4, 5]. Hence, knowing the possible impact of grid-connected PV systems on distribution networks can provide in advance feasible solutions for operation improving.

The over-voltages, harmonics, frequency fluctuations or rapid voltage variations (flicker) can be outlined as possible effects that PV systems may impose on PQ in distribution systems due to the fluctuation in solar radiation. The factors influencing the PQ are generally varied and the interactions between these factors are complex. The more the number of the disturbing loads in interaction with PV-grid connected systems, the more the complexity.

The present paper points out the impact of a 5 MW PV system on the PQ level in the MV distribution network in which this one is connected. A particular attention is paid to the flicker propagation in the network and its sources’ location. The experimental analysis is based on field measurements for different operation configurations of the interconnecting distribution grid.

II. TEST CONDITIONS FOR PQ ANALYSIS IN DISTRIBUTION NETWORK WITH GRID-CONNECTED PV SYSTEMS

The capability of the power system to absorb the PQ disturbances is depending on the fault level at the point of common coupling. In weak networks or in power systems with a high PV generation penetration, the integration of these sources can be limited i.e by the flicker level that must not exceed the standardized limits. The PV systems interconnected to the main grid with the help of power electronics converters can also cause important current harmonics.

The MV grid-connected PV power plants (PVPP) should
fully respect the requirements of Electricity Distribution Grid Code, as well as Romanian Norm Technical requirements for photovoltaic power plants connected to the Romanian National Electric Grid [6, 7, 8, 9, 10]. Accordingly, the compatibility levels of flicker severity Plt is 1 p.u. in conformity with the EN 50160 specification at MV. The practical assessment of flicker and corresponding indices is an important area of further research, as the implications of meeting the Plt requirements of one unit is significant for utilities and their customers.

Particularly the present study was performed as an initiative of a local grid operator to solve the numerous recent complains of its grid user after connection of a PV system regarding especially the voltage fluctuations over-exceeding the unity. The studied PV system is a 5 MW one and is a direct-coupled one, without electrical energy storage, connected to the 20 kV utility grid. It injects in the power system a power that follows the intermittency of the primary energy source and important voltage variations occurred at the PCC. Determination of voltage fluctuations (flicker effect) due to output power variations of PV systems is difficult, because depend of the weather conditions, generator’s characteristics and network impedance.

A measurement campaign could be a more efficient way to assess flicker levels produced by this type of generation than the use of flicker prediction algorithms. Taking into account that the solving of grid customers complains asked for a rapid resolution, the grid operator used the practical measurement results to evaluate the flicker propagation through its network, its severity and consequent measures.

Based on operator’s experience and requirements, two base configurations were chosen for the connection network in order to investigate the impact of the PV system on the flicker severity without power plant’s service interruption. The PV power plant impact on flicker severity in a normal operation grid topology, named as Config1 and given in Fig.1 is compared with the case of a temporary network configuration, named as Config2 and given in Fig.2.

Under normal operation the power is injected by PVPP upstream of the distribution grid, toward substation SS1. SS1 is a 110/20 kV distribution substation, equipped with two 10 MVA power transformers, one of them being in continuous operation and the other serving as permanent reserve. During temporary operation the power is injected by PVPP downstream of the distribution grid, toward substation SS2. Both of the SS1’s transformers are in operation this time. The consumers supplied through SS1 are split between the two busbars’ sections as following: the consumers supplied from OVHL 1-2 are connected to section BbII, while the other group of consumers (mainly petroleum installations) are connected to section Bb II.

By performing test measurements in both grid configurations the flicker severity contribution of each group of the network could be estimated and the impact of the PV system could be properly evaluated without plant’s interruption.

![Fig. 1 PVPP connection into normal operation configured distribution grid – Config1](image1)

![Fig. 2 PVPP connection into temporary operation configured distribution grid – Config.2](image2)

### III. EXPERIMENTAL RESULTS

#### A. Purpose of experimental analysis

This experimental analysis aims to support the distribution network operator to evaluate the correct contribution of PVPP at the flicker severity in the MV grid at which it is connected. This network area is feeding different types of loads (almost 4.5 MVA average load), and particularly the petroleum installations (almost 1.5 MVA average load) containing variable speed drives and supplied connected mainly to the feeder OVHL 1-3. The voltage flicker at the MV network is the combined result of emissions from loads connected at this voltage level and flicker transferred from the HV grid. Therefore, the flicker emissions from individual installations...
are superimposed and determine the overall voltage flicker level in the network. By using different network topology the potential flicker sources could be isolated, without supplying interruption and the contribution of the PVPP with a stochastic generation to flicker can be more accurately determined.

B. Measurement conditions and tools

A set of synchronized measurements have been performed in the 20 kV radial distribution network area boarded by the two 110/20 kV distribution substations, named SS1 and SS2. PQ meters have been installed in six strategic measurement points:

- M1 (available in both configurations): 20 kV BbI of SS1
- M2 (available in both configurations): 20 kV cell of OVHL 1-2
- M3 (available in both configurations): 20 kV PCC of PVPP
- M4 (available in both configurations): 20 kV busbar SS2
- M5 (available in Config2): 20 kV BbII of SS1
- M6 (available in Config2): 20 kV OHVL 1-4 with petroleum installations’ loads

Power analyzers of Fluke 434/435 type are placed in M2, M3 and M5. Chauvin Arnoux CA8335 equipments are located in M1, M4 and M6.


The measurement data were collected over one-week period in each network configuration for solar irradiance under similar weather conditions. Sets of 7x24x6=1008 ten-minutes average-values have been supplied at each measurement site. By sorting the measured data, the weekly 95th percentile values of the Plt values are statistically determined and compared to the unitary compatibility value.

C. Measurement results

The following PQ aspects were monitored and reported: frequency, supply voltage variations, harmonic distortion, supply voltage unbalance, flicker. In this work a special attention is granted only to the rapid voltage fluctuations - flicker. So that, a snapshot view on the flicker severity for the two network configurations are reported in as in Fig. 1-4.

![Fig. 1 Time evolution Plt1 at 20 kV PCC of PVPP (M3) vs. Plt1 at 20kV busbar of SS1 (M1) in Config1](image)

Table I shows the main statistics of the 95% Plt weekly values measured at three phases in the distribution network to which the PVPP is connected.

a) Practical considerations regarding Config1 – Fig. 1, 2

- In this configuration the PVPP has fully operated with a maximum output power of 4.4 MW. The flicker 95% Plt factor in 20 kV PCC of the PV system (M3) has exceeded the limit on all 3 phases.

![Fig. 2 Plt distribution in PVPP’s distribution network for Config1](image)

![Fig. 3 Time evolution Plt1 at 20 kV PCC of PVPP (M3) vs. Plt1 at 20kV busbar of SS2 (M4) in Config2](image)

![Fig. 4 Plt distribution in PVPP’s distribution network for Config2](image)
The flicker Plt factor exceeded also the unit limit on all phases on 20 kV secondary busbars of substation SS1 (M1).

The time variation of Plt recorded in 20 kV SS1 is similar to that one recorded in the PCC of PVPP - see Fig.1.

For 4th measurement location, the 20 kV busbars of substation SS2 (M4), no limit exceeding was registered for flicker Plt factor.

Nevertheless, the higher values of the Plt in 20 kV SS1 compared to the flicker severity in PCC of PVPP has suggested an additional contribution from the loads connected to 20 kV of the SS1 substation busbars or from upstream of this substations. Further investigations have been requested.

b) Practical considerations regarding Config2 – Fig. 3, 4

- In this configuration the PVPP has fully operated with a maximum output power of 4.3 MW. The flicker 95% Plt factor in 20 kV PCC of the PV system (M3) has also exceeded the limit on all 3 phases.
- This time the PV flicker behavior’s influence is detected in the time evolution of the flicker Plt measured on 20 kV busbar of SS2 (M4) – see Fig. 3. Here the 95% Plt exceeded the unitary value, too.
- The flicker Plt factor exceeded also the unit limit on all phases on 20 kV secondary busbars section BbI of substation SS1 (M1), but it is lower than the values registered in the previous configuration. The influence of the loads connected to its busbars is considered this time.
- The flicker Plt factor on the other busbar section BbII of substation SS1 (M5) exceeded also the unit limit on all phases on 20 kV. Due to the actual network configuration, this fact is determined solely by the flicker contribution of the petroleum installation loads connected supplied form this substations (M6).

The propagation of flicker Plt factor through the distribution network buses leads to the conclusion that responsibility not clearly belongs to a single source (in this case CFV), but rather it is an effect of interaction between different flicker sources to which contribute more factors: e.g. network configuration, operation mode of PVPP, atmospheric conditions. The increased value of the Plt factor at 20 kV SS1 without PV system feeding this network area suggests that in certain operating conditions the PVPP may have even a slight beneficial effect. On the other hand, its connection to the network section including substation SS2 has relatively little influence on the overall level of disturbance.

Phenomenological explanation is the fact that voltage changes are directly related to reactive power flow that occurs among distributed reactive components, depending on the operating conditions of the network, its composition and topology, and being strongly favored by power electronics applications (inverters).

By considering the PV having a singular culpability for flicker severity source of disturbance CFV is risky. There is rather about the effect of interaction with consumers in the area, closely related to network configuration.

In these circumstances the recommended measures should target not eliminate the cause, but the consequences by ensuring an efficient control of reactive power in the buses with disturbance sources.

IV. CONCLUSIONS

The renewable sources interconnected with the main supply can influence the PQ at the point of common coupling and generate electromagnetic disturbances that must not exceed the stipulated limits. The existing trend of installing more renewable sources implies the establishment as accurate as possible of their impact on power system operation.

In this paper the voltage fluctuations determined by a 5 MW PV power plant’s power variations are analyzed, for two network configurations, in order to properly establish the plant contribution to the flicker severity. The photovoltaic plant, connected to the power system through power electronic converters determines flicker fluctuations that should respect the regulations recommendations. A better characterization, from the practical point of view, of the flicker severity determined by PV power plants interconnected to the mains supply through power electronic converters is necessary, based on experimental analysis.

REFERENCES


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