CONSIDERATIONS ON PHOTOVOLTAIC POWER PLANT POWER QUALITY REQUIREMENTS

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ABSTRACT

The paper provides a description of the Power Quality(PQ) Romanian regulations, including wind power plant and solar power generation. In order to meet the international PQ standards requirements, TSO has issued a review of the national technical norms on flicker and harmonics and has optimized the technical norms for connection of Wind Power Plants (WPP)&Photovoltaic Power Plants(PVPP). Power Quality Monitoring System (PQMS) creates a necessary statistical database for development of PQ regulation and the ascertainment of contractual conditions.

Second part of the paper presents the difficulties encountered when, for several different sites connected at MV level, the values of long term flicker levels are greater than 5 when recorded during conformity testing.

Main finding is that there is not an actual flicker phenomenon. Instead, the voltage events (dips and interruption) lead to individual 10 minutes high values for short time flicker P_{st}.

There still remains the problem of detecting the cause of voltage events since interruptions and voltage dips occurrence is higher in case of MV overhead lines where PVPP are connected.

INTRODUCTION

Romanian Power Grid “Transelectrica”/“Electrica” are the Transmission/Distribution System Operator and the Metering Operators of the Wholesale Electricity Market/ Retail Electricity Market. These companies are interested in using Smart Grid technologies and a very important information data source is the nationwide Power Quality Monitoring System (PQMS), presented at last CIRED Conference. The discussions during 2013 CIRED meetings emphasized the necessity to provide a more detailed analysis of data accumulated during PQMS operation. We now focus on the Photovoltaic Power Plants PQ data provided by PQMS when the new legislation that requires conformity certificates for Distributed Generation was enforced.

The paper also describes actual examples for selected incidents in addition to detailed investigations, benchmarking & best practice of monitoring applications. Because conformity tests can prove very important when financial interests are involved third part of the paper is questioning the use of EN 50160 limits for flicker when talking about PVPP.

As many PVPPs are already in operation, reports used for certification are available. In most cases, we noticed a minimal impact on PQ parameters concerning voltage level and voltage THD but significant flicker levels. High flicker levels are recorded when there is a sudden change in energy production. This is a typical situation for PVPP connected to MV network. When energy production level is low due to weather condition the long term flicker becomes even worse.

REGULATORY FRAME

As part of the synchronous system in Continental Europe, the Romanian system Operator is involved in new Pan-European Network Codes (NC) drafting. The NCs elaborated by ENTSO-E working groups prioritize the supply security consolidation and determines an harmonized performance assurance in the Common European Energy Market.

The first two NCs: “Requirements for Generators” (RfG) and “Demand Connection Code” (DCC) define generation and consumers’ access requirements. The DCC establishes the requirements regarding PQ: “All Transmission Connected Demand Facility Owners and Transmission Connected Distribution Network Operators shall ensure that their connection to the Network does not result in a level of distortion or fluctuation of the supply Voltage on the Network, at the Connection Point. The level of distortion shall not exceed that allocated to them by the Relevant TSO". Article 25. states that, the RfG includes requirements for module generation connection regarding frequency and voltage range, reaction on dips - fault or low voltage ride through. The end scope of the NC is to assure that all connected users, especially potential voltage disruptors are verified and accepted in the grid only if they are “clean”.

Based on these drafts, the Romanian TSO has undertaken two actions.

First, the TSO has performed a review of the national technical norms on flicker (year 2013) and harmonics (year 2014) - resulting in performance standards and upgrade methodology application.

Second, the TSO optimized the technical norms for connection of the new power sources, as Wind Power Plants (WPP) & Photovoltaic Power Plants (PVPP) - an obvious requirement for the power quality. The TSO has also developed a methodology for monitoring the PQ at

TSO/DSO or TSO/significant-users interface – including continuous and temporary measurements and verifying/testing the new connected users.
The significant users and interface substations with DSOs are monitored through the TSO's PQMS (more than 53 metering points). In case of systematic errors or limit violations in connection points with many disturbance sources, dedicated PQ analyses are initiated.
The connection rules for WPP & PVPP specify that the compliance with PQ standards is mandatory. Fulfilling the requirements is subject to four steps: Wind turbine (WT) & inverters technical certification check, study of PQ and reactive power control in the connection point, monitoring of entire WPP or PVPP in the connection point over a minimum of 2 weeks during the performance tests, and (for some units) continuous monitoring.
All WT & inverters which equip each Power Plant (PP) > 5 MW must present the certification with test records respecting IEC 61400 or IEC 016. Based on the records, the reactive and disturbance studies can highlight the necessity of compensation with auxiliary equipment. The power plants conformity with connection requirements is the subject of technical documentation and certification of WT, inverters, and PP tests. PP tests refer to active power checks via frequency simulation at different ramp rates (steps of more than 20% of rated power) and to reactive and voltage control in the connection point – this includes different ramp rates and different tap changer positions. During all those tests, PQ is strongly affected by a dynamic and wide regimen of functions, and its analysis can highlight extreme values.
The certification methodology mandates PQ analysis during tests (over a minimum of two weeks) and in case of nonconformity the PP license is postponed until corrective measures are taken. WPPs & PVPPs larger than 5 MW must be equipped with a class A PQ analyzer in the connection point, which will be integrated into the DSO/TSO PQ monitoring system. Analysis of several test records (more than 80 PPs) checks for extreme values during tests and verifies good behavior in operation.

THE ROMANIAN FLICKER NORM

Following the PQ monitoring conducted by Transelectrica in the CCPs TSO-DSO-disruptive consumer, significant voltage values fluctuations were identified. During 2013 Transelectrica contracted ISPE to review the Romanian Energy Prescription no. 142/1980 and to convert it into Romanian Energy Technical Norm "Norm regarding limitation of voltage fluctuation and flicker in the power transmission and distribution networks", in addition to [1, 2, 3, 4].
The overall objective of EP 142/1980 revision is the compliance with the international, Romanian standards, and the expansion of the scope to the transmission network. Specific objectives are to complete the existing prescription by defining the phenomenon of flicker and all its characteristic parameters, defining the procedure to be used to determine the existing flicker and setting the limit of perturbations allowed to each user, as well as indicating solutions to limit the effect of those voltage fluctuations.
The present norm establishes the procedure used to determinate the disturbance quotas allowed for the users in the connection points, meant to increase network capacity to undertake disturbance. The norm also presented the conditions for connecting the loads generated by wind power plants with voltage fluctuations. Planning levels in CCPs are specific for the power supplier / network operator for all voltage levels.

Table 1.The planning levels for flicker

Flicker indicator	Planing levels MV	HV – UHV *
P_{st}	0.9	0.8
P_{lt}	0.7	0.6

*Some Power Systems differentiate between the HV and UHV. Thus for UHV the considered values are Pst = 0.7 and Plt = 0.5. These limits are not in conformity with the IEC recommendations.

Table 1 presents the indicative values related to the planning levels for Pst and Plt in MV, HV and UHV networks.
In order to be connected to the network, new users need to comply with the flicker limits. Compliance must be proved through calculations determining the flicker in the CCPs. Calculations are made based on technical documents and certificates of flicker emission measurement considering the minimum short-circuit power of the connection node. During the test, the users are monitored and will obtain the connection notice upon compliance with the granted flicker emission quota.

FIELD MEASUREMENTS

During the summer of 2014 all PVPP connected to MV network belonging to Sibiu subsidiary of DSO FDEE Transilvania Sud had to be certified according to the new regulations regarding technical conditions imposed for grid connection. Power Quality limits were observed for eight PVPP. For this purpose data were collected from network analysers installed in Common Coupling Point of each PVPP using Permanent Monitoring System.
EN 50160 reports were generated for each of them during one month. For three PVPP under scrutiny all PQ indices were inside limit. In case of the remaining five, long time flicker P_{lt} was the only PQ indicator that was over 0,1, which is in the admissible limit. Values over 5 are usual for those PVPP's.
For further consideration we used data from permanent PQ monitoring equipment installed in common connection point in case of four PVPP's:

- PVPP Talmaciu (2,8MW) connected to MV OHL Vestem-Talmaciu
- PVPP OCNA (3,2 MW) connected to MV OHL Sibiu-Ocna
- PVPP Sacel (2.9 MW) connected to MV OHL Orlat-Saliste
- PVPP Miercurea Sibiului (10MW) only one of the four MV loops connected directly on Miercurea 110/20/kV substation Busbar.

Graphical representation contains data for only one phase and for a reduced period of time (to improve readability) and is a sample extracted from the one year database. Even so it can be used to highlight when higher flicker values occurs (aspects that can be found on all phases and for extended periods).
Figure 1 presents the correlation between Line to Line voltage and long term flicker. For each voltage trend the minimal and maximal value corresponding to each 10 min average value is plotted. This way becomes clear that high flicker levels occur when voltage events such as sags and interruptions are recorded.
In Table 2 the actual values are presented in the case of PVPP Talmaciu. It can be observed once again that the flicker is recorded only in the 10 min interval which is corresponding to a short interruption.

Table 2 – Values recorded for flicker current and voltage

Time	Pst L1 avg	Plt L1 (7200s) avg	Current L1 [A]	Line Voltage L2-L1 avg[kV]	min[kV]	max[kV]
8/20/14 5:10:00 AM	0.38		0.98	20.62	20.57	20.68
8/20/14 5:20:00 AM	0.15		0.98	20.66	20.59	20.71
8/20/14 5:30:00 AM	0.11		0.97	20.71	20.66	20.75
8/20/14 5:40:00 AM	0.12		0.97	20.72	20.67	20.76
8/20/14 5:50:00 AM	0.10		0.97	20.78	20.70	20.84
8/20/14 6:00:00 AM	0.09		0.96	20.82	20.77	20.87
8/20/14 6:10:00 AM	0.09		0.96	20.84	20.78	20.88
8/20/14 6:20:00 AM	**10.15**	**Interruption**	0.01	20.84	0.00	21.06
8/20/14 6:30:00 AM	**1.23**		2.00	20.87	19.70	20.95
8/20/14 6:40:00 AM	0.10		2.27	20.90	20.82	21.04
8/20/14 6:50:00 AM	0.11		2.45	20.98	20.92	21.03
8/20/14 7:00:00 AM	0.10	**4.48**	2.82	21.02	20.98	21.06
8/20/14 7:10:00 AM	0.11		3.12	21.00	20.94	21.04
8/20/14 7:20:00 AM	0.11		3.43	20.99	20.95	21.03
8/20/14 7:30:00 AM	**0.49**	**Ground Fault**	3.98	20.98	19.63	21.29
8/20/14 7:40:00 AM	**14.97**	**Interruption**	0.00	20.91	0.00	21.26
8/20/14 7:50:00 AM	0.15		6.62	20.69	20.60	20.79
8/20/14 8:00:00 AM	0.13		9.25	20.67	20.60	20.73
8/20/14 8:10:00 AM	0.10		11.53	20.67	20.61	20.72
8/20/14 8:20:00 AM	0.10		13.98	20.66	20.60	20.69
8/20/14 8:30:00 AM	0.39		16.44	20.66	19.95	20.70
8/20/14 8:40:00 AM	0.38		19.35	20.67	19.31	20.72
8/20/14 8:50:00 AM	0.35		22.31	20.60	20.50	20.72
8/20/14 9:00:00 AM	0.34	**6.61**	25.49	20.59	20.52	20.63
8/20/14 9:10:00 AM	0.32		28.15	20.65	20.55	20.77
8/20/14 9:20:00 AM	0.33		30.87	20.71	20.62	20.81
8/20/14 9:30:00 AM	0.61		32.70	20.72	19.63	20.89

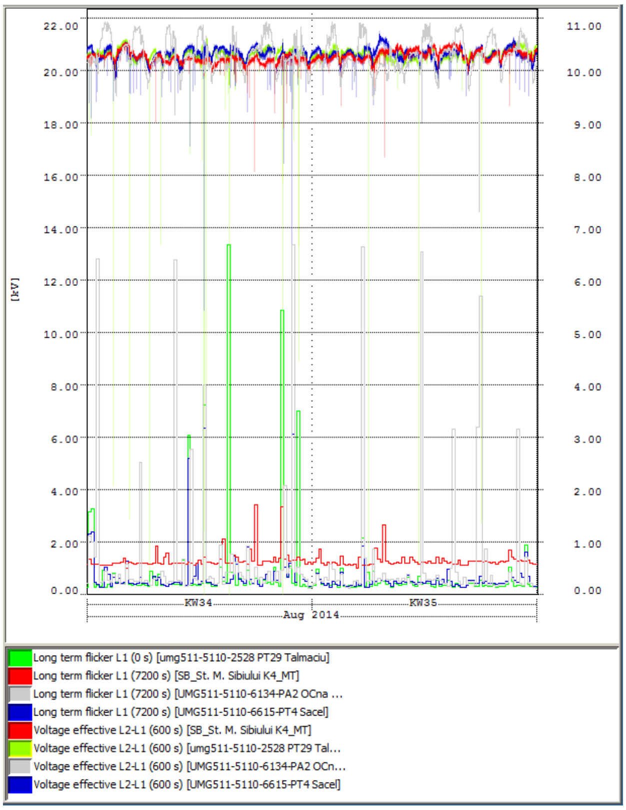


Figure 1 Correlation between flicker and Line Voltage Level in case of four different PVPP connected to MV network.

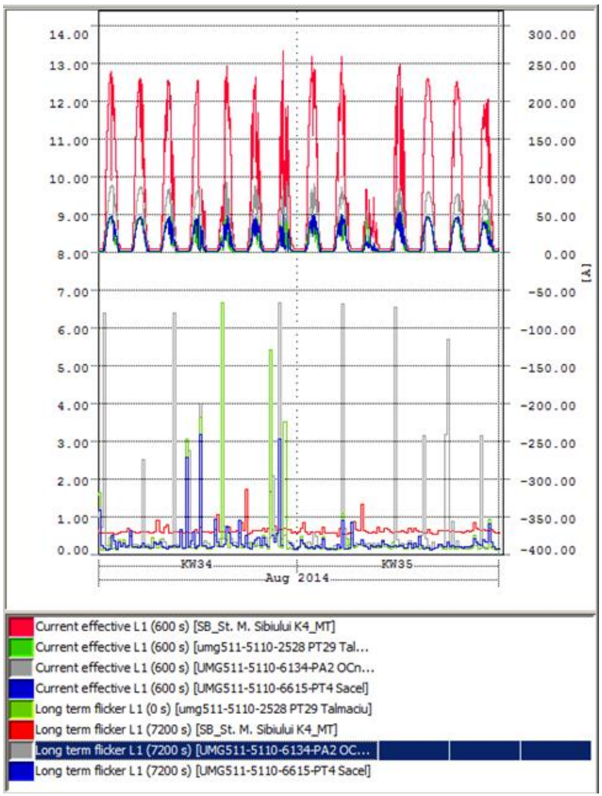


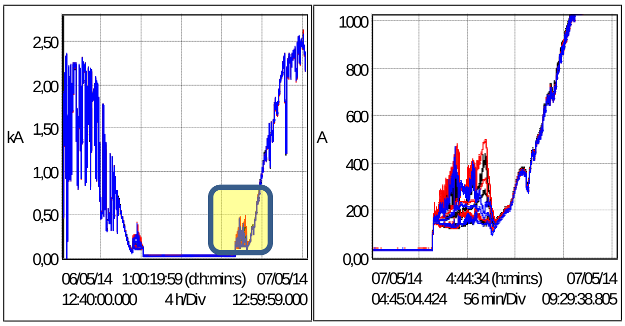
Figure 2 Correlation between flicker and load in case of four different PVPP connected to MV network.

Correlation between flicker level and load is shown in figure 2. On the left axis are plotted the P_{lt} 2h values in case of four PVPP's recorded during two weeks in august 2014.

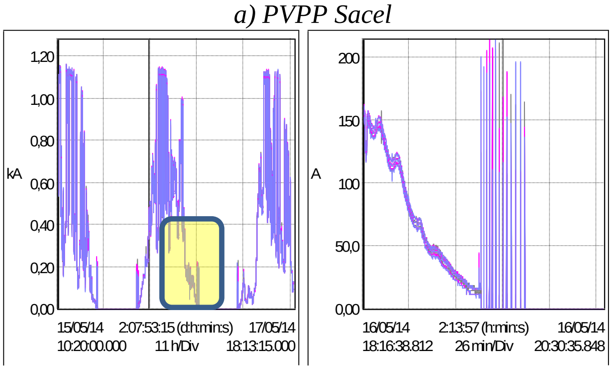
On the right axis are plotted with the same colour the corresponding currents.

- Early in the morning and late in the evening when production of electricity is close to zero.
- When production has sudden variations especially during cloudy days.

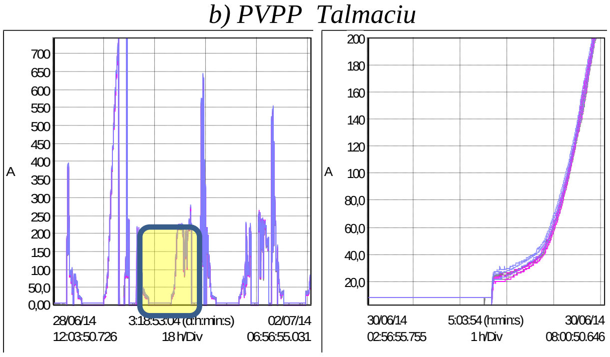
Taking into account that the non-compliance with PQ emission limits could lead to serious consequences for the owner of PVPP installation, including disconnection from the network, a more focused analyse had to be performed. A series of detailed measurements were taken on low voltage side at the inverter output that can give an insight of the causes which can generate high values for the recorded flicker level.



a) PVPP Sacel



b) PVPP Talmaciu



c) PVPP Miercurea

Figure 3. Recordings of current produced by different PVPP's.

Figure 3 presents samples taken from recordings made on LV side in case of three PVPP's with mobile network analysers. A higher resolution of 1 second was programed as an interval between two recorded values. Measurements were taken during conformity tests carried out for PVPP plant certification.

Two graphs are presented in case of each PVPP. On the left side is represented the trend of produced current over several days. On the right side is represented a detail view of current variation during periods with low daylight early in the morning or late in the evening.

In case of PVPP Sacel (Figure 3.a) during those periods the values of phase currents differ very much one from the other.

In case of PVPP Ocna (figure 3.b) a series of "pulses" were detected when the inverter started and stopped. This is the case encountered also for other PVPP's already in operation.

Both cases show that the inverter has a very tough functioning mode. If during this period a sudden voltage variation occurs (in case of voltage sag) a chain of events can lead to high currents and plant disconnection from the grid. Owner of PVPP's reported numerous power electronics faults after unplanned interruptions.

If the inverter is started only when there is enough daylight to ensure a steady flow of generated power as in the case of PVPP Miercurea (Figure 3.c) the probability of severe events diminishes. This translates then in low "flicker" levels.

For a pertinent conclusion more measurements are necessary. Recordings with less than a minute resolution require large storage capabilities. Mobile network analysers must be replaced for this purpose with permanent ones. We also consider using other measuring devices such as Phasor Measurement Units to detect the cause of severe voltage events in MV networks where large inverters are connected.

CONCLUSIONS

Applying the Romanian Engineering Practice the new Romanian Energy Technical Norm regarding flicker, determines the rules for TSO and DSO and establish the connection conditions in common connection points. We pay attention to end users generating voltage fluctuations that are leading to flicker effect, in aim not to disturb the operation of other users connected in the same node and to keep the PQ parameters according to the regulations.

PQ Management has to integrate the technical, legal issues / regulatory and managerial aspects of PQ in the entire National Power System for all operators in the energy market. The main objective is the functioning of the PQMS respecting the conditions of providing the security power supply for final users and the economic efficiency of operations.

The additional analysis performed during year 2014 revealed that in case of PVPP's:

-High ''flicker'' values are accompanied by other PQ events such as voltage dips or interruptions.

-Simultaneous measurements in low voltage network show little propagation effect.

-The ''flicker'' recorded at MV may be a ''ghost effect'' of voltage dips and short interruptions.

-The probability of severe events is greater in case of PVPP put in operation when there is no daylight available to ensure a steady power flow.

The end scope of the network connection is to assure that all connected users, especially potential voltage disruptors are verified and accepted in the grid only if they are "clean". The aim of these concentrate efforts addresses to existing systems, to reduce the power losses in the electrical power system, to limit the perturbations and to guarantee the quality level of services for all the customers.

An important debate that emerges is that Romanian National Energy Authority has an important role in the PQ development. To ensure the transparency and the harmonization of stakeholders interests, the Regulator should consult experts in the economic and academic field and the interested operators [11]. The role of a "watch dog" in the energy market has to be shown by the regulator not only in the relationship with DSO – final user, but also in the relationship with TSO / DSO energy producers from renewable sources.

The harmonization of secondary regulations in the PQ field is a success factor in the implementation of PQ strategy; there will be correlated provisions from the technical codes of electrical networks, from performance standards for DSOs and TSO services.

Non-discrimination principle needs to be applied in the regulations of energy and especially in the PQ. It should be emphasized that no difference should be made between New entrants (new clients, which have to be connected to the grid) and Existing clients. The allocation of perturbations rates both for new and disruptive customers and for each of the existing ones should be made based on transparent and nondiscriminatory rules.

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