ISLANDING EFFECTS IN DISTRIBUTION NETWORKS – A CASE STUDY

Ion DOBRE
Niculai STANCIU
Electrica FDEE TS S.A.– Romania
dorel.stanescu@electricats.ro

Dorel STĂNESCU
Electrica FDEE TS S.A.– Romania
niculai.stanciu@electricats.ro

Mihaela ALBU
Univ. Politehnica Bucuresti - Romania
mihaela.albu@upb.ro

ABSTRACT

The study presents the challenges met by a distribution operator in unbalanced conditions, i.e. when the energy produced within a contour area by Distributed Generation (DG) units is greater than the load in the considered area. Analyse of two islanding events shows that new technologies must be implemented taking into consideration all particularities at a certain connection point in order to avoid harmful effects. During this study the use of Phasor Measurement Units (PMUs) in medium voltage network for early detection of islanding conditions was of great help due to their ability to measure frequency with high accuracy and to deliver data with high reporting rates (50 frames/s).

INTRODUCTION

European companies and national authorities are focusing on renewable energy sources for some time now. Incentives for investments in this field targeted both development of new sites and bonuses for the so-called “green energy” production and therefore many projects including small power plants are either already operating or will be commissioned in near future.

In contrast, reinforcement of existing distribution networks is done at a slower pace, causing many setbacks: for example, renewable resources are often available in less economically developed areas or at the far end of radial distribution networks.

The existing distribution networks were designed mostly with radial configuration. When new capacities installed in some of the distribution grid nodes exceed the local consumption, reverse power flow appears. For this reason the directional principle for the protections’ coordination is not used on medium voltage networks. Introducing new generators at the far end of the medium voltage network’s feeders can lead to the loss of the protections’ selectivity [1]. The first section of this paper presents the current situation in one subsidiary of Electrica S.A., a Romanian DSO, taking into account both existing facilities and new projects developed in the area.

Another result is the potential islanding of some of the network sections. In this respect we performed a study concerning a medium voltage network (see Figure 1) where a newly commissioned hydro power plant (node 4 in Figure 1) is sharing the same distribution feeder (number 1) with other two very old hydro power plants (number 2 and 3). The analysis starts with the focus on how the voltage level is influenced by distributed generation, using data collected from PQ monitoring equipment installed in those locations. Then we look more into detail to one particular event when islanded operation occurred (figure 2) leading to serious events in the neighbouring area. We present the causes, the interdependencies between SCADA and Distribution Automation Systems, focusing on the gap between older and new installations.

DISTRIBUTED GENERATION

DG units are generally a rated power less than 10 MW and their operation is constrained by the availability of distribution network connection. The general requirements are enforced [2-5] by the Romanian National Regulation Authority for Energy (ANRE).

When electrical power market was liberalized and the green certificates market was developed, the promotion of energy production from renewable resources lead to the high investment motivation for distributed generation.

The renewable resources are usually available in spots far from to the consumption centers, in rather isolated areas, where the network conductors’ cross section is low and where generally the technical state of the network is not very good. In order to derive a new DG connection solution, a detailed analyse is required, for each particular case. Therefore it is possible to meet situations where the cost of network refurbishment or the expenses involved by building a new line are comparable with the investment costs.

The electrical energy generated from some of the renewable sources (wind, solar) depends from the weather conditions, and it is usually non-controllable and

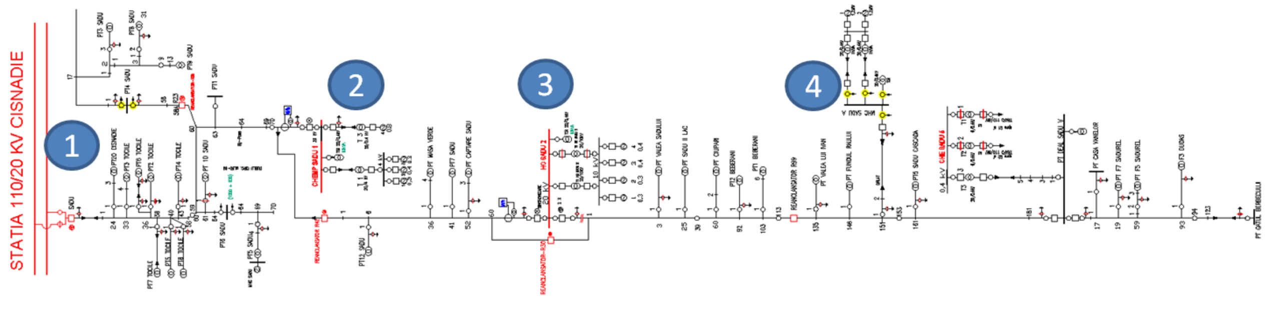


Figure 1. Single line diagram for MV feeder with indication of measurement points (MP)

has an intermittent nature, following the weather conditions; therefore the clients in the DG proximity could alternatively be in the situation to be supplied from the source nearby (when the generator is operating), or from far away, when, for example, they are supplied from the substation transformers.
Several large projects, in different stages of execution, are currently implemented in Romania. One of these, the Distribution Automation System, is already operational and includes 168 MV/LV substations, 611 reclosers and 616 switch disconnectors. All devices are remotely operated from a dispatch center and provide real time data from the supervised MV network. DG installations have to be integrated in this system in order to achieve full control of distribution network.

CASE STUDY

Measurements presented in this paper were taken (during 2014) in different nodes of the same MV feeder operated by to FDEE Transilvania Sud, the DSO in central part of Romania. This MV line has some particularities:
- it supplies customers located in a long (30 km) and narrow valley in Carpathian Mountains.
- includes two very old hydroelectric power plants (commissioned between 1890 and 1920, i.e. more than one hundred years ago), which are connected to this line. In fact, those generators and corresponding MV line were part of the first public power installations in Romania [6] and in operation ever since.
- at the MV line far end, a modern hydroelectric power plant (2 x 1,2 MW) was commissioned in 2013.

This particular arrangement "in cascade" raised some problems when the new installation reached full capacity: firstly, a number of unwanted trips caused by overvoltage have been reported, and secondly, several complaints on the power quality level in the area have been registered.

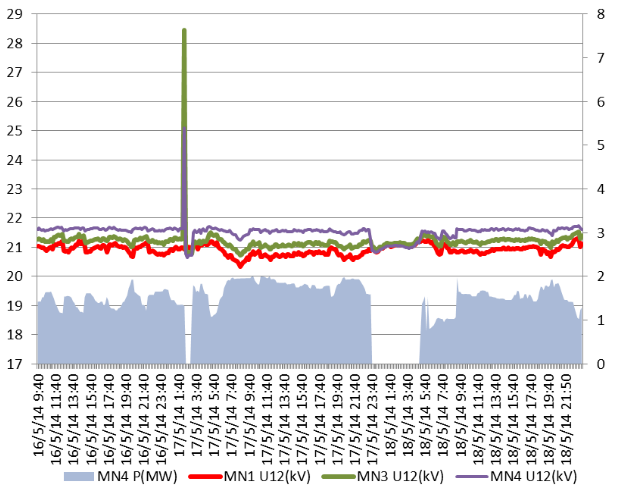
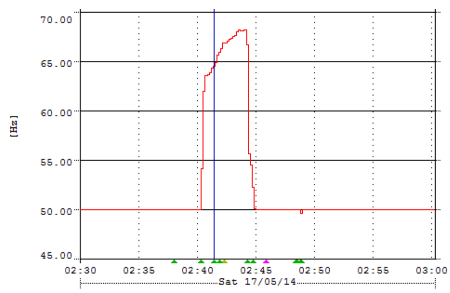


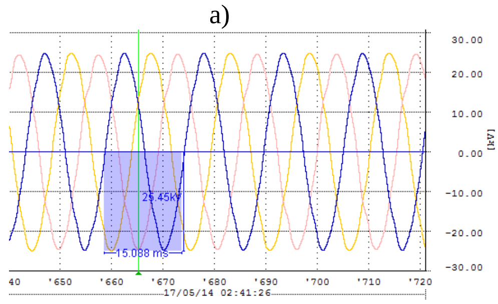
Figure 2 Voltage levels (rms) in three different monitoring nodes (MN1-MN3) and the generated active power in MN4

This situation led to a monitoring campaign intended to determine the cause of those events. Simultaneous measurements were taken during May 2014 at:
- Monitoring Node 1 - MN1, inside the HV/MV substation where the feeder is connected.
- MN3 , the connection point of CHE Sadu 2 (one of the old HPP, 4 x 0.5 MW)
- MN4 at the far end of the line where the new installation MHC SADU A (2 x 1,2 MW) is connected.

Results are summarized in figure 2. Voltage levels for three measuring points indicate that there is indeed a voltage rise of 5% at the far end of MV line when MHC SADU A is in operation. On the other hand, the voltage drop when production from MHC SADU A is stopped is less than 1%. Figure 2 shows the line voltages (rms values) in the 3 monitoring nodes (MN1—MN3), together with the total active power transferred in MN4 (mean 10 min values)
To be noted that the measurement chain comprises voltage instrument transformers class 0,5 and current instrument transformers class 0,5s and PQ analyzers with maximum tolerated error 0,1%, which results in a maximum measurement uncertainty of 104,4 V for the MV side of voltage measurements (here of interest). Recorded rms values for voltages in all metering points fall inside the admissible interval; however, on 17 May 2014 at 02:40, an event of different magnitude was recorded when line to line voltage reached maximum value of 28 kV (i.e. 40% overvoltage).



a)



b)

Figure 3 Islanding event 17 may 2014;
a) frequency rise; b) Line-to-earth voltage waveforms

This corresponds to an islanding event occurred when the following different conditions were simultaneously met:
- all three power plants were in operation close to their

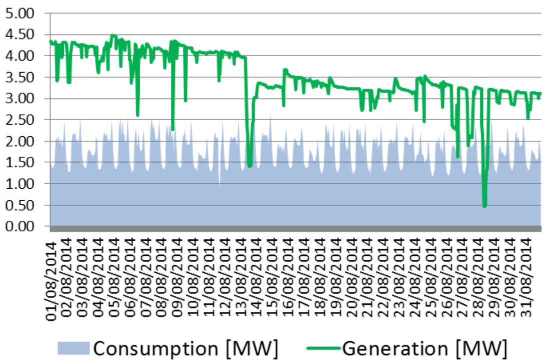
maximum capacity.

- consumption was very low at midnight in early summer.
- the feeder was disconnected in Cisnadie substation during an earth fault clearing.
- overvoltage protection in CHE Sadu 1 failed to operate.

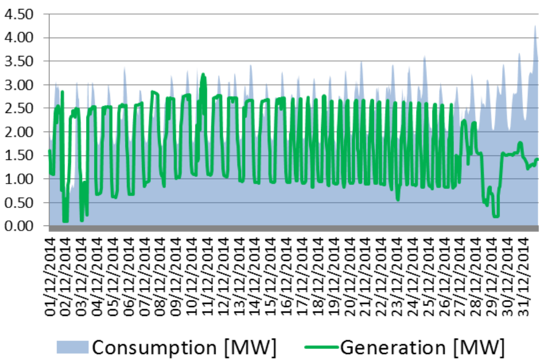
From transient waveforms recorded during this event resulted the plots presented in figure 3.

The consequences of this event were serious. More than 100 complaints were filled by affected customers. Some equipment was also damaged including several electronic revenue meters. During event investigation several issues were identified:

- missing correlation between Distribution Automation System and protection settings;
- Earth-fault protection settings implemented in reclosers can cause unwanted autoreclosing cycles in case of intermittent earth-faults;
- Some inadvertence found in network analyzers related to frequency recordings; for instance, abnormal values were recorded during voltage interruptions.
- Lack of information included in SCADA and DMS systems for old installation.
- Need for reliable and fast ICT infrastructure.



a) Load and generation profile during summer



b) Load and generation profile during winter

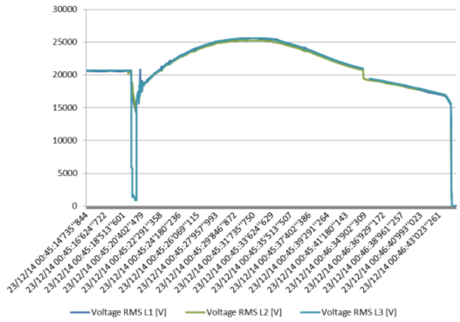
Figure 4 Comparison between load- and generation profiles; a) summer; b) winter

We also looked at the operation conditions over longer periods. As seen in figure 4, during summer months, the generated power exceeds the load and thus the potential damage in case of islanding is higher. During winter, consumption increases and most of the time is higher than the available generated power and therefore, even in case of an islanding event, the danger of overspinning is reduced.

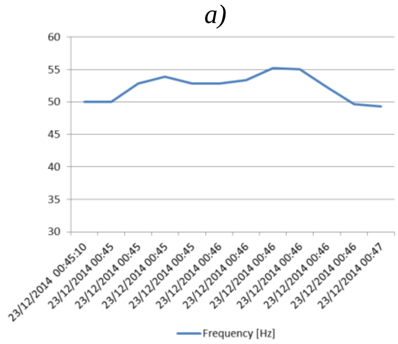
All considerations presented above highlighted the need of a much more detailed investigation of the causes and circumstances that can lead to this kind of events.

CAN PMU's SOLVE THE PROBLEM?

During December 2014, a new measurement campaign was initiated in collaboration with the MicroDERLab team at Politehnica University Bucharest. The measurement infrastructure included [7] this time also two Phasor Measurement Units for recording frequency, rate of change of frequency (*rocof*) and voltages, with a 50 frames per second reporting rate.



a)



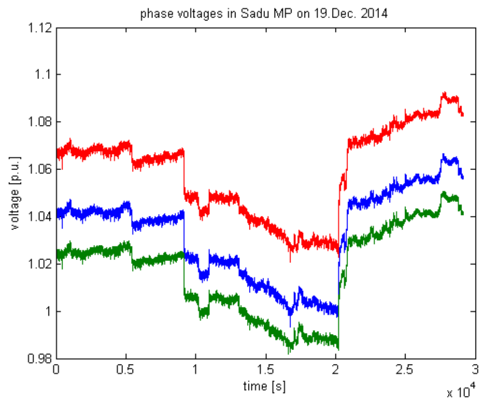
b)

Figure 5 Islanding event 23 Dec 2014; a) Line to line voltages (rms) trend b) frequency;

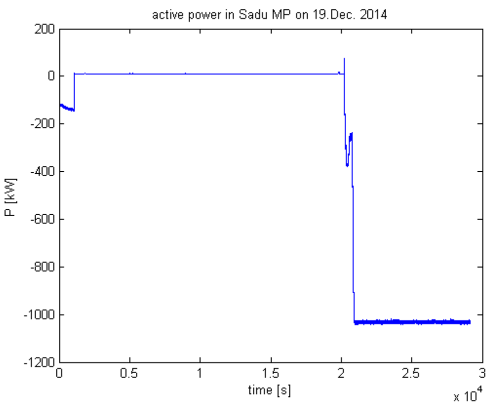
A phasor measurement unit (PMU) is a synchronized measurements device, able to offer both magnitude and phase angle. PMUs are used for voltage and current phasor measurements. PMU standards [8] give detailed information on uncertainties associated with phasor measurements. Because PMUs are not PQ-dedicated equipment (although some include PQ modules [9]), one can use them in order to have access to detailed information on frequency (and rocof). Voltage and current phasors are accurately time-stamped, as PMU is synchronized with a GPS to a common time reference. The maximal uncertainty associated with the local measurement channels is for frequency less than 1 ppm (0.0001%) of reading, plus time base error [10] while for the time stamp is 1 μs plus time base error; time base error is less than 1 μs, when locked to at least one satellite with correct position [10].

Because most of the PQ measurement equipment in use follow the data aggregation paradigm [11-14], the low reporting rate of such equipment is correlated with the information filtering [13] and give only limited insight on phenomena, as it is shown in Figure 5.

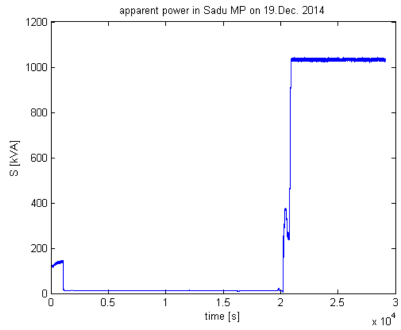
The PMUs have been capable to follow the change of power direction in Sadu MP (on 19th Dec 2014), together with the rate of change of frequency variation [15], as it is shown in Figure 6. One can easily observe that the highest variation is exhibited by the *rocof* signal (Figure 6 f), while the reactive power exchange shows noisy effects due to the transient conditions. One can see that, although the operating conditions changed at moment t_1= $0.1\bullet10^4$ s and t_3=$2\bullet10^4$ s, the "system event" occurred at t_2 =$0{,}4\bullet10^4$ s and t_3, as highlighted by the *f* and *rocof* signals
.



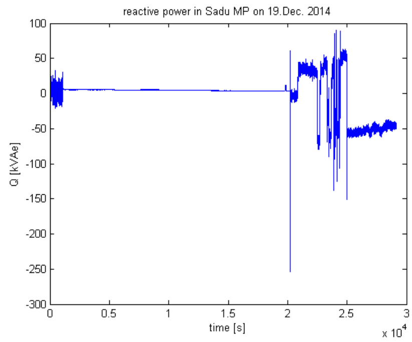
a)



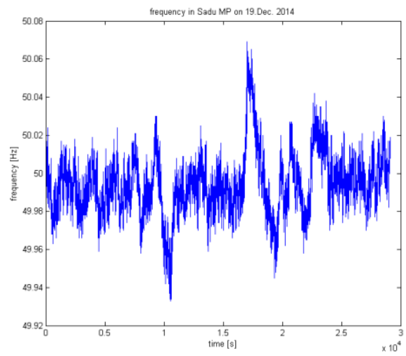
b)



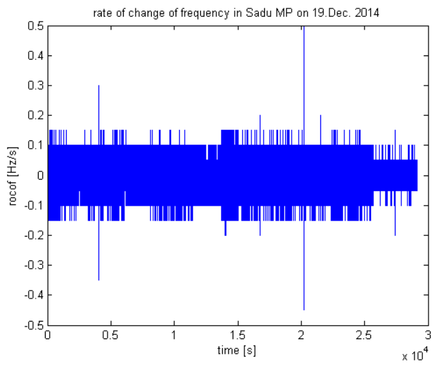
c)



d)



e)



f)

Figure 6 Islanding event 19 Dec 2014; a) Line to line voltage (rms) trend b) frequency ; a) – voltage variation (rms, p.u.); b) active power exchange; c) apparent power exchange; d) reactive power exchange; e) frequency variation; f) rate of change of frequency variation

CONCLUSIONS

In order to assess the operation states of an active distribution network, information with higher than presently available resolution and accuracy is needed. Phasor Measurement Units are capable to give insight to such details. Presently there are in use aggregation algorithms inherited from power quality standards like the IEC 61000-4-30 set, but no algorithm is yet specified for rocof reporting. In this paper, data from measurement campaigns organized in various nodes of a specific distribution network section, with several DG units, has been analyzed. Early results indicate that, instead on focusing only on anti-islanding protection, other PMU signals can be used to control islanded operation under a specified set of conditions.

ACKNOWLEDGEMENT

The authors wish to thank Razvan Roman for pursuing the measurements campaign. The support of Arbiter Systems, Inc. is gratefully acknowledged.

REFERENCES

[1] Viawan, F.A., Karlsson, D., Sannino, A., Daalder, Jaap, "Protection Scheme for Meshed Distribution Systems with High Penetration of Distributed Generation," *Proc. of the Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources*, Clemson, SC, 14-17 March 2006,

[2] ANRE, Romania, "*The Electricity Distribution Grid – Standard of performance"*, 2007;

[3] ANRE, Romania, *"The Electricity Distribution Grid - Technical code"*, 2004

[4] ANRE, Romania*,"Technical conditions for the connection of wind power plants to electricity grids of public interest"* NT no. 31, 2013

[5] ANRE, Romania, *"Procedures for connection during the test period and certification of technical conformity for wind and solar power generation."* ORD no. 74, 2013

[6] Corneliu Paslaru, coord., "File din Istoria Energeticii Romanesti" (*History of the Romanian Power Systems*, in Romanian), Electrica S.A., N'Ergo, 2007

[7] Mihaela Albu, "Dual Data Aggregation for Power Quality Assessment", *Proc. of the I2MTC '14. IEEE Instrumentation and Measurement Technology Conference*, Montevideo, Uruguay, 13-15 May 2014

[8] C37.118.2-2011 - IEEE Standard for Synchrophasor Data Transfer for Power Systems

[9] Arbiter Systems, Inc., Arbiter1133a manual, available at www.arbiter.com/files/product-attachments/1133a_manual.pdf

[10] Arbiter Systems, Inc., Arbiter1133a Data Sheet, available at www.arbiter.com/files/product-attachments/1133a.pdf

[11] IEC 61000-4-30 ed.2, *"Testing and measurement techniques – Power quality measurement methods"* / 2008;

[12] EN 50160, ed.2, *"Voltage characteristics of electricity supplied by public distribution system", 2010*

[13] Mihaela Albu, Ana Maria Dumitrescu, "Applicability of Synchronised Measurements in Modern Distribution Grids. A Discussion*"*, *Proc. of the IEEE Applied Measurements for Power Systems Workshop AMPS2014*, Aachen, 25-27 Sept. 2014

[14] H.Albert, S.Gheorghe, N. Golovanov, L. Elefterescu, R. Porumb, *Power Quality. Contributions, Results, and Perspectives*, AGIR, Bucharest, 2013

[15] M. Albu. A. M. Dumitrescu, R. Popovici, "Rate Of Change Of Frequency. – A Power Quality Descriptor", *Proc. of the IEEE 16th international conference on harmonics and quality of power (ICHPQ 2014)*, Bucharest, Romania, pp312-316