IMPACT OF DISTRIBUTED GENERATION ON DISTRIBUTION NETWORKS

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ABSTRACT

Right now, the DSO need to perform very important tasks in order to be able to manage the different challenges laying ahead.

Electrica S.A. is the largest DSO company in Romania and is focused on constructing a coherent strategy for Smart Grid implementation. In the beginning, this paper presents the steps taken in recent years in this direction and also the key points in the strategic development of different Smart Grid components in order to integrate them in the same efficient system. The legal environment and recent regulations are briefly introduced to picture the constraints imposed on development and operation of existing networks.

Taking into account the current trend for consumption, each DSO must shift its attention to new targets in order to sustain economic development such as:

- *Developing a new business model*
- *Invest in distributed generation and energy storage*
- *Making profit less dependent from energy sales.*

After that, the paper presents a detailed look into the Distributed Generation (DG) influences in the future architecture of distribution Networks. Very important issues like VPP (Virtual Power Plant) and DR (Demand Response) are discussed insisting on particularities of the Romanian grid. One of those issue, very important to us, is how a DG greater than a certain limit in one area influences the energy losses.

In this respect we performed a study concerning a medium voltage network (see figure 1) where new power plants using different renewable resources were connected (one 0,5 MW Photovoltaic PP and one 2.5MW Wind PP).

The analysis begins focusing on the energy losses and on how the DSO has to adapt its operational procedures to cope with this additional stress on the network. The study was performed for three situations:

- 1. 0% penetration of DG (or similar 0kWh production). In this case a methodology for losses calculation in case of passive network is proposed.

- 2. 0-23% penetration of DG. This is the acceptable level for DSO and the methodology for losses calculation is updated.

- 3. Over 23% penetration. In this case a curtailment of production level is needed (0-30%-60%-90% or even 100%) in order to avoid unacceptable losses.

Then we look more into detail to see if all components are realized according to the general development strategy, where the week points are and mostly how to improve the current situation.

INTRODUCTION

Commission Directive 2003/54 / EC defines distributed generation as the generators connected to the distribution network and considers that the power injection takes place in the distribution network nodes, and not at all through the transmission network.

This conducted to the necessity of developing unified methodologies suitable to determine the optimal penetration level of distributed generation in the electricity distribution activity, a real and strictly necessary problem because EU countries are differently (de)favoured in terms of primary energy resources, some of them, like the UK and Germany having abundant coal resources and others, like the countries neighbouring the North Sea being rich in oil.

The process of reaching a decision regarding the determination of the optimal penetration level of distributed generation in distribution network highlights the following aspects : even if in terms of costs a consensus was reached , the terms of benefits resulting from establishing an optimum could not be defined unitary by all interested parts, the benefits being usually attributed to secondary issues such as the reduction of Technical Loses (the real benefit obtained from the penetration of distributed generation, is a balanced load , an optimal powers flow phases, and the possibility to generate the power in the same in the same node is consumed).

A much more serious problem is the costs assignment between the distributed generation power producer and the DSO, especially in the context of the end user, who bears all costs in the end. A transparency of the power market must be ensured especially because, the decisions and the behaviour of the end user can have a beneficial impact on the utility in the common interest of the community.

Therefore is required to identify the effects of distributed generation penetration, to analyses those effects, to calculate costs or intrinsic benefits related to those effects, to perform a cost-benefit analysis and to develop the best plan for allocating costs and benefits among power producers using distributed generation and DSO in order to maximize the benefit of the community. The purpose of this theoretical approach is the development through case studies of a technique that will lead to an optimal penetration level of distributed generation that will improve the operation of the distribution network in the long term.

The analysis of the effects of distributed generation penetration in the distribution network involves the identification of load curves for used power and

distributed generation: this comparison determines the existence of synchronism between the rate of penetration of distributed generation and the power demand dynamic and, if there is no synchronization, it will determine the "sliding " between the two.
This will help identifying the effects of generation distribution penetration, the volume (quantities) of Construction and Assembly works necessary to consolidate the distribution network, quantities and technical characteristics of the equipment that will assure an active management of exploitation of distribution penetrated distributed generation.
The equipment used must ensure an active operational management through proper data acquisition solution design using SCADA-DMS, through implementation of locator for detecting, identifying, locating, isolating and clearing faults and the possibility of calculating real-time load flow.
This allows control of distributed generation penetration in the distribution network in harmonious manner and allows a "modulated" rate of Construction and Assembly works needed to strengthen the networks.

TECHNICAL ASPECTS OF DISTRIBUTED GENERATION PENETRATION ON THE NETWORKS

Distributed generation is essential to the new concept of the distribution network: the source is in the immediate or distant vicinity of the user (consumer / prosumer), so, compliance with the limits of voltage admissible limits and the reduction of Technical Loses are no longer unsolvable problems.
The required investment in the distribution network are reduced , the financial risks are significantly reduced, the problems related to lower usage of the facilities and / or problems caused by overloading power distribution network disappear.
The operation is simplified, but problems related to the uncontrolled circulations specific to of looped topology arise, there is an increase in the short circuit powers, and the whole problem related to primary switching equipment and the design of protections that are "condemned" to operate in complex the conditions of looped topology gets more complicated.
With the so-called penetration level of distributed generation in the distribution network increases the risks related to the continuity in power supply of the users and therefore there is an increased uncertainty in the power quality.
The inevitable cycling variation of the power injected in the distribution network leads to both higher risks for the continuity in power supply , maximizing short-circuit power, and increases the uncertainty in the power quality amplifying the phenomenon of sinusoids deformation.
Therefore it is necessary to quantify these phenomena, hence the importance of some indicators such as the local indicators the so-called "site indices" referring to individual users / consumers and / or global indicators , the so-called " system indices " referring to the assembly of all users of a distribution network : those indicators must rigorously define the power quality in a distribution network based on the penetration level of distributed generation.

Power Quality indicators

These indicators are intended to determine the impact the penetration of distributed generation has on power quality, so in principle they are power quality indicators. The Evolution of power quality indicators according to the penetration level of distributed generation can be quantified using formula (1) [1] This reflects the improvement or deterioration of any power quality indicator values in the presence of distributed generation in one hand and the value of power quality indicator in the absence of distributed generation in the other:

$$X = \frac{X_* - X_0}{X_0} 100[\%] \qquad (1)$$

where:
X — the variation percentage of PQ parameter,
X_* — the value of any of the PQ parameters in the presence of a certain amount of distributed generation and a certain load at a given total distributed power
and
X_0 — the value of the same PQ parameter in the absence of distributed generation and the same total distributed power.

Maximisation of the penetration level of distributed generation by minimisation of Technical Loses

The pronounced reduction of the Technical Loses by increasing penetration of distributed generation in distribution network is one of the DSO main concerns: the implementation of distributed generation caused major difficulties for the DSO's and a critical-analytical attitude acknowledges that there are natural limits to penetration of distributed generation and so, the maximisation of penetration of distributed generation needs to be limited [10],among others by the existence of a minimum Technical Loses.
It is therefore necessary to maximize the penetration of distributed generation minimizing the Technical Loses, assessing the possibility of reaching an optimal penetration level of distributed generation.
The objective cause of this approach are the radically changed load flows in the distribution networks penetrated by distributed generation, and for this reason, the third tool used to achieve transparency in the exploitation of distribution network (in addition to data acquisition using SCADA systems that control the uncertainties regarding the continuity of power supply for the users and the power quality and the fault indicators

that control the risks regarding the integrity of the volume of electrical facilities), is the possibility of viewing the power flow in real-time using DMS functions.
The Technical Loses redistribution due to changes in the load flows related to the distributed generation penetration can be used as a control technique in the operation of the distribution network in order to eliminate the inherent difficulties caused by distributed generation penetration.
The penetration level of distributed generation and the dispensation of generators in the network nodes, are given the Technical Loses variation depending on the topology of distribution network.
This is one of the major concerns in the work concept definitions, in developing and in defining the constraints used to optimise the objective function and checking the function using a case study.

PROPOSED CASE STUDY:

20KV OVERHEAD LINE FRUMUŞITA –SPP9

To analyse the impact of distributed generation on the operation of the distribution networks a rural 20kV axis was selected , with the normal operation diagram presented in Figure 1. Supplied from a 110 / 20kV transformer station and providing power to 13 PTA 20 / 0.4 kV, as passive nodes and connecting to the network three distributed generation sources: a Photovoltaic PP of 500kW, an asynchronous generator of 1MW Wind PP 1 and a synchronous generator of 1,5MW Wind PP 2.
In order to monitor in real-time the active and reactive power, and the voltage in the nodes of the of 20kV OHL rural axis Frumusita- SPP9 smart meters are installed on the low voltage winding of the 13 PTAs, as well as in the common connection points of the two distributed generation plants (PCC: PhPP and WPP 1 + WPP2) and in the 20kV cubicle located in the transformation station.
The smart meters can be read through GPRS communication in real time (at every 15min or hourly) using the smart metering system (AMM) Converge, from the DSO's headquarters.
Besides these intelligent equipment in the active node PCC-PVPP a power quality monitoring device, type MAVO10Sys is installed and communicates via GPRS with the Distribution Management System platform for measurements and of power quality control (PQM).
The distributed generation plants are integrated in a rural axis automation system (Distribution Automation platform), which through the two reclosers installed in the two PCC are providing the operating service in the Distributed Generation Operating System, system which also uses information provided by the power producers SCADA-EMS system.

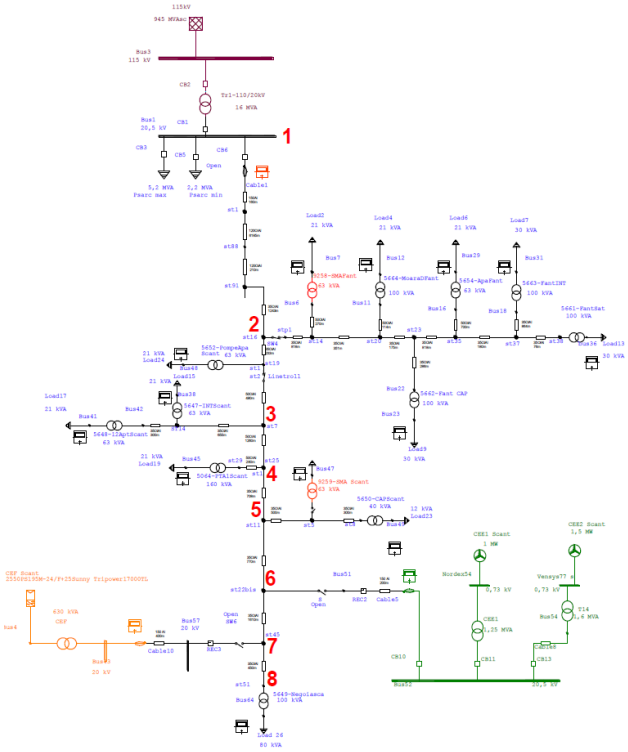

Figure 1 Single line diagram of 20kV network used for tests and measurements

Calculation of power losses

20kV Frumusita - SPP9 network was been modelled (see diagram in Figure 3.1) using ETAP software v.7 / v.11. Using the Load Flow Analysis module there have been modelled the active and reactive power flow through the 20kV network nodes, related to a maximal value of the load of 338kW and a value of active power losses in the network about 4,5kW (we considered the losses in iron of the power transformers are about 2kW), so the percentage power loss is about 1.36%.
Note that for the power flow calculations, maximum active power in the passive nodes of the network were the readings of the winter peak load.
As seen in figure2 the sum of injected power is over 9 times greater than maximum consumption peak which is around 330kW.

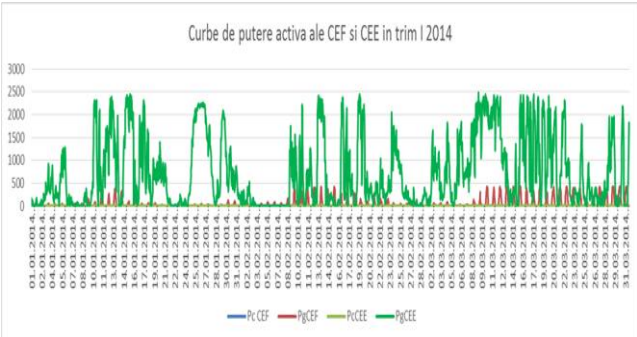

Figure 2. Generation profile

If the penetration degree of distributed generation is zero the active power loss from medium voltage networks is shown in Figure 3 , determined using smart meters from the Converge AMM System that also monitors the voltage in the network nodes.

The hourly percentage power losses range between 3.99% -6.06%, for the maximum values of hourly active power ranging between 201 kW and 390kW.

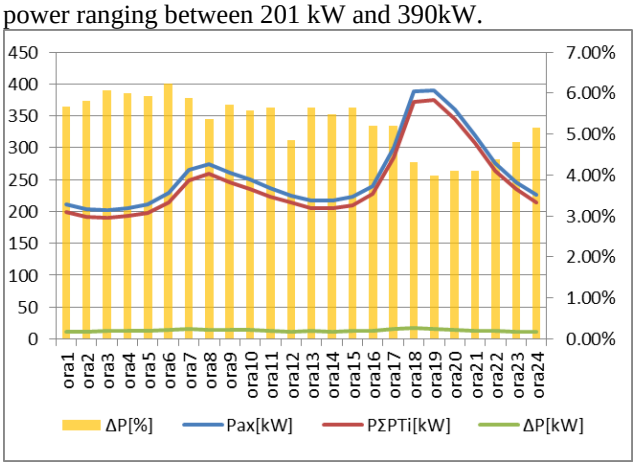

Figure 3. Calculated power loses

Using the Load Flow Analysis module have been determined the losses of active power in the 20kV rural axis using the following operating diagrams: without DG, with the PhPP, with the WPP1 , with WPP1 +WPP2. Results are presented in Table 1.

Table 1 – Power losses related to the penetration level of distributed generation sources

Grad penetrare optim	P_{CEF}[kW]	ΔPCEFW	ΔP_{CEE}[kW]	P_{CEE1}[kW]	Grad penetrare optim	$P_{CEF+CEE1}$[kW]	ΔP
	0	4,50	4,50	0		0	4,50
31,36%	106	4,00	3,90	101		103	3,90
57,40%	194	4,20	3,70	194	61,24%	207	3,80
	281	5,00	4,10	296		287	4,00
	369	6,40	4,60	400		397	4,90
	456	8,30	6,10	492		498	6,30
			7,90	596			
			10,10	694			
			12,80	802			
			15,70	896			
			19,20	995			

Note that the minimum value of active power losses in an network with a maximum used power of 338kW depends on the penetration level of distributed generation, on the type of distributed generation and on their way of aggregation.

Figure 4 shows how the evolution of distributed generation penetration level influences the evolution of active power losses in the network (it may increase about 9 times in case of distributed generation operating at full capacity of approx 2,8MW, compared to the situation in which only the power consumption of 0,34kW is considerated)

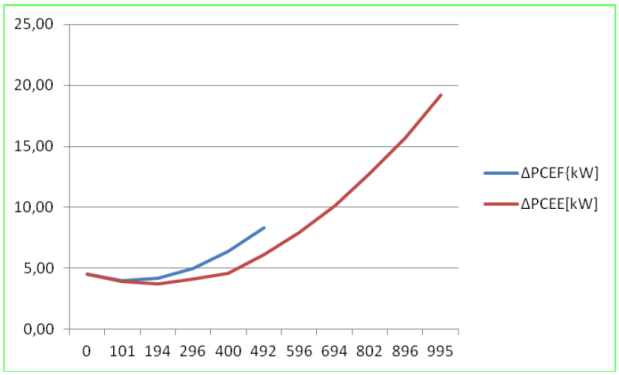

Figure 4- Evolution of the active power losses [kW] depending on the penetration level of distributed generation.DG[kW]

In figure 5 the evolution of voltage in different network nodes is presented for different scenarios. Minimal voltages occur when there is no DG production. Voltages increase with different combination of DG power injected in to the network.

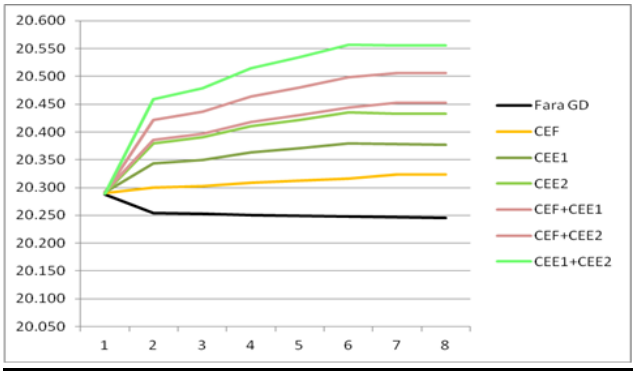

Figure 5 – Node voltages for different DG amount

Considering that the for the network mentioned in the study the PQM are integrated trough DA(reclosers) in the DSO SCADA-DMS system ,using the SCADA-EMS systems of the two producers and the smart metering platform MMA Converge, further study opportunities that will assess the impact of distributed generation on that network will lead to important conclusions for a more efficient operation of the managed network at adecvate performance standards.

Installing three PMU (one in 20kV cubicle from the transformation station that conects to the respective network, one in photovoltaic power plant and one in the wind power plant) will help to continue the research and to evaluate the quality parameters according to different degrees of penetration of distributed generation.

CONCLUSIONS

The Impact of distributed generation on the network operator`s activity requires that the distribution management system with its components (the DMS-SCADA System integrated in the GIS System, the Automation System for Transformation Stations-

SCADA, Feeders Automation -DA / axes - Reclosers + STC , the Distributed System of Power Quality Control - PQM, the flexible alternative current transport systems – FACTS) to be interoperable with the distributed generation operating system-DER (EMS SCADA Systems of the distributed generation sources with VPP) and the Smart Metering System (AMI Advanced metering infrastructure and the " back office" systems of metering - MDM, SAP I-SU). If these components are integrated the premises of transition to the concept of smart electrical grids is achieved.

At the same time direct generation penetration level influences DSO business model (BAU) on two operation components monitored by the regulator (the evolution of power losses in the networks and the variation of the quality parameters of the power distributed to the network users).

Optimizing the technical loses and voltages in network nodes can lead to proper determination of optimal DG penetration level. Results in table 1 show that, in case of studied network, the optimal penetration level is somewhere between 23%-50%. This corresponds to maximum transport capacity of the portion with the smallest section contained in the distribution network.

In other countries RTU's are used to reduce the delivered power to 90%, 60% or 30% of nominal capacity in order to balance local consumption. In some cases the production is stopped completely in case of "curtailment system".

In terms of planning the operation of distribution networks, mutations also occur in terms of distributed generation: the **penetration level** of distributed generation should not be maximized because, at some point, the Technical Loses no longer decrease, but increase sharply, the costs-benefits ratio has the optimum value before having reached the minimum Technical Loses, leading to cost-benefit ratio alteration in the case of Technical Loses continuing decrease to its minimum.

It is necessary therefore to optimize the penetration of distributed generation in distribution network nodes, not to maximize it.

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