Assessing the impact of micro generation in radial low voltage distribution networks taking into consideration the uncertainty

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Abstract: The increasing penetration of micro generation units in low voltage distribution networks and the need for evaluating the potential benefits and also the potential negative impacts of such penetration ask for detailed assessment tools and methodologies. The impacts of a single small-scale unit (<5,75kW) is, probably, negligible. However, the aggregate contribution of many small capacity units can be significant and an adequate assessment of the impacts is needed in order to prevent some undesirable effects and in order to accurately compute the benefits of such units. This paper presents a methodological approach that allows an adequate assessment of micro generation impacts on radial distribution networks based on Monte Carlo simulations to reproduce both demand and generation behavior, and using scenarios to deal with the uncertainty about micro generators placement. Besides, the use of both generation and demand diagrams of high resolution allows to adequately assess the voltage values variability in different buses.

Keywords: *Micro-generation, LV radial distribution networks, Losses and voltage profile assessment*

1. Introduction

In traditional power systems, without distributed generation or micro-generation units, power flows from substation to the end-user loads and power systems are designed for such behavior. The utilization of micro-generation units might, however, impact the flow of power and voltage levels and eventually cause reverse power flows. Thus, some problems may arise and should be taken into consideration when promoting this type of generation. For a given load and generation levels the impacts of micro generation on distribution networks depend, among others, on both the location and size of micro generation systems. Several methodologies dealing with different issues raised by the dissemination of micro-generation have been proposed in the literature [1]-[9]. However, load demand and the output of micro generation units vary widely over the time and typically micro generation systems location is not known in advance. The uncertainty associated with both generation systems location and load/generation levels makes hard an accurate assessment of the impacts of those generation systems on the radial distribution networks. Namely, the impacts on the voltage profile and power losses, but also eventual changes in power flows direction should be carefully accounted for. On the other hand, an adequate assessment of the impacts on voltage profiles asks for both an adequate time resolution in the representation of demand and generation and the usage of real load and generation diagrams not averaged ones. Averaged load diagrams and inadequate time resolution of load diagrams do not allow capturing the real impact on buses voltage profile. Even 15 minutes time resolution may provide only indicative values for changes in voltage profiles provoked by micro generation systems.

The main contribution of this work is the capability of making a daily basis analysis with a proper time resolution allowing for an adequate assessment of voltage impacts and the ability to deal with uncertainties that exist at both available generation and at the demand level.

The structure of the paper is as follows. In section 2 the methodological approaches to compute power flow and the demand and generation models are presented. Also, the different scenarios used to deal with the possible different locations of micro-generation units are presented. Follows, in section 3, the case study while, in section 4, the results are shown. Finally, in section 5, some conclusions are drawn.

2. Methodology

In order to properly assess the impacts of micro-generations units on voltage profile and on the losses in a radial low voltage (LV) network, suitable demand and generation models and adequate power flow algorithms are necessary. Demand and generation models should be able to tackle the uncertainty that exist in both generation and in the demand, and the power flow algorithms need to take into consideration the intrinsic characteristics of distributions circuits which typically are unsymmetrical and unbalanced. Some proposals for dealing with some of these issues can be encountered in the literature [10][11]. However, a detailed analysis at the LV network level taking into consideration demand and generations variability is not available. The methodological approach followed in this work allows such detailed analysis, namely regarding the impacts on voltage levels and on power losses, while taking into consideration the uncertainties associated with both the demand and the generation. In order to deal with the uncertainty of both the demand and generation we use Monte Carlo simulations to generate all possible realistic load/generation diagrams. The Monte Carlo simulations carried out to obtain demand diagrams, different for each customer, were based on information collected from load profiles obtained during monitoring campaigns. Namely, for each time interval, a probability density function characterizing the behavior of the demand was identified and used in the Monte Carlo simulations. For every customer (bus) different load profiles, obtained from field surveys, are considered. In the study carried out, in order to account for different possible amounts (number) and locations (buses) of micro generation units several scenarios have been simulated. The developed software tool allows the use of any time resolution to represent load profiles and generation.

The variability of the demand is, most of times, associated with the utilization of energy services (heating, cooling, tv, computers, lighting, etc) according to the needs of the end-user. Consequently, energy consumption varies throughout the day and is different for different days (Figure 1). Adequate models for reproducing the demand taking into account such variability must produce realistic load curves and not averaged load curves and should have a proper time resolution that allowing capturing the impacts on the voltage levels. Therefore, average demand curves with a time resolution too high, for instance hourly demand models (Figure 2), are not adequate for such evaluation. In order to run Monte Carlo simulations, for every time interval adequate probability distributions have been identified based on data collected, thus allowing the generation of realistic load diagrams for different days of the week and different periods of the year. The uncertainty associated with the photovoltaic and wind generation is modeled also by using Monte Carlo simulations with normal distribution probability. Several scenarios regarding the number of micro-generation units and location have been analyzed. “A” is the scenario with no micro-generation units (MGU); in scenario B there are only 5 MGU, for evaluating the impacts of a low level MG penetration; in scenarios C – G there 10 MGU, located in different buses. In scenario C MGU distributed throughout the network; in scenario D (E) MGU are preferably located in buses far (near) from the distribution transformer (DT), allowing to evaluate the impacts as a function of the distance from DT; and in scenario F(G) MG units are mainly in the phase with higher (lower) demand, allowing to assess the impacts as a function of the demand level. These scenarios are summarized in Table 2. The implemented algorithm for computing power flows is the forward/backward sweep method based on successive sweeps until the convergence is achieved [12]-[15].

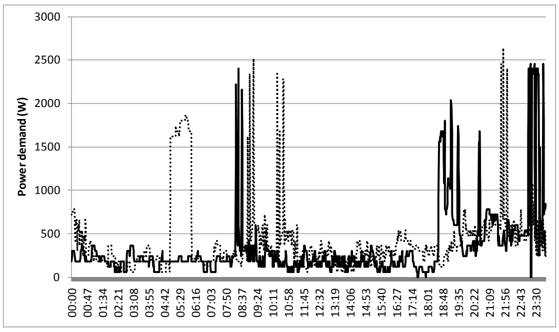

Figure 1- Energy consumption patterns in two consecutive days for the same residential consumer.

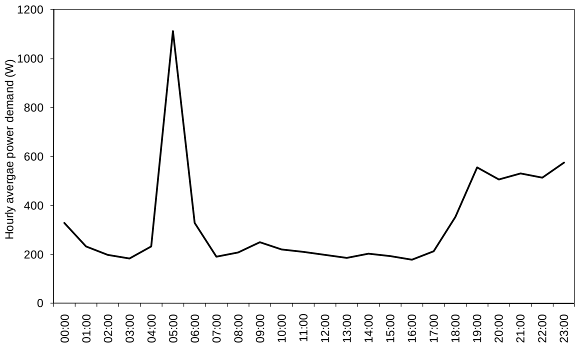

Figure 2- Hourly averaged load diagram for the residential consumer of Figure 1.

3. Case study

A real urban low voltage radial distribution network data has been used in this case study. The network has 38 buses, 28 feeding residential consumers and 8 distribution buses (points of connection). There are no losses at the distribution buses and the neutral is grounded in every bus. The distribution transformer is a 30kV / 400V-230V 160 kVA transformer. Figure 3 shows the layout of the network. Besides residential consumers we have also street light.

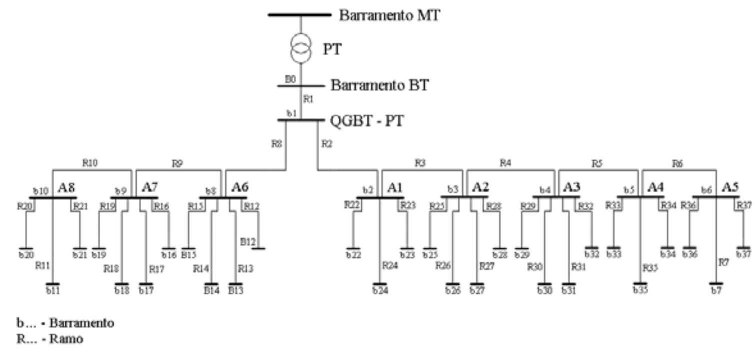

Figure 3- LV distribution network being analyzed.

Most residential customers are single-phase consumers. In Table 1 the contracted power and the phase for every consumer are shown. Phase "A,B,C" means a three-phase consumer. According to the Portuguese legislation (decree-law 363/2007) the aggregated power of all micro-generation units installed in a LV distribution network cannot exceed 25% of the distribution transformer capacity and in order to access special-regime (premium) of the PV feed-in-tariff scheme the individual capacity of the micro-generation units is limited to 3.68 kW, meaning that in this LV network can be installed at most 10 units. In this work all MG units have 3,68 kW capacity and are consumer owned.

Table 1- Placement of microgeneration units.

Bus	Phase	Contracted Power	Bus	Phase	Contracted Power
1	A	6,9 kVA	**24**	C	6,9 kVA
7	A	6,9 kVA	**25**	B	6,9 kVA
11	A	6,9 kVA	**26**	A,B,C	10,35 kVA
12	C	6,9 kVA	**27**	C	6,9 kVA
13	A	6,9 kVA	**28**	A	6,9 kVA
14	C	6,9 kVA	**29**	C	13,8 kVA
15	B	10,35 kVA	**30**	A	6,9 kVA
16	A,B,C	10,35 kVA	**31**	B	6,9 kVA
17	B	10,35 kVA	**32**	B	10,35 kVA
18	C	10,35 kVA	**33**	C	10,35 kVA
19	A	6,9 kVA	**34**	B	6,9 kVA
20	C	10,35 kVA	**35**	A	10,35 kVA
21	B	10,35 kVA	**36**	C	10,35 kVA
22	B	6,9 kVA	**37**	B	6,9 kVA
23	A	10,35 kVA			

In order to deal with the uncertainty of demand and of the generation, 300 simulations per interval of time have been done. Total computer time was 1200 seconds. Regarding the location of micro-generation units (MGU) 7 scenarios have been analyzed, as described in Table 2.

Table 2- Different scenarios for the placement of micro-generation units

Scenario	Characteristics
A	Reference scenario, with no micro-generation units.
B	5MGU, to assess the impact of low level MGU penetration.
C	10 MGU spread throughout the circuit.
D	10 MGU mainly connected in remote buses.
E	10 MGU mainly connected in buses near the distribution transformer.
F	10 MGU connected mainly in highly loaded phase (B).
G	10 MGU connected mainly in phase with lower demand (C).

4. Results

4.1. Power Flows

In the following table the average active and reactive power flows at the DT and the amount of energy drawn from the grid to feed the consumers are shown. The difference between each alternative scenario (B-G) and the reference scenario (A) is also presented. One can see the reduction of power drawn from the grid through power transformer as a result of micro generation units

In Figure 4 the power flows at DT for scenarios A-C are shown. Negative values mean that reverse power flows exist, as in scenario C (high photovoltaic penetration). Dealing with photovoltaic units means the main changes regarding the reference scenario occur during the day. As MGU are operating at unity power factor there are no differences regarding the reactive power flows.

Table 3- Power flow at the distribution transformer and energy drawn from the grid.

	Sce. A	Sce. B	Sce. C	Sce. D	Sce. E	Sce. F	Sce. G
Hourly averaged active power (kW)	17,96	13,89	9,81	9,81	9,80	9,82	9,81
Daily active energy (kWh)	430,99	333,28	235,48	235,55	235,20	235,74	235,38
Differences regarding scenario A(%)	0	-22,67	-45,36	-45,35	-45,43	-45,30	-45,39
Hourly averaged reactive power (kVAr)	12,99	13,01	13,02	13,03	13,01	13,04	13,20
Daily reactive energy (kVArh)	311,66	312,16	312,58	312,66	312,27	312,86	312,48
Differences regarding scenario A(%)	0	0,163	0,298	0,321	0,197	0,388	0,264

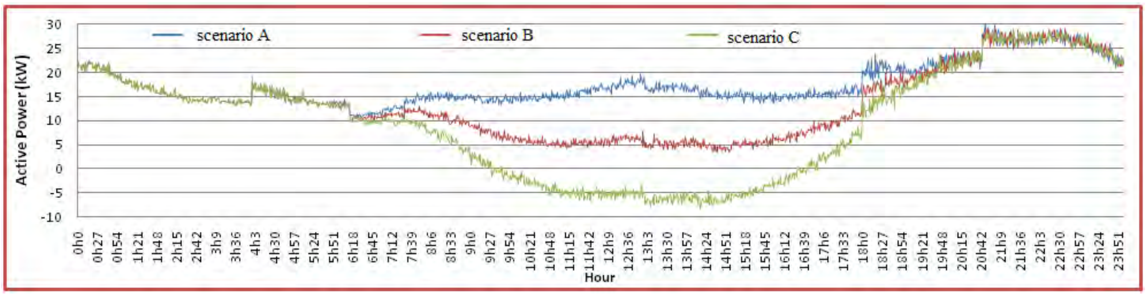

Figure 4- Active power flow at distribution transformer (scenarios A-C).

4.2. Power Losses

In Table 4 the active and reactive power losses are presented as well as the differences regarding the reference situation (scenario A). For low level MGU penetration (scenario B) there is a reduction in losses. However, when MGU penetration increases losses depend on the location of MGU. Typically there is a reduction in losses, not as big as in scenario B, but some situations, like in scenarios D and G, might present higher losses. In scenario G, MGU are connected mainly in the phase with lower demand (phase C) resulting in a strong current flow increase in this phase and thus an increase in losses. In scenario D, MGU are mainly connected at remote buses resulting in longer distances for power flows and thus higher resistance. An interesting situation that may occur when MGU penetration increases is that the power losses maximum value can occur during the higher outputs from MGU and not in the periods of higher demand.

Table 4- Losses for the different scenarios

	A	**B**	**C**	**D**	**E**	**F**	**G**
Active power losses (W)	87,78	79,77	83,65	88,92	85,05	84,60	93,70
Daily active losses (kWh)	2,107	1,914	2,008	2,134	2,041	2,030	2,249
Variation regarding A (%)	0	-9,13	-4,70	1,30	-3,11	-3,62	6,75
Reactive power losses (VAr)	23,81	21,05	21,73	22,90	22,03	22,29	24,93
Daily reactive losses (kVArh)	0,571	0,505	0,522	0,550	0,529	0,535	0,598
Variation regarding A (%)		-11,58	-8,72	-3,84	-7,48	-6,40	4,70

4.3. Voltage

Following figures show the voltage values in the 38 buses of the network at 12:00h, for the different scenarios. In general voltage profile improves when MGU are connected. Typically, higher voltage increase occurs in the buses and in the phases where MGU are connected. There is, however, a decrease in voltage values in phase B in buses 8, 9 and 10. These decrease might be due to the introduction of MGU in buses 11 (phase A) and 18 (phase C) reducing the magnetic coupling between phases A and C and the phase B thus leading to a higher voltage drop in phase B. From Figure 6-scenario D) to Figure 6-scenario G) one can see that the voltage profile in the network is highly dependent on the location of MGU. When the MGU are located in remote buses (scenario D) the impact on voltage level is higher compared with the scenario in which MGU are connected near the DT (scenario E). When MGU are mainly located in a single phase (scenario F – phase B, high demand; scenario G – phase C, low demand) the voltage value in the phase increases strongly but is higher when MGU are located in the low loaded phase (scenario G).

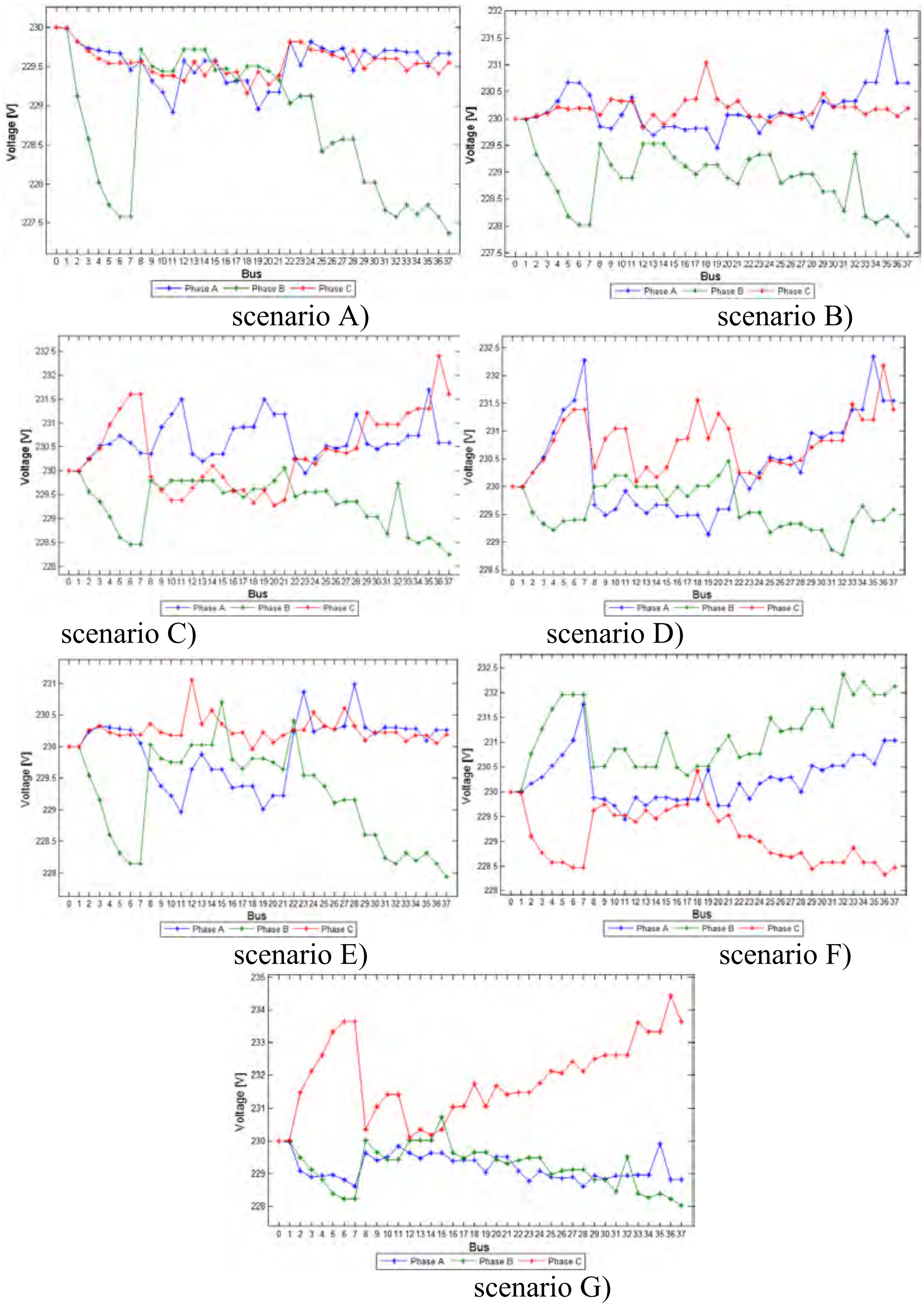

Figure 5- Voltage values at the different buses for all the scenarios

Figure 6 shows the variation in voltage profiles due to the variability of demand or/and micro-generation. For example, according to the collected data, voltage in bus 35 may vary between 229,6V and 234V. In some buses the voltage variation range is much higher (for example, in buses 7, 11, 35) than in other buses (for example, 8, 12, 14, 15). In figure 6 circles show the average voltage values in each bus.

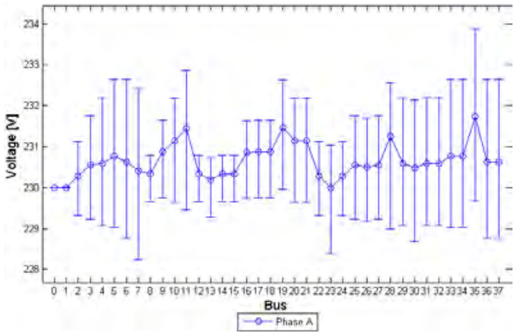

Figure 6- Variation of voltage profile at 12h in phase A due to demand uncertainty and micro-generation variability.

The single-phase nature of both most end-use loads and of micro-generation units at residential level together with the unsymmetrical nature of the LV distribution networks may result in unbalanced voltages. In Figure 7 the unbalance of voltage at bus 36 for the different scenarios is shown. G is the scenario presenting the highest voltage unbalance, resulting from micro-generation occurs mainly in the phase with the lower demand/higher voltage.

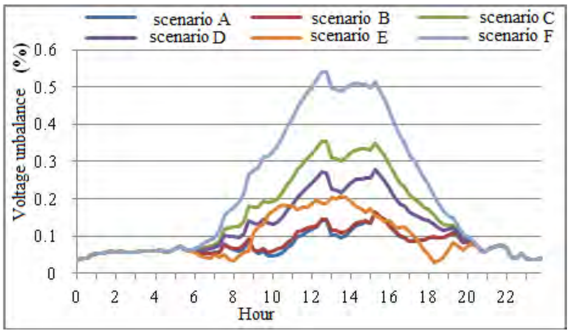

Figure 7- Voltage unbalance at bus 36.

5. Conclusions

The increasing penetration of micro-generation on LV distribution networks will impact the flow of power, with possible reverse flows, and voltage levels on the network. It is clear that besides the detailed assessment of those impacts, the accurate calculation of benefits pointed out to this type of generation, such as losses reduction, needed to be carried out. In this work Monte Carlo models have been used to reproduce the demand and available micro-generation in a LV distribution network, taking into account the uncertainty associated with both the demand and generation, in order to allow a detailed assessment of the impacts of MGU in the power flows, voltage levels and unbalance and in the power losses. By using load diagrams developed from interval metering in each consumer and Monte Carlo simulations it is possible to use realistic demand patterns with adequate time resolution.

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