PORTUGUESE LV EXPECTED INVESTMENT NEEDS UNTIL 2020 ASSOCIATED WITH THE ELECTRICAL VEHICLE AND MICROGENERATION INTEGRATION

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ABSTRACT

The number of electric vehicles (EV) and microgeneration (μG) units connected to LV grids are expected to increase significantly during the present decade. Both EV and μG units have an impact on the operational conditions of LV grids – namely concerning power flows and voltage profile – that, in some cases, will force the DNO (Distribution Network Operator) to reinforce or expand those grids in order to guarantee an adequate quality of service to the end users.

This paper presents a probabilistic methodology that enables the DNO to estimate LV reinforcement necessities up to 2020 due both to EV's and μG units.

INTRODUCTION

EV's and μG units have a different impact on the grid. Although EV's have a behavior similar to the loads already connected with the grid (steady-state), the number of loads that are due to connect with the grid, combined with the peak demand of each EV (on this analysis 3 kW were considered), during slow charging, will have an impact on the voltage profile on LV networks. Plug-In Hybrids (PIH) were also considered on this analysis. It is expected that these vehicles have a peak demand during charging times similar to EV's, even though they absorb less energy (smaller charging time). However, should they charge during peak load hours, they have a similar contribution to peak demand.

As for μG units, considering mainly solar-based units – the vast majority of the units already deployed in Portugal – they may induce reverse power flows towards MV/LV substations during low load hours, possibly originating overvoltages during those periods.
This paper presents different scenarios concerning the number of EV's and μG units expected to connect with the Portuguese LV grids up to 2020. LV grids are characterized using two typical networks, representing rural and urban grids operated by EDP – Distribuição (EDPD), the Portuguese DNO.

For each of the typical networks considered, different scenarios were built internalizing the expected variability concerning the number of EV and μG units that will connect with the networks until 2020, as well as for their location in any network.

The location of the units on each typical network is randomly assorted and the expected investment needs are calculated in order to correct for eventual degradation of quality of service as defined by EN 50 160 [1], as well as for violations of other equipment rating and standard parameters. The investment needs and their corresponding probability of occurrence can be extrapolated to the overall investment requirements for each of these typical networks.

For the assessment of investment needs on each typical network, simulations were performed considering typical load diagrams for end users, EV's and μG units. Most of μG units expected to emerge in Portugal will be photovoltaic, producing energy essentially at noon.

Load diagrams in residential areas have peak loads during late afternoon, when there is negligible solar energy production. It is expected that some EV's will start recharging their batteries at late afternoon, increasing the demand during that period, while others will start recharging during low load hours (depending on the tariff system after 22h00 or 24h00), when tariffs are lower and the impact on the LV network is smaller. On these simulations it was considered that 25% of EV's and PIH contribute to the peak demand (are insensitive to incentives provided by the tariff system).

TYPICAL LV NETWORK SELECTION

Typical LV networks are intended to represent the universe of existing networks. They represent, therefore, the average characteristics expected on similar LV networks (concerning average number of loads connected, average contracted power supply, average LV network length, conductors employed and losses).

For this analysis, two typical networks were used – one connected to a 100kVA MV/LV substation (a rural network) and another connected to a 630kVA MV/LV substation (an urban network). These networks are expected to present different behaviors in the presence of EV's or μG units.

100 kVA MV/LV networks

This typical network (rural) was developed in order to represent 25% of the LV networks operated by EDPD, and to which 15% of the total number of consumers are connected. Typical 100kVA MV/LV substations have two LV feeders connected to, with mostly overhead lines and with a total length of about 2,000 m. This typical network is presented on Fig. 1.

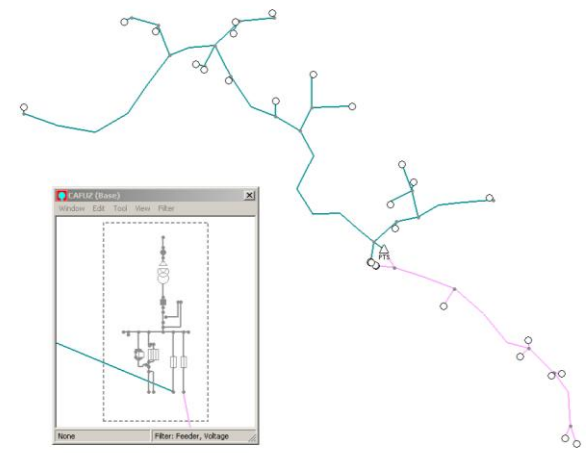

FIGURE 1 – TYPICAL LV GRID CONNECTED TO A 100 KVA MV/LV SUBSTATION

630 kVA MV/LV networks

This typical network (urban) was developed in order to represent 20% of the LV networks operated by EDPD, and to which 33% of the total number of consumers are connected. Typical 630kVA MV/LV substations have six LV feeders connected to, with mostly underground lines and with a total length of about 2,100 m. This typical network is presented on Fig. 2.

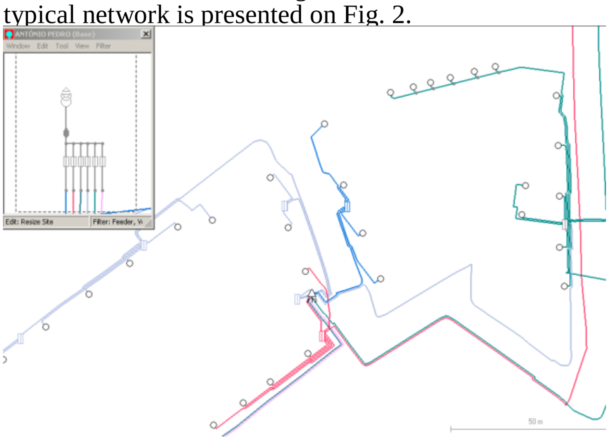

FIGURE 2 – TYPICAL LV GRID CONNECTED TO A 630 KVA MV/LV SUBSTATION

ANALYSIS METHODOLOGY

There are 6.2 million costumers connected with the Portuguese electrical network, and this number is not expected to change significantly in the foreseen future. The number of EV's and PIH's in circulation in Portugal in 2020 is expected to be, respectively, 200,000 and 400,000 vehicles. It is foreseen that 81,500 μG units will be installed in Portugal until 2020 (this number exceeds the objectives stated in [2]).

Based on the expected number of units and given the number of customers connected with each typical LV network, it is possible to estimate the probabilistic distribution of connected units to each network. This distribution is a Poisson distribution.

Peak load demand in LV grids is expected to increase about 20% between 2011 and 2020, regardless of EV's, PIH's or μG units. These typical networks were simulated considering that load increase. The networks were then reinforced where excessive voltage drops or current restrictions are expected to appear due to that load increase, considering EDPD's best practices [3]. The impact associated with the connection of EV's, PIH's and μG was considered after all upgrades associated with normal load growth was considered, thus rendering reinforcement necessities specifically associated with EV's, PIH's or μG units.

EV's and PIH's

It is expected that the total number of EV's and PIH's in circulation in 2020, in Portugal, will be around 600,000 vehicles. The Portuguese tariff system discriminates between peak, full and off-load hours, thus providing an economical incentive for the connection of loads during periods of time for which they don't contribute to the peak load of the system or of distribution grids. It is foreseeable that by 2020 the tariff system will continue to provide such incentives, further developed with the progressive deployment of smartmetering technologies.

However, some EV's and PIH's are expected to contribute to the peak load of the system, regardless of the incentives offered not to do so. On these simulations it was considered that 25% of the EV's and PIH's will contribute to the peak load when recharging (with a peak consumption of 3kW). These 150,000 vehicles were distributed both through the 100kVA and the 630kVA networks, proportionally to the number of costumers connected to each grid. The Poisson distribution for the expected number of unit in each network renders the probabilities given in Table 1 for having a certain number of vehicles on each grid.

TABLE 1 – PROBABILITY DISTRIBUTION OF THE NUMBER OF EV'S AND PIH'S CONTRIBUTING TO THE PEAK LOAD OF TYPICAL NETWORKS

	Probability									
# EV's and PIH's	# 0	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8	# 9
100 kVA	0.287	**0.358**	**0.224**	**0.093**	0.029	-	-	-	-	-
630 kVA	0.013	0.055	**0.121**	**0.176**	**0.192**	**0.168**	**0.123**	**0.077**	0.042	0.020

The different scenarios that were simulated are highlighted in Table 1, covering the most relevant cases concerning the definition of reinforcement necessities.

μG units

It is assumed that 81,500 μG units will connect with Portuguese LV networks until 2020. These units – mostly solar, monophasic and with a 3.68kW rated capacity – produce energy during the day and are not dispachable (i.e., they produce whenever there is solar light).

Although in some circumstances they might reduce power flows on LV grids, in order to assess the investment necessities associated with the interconnection of μG units it is necessary to simulate the worst-case scenario – when μG units are producing at peak capacity and load consumption is at the minimum level, with possible appearance of overvoltages on the LV network. This scenario –

combination between maximum production and minimum load – is expected to occur frequently.

These μG units were distributed through the 100kVA network, proportionally to the number of costumers connected with the grid. The Poisson distribution for the expected number of μG units in each network renders the probabilities given in Table 2 for having a certain number of units on the 100kVA grid.

TABLE 2 – PROBABILITY DISTRIBUTION OF THE NUMBER OF μG UNITS ON THE 100 KVA TYPICAL NETWORK

	Probability				
# μG's	# 0	# 1	# 2	# 3	# 4
100 kVA	0.509	**0.344**	**0.116**	**0.093**	0.026

The different scenarios that were simulated are highlighted in Table 2, covering the most relevant ones concerning the definition of reinforcement necessities.

SIMULATION RESULTS

All LV simulations were performed using DPlan, the network simulation software used by EDPD. As the impact associated with the connection of both EV's and PIH's is very different from the impact associated with the connection of μG units, these simulations were performed separately.

EV's and PIH's impact on LV networks

The impact associated with the connection of EV's and PIH's was assessed both on the 100 kVA and the 630 kVA typical network. It was considered that 25 % of all plug-in vehicles contribute with 3 kW (monophasic) to the peak load of the system, while the other vehicles have no significant impact on the peak load and, therefore, on the voltage profile of the network. Harmonic distortion impact was not considered on this analysis.

Simulations were performed in order to assess which branches would have to be reinforced should a given number of vehicles connect downstream those branches. Evaluating the extension of the branches where undervoltages would appear as a result of those loads, given total network length and the probability of any number of vehicles connecting to any specific location on the network, it is possible to assess expected reinforcements needs for any scenario. Total expected reinforcement needs correspond to the sum of all the relevant scenarios, weighted by the probability of occurrence of each scenario.

100 kVA typical network

Simulations were performed considering the impact associated with the connection, during peak load hours, of one, two or more than two vehicles (i.e., three or four). These vehicles were randomly placed on the network, assessing the probability of causing undervoltages severe enough to require reinforcements. Thus it was possible to assess the probability of a given number of vehicles contributing to the peak load originate the necessity of investing in network reinforcements.

The 100 kVA typical network is 2,102 m long. Results for the line length to be reinforced for any given number of vehicles connected with the grid are presented in Table 3.

TABLE 3 – REINFORCEMENT NECESSITIES ASSOCIATED WITH PLUG-IN VEHICLES (100 KVA TYPICAL NETWORK)

# EV's and PIH's	Line lenght to reinforce (m)	Racio reinforcement/ total line lenght	Probability of the # vehicles (Poisson)	Reinforcement Probability	Expeteded reinforcement lenght (m)
1	565	0.269	0.358	0.0962	54.4
2	791	0.376	0.224	0.0843	66.7
>2	309	0.147	0.132	0.0194	6.0
TOTAL					**127.0**

Results presented in Table 3 show that the appearance of plug-in vehicles is due to originate the need to reinforce 127 m of line length on the 100 kVA typical network (6 % of total line length for this typical network).

630 kVA typical network

Simulations were performed considering the impact associated with the connection, during peak load hours, of any given number of vehicles. These vehicles were randomly placed on the network, assessing the probability of causing undervoltages severe enough to require reinforcements. Thus it was possible to assess the probability of a given number of vehicles contributing to the peak load originate the necessity of investing in network reinforcements.

The 630 kVA typical network is 2,125 m long. Results for the line length to be reinforced for any given number of vehicles connected with the grid are presented in Table 4.

TABLE 4 – REINFORCEMENT NECESSITIES ASSOCIATED WITH PLUG-IN VEHICLES (630 KVA TYPICAL NETWORK)

# EV's and PIH's	Line lenght to reinforce (m)	Racio reinforcement/ total line lenght	Probability of the # vehicles (Poisson)	Reinforcement Probability	Expeteded reinforcement lenght (m)
1	0	0.000	0.055	0.0000	0.0
2	77	0.036	0.121	0.0044	0.3
3	224	0.105	0.176	0.0186	4.2
4	101	0.047	0.192	0.0091	0.9
5	181	0.085	0.168	0.0143	2.6
>5	54	0.025	0.262	0.0067	0.4
TOTAL					**8.3**

Results presented in Table 4 show that the appearance of plug-in vehicles is due to originate the need to reinforce 8 m of line length on the 630 kVA typical network (less than 0.5 % of total line length for this typical network).

μG's unit impact on LV networks

The impact associated with the connection of μG units was assessed on the 100 kVA typical network. It was considered that these units could originate reinforcement needs should they cause an overvoltage on the network. The μG units were simulated producing at full capacity (3.68 kW monophasic) during low load hours. Harmonic distortion impact was not considered here.

Simulations were performed to determine which branches would have to be reinforced should one, two or more μG units connect. Knowing the extension of the branches where overvoltages would appear for any given number of units, total network length and the probability of any given number of units connecting to any grid, it is possible to assess the expected reinforcement needs for any scenario. Total expected reinforcement needs correspond to the sum of all the relevant scenarios, weighted by the probability of occurrence of each scenario.

100 kVA typical network

Simulations were performed considering the impact associated with the connection, during off-peak load hours, of one, two or three μG units. These were randomly placed on the network, assessing the probability of causing overvoltages that require reinforcements. Thus it was possible to assess the probability of a given number of μG units originating overvoltages that originate the necessity of investing in network reinforcements.

The 100 kVA typical network is 2,102 m long. Results for the line length to be reinforced for any number of μG units connected with the grid are presented in Table 5.

TABLE 5 – REINFORCEMENT NECESSITIES ASSOCIATED WITH μG UNITS (100 KVA TYPICAL NETWORK)

# μG	Line lenght to reinforce (m)	Racio reinforcement/ total line lenght	Probability of the # μG (Poisson)	Reinforcement Probability	Expeteded reinforcement lenght (m)
1	290	0.138	0.344	0.0475	13.8
2	0	0.000	0.116	0.0000	0.0
3	0	0.000	0.093	0.0000	0.0
TOTAL					**13.8**

The results presented in Table 5 show that the appearance of μG units is due to originate the need to reinforce 14 m of line length on the 100 kVA typical network (less than 1 % of total line length for this typical network).

CONCLUSIONS

This paper presents a methodology that allows assessing probabilistic investment needs associated with the appearance of EV's, PIH's and μG units. These technologies are still in the early stages of adoption and the number of units that will connect with the LV network for any given period is uncertain and related with the expected technological development.

However, these technologies are due to present an impact concerning the LV networks operational conditions and, therefore, DNO's must estimate that impact that can influence investment planning on distribution networks, particularly LV.

Even though, on average, a small number of EV's, PIH's and μG units are expected to connect with each LV network, the probability of surpassing the average is quite significant. Therefore, despite investments need being negligible for the average network, the average investment may become significant. This is because reinforcements on networks that happen to have a high number of units can be higher enough to compensate for the low probability of having such number of units.

EV's and PIH's are expected to originate the need to reinforce, on average, 127 m on existing LV networks connected with 100 kVA MV/LV substations (rural), and 8 m on existing LV networks connected with 630 kVA MV/LV substations (urban).

This paper presents the expected reinforcement needs associated with the connection of μG units with LV networks connected with 100 kVA MV/LV substations. Reinforcement needs (14 m) are smaller than the ones associated with EV's and PIH's.

The methodology presented on this paper might be further refined in order to assess the combined probabilistic necessities associated with all the aforementioned technologies (which is expected than the sum of individual technologies, i.e., for the 100 kVA network it would be less than 127 m estimated for EV's and PIH's with 14 m estimated for μG units).

Furthermore, this methodology can be enhanced in order to assess other LV typical networks representative of the remaining LV grids operated by EDPD, thus given the overall picture associated with the impact associated with the connection of EV's, PIH's and μG units until 2020.

REFERENCES

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[3] EDP – Distribuição Energia, S.A., 2010, *Guia Técnico de Planeamento de Redes de Distribuição*, Internal Document.