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Identifying Management Procedures to Deal with Connection of Electric Vehicles in the Grid

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Abstract—**This paper describes a research developed to identify management procedures to deal with the charging of Electric Vehicles (EVs) batteries in scenarios characterized by a large scale deployment of this new kind of load. Three approaches were studied: dumb charging, dual tariff policy and smart charging. To assess the efficacy of such procedures, the grid integration of EVs was pushed to its limit for each of the adopted charging management approaches. A Medium Voltage (MV) grid, representative of a residential area distribution grid in Portugal, was used as testing environment. Several shares of EVs technologies were considered for different integration scenarios. Voltage profiles and branch congestion levels were evaluated, for the peak load hour, for grid technical limits checking. Losses were also evaluated for a typical daily load profile.**

Index Terms—**Congestion Management; Distribution Networks; Electric Vehicles; Management Procedures; Smart Charging; Voltage Control.**

I. Introduction

DISTRIBUTION grids have been structured and optimized in order to be capable to feed local consumptions with increased reliability and efficiency, taking into account the types of loads they have to feed.

The foreseen shift in the mobility paradigm, where traditional combustion engine vehicles will be replaced by Electric Vehicles (EVs), will add a new concern to the grid planning and expansion problem [1]-[6]. The uncertainty related to when and where EVs will charge will thus become a critical issue that needs to be considered to guarantee an efficient and robust operation of the electricity networks.

In this paper, a typical Medium Voltage (MV) electricity distribution network, installed in residential areas in Portugal, is used in order to assess the impact of integrating different levels of EVs in the grid. This study pretends to determine how voltage profiles, losses and power lines' congestion levels behave when the grid is subjected to different integration levels of EVs and when different charging methods are applied.

These impact assessment studies will allow the identification of solutions to be adopted in the future, in order to accept massive integration of EVs in electricity grids, trying at the same time to minimize the need for reinforcements or changes in the existing electrical network infrastructures.

II. Management Procedures

As it was previously referred, this paper addresses the impact of the EVs charging on the distribution network steady state operating conditions. Three management procedures were identified for the purpose of the presented research: dumb charging, dual tariff policy and smart charging.

In the dumb charging approach it is assumed that EVs' owners are completely free to connect and charge their vehicles whenever they want. The charging starts automatically when EVs plug-in and lasts for the next 4 hours. This approach should be described as a no control strategy but it is particularly important as it provides a measure for the assessment of the efficacy of the other management procedures.

The dual tariff policy intends to simulate a situation where electricity is cheaper during some specific hours of the day. In Portugal the period of occurrence depends on the contract established between the client and the trader. For this research, the cheaper period was defined combining all the available policies, resulting in a low price period from 11 p.m. to 8 a.m.. It was supposed that the economic incentive provided by this policy was enough to make 25 % of EVs' owners to change their charging to the cheaper period.

The smart charging strategy envisions an active management system, where there is a hierarchical control structure. It continuously monitors all the elements connected to the grid and its state exploiting the concepts used for the management of Microgrids and Multi-Microgrids [7], [8]. This type of management provides the most efficient usage of the resources available at each moment, enabling congestion prevention and voltage control. In order to make of this a winning concept, it is crucial to guarantee the commitment of EVs' owners to it. Thus it was assumed that the economic incentive provided to EVs' owners was sufficient to make 50% of them to let the hierarchical control structure manage their batteries charging. Hence the system has flexibility to charge EVs during the period they are connected, instead of the charging take place automatically when they plug-in. An optimization approach was adopted to define the rational behind this charging strategy, where maximizing the

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integration level of EVs is the main goal. This problem is described by (1).

$$\text{Max } EV\ integration$$

$$\text{subject to} \quad V_i^{\min} \le V_i \le V_i^{\max}, i \in [1, l] \qquad (1)$$
$$S_j \le S_j^{\max}, j \in [1, m]$$
$$E_{k,\Delta t}^{EV} = E_{k,\Delta t}^{EV\ required}, k \in [1, n]$$

Where:

l is the number of buses;

m is the number of branches;

n is the number of EVs;

V_i is the voltage at bus *i*;

$V_i^{\min} / V_i^{\max}$ are the minimum/maximum allowable voltages at bus *i*;

S_j is the apparent power flowing at branch *j*;

$S_j^{\max}$ is the maximum allowable apparent power flow at branch *j*;

$E_{k,\Delta t}^{EV}$ is the battery energy level of the EV *k* at the end of the connection period *Δt*;

$E_{k,\Delta t}^{EV\ required}$ is the required battery energy level for EV *k* at the end of the connection period *Δt*.

This optimization procedure was performed iteratively by increasing EVs integration in a stepwise manner until it provokes the saturation of the grid. The result obtained, which was the optimal charging diagram, under the considered constraints, for the smart charging EVs saturation scenario (scenario 4), was afterwards applied to the scenarios with lower EVs deployment levels (scenarios 1, 2 and 3). The characteristics of the mentioned scenarios are presented in Table I.

Concerning EVs batteries constraints, the target energy level per vehicle is defined by their owner for the end of a certain *Δt* period starting at the plug-in moment. In order to define worst case scenarios, this energy level was assumed to correspond to a full charge for all plugged-in EVs.

III. Grid Architecture

Fig. 1 describes the electricity distribution network used in this research, corresponding to a typical semi-urban, 15 kV, Medium Voltage (MV) grid. The clients of this type of grid are mainly residential consumers, providing a good platform for studying the impacts of EVs' connection.

It was assumed that each MV/LV (Low Voltage) transformer, represented by a triangular shape in the figure, plus the downstream LV grid, have the capability to accommodate all the EVs considered in each scenario. This assumption allows focusing the study in the MV grid, as it is intended with this paper. In this type of grid the contracted capacity for each LV residential client averages 6.9 kVA. In Portugal, each client has to contract a maximum capacity with the trader, which roughly represents the client's peak load.

This grid despite being meshed is explored using a radial configuration, as shown in Fig. 1 (the dashed branches are opened), and has two feeding points, represented by the round shapes in the figure, energizing two separate areas. The specified voltage in the feeding points is 1.05 p.u..

Typically there are two main problems associated to these networks that arise with an increase in load. The branches around the feeding points are expected to reach high congestion levels, while the buses more electrically distant from the feeding points are expected to face voltage drop problems.

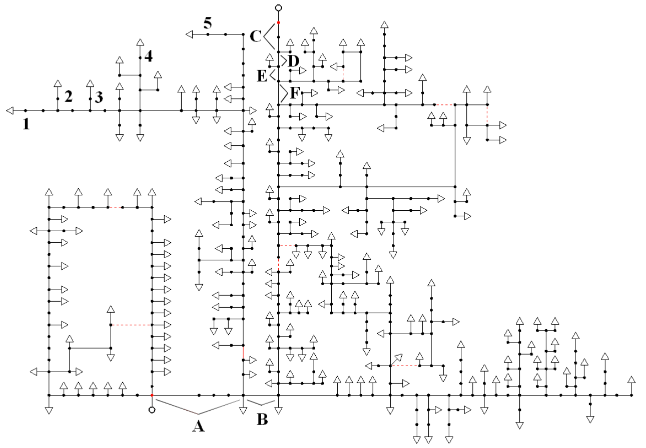

Fig. 1. Medium voltage distribution network (15 kV). The numbers 1 to 5 identify the buses that are more prone to having voltage problems. The letters A to F identify the most congested branches.

For the grid under study, the typical load diagram is depicted in Fig. 2, which was built considering the presence of a small industrial component, some commercial loads and a large number of household loads.

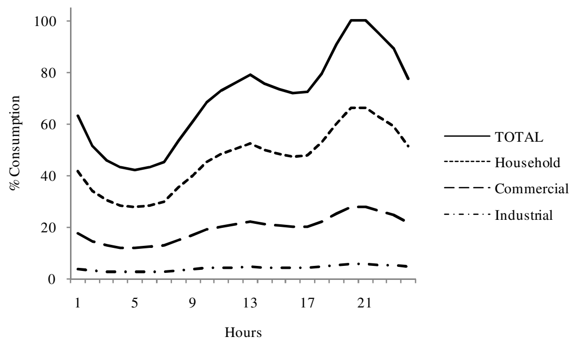

Fig. 2. Load profile during a typical day.

The household, commercial and industrial diagrams were combined taking into account the proportion of installed power related with each type of these consumers. Thus, the final diagram has a contribution of nearly 66% of the household, 28% of the commercial and 6% of the industrial, as these are the proportions of installed power related with each type of load within this grid. The energy consumption in this grid for a typical day is 277.1 MWh.

IV. EVs Characterization and Modeling

The total number of vehicles considered to be related to the geographical area of this grid was determined considering an average value of 1.5 vehicles per household. This value was kept constant along the five case scenarios studied, whereas the share of EVs was increased from 0% in the base scenario (scenario 0) to 52% in the fifth one (scenario 4), as it is shown in Table I.

The EVs fleet considered includes plug-in hybrid vehicles and two types of full electric vehicles, each one of them with a different charging rated power: 1.5 kW for hybrid, 3 kW for the medium EV and 6 kW for the large EV. The charging time was assumed to be 4 hours for all EVs, resulting in a battery capacity of 6, 12 and 24 kWh, respectively [9]-[15].

It is important to notice that this energy consumption refers to a worst case scenario since it is considered that all EVs charging occur in the same day. If it is likely to happen that the plug-in hybrid charges every day, the same it is not true for the medium and the large EVs, as their batteries have enough capacity to fulfill the mobility needs of some of the drivers for more than 2 days.

The medium EV and the large EV intend to represent cars with different driving ranges developed by automotive manufacturers to face different customers' needs.

TABLE I
SCENARIOS DESCRIPTION

Scenario	0	1	2	3	4
N.º of Vehicles	12744	12744	12744	12744	12744
EVs %	0%	5%	10%	14%	52%
Hybrid Share	-	70%	40%	30%	10%
Medium EV Share	-	15%	30%	35%	45%
Large EV Share	-	15%	30%	35%	45%
Energy consumption for the selected day (MWh)	277.1	283.2	294.0	301.7	388.1

In scenario 1 it was considered that the share of hybrid EVs was 70% regarding the total number of EV. The remaining 30% was equally split by the medium and the large EVs. This distribution was chosen since it is almost certain that plug-in hybrid vehicles will be massively sold in the markets far before full electric vehicles. However, the increase in fuel prices, the evolution in batteries' technologies and the need to reduce greenhouse gas emissions are strong arguments that are expected to boost full electric vehicles sells. These assumptions were taken into account when defining the remaining scenarios, where the share of hybrid EVs gradually decreases until it reaches 10% in scenario 4.

V. Impact Assessment

In order to assess the impact of the previously described growth of EVs penetration on the voltage profiles and power lines' congestion levels of the selected MV distribution grid, PSS™E was used to perform steady-state simulations. Power flow studies, for the load peak hour, were conducted for each of the considered scenarios. Only load peak hour was selected for this purpose as grid restrictions should be considered for the worst case scenario. To assess the daily losses, 24 power flows per scenario were performed (one per hour), considering the network base load plus EVs load, according to the scenario under study.

This procedure was repeated for each EV charging management procedure.

A simple approach aiming to weigh up the maximum share of EVs that can be safely connected into the grid, using all three approaches described before, was created. The rationale for the dumb charging and the dual tariff policy was to increase the load in small steps until a violation occurs, for either voltage or branches congestion limits. For the smart charging the approach was different. The maximum share of EVs that can be safely connected into the grid was determined from the solution of the optimization problem, as described in (1).

The EVs load profiles obtained, for the three charging methods, during one entire day, are presented in Fig. 3.

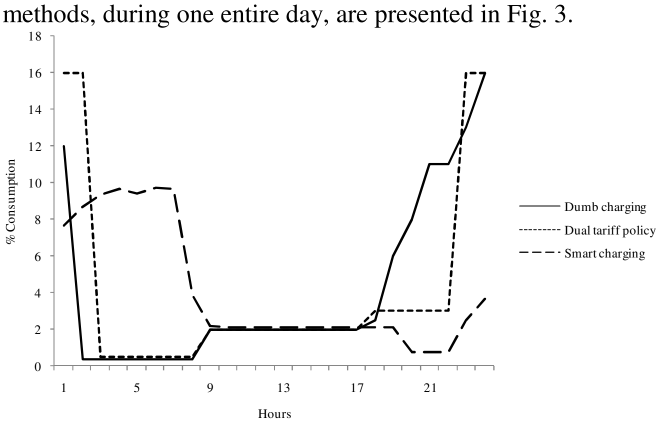

Fig. 3. EVs power consumption along the day for the three charging methods studied.

Results obtained for the three charging solutions are shown in the next subsections.

A. *Dumb Charging Results*

To establish a proper comparison between the several created scenarios, the results regarding network impact assessment were compiled into tables and figures presented along the next sections. The voltage levels in some critical buses and the congestion levels in the worst line sections were analyzed, as well as the losses along one entire day.

Looking at Table II it is possible to evaluate the effects of EVs penetration in the voltage profiles of some buses electrically distant from the feeder. As the number of EVs increases, the voltages in these buses drop to values far below the reference bus voltage.

The average voltage drop in the five most critical buses, when comparing scenarios 0 and 4, is 9.1% which is not acceptable at all. Bus 1, which is the farthest from the feeder, experiences the largest voltage change. All the other grid nodes not included in Table II suffer similar changes in their voltages, but the five presented are those with bigger drops.

TABLE II
VOLTAGE LEVELS – DUMB CHARGING

	Voltage (p.u.)				
Bus	1	2	3	4	5
Scenario 0	0.961	0.962	0.962	0.962	0.964
Scenario 1	0.957	0.958	0.958	0.958	0.960
Scenario 2	0.951	0.951	0.951	0.951	0.953
Scenario 3	0.945	0.946	0.946	0.946	0.948
Scenario 4	0.873	0.874	0.874	0.874	0.878

Fig. 4 shows bus 1 voltage for the 5 scenarios and a dashed line indicating the voltage lower limit (0.95 p.u.). As one can observe, voltage lower limit is reached in scenario 2. Thus, 10% EVs integration represent the feasible limit for the dumb charging approach.

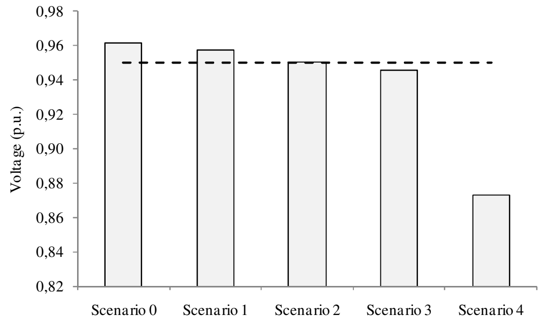

Fig. 4. Bus 1 voltage for the dumb charging approach.

Table III shows the congestion levels evolution, in six of the most loaded line sections within the grid. As expected, the most problematic spots are located near the feeders once all the power demanded flows through the lines adjacent to it.

TABLE III
BRANCHES' CONGESTION LEVELS – DUMB CHARGING

	Line ratings (%)					
Line section	A	B	C	D	E	F
Scenario 0	71.7	63.5	43.2	43.1	42.9	35.1
Scenario 1	74.8	66.4	45.5	45.3	45.2	36.7
Scenario 2	80.1	71.4	49.6	49.3	49.2	39.4
Scenario 3	84.1	75.1	52.4	52.1	52.0	41.4
Scenario 4	140.0	127.8	96.2	95.5	95.2	70.2

The average increase in the congestion levels of the six line sections, when comparing scenarios 0 and 4, is 110.4%. The biggest changes were observed in line sections C, D and E. Their ratings increased by 122.7%, 121.6% and 121.9%, respectively. The maximum allowable rating was surpassed in lines A and B.

Line sections C, D and E also reach preoccupant levels in scenario 4, but without exceeding their transmission capacities. The power flows through all the other branches along the grid raises as the penetration of EVs increases, but never reaching ratings above 85%.

The values of the daily losses, when the dumb charging approach is implemented, are presented in Table IV.

TABLE IV
DAILY LOSSES – DUMB CHARGING

Daily losses (MWh)				
Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
10.21	10.76	11.78	12.58	25.08

B. Dual Tariff Policy Results

Table V shows the effects of EVs penetration in the voltage profiles of the same buses analyzed in the dumb charge section. Logically, as the number of EVs increases, the voltages in these buses drop to very low values.

TABLE V
VOLTAGE LEVELS – DUAL TARIFF POLICY

	Voltage (p.u.)				
Bus	1	2	3	4	5
Scenario 0	0.961	0.962	0.962	0.962	0.964
Scenario 1	0.960	0.961	0.961	0.961	0.962
Scenario 2	0.957	0.958	0.958	0.958	0.959
Scenario 3	0.951	0.952	0.952	0.952	0.953
Scenario 4	0.859	0.860	0.860	0.860	0.863

The average voltage drop in the five buses, when comparing scenarios 0 and 4, is 10.6%. Again, bus 1 is the one that experiences the largest voltage change.

Fig. 5 shows bus 1 voltage for the 5 scenarios and a dashed line indicating the voltage lower limit (0.95 p.u.). As one can observe, voltage lower limit is reached in scenario 3. Thus, 14% EVs integration represent the limit for the dual tariff approach.

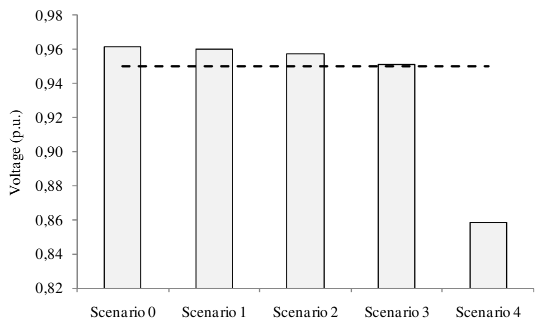

Fig. 5. Bus 1 voltage for the dual tariff policy.

Table VI shows the congestion levels evolution, in the same six line sections presented in Table III.

TABLE VI
BRANCHES' CONGESTION LEVELS – DUAL TARIFF POLICY

	Line ratings (%)					
Line section	A	B	C	D	E	F
Scenario 0	71.7	63.5	43.2	43.1	42.9	35.1
Scenario 1	72.6	64.3	43.9	43.7	43.5	35.5
Scenario 2	75.3	67.4	47.3	47.1	46.9	37.2
Scenario 3	80.0	71.7	50.6	50.3	50.1	39.5
Scenario 4	150.6	137.0	102.6	101.9	101.6	75.5

The average increase in the congestion levels of the six line sections, when comparing scenarios 0 and 4, is 125.3%. The biggest changes were observed in line sections C, D and E. Their ratings increased by 137.5%, 136.4% and 136.8%, respectively. The maximum allowable rating was surpassed in all the lines except F.

The values of the daily losses, when the dual tariff policy is implemented, are presented in Table VII.

TABLE VII
DAILY LOSSES – DUAL TARIFF POLICY

Daily losses (MWh)				
Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
10.21	10.70	11.60	12.33	24.52

C. Smart Charging Results

Table VIII shows the effects of EVs penetration in the voltage profiles of the same buses analyzed in the previous sections.

Once again, as the number of EVs increases, the voltages in these buses drop, but this time they don't drop below the limit of 0.95 p.u..

TABLE VIII
VOLTAGE LEVELS – SMART CHARGING

	Voltage (p.u.)				
Bus	1	2	3	4	5
Scenario 0	0.961	0.962	0.962	0.962	0.964
Scenario 1	0.961	0.962	0.962	0.962	0.963
Scenario 2	0.961	0.961	0.961	0.961	0.963
Scenario 3	0.960	0.961	0.961	0.961	0.962
Scenario 4	0.950	0.950	0.950	0.950	0.952

The average voltage drop in the five buses, when comparing scenarios 0 and 4, is 1.2%.

Once more, bus 1 is the one that experiences the largest voltage change.

Fig. 6 shows bus 1 voltage for the 5 scenarios. The dashed line indicates the voltage lower limit. As one can observe, voltage lower limit is reached in the last scenario. Thus, 52% EVs integration represent the limit for the smart charging approach.

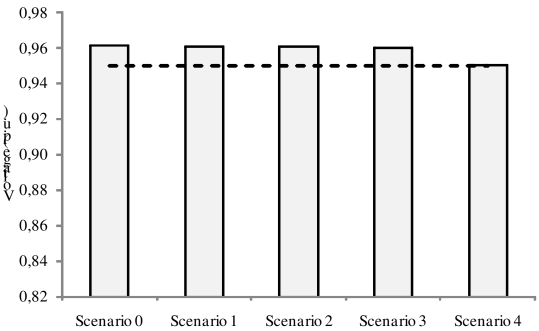

Fig. 6. Bus 1 voltage for the smart charging strategy.

Table IX shows the congestion levels evolution, in the same six line sections presented in Tables III and VI.

TABLE IX
BRANCHES' CONGESTION LEVELS – SMART CHARGING

	Line ratings (%)					
Line section	A	B	C	D	E	F
Scenario 0	71.7	63.5	43.2	43.1	42.9	35.1
Scenario 1	71.9	63.7	43.4	43.2	43.1	35.2
Scenario 2	72.2	64.0	43.7	43.5	43.3	35.4
Scenario 3	72.5	64.3	43.9	43.7	43.5	35.5
Scenario 4	81.7	74.4	54.6	54.2	54.1	40.6

The average increase in the congestion levels of the six line sections, when comparing scenarios 0 and 4, is 20.8%. The maximum allowable rating was never surpassed in any line.

The values of the daily losses, when the smart charging approach is implemented, are presented in Table X.

TABLE X
DAILY LOSSES – SMART CHARGING

Daily losses (MWh)				
Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
10.21	10.57	11.24	11.76	19.58

VI. RESULTS ANALYSIS

A. Voltages Profiles

When analyzing the worst bus voltage (bus 1) for the different charging methods, results show that voltage is the limiting factor to higher levels of EVs integration. For the same integration level, voltage lower limit is reached first than branches maximum rating.

Fig. 7 shows the worst bus voltage for each scenario when the three different charging methods are applied. Once again, the dashed line indicates voltage lower limit.

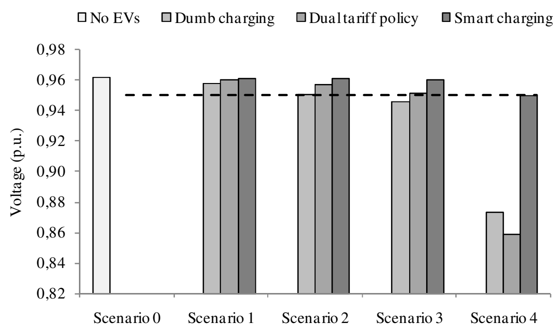

Fig. 7. Bus 1 voltage for all the scenarios and for the different charging methods studied.

As one can observe, the smart charging always attains the best results. The dual tariff policy provides better results than the dumb charging in all the scenarios, except in the last one. For low integration levels the dual tariff policy has a positive impact in the grid performance, but, for higher integration levels, it is not a good strategy since it concentrates a high number of EVs charging simultaneously at 11p.m..

B. Branches' Congestion Levels

Even though this is not the most critical aspect of this network, branches' congestion is also an issue that deserves special attention given that it can be the limiting factor to high levels of EVs integration in networks with different characteristics from the one analyzed in this paper.

Fig. 8 shows the rating percentage of the most congested branch (branch A) for each scenario when the three different charging methods are applied. The dashed line indicates the rating limit.

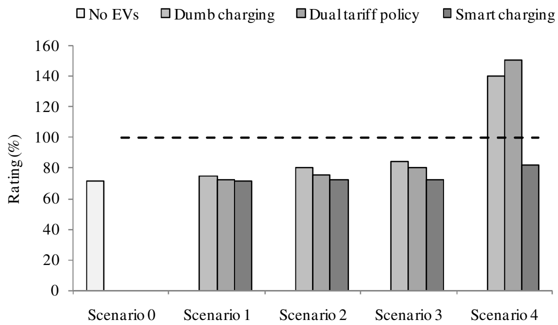

Fig. 8. Branch A congestion level for all the scenarios and for the different charging methods studied.

Again, the smart charging attains the best results, followed by the dual tariff policy, which provides better results than dumb charging in all scenarios, except in the last one. For low integration levels the dual tariff policy has a positive impact in the grid performance, but, for higher integration levels, it happen the same that occurred with the voltage at bus 1.

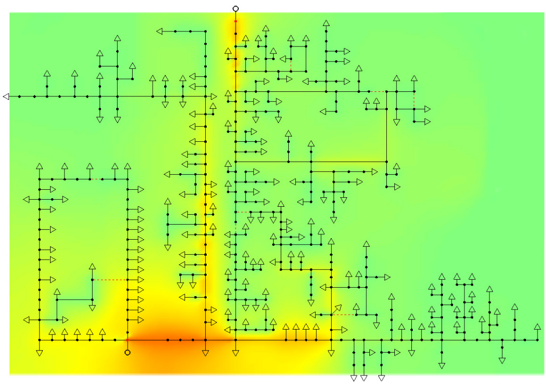

Fig. 9. Branches congestion levels for scenario 0. Grading between light green and red, stand for increasing values of congestion, from 0 to 100%.

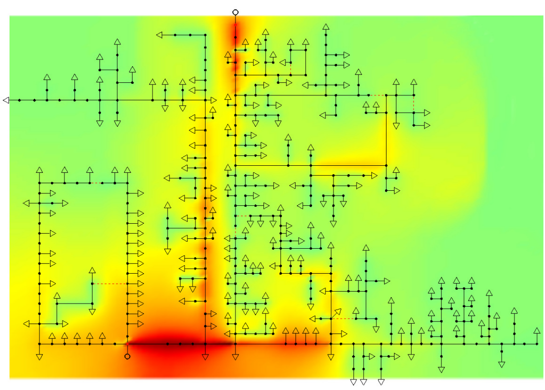

Fig. 10. Branches congestion levels for scenario 4 considering the dumb charging approach. Grading between light green and red, stand for increasing values of congestion, from 0 to 100%.

Fig. 9 to 12 show an overall comparison of branch loading for scenarios 0 and 4, in order to provide a more clear picture of the three charging methods impact in this matter.

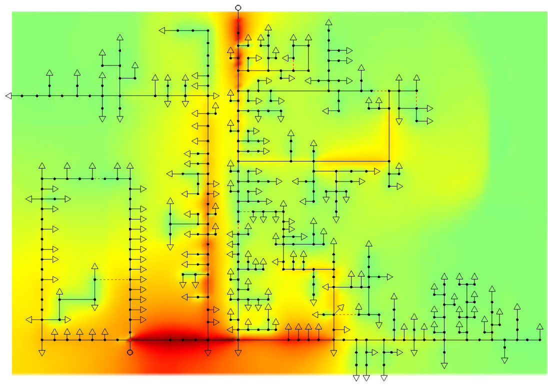

Fig. 11. Branches congestion levels for scenario 4 considering the dual tariff policy. Grading between light green and red, stand for increasing values of congestion, from 0 to 100%.

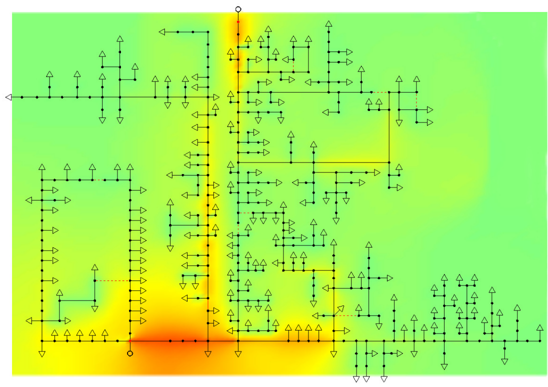

Fig. 12. Branches congestion levels for scenario 4 considering the smart charging strategy. Grading between light green and red, stand for increasing values of congestion, from 0 to 100%.

C. Losses for the Selected Day

Fig. 13 shows the absolute values of the losses for the selected day (bars), referred to the left vertical axis, and their value relative to the overall energy consumption (crosses), referred to the right vertical axis.

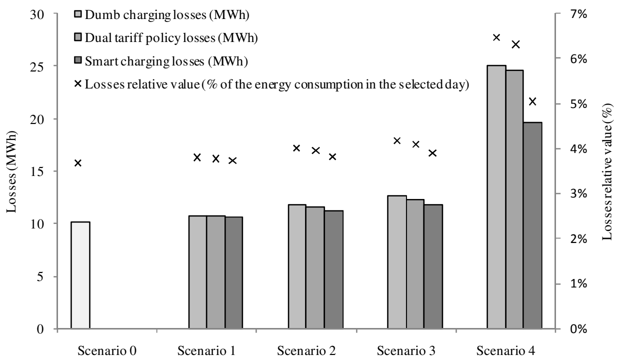

Fig. 13. Losses absolute values for the selected day (bars), referred to the left vertical axis, and their value relative to the overall energy consumption (crosses), referred to the right vertical axis.

As expected, the smart charging method is the one that provides better results since it optimizes the load distribution along the day, minimizing the occurrence of peak periods where load reaches very high values. The peak periods are the most critical for the losses as they are proportional to the square of the current, which is very high in such conditions.

The worst charging method in all the scenarios is the dumb charging since it provokes the occurrence of the higher number of peak periods. Even in the fourth scenario, where the dual tariff policy causes the highest peak load, the dumb charging still attains worst results.

D. Network Load Diagrams

As explained before, in order to guarantee acceptable robustness levels and proper dimensioning of HV/MV distribution substations, network planning needs to take into account the peak load, which is the moment where the system is subjected to the more demanding operating conditions. Thus, it is of most importance to analyze the impact of EVs charging into the network load diagram.

Table XI presents the peak load, in MW, for all the scenarios considered and for all the charging methods implemented.

TABLE XI
PEAK LOAD

	Peak load (MW)			
	No EVs	Dumb charging	Dual tariff policy	Smart charging
Scenario 0	16.60			
Scenario 1		17.28	16.79	16.65
Scenario 2		**18.46**	17.50	16.73
Scenario 3		19.31	**18.73**	16.79
Scenario 4		30.66	32.55	**18.43**

With the dumb charging approach the load in the peak hour increases 85%, from scenario 0 to scenario 4, whereas with the dual tariff policy it increases 96%. When the smart charging method is applied the peak load only increases 11%, which is an outstanding achievement considering that 52% of EVs represent 6608 vehicles demanding 111MWh during one day. The bold values presented in the table are the peak load values obtained, for each charging method, when the maximum allowable percentage of EVs is reached.

The network load diagrams obtained for scenarios 1 to 4, for the entire day, are presented in Fig. 14 to 17.

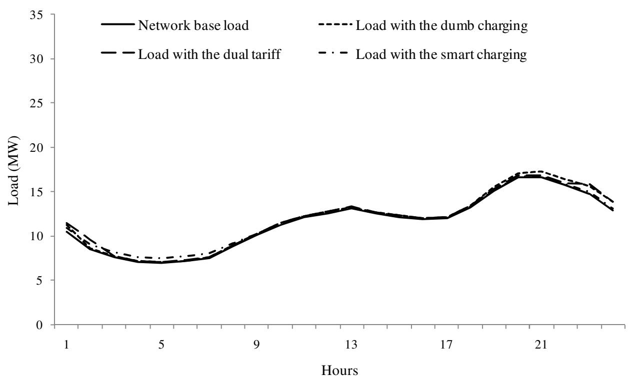

Fig. 14. Network full load diagram for scenario 1 (5% EVs integration).

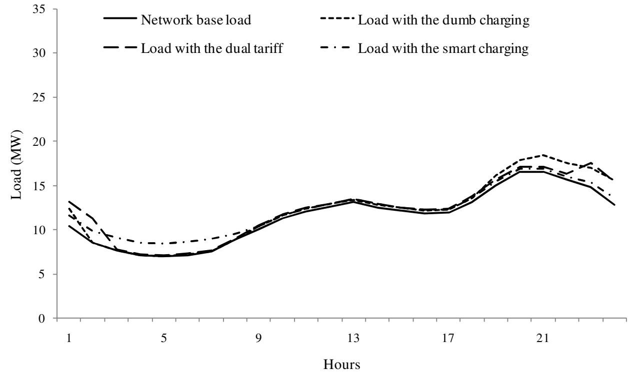

Fig. 15. Network full load diagram for scenario 2 (10% EVs integration).

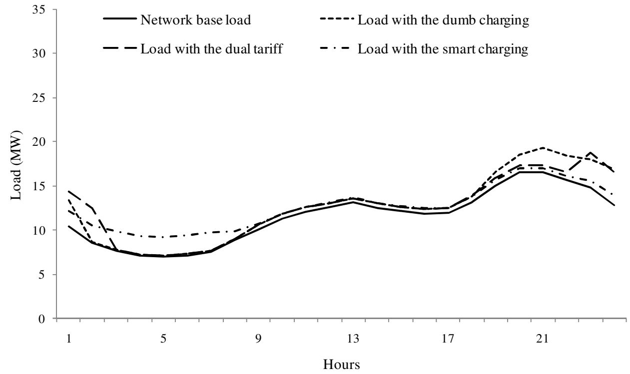

Fig. 16. Network full load diagram for scenario 3 (14% EVs integration).

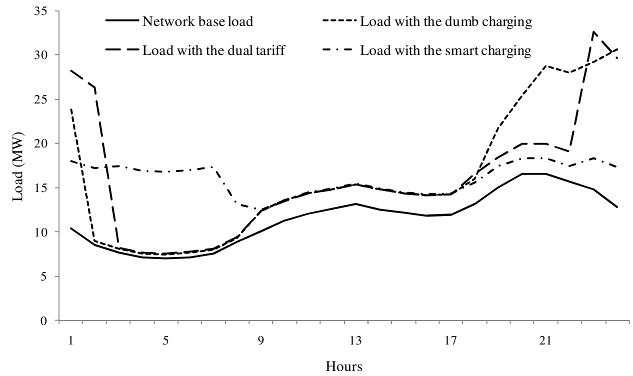

Fig. 17. Network full load diagram for scenario 4 (52% EVs integration).

It is interesting to notice that the peak hour for the dumb charging approach changes from 9 p.m. to 12 p.m. in scenario 4, whereas with the dual tariff policy it changes from 9 p.m. to 11 p.m., but this time the change occurs in scenario 2. For the smart charging, the peak hour is 9 p.m. and it is kept constant along all the analyzed scenarios.

VII. CONCLUSIONS

By analyzing the results presented before it is easy to understand that the system can handle, up to a certain level, the penetration of EVs without changes in the electricity network if a dumb charging approach is used. We may conclude that when the share of EVs reaches around 10% of the total existing vehicles in this residential area, there is the need to reinforce the grid.

Observing load values at the dwelling level, one concludes that for such an approach, in Portugal, the contracted power would require an average increase from the most common 6.9 kVA to 10.35 kVA.

These results are quite interesting since they show that grid restrictions may limit the growth of EVs penetration, if no additional measures are adopted. Two different approaches can then be implemented to deal with this problem, allowing the integration of a higher share of EVs while avoiding capital expenditures by the utility in network reinforcements:

1. A simple dual tariff approach, where economic incentives are provided to EVs owners to shift their vehicles' charging to off peak periods;
2. The adoption of an active charging management approach, where batteries load is distributed along the valley hours. By using such methodology it is also possible to monitor the grid operating conditions at each moment, enabling a more efficient usage of the resources available, like for instance renewable power sources.

The dual tariff policy proved to be more effective than the dumb charging approach, improving the integration capability of this grid up to 14%. Yet, this result was attained when using the current dual tariff policy framework and, most likely, it can be improved if a dedicated and dynamic dual tariff for EVs is created.

This paper proves that a smart charging approach is the most effective charging control technique, as by applying a simple set of rules EVs deployment capability was increased to 52%. This value was limited due to the fact that only 50% of the EVs owners were committed to the smart charging scheme, which increases peak load considerably for such integration level. Moreover, this smart strategy can be fairly easily updated with different objectives for the optimization problem, for instance, to minimize losses or to work on a market model or even to maximize renewable energy exploitation [16]-[18].

Furthermore, the concept of Smart-Metering needs to be exploited in the EVs management context [19]. This can be done by an onboard metering device that receives periodic energy prices when plugged, meaning cheaper prices for the clients and a better exploitation of the renewable energy production.

Although having studied a MV grid, it might happen that the first bottleneck is likely to occur on the LV network and their MV/LV transformer. This means that a bottom up approach should be followed by analyzing each LV network in a first stage of this procedure.

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IX. Biographies

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