ELECTRIC VEHICLES' IMPACT ON THE PLANNING OF THE MILAN DISTRIBUTION NETWORK

Giuseppe MAURI
RSE SpA – Italy
Giuseppe.Mauri@rse-web.it

Enrico FASCIOLO
A2A SpA – Italy
Enrico.Fasciolo@a2a.eu

Stefano FRATTI
A2A SpA – Italy
Stefano.Fratti@a2a.eu

ABSTRACT

The study addresses the impact on planning of Low Voltage (LV) distribution grids within the urban area of a major Italian municipality due to the introduction of the Electric Mobility. It takes into account that, in this area, the diffusion of Electric Vehicles (EV), will be greater than in the rest of Italy. Two scenarios are analyzed. In the 2020 scenario, the expected penetration of cars in LV distribution grids, will require substitution of a small amount of MV/LV transformers, while in the 2030 scenario, the amount of EV recharging on LV networks will double, since all additional EV will use fast charging stations connected to MV lines. In the worst case, less than 3% of MV/LV transformers will need to be considered for substitution. Hosting capacity of lateral feeders, feeders and main feeders of each LV grid are also evaluated. For this purpose data collected by the smart metering systems become very helpful. The hosting capacity is calculated as the difference of the rating of each cable and load curves obtained integrating load curves recorded by customers' smart meters.

INTRODUCTION

Electric Vehicles (EVs) provide very promising opportunities for the future development of a sustainable private transport sector. Italy, with about 60 million inhabitants, almost 37 million cars and more than 200 municipalities with over one thousand registered cars per square kilometres, may largely benefit of better quality of air as the result of deployment of electric vehicles. Additionally all the Italian distribution grid is already equipped with a smart metering system. That makes Italy an ideal place for deploying an EV smart charging infrastructure. Within this context, a national research project funded by the Ministry of Economic Development started at RSE with the aim of investigating the main technical, environmental and economic issues related to the potential penetration of plug-in electric vehicles.

This paper addresses one of the topic investigated within this project, in particular the assessment and planning of low voltage distribution networks in the urban area of the city of Milan, one of the major Italian municipality which is considering the introduction of the electric mobility. In this context two scenarios are analyzed taking into account that diffusion of Electric Vehicles (EV) in urban areas will be greater that in the countryside. The first scenario considers that, at 2020, 10% of the total circulating vehicles in Italian major cities will be EV and that they will be mostly recharged on low voltage distribution networks (about 18 EV per transformer). The second scenario considers that, at 2030, 20% of the total circulating vehicles in the same urban area will be EV, recharged on LV distribution networks (about 36 EV per transformers) while the remaining (in addition to the 20%) will use fast charging stations connected to MV lines.

EV CHARGING PROFILE

For estimating the charging profile on LV grid, it is necessary to estimate how many EVs can be charged in public and private parking area at any time of the day and night. Considering data from the census made available by ISTAT [1, 2], that people owning a private parking area shall be more inclined to buy an EV and that they will be also likely to charge their vehicle during the night (car not used and cheaper energy rate), makes possible to estimate that, at the most, 64% of the energy for charging EV might be allocated during the night and that at least 36% might be allocated during the day. Moreover taking into account the hourly distribution of travels by car in the urban area of Milan, the EV charging profile can be shaped both as inversely proportional to such distribution, still keeping the 64% night / 36% day allocation. Additional assumptions regards: the average energy that has to be recharged per day, which is function of the distance travelled by the car in the day; and that the majority of the EV users having a private parking area, are likely to plug their car as soon as they get home in the evening, thus concentrating the electricity demand in the evening and in the beginning of the night. With all these considerations a likely charging profile for charging EV in urban areas is drawn in Fig. 1.[3].

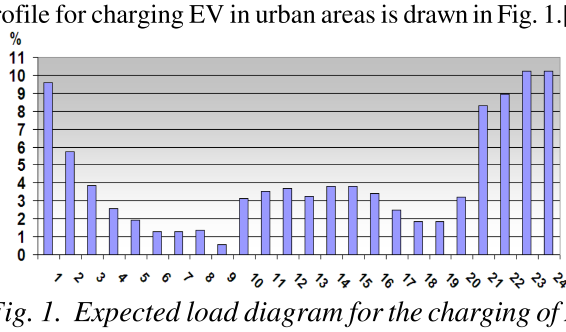

Fig. 1. Expected load diagram for the charging of EV

in major Italian cities.

IMPACT ON MV/LV TRANSFORMERS

The charging profile highlighted in Fig.1, is to be added to load profile of MV/LV transformers. That is possible since the utility that manages LV networks of the city of Milan, may count on an advanced real-time monitoring system which monitors most of the MV/LV transformers (3500 out of 5700 the MV/LV transformers). Adding the load diagram expected for the charging of EV in major Italian cities to the characteristic load diagram for residential and tertiary areas (blue curve in Fig. 2 and Fig. 3) produces respectively red lines in same figures. The resultant profile for residential area is worse than the one for tertiary area since the peak EV power demand adds-up to the existing pick power demand that happen during evening time.

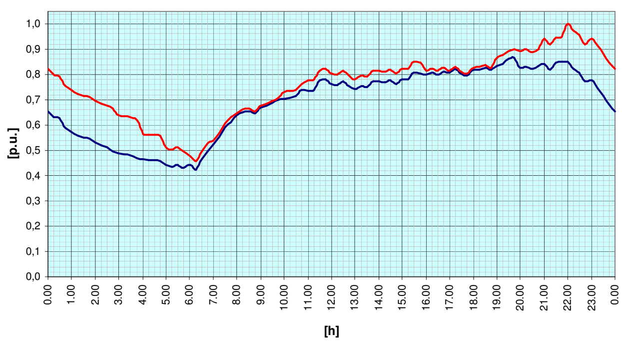

Fig. 2 – Base residential load (blue), contribution of EV charging (red)

The situation is not so worse for LV grids in tertiary areas. Here cars are normally left for charging off-peak time, so EV diffusion in these areas may contribute to smoothing load diagrams.

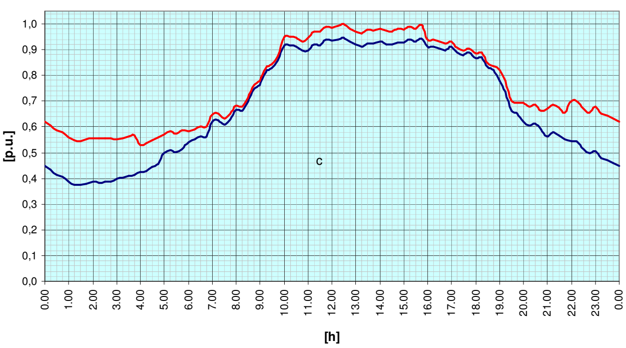

Fig. 3 – Base Tertiary load (blue) contribution of EV recharging (red)

IMPACT ON MAIN AND LATERAL FEEDERS

Data collected by the smart metering system allows the construction of load curves for all LV users. Knowing the topology of LV networks, allows to aggregate load diagrams in any node of the grid, thus making possible to produce load diagrams for each lateral feeder, main feeder up to the transformer as shown in Fig. 4 (Cyan lines). Additionally, knowing rates for each cable (main feeders and laterals feeders) and transformers, allows evaluating the hosting capacity both in term of "maximum power" that can be made available for EV recharging (dark blue line) and "maximum additional energy" that may flow through each main feeder, lateral feeder and transformer in any given timeframe (e.g. 168h) within network technical constraints. The systematic analyze of load diagrams for all trunks of LV networks allows identifying both the "hosting capacity" (the maximum number of car that can recharge in parallel) and network components which upgrading becomes necessary.

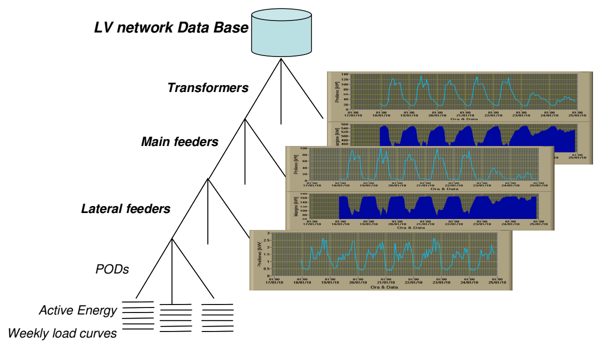

Fig. 4 - Load and hosting capacity for transformers, feeders and lateral feeders of a LV distribution network

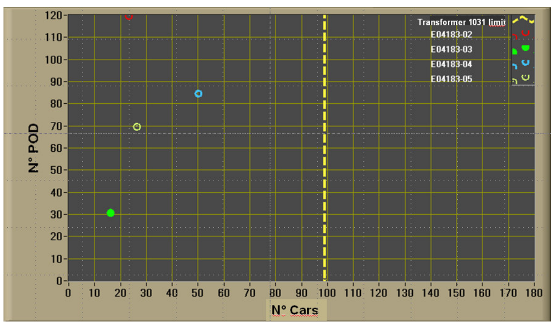

Fig. 3 - Transformer limit (dash yellow line) versus main feeders (worst case scenario)

"UNCONTROLLED" CHARGING

The knowledge of the network margins can be used for evaluating the maximum number of cars that can be recharged in parallel both for slow mono phase charging (3.3 kW or 6.6 kW) and for fast three phases charging

(10kW and 20 kW) without any control of the EV charging point. That is done dividing available power available from the network with the power made available by the EV charging point. Fig.4 represents, for each of the 5 lateral feeders, the number of cars that can be simultaneously charged, versus the limit of the main feeder. It is clear that the bottleneck is the main feeder (yellow line). Its hosting capacity is smaller than in any of its lateral feeders. Additionally, the same figure shows the number of customers (POD) that are connected to each feeder. That is useful information since the more PODs are present, the more EVs are likely to be deployed. The same can be done also for transformers as shown in the example shown in Fig. 5.

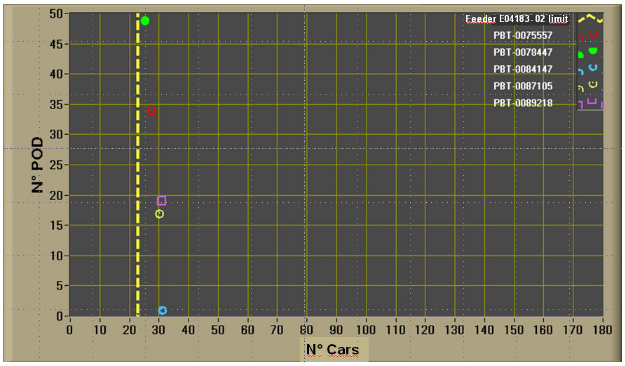

Fig. 4 - Main feeder limit (dash yellow line) versus lateral feeders (worst case scenario)

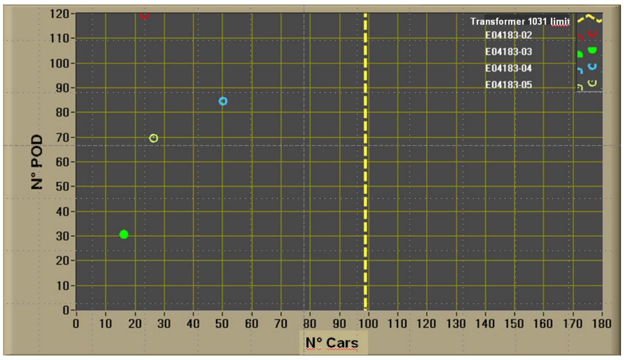

Fig. 5 - Transformer limit (dash yellow line) versus main feeders (worst case scenario)

"SMART" CHARGING

Knowing the energy margin that may flow in each branch of the LV grid allows evaluating also the maximum theoretical number of cars that may be recharged in the LV grid using "smart charge", that is a charging point connected to a smartgrid controller. For doing that, additional data are needed: i) average length driven by EVs in one week, month or year; ii) average specific energy [Wh/km] requested by EV. Taking into account an average of 12.000 [km] raided in one year and an average specific consumption of 180 [Wh/km], the main feeder represented in Fig. 6 may host up to 414 cars with "smart charge", while using an "uncontrolled" low voltage Charging station, it may charge, at the same time, up to 23 cars during "peak" times or 38 cars during "off-peak" hours.

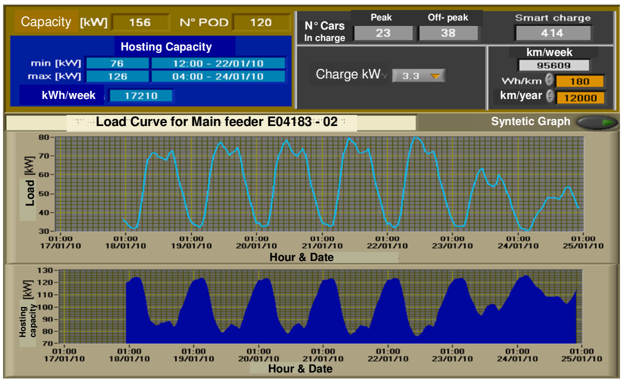

Fig. 6 - Main Feeder limit (168h)

CASE STUDY

The methodology above explained, has been applied in the Milan urban area. A sample of LV grids has been analysed. Results are synthetically summarised by cumulative curves in Fig. 8, Fig. 9 and Fig. 10. They show that quite a number of cars can already be simultaneously recharged with slow 3.3 kW charging without reinforcing the network and without any remote charging control, while remote charging control is compulsory for deploying fast charging.

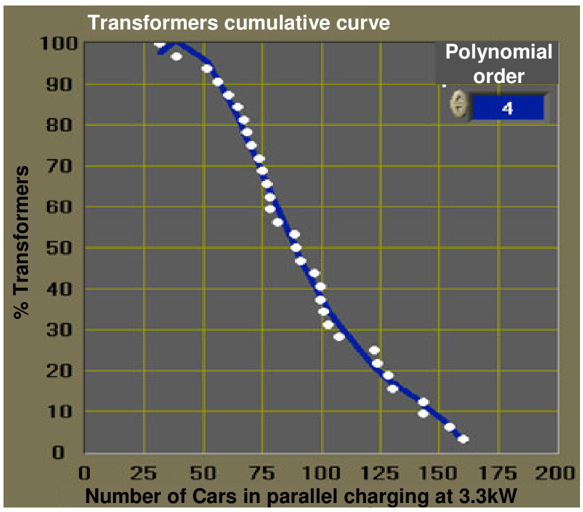

Fig. 8 - EV parallel charged versus transformers

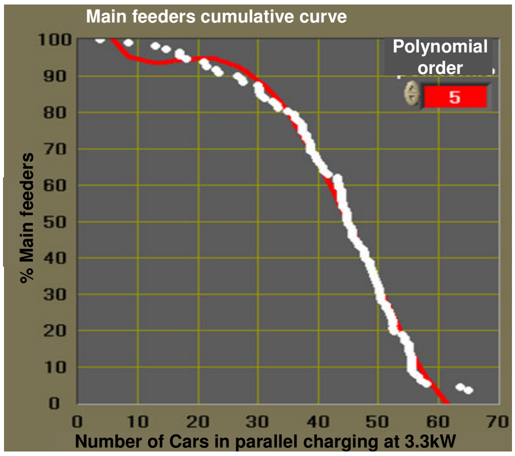

Fig. 9 - EV parallel charged versus main feeders

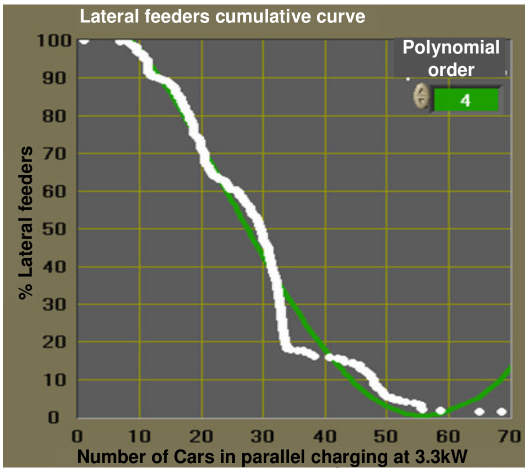

Fig. 10 - EV parallel charged versus lateral feeders

For the urban area of Milan, transformers usage versus their maximum admissible power is represented in Fig. 11. In that case, the EV 2020 scenario with an average of 18 cars per MV/LV transformers in residential areas, will require the substitution of transformers in substations with peak power demand higher than 93% (i.e. 1% of transformers), while in case of tertiary networks, only when peak power demand will be higher than 97% (i.e. 0.3% of transformers). In the 2030 scenario, the expected penetration of an average 36 EV per LV network, will require transformers' substitution when peak power reaches 86% (i.e. 2.3% of transformers) in residential areas, and when peak power demand reaches values greater than 94% (i.e. 1% of transformers) in tertiary areas.

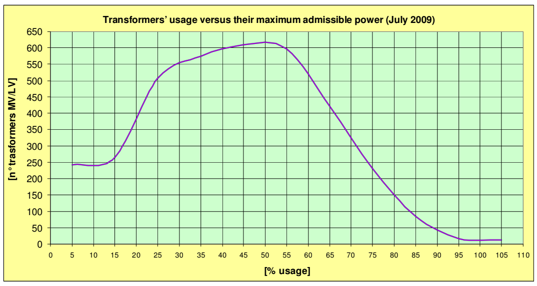

Fig. 11 – Number of transformers versus usage (maximum peak load)

RESULTS AND CONCLUSIONS

The paper addressed the assessment and planning of low voltage distribution grids in the urban area of a major Italian city considering the introduction of electric mobility. Data collected by smart metering system, knowledge of topology of LV networks and technical data for all components, allowed the construction of load curves and evaluating the hosting capacity both in term of "maximum power" available for recharging of electric vehicles, and in term of the "maximum additional energy" that may flow on the LV network within network technical constraints.

That information was used to evaluate the maximum number of cars that can be recharged in parallel both for slow mono phase and for fast three phases charging and the "maximum theoretical" number of cars that may be recharged in the LV using a "smart charge" system. The expected penetration of EV at 2020 and at 2030 will require substitution of a small amount of transformers, main feeders and lateral feeders which can be easily identified using the methodology that was presented.

Acknowledgments

Acknowledgments, if required, should appear in a section immediately before the reference section, or the endnote section, if there is one.

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