DISTRIBUTION NETWORK PLANNING IN PRESENCE OF FAST CHARGING STATIONS FOR EV

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ABSTRACT

The concept of electrical-mobility in opposition to the present oil-mobility is becoming even more attracting worldwide. Fast Charging Station (FCS) refers charging stations with nominal power equal or higher than 50 kW. Consequently, FCS requires high power and they must be connected to MV networks. For that reasons, it is crucial to analyze these situations and to model the impact of FCS on the electric network, in order to correctly plan the expansion of the MV system. In the paper, specific studies will be performed on a real MV distribution network of the A2A utility sited in the district of Brescia (Italy), in order to quantify the impact of the FCS and to identify the most suitable planning solutions needed to allow the effective integration of EV and boost electric mobility.

INTRODUCTION

The transport sector currently relies on fossil fuels, causing a significant part of greenhouse gas emissions. The passenger car is the major consumer of energy, accounting for more than half the total transportation energy. In this context, under the pressure of even more severe environmental constraints, the electrification of the transportation sector is becoming even more attractive worldwide, due to the dependency reduction form liquid fuels in this sector and the increment of primary energy sources diversity used in countries' energy mixes. The electrical mobility is founded on the usage of battery powered electric vehicle (EV) and Plug-in Hybrid Electric Vehicle (PHEV) as the main future technology to combat greenhouse gas emissions [1].

Key questions are when and where drivers would recharge their vehicles. The primary source of charging will rely on normal charging boxes, located at home or in the parking at work and operated manually by the driver or, preferably, managed remotely by a suitable control system (of the local distributor or of an independent aggregator) [2]. In both cases, 3 kW AC slow chargers will be spread in the LV network (home chargers) or concentrated in some parking lots and connected to the LV or MV network. It should be observed that without controlled charging, large deployment of electric mobility could increase power flows in the distribution networks, particularly during peak electricity demand, causing critical network operation conditions (feeders overloading and voltage drops) [3].

Alternative to the slow charges, fast charges will occur when previous charging options are not available or when, in the middle of a trip, the battery approaches minimum SoC (State of Charge). Fast charging refers to DC charging stations with nominal power equal to or higher than 50 kW. Some European OEMs expect a charging rate of up to 100-120 kW for a typical EV battery as a realistic target for DC fast charging in year 2020. Consequently, a Fast Charging Station (FCS) will be characterised by high momentary peak power absorptions and they must be connected to MV networks.

For those reasons, it is crucial the representation of the FCSs in order to assess their impact on the electric distribution network and to correctly plan the expansion of the MV system. The first step of this representation is the daily profile of the power demand absorbed by an FCS during the day. In the recent Literature, some models were proposed starting from real data of typical travel patterns [4]-[5]. In the paper, such models will be included in a specific distribution planning tool for MV distribution network, developed in the past years to deal with all the uncertainties that characterize the future scenario of the distribution system. Specific studies will be performed on a real MV distribution network of the A2A utility sited in North of Italy, in order to quantify the impact of the FCSs and to identify the most suitable planning solutions needed to allow the effective integration of EV and boost electric mobility.

DISTRIBUTION NETWORK PLANNING

Traditionally, distribution networks are sized to cope with the worst-case scenario of a given load forecast and in a way that minimum or no operation is required. This approach, known as 'fit and forget', is carried out in a deterministic way, i.e., without considering uncertainties (the loads are modelled with their peak demand). Each planning alternative considered is technically assessed taking account of the load conditions for the corresponding planning horizon and, if it is not technically feasible, network reinforcements are applied. The most cost-effective solution is the planning alternative likely to be adopted. While this passive way of planning and operating distribution networks has proven cost-effective in the last decades, it might in the future become a barrier for increasing penetrations of renewable generators and non-conventional loads, like the EVs. Indeed, with the increment of uncertainties brought by these new distribution system's customers, the 'fit and forget' approach results in massive network investments only motivated to deal with worst-case scenarios that may have an extremely low probability of occurrence.

In order to overcome the limitations previously stated, new planning procedures have to be developed, able to cope with all the uncertainties introduced in the distribution system. This goal suggests both the use of probabilistic models, to better represent planning data, and the introduction of the risk concept in the selection of planning alternatives [6]. The results of the probabilistic network calculations are the stochastic representations of the nodal voltage and branch current variables. Technical constraints can then be verified with a relative confidence (acceptable risk of violation). By so doing, cheaper planning schemes (in respect to the ones obtained with the 'fit and forget' approach) may be rationally adopted being aware of the (low) risk accepted.

In last decade, a software tool based on probabilistic techniques has been developed that allows the optimal planning of MV distribution networks, taking account of the expansion over time and usual technical constraints [7]. The optimization procedure minimizes the generalized cost of the network constituted by the CAPEX (investments for new lines, for upgrading existing lines and primary substations, and for network automation) and the OPEX (losses and maintenance). The optimal solution has to comply with constraints on the voltage profile, the maximum exploitation of assets, etc. The random behaviour of both distributed generation and loads is represented with normal probability density functions (*pdf*) and the network calculations are performed by a tailored probabilistic load flow algorithm. In the paper, this planning tool has been used to estimate the impact that FCSs could have on a real MV distribution network, highlighting the importance of the charging profile assumed and the methodology used for the calculations (traditional or probabilistic) [8].

EV CHARGING PROFILES

For estimating power demand of a FCS, it is necessary to make an assumption on the number of EVs that need to be charged in each station at any time of the day. Considering the Italian case and data available from the national census, people owning a private parking place shall be more inclined to buy EVs and to charge their vehicle during the night (car not used and cheaper energy rate). This hypothesis makes possible to estimate that in Italy at the most 64% of the energy for charging EVs circulating in 2030 would be allocated during the night and at least 36% would be allocated during the day [9]. As further assumption, the charging energy absorbed during the day has been split between slow charging boxes (6%) connected to a LV network and fast charging stations (30%) connected to the MV network. Moreover, taking account of the actual daily average journey (about 35 km) and the energy demand per kilometer (0.15 kWh/km), the daily average energy demand of each EV is expected to be around 5 kWh/day.

This general analysis has been adapted and adjusted to the specific characteristics of the Italian region considered. The study described in this paper refers to a MV network owned by A2A and located on the north Shore of Garda Lake. This network has been chosen due to the expected construction in the coming years of a large tourist area that could lead up to a large use of EV. The consumption of electricity of the existing petrol stations, which will be converted to hybrid distributors with the installation of fast charging equipments, has been estimated taking account of the strong increment of cars in the area of interest during the summer (tourist) period. It has been also assumed that the mobility profile is the same of the city of Milan [4], scaled on the number of cars circulating in the province of Brescia.

Two charging profiles have been adopted in the simulations. The first electricity demand profile (case A – Fig. 1) has been assumed proportional to the mobility profile: being the considered MV network related to a famous tourist area, the majority of the EV's drivers has not the availability of home charging boxes and they have to recharge during the journey. In other words, case A is based on the current refueling habits of ICE vehicles.

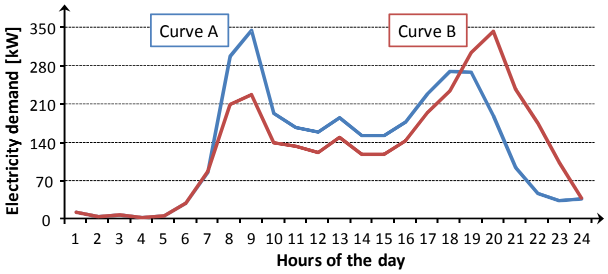

Fig. 1 – FCS electricity demand profiles.

A different assumption can be made taking account of the peculiarity of a tourist location. Indeed, being EV's fast charging generally longer than the current ICE's refueling (about 20-30 minutes versus few minutes), it is plausible that tourists wish to charge their EVs in the late evening before returning to their hotels or at the beginning of the night immediately after the dinner, in order to have the vehicle ready to start in the morning. This hypothesis should increase and delay the evening peak demand in respect to the energy consumption of case A. Hence, a second FCS demand profile (case B – Fig. 1) has been derived and adopted for the simulations.

RESULTS AND DISCUSSION

As aforementioned, a real MV distribution network of the A2A utility located on the north shore of Garda lake

(Italy) has been used for the simulations. In order to exalt the understandability of the planning results, only the most critical section of the real network has been used (Fig. 2). This portion is formed by 140 MV/LV secondary substations that absorb a summer peak demand of about 8 MW from an old primary substation (“Tremosine”). The network is weakly meshed but radially operated with two emergency resupply paths: one from the south (primary substation of “Toscolano”) and one from the north (different DNO).

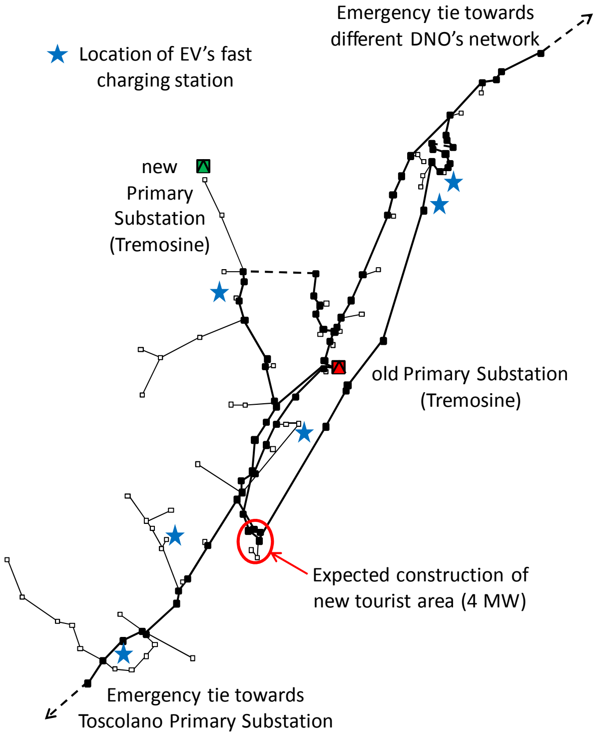

Fig. 2 – A2A MV Distribution network.

The planning period considered for the study is 5 years long. For each MV/LV node a constant power demand growth rate of 2% per year has been assumed. All loads have been modelled with the same daily demand profile, suitably scaled for each node from the measurements collected in the primary substation (Fig. 3).

The long overhead lines and the extended laterals make this network electrically weak and, consequently, problems of voltage drops may arise in specific loading conditions and/or during emergency configurations. The existing network is characterized by a low quality level, due to the low reliability of the old primary substation. This critical situation will be exacerbated due to the expected strong increment of demand (up to 4 MW). For these reasons, the construction of a new primary substation has already been planned, with the contemporary decommissioning of the old one.

It must be observed that the planning results showed in this paper cannot be directly compared with the network expansion plan already decided by the DNO, because the planning tool used does not take account of all the planning specifications usually adopted by A2A. On the contrary, the results can be fruitfully used for comparative analyses among the different cases studied.

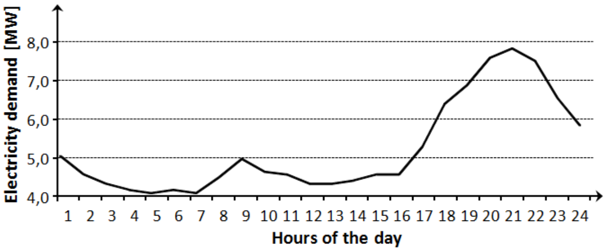

Fig. 3 – Loads demand profiles.

With the probabilistic planning approach, the uncertainty of the demand has been modelled by means of normal *pdf*: in each hour, the demand of load and FCS is represented by an expected value, μ_P, and a standard deviation, σ_P. For the traditional ‘fit and forget’ approach, the standard deviations have been nullified and the expected values in each hour have been matched to the maximum value derived from the probabilistic representation ($\mu_P + 3\cdot\sigma_P$). Moreover, in the probabilistic approach an acceptable risk of 5% to overcome technical constraints has been assumed, whereas for the ‘fit and forget’ approach no risk has been accepted.

It has been hypothesized that six 350 kW FCSs will be allocated in the same position of the actual petrol stations, which will be converted to hybrid distributors. As assumption, the secondary substation of each FCS has been connected in antenna to the MV network.

Table I reports the network expansion investments (CAPEX) for all the planning optimizations performed; the costs are actualized to the Net Present Value and do not take account of the investments for the new primary substation (invariant term of the Objective Function).

Table I. CAPEX for planning approaches

Planning approach	**without FCS**	**with FCS**	
		Case A	Case B
Traditional (deterministic)	1100 k€	1589 k€ (+44%)	2128 k€ (+93%)
Modern (probabilistic)	837 k€	928 k€ (+11%)	1017 k€ (+22%)
	–24%	–42%	–52%

Without FCSs (reference cases), the integration of the new primary substation requires the building of some new branches (underground cable with a cross section of 185 mm^2), with a total length of 9 km, for the probabilistic planning approach, or 10.7 km, for the traditional one. In both planning approaches, as expected, the voltage regulation requires also several upgrades of the existing 25 mm^2 and 40 mm^2 overhead conductors with 70 mm^2 cross section and the existing 95 mm^2 underground cables with 185 mm^2. The difference between the deterministic and the probabilistic approach is relatively small (24% of CAPEX reduction), because the level of uncertainties that characterise the planning scenario is low (related only to conventional loads).

The installation of the FCSs causes a growth in the network investments, due to the 2 MW of additional peak demand. First of all, it must be noted that the simple cost of their connection to the MV distribution network has been estimated in about 90 k€. Secondly, it is evident from Table I the major impact of the second FCS demand profile (case B) hypothesized, due to maximum power absorption nearer the peak of the conventional load.

Analysing firstly the traditional planning approach, it is manifest the CAPEX increment due to the FCS's connection. Heavier upgrades of existing branches are necessary and additional new connections have to be built. However, as mentioned before, the greater part of these costs is motivated only to solve rare extreme operating conditions (simultaneous maximum power absorption from all the loads and the connected FCSs during some specific emergency configurations). This observation is confirmed by the results obtained with the probabilistic planning approach. Indeed, having in mind the investment figure for FCS's connection, with the less stressful charging demand profile (case A) the optimal network scheme is essentially the same as the reference one, whereas with the more stressful profile (case B) the increment of the network investments is reasonable. The strong savings versus the traditional planning approach have been achieved accepting an extremely low probability of technical constraint violation: for instance, the network scheme in case B is characterised by a risk equivalent to suffer a voltage drop slightly larger than 10% in few nodes for less than 5 seconds per year.

CONCLUSIONS

The simple direct connection of fast charging stations to the MV distribution network may cause significant investments for the DNO. The results shown in the paper have highlighted the importance of the power demand profile representation on the entity of this impact: if some assumptions were incorrect, the network investment would be overestimated or underestimated, resulting cost-ineffective or causing power quality deterioration. Therefore, in-depth studies should be performed on modelling the future behaviour of EV's drivers.

Secondly, even with the correct model, the negative impact of the power demand growth due to FCSs can be still large, particularly when the distribution system is not strong enough. Hence, mitigating solutions should be deeply investigated, as for instance the "soft" connection of the FCS through the integration of dedicated energy storage devices [5, 10]. Also the optimal allocation and sizing of the FCSs may be fruitful to reduce investments, without omitting the potential benefits brought by the active management of the distribution network.

Finally, it is fundamental to emphasize the application of the correct methodology to perform MV distribution planning studies in the future scenarios. Uncertainties are still growing, introduced by renewable generation and unconventional loads, and probabilistic approaches are becoming essential [8].

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