

## TECHNICAL IMPACTS OF ELECTRIC VEHICLES CHARGING ON AN ITALIAN DISTRIBUTION NETWORK

Matteo DE MARCO  
Politecnico di Torino– Italy  
matteo.demarco@gmail.com

Erotokritos XYDAS  
Cardiff University – UK  
XydasE@cardiff.ac.uk

Charalampos MARMARAS  
Cardiff University - UK  
MarmarasC@cardiff.ac.uk

Dr. Liana M. CIPCIGAN  
Cardiff University – UK  
CipciganLM@cardiff.ac.uk

Prof. Maurizio REPETTO  
Politecnico di Torino– Italy  
maurizio.repetto@polito.it

Dr. Maurizio FANTINO  
Istituto Mario Boella – Italy  
Maurizio.fantino@ismb.it

### ABSTRACT

*To prevent climate changes, the leaders of European Union declared environmental targets for 2020, known as 20-20-20 targets. These targets aim at a 20% reduction in greenhouse gas emissions and energy consumption of the 2020 projected levels, as well as a 20% increase in the renewable energy penetration in the total energy production. The electrification of transport offers a good opportunity to decrease CO<sub>2</sub> emissions and increase the national energy security. Electric vehicles (EVs) are a mobile source of electricity demand, charging for relatively long periods of time and as a result of this, EVs could place significant coincident demand on the system. This increase in the system's peak demand may cause transformer and cables overloading and violation of the voltage limits. The main aims of this research was to evaluate the impact of Electric Vehicles on a real Italian distribution network, located in the north Italy, considering different levels of EVs penetration, initial battery state of charge and EVs charging scenarios.*

### INTRODUCTION

Environmental factors are driving Europe to adopt new policies and regulations towards a low carbon future [1]. As estimated in [2], road transport is a significant contributor to greenhouse gas emissions, being responsible for approximately 23% of all CO<sub>2</sub> emissions of EU Members. Electromobility offers a tempting alternative solution for transportation, given the fact that the “tank-to-wheel” efficiency of an electric vehicle is about three times higher than the efficiency of an internal combustion engine (ICE) vehicle [3]. EU funded projects like “Green eMotion” [4] and MERGE [13, 15], promote the electrification of transport by researching all possible aspects of EV penetration in societies.

Electric vehicle charging is a new type of electricity demand for the electric power systems, with special characteristics. Large scale integration of EVs requires an efficient management of the charging infrastructure and analysis tools are required to determine the effects

of adding large numbers of mobile loads to the grid. Even small clusters of uncontrolled vehicles charging at peak periods could significantly stress the distribution system, slowing EVs adoption and requiring major infrastructure investments [6].

According to literature, several scenarios exist regarding the charging profiles of the electric vehicles. In the early stages of EV integration, the number of the EVs is expected to be relatively small, and the EV owners will charge their vehicles mainly at home, without any controlled scheme [5]. With the EV number gradually rising, the EV owners could be incentivised to charge their vehicles following a Dual-Tariff scheme, to reduce their energy cost and at the same time decongest the peak hours [5]. In more mature stages of EV integration, advanced control algorithms for EV charging will be applied to optimize the network operation and increase the contribution of Renewable Energy Resources (RES) to the power system [5-11].

The main aim of this research was to study the impact of the different EV charging scenarios on a real Italian distribution network. Three different scenarios were considered, the Uncontrolled, the Dual-Tariff and the Smart charging scenario. A case of EV charging from renewables was also studied, considering EV charging events at a commercial area using power from Solar Panels.

### NETWORK TOPOLOGY

The modelled network consists of a three-phase source at 132kV; 132kV/15kV and 15kV/0.4kV transformers, 29 commercial loads connected at medium voltage and 26 residential loads connected at low voltage. Each low voltage load consists of 82 to 322 customers depending on the power demand. Figure 1 shows a schematic representation of the network.

The network was modelled in GridLAB-D software, a power distribution system simulation and analysis tool. GridLAB-D was developed by the U.S. Department of Energy (DOE) at Pacific Northwest National Laboratory (PNNL) under funding for Office of Electricity in collaboration with industry and academia [12].

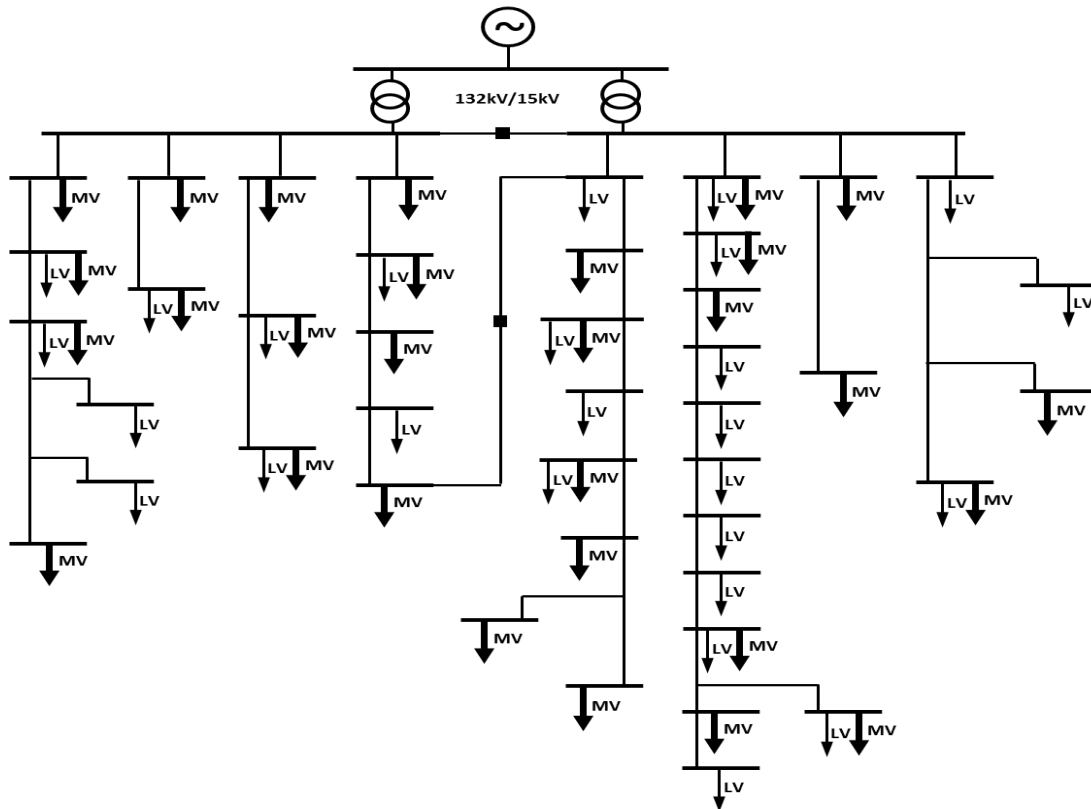


Figure 1. The Italian distribution network.

## CASE STUDIES

In Italy, passenger vehicles represent 75.4% of all vehicles on the road, while currently 0.1% of those are EVs [14]. The EV uptake will increase in the following years and for this research a 10%, 35% and 70% EV uptake was used for the year 2030 [13]. Using the average daily trip distance presented in [15], along with an average EV battery capacity of 30kWh, the State of Charge (SOC) of the battery was calculated. Battery Initial State of Charge (ISOC) was considered as the energy requirements of each charging event. The representative levels of 30% and 75% battery ISOC were assumed.

### Uncontrolled Charging Scenario

In this scenario, EVs are charging completely independently and random, without any control. The charging events mainly occur at evening hours when the EV owners return home after work.

Figure 2 presents the demand profile for the uncontrolled charging scheme, while Figure 3 shows the voltage drop at the charging point for different EV uptakes and different battery ISOC.

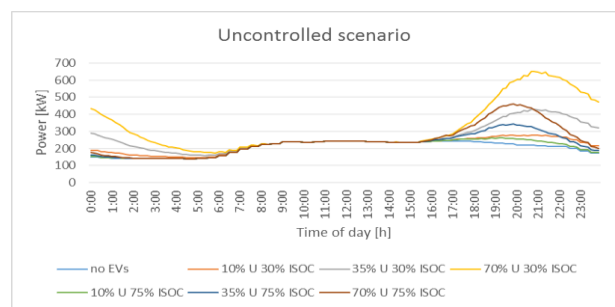


Figure 2. Demand Profile for the Uncontrolled charging scenario.

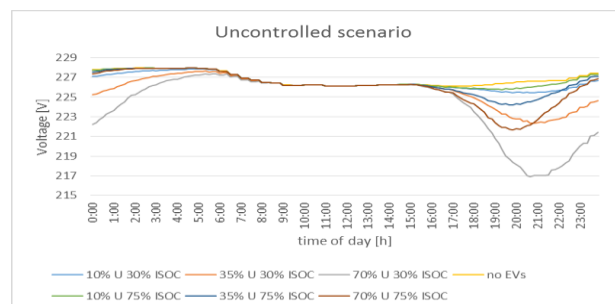


Figure 3. Voltage drop for the Uncontrolled charging scenario.

As expected, the worst case scenario occurs through the combination of minimum battery ISOC (30%) and maximum EVs uptake (70%). In this scenario, the voltage reaches the lowest value of 217 Volts at 21:00, when the demand is 640kW (peak value). This peak value is due to the combination of the peak residential demand and EV charging demand.

According to CEI EN 50160 [16], the rated value of the phase to neutral voltage is 230 Volts and the maximum admitted swing is  $\pm 10\%$ . Therefore, the bottom value of 217 Volts does not exceed the lower limit of 207 Volts. However, the transformer is overloaded due to the high demand.

### Dual-Tariff Charging Scenario

In order to reduce the electricity demand during the day, a dual tariff pricing policy (different price for day and night) from the energy supplier is assumed. Therefore, the EV owners would prefer to charge their vehicles when the electricity price is low, so the charging events start in late evening hours.

Figure 4 illustrates the demand profile for the Dual-Tariff charging scenario, while Figure 5 presents the corresponding voltage drop for different EV uptake levels and battery ISOC.

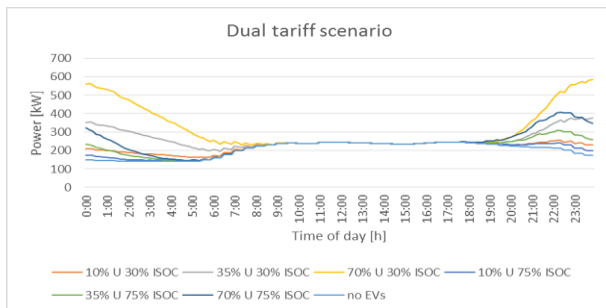


Figure 4. Demand profile for the Dual tariff scenario

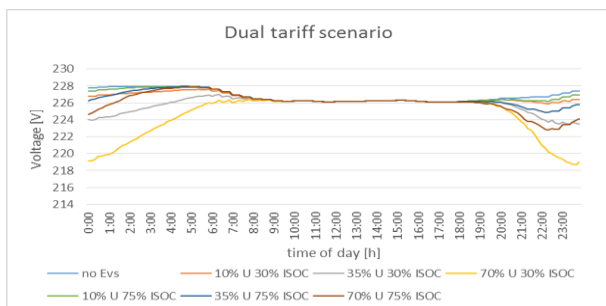


Figure 5. Voltage drop for the Dual tariff scenario

The peak value of the EV charging demand, as well as the lowest value of the voltage is shifted by 3.5 hours from 21:00 to 00:30. The total demand peak is reduced by 16% from 650 kW to 560 kW as the EV load profile reaches the peak at a different hour than the residential

load profile. Figure 5 shows that the voltage drop is also reduced from 13V to 11V.

The power peak is reduced, but the transformer is still overloaded, while the voltage is into the permissible limits.

The dual tariff scenario demonstrates the possibility of limiting the impact of EV charging in the distribution network through financial incentives.

### Smart Charging Scenario

In the smart charging scenario, the EVs charging is assumed to take place in the off-peak hours of the residential load profile, filling the valleys of the demand curve.

Figure 6 presents the demand profile and the Figure 7 illustrates the voltage drop at the charging point for different EV uptakes and battery ISOC levels.

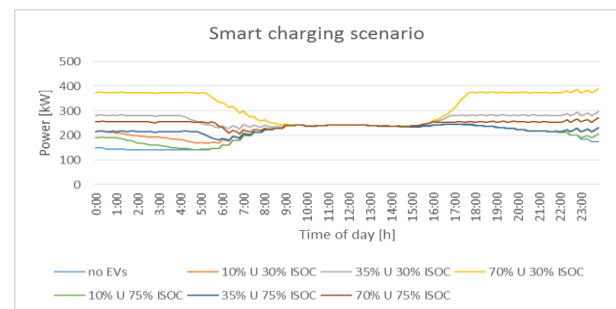


Figure 6. Demand profile for the Smart charging scenario

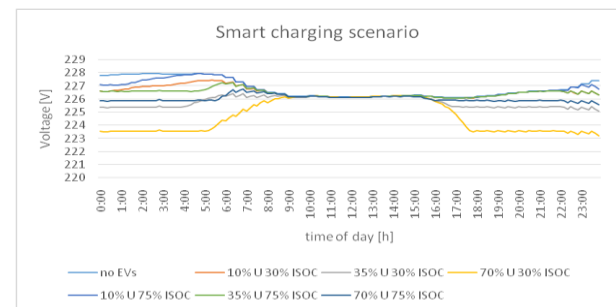


Figure 7. Voltage drop for the Smart charging scenario

Figure 7 displays an improved voltage profile for every case. The lowest value of 223.5V is measured in the worst case scenario (70% EV uptake and 30% battery ISOC). The voltage drop is reduced by 65% (from 13V to 4.5V) compared to the Uncontrolled scenario and by 59% (from 11V to 4.5V) compared to the Dual tariff scenario. The demand peak reduction reaches the 35% for the case of 70% EV uptake with 30% battery ISOC, while all other cases show a decrease in the peak. The overload is reduced by 67.5% compared to the uncontrolled scenario and by 60.6% compared to the dual tariff scenario.

This scenario demonstrates that the DSO could reduce the impact of EVs in the distribution network significantly by implementing a smart charging control strategy.

### Charging EVs from Solar Panels

Solar energy can play an important role in lowering greenhouse gas emission by replacing coal-powered energy source with clean, renewable solar photovoltaic (PV) technology in order to reach the 20-20-20 targets of the European Union [1].

In this case study charging the EVs from solar panels was considered. The EV owners have the possibility to charge their vehicle from the solar panels at work, reducing the need of charging when they return home. Two levels of installed PV were assumed to exist in the parking lots of the EV owners' work premises. Following this charging pattern the EV charging demand during the night is expected to be reduced, since the EVs arrive at home with a higher battery state of charge.

For this case study photovoltaic panels were modelled in Gridlab-D with different generation profiles and power. The online tool PVGIS [17] was used to generate the profiles for PVs placed in the geographical area of the real distribution network (north Italy). Two profiles were generated, one for winter and one for summer, with capacities of 135kWp and 270kWp, presented in Figure 8.

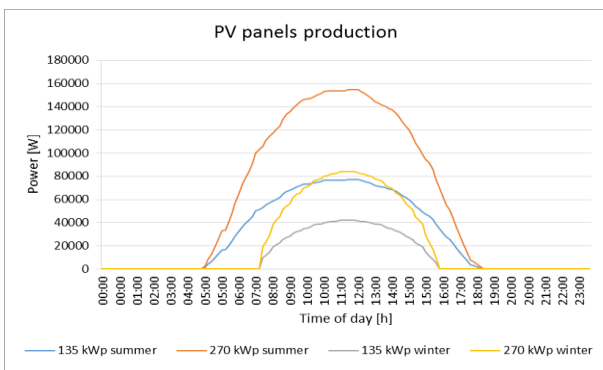


Figure 8. PV panels generation profiles

Considering the worst case scenario of EV uptake and battery ISOC (70% penetration with 30% ISOC), the voltage and power profile were calculated for all charging scenarios (Uncontrolled, Dual tariff and Smart charging). In order to highlight the improvements from the best charging strategy, only the improvement from the Smart Charging Scenario is presented in Figure 9 and Figure 10.

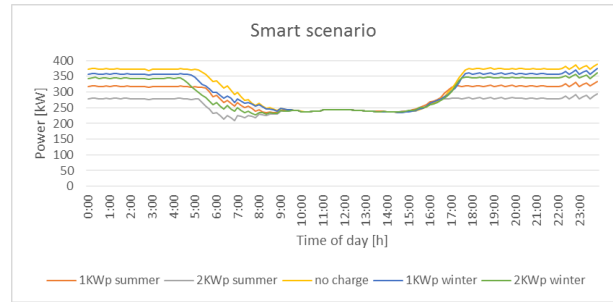


Figure 9. Demand profile for Smart Charging after charging from PV at work

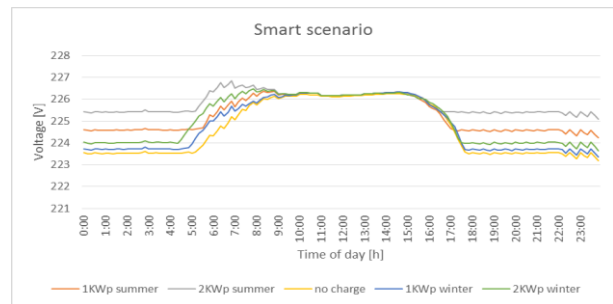


Figure 10. Voltage drop for Smart charging after charging from PV at work

Considering the 135kWp case in winter, Figure 10 shows an improvement between 0.1V and 0.2V, while Figure 9 illustrates a reduction of demand by 12kW. In the summer the situation is completely different. Considering the 135kWp case the voltage figure lists a reduction of voltage drop by 1V (ten time better than winter) and the Figure 9 shows an improvement of 50kW (four time better than winter).

In the summer the improvements for voltage and power are significant because the network is located in north Italy so the PV power generation is significantly higher. In the winter the weather is not generally sunny and the performance of the PV panels is decreased.

This case study demonstrates a reduction of the impact of EVs in the distribution networks compared with the case study without charging capability from solar panels at work.

The impact of EVs in the distribution networks can be further reduced through a combination of a smart charging strategy with charging from PV generation.

## CONCLUSIONS

The increasing EV charging demand is a new challenge for the management system of the future distribution networks. This demand is an additional load on the distribution networks, and EVs charging at peak periods could significantly stress the distribution networks requiring major infrastructure investments.

This research demonstrates that the distribution networks are highly sensitive to the EVs uptake and charging strategy. This research also shown that if the suitable EV charging strategy is used, the existing grid will support a significant number of EVs avoiding network reinforcements. The smart charging regime can minimize the impact of EVs charging on the distribution networks comparing with the uncontrolled and dual tariff charging regime.

Charging capability from solar panels at work will have a beneficial effect in the reduction of peak demand. The research shows a 50kW reduction of EV charging demand in the summer.

A real distribution network located in the north Italy was used for a realistic analysis.

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