Electric Vehicle CPMS and Secondary Substation Management

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***Abstract* — The increasing adoption of Electric Vehicles (EVs) is leading to a fast transition on electrical distribution networks, where charging stations are being deployed on a large scale to accommodate the EV users' needs. Considering distribution networks were typically not prepared to accommodate a large deployment of EV charging stations, as they tend to require large amounts of energy from the grid in short periods of time – leading among others to lines congestions and voltage issues- and with a volatile demand profile resulting from the variability of consumption, there is the need of finding new solutions to cope with these challenges in order to guarantee the efficient and safe operation of the networks, while maximizing the availability of power to satisfy consumers' needs. This paper presents an innovative Electric Vehicle Charging Point Management System (EVCPMS) that more than a solution capable of effectively tackling these technical operation problems through the management of charging infrastructures is also endowed with customer-oriented services, enabling user's management, such as automatic billing different energy profiles and administration functionalities.**

***Index Terms*—Electric Vehicle, Smart Charging, Distribution Networks;**

I. Nomenclature

CPMS	Charging Point Management System
DMS	Distribution Management System
DSO	Distribution System Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
HV	High Voltage
LV	Low Voltage
MV	Medium Voltage
SCADA	Supervisory Control and Data Acquisition
SCM	Smart Charging Management
OMS	Outage Management System
WFMS	Work Force Management System

II. Introduction

THE increasing awareness of consumers about the climate changes and the economic attractiveness of Electric Vehicles (EVs); massive rollout of new charging infrastructures such as fast charging stations, public and domestic charging points and private charging stations in distribution networks namely at the Low Voltage (LV) level, is expected at the upcoming years. Hence, it will lead to the growing of demand at the distribution networks, which have not been designed to accommodate such load types, and thus may pose several impacts to their operation, namely: lines congestions resulting from high demands during periods of charging and voltage sag situations, as well as increased grid losses [1]. The combination of all these effects possibly urge the necessity to reinforce particular component part of the networks (i.e. lines, transformers) [2]. In order to mitigate periods of high consumption that would require investments in the reinforcement of the existing electrical infrastructures and/or new electric infrastructures, and to maintain high standards of energy efficiency, continuity of service and energy quality, it becomes necessary to introduce new systems and solutions to optimize the operation of distribution networks. On top of that, the monitoring capabilities at the Low Voltage (LV) levels is typically limited. In fact, in other networks such as Medium Voltage (MV) and High Voltage (HV) networks, their monitoring is required in order to ensure a safety supply of the energy and control the impacts of external actions to the systems (e.g. faults) in the assets. Consequently, the DSOs have mostly redirected their investments to MV and HV networks. Nonetheless, with the ongoing changes in LV networks this paradigm is changing, and the importance of these networks in the overall electrical power system is growing.

This work presents a novel system that provides the efficient management of EV charging points as well as the management of the Secondary Substation, comprising two distinct modes: i) the planning mode, where the EVs charging stations are operated considering the expected network conditions and demand needs on a short-term – up to 24h ahead and ii) near to real time operation where the planned EVs charging stations operation is adjusted to take into account the real operation conditions. The focal point of this system is to avoid the increase of the peak load ensuring the safe operation of electrical networks within the admissible technical limits (e.g. within lines capacity). Besides the management itself through the CPMS, this paper also details the required equipment to be installed on the field in order to accomplish the optimized operation of the EV charging infrastructures. A discussion about the evolution of the DSO business model is also provided in this paper.

III. Exploitation Models of EV Charging Infrastructures

In this section the typical actors involved on the EV charging value chain, will be briefly discussed.

- **DSO:** typically the entity responsible for the operation and management of distribution networks – High, Medium and Low Voltage networks. For this purpose, the DSO typically owns systems such as Supervisory and Control Data Acquisition (SCADA)/Distribution Management System (DMS) for the monitoring and general overview of the state of the network. It also owns other systems such as the Outage Management System (OMS) and Work Force Management System (WFMS) for addressing the network operation problems related with the continuity and quality of service.
- **CPO**: Charge Point Operator: entity that technically manages all the EV infrastructure assets, depending of existing country regulation – this role can be assured by the DSO or other entity.
- **eMSP:** Electric Mobility Service Providers, which is the entity that can explore the economic side of the EV charging infrastructure, namely by selling energy for charging purposes.
- **CPMS:** Charge Point Management System that is a software system that manages the charge point infrastructure – can manage either the technical and economic aspects of the charging infrastructures.
- **EV Driver:** Person or entity who owns an EV car and can use the public or private facilities for charging purposes.
- **EVSE:** Electric Vehicle Supply Equipment responsible for the charging of the EV. It is an equipment that is able to charge EV batteries with AC or DC loads and with different rated powers depending on the type of equipment.
- **Private parking:** can be a condominium, industry or other entity who has private owned EVSEs to be shared among users such as the case of an EV fleet.

The technical and economic exploitation of the charging infrastructures can be carried out under different strategies, depending on different conditions such as the existence of a regulated or non-regulated market. In such a way two different operation models can be considered, as described following.

A. DSO Exploitation Model

On the DSO model, illustrated in Figure 1 and Figure 2, the DSO owns the EV infrastructure and can explore commercially the infrastructure or not (similar to regulated / non-regulated energy market). In this case the DSO also owns and manages the CPMS as well as is responsible to maintain the EV infrastructure, communications, demand response program and MV/LV network technical parameters.

In the case of non-regulated market, the DSO can have an interface so that the eMSP can connect to the CMS. In this case the eMSP is responsible for first level helpdesk with EV drivers, billing, interface with financial payment services, EV drivers' services such as EV portal and mobile applications.

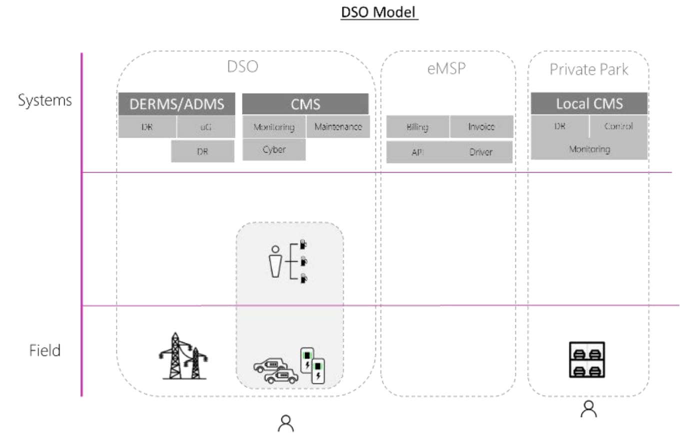

Figure 1: DSO model architecture

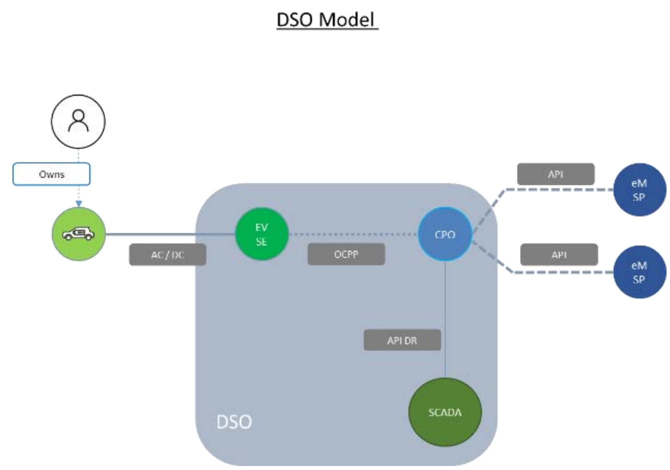

Figure 2 : DSO model involved actors

B. Operator Exploitation Model

The **operator model,** depicted in Figure 3 and Figure 4, is based on a totally deregulated market where the EV infrastructure installation, maintenance, CPMS management are solely managed by other entities different from the DSO. In this case, the DSO will be further about technical parameters on LV network, demand response and products for load management on EV infrastructure.

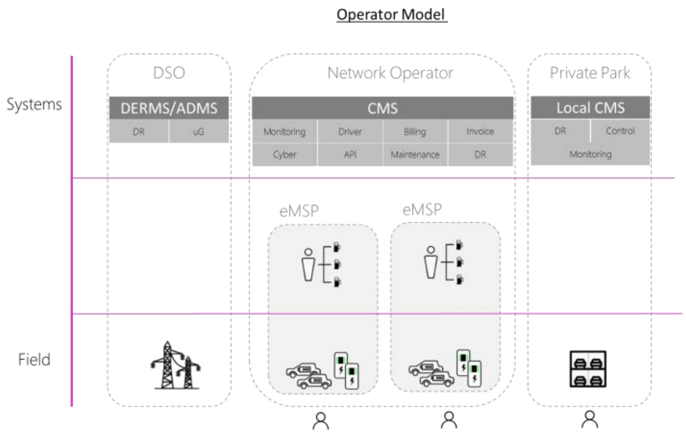

Figure 3 : Operator model architecture

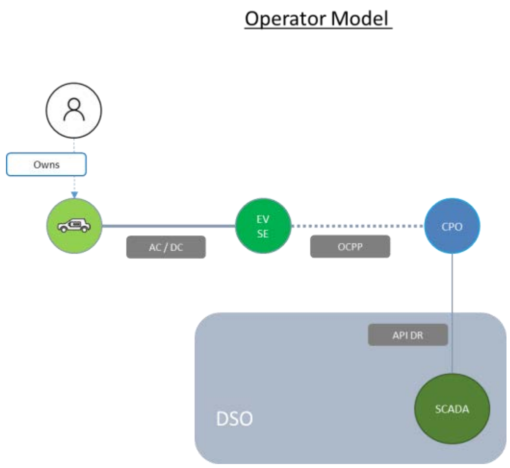

Figure 4: Operator model involved actors

IV. Proposed Solution

A. Field Equipment

As previously mentioned, distribution networks are typically not prepared to accommodate a large rollout of EVs and their subsequent charging infrastructures, since these assets typically require large amounts of power in short periods which would require investments in the reinforcement of the distribution networks. The lack of measurements (i.e. not fully observable system) is addressed by the deployment of a small number of sensoring equipment, as further explained. This information gathered by the sensors will be obtained and processed in order to essentially manage and operate the network and the downstream connected EV charging points.

The proposed architecture for the equipment to be installed on the secondary substation is described on Figure 5.

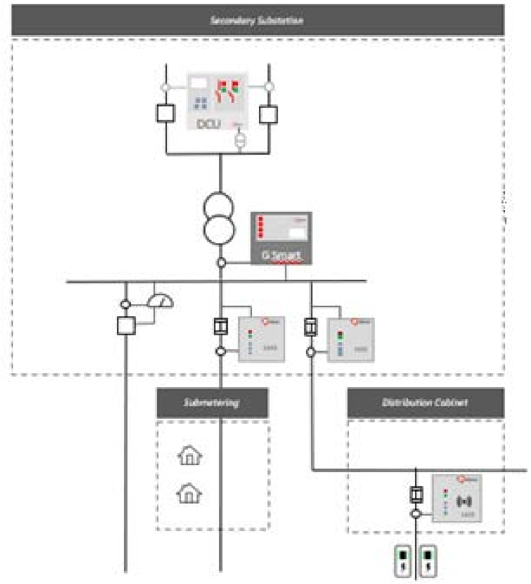

Figure 5 – Equipment deployed on Secondary Substation.

The equipment that can be installed on the secondary substation and in the network is:

- **MV panels controller**: this equipment (EFACEC DCU220) is an equipment that is able to monitor and controller several MV circuit breakers capacitor banks and other Intelligent Electronic Devices (IEDS). It is capable of performing fault detection under different protection schemes (e.g. overvoltage and undervoltage), battery management and SCADA integration using standard communication protocols such as the IEC 870-5-104 or DNP. This equipment will be the main responsible for providing information to SCADA systems regarding the operation condition of the MV network;
- **Distribution Transformer Controller (DTC):** this equipment (EFACEC GSmart) is a data concentrator with the capability of gathering data from smart meters and other deployed sensors in the networks, using Radio Frequency (RF), Power Line Communications (PLC) and other heterogenous communication technologies. It can be integrated with high level systems such as Head End System (HES) that are property of the DSO. It is also featured with control capabilities being also capable of monitoring variables on the secondary side of the distribution transformer such as voltage, current and active and reactive power flows.
- **LV Feeders Sensors:** this equipment (EFACEC LVS3) is to be installed on LV feeders throughout the network, and is able to monitor voltage, current, power, energy, fuse blown. On top of that, it is also capable of performing a continuous assessment of the energy power quality by measuring among others overvoltages, undervoltages, power failures (both duration and frequency) and Total Harmonic Distortion (THD). With these sensors it will be possible to compute a reliable state of operation of the LV network.

B. Charging Point Management System

The EV CPMS solution proposed is shown in Figure 6. The CPMS consists of several modules with the following functions:

- **Integration with EVSE:** the CPMS is able to integrate with different EVSE suppliers, typically using open standards like OCPP (Open charger point protocol). The CPMS has the OCPP version 1.6 which enables among others to send a planned rated power consumption to the EVSE attending to the operation conditions in the network;

- **Tariff management:** module that calculates tariffs for energy sessions. This module is customized and can be adjusted to the preferences of the entity responsible for commercially managing the charging stations;

- **API and integration with eMSP:** Application Program Interface (API) to interface the CPMS with the different eMSP;

- **Smart Charging Management:** module that is capable of interface with several modules such as the SCADA, the EVSE and also with EV driver portal, where customers can for instance plan an EV charging. This module is responsible for collecting technical information regarding operation conditions of the network, as transformer load profiles, voltages and power flows gathered by sensors in the networks and users' information to afterwards operate the EV charging stations. It also gathers load forecast information for the secondary substation– typically provided by the SCADA/DMS. Load forecast: the load forecast is the module (possible already included on SCADA).

The operation of the SCM is performed in two distinct modes: i) planned operation, comprising the short to medium term (few hours ahead) – where the SCM sends and optimized charging schedule for EVSE and the near to real time operation where the SCM adjusts the planned operation to the real operation conditions of the network.

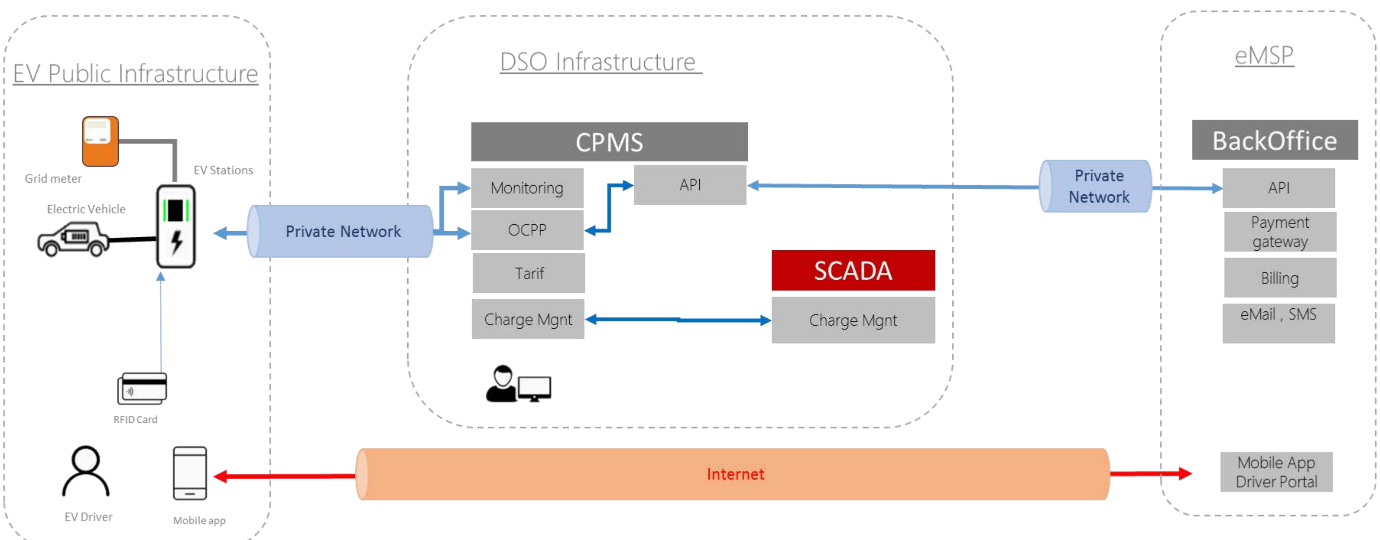

Figure 6 – EV CPMS overall system architecture.

C. Smart Charging Approach

Figure 77 illustrates in detail the interactions between modules for the smart charging of the EVSE. At first place the EV Driver requests a start session – request for starting the charging of an EV -, and the EVSE will request authorization to the CPMS using the OCPP protocol. Afterwards, the CPMS will identify to which secondary substation the EVSE is connected to. This information will be then used by the CPMS to request to SCADA/DMS information about the current and forecasted operation conditions for the network. Finally, using the EV driver information and load forecast will calculate the optimized charging schedule. The optimized schedule will be then transmitted to the EVSE through OCPP protocol.

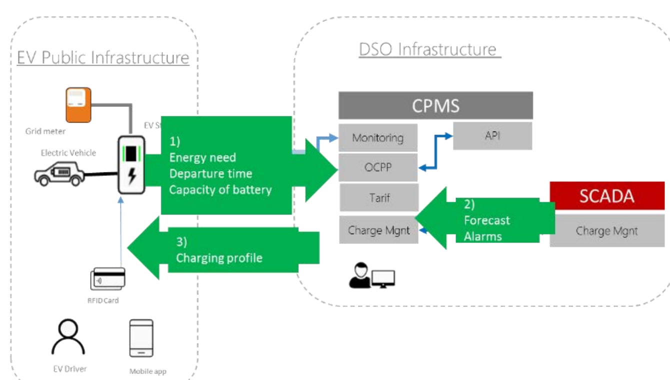

Figure 7 – Interaction flow during smart charging.

The internal algorithm of the CPMS takes into account the following variables for proceeding to the optimization of the EV charging:

1. EV Driver / car requests
   a) Departure time
   b) Capacity of battery need energy
2. Secondary substation transformer load
   a) Get from SCADA the 12h/24h load forecast of the transformer
3. Existent load schedules
   a) Even if the session request is new, it´s possible that the secondary substation has already active sessions, so they shall be used for the schedule optimization
4. The last consideration for the algorithm is the charging restriction of the EVSE and other equipment such as:
   a) Maximum and minimum charging power limit
   b) Available (rated) power of the facilities

Finally, the optimization module computes the EV charging profiles with the objective function of flattening the load diagram of the distribution network and to avoid technical operation problems in the network such as lines congestions, using all the above-mentioned considerations.

V. Results

In this chapter is detailed an example of the results obtained when the smart changing is used.

In Figure 8 is illustrated the interface used by an EV driver to request a charging of an EV. The user introduces several information such as the departure time.

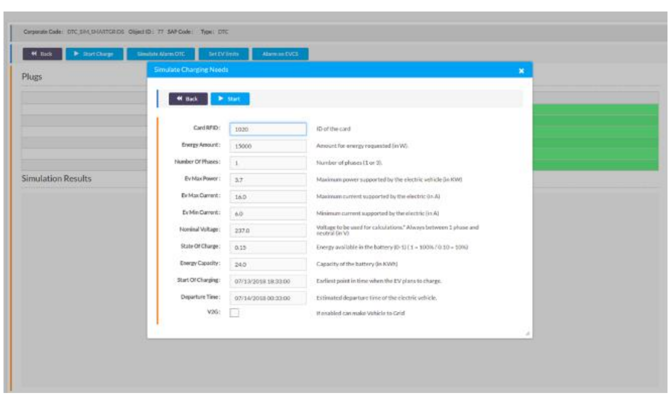

Figure 8 – EV Driver Request example.

Based on the information introduced by the EV drivers, the CPMS allocates to each EVSE a charging profile attending to the operation conditions of the network. Figure 9 shows the existing EVSEs allocated to the secondary substation transformer, and the line chart depicts the different EV charging profile to send to different EVSEs.

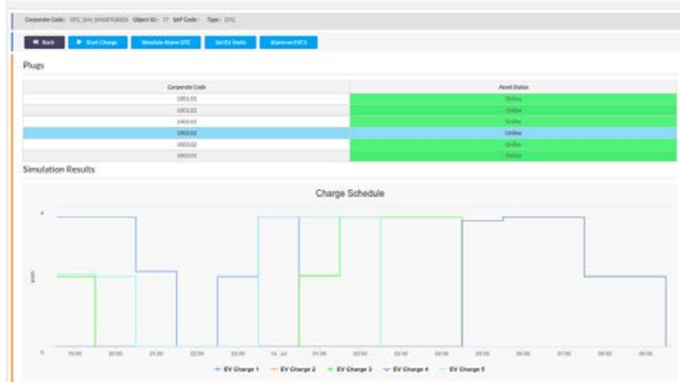

Figure 9 –EVSE charging profile allocation to a secondary substation.

With the smart charging is possible to change the load profiles on the secondary substation by managing EV charging. The comparison between Figure 10 and Figure 11 allows to identify the difference in peak loads at the secondary transformer, between an optimized charging solution and non-optimized.

Through the analysis of Figure 10 it is possible to observe that the non-optimized schedule has a peak charging need of 12kW, while on the optimized scheduled charging process - Figure 11 , the maximum peak is around 8 kW. This way, it was possible to perform peak shaving at the level of the secondary substation.

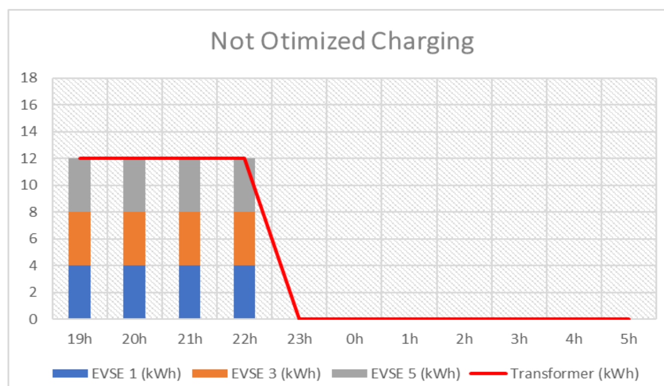

Figure 10 – Non-optimized charging profile.

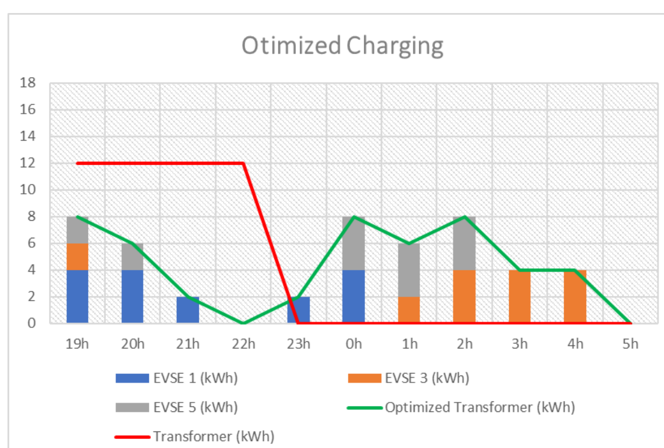

Figure 11 – Optimized charging profile.

VI. Conclusions

The EV Market is starting to grow, being driven by the arise of normative and regulations such as the European Union directive 2014/94, that recommends the creation of alternative charging infrastructure, with a relation of 1x EVSE to 10x EV Cards. This lead DSOs and Energy regulators to persevere to endeavour for new control and management functionalities based on advanced automation and monitoring, in order to address all the operation challenges posed by the large integration of EVs and microgeneration. .

Although distribution systems can handle the integration of EV up to a certain level without any load management functionalities, their integration in a large scale will surely oblige DSO to invest in network reinforcements. An alternative path is the implementation of EV charging management systems that can adapt the EV load profiles to the network needs.

A novel EV CPMS was presented in this paper, which is designed to control the EV load considering simultaneously the EV characteristics, the EV owners' requirements and the electricity network technical limitations. The system is developed with the capability of being integrated with existing commercial equipment for smart grids, such as SCADA/DMS systems.

The main differentiating aspect of the EVCPMS with smart charging is that DSOs can differ investments in the reinforcement of distribution networks while increasing the adoption of EV charging infrastructures in these networks.

VII. References

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VIII. Biographies

Konstantinos Kotsalos was born in Athens, Greece in 1991. He received his diploma degree in Electrical and Computer Engineering in February 2015 from National Technical University of Athens (NTUA). His thesis covered an extended research in Decentralised Voltage Regulation for Radial MV Networks with high presence of Distributed Generation. In 2015 he accomplished his military service. From January to June 2016, he was involved in two SCADA projects of the Greek DSO (HEDNO) as representative engineer of Efacec. Currently he is conducting his PhD research at Efacec in collaboration with Faculdade de Engenharia da Universidade do Porto (FEUP), as member of INCITE network. Among his main research interests are Integration of Distributed Energy Resources, Power System Analysis, Voltage Regulation and Multi-agent Based Systems.

Luis Marques was born in Paredes, Portugal in 1993. He received the M.Sc. degree in electrical engineering from the Faculty of Engineering, University of Porto, Porto, Portugal, in 2016. Currently, he works in the R&D of the Smart Grids division of the Automation Business Unit, EFACEC, Porto, Portugal. His work is focused on the research and development of new solutions that allow to improve the operation and management of electrical power systems, being involved in several pilot projects, with national and international partners. His research interests include distributed generation, smart grids, demand response, automation and optimization of distribution networks.

Filipe Campos was born in Guimarães, Portugal in 1973. He receives diploma degree in Electronic and Informatic in 1997 and MSc degree in electrical engineering from the Faculty of Engineering, University of Porto, Porto, Portugal, in 2003. He has 20x years' experience in R&D for system in SCADA, SCADA protocols, HV-MV Automation and SmartGrids. Currently he is R&D Manager for SmartGrids