

4.1 Final publishable summary report

Executive Summary

The future massive integration of Electric Vehicles (EV) in electricity grids is very likely to pose several challenges to power systems' operation and expansion. However, the potential flexibility of the load associated to the EV charging offers the opportunity to provide a new category of services to the system operators, which will effectively contribute for "smartening" the grids, facilitating the transition towards the Smartgrid paradigm. This is further enhanced, as EV will require the use of batteries with high energy storage capacity. The extensive deployment of EV might also contribute to integrate larger amounts of Renewable Energy Sources (RES) in EU countries' power systems, contributing to the reduction of the greenhouse gases emissions and the external dependency of primary energy. The MERGE Project addressed this topic in a holistic perspective, seeking to evaluate all the possible effects of the introduction of EV that are directly relevant to the future development of the power system. The evaluation performed covered a wide variety of subjects, such as the modelling of the EV and of its most relevant components, steady state operation, intermittent RES integration, system stability and dynamic behaviour, power quality issues, system restoration schemes, the planning of electricity generation/transmission/distribution infrastructures, reserves adequacy, regulatory aspects, business models, effects on markets, etc. Novel network structures foreseen in the transition to the Smartgrids paradigm including smartmeters, microgrids, virtual power plants, etc, have been considered.

The first concern of the project was to specify the technologies that enable an efficient integration of EV in EU electricity grids, such as EV charging infrastructures, smart meters and communication platforms. Taking into account these specifications, a set of methodologies and an evaluation suite were developed, composed of several simulation tools, which were used to perform a thorough assessment of the technical, economic and environmental impacts that are expected to arise from the large scale deployment of EV. The methodologies and tools developed constitute a very important milestone of the MERGE Project, as the majority of them can be directly used to analyse the EV impacts in any electricity network.

Alongside with the impact assessment studies, several conceptual solutions to manage large scale integration of EV were proposed. Examples of these concepts are the smart charging scheme, the EV supplier/aggregator entity, the identification of the interactions among different system agents, as well as the associated information flow, and the EV participation in primary frequency control and in the operation of the automatic generation control.

The main conclusions of the work developed in the MERGE Project are that the magnitude of the EV impacts are influenced by several factors, like the EV integration level, the EV owners' behaviour, mobility patterns, the networks' load profiles and their technical characteristics, the number and location of fast charging stations in the grid and the EV charging modes, among others. Regarding forecasts for the EV integration levels in 2020 and 2030, it was concluded that, independently of the charging strategy adopted, no relevant technical problems are expected to occur in the majority of the European power systems until 2020. Conversely, in 2030, several problems may arise, if uncontrolled EV charging approaches are adopted, which will lead to large investments in network reinforcements. Nevertheless, these problems may be solved if proper controlled charging schemes and appropriate regulatory solutions are implemented. Besides postponing network reinforcements, the controlled charging schemes allow integrating larger amounts of RES without jeopardizing network normal operation.

The overview of the results obtained in the MERGE project clearly indicates that the path to safely integrate large quantities of EV in the power systems, without making large investments in grid reinforcements, is to implement mechanisms that allow managing the EV charging not only taking into account their owners' requests, but also the networks' technical

restrictions. Nevertheless, as it was clearly referred in the Project, the adherence to these controlled charging schemes should always be a decision of the EV owners. Thus, it is of utmost importance to timely define and implement adequate incentives' policies, attractive enough to make EV owners willing to participate in such controlled charging schemes. Additionally, it was concluded that the standardization of EV charging equipment should be tackled in order to guarantee an effective implementation of the EV charging management strategies and control schemes developed within the Project.

Another important conclusion drawn from the work developed is that different levels of EV integration have different requirements on design of electricity markets and network regulation. Three distinct phases regarding the evolution of the EV deployment have been identified by the MERGE partners, which are related with immediate, mid-term and long run EV deployment. For each of these phases, several policy and regulatory recommendations were provided. In summary, the biggest immediate challenge is to foster the uptake and create confidence in this new technology. Further on, figures facilitating the integration of EV via aggregation and market participation should be addressed. Finally, in the long run, more complex and technically challenging services, like the provision of reserves, should be made possible.

Project context:

Electric power systems are facing a major new challenge (and hence opportunity): the future massive integration into the electric grid of hybrid/pure electric plug-in vehicles (EV). The stimulus of this change is that electricity is likely to become the preferred energy vector for a new generation of road vehicles. Although conventional fossil fuels can be used to generate electricity to feed EV, this project will focus on the quantification of the allowable amount of renewable energies that can be integrated into the electric power system, as this is a more desirable option, which would greatly reduce CO₂ emissions.

The plug-in EV technologies which are likely to be developed over the next 20 years for the global vehicle market are: plug-in hybrid electric vehicles (PHEV) and pure electric vehicles (EV). Pure EV are driven only by electric power stored in batteries, while current plug-in hybrid electric vehicles also use mechanical power obtained from internal combustion engines. While hybrid vehicles are expected to be massively sold in the markets in a near future, pure electric vehicles should take a little longer to attain considerable market shares. Nonetheless, the economic incentives provided by policy makers, the oil and gas prices evolution and the growing pressure to reduce CO₂ emissions are important variables which might influence the deployment of both technologies along the next few years. In the following "Electric plug-in and plug-in hybrid vehicle" are referred by "EV" only.

Nowadays, distribution/transmission grids and power system architectures still follow planning rules and procedures defined for a traditional operational paradigm. However, the planning problem is becoming more complicated by the fact that a considerable number of assets of the European transmission and distribution networks are approaching the end of their useful life and will need to be replaced. The SmartGrids paradigm may respond to these challenges. It brings considerable changes to power system planning and operation that will ease the introduction of the large scale distributed loads/storage that electric plug-in vehicles represent. However, in order to avoid unpleasant surprises in the future, it is necessary to identify and prepare preventive solutions for the operational problems that might appear as a result of progressively increasing EV deployment.

In terms of the electric power system, EV can be considered as:

- Simple loads, e.g. when their owners charge the batteries at a certain rate at any time;
- Dynamic loads/storage devices, if their owners define a time interval for the charging to take place, allowing some EV management structure to control the process. From the grid point of view, this approach provides elasticity of these new loads, allowing the management structure reducing/increasing its values (or even request the battery to inject active power into the grid) when such action is needed.

Looking to EV as a simple load, it represents a large power consumption, which can easily amount to half the power consumed in a typical domestic household at peak load. Thus it is easy to foresee major congestion problems in already heavily loaded grids and voltage profile problems in predominantly radial networks, particularly if the peak load periods coincide with EV charging periods. Hence, if no load management strategies are defined, significant technical problems will occur and their drawbacks might even be larger than the economic/environmental benefits arising from electric vehicles usage. These management strategies can be adopted in two ways: a) by developing a dynamic price signal approach such that EV will charge predominantly during low energy price moments or b) by developing a technical management system such that charging can be distributed during valley hour periods and at times when there is large renewable power generation.

Furthermore, EVs can be regarded also as dispersed energy storage that can be provide ancillary services, i.e. provision of primary and secondary reserves, congestion relief in some grids by shaving peak loads and improvement of system dynamic behaviour in normal and emergency conditions. This is the Vehicle-to-Grid (V2G) concept that if adopted could also provide additional revenue for vehicle owners.

There are two ways of accommodating the presence of EV battery charging in the distribution grids. The first is to plan for new networks in such way that they can fully handle the new loads, regardless of the control scheme, requiring heavy investment in network reinforcements. The second is to create a smart management system that fully integrates EV in the power system, exploiting also their potential to store energy and thus optimizing network investments. The latter is, of course, the way that needs to be pursued.

Progressive replacement of conventional vehicles by EVs will require two types of interfacing structures:

- a) charging stations used to charge fleets of EV or to charge EV that require fast charging, including battery replacement stations, and
- b) domestic or public individual charging/grid interface points for slower charging.

Both cases need to be considered when addressing the problems that will result from this vehicle technology shifting. While the investment in a station to replace batteries in urban areas, covering a high number of EV, makes economic sense, the individual charger is the solution that fits rural areas better. When EV are required to make longer journeys, battery replacement stations will start appearing outside city areas, perhaps nearby main roads. Still, EV individual chargers are expected to be the main interfacing structure with the grid, given that they are more convenient for EV owners and more attractive to Distribution System Operators (DSO), as they can be used as for dispersed storage. In any case, the development of standards for connecting EVs to power grids still requires significant efforts.

Main Conceptual Approach involved in the Project

The conceptual approach developed in the project consists of two synergetic pathways:

- Development of a management and control concept that will facilitate the actual transition from conventional to electric vehicles - the MERGE concept (Mobile Energy Resources in Grids of Electricity) ;

- Adoption of an evaluation suite of tools based on methods and programs enhanced to model, analyze, and optimize electric networks where EV and their charging infrastructures are going to be integrated.

The MERGE concept differs from the projects developed so far to study the Dispersed Energy Resources (DER) deployment in one important aspect: it considers that the resources are mobile in terms of their connection to the grid. By considering the impact that DER had in electrical grids and the need for specific control strategies, analogies are being derived and adapted to the case of mobile resources, that can be either consumers (when in charging mode) or producers (if batteries deliver stored active power to the grid).

Project Mission

The project mission is the evaluation of the impacts that EV will have on the EU electric power systems regarding planning, operation and market functioning. The focus is placed on EV and SmartGrid/Microgrid deployment aiming to renewable energy increase and leading to CO₂ emission reduction through the identification of enabling technologies and advanced control approaches.

Scientific & technical objectives:

The main scientific and technical (S&T) objectives of this project are:

1. To develop a management and control concept – the MERGE concept – and to identify potential smart control approaches (both centralized and decentralized) to be adopted by system operators, based on the SmartGrid and MicroGrid concepts, to allow the deployment of EV without major changes in the existing network and power system infrastructures;
2. To provide insights into the dynamic behavior of power systems having a large penetration of EV together with intermittent RES, concerning balancing and black start procedures and all other aspects related to grid dynamic operation and control;
3. To address the impacts on generation and grid infrastructures planning, evaluating at the same time the required/deferred investments due to the simultaneous presence of intermittent RES and EV in the grid;
4. To identify the most appropriate ways to include EV into electricity markets, including an evaluation of how smart metering should take the presence of EV into account;
5. To propose a regulatory framework capable of: a) treating EV users in a fair and non-discriminatory way and b) defining a way to deal with the additional investments in control and management structures that network utilities will have to make, in order to reliably accommodate a large number of EV;
6. To provide quantitative results on the impact of integrating EV into the grid of EU national power systems. These results refer to load consumption profiles, generation schedules, power flow patterns (allowing network losses, congestion levels and voltage profiles evaluation), power quality and CO₂ emissions;
7. To provide an evaluation computational suite able to identify and quantify the benefits that a progressive deployment of the MERGE concept will bring to the EU national power systems, taking into account several possible smart control approaches.

Work performed throughout the project and main results achieved

Specifications for an Enabling Smart Technology

- The technologies required to achieve plug-and-play for the connection of electric vehicles to the electric grid were specified. A review of the power stage and

information and communication technology (ICT) stage of the existing charging technologies was conducted leading to recommendations. Details on the sequence of steps taken during a charging process, a discussion on different payment methods, and considerations for battery longevity were made. The ICT design including communication paths between the involved stakeholders were introduced for a variety of Charging Point (CP) locations.

- Existing smart metering solutions and, standards enabling the connection of smart meters with other devices were analysed. The high level requirements for the future smart meter enabling access to EVs were defined.
- The Microgrid (MG) concept was enhanced to include EVs smart control. The multi-agent control strategy was adapted to better exploit EV as mobile energy resources, focusing on the required agents to integrate EV in the MG. Charging strategies and possible ancillary services to be provided by EV were defined for frequency (primary and secondary reserves provision) and voltage (local and coordinated) control.
- The Virtual Power Plant (VPP) concept was presented as an effective structure for the integration of electric vehicles in electricity grids. Possible VPP realisations were classified based on the control method and the combination of the resources aggregated to form a VPP.
- Traffic patterns and human behaviours of drivers from across Europe were examined to provide an overview of current vehicle usage patterns. An online questionnaire was designed in several European languages and distributed by all Project MERGE partners. This questionnaire was filled in by more than 1500 people from a number of countries in Europe including UK, Germany, Spain, Ireland, Greece and Portugal

Learning from EV field Tests

Three EV field tests have been studied in Germany, Norway and Ireland providing useful information about the: user behavior, driving distances, ambient temperature, energy consumption of EVs, technical details of EVs and batteries as well as information about charging stations used in the field tests. The main interesting remarks are:

- Multi-car families are well suited to EVs as most journeys are short and within the EV driving range. Commuting journeys allow time to recharge when parked, as parking is typically of 4 hours + duration. Food shopping journeys also involve parking of 1-2 hours which can facilitate charging. Accordingly, workplaces and food shopping areas are good places to locate EV chargers.
- The actual range of an EV in practical conditions is likely to be significantly less than the range predicted by the New European Drive Cycle, as real life driving involves sharper acceleration and deceleration and a wider range of speeds. EV users would benefit from the assessment of EV range based on drive cycles appropriate to their location and driving pattern. In addition emission and economic analysis of EV could be skewed if the NEDC is used, as this drive cycle has been constructed with ICE in mind, and is not tailored to capture issues associated with EV driving such as regenerative braking.
- The volume of data to transfer was also an issue. In the Dublin field test study for instance, the initially sample rate of 10 seconds for continuous data had been chosen but this did not give the granularity desired, and a per second data stream was preferred. However on attempting to increase to a 1 second sample rate it was found that our GPS tracking device was unable to handle this data throughput, although a 5 second update frequency was achieved. Investigations into increasing the sample rate are on-going.
- Home Charging is sufficient for most users, with most journeys being of similar length whether EV Chargers were available locally or not. However for longer

journeys the availability of Public Chargers is essential, particularly on motorway routes between cities, where fast chargers would be most appropriate

Developing Evaluation Capability

- Battery capacities, charging rates, commercial data on available and prototype EVs for data modelling are provided. Information on battery chemistry, battery capacity, drivetrain power, charging rates, costs of battery packs, ageing effects of batteries has been collected, Vehicle to CP communication requirements are explained.
- Several existing software simulation tools were adapted and enhanced to include EV / grid interface models. These include software packages for steady state and dynamic analysis of power systems, i.e. IPSA, MATLAB/SIMULINK, EUROSTAG, PSSE/E, Fuzzy and Probabilistic tools, etc.
- The ROM model simulating market issues was updated to account for EV presence and a dynamic game theory algorithm in which EVs act to maximize their market payoff was developed.
- An enhanced version of the RESERVE model has been developed, in order to assess the impact of EV in the long-term operating reserve.
- Modifications were performed to the reference network models (RNMs) to facilitate the analysis of the possible impacts of EVs on additional investments in distribution network planning and operation.
- A power quality assessment tool was developed for assessing three main power quality issues related to EVs namely voltage drop, voltage unbalance and voltage harmonic distortion. (during the second year)

Assessing Impact from EV Presence

- Representative transmission and distribution European networks/systems from Spain, Greece, Portugal, Germany and UK have been identified to be analyzed in other tasks in the following WP3 and WP4. Network and generation sub-systems include present and future operating scenarios for short term time horizons.
- Three EV penetration scenarios (realistic, aggressive and very aggressive) for the 2020 and 2030 were identified for each EU country under study (Germany, Greece, Spain, UK, and Portugal).
- The additional EV charging demand and its impact on a system (annual and daily) load diagram curve were identified for five EU countries (Portugal, Spain, German, UK and Greece considering different charging strategies (dumb, multi-tariff and smart). In the “Dumb charging” scenario, where EV battery charges as soon as EV is plugged in, proved to be the worst scenario since EV demand coincides with the high domestic consumption. The benefits of developing charging infrastructures at workplaces were identified. In the “Dual-tariff” scenario, EVs are programmed to charge during low energy price periods, results in an instantaneous increase of EV demand at the beginning of the low pricing period which can affect the operation of strained networks. more effective than dumb charging. Finally, in the “Smart Charging” mode, the additional EV load is considered as manageable one, is the most effective charging strategy compared to previous ones; however its implementation will require advanced management models.
- The expected EV deployment is an important factor that affects the impact of EV demand in the generation system Thus, a reliability assessment analysis of the Hellenic and Iberian (Spanish and Portuguese) power systems has been performed. The analysis is focused on the EENS (Expected Energy Not Supplied) reliability

indexes. The impact of low EV deployment on static and operating reserves is limited whereas high EV penetration levels can essentially affect them. Furthermore, “Dumb Charging” proved to be the worst case scenario presenting the highest value of EENS index for both the static and operating reserve assessment.

Based on the EV deployment analysis and the analysis of EV charging demand, the impact from the EV presence has been studied, in terms of grid operation and planning, studying different EU transmission and distribution networks. More specific:

❖ Grid Operation Analysis with EV presence, considering different EV penetration levels and charging strategies (dumb, dual-tariff and smart):

- A steady state grid analysis was performed for three EU countries (Spain, Portugal and Greece). Their transmission systems as well as various distribution networks (rural, urban and touristic) from the studied countries were simulated and the impact of EV presence in system operation was analysed in terms of branches congestion levels, energy losses and voltage profiles. Even though the quantitative results of the steady state analysis are grid sensitive, some general conclusions can be derived:

- a) The results of the steady state analysis showed that the additional demand of the considered EV integration levels (based on Ricardo’s survey) is not high enough to considerably affect the operation of the transmission system. The voltage profiles and line loadings remain within acceptable bounds even in the worst case (“dumb charging” - maximum EV deployment).
- b) The mass deployment of electric vehicles in electrical distribution grids is very likely to provoke several changes in grid operating conditions namely branch overloading and changes in voltage profile. The dumb charging revealed to be the most problematic charging mode, as it provokes a considerable increase in the networks peak load, with negative consequences in what regards voltage profiles, branches overloading and energy losses. The dual tariff strategy can be an effective charging strategy for some networks, provided that pronounced valley periods exist in the daily load diagrams and that they occur more or less during the same daily periods. Nevertheless, it should be stressed that the instantaneous increase of the EV load verified in the beginning of the lower energy price period, due to a large number of multiple tariff adherents starting their charging almost simultaneously, might provoke several technical problems in some networks, namely in those operating in more strained conditions. The smart charging is the charging mode that allows obtaining better results, as the envisaged mechanisms to manage the EV charging enable a better exploitation of the resources available at each moment, preventing the occurrence of voltage problems and branches’ overloading. More specifically, urban networks are usually composed by short lines and are subjected to high power demand levels, they are very likely to face branch/transformer overloading problems faster than voltage drop issues. Rural networks have usually long radial lines, which provoke considerable voltage drops. Thus, low voltage problems are expected in these grids, namely in the buses farthest from the feeding points.

Furthermore, the location of the fast charging stations should be carefully analysed, as they might provoke severe voltage violations or branches overloading, due to the large amount of power that they may consume when in full operation. In fact, the studies performed have

demonstrated that the overload problems identified in two of the studied networks were likely provoked by the power consumed in fast charging stations.

The analysed systems can handle, up to a certain level, the penetration of EV without concerns to the networks' infrastructures. However, it was verified that the maximum number of EV that can be safely integrated in the networks depends on the charging schemes adopted by the EV owners. From the three strategies analysed (dumb charging, dual tariff charging and smart charging), smart charging yielded better results in all the case studies addressed, since it was possible to reach higher EV integration levels without violating the networks' technical restrictions.

Concluding, from the results obtained, independently of the charging strategy adopted, it is possible to state that no relevant problems in the MV networks are expected to occur until 2020 due to the foreseen EV integration levels. Conversely, in 2030, several problems are expected to arise, namely if dumb charging or dual tariff are adopted. However, the forecasted problems may be entirely solved if the smart charging is largely implemented

- c) For the LV distribution network analysis, dumb charging has proved to be too demanding for the networks and implies the need of large investments in order to avoid technical violations (under voltages and branch overloads) as well as to guarantee the quality of service. In fact, the load unbalance factor is high in some scenarios, particularly for the rural network, but the voltage unbalance factor is well below the limit imposed by the EN 50160 standard. In turn, the dual tariff approach tends to relieve the most demanding EV load hours but the concentration of EV load creates a new demand peak between late night and early morning that causes many problems such as branch overloads. Finally, the Smart charging strategy presents the best overall performance as it tends to flatten the load curve, has the lowest number of under voltages and lines overload and also reduces system losses and presents the best result in terms of voltage imbalances.
- A Spatial-Temporal analysis was performed in UK MV distribution networks considering the correlation between the highly mobile nature of population and the EV charging demand. It is proved that since EV behave as mobile energy loads/resources, EV charging loads have a close relationship with daily human behaviour. Therefore an EV impact analysis should take EV movement into consideration which will reduce uncertainties of the EV charging load and so reduce the cost of the electric power system reinforcement.
- The effects of EV charging load on voltage drops and voltage harmonic distortions were identified through a power quality assessment analysis. From the power quality analysis, it is concluded that by proper shifting of EV loads at lower consumption hours much higher penetration levels of EVs may be integrated into the distribution systems without violating power quality requirements specified in the standards
- The impact of EV deployment in the electricity energy price and CO₂ emissions was analysed for the Spanish, Portuguese and Greek system. The integration of EVs into power system results in the increase of the system load, no matter what charging strategy is adopted. Thus, additional generation is required to fulfil EV charging needs. The different charging profiles are based on different charging hours. The smart charging strategy implies charging during valley hours, the dumb strategy would mean charging during peak hours, and for the multi-tariff strategy the charging is performed during both peak and valley hours. The time

allocation of the EV demand, provokes significant changes in the generation mix which are mainly absorbed by coal and CCGT units. However, the generation units committed at each day time depends highly on the generation and grid capacity of each studied network.

In general, it is expected that the deployment of a higher amount of EVs into the system would slightly increase the CO₂ emissions of the power system. Nevertheless, the CO₂ increase changes depending on the charging strategy adopted. Since the generation mix for EV supply is case dependent, the CO₂ footprint is case dependent as well.

The mass deployment of EVs will produce an increment in the specific cost of the system. Dumb charging results in the highest increase of the system specific cost compared to the other two charging strategies. The percentage increase of the specific cost in case of dual-tariff and smart charging depends on the generation mix of each country.

At the light of the results obtained, it would be recommendable to adopt an “intelligent” charging profile to avoid negative impacts of the EV deployment. This charging profile has to be adapted to each particular power system and to the number of EVs deployed in it.

- The integration of EVs under the VPP concept was assessed in terms of RES integration level and system reserve requirements. . This issue is approached by two complementary analyses, a micro and a macro one. In the micro analysis, the management model of generation and demand (including EVs) for balancing the power excess or deficit inside a VPP is examined. On the contrary, the macro approach is a system-wide dispatch evaluation of the VPP operation where the benefits of the EV deployment are discussed from the System Operator point of view. A German and Spanish VPP model were studied. The results showed that the deployment of EVs under the VPP concept can balance the intermittent production of RES allowing higher level of RES generation to be integrated into the system and consequently reduce the operation reserves required by the system operator.
- The increase in the amount of renewable power sources, namely wind, which can be safely integrated in four EU countries (Greece, Germany, Spain and Portugal), due to EV integration as storage units, was identified through a dynamic grid analysis and an operation reserve assessment analysis. The RES integration level is maximised when EVs are treated as manageable loads (smart charging) while it is minimised in the case of dumb charging. Furthermore, the stability of the system, assuming a system disturbance, is analysed provided high RES integration and EV deployment. It can be concluded that under an unbalanced grid operation the deployment of EV under dumb charging strategy may lead to a blackout, while this can be prevented by shedding the EV demand in case of smart charging. The V2G capabilities of EVs were also analysed and it proved to be less efficient than EV load shedding. However, the availability of V2G operation is much higher than that of EV load shedding.
- The technical benefits of EV presence, under the Microgrid and More-Microgrid concept, in case of emergency operating conditions have been evaluated. By adopting innovative EV control strategy based on frequency-droop characteristic it is possible to take advantage of the EV flexibility, which can act both as a controllable load or storage device depending on the MG frequency. In case of a major system disturbance causing a general blackout or in case of an unsuccessful islanding procedure, the MG local generation capabilities and the EV can be exploited in a controlled and coordinated way for service restoration purposes by adopting local self-healing strategies. Regarding the MG restoration procedure, EV can be regarded

as flexible storage unit which can be connected to the LV network with initial zero consumption, causing the minimum impact as possible.

❖ Long-term system planning, considering different EV penetration levels and charging strategies (dumb, dual-tariff and smart):

- The required investments and grid reinforcements in the distribution networks due to EV deployment were identified, analysing six different EU networks (Spanish and Greek). From this analysis it is concluded that the investments are not expected to be very significant in year 2020 irrespectively of the adopted EV charging strategy. However, in year 2030 the required reinforcements may be quite high in case there are no strategies for EV charge. Dumb charging proves to be the most costly solution, requiring high reinforcements, while the costs are minimized in case of smart charging. More specifically, in urban areas more reinforcements are expected in MV/LV transformers than in feeders due to capacity issues. On the contrary, in rural areas more reinforcements are required in feeders in order to ensure the voltage limits.

The integration of EVs can be achieved either as individual units in the LV network or as one aggregated unit in the MV network. In the latter case, the connection costs are diminished.

- The adequacy of the generation system of three European countries (Spain, Greece and Portugal) was analysed considering different scenarios for demand, RES penetration levels, fuel prices, CO₂ prices and interconnection plans. The results indicate that the effect of low levels of EV Penetration on generation adequacy is insignificant regardless the charging policy adopted. On the other hand for medium and high EV penetration cases, dump charging and dual tariff policies would require extensive generation expansion plans. Since the generation expansion of the power system is a result of market forces, it is not guaranteed that the required installation would be materialized. Smart charging policy achieves better results, since added capacity is not required even for the high EV penetration case. The results are also encouraging regarding the merits of EV Penetration on the RES deployment. High levels of EV penetration combined with dual tariff or smart charging, leads in decrease of RES spilled during the year, as well as the number of hours with RES surplus. In addition part of the energy needs of EVs is served by RES that would have been spilled otherwise.

Additionally, the generation system adequacy is assessed by analysing the static and operation reserves. It is observed that when the penetration of EV is very aggressive, the loss of load risk and the risk of not having sufficient operation reserve might increase considerably. This risk can be reduced if enhanced control strategies for charging EV are adopted, like smart charging or smart charging with EV load control. In addition, smart charging with EV load control is the only strategy that allows obtaining similar estimates of the reliability indices to those of the scenario with no EV.

- The adequacy of the Greek and Iberian transmission system in 2020 and 2030 was assessed through a probabilistic and fuzzy analysis respectively. It is observed that transmission networks are robust enough to integrate the expected number of electric vehicles till 2030. The possibility of congestion occurrences or voltage out of the acceptable range occurred only in very extreme cases created “ad hoc” to stress the systems.

Regulatory Issues and Business Models for Efficient Integration of EV

- The key actors related with the deployment of EVs have been identified and a vision with quality assessment of how power system participants will be affected has been provided. Different business models have been developed and the threats and opportunities for each agent under the new situation have been analyzed.
The main results of the conducted research are the following:
 - Two new agents are identified as critical for EV charging: the charging point manager (CPM) and the EV supplier-aggregator (EVS-A)
 - Depending on the charging location (private or public areas) with private or public access several charging modes has been identified. The role of CPMs and EVS-As are also described for those charging modes. Finally, two stages are proposed for charging control alternatives: i) short-term modes based on uncontrolled or basic control modes, and ii) long-term modes where V2G applications are implemented.
 - DSOs are entities proposed as the best option for developing public charging infrastructure. In this case, as DSOs are regulated entities, the recovery of investments is the critical issue to be taken into account by regulators.
- An expert survey has been conducted to identify the main hurdles regarding the integration of EV in electricity grids, in particular regarding the design of day-ahead and intra-day markets, the design of balancing markets and reserve markets or procurement of operational reserves, the incentives and revenues allowance for Distribution System Operators and the design of network tariffs. Recommendations have been provided to tackle these issues. No major barriers have been identified in the day-ahead and intra-day markets for the participation of EV Supplier-Aggregators. Regarding balancing markets and reserve markets or procurement of operational reserves, several design issues should be reviewed: in particular,
 - Relaxation of tight access rules for demand side participation (minimum load and site restrictions)
 - Possibility of Evaluation Periods to assess firmness of capacity provision similar to “commissioning period“ for new power plants
 - Distinguish between up and down reserve capacity bids to allow for flexibility of EVSA
 - Close clearing to physical delivery for minimizing forecast errors
 - Define / Establish EV – DSO – EVS-A – TSO real-time communication requirements
 - The remuneration mechanism applied to network distribution activities should be revisited:
 - Recovering of investments costs associated to EV deployment, due to an increment of demand (contracted power and served energy), and also due to any mandatory public infrastructure deployment.
 - Incentives to reduce energy losses and to improve quality of service
- Three different stages or phases in the deployment of EVS have been identified: the Catalyst phase, the Consolidation phase and the Advance phase. For each phase, the main policy target, the expected business models will differ.
 - The Catalyst phase will prioritize breaking down potential EV adopter psychological barriers. It will mainly base on home charging. The goal is to attain a threshold number of EVs, critical to extend the adoption of EVs. Economic incentives for adopting EV mobility, The electricity system and in particular the distribution network will adapt to EV deployment and not vice versa. EVs considered as simple, non-discriminated electricity loads. No imposition of load controllability, but implementation of energy Time of Use Tariffs which will require the installation of dual-time meters (eventually smart meter).

- The Consolidation phase will give priority to the appearance and operation of EV Supplier-Aggregators and the implementation of EV charging controllability modes. The aggregation of a large number of EVs and the availability of control, communication and metering infrastructures due to the progressive deployment of the smart grid concept, will economically justify EVSAs offering load management services to DSOs and the TSO. Primary frequency control, within the smart charging concept, looks promising and can be considered also in the consolidation phase, specially for island grids.
- The Advanced phase, once the EV deployment consolidated, will focus on reinforcing the whole extent of services that EVs' battery storage capabilities may offer to the electricity grid. This will include V2G services that require bidirectional energy interchange between batteries and the grid.
- A coherent roadmap of policy and regulatory recommendations has been set for three different phases in the deployment of EVS, namely in the short, medium and long term.

Dissemination and Exploitation

- The project web-page has been organized and maintained from the beginning and has been used for public access of approved deliverables and documents. The MERGE concepts and ideas developed throughout the project have been presented in various conferences and international meetings and published in journals and conference proceedings. Contacts with G4V have been established and three common workshops have been organized. Further dissemination has been achieved through CIGRE, EURELECTRIC, EDSO for SmartGrids and other organizations. MERGE partners have contributed to the IEC61851 Standard.

Expected final results and their potential impact and use

The final results of the MERGE project are:

- A set of new management and control concepts that will facilitate the safe integration of EV into electrical grids, using as much as possible renewable energy for battery charging;
- An evaluation suite of simulation tools capable of analysing the impacts and the adequacy of the different EV integration control strategies in the electric power system considering different EV deployment levels; by using this simulation suite it will be possible to identify the necessary related policy and regulations, as well as to plan the technical evolution of the required generation and network infrastructures.

These results will have the following potential impacts:

Technical / Regulatory

The development of control and management techniques and the suite of tools developed within MERGE will help mitigation of the technical impacts caused by the future large deployment of EV and will help in the understanding of the following technical and regulatory issues:

- Branch congestion problems and large voltage drops in distribution grids due to simultaneous charging of a large number of EV; network reinforcements required when fast charging is considered in future large scale EV deployment; Increase in active power losses; Power quality problems due to the presence of a large number of EV power electronic interfaces and in the case of EV single-phase charging imbalance;
- Change in global load profiles, which will impact the hourly generation scheduling. In the future, as renewable sources penetration will increase advanced tariffs and dynamic pricing should encourage EV demand when RES generation is available;
- Changes in electricity markets behavior and on electricity prices due to a large presence of EV, behaving as loads or as units that deliver energy back to the grid. Evaluation of how smart metering should take the presence of EV into account is developed;
- Regulatory procedures to deal with the presence of EVs as consumers / storage devices (EV) in order to treat EV users in a fair and non-discriminatory way and to deal with the additional investments in control and management structures, in order to reliably accommodate a large number of EV;
- Changes in system dynamic behavior due to the presence of a large number of charges that can be dynamically adjusted through advanced battery grid interfaces;
- Effects on conventional system reserve levels since the dynamic characteristics of EV batteries can be exploited for system balancing;
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Social / Environmental Impacts

- Contributions for reduction of CO2 emissions and mitigation of climate change. The adoption of advanced management and control solutions will critically help EV integration in the electrical grid and will contribute to the reduction of active network losses;
- Contributions to improve quality of life by decreasing traffic noise, namely in urban environments;
- Contribution to the increase of the public awareness regarding the correct use of energy.
- Contribution to the increase of employment in the automotive industry including all the complex supply chain of small medium and large suppliers as well as by creating new job positions in the electric manufacturers industry that will have to develop and produce new devices.
- Contributions to increase EU export potential in HighTech for the related technologies.

Address of project public site: [http:// www.ev-merge.eu](http://www.ev-merge.eu)