DUAL TARIFF CHARGING CONTROL FOR LARGE EV FLEETS

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Abstract: In the forthcoming years, a significant deployment of Electric Vehicle (EV) technologies, plug-in hybrid and pure battery EVs, is expected. Uncontrolled charging can affect significantly the normal operation of the power system and result in premature grid reinforcements. Dual-tariff scheme can be effective provided that EV uptake is not high. This paper presents an enhanced dual-tariff distributed EV management approach for handling large EV fleets. The proposed management scheme allocates efficiently the EV charging demand during the low energy price period achieving a "valley filling" affect.

1 INTRODUCTION

In the forthcoming years, a significant deployment of Electric Vehicle (EV) technologies, plug-in hybrid and pure battery EVs, is expected. This is indicated by several prospective studies for instance EPRI&NRDC (2007), Valentine-Urbschat & Bernhart (2009), Electrification Coalition (2009), IEA (2009), National Academy of Sciences USA (2009) and The Royal Academy of Engineering UK (2010). Even though there still exist significant technological and economic barriers mainly related to the storage technologies, the future of electric vehicles (EVs) seems to be rather promising considering their energy efficiency and environmental advantages compared to the conventional transportation.

The integration of plug-in electric vehicles into electric power systems can be envisaged into three phases 0. In Phase I, the major objective is to facilitate the EV uptake. In this phase EVs will be regarded as mere additional loads like any other conventional load. As the EV penetration ratios become more significant the network operation is likely to be affected. Thus, in Phase II, potential charging control concepts should be developed to manage the additional EV load. This will enable the emerge of new business models such as the one of EV Supplier-Aggregators (EVS/A) which will be responsible for managing large EV fleets, either in private or public charging places, through bilateral contracts. In Phase III, a very optimistic and long-term scenario has been identified by introducing the bidirectional exchange of power between the grid (Grid-to-Vehicle operation, G2V) and the vehicle battery (Vehicle-to-Grid operation, V2G).

This paper focuses on the second development stage (Phase II) of electric vehicles and aims to investigate the deployment of conventional demand management concepts, such as the dual-tariff one, for controlling EV charging. The scope is to envisage the possible network impediments that may prevent the implementation of the dual-tariff charging scheme and propose an enhanced dual-tariff EV management approach which enables a more efficient EV integration regarding the network operation. The proposed EV management scheme is a decentralised, price-based control which allocates the EV demand among the low energy price hours in a 'valley filling' concept. The operational framework for the implementation of the enhanced dual-tariff EV charging control is base on the Multi-Agent System (MAS) technology.

In Section 2, the energy requirements that fulfil EV charging needs during Phases I and II are identified considering different penetration level scenarios. The resulted charging profiles enable the estimation of the grid impact of EV deployment. In Section 3, the proposed enhanced dual-tariff EV management scheme is analytically described. Conclusions are drawn in Section VI.

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2 IDENTIFYING EV CHARGING NEEDS

The integration of EVs into power systems is expected to increase the system demand due to the charging needs of EVs. The amount of this additional EV demand depends mainly on the EV penetration level and the EV owner's driving profile (travel distance, battery consumption). The time of EV plug-in and the available type of charging (Modes1, 2 & 3) (Bending et al., 2010)-0, State of the art charging infrast] defines the grid impact of the additional EV demand.

Figure 1 presents the simulation tool developed to identify the additional EV demand in the first and the second EV deployment stages. The inputs of this model are described below:

- ***EV deployment scenarios:*** Different number of EVs can be used regarding different penetration (high, middle, low) scenarios.
- ***Classification of EVs:*** The plug-in EV technologies can be classified into two general categories:
  - the plug-in hybrid EV (**PHEV**) and
  - the pure battery EV (**BEV**)

  BEV can be further subdivided into further subcategories according to their technical characteristics as:

- **L7e** : small city purpose vehicles
- **M1** : 4-seater passenger vehicles
- **N1** :carriage of goods with a maximum laden mass of less than 3,500 kg
- **N2** : maximum laden mass of 3,500 kg to 12,000 kg for commercial purposes

- ***Trip Length:*** This parameter describes the daily distance covered by an EV between two successive charging cycles and thus the corresponding amount of charging energy.
- ***Battery consumption:*** Average energy consumption over travelled distance (kWh/km) can be considered per each EV type.
- ***EV demand:*** The total battery demand requested from the grid, considering the losses of the charger's power electronics (15%).
- ***Availability of charging:*** The charging can be initialised once (home charging) or multiple times per day (home/work/commercial charging).
- ***Time of plug-in***: The time of EV plug-in defines the initialisation of the charging period, especially in case of uncontrolled charging.
- ***Charging Scheme***: It depends on the EV deployment stage.
  - *Uncontrolled charging:* It is the plug and play connection of Electric Vehicles into the grid which happens after the last trip of each day or when a charging point is available and there is no need for mobility.
  - *Dual-tariff Charging:* It's a market way of controlling energy demand in order to promote energy demand in off-peak hours.

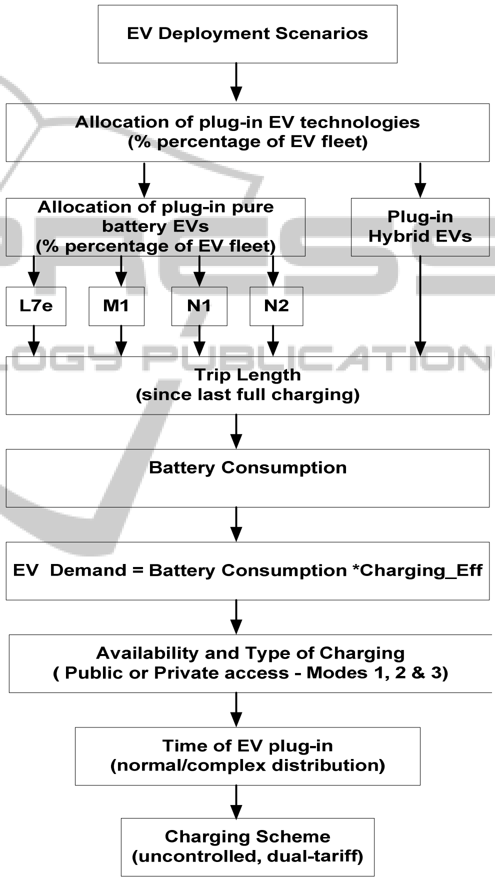
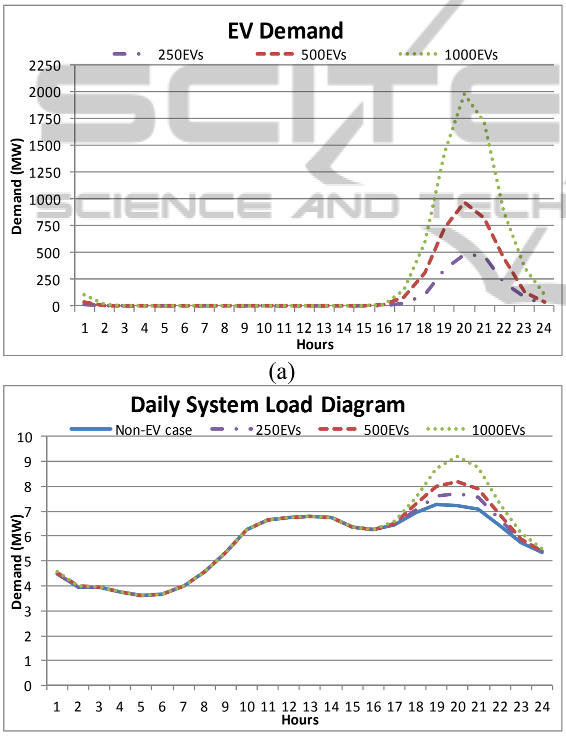


Figure 1: Simulation Model identifying EV demand.

For the purpose of EV demand analysis, three hypothetical EV fleets of 250, 500 and 1000EVs, (for low, middle and high EV deployment respectively) have been considered. Only pure battery EVs have been considered for simplicity and it is assumed that L7e=1%, M1=88%, N1=10%, N2=1% as a percentage of the total fleet. Moreover, the travel distance of EVs has been simulated by an exponential probabilistic density function with mean value 40km. Different average battery consumptions over travelled distance per pure battery EV type has been assumed: L7e=0.13, M1=0.16, N1=0.24, N2=0.8 kW/Km.

Figures 2 and 3 present the results of the simulations, exploring the tool of Figure 1, for home charging (Mode 1 charging), considering different EV deployment scenarios.

Figure 2(a) presents the EV demand of uncontrolled home charging assuming that the EV plug-in time is defined by a normal distribution with mean value at 8:00pm. Figure 2(b) shows the impact of the additional EV demand in the typical daily winter load diagram of a Greek urban network [Merge 3.1]. In case of uncontrolled home charging strategy, the EV load is coincided with the increased domestic consumption increasing the daily load peak by 5.8%, 12.53% and 26.42% for the respective EV penetration levels.

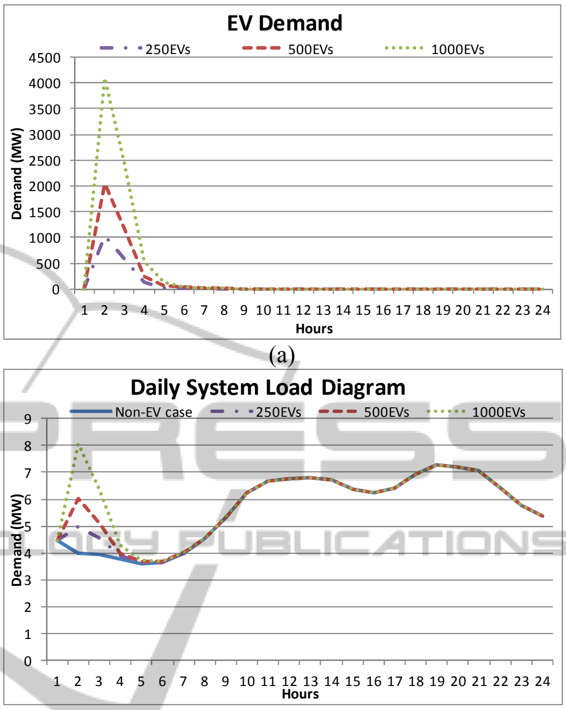


(a)

(b)

Figure 2: EV demand for uncontrolled charging.

Figure 3(a) presents the EV demand when a dual-tariff market model. The winter low energy pricing period in Greece is between 11pm-7am. Dual-tariff charging is more effective than the uncontrolled charging since it enables the shifting of the EV demand from high loading hours to off-peak ones namely valley-hours. However, there is an instantaneous increase of the EV load verified at the beginning of the low energy price period. In case of 1000EVS, a new system load peak occurs due to EV demand, which is increased 10.76% compared to the initial one. This might provoke several technical problems in some networks especially to those that operate in strained conditions and the EV deployment is high. Premature grid investments would be inevitable.



(a)

(b)

Figure 3: EV demand for dual-tariff charging.

The allocation of the EV demand among the low energy price hours under a "valley filling" concept could enable a more efficient network operation increasing simultaneously the maximum allowable EV integration levels without considering network reinforcements.

3 A MULTI-AGENT SYSTEM EV MANAGEMENT CONCEPT

This section presents a decentralised, multi-agent system solution for the coordinated charging of plug-in EVs aiming to avoid the instantaneous increase of the EV demand when low energy price period starts. The schematic overview of the proposed multi-agent system is depicted in Figure 40.

DSO agent is responsible for monitoring and ensuring the secure and reliable operation of the distribution network.

EVS/A agent is a new business model 0 which is expected to emerge during the second EV

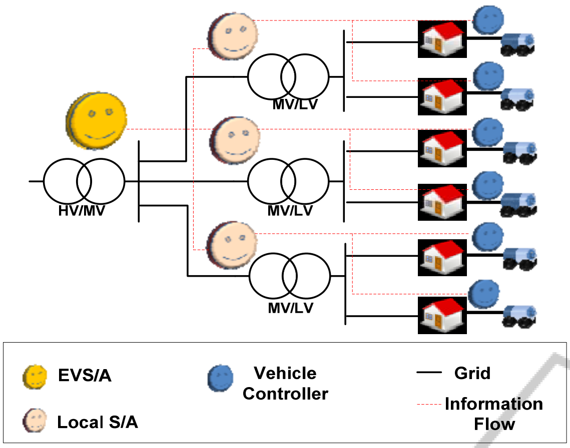


Figure 4: Agent coordination structure.

deployment stage and will be responsible for purchasing energy from electricity market and managing large EV fleets. An EVS/A agent can offer additional load management services incentivized by the DSO agent contributing to a more efficient, in terms of losses, voltage drops, grid loading, operation of the grid.

Local EV/A agents are located at the secondary substations (MV/LV). They are responsible for aggregating the demand of the EVs parked at a specific geographical area. The aggregated profiles are communicated to the EVS/A.

Vehicle Controller (VC) agents represent the EVs to the upstream network. The VC agents have the ability to act autonomously and the intelligence to take decisions that fulfil individual goals.

The multi-agent EV charging management concept is a price based one. The EVS/A agent is responsible for defining hourly series of prices which are directly proportional to the grid area loading. The prices set by EVS/A are not the actual market prices, but pricing signals reflecting that higher non-EV and EV demand results in higher market prices.

Based on EVS/A's pricing policy, the VC agents define their charging strategy aiming to minimise their virtual charging cost. The objective function of a VC agent can be found in 0. According to this formula, the best charging strategy of every VC agent is balanced between the charging price and the cost of deviating from the average charging strategy. Thus, VC agents are less aggressive in charging the cheaper valley hours.

The coordination mechanism consists of the following steps:

1. DSO provides EVS/A with the hourly available power for charging without exceeding the domestic area's peak load, for the whole low energy price period.
2. EVS/A defines the pricing policy in accordance to the grid area loading.
3. VC agents communicate their best charging response to the local EV/A
4. Local EV/A agents aggregate the charging demand of a small geographical area and provide one load profile to EVS/A.
5. EVS/A agent evaluates the VC agents' response and reschedules its pricing policy. It also provides the hourly average value of the EV charging demand.
6. Steps 3-5 are repeated until no better charging response can be achieved.

Figure 5 presents the EVS/A pricing strategy for the example of Figure 3. Figure 6 shows the total non-EV and EV demand after each round. It can be seen that at each round, the charging instants with smaller non-EV demand are assigned to a larger individual EV charging and average charging rate. After a few oscillations, the presented multi-agent coordination mechanism provides a "valley filling" effect during the low energy price period defined by the specific dual-tariff scheme.

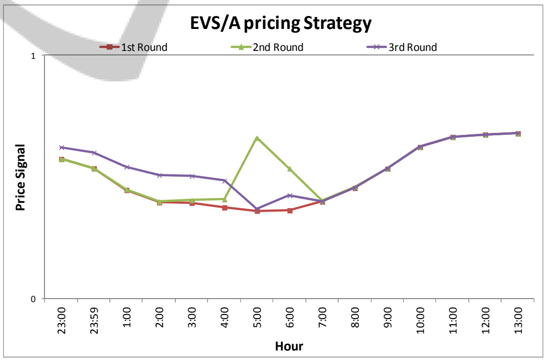


Figure 5: EVS/A pricing strategy.

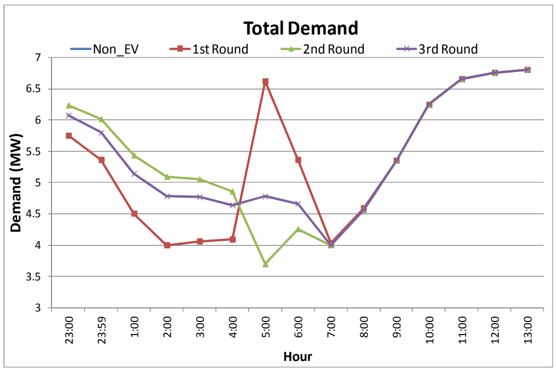


Figure 6: Total demand.

4 CONCLUSIONS

The implementation of current simple dual tariff schemes results in instantaneous increase of the EV demand at the beginning of the low energy price period. In case of high EV deployment levels, the additional EV demand can affect the operation of some networks, mainly those which are already strained. This issue can be handled by the presented enhanced dual-tariff multi-agent EV management approach. In this approach, a new business model of EVS/A has been introduced being responsible for purchasing power from the market and managing EVs demand. EVS/A agent coordinates the EV charging operation by providing virtual pricing incentives to VC agents. The VC agents act autonomously trying to satisfy their individual goals considering the EVS/A pricing policy. The tracking parameter within VC agent's objective function enables the effective allocation of EV demand during off-peak hours achieving a "valley filling".

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APPENDIX

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