Smart Charging Management System of Plugged-in EVs Based on User Driving Patterns in Micro-Grids

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Abstract

Micro-grid system stability and security is becoming recently a challenging issue due to the high penetration of renewable energies in power production like wind and solar regarding their unpredictable nature. Furthermore, the presence of Electric Vehicles (EVs) in the near future in households is inevitable as the EVs worldwide popularity is growing. In this paper, a smart control method is proposed for the plugged-in EVs charging procedure applying smart grid capabilities. Essential grid operation constraints including overload occurrence prevention, market energy prices tracking are taken into account. The proposed control method is evaluated in a modified micro-grid in the MATLAB/SIMULINK environment. Real data of users driving behaviors utilized from performed studies is applied into the model to obtain realistic results. Different worst case scenarios are derived in a day time horizon to show the effectiveness of this smart charging method. The results demonstrate the positive impact of this methodology in saving operational costs and increasing system stability.

Introduction

With the worldwide growing popularity of Electric Vehicles (EVs), the investigation of their available potentials and effects on the power grid operation is inevitable. One of these impacts could be the extra load that will be imposed to the grid while people plug their cars into the grid and start to charge. This could be very harmful to the grid because of probable overloads and consequently additional operation costs due to expanding the grid and installing new components like power lines with higher capacity [1]. Therefore controlling the charging procedure of the EVs considering essential grid operating constraints could help overcoming this problem and allow the grid operators to manage their grid with no additional costs. Furthermore the EV's batteries could also be applied for grid regulation purposes for maintaining the grid stability due to their characteristics of lower energy and quick response time [2-3], by mean of services such as voltage and frequency regulation [1], [3]. Especially in micro-grids where most of the power production is delivered by renewable energies like wind and solar plants, the EV's batteries could perform an important role for smoothing their natural intermittency and ensuring grid-wide stability [2], [4-5]. Applying smart grid capabilities could provide real time information about the State of Charge (SOC) and the amount of available power capacity from all plugged-in vehicles [3], [6-7] to help the grid operators to control their charging procedures and available regulation capacity. An aggregator is necessary to deal with the SOC and plug-in time of the vehicles to provide an optimal charging plan to obtain minimal operation cost and regulation service on the appropriate large-scale power [8-9]. The minimum and essential requirement for the vehicle owners to join this kind of services is to be guaranteed the charge of their battery to a desired level by the next driving time. In addition some incentives such as direct payment or lifetime warranty of the battery should be given for voluntary participation of the vehicle owners [10-11].

Research Objectives and Methods

As it was mentioned in the previous section, developing a Smart Charging Management system (SCM) for the EVs could be very attractive for the system operators. The main objective of this research is to show how applying this method could help in saving charging costs and increasing the system security and stability without limiting the EV owners driving behaviors and wishes. In this paper a SCM method due to essential constraints including, overload occurrence, SOC and plug in state of the EVs, next travelling time and market energy prices is presented. Moreover, the system voltage will be measured in specific periods to avoid exceeding the minimum and maximum voltage limits [1], [3]. Anytime the system voltage varies from its limits, a signal will bring voltage compensate facilities in action to overcome the problem. The positive effect of applying this management system in reducing energy cost and maintaining the grid stability with the current infrastructures is shown in the following sections. The simulated micro-grid and the proposed SCM system are defined as follow.

Micro-grid Test System

The studied micro-grid in the Matlab/Simulink environment is shown in Figure 1. This micro-grid contains wind turbines, solar panels and a diesel generator for producing power and residential households, an asynchronous machine as the system load and EVs.

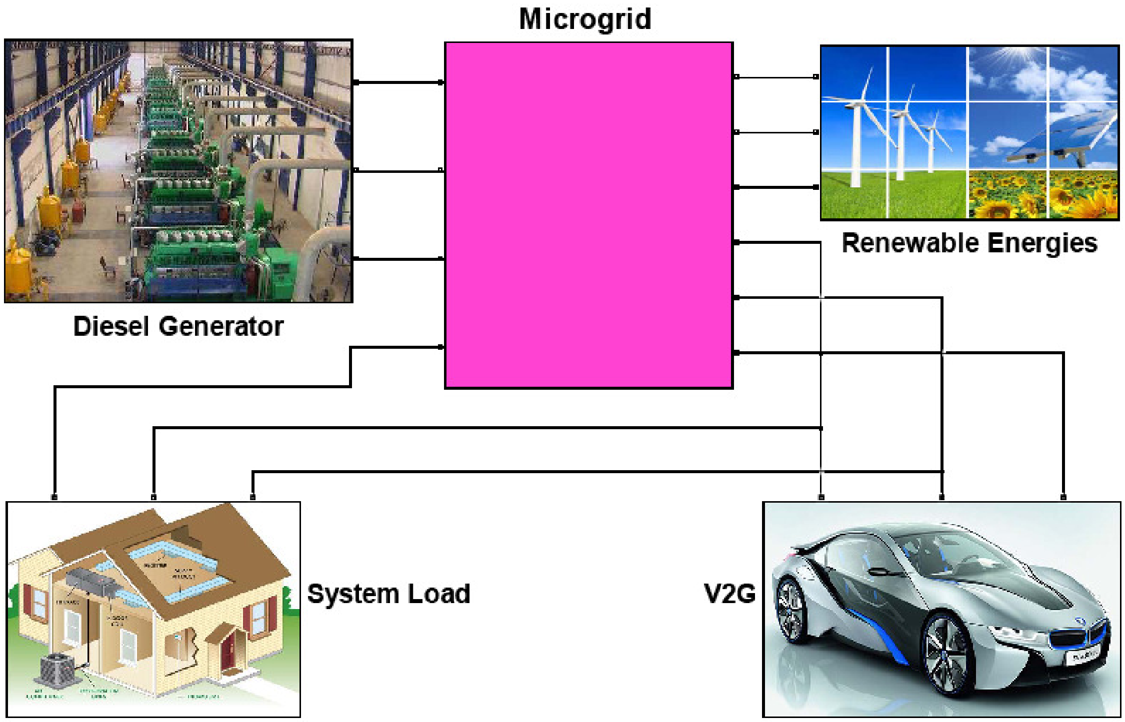

Figure 1: Simulated Micro-grid System

The amount of the generation and consumption are listed in Table 1.

Table 1: Amount of the system generation and consumption

Generation Units	Generated Power (MW)
Diesel Generator	15
Wind Turbines	4.5
PV Plant	8
Loads	Consumed Power (MW)
Residential Loads	10
Asynchronous machine	0.16
Electric Vehicles	4

In the following case studies and simulation, it is assumed that the micro-grid operates in an isolated mode so that there is no power injection from the main grid to the network.

Proposed SCM system

Figure 2 demonstrates the proposed SCM system. This system applies different necessary signals including the SOC of the EVs batteries, vehicles plug in state, the next traveling time, overload occurrence, regulation market status and energy market price tracking. Other input signals will be measured using smart grid capabilities and will be sending to the SCM system which finally creates a charging signal by mean of Fuzzy logic controller. In other words, the system decides due to developed Fuzzy rules according to the input signals, when the cars will charge to decrease charging costs and prevent probable overload occurrence in the grid and other grid stability constraints.

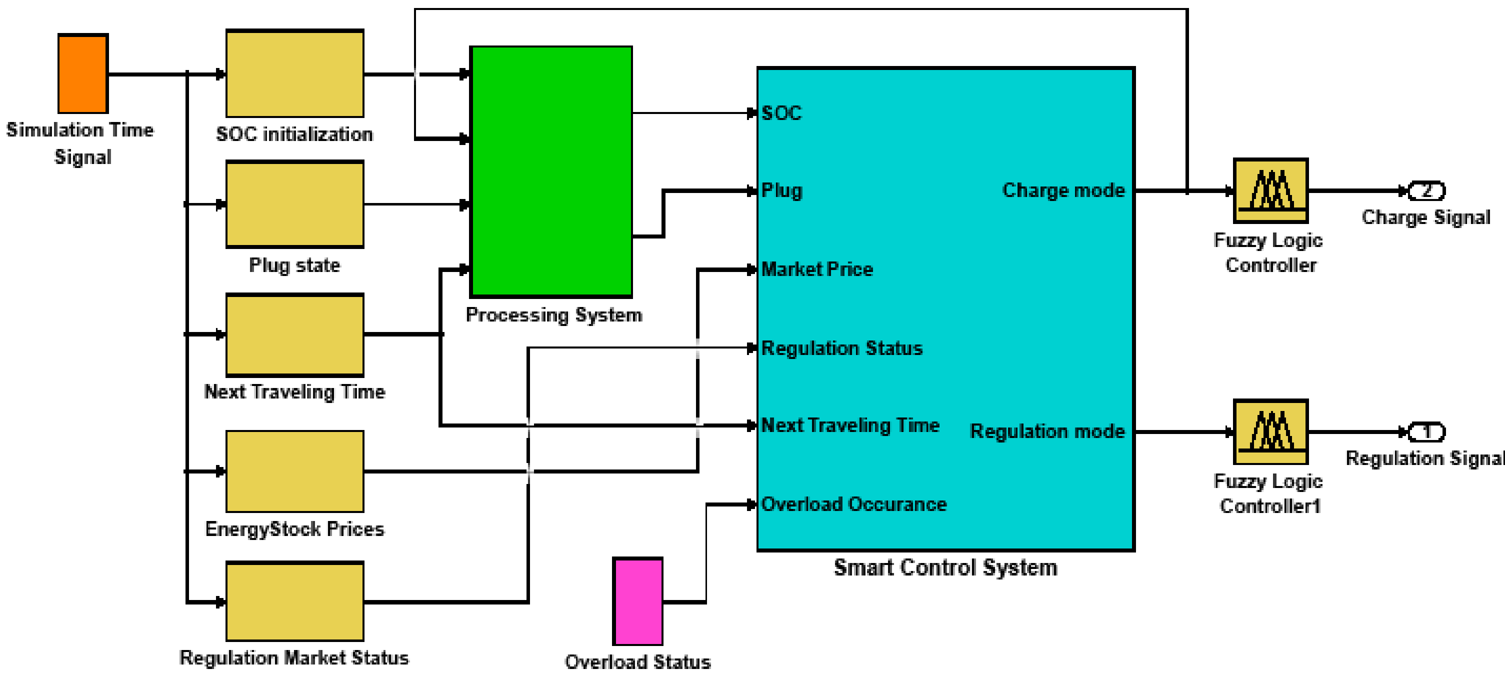

Figure 2: The proposed SCM System

Input Signals Introduction

The input signals will be introduced as follow:

- The SOC signal informs about the state of charge of the EVs batteries during the continuous simulation time (24h).
- The Plug signal is about the plug-in state of the EVs during the simulation.
- The Market Price signal is the hourly energy price that will be called from the EEX energy stock market in Leipzig Germany [12].

- The next traveling time signal will be supplied by the EV owners (via smart phone or PC) and the existing database of their driving patterns.

- The Overload Occurrence signal receives data from the smart meters about the transmitted power through the power to prevent overload occurrences and probable black outs.

Through the smart control system, the input signals are converted to simple digital signals which lead to faster decision making by the controller. In order to clarify more the procedure, two signals are illustrated. In the plug signal, the digit 1 means that the EV is connected to the grid (i.e. digit 0 indicates that the EV is not connected to the grid). In the next travelling time signal, if the travelling time is less than a specified duration time, the controller converts the signal to digit 1 and decides based on the specific criteria in charging or not charging the EVs.

Fuzzy Controlling System

As it was mentioned previously, a fuzzy logic controller is used to decide when the cars start to charge. Regarding the introduced input signals, membership functions for any input signal and a series of related fuzzy rules are developed and applied in this work. This fuzzy controller could decide very fast the charging status of the EVs due to the input signals status. As an example, if there is currently a high, medium or low energy price in the market or an overload occurrence and etc what should the best solution be. Figure 3 demonstrates this Fuzzy logic controller. The displayed flowchart In Figure 4 describes completely the decision mechanism of this fuzzy controller due to the input signals.

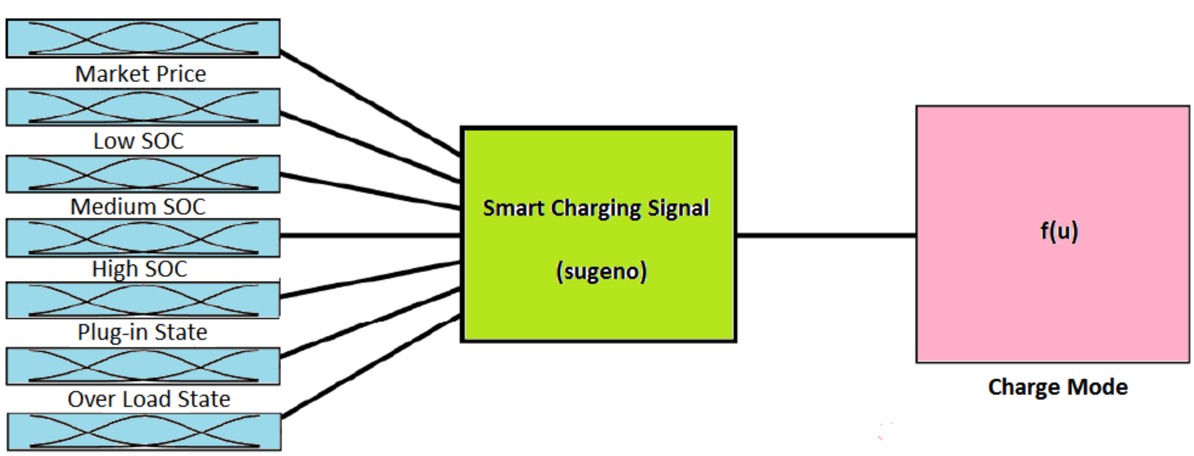

Figure 3: Fuzzy Logic Control System

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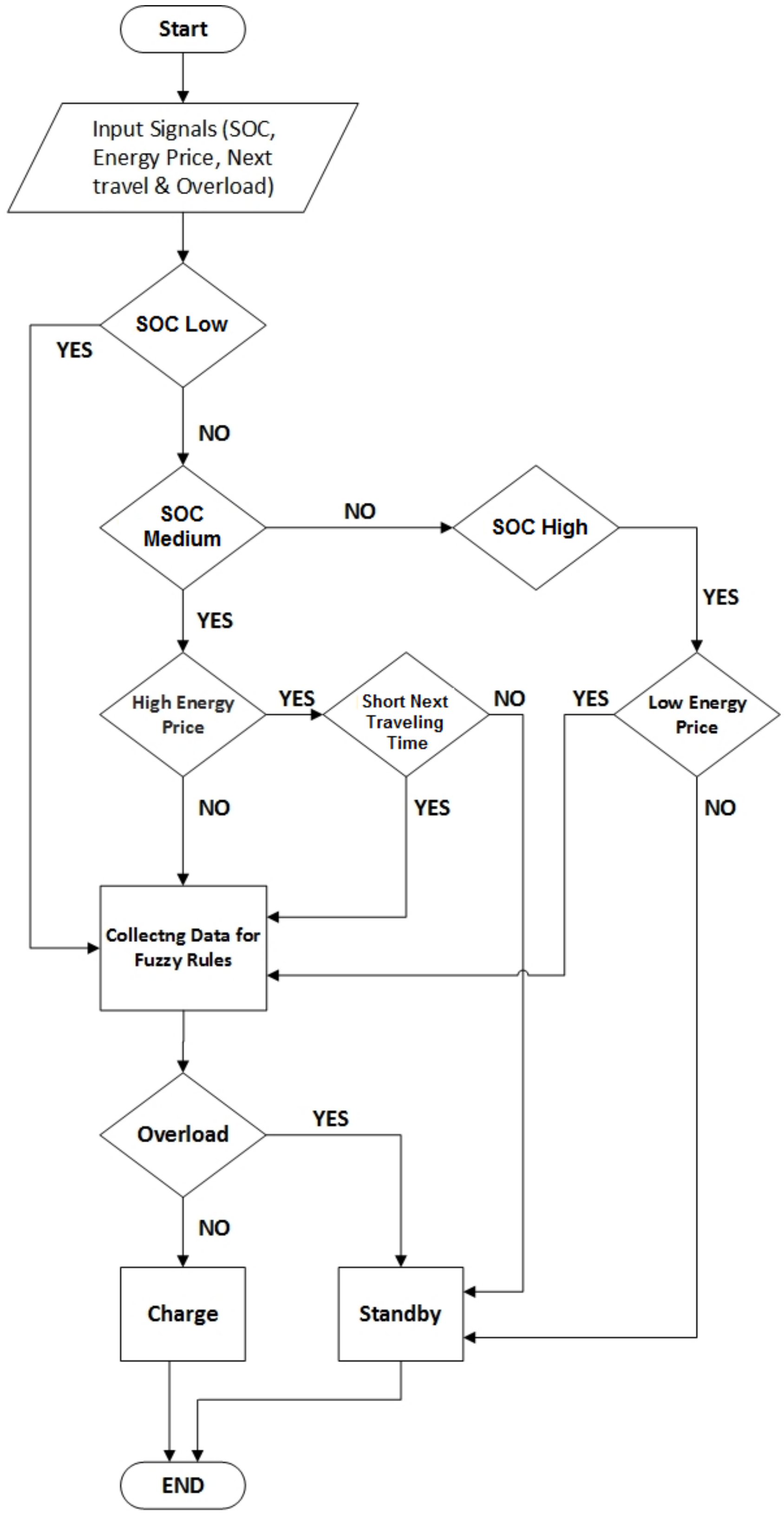

Figure 4: Fuzzy Logic Control System Mechanism

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Simulation and Results

The Simulation of the micro-grid system has been run in two different modes to see the positive effect of the proposed SCM system in decreasing the charging energy costs. The comparison of the amount of charged energy of the EVs considering the SCM system and without it is shown in Figure 5.

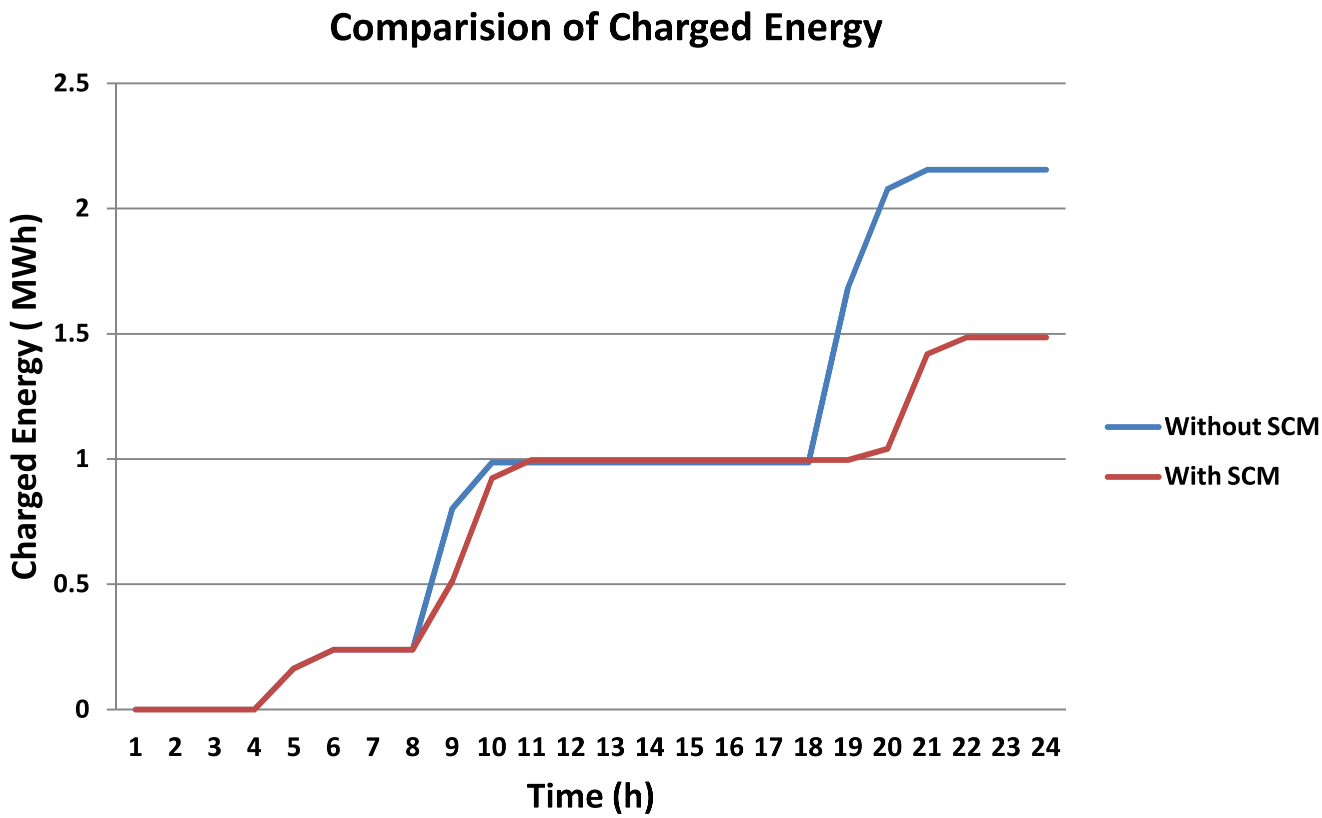

Figure 5: EV daily charged energy with and without SCM system

As it is observable in Figure 5, the EVs charged energy has decreased mostly at two periods, in case of applying the SCM system. The first time span is from 8:00 till 10:00 am, and the other one is from 6:00 till 12:00 pm. The most decrease of energy charging happens at 8:00 pm which is predictable because of the highest energy price at this time of the day. Based on this figure, if the SCM system wouldn't came into action, the car holders would charge their cars immediately after they arrived home without considering essential constraints like the energy prices or overload occurrence. The SCM system didn't just shift the charging hours to save costs but furthermore, the EVs with high SOC (in this case 85% battery charge is assumed) will not charge their cars at medium and high energy prices at all, because it is not necessary to charge the batteries always up to 100% for covering their regular distances. This is why the daily charged energy with SCM is less than the amount of energy without SCM. In case of long trips and travels, the EVs would charge at any energy price to catch a fully charged car before the trip to maintain the driver's comfort.

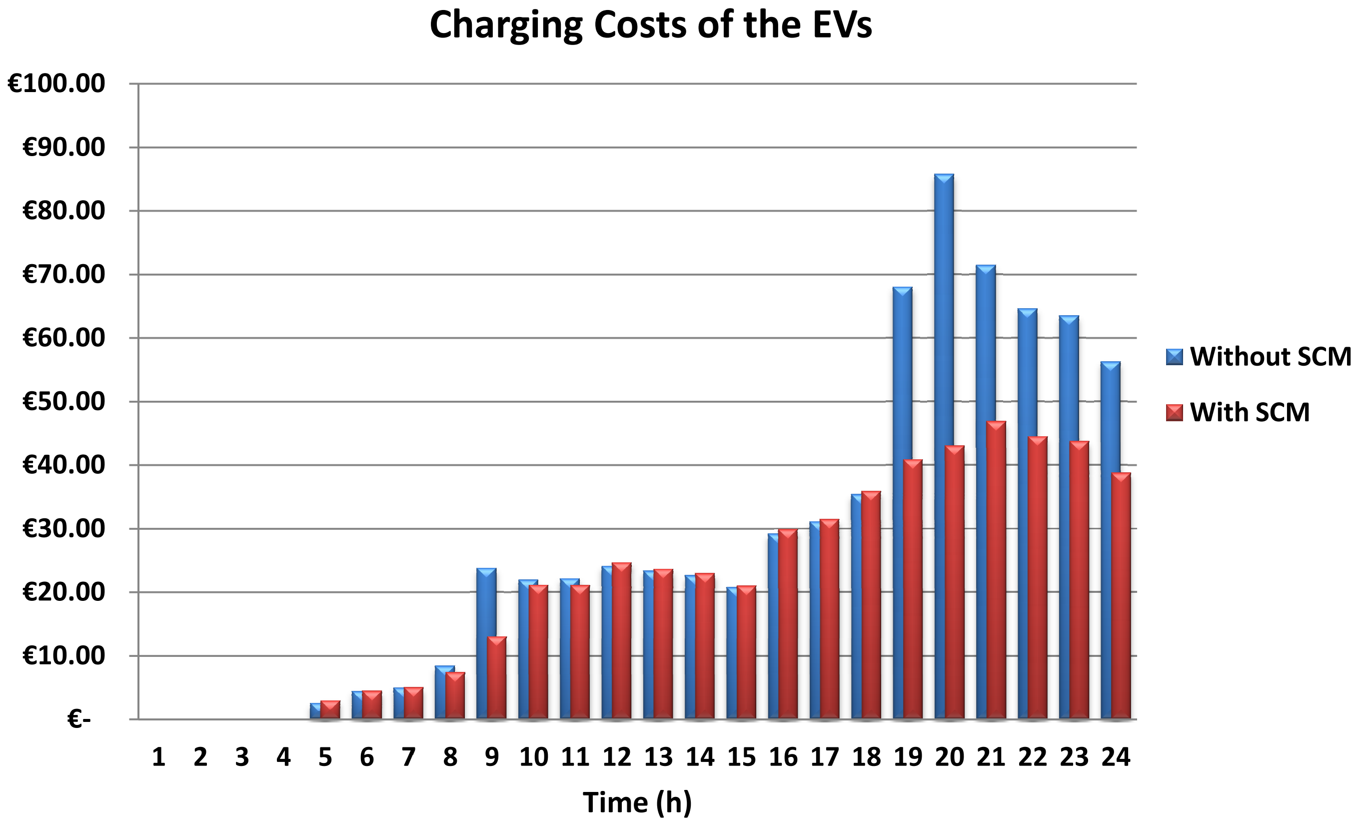

Figure 6: EV daily energy cost

In this regard, a comparison of the energy costs is depicted in Figure 6. As it was expected, the energy costs have decreased in peak load hours. As it was mentioned before the most cost savings happen at 8:00 pm, where the energy price reaches the highest value during 24 hours. It is also considerable that the charging costs are higher at 12:00 am till 18:00 pm, even using the SCM system. These higher energy costs are resulted from the less energy prices at this frame of time. However, there will be cost savings during the day as it will be shown in the following graphs.

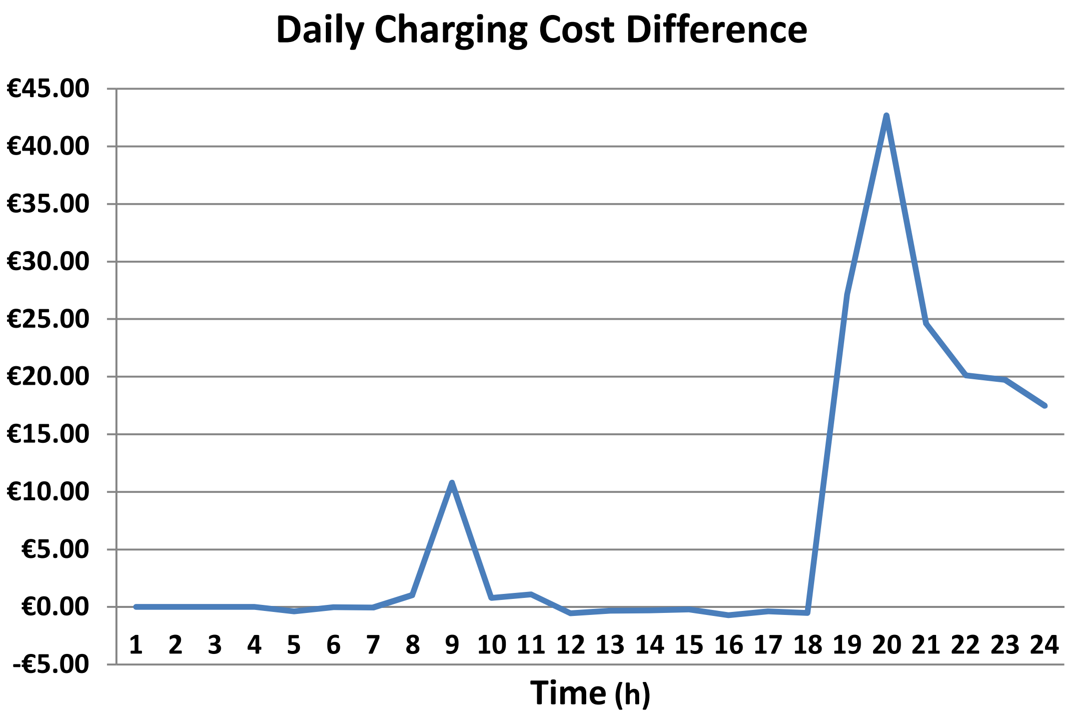

Figure 7: Daily charging cost difference of two modes

This cost difference could be better observed in Figure 7, which results a daily cost saving of up to €162, when applying the SCM system.

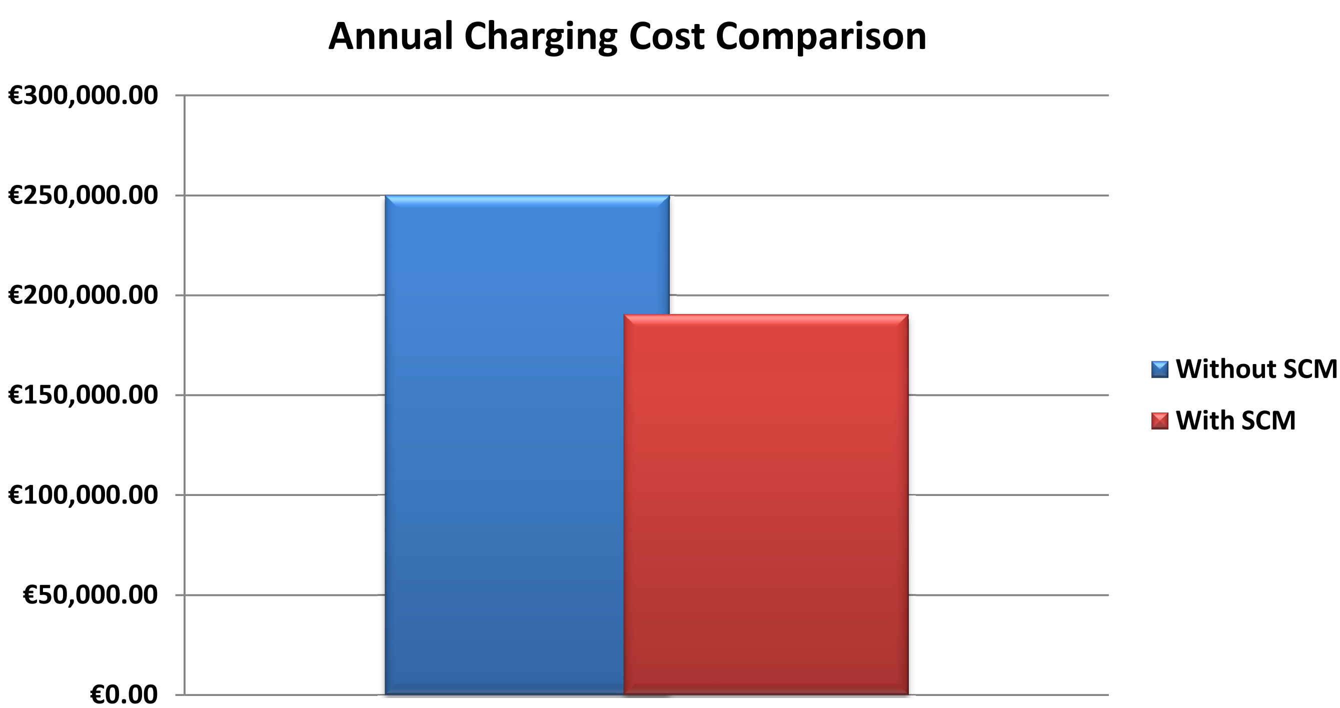

Figure 8: Annual charging cost comparison

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According to Figure 8, this amount of money could be extrapolated to a year and results an annual charging cost saving of around €59000 which is a considerable amount of money. In addition due to the SCM system there is no overload occurrence in the grid after adding the EVs to the grid as extra loads.

Conclusion

The simulation results show the positive effect of applying the SCM system in power grids, especially micro-grids. Through using this proposed smart system, the grid operator could avoid extra cost for new grid facilities and components for supplying the added EVs with energy. Furthermore, the EV owners saved an annual charging cost of around €59000, which could be a noticeable incentive for the owners to plug their cars to the grid anytime they arrive home or have a chance to, while becoming charged cars for the next trips. These plugged-in EVs could also be applied for grid regulation purposes which could help grid operators in saving regulation cost and maintaining a stable grid with existing infrastructures and bring additional income for the EV owners. A Smart regulating system could be investigated in future works.

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