UNIVERSIDADE DA BEIRA INTERIOR
Engenharia

Optimal behavior of a PEV parking lot in renewable-based power systems

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Dissertação para a obtenção do Grau de Mestre em:
Engenharia Eletromecânica
(2º Ciclo de Estudos)

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Covilhã, Junho 2015

This work was supported by FEDER funds (European Union) through COMPETE and by Portuguese funds through FCT, under PEst-OE/EEI/LA0021/2013. Also, the research leading to these results has received funding from the EU 7th Framework Programme FP7/2007-2013 under grant agreement no. 309048.

Dedicatory

To my family, especially my parents and girlfriend, who always believed in my capabilities and support me unconditionally.

Acknowledgement

I would like to express my gratitude first, to my supervisor Prof. Dr. João Paulo da Silva Catalão.

I would also like to recognize and thank the help of my laboratory colleagues who helped me achieve this goal. Especially Dr. Miadreza Shafie-Khah who's help was essential in order to complete this work.

I cannot forget the Sustainable Energy Systems laboratory (SES), Located in University of Beira Interior; laboratory associated with *"Instituto de Engenharia de Sistemas e Computadores – Investigação e Desenvolvimento"* (INESC-ID), because without the available resources in SES laboratory, it would not be possible to carry out this work.

I also want to thank the University of Beira Interior for all the support, care and resources made available in these years, and therefore, I consider it as my second home. In this way, my respectful thanks to all personnel who composes the University of Beira Interior, especially that ones who composes the Electromechanical Engineering Department for their excellent work.

To all my colleagues and friends who are also an integral part of my life, who shared with me in the good and bad times their lives too, I want to express my gratitude for all the support, especially whom helped me, supported me and gave me their precious time to help me especially in my hardest times.

Resumo

Tem havido muitos desenvolvimentos em relação a veículos elétricos com tecnologia Plug-in (PEVs), sendo um tema abrangente com bastantes tópicos a serem estudados, sendo que existem também diferentes abordagens do tema por diferentes autores. Tendo isto em consideração, o objetivo inicial será a recolha de informação relativo a esta área e a sua sumarização de modo a possibilitar uma maior compreensão sobre a área. De seguida, o modelo desenvolvido será efetuada a sua análise, tendo em consideração alguns destes desenvolvimentos mencionados previamente.

Primeiramente um estado da arte será apresentado onde os recentes desenvolvimentos na área serão apresentados. Estes desenvolvimentos incluem a possibilidade de gestão e manuseamento dos veículos, controlados ou descontrolados (i.e. agregador), e a possibilidade da utilização das tecnologias veiculo para a rede (V2G) e rede para o veículo (G2V) é analisada. De seguida, são analisado os mercados de energia onde serão apresentados casos reais e diferentes tipos de Mercado serão descriminados. A interação dos PEVs com algumas energias renováveis (e.g. Solar, Vento e biomassa) é apresentada. Finalizando modelos de PEVs serão categorizados fazendo distinção entre eles, entre tipo de modelos, variáveis, métodos aplicados, e os parâmetros considerados por estes mesmos.

Como caso de estudo é apresentada a análise de um modelo que conta com um parqueamento de PEV, inclui energias renováveis. O objetivo é o de analisar os efeitos das energias renováveis na participação do mercado do parqueamento e o impacte na rede de distribuição. Esta análise será feita pela variação na potência instalada das renováveis, localização na rede do parqueamento e variação nas limitações do modelo.

Palavras-chave

Rede de distribuição, Estratégia de gestão, veículos elétricos com plug-in, parqueamento, energias renováveis, programação estocástica.

Abstract

There have been a lot of developments in terms of Plug-in Electric Vehicles (PEVs) regarding many different subjects, and with some variations between authors. On this basis, it is intended to sum up a lot of contents being approached, and help understanding them. Followed by the development and analysis of a model in order to better understand the functionality of these new developments.

First a state of the art is presented where the new development are presented, these will include management of the PEV's, uncontrolled or controlled (i.e. aggregated) and their capability of using V2G and G2V technologies are analyzed. Afterwards, electricity markets are approached where real world applications are shown and different market types are categorized in order to a better understanding of the subject. The interaction of the PEVs with some renewable energy resources (e.g. solar, wind and biomass) is presented. To finalize, models of PEVs are categorized and multiple types of modules, the related variables, applied methods, and the considered parameters are presented.

For a case analysis, a model that includes a parking lot of PEVs will be studied, which includes renewable energy resources, wind and solar. The objective is to analyze the impact of these on the market participation of the parking lot and also on the distribution grid. These analyses will be made on size variations, grid placement and also constraint variations of the model.

Keywords

Distribution network, offering strategy, plug-in electric vehicle, parking lot, renewable energy resources, stochastic programming.

Resumo Alargado

Com os mais recentes problemas encontrados pela humanidade de tentar reduzir as emissões de CO_2 tem havido imensos desenvolvimentos tecnológicos. Um dos mais recentes desenvolvimentos a ter um impacto no mercado é os veículos elétricos, nomeadamente os Plug-in. Tem havido muitos desenvolvimentos em relação a veículos elétricos com tecnologia Plug-in, sendo um tema abrangente com bastantes tópicos a serem estudados, sendo que existem também diferentes abordagens do tema por diferentes autores.

Tendo isto em consideração, o objetivo inicial será a recolha de informação relativa a esta área e a sua sumarização de modo a possibilitar uma maior compreensão sobre a área. Esta sumarização tem o intuído de dar uma ideia geral do tema numa perspetiva de desenvolvimento de um modelo de um parque de estacionamento para os mesmos. O objetivo deste parque de estacionamento será o da implementação numa situação real de modo a incentivar o aumento de veículos elétricos, devido aos seus benefícios. Depois da apresentação do modelo desenvolvido e a sua análise será apresentada, sendo que terá em consideração alguns dos estudos analisados e mencionados previamente.

Seguindo as ideias anteriores primeiramente é apresentado um estado da arte onde os mais recentes desenvolvimentos na área serão apresentados. Estes desenvolvimentos incluem o tipo de gestão e manuseamento dos veículos, controlados ou não (i.e. agregador). O tipo de gestão é algo bastante influente no sistema como irá ser observado posteriormente, tendo impacto no desempenho do veículo e no sistema de carregamento do mesmo. Em seguida, uma análise sobre a possibilidade da utilização das tecnologias veículo para a rede (V2G) e rede para o veículo (G2V) é feita, de modo a entender as suas potencialidades.

Para além do tipo de carregamento e gestão é necessário entender como estes podem interagir com o mercado e por isso o tópico seguinte aborda os mercados de energia. Aqui serão mostrados casos reais e diferentes tipos de mercado serão descriminados. Também vão ser demonstrado os melhores tipos de mercado para a participação dos veículos elétricos.

Em seguida é apresentado um fator que influencia esta participação nos mercados a nível do modelo. Esse fator é a interação dos PEVs com algumas energias renováveis (e.g. Solar, Vento e biomassa), sendo bastante importante devido à potencialidade de aproveitamento de energia destas mesmas. Sendo que em certas horas existe excesso de energia no sistema mesmo para aplicações domesticas, a potencialidade da interação entre as energias renováveis e os PEVs é imensa. Para terminar os tópicos do estado da arte é feita uma análise aos modelos de PEVs, que serão depois categorizados fazendo distinção entre eles.

Os modelos contêm vários elementos próprios que serão abordados individualmente. O primeiro tópico será o tipo de modelos, probabilísticos, determinísticos ou estocásticos sendo estes os principiais. Seguindo isto irá ser abordado horizonte temporal dos modelos, curto ou longo prazo, e dentro desses as suas subcategorias temporais serão então também abordadas. Outro tópico a ser abordado é o das variáveis utilizadas nos modelos, distinção entre diversos modelos de modo a tentar explicitar as mais utilizadas e também as utilizadas em parques de estacionamento.

Conhecendo as variáveis, é necessário também determinar como são tratadas estas variáveis no geral, se será por métodos estocásticos, probabilísticos ou determinísticos. Vários modelos são demonstrados neste capítulo, sendo um deles o modelo de uma estação de PHEV outro de um método de gestão de um parque de estacionamento, um de modelação do agregador do PEV e por fim um de modelação da rede.

Estes 4 modelos são os tópicos essenciais a focar a gestão do parque, a modelação do agregador e a modelação da rede, no modelo aqui desenvolvido. Este modelo não está inteiramente ligado a estes modelos, sendo bastante diferente; no entanto leva considerações destes mesmos. Para terminar este capítulo 2 tópicos são abordados: um relativo às restrições do modelo e custos associados, e o outro são considerações do modelo que devem ser feitas ao sistema de potência.

Após o estado da arte é apresentado então o modelo em questão que foi desenvolvido a partir de muitas das ideais geradas do estudo de modelos previamente feitos e de ideais próprias. O modelo é apresentado em duas partes; na parte inicial é apresentada a vertente do mercado onde inicialmente está a equação de lucro, sendo constituída por elementos de geração de lucro e também por elementos de custos. Em complemento a esta vertente são demonstradas também algumas restrições para o sistema.

Seguido o estudo de mercado, são apresentadas em maior pormenor as equações de estudo do sistema, onde todas as equações que foram aplicadas se encontram descritas. Após a apresentação do modelo é então descrito como foram tratadas as variáveis incertas, descriminando os métodos aplicados às diferentes variáveis estocásticas no sistema. Para terminar é apresentado um gráfico de fluxo onde se encontra descriminado passo a passo como se faz o processamento do programa e as variáveis de entrada, os resultados que obtemos e as equações utilizadas.

Seguido da descrição do modelo é feita então a sua análise, sendo que esta análise será feita em 3 partes. A primeira análise será feita com o objetivo de analisar o impacto que diferentes energias renováveis têm no funcionamento do modelo, isto é, no impacte na participação do mercado e no impacte na rede a que este mesmo se encontra associado.

Para este efeito é feita uma análise de 3 casos sendo, o primeiro caso o estudo sem nenhuma energia renovável, o segundo caso um estudo com energia eólica com uma potência máxima de 200kW e o ultimo caso será um estudo com energia fotovoltaica também com uma potência máxima de 200kW. Desta análise serão obtidos os resultados para os diversos mercados, energia normal, reserva, e regulação.

A análise feita à rede pretende determinar o melhor local para a implementação do parque de veículos elétricos tendo em consideração as diferentes energias renováveis. Posteriormente para essa localização, visa determinar o impacte da aplicação das energias renováveis na tensão nodal.

O segundo caso de estudo será a influência da capacidade instalada de renováveis, como isso impacta a participação do mercado e também a rede. Neste caso é realizada a variação de 200kW em 200kW, tanto para eólica como para fotovoltaica.

Disto podemos tirar conclusões sobre como cada energia renovável influencia o comportamento da participação de mercado do parqueamento e foi retirada a curva de crescimento dos mesmos para ver como essa varia com o aumento da potência.

Como ultimo caso de estudo será feita uma análise no impacte das limitações impostas ao modelo, nomeadamente na restrição nos transformadores. Os transformadores têm impacto na limitação de obtenção e venda de energia no estacionamento. Para isso foi realizada uma análise variando esse valor entre 0.7 a 0.95. Este valor terá impacto tanto no lucro como também na manutenção.

Depois de concluída a análise são então apresentadas as conclusões de todos estes casos estudados, que demonstram o funcionamento do modelo sobre varias condições de funcionamento.

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Acronyms

BEV	Battery enabled vehicle
DR	Demand response
G2V	Grid to vehicle
GEV	Grid enabled vehicle
ICE	Internal combustion engine
ISO	Independent system operator.
p.u.	Per unit
PEV	Plug-in electrical vehicle
PHEV	Plug-in hybrid electric vehicle
Pss	Power Substation
PV	Photovoltaic power plants
Reg	Regulation
RER	Renewable energy resources
Res	Reserve
SOC	State of charge
V2G	Vehicle to grid

Nomenclature

Act	Activated reserve by ISO
Cap	Capacity of PEV battery
Cap,Res	Capacity payment for reserve market
Cd	Cost of equipment degradation
D	Demand
ΔS	Upper limits of discretization of apparent power
down	SOC departure less than scenario
En	Energy
EV	Electric vehicle
η	Charge and discharge Efficiency
F	Partition segment of the blocks
F	Maximum number of blocks to linearize
Γ	Penalty ratio for not delivering the offered energy
G2PL	Injection of the grid to the parking lot
G2V	Grid to vehicle
I, I2	Current flow and square of the current flow
i,j	Buses
λ	Price
N	Number of parked PEVs
N	Number of buses
NOM	Nominated amount
ω	Scenarios
P, Q	Active and reactive power
PL2G	Injection of the parking lot back to the grid
π	Scenario Probability
R	Resistance
R-down	Regulation down

Res	Reserve
RN	Renewable generation
R-up	Regulation up
S	Sub-transmission
SOC	State of Charge
t	Time
unavail	Being unavailable to inject to the grid
up	SOC departure more than scenarios
V, V2	Voltage and square of voltage
V2G	Vehicle to grid
X, Z	Reactance and impedance
γ	Rate of charge and discharge of parking lot

Chapter 1

Introduction

This introduction has been divided in multiple subjects in order to better understand and differentiate them. The first part, framework, is to introduce the reader in the situation and give a general idea of all the concepts which will be used throughout the entire dissertation. Next, the motivation and the objectives of this dissertation are presented. Finally, the structure of the dissertation is explained chapter by chapter.

1.1 Framework

A new subject being introduced in today's society is the concept of plug-in electric vehicles. This inclusion of this new type of vehicles can lead to a new era in the electricity market. This is a concept that still needs a lot of acceptance due to the restrictions that it brings to the users currently. It is also necessary to develop an overall functional environment to the whole concept.

For this matter there have been made a lot of developments in the last few years regarding not only the plug-in electric vehicles (PEVs) but also plug-in hybrid electric vehicles (HEVs). These developments can be widely diversified with multiple approaches as it is a new subject being introduced in the market.

There have been a lot of ideas of how to manage and how to work with the PEVs. A lot of the concepts are based on home charging and home management by using vehicles as storage units, other concepts are the idea of using exchange station for battery in order to help for long trips, and another concept which has been heavily focused on are the usage of parking lots.

The idea of having a parking lot for electrical vehicles is an idea which should be heavily considered. As there are parking lots for normal vehicles there will obviously be a need for these kind of parking lots. The idea here was to approach a very recent subject which is the interaction of a parking lot with renewable resources to study its impact on the parking lot, market participation and the grid. In order to do so, the state of the art was studied first.

The importance of the studies regarding these subjects is that with the pace that it is all evolving in all areas it is hard to keep up with all the recent developments, models and studies. Therefore, there is a need to compile and develop a state-of-the-art in order to see what's being done, what needs to be improved and how it can help develop the model for the parking lot in question.

The state of the art will be the second chapter of the dissertation, but here in this chapter the main concepts behind it will be explained in order to help people understand the need for this work and how it can help improve the future.

There have been a large number of literature surveys in this context. These literature surveys such as [1], [2], are a good start to the methodology to follow in order to categorize the subject.

These reports explain the V2G concept and the market types, having focused on the economic and technical management of an aggregation agent for electric vehicles. Here it was tried to approach all the subjects, with also a focus towards the models.

To this end, here not only will be categorized the studies on the aggregator and the markets but also presented the models that enable to understand how to manage PEVs and their charging/discharging, battery degradation, etc. The main goal is to give a specific idea about the economic part and also on the modeling and different types of models and how to manage them.

There have been a large number of models and approaches in terms of PEVs over the last few years, focusing mainly on three kinds of model categories which are deterministic [3], probabilistic [4] and stochastic [5] models; it has been a challenge to find the best model and the best management possible.

Some models do not use any variables that others do, there is not only one ideal model since all of them have certain components that can be considered beneficial in comparison. The most relevant models are presented and discussed, enabling for the development of a better one. The remainder of the state of the art is to tackle some important subject, which will be mentioned next.

First, the PEV management and V2G capability are presented. For PEV management it is shown that the current state of up to date studies, whether they consider PEVs controlled, aggregated/managed or completely uncontrolled, an approach from many perspectives from multiple studies is taken into consideration as for example in [6]. Then, it is intended to determine if current studies have been considering V2G capability for the PEVs and we present a couple of papers in order to determine that like for example [7].

Second part, is dedicated to categorizing the studies based on the market viewpoint. The first topic in that section regards which type of markets that PEVs participate and if they participate by selling or buying electricity. For this topic we present some real life market in this case Singapore [8] where it is explained the perspective and the different markets that it participates in.

Some papers on markets are also referenced, which have been found relevant for the subject mainly spinning and non-spinning reserve, regulation market (voltage and current) and ancillary services. This is a big focus of this work for a couple of reasons, first being the necessity to lower the costs of energy, the idea of being able to provide fast energy in regulation and reserve is a big concept to help and lower the costs of energy production. Other ideas behind this is also to help lower the costs of electricity at home. Also the ability to make money out of this capability of the vehicles we buy is very important in order to help and reduce the costs of battery maintenance and also the buying price.

For the second topic, the interaction of PEVs with renewable power sources and demand response programs is explored. Three different renewable energy sources are looked over, including photovoltaic, wind and biomass. The interaction of this kind of parking lots is pretty important for one big reason, free energy.

The ability of obtaining free energy with a onetime only cost of implementation and making a profit or lower the costs of home appliances is a very appealing idea. But as an example from PV's the peak of production is lagged behind the peak of consumption. So if we had a way to retain that power and then using it without extra costs it would be a wonderful ecosystem. And this is the potential of this concept.

But the most important part in order to understand are the models, which is the main focus of this dissertation. There are a large number of features starting by the type of models that are used, where the main models are deterministic models, probabilistic models and stochastic models as mentioned previously.

Another point of study is the timeline is taking into consideration. There are two big groups of time lines, short term and long term analysis. Short term can be divided in two different time aspect, these are models with day-ahead [9] and real time [10] managements. Long term doesn't usually have any sub groups.

The main difference between both would be that for short term the approach is focusing normally in only in a daily basis. Comparing then the 2 sub categories of both day-ahead allows the management of the PEVs by prediction of the next day, which in turn predicts all the aspects from statistical data.

The real-time case does not need any previous data and reacts according to current conditions. Long term is another approach which is used more on a viability analysis, to study long term applications. The long term is also different on the variables since it considers for example maintenance costs, while for short term analysis these are not included.

Another big point and maybe one of the most important subjects of this study regarding other models is how to handle uncertain variables. There is a need to do this because there are no actual real values due to being a very recent subject. There is concrete data regarding parking lots of plug-in electrical vehicles.

Hence, multiple papers where analyzed (e.g. [11], [12], [13]) in order to pin out which models are the most common and how these models' variables are handled. So with this we rounded up the variables being used in all these papers and determined 3 techniques being used for these kind of variables. One is to use them deterministically, meaning to give them values. Second use it probabilistic to give a distribution to the variables. Other is just using it stochastically meaning you don't know the value you just let the program calculate it for you from the equations.

After studying the general ideas behind the models there is a need for a more specific approach of the subject which lies in studying other features of the models. This starting with what kind of parameters are considered in models like infrastructure cost, V2G-Inverters, battery degradation, fleet management and SOC.

Here what was verified was exactly what was expected, the V2G-inverters, and infrastructure costs have been considered but only for long term analysis studies. While the rest of the costs like battery degradations, SOC and all other have been considered in all models which have been studied here.

With this topic, different approaches were found in different papers (e.g. [14], [15] and [16]). Also the interaction with the electricity network is considered to indicate which works have used the distribution or the transmission network.

To finalize the study, some features of the electricity system are investigated. These features include security, reliability, adequacy, quality, stability, loss, frequency and voltage control. There are many reports for the mentioned features such as [17] and [18].

Between the topics, some equations are considered in the literature that are found relevant in order to formulate a PEV model. These are features very important to both the user and the distributer.

The most important features that are seen here for the user are obviously stability, reliability and security. These features are important because they are features that might affect the life of the owner. Reliability and stability are obviously a big concern, since it is not good for the customers to just be home and then lose power. So there is a need to guarantee these features when including the PEV in the network.

The other big concern should be obviously security, since these days there is an increased necessity of feeling secure at home. Electricity patterns and charging patterns exposed can be a big concern for the consumers as it can lead to feeling unsafe. So it is necessary to guarantee the customers safety.

Moreover, frequency and voltage control, adequacy, losses, among other issues, are big concerns for the distributer. All of these are problems that can lead to maintenance and costs that are unwanted. So guarantying the full working ability of the systems with minimal losses is a necessity for the distributer. All of these issues have been considered when developing this work.

1.2 Motivation and Contribution

This work has been originated due to the identification of needs for new and upcoming technologies bringing a huge impact to society. One of the major technologies with high tendency in the society is the electrical vehicles.

Electrical Vehicles have had a huge growth in the last few years. But with the development of this kind of vehicle there is a need to research and find solutions for the overall ecosystem involving the electrical vehicles.

One of the upcoming needs is the creation of parking lots for these vehicles. This can be a major boost on the acceptance and future of the electrical vehicles.

Environmental issues and sustainability are a big concerns for today's society, therefore another point of motivation is to make the parking lot more sustainable. In order to tackle this issue, renewable energy resources where considered as part of the model.

But this inclusion may bring some problems to the workability of the parking lot and also the grid in which this has been included. This kind of study with all these considerations and ponderation hasn't been made yet, which is a novel contribution this dissertation aims to provide. So the objective of the model is to innovate and create some opportunity for future application and further development.

The novel contribution that it is intended with this dissertation is to provide all the information necessary for a better management of the distribution system. This is intended to be provided by developing a model after obtaining information from multiple studies previously validated by other investigators, and with some elements of own self. This models intendeds to study the market participation of the parking lot with different scenarios. It will be investigated from multiple perspectives in order to find the optimal point of working ability.

The proposed model covers multiple scenarios with different types and sizes of RERs on different buses of a distribution system and finds the optimal behavior of the parking lot. The scenarios for RERs that are used for the model are photovoltaic and wind, using Spain as reference.

The Spanish system is also taken into account for prices and the electricity market. Multiple uncertain variables are taken into account for the model, where a stochastic programming approach is used in order to tackle this problem. A comparison between 3 cases will be employed, the case with: no renewable energy, with wind and with photovoltaic energy.

The impact of the RERs on the market participation will be initially studied, comparing scenarios for all the 3 cases mentioned previously. Following that the impact of size and type of RERs and their location is investigated as well as the combination with the management of a parking lot, which is necessary for its implementation. Finally, a variation on the limitations of the system will be tested to see the impacts it has, mainly the substation capacity limit.

1.3 Structure

The structure of this dissertation is divided into five chapters, each consisting of multiple subchapters. Here the chapters will be depicted in order to give a general idea of how it's organized in order to help the reader. The first chapter is the introduction where this is included. The introduction consists of three parts.

Framework where the situation of the subjects will be introduced in order to allow the reader to get acquainted with the subject in general. Then the motivation and contribution of this dissertation. Finally, the structure of the thesis is presented.

Second chapter is the state of the art. In this chapter the most current information regarding the subject of this area will be presented for better understanding of the subject. This chapter has been divided in 4 subchapters, first one is a small introduction on PEVs where the current situation in terms of models and products is done. Following is how to manage and charge the PEVs.

Third type of markets and an analysis on which markets they can participate in. Then to end the chapter there is a high focus on the model part. This model part has the objective of finding common denominators between all the models in order to find what is being used and researched in order to help develop the model in this dissertation.

Chapter three consists on showing the mathematical model of a PEV parking lot; here the formulation for the model will be presented divided in two parts. First part of the model is the market part where it considers both the incomes and costs and explains it in detail.

Second part of the models consists on the grid analysis where also the formulation is presented and explained. On this chapter it will also be presented a flow chart of the model and how the uncertain variables where characterized in order to simplify the obtained results from the model.

Chapter four presents the results of the proposed model and concluding remarks regarding these results. The results have been divided in 3 parts each one representing a study that has been applied to the model.

First study will consist on the analysis of the impact of different types of renewable energy resources, where the difference between the impact of Wind, PV and no renewable will be studied.

This study will cover both the market analysis to figure out what parts the parking lot participates with each individual energy. Another analysis is the grid analysis to see the impact of the renewable energy resources on the grid.

The second interaction that will be done is varying the energy resources size. This is done to try and see also how the market interaction varies with renewables size and how the profit of the parking lot is influenced by it. This will obviously be done only for wind and PV. A grid analysis will also be employed to this in order to see also the impacts that size has on the grid.

Final analysis will be the variation on the limits of the substation values. This substation limits the power that goes through the transformer to the vehicles; here an analysis will be done by varying this value for the base value that was done for different RER analysis. A grid analysis will also be deployed.

To finalize, the last chapter will consist on summarizing the conclusions that can be taken from the model and the results, doing a very detailed comparison between them. Also, the papers which have originated from this model will be presented.

Chapter 2

State-of-the-Art

In this chapter the state of the art regarding electrical vehicles and all features associated with it are summarized from previous works of multiple people. The objective of this chapter is to get a better understanding of the current technologies and methodologies employed in the area. This chapter is divided into 4 parts first being a general overview of plug-in electric vehicles. Second part is the PEV management, where it is included the type of management employed in the area, followed by a model showing a methodology of management. After the management is overseen the electricity market interaction is taken into account where first the types of electricity market are shown and expressed. Interaction with renewable energy resources is also talked about in this part, showing different types of energies that have been studied in connection to the PEVs. To finalize, modeling of the PEVs and other features are studied. Type of models, type of variables, considerations, and network features are the main subjects for the topic.

2.1 Plug-in Electric Vehicles

A plug-in electric vehicle (PEV) is any motor vehicle with rechargeable battery packs that can be charged from the electric grid, and the electricity stored on board drives or contributes to drive the wheels for propulsion. Plug-in electric vehicles are also sometimes referred to as grid-enabled vehicles (GEV), which can be considered vehicle-to-grid (V2G) technology enabled.

PEV is a subcategory of electric vehicles that includes battery electric vehicles (BEVs), plug-in hybrid vehicles, (PHEVs), and electric vehicle conversions of hybrid electric vehicles and conventional engine vehicles. Even though conventional hybrid electric vehicles (HEVs) have a battery that is continually recharged with power from the internal combustion engine and regenerative braking, they cannot be recharged from an off-vehicle electric energy source, and therefore, they do not belong to the category of plug-in electric vehicles.

A battery electric vehicle uses chemical energy stored in rechargeable battery packs as its only source for propulsion. BEVs use electric motors and motor controllers instead of internal combustion engines (ICEs) for propulsion.

A plug-in hybrid operates as an all-electric vehicle or BEV when operating in charge-depleting mode, but it switches to charge-sustaining mode after the battery has reached its minimum state of charge (SOC) threshold, exhausting the vehicle's all-electric range.

Some recent examples of this kind of cars are the BMW i3, Chevrolet volt, and the Tesla cars. For plug in hybrid there are quite a few also but the most known example would be the Toyota Prius.

2.2 Plug-in Electric Vehicle Management

Due to the subject of plug in electric vehicles been so recent, studies have to be made in order to figure out how it should be inserted into society overall and what are the considerations and requirements to do so. One of the topics that should be overseen is the management of the plug-in, as for example whether it should be managed or uncontrolled. What would be the markets players involved in the matter and how would it work. For that matter in this subchapter of the state-of-the-art, all of the above will be overseen and explained extensively.

2.2.1 Type of control

PEV management is essential to figure out the whole picture of how the system works. There have been many studies on both aggregated/managed and completely uncontrolled PEV's. The most recent studies are mainly focused on aggregated/managed PEV due to finding that the disadvantages of the uncontrolled PEV scenario are quite impactful on how the system works overall.

The idea behind the aggregator or managed solution consist in the usage of a computer or a remote control which can control the system as a whole. It can either consist of only one vehicle or of a full fleet depending on the system. The uncontrolled scenario is a more simplistic method where you simply connect the car to the grid and charge when necessary.

An example of a study that studied in depth the idea behind uncontrolled charging versus the smart charging or aggregated charging is [6]. In this study different scenarios for charging are presented, including uncontrolled domestic charging, uncontrolled off-peak domestic charging, smart domestic charging and uncontrolled public charging throughout the day. The worst case scenario was found to be uncontrolled domestic charging where all vehicles charged at the same time. In this case, the charging would impact the local distribution in terms of capacity limit. This impact was due to the charging at home at peak hours, which is the normal time when people arrive at home, leading to high intensity charging and causing impacts to the distribution grid. In the second case, uncontrolled off-peak domestic charging improves the results because the charging will not occur during off-peak hours, which will not lead to the same scenario as the previous case. In the third scenario, smart domestic charging as the charging is controlled to optimize accordingly to the needs of filling the load curve, it improves the sales and will not overload the system.

This kind of system can help improve not only the load as mentioned but also can help manage the maintenance of the battery, and can also help buying energy during certain hours of the day in order to pay less for the electricity. The last scenario presented uncontrolled public charging throughout the day, which can be divided into three topics; namely, industrial where people charge while at work, commercial charging, and residential charging at night. In this case, there would be a peak while people are at work. In this scenario, it shows that the industrial and commercial loads cannot absorb EV charging load without exceeding the natural peak load if all EVs start charging at the same time. From this it can easily be taken as a conclusion that smart charging helps the maintenance of the system and can improve the usage of the PEV extensively.

In [2], it is intended to show the effects of uncontrolled charging on distribution equipment. In the study it is compared both cases of uncontrolled and controlled charging and the results concluded that uncontrolled charging for a PEV with 50% penetration, the transformer life is reduced by 200-300%. Comparing the scenario of uncontrolled and smart or controlled charging, the controlled charging increases the life expectancy of the transformers by 100-200%. So with this it can be concluded that using a smart charging methodology maintenance cost will be reduced drastically.

In [19], an investigation of uncontrolled and controlled charging PEVs behavior with different penetration levels to show their impacts on the electric grid. One of the presented cases has been studied on the modified IEEE 23 kV distribution system, where it is observed that high (63%) or low (16%) penetration of the PEV with the uncontrolled charging results in severe voltage deviations of up to 0.83 p.u., high power losses and higher costs in generation. The consequences of the uncontrolled charging in this study show that smart charging reduces line losses and higher system stability.

In [5], an uncontrolled PEV load modeling is presented; in this study it is suggested that when users randomly plug in their vehicles that the user must choose the type of charging adequate to their needs and their car. Forecasting tools to predict the charging levels are used. It is also stated that because unregulated charging can cause power spikes and safety margins in the power grid, they suggest the use of charging incentives for specific times or locations in order to regulate the power. In some way it is suggested an aggregated/managed charging, it can be uncontrolled but by giving this incentives they influence people to charge in a certain pattern; the only people that wouldn't use this is if it was an inconvenience for them to go to that certain location, if it was an emergency that they need charge at that precise moment or if they didn't need the money. So in this case it would seem a bit of a contradiction calling it an uncontrolled charging when it is being managed by giving incentives. The only reason it is considered an uncontrolled system is because the decision is made by human instead of a computer choosing the time that it would be charged.

The charging of the PEV can be controlled by the operator itself that can manage it accordingly to its needs, using smart charge like functions to maximize the charging taking into consideration some factors. These factors can be like minimum battery at a certain time that for example the user goes to work, so the function can manage the charging at the lowest price during the time he let it charging and the time he needs the car to go to work. Although for the new coming V2G concept there is a need for aggregation. This because V2G concept consists on supplying to the grid power, and also buying it back. This management needs to be done by an aggregator. Home users can't negotiate directly to operators they need a mediator for that which is the role of the aggregators.

In [20], an aggregator based market is presented. It is shown how the market works and the roles of each individual entity, aggregator and user. From the operator point of view, the objective it will be a minimization of cost; for this to be done it will be necessary to even the load curve so there is no need to turn on power plants or purchase electricity from other entities. By using the V2G concept they reduce the costs of these problems. In this study a minimization solution from the operator point of view is presented, and monetary rewards to the aggregators so that they can negotiate on their behalf are attributed. As said before because home users can't interact with the operator itself they need to enroll in a demand response program which is provided by the aggregator. The aggregator's role is to provide demand and response services to the operator and to guarantee a reduced electricity bill to the users. It presents a profit maximization solution for the aggregators. It is also adresses the problem from the user's point of view where they get monetary rewards for consuming off-peak and their objective is to get either a reduced electricity bill or monetary pay. This can be used for maintenance and pay-off the price difference between a gas car and an electrical car, making it appealing for the user to get an electrical car. The study presents the equations to maximize the net payoff to the user, which will be shown a bit further.

With this it is intended to present the aggregator scheme and how the overall system works, while there might be some variations in the equations used but the idea behind is the same. Taking into consideration both scenarios the uncontrolled and the aggregated, it presents the differences, the advantages and disadvantages of both. Starting with the aggregated scenario there won't be an overload of the system because it is controlled by the operator, so the end user has the advantage of the monetary rewards, and the operator saves on operational costs for power plants and other power sources.

The uncontrolled scenario brings a lot of disadvantages starting with the degradation of the PEV's, the peak problems presented, and a worst efficiency. So with this present it can be concluded that the aggregated/managed is a better scenario than the uncontrolled one.

2.2.2 Vehicle to grid and grid to vehicle

With the current development of the technologies it allows us for and increasing management of the PEV in the previous subchapter it was introduced the concept of V2G which is vehicle to grid. This concept is quite recent and with an increasing tendency of implementation. Some companies have started to introduce the possibility of V2G and G2V in the chargers supplied to homes for the PEV owners.

This technology bring high potential for regulation of the energy load curve allowing to give more stability to the system without using high expensive methods. As an example at peak hours when there is high demand, and maybe the predictions were a bit on the down side compared to the what really happened there is need to regulated and supply extra to the grid or buy from other countries. On a big scale using PEVs and the V2G technology will allow for this regulation at lower costs.

There has been an increasing tendency for the inclusion of grid-to-vehicle and vehicle-to-grid capability in the models. For example in [7], [21]–[23] all of these include V2G and/or G2V capability consideration in the models. There may be different approaches, markets, battery degradations, all or some of which are included in their algorithms for the subject, but the inclusion of this technology is very much present and considered.

As for an example in [7] it is tried to present a strategy for peak reduction in urban regions in Brazil in a smart grid environment, for this they develop a model taking into consideration V2G and G2V.

In another example [21] is developed an algorithm for integration of the V2G in the current market and study its potentialities, grid penetration and the introduction into the ancillary service market.

Seeing from the previous 2 examples it shows that the same concept can be applied to different problems. Being the first the peak reduction and the second one as an ancillary service. It can be a great technology to be diploid at a big scale not only for the consumer which gets rewards from selling to the grid at certain hours and buys at lower prices giving it a lot of potential. Obviously a problem here is that the highest priced hours are the ones people are at home which won’t allow for a good managing. Although a concept for companies parking lots is also a good thing to take into consideration for implementation which would allow the company to make a profit out of the parking lots and help the distribution system in the meantime.

2.2.3 Models of plug-in electric vehicle management

The presented models of PEV in the literature can be classified into three major categories; namely, operator viewpoint, aggregator viewpoint and users/owners viewpoint. The overview of the models is presented as follows.

Operator viewpoint:

In order to meet demand, the operator has either to activate power plants or to purchase electricity from third parties. The cost of generating electricity power is generally assumed to vary with time, due to the time-varying availability of supply, e.g. from renewable sources. However, for any given time slot t cost is a strictly increasing and convex function $c_t(y_t)$ of the corresponding total load $y_t \geq 0$.

If the operator could directly control the loads, its objective would be formally expressed as below where daily load profile vector $y = \{y_t : t \in T\}$:

$$\max_{y} \pi W - \sum_{t \in T} c_t(y_t) \tag{2.1}$$

Subjected to:

$$\sum_{t \in T} y_t = W \tag{2.2}$$

where W denotes watts and π represents the fixed price per watt.

Since the operator has no means to exercise direct control over the user demands, alternative means of indirect control such as dynamic pricing have been proposed. A method of using a mediator or in other words the aggregator has been used. The operator provides monetary rewards $\lambda = \{\lambda_j \geq 0 : j \in A\}$ to the aggregators, so that they perform DR on its behalf. y becomes dependent of λ. The operator is willing to provide a portion $\hat{\lambda} = \sum_{j \in A} \lambda_j$ of its DR gain to the aggregators.

The DR gain is the reduction of the power generation cost that results from reward λ and is given by (2.3):

$$\Delta c(y(\lambda)) = \sum_{t \in T} \Delta c_t(y_t(\lambda)) = \sum_{t \in T} [c_t^0 - c_t(y_t(\lambda))] \tag{2.3}$$

where c_t^0 is the power generation cost at timeslot t if no DR is applied.

Due to the presence of the aggregators the operator's problem is no longer a maximization of profit but a minimization of cost:

$$\min_{\lambda} \sum_{t \in T} c_t(y_t(\lambda)) + \lambda \Delta c(y_t(\lambda)) \tag{2.4}$$

Subjected to:

$$0 \le \hat{\lambda} \le 1 \tag{2.5}$$

$$\lambda_j \ge 0 \quad \forall j \in A \tag{2.6}$$

The objective function of the operator captures all its expenses in a DR market, i.e. both power generation cost and its reward to the aggregators for their services. This allows the operator to know the profit they will make according to the rewards they give.

Aggregator viewpoint:

Since small users (e.g. EV owners) cannot negotiate directly with the operator, they enroll in a DR program provided by an aggregator that aggregates several small residential DR assets into a larger unit, in order to increase their negotiation power. Given that each user is assigned to an aggregator through a contract, we denote with d_j the set of demands of all the users (i.e. from all individual appliances) under aggregator j.

The strategy of aggregator j constitutes of the compensation vector $p_j = \{p_{jt} : t \in T\}$. Let $d_j = \{\mathrm{d}_{jt} : t \in T\}$ denote the cumulative load of aggregator j at time slot t, over all the demands in d_j, that results from compensation p_j.

From the side of aggregator j, the DR gain Δc of (3) depends on its own compensation strategy p_j, but also on the compensation strategy of aggregators other than j denoted by $P_{-j} = (p_1, \ldots p_{j-1}, p_{j+1}, \ldots p_j)$. The same holds also for the actual reward received by aggregator j, since power generation cost at time slot t is a function of the corresponding total load, $y_t = \sum_{j \in A} d_{jt}$.

The objective of aggregator is to maximize its net profit by solving the following optimization problem:

$$\max_{p_j} \lambda_j \Delta c(p_j, P_{-j}) - \sum_{t \in T} p_{jt} d_{jt}(p_j) \tag{2.7}$$

Subjected to:

$$p_{jt} \geq 0 \ \forall t \in T \tag{2.8}$$

The first term corresponds to the reward received from the operator, while the second term is the compensation provided to the users.

Users/owners viewpoint:

At home, under the current model of flat pricing, users tend to use their appliances at the most convenient time throughout the day, driven by their personal preference. For example, most people activate cooling within the hottest period of a day, thus creating demand peaks. It is defined $x_i^0 = \{x_{it}^0 : t \in T\}$ as the reference consumption profile of appliance i that reflects its preferable power consumption profile in the absence of any DR incentives.

The users issue a set of demands D for the following day. Total daily electricity requirement of W_i Watts. We assume W_i to be fixed and independent of the provided rewards. The operator charges a flat price π for each Watt of consumption, which incurs a fixed daily cost of πW_i for demand i.

User problem is get the maximum profit possible overall which goes by:

$$\max_{x_i} \sum_{t \in T} [x_{it} p_{jt} - V_{it}(x_{it})] \tag{2.9}$$

Subjected to:

$$x_{it} \geq 0, \forall_t \in t \tag{2.10}$$

$$\sum_{t \in T} x_{it} = W_i \tag{2.11}$$

where the disutility function v_{it} captures the dissatisfaction caused due to deviation from the reference consumption. Function v_{it} may be taken to be convex, since the differential dissatisfaction of a user increases as the amount of deviation from the reference power consumption increases. An indicative example of such a function that was used throughout this case being analyzed is:

$$v_{it}(x_{it}) = v_i(x_{it} - x_{it}^0)^2 \tag{2.12}$$

In this case $v_i \geq 0$ is called the inelasticity parameter of demand i. This elasticity parameter changes between tasks, tasks that have low values are tasks that don't cause so much dissatisfaction to the user as washing machines, people don't mind washing clothes at different hours, but tasks like cooking on electrical stoves or so can influence the satisfaction of the client. So this parameter is considered here in this model.

This model was taken from [20] which was found the best overall model to exemplify the work of the whole network is tending to become.

Overall from the previous model the ideas that can be drawn from it are mainly the roles that are being considered now to the electricity market. This model is obviously not particular for PEV but gives a general idea of the behavior of the market around it. Instead of considering home appliances in the user part it can be considered a PEV and it's adapted to the subject in question.

2.3 Electricity Markets

In order for a better management there are a couple of ideas that need to be explored to complement a decent management. The ideas presented here follow on the subject of electricity markets. Electricity markets bring a great deal of importance for the whole PEV management idea.

There are a lot of markets of electricity now a days so there is a need to explore and elaborate on them all and find out which fits this management better and what brings the most advantage again for both users and for the operator side.

Other point that is related to the electricity market and bring some importance is the interaction of the PEVs with other market players.

The main focus here is the interaction with renewable energies, and explore the idea of this interaction bringing more potential for these technologies.

So in this subchapter all of these topics will be approach in order to provide an overall understanding regarding the subjects mentioned.

2.3.1 Types of electricity markets

There are different types of markets which are applied differently in many countries according to the legislation. Every country have different approaches and different resources which can provide the electricity in the country so this will also change prices and all things associate with the energy market.

So for further analysis of the market a research regarding the types of market, and which are considered to the ideal for the participation of PEVs. A literature search was done for this analysis. With this the best and broader studies are mentioned for best understanding

In [8] a price-responsive strategy for a market using the V2G concept is presented, the market considered in the study is Singapore. For markets they start by describing the base, central and peak load. So it is stated that 96% of the electricity generation is provided by gas and oil power plants, and that whit the flexibility it allows to cover the previous stated 3 types of loads. As a result there is only one entity to regulate the electricity market. As these sources and highly reliable whit low fluctuations and the electricity market is easy to predict its and efficient method to use. Because of their efficiency and low cost, it is not a viable market for the use of V2G concept. Another kind of service provided is the ancillary services which consists in compensating the fluctuations, depending on the durations of time which they are providing the ancillary service which is divided in to 4 categories regulation, and primary, secondary and contingency reserve.

In a normal market, providers of these kinds of services would get compensation for providing these services, or if there was too much power for holding the power generation which is good for cars with V2G and G2V implementation. The difference in the Singapore market which is stated in this study is that these kinds of compensations do not exist, due to the law applied in the country.

In [24] it is stated that with the development of smart grids and V2G technology, it is easy for people who own PEVs to inject power to the grid and receive power at all times. With this it can be injected power at peak times to obtain maximum revenue and charge at off-peak times where the price is the minimum.

V2G networks are an important part of smart grids due to their capability of providing better ancillary services than traditional approaches, as for example dams. It is stated that the biggest challenge of the V2G in the power system, is giving the ability to control it.

In [25] the author considers that PEVs with the V2G implementation, it can't be consider a power source, the V2G is a form of storing energy and then releasing it. Whit this said, PEV's can't produce new electricity for the system, the only useful thing that PEV's can be applied is for storing energy, off peak, unwanted renewable energy and base-load energy. Then after storing the electricity they can resupply using the V2G whenever it was necessary, they suggest supplying the system at peak periods so it wouldn't be necessary to peak fossil fuel plants.

Taking into consideration the last papers, as mentioned the PEVs are good for ancillary services, with V2G and G2V tech because of their fast charging and discharging, ability to store power and provide when needed. The idea of selling in peak power is where maximum profits come from, obviously they wouldn't provide the entire peak just a part of it with the base load power, but this can only happen in markets where they give compensation for selling and buying power, although there are countries where this does not happen like the example of Singapore mentioned above. There are also a couple of other studies regarding other countries like for example Germany in [26] where the previous does apply. The base load because of their low prices of production would obviously be kept being provided by power plants.

Taking into consideration that the base load has been mostly discarded by all the literature previously mentioned and all the literature not mentioned, it won't be a topic of discussion or used further in this work. Now the other types of market mostly mentioned for the usage of the V2G is reserve and regulation.

The concept behind the reserve market generators is to supply the ability to increase their production if called to do so. These kind of market provides not only payment for the amount sold for the market but also according to the time and power that are available to do so. There are multiple types of reserve, regulation reserve, spinning reserve and non-spinning reserve. Spinning and non-spinning reserve are positive quantities which allow unidirectional flow of energy. Regulation Reserve on the other hand allows for bi-directional control same as the PEVs V2G and G2V concept. Generally the market participation in this market has a low probability.

Regulation market works differently the objective of regulation as the name indicates is to regulated the curve providing stability to the curve. It works bidirectional regulation up or down, when it's providing regulation up power is injected into the grid, and for regulation down it consumes for the grid to provide the regulation.

This is a great asset for PEVs due to the fast response time, unlike many other generation providers like dams and so on. This regulation is done in many forms like voltage and frequency regulation, although the most common throughout recent studies has been frequency regulation.

There have been a lot of studies regarding different types of market that do not apply to real life markets but only as an overall study, there are a lot of markets that this kind of idea can be applied. For example, regarding spinning and non-spinning reserves there are some reports like [19], [27], [28], [29] that take these kinds of market in consideration. References [25] and [30] are presented regulation market. Ancillary services, voltage and frequency regulations are presented in [2], [21], [23] and [29].

2.3.2 Interaction between the PEVs and other market players

With the increase of the growth of the sustainable overall system there's a need to try and join all of the components of the system together. One of the main assets that can be helpful and help the PEVs is renewable energies. The management of both together can be a huge development for both areas. There are a many of studies that connect other resources with PEVs most of them have studied the huge potential behind interactions with mainly renewable energy sources some examples regarding this matter can be found in [3], [7],[10], [31] and [32]. In particular, two renewable energy resources, photovoltaic and wind, have been widely more studied then the rest.

Photovoltaic has a huge potential mostly during summer as it is known is where this resource is at its best due to being the time of the year where the sun provides the most energy. Although even during the summer the profile of the photovoltaic has a peak during the day but provides nothing at night. Due to mobility this can provide a problem to charge at home, but can be a great asset for companies to have in the parking lots as an example.

As an example, [3] studies the interaction of the photovoltaic panel in the roof top of a house with a PEV. The study proposes to use a Markov chain model in order to simulate the charge and discharge processes that occur in energy storage, which enables to estimate the charge level of energy storage system at the end of any day, using the photovoltaic and the PEV. Also using photovoltaic there are studies regarding the storage of this energy and then later utilization such as [29], [33]. Although these do not take into consideration the mobility issue of the photovoltaic energy.

In terms of wind energy that subject is more specifically approached in reports like [32] and [33]. Due to the high wind fluctuation this leads to a high variation in the power generation, which must be balanced by other sources.

The battery storage-based Plug-In Electric Vehicles may be a possible solution to balance the wind power variations in the power systems with high wind power penetrations. In [33], the integration of plug-in electric vehicles in the power systems with high wind power penetrations is studied.

From these studies it is shown that the PEV interaction provides a good possibility to regulate the power from these sources. From multiple perspectives, not only as a storage unit, when production exceeds the supply but also as regulatory help for fluctuations where it needs compensation.

There are also some studies regarding some other areas like for example [31],[34], [35] here is shown other types of renewable energy interaction which is biomass energy which they state that studies indicate that bioelectricity for use in a vehicle is a more effective use of biomass than conversion to biofuels. This area is not widely explored but these papers mention a great perspective for a better analysis.

Overall as shown previously there are multiple types of studies regarding the interaction of PEVs with renewable energies. The less studied of them all are biomass which could have a great potential as said by the references presented. On the other hand there are a lot of studies regarding the two main energies considered, wind and photovoltaic.

There are two energies that have had a great focus compared to the rest of them not only due to the storage potential but also for regulation of these kind of energies, there are also a couple of real life application studies as mentioned in Brazil for example. In table 2.1 it is shown a comparison of some studies regarding this area.

There are other types of interaction besides interaction with renewable resources as for an example demand and response programs. For demand response programs there have been studies regarding this subject like in [20], [24], [36], [37].

The concept of a demand and response taking in to consideration a smart grid is, all smart appliances and multi-agent systems will be operated by settings on a smart meter. The customer will turn smart appliances on and off and charge the plug-in electrical vehicle based on the priorities that have been set.

The customer can turn on the maximum number of smart appliances and charge a plug-in electrical vehicle at minimal cost of electricity, maximizing its profit or savings. This program suggest not an aggregated view of the problem but more of a customer centralized operation.

Table 2.1. Types of renewable sources interacted with PEVs

Studies	Renewable sources interaction		
	Wind	Solar	Biomass
[1][3]		X	
[2][7]		X	
[3][10]		X	
[4][31]	X	X	X
[5][38]	X		
[6][39]	X		
[7][32]	X		
[8][34]			X
[9][35]			X

2.4 Modeling the Plug-in Electric Vehicles

Modeling the PEV is a hard task to tackle, so in order to do this a broad research of other models and what's has been done so far was done. There are a lot of sub topics that need to be looked at when trying to build a model. The first topic is the type of model that has been used for what type of problems if it's either probabilistic, stochastic or deterministic. Following this the type of data in terms of time line, long term or short term, and in these which sub time lines have been implemented in the models so far. Then a more broad research of types of variables, constraints, costs, and all the other overall features from the grid, network and others has been done. With this a model can be built based on the ideas overall picked up, and try and compliment with other ideas so a better model can be implemented.

2.4.1 Type of models

There are many models with pretty different approaches to the problem, the main models used are the probabilistic, deterministically and stochastically. Deterministic problems are the ones which use only fixed data, this generally is used for verification where we use all the same data in order to verify the problem.

Probabilistic problems as the name indicates it uses probability to generate data. As far as stochastic goes uncertain variables are used where you can't predict what happens.

Taking these into consideration in terms of probabilistic, there are reports like [4], [40], [41] although this last one considers some variables deterministically.

The main difference expressed in the papers is the productiveness of the models is better for probabilistic than for deterministic ones. It is explained in [40] the advantage of using probabilistic instead of deterministically is that a single charging station cannot know which charging station has the shortest queue unless some information is exchanged among stations. Using the probabilistic approach does not require any direct exchange of information and thus has good scalability properties.

As for a deterministic approach we have for example [3] where it is done exactly the opposite of the above, it has a central manager that controls all the stations, and the objective of that control is to deterministically manage the charging station in order to maximize the profit. In [1] which is a review paper, it presents different probabilistic and also deterministic models from other literature.

For stochastic models there are a lot of different approaches and models. For example in [5] it is used a stochastic model based on queuing theory for EV charging demand.

In [42] a bi-level type of charging is taken into consideration. Another example in [43] where the problem of V2G services is formulated as a mixed-integer stochastic linear program.

Most models found are based on deterministically or probabilistic models, although some of the variables used in the problem can be considered stochastic, the models use data collected in real time management to make them probabilistic or deterministic. This allows for a better study of the model that then can be applied to real market scenarios. If studying a single PEV probably not because there are already PEV owners throughout the world. And there is real data available for studying. In table 2.2 a distinction from type of models between the literatures is presented.

Table 2.2. Types of uncertainty models

Studies	**Type of models**		
	Deterministic	Stochastic	Probabilistic
[1][5]		X	
[2][23]			X
[3][24]		X	
[4][25]			X
[5][26]			X
[6][32]	X		
[7][43]	X		X
[8][48]		X	

Talking specifically regarding the subject at matter the models behind PEVs cannot use deterministic data, when studying a parking lot. This is due to the simple fact that there no data regarding the subject of the behavior behind the parking lot for most variables as for example state of charge of vehicles, battery conditions, type of vehicles. So obviously there is a need to use stochastic or probabilistic methods for parking lots.

2.4.2 Time horizon

Time horizon is an important factor to be explored in the model. The first factor that needs to be overseen is whether it is used short term or long term models. The advantages and the differences between them. Inside short term there are also 2 sub methods, day-ahead and real time. A distinction between both is also necessary in order to depict the advantages between both.

The main focus that is found in current models being developed are short-term markets, the studies that are made as for an example [44] where to simulate using short-term real-time. Long term is not being applied in models, but in studies to see if it compensates the investment. But for market, economical modulation, tariff, and other its being used short term modeling.

In terms of short term for example in [9], [29] ,[45] and [46] it is used the Day-ahead market, where the market which is used consists of the distribution system operator which predicts congestion for the coming day and publishes prior to the begging of the day the markets conditions, the prices and the places where it will be cheaper or the other way around. This brings the possibility of higher efficiency due to the prediction avoiding maybe some unwanted situations for the system.

For another short term method it can be explored the real-time method, and for example like in [10], [22], [47], [48]. The algorithm operates in real time and does not require any prior knowledge of the statistical information of the system. This means that this kind of method is an action-response kind of method it requires a better reaction time in order to correspond to the market needs, and respond accordingly which can either be an advantage or a disadvantage.

Comparing first short term versus long term like explained previously for modeling it is better a short term method because not only it conducts to a shorter analysis to the efficiency of the model, but also it's easier to find flaws and it's better to scale if necessary. Although obviously for a better analysis for wide implementation a long term analysis is required in order to understand if it is viable or not to implement these kind of system.

For comparison between both short term. Day-ahead is more of a prediction tool where obviously they can be mistaken, but generally there are intervals for these predictions and are quite accurate.

Real-time can lead to unpredicted situation which the system can't handle contrary to the day-ahead, but also doesn't need to do the data analysis that day-ahead does.

In table 2.3 a time horizon comparison between the literatures is presented. This time horizon focuses main only the distinction between short term time frames, day-ahead and real-time.

2.4.3 Uncertain variables

An overall perspective of the considerations that are made in models this time about the variables used in the models is necessary. This allows to understand what are the major variables have been used and how they have been considered.

Uncertain variables are considered variables that don't have a standard value and we can´t be sure of the variable. So models are generally used to determine those variables, or scenario generation is also used to tackle this problem.

There are very different models that use different variables, in papers like [4], [10], [11], [20], [21], [47] and [12] are different models, all with different approaches. But there are always constant and similar variables to them.

For example comparing most of their model we can find stochastic variables common like the number of cars or batteries (referred as batteries and not car in one paper), the price of the electricity, the SOC of the cars, the maximum SOC of the cars, diving behavior is also considered in one of the models, and also the state of the battery.

Table 2.3. Types of time horizon studied in the literature

	Time Horizon	
Studies	Day-ahead	Real-time
[1][9]	X	
[2][10]		X
[3][22]		X
[4][29]	X	
[5][43]	X	
[6][44]		X
[7][47]		X
[8][48]		X
[9][49]	X	

In [10] is presented a given problem and all the considerations and uncertain variables regarding it. The objective of the paper is to develop a modeling system for a parking lot of possibly and university campus, which contains around 1500 parking spaces.

The uncertain variables are the percentage of cars parking daily, the size of the cars if they are small cars mid-size SUV's or full-size SUV or picks-ups because of their energy consumption.

Other uncertain variables are the arrival and departure of the vehicles and their initial state of charge when they arrive at the park. This is a very interesting paper which considers an overall of the main variables which have been found most relevant for the modeling of a parking lot.

In [36] a model of charging and discharging is presented, it is considered a lot of different variables from which include some stochastic. The variables that are present in this work consist of driving patterns, the state of the battery which its degradation is the main concern because it can be influenced by a number of different random factors, the electricity price, the current state of charge, and the maximum SOC, here they do not consider the number of vehicles.

In [13], it is used a different approach where it is used state-of-energy instead of state-of-charge, justified because of the easy derivation of power and energy quantities in the model.

SOC is a more accurate variable for describing battery state, as it includes cell voltage variations. However at the aggregator level where the charging power of thousands of EV is estimated, the SOE variable that includes battery characteristic like they present is more simplistic for that scale.

In general there might be some variations between models, like in the previous case the model is for a particular unit so they do not consider the number of vehicles, for other cases they might consider the number of vehicles but not consider the driving pattern like one of the papers referred.

But in general most of them use the stochastic variables mentioned above in their models. This is an important step to figure out which variables are the most adequate to model parking lots, or other type of modeling.

In table 2.4 a round-up of multiple papers show the different variables found throughout the literature.

Table 2.4. Types of variables presented in the literature

Studies	Variables					
	Nº vehicles	SOC	Time	Driving patt.	Price	SOE
[1][4]		X	X	X		
[2][10]	X	X	X	X	X	
[3][11]	X		X		X	
[4][12]	X	X	X	X	X	
[5][13]	X		X		X	X
[6][20]	X		X		X	
[7][21]	X	X	X		X	
[8][38]		X	X	X	X	
[9][47]			X		X	

2.4.4 Stochastic techniques

In order to handle the uncertain variables there are multiple techniques which can be applied to these variables in order to make the model work. Some of this are mentioned underneath for better understanding of the subject.

There are a couple of different methods applied to uncertain variables. As for an example in [10] for the uncertain variables it was developed a statistical probability distribution in order to simplify it. This statistical distribution generates a scenario based on the distribution chosen there are many types of distribution like Gaussian distribution. Then these scenarios can be applied to the model.

In [29] the uncertain variables are the uncertain energy prices, balancing prices, stochastic energy availability, and demand. The method applied here is deterministic method in order to simplify the uncertainties and problem. They attributed values to the uncertain variables which they thought to be fit in order to teste the model.

The following studies [5], [11], [41], [50], [51], are some examples of different methods which tackle these kind of variables .In particular in [5] where it is used a stochastic model, based on queueing theory they have a lot of stochastic variables, customers randomly arriving, EVs being randomly plugged in, and others. In the study, it is approached the differences between the 3 methods of supplying the demand response, day-ahead and real-time.

The way that these unknown variables are treated is by using a statistical method trough estimating and forecasting by using historical data. This usage of previous data makes the statistical distribution more precise because it's based on actual historic data.

2.4.5 Modeling PHEV exchange station

Here a deterministic integer programming model is presented this model looks at scheduling multiple PHEV exchange station operations, it is intended to take as an example of a modulation of a PEV parking lot.

It is assumed that there exists a central manager that maximizes profit over all locations and the finite time horizon of the problem. The objective function maximizes the total profit. [11]

The model is expressed as follows (13):

$$\sum_{t=1}^{T}\sum_{j=1}^{n}\left(p_e\left(x_{pjt}+\alpha x_{sjt}\right)-p_e\left(r_{jt}-\left(x_{pjt}+x_{sjt}\right)\right)-\pi\sigma_j\left(x_{cjt}^{+}+x_{cjt}^{-}\right)\right) \tag{2.13}$$

Subjected to:

$$x_{cjt}^{+}\leq b_j-x_{fjt},\ for\ j=1,\dots,\ n,\ \ for\ t=1,\dots,T \tag{2.14}$$

$$\left(x_{pjt}+x_{sjt}\right)+x_{cjt}^{-}\leq x_{fjt},\ for\ j=1,\dots,\ n,\ \ for\ t=1,\dots,T \tag{2.15}$$

$$x_{fjt+1}=x_{jft}-\left(x_{pjt}+x_{sjt}\right)+x_{cjt}^{+}-x_{cjt}^{-},\ for\ j=1,\dots,\ n,\ \ for\ t=1,\dots,T \tag{2.16}$$

$$x_{cjt}^{+},x_{cjt}^{-}\leq k_j,\ for\ j=1,\dots,\ n,\ \ for\ t=1,\dots,T \tag{2.17}$$

$$x_{pjt}\leq r_{jt},\ for\ j=1,\dots,\ n,\ \ for\ t=1,\dots,T \tag{2.18}$$

$$\sum_{j\in\phi}x_{sjt}\leq\sum_{j\in\phi}\left(r_{jt}-x_{pjt}\right),\quad \forall\phi\in\Phi,\ for\ t=1,\ \dots,T \tag{2.19}$$

$$x_{pjt}\geq\beta_p r_{jt},\ for\ j=1,\dots,\ n,\ \ for\ t=1,\dots,T \tag{2.20}$$

$$\sum_{j\in\phi}x_{sjt}\geq\beta_s\left(\sum_{j\in\phi}\left(r_{jt}-x_{pjt}\right)\right),\ \forall\phi\in\Phi,\ for\ t=1,\ \dots,T \tag{2.21}$$

$$\sum_{j=1}^{n} x_{cjt}^{+} \leq c_{tout}, \; for \;\; t=1,\ldots,T \tag{2.22}$$

$$\sum_{j=1}^{n} x_{cjt}^{+} \leq c_{tin}, \; for \;\; t=1,\ldots,T \tag{2.23}$$

$$0 \leq x_{fjt} \leq b_j, \;\; for \; j=1,..., \; n, \;\; for \;\; t=1,\ldots,T \tag{2.24}$$

$$x_{fj0} = b_j, \; for \; \mathrm{j}=1,\ldots,\mathrm{n} \tag{2.25}$$

$$x_{fjt}, x_{pjt}, x_{sjt}, x_{cjt}^{+}, x_{cjt}^{-} \in \left\{\mathbb{Z}^{+} \cup 0\right\}, \;\; for \; j=1,..., \; n, \;\; for \;\; t=1,\ldots,T \tag{2.26}$$

where T denotes the Time horizon. N is the number of exchange locations. Φ represents the set of all clusters. p_e is the Price to exchange a battery. α denotes the discount rate if an exchange request is satisfied at a secondary location. r_{jt} states the number of exchange requests at location j at time t . π represents the power price (earnings) to charge (discharge) one battery at time t. σ_j denotes the normalized energy received (for charging) or given (for discharging) when charging one battery at location j. b_j is the number of batteries at location j. k_j represents the number of plug-ins available for charging/discharging at location j . β_p and β_s denote the customer service level for primary and secondary customers, respectively. C_{tout} is the capacity of the power grid eligible for charging batteries (grid to exchange locations) at time t. C_{tin} is the capacity of the power grid eligible for discharging batteries (exchange locations to grid) at time t. x_{pjt} and x_{sjt} represent the variables of the number of primary and secondary batteries exchanged at location j at time t, respectively. x_{cjt}^{+} and x_{cjt}^{-} are variables of the number of batteries charging and discharging at location j at time t, respectively. x_{fjt} denotes the variable of the number of full batteries at location j at time t.

2.4.6 Modeling the V2G parking lot

The V2G units are either charging or dis-charging their batteries. For n of V2G units supplying power to the grid, and vehicles charging their batteries, the net power P_{net} to the grid is given by:

$$P_{net} = \sum_{i=1}^{n_0} P_{EVoi}\left(1 - e^{-\frac{\beta_i t_{si}}{t_{max}}}\right) - P_{max}\left(n_d - \sum_{i=1}^{n_d} e^{-\frac{\alpha_i t_{ci}}{t_{max}}}\right) \tag{2.27}$$

where α_i and β_i are, respectively, the battery charging and discharging constants for an ith V2G unit, requiring charging time t_{ci}, and discharging time t_{si}. The parameters $P_{\max}$ and P_{EVo}, respectively, represent the maximum battery capacity and initial power in the V2G battery. This allows to calculate the net worth of in and out power and with it calculate other factors like profit and other factors.[10]

2.4.7 Terms of costs and constraints

There are many different parameters considered in different papers, here it will be presented some parameters that are considered followed by a few models to exemplify. These parameters can be considered constraints to the model. These constraints vary from model to model according to the variables considered in them going from costs limitations, voltage, power and other limitations.

For first analysis the model presented in [36] considers couple of different parameters. One of the main focus is on the battery degradation which is explained all the theory behind it and presented the factors that influence the battery degradation. These factors consist in temperature, number of cycles, SOC swing, charging rate, and waiting period between charges and SOC in swinging periods. As consequence of this it is taken in consideration the SOC in order to predict the battery's degradation. Other parameters are considered in this model is the grid power and grid management.

Another model is presented in [46], in this one it also begins by modeling the battery degradation, for this it is considered a lot of different parameters, open circuit voltage, internal resistances and the capacitance, with this they can get the terminal voltage in order to model the battery. For the battery modeling it is also considered the SOC, in 3 views the current SOC, minimum SOC and maximum SOC, in order to know the state of the battery, using these parameters the capacity loss of the battery can be modelled.

These previous parameter are used in parallel with monetary, time and energy parameters in order to do an economic analysis of the system.

There are a couples of other papers that develop models with different parameters for example [14], also bases the study on the research of the battery to begging with here it is also considered the SOC and uses driving cycles and charging strategies in order to simulate PEVs. In [15] a study of an EV fleet is performed which is one of the parameters, and study the vehicles that drive multiple distances and charge in order to analyze the charging curve of a day of charging. In [16] it is presented a Markov model in order to optimize fleet management, other parameters considered are maximum/minimum rate of charge, maximum and minimum storage of the battery, time varying electricity price, charging and discharging battery efficiency, battery capacity and diving patterns.

Another approach that's been used in terms of battery management for example in [52] is the idea of battery swapping station which is a parameter that is present in the model, where the battery station determines optimal charging/discharging schedules for batteries, identifies the batteries that should be replaced to match the battery demand.

All of the parameters mentioned previously are essential for a development of a good model, although having all of them doesn't mean the model will be more complete then others. Some might need a simpler model with less parameters to prove the point their trying to show. Overall the biggest parameters to be considered are all features regarding to battery, charging, discharging, SOC, degradation and others, prices (if doing an economic analysis), scheduling of vehicles arrival and departure, and if modeling also the grid those should also be considered.

There should be a couple of other parameters like V2G inverters and infrastructure costs that should be considered, but are not generally. These have been introduced only long term scale economic analysis, mainly because there are investment costs for long term so there is no point in using them in a short term analysis like most models do as far as the studies found and mentioned here.

2.4.8 Modeling a PEV aggregator

Here follows an example of the implementation of multiple variables mentioned previously. In this model, the PEV has been optimized taking into consideration the driving patterns and battery degradation. The details of the model have been explained below.

First consideration in the model mentioned by the study is the driving behavior. Driving behavior is modelled using the probabilities introduced in a reference of theirs and given from different mobility surveys.

The driving time of the trip m , $t_{drive,m}$ is calculated according to the linear function:

$$t_{drive,m}\left(k\right)=0.7211k_m+5 \qquad (2.28)$$

Here in this equation k_m represents the distance driven by driver m .

In order to calculate the operation schedule of the PEV agent, the following mobility parameters are necessary. The first is the energy used during the trip this is calculated as follows:

$$SOC_{n,t+tdrive}=SOC_{n,t}-\frac{k_m\eta_{km}}{E_{bat}} \qquad (2.29)$$

The SOC after the new trip will be the initial SOC subtracted to the distance multiplied by the conversion efficiency of the electricity into mechanical energy, divided by the usable energy of the battery.

To calculate the period of optimization it is needed to have the grid management time which is calculated using the current time and the next trip time and the driving time given by $t_{start,\mathrm{m}}$, $t_{start,m+1}$ and $t_{drive,m}$ respectively. Then management time then is given by:

$$\Delta t\left(m\right)=\left(t_{start,m+1}-t_{start,m}\right)-t_{drive,m} \qquad (2.30)$$

And finally the necessary energy for the next trip is calculated by

$$SOC_{n,\Delta t}=\frac{k_{m+1}\eta_{km}}{E_{bat}} \qquad (2.31)$$

As alternative, it is said a 100% SOC can be used.

This management is helpful for both the user and the operator side. With this it is known the driving pattern of the user giving by the time of the next travel.

This is used to calculate da state of charge necessary for that trip. Then with this a management of the state of charge of the car can be done to fit the users need according using driving pattern as a variable.

Second consideration for this model is battery degradation. Three models of control have been suggested for the battery, the first one consists on a model based on the depth of discharge, and accordingly the battery degradation is influenced by the depth of discharge (DoD). The life cycle depends on the DoD by the function:

$$N_{cycle} = a \cdot DoD^{b} \tag{2.32}$$

The parameters a and b that vary with each battery for example they suggested that for li-ion batteries $a = 1331$ and $b = -1.825$.

The discussed model indicates the highest lifetime for a fully charged battery without cycling. However, when considering calendar life, a SOC of 100% is the most demanding condition. This contradiction indicates a weakness of the model.

The second model which is based on energy throughout there are no formulas, it is stated that for some batteries the DoD is not the most important factor but the capacity fade is. Then it is used as an example the A123 systems and use their website for consultation.

The last model is Discharge Costs. When the battery is discharged, the degradation costs are a function π (DoD_{start} , DoD_{end}). Additional parameters are the cost for the battery C_{bat} , and the usable energy of the battery E_{bat} .

$$\pi(0, \mathrm{DoD}) = \frac{C_{bat}}{N_{cycle(DoD)}} \tag{2.33}$$

The costs for one processed kilowatt-hour is given by:

$$\pi_{energy}(0, DoD) = \frac{C_{bat} DoD E_{bat}}{N_{cycle}(\mathrm{DoD})} \tag{2.34}$$

The general degradation costs is then give by:

$$\pi(DoD_{start}, DoD_{end}) = \pi(0, \mathrm{DoD}_{start}) \;\; for \;\; DoD_{end} < DoD_{start} \tag{2.35}$$

The cost per discharge unit π as a function of the DoD before the discharge is given by:

$$\pi_{unit} = \pi\left(DoD, DoD+1\%\right) = \pi\left(0, DoD+1\%\right) - \pi\left(0, DoD\right) = \quad (2.36)$$

$$= \frac{C_{bat}}{N_{cycle}\left(DoD+1\%\right)} - \frac{C_{bat}}{N_{cycle}\left(DoD\right)}$$

2.4.9 Modeling the grid

The modeling of the grid is an important consideration to take into account due to the limitations that it will put on the model. This due to voltage limitations on the transformers, limit of flow through lines, and consider losses on the lines is also important. A factor that should also considered is study the grid for better grid placement and minimize transportation losses derived from previously mentioned factors.

In the literature they main focus of PEVs has been as a distribution role in the electricity network, this can be found in [2] , [28], [53] . The burden of electric mobility will be mainly on the distribution system that, particularly during the peak hours, will be exposed to critical operation conditions by a high number of high density simultaneous loads. V2G technology by adding control capabilities to charge and discharge of cars' batteries can exalt the benefits from their whole energy storage capacity. Distributors can then be helped in the active management of the network by the services. As for transmission no models were found that suggested any tendency for that as far.

Considering all of this a combination of optimization study for the grid in connection to a parking lot has not been done. While they do consider the grid but more on a saturation perspective so it doesn't over load. But the other consideration regarding grid placement of the PL and sorts should be studied. Although this can be explained because due to the PL being a very recent area of study and still haven't gone so far or there is still too little information around it.

2.4.10 Features of the power system

There are some important elements that need to be considered in order to guarantee a good service and also help a better performance of the power system.

Security is one of the features that should be researched because of security of the home user is very important. The smart interaction between user and operator where they have access to the user patterns is a bit worrying because, not only through PEV's but also using domestic appliances patterns of home usage can be made which can present a high security risk to the user. This does not really regard only PEV's studies but also smart grid studies regarding V2G and PEV's [17] studies security network for the subject, while other PEV's studies they only study the security of supply and power.

Security can be a real concern, so this should be way more considered. Although obviously not on the modulation part because this does not influence the model and the simulations and all of that. But for implementation in big scale and for home user it should be considered.

There are papers that present their method to solve some features that they consider to be a problem, for example considering the reliability of the system [18] presents a solution for better reliability with the suggestion of the usage of a converter.

For losses there are these two papers present and consider these kind of system feature [1], [54] this last one is more focused on the losses and presents a lot of way to minimize it and how it influences the system and tools for system optimization.

A big part of the losses being the grid and everything associated with it which was considered in the last subchapter. The grid represents an external part of the system the main considerations in the previous mentioned papers is more focused on the PEV system individually not as a parking lot.

In [55] the soul of the study is regarding power quality improvement in a smart grid involving EVs, it evaluates scenarios in order to see the consequences of the PEV's in large scales.

In [56] it is stated that V2G control has the potential to provide frequency regulation service for power system operation from electric vehicles. A decentralized V2G control method is proposed for EVs to participate in primary frequency control.

And then there are some that approach all the subjects in a generalized way, for example [2] speaks a little about all the subjects previously mentioned voltage and frequency control, stability, reliability and efficiency.

The previous elements mentioned are important not only for the user but also for the operator. For the user the most important elements are the security and the reliability. Security is always important on a personal level and the reliability is important for the satisfaction of the client.

All the other elements are more important for the operator, if all of them are working more effectively and with good regulation it will have less losses, reduced maintenance which leads to a bigger profit overall.

2.4.11 Modeling the features of power system

Here it will be presented formulation for controlling multiple fixtures of the power system. First power loss formulation will be presented.

The per unit optimal power loss reduction, $\Delta P_{LS\_V2G\_opt}$, for a single vehicle is defined as

$$\Delta P_{LS_{V2G_{opt}}} = 3c\alpha X_1\left[(2-X_1)+\lambda X_1 - c\right] \tag{2.37}$$

Where the quantity x_i represents the position of the *ith* V2G parking lot and c is the sizing, while the load pattern λ defines the loading characteristic of the line segment ($\lambda = 0$) represents uniformly distributed load, while represents lumped loads). Hence, the range, $0 < \lambda < 1$, defines the bounds of possible load pattern. The following parameters are define

$$c = I_c\left(I_1\right)^{-1} \tag{2.38}$$

$$\lambda = I_2\left(I_1\right)^{-1} \tag{2.39}$$

$$\alpha = \left(1+\lambda+\lambda^2\right)^{-1} \tag{2.40}$$

The quantities, I_c , I_1, and I_2, are, respectively, the injected reactive current, the reactive current at beginning, and at the end of the of feeder line segment. The parameters of $\Delta P_{LS\_V2G\_opt}$ are obtained online for real-time computation of the power loss.

Second energy loss formulation is presented

The per unit optimal energy loss reduction, ΔEL_{opt_V2G} , in a three-phase distribution line segment is defined as (for n=1) is

$$\Delta EL_{opt\_V2G} = \frac{3\alpha c}{1-\lambda}\left[F_{LD} - c + \frac{c^2}{4F_{LD}}\right]T \tag{2.41}$$

$$F_{LD} = \frac{Q}{S} \tag{2.42}$$

where T is the total period of supply.

Here the formulation for voltage stability will be presented. The computational equation can be formulated as below:

$$VSI_m = (2\frac{V_m}{V_k}\cos\left(\delta_k - \delta_m\right) - 1)^2 \tag{2.43}$$

where VSI_m is the voltage stability for node m. V_m and V_k are node voltage at m and k, respectively. δ_m and δ_k represent the voltage angle at node m and k, respectively.

The voltage stability margin (VSM) of a feeder is given by,

$$VSM_{k,m} = \prod_{i \in \Omega} VSI \tag{2.44}$$

where VSI is the voltage stability complex and Ω is a set of branches constituting the enter length of the feeder. A feeder with the lowest value of VSM is considered the weakest feeder this can be defined as

$$VSM_{sys} = \min\left(VSM_1, VSM_2, \ldots, VSM_j\right) \tag{2.45}$$

where j is the number of feeders in the system. The system VSM_{sys} is an indicator of the nearness of the system to voltage collapse.

Chapter 3

Modelling

In this section a description of the model will be made. The model aims to cover a very recent topic, which has the objective to study the impact of the localization and the size of different renewable energy resources in the distribution system, on the behavior of parking lot. It is taken into consideration that the distributed generation needs to be modeled because of the previous problem in order to prevent certain unwanted situations in our distribution system for example voltage losses.

The previously mentioned features will give an overall performance ability of the model which could further on be used as a base model for other works or even real life applications. Here in this chapter a description of the model's equation and the modeling of the uncertainties which are considered in the model will be explained in detail.

3.1 Parking Lot Model

The objective is to optimize the behavior of parking lot operator; this optimization is mainly focused on the maximization of the profit of the parking lot. This results from market interactions and individual contracts with PEV owners. However, as mentioned above both the distribution network and the RERs can influence the behavior and the outcome from the parking lot. Therefore, here both the factors are taken into consideration in order to determine the best behavior of the parking lot.

3.1.1 Objective function

The objective aims to maximize the profit of parking lot operator. As can be seen in (3.1), the profit is resulted from the incomes and the costs. Being the incomes the positive and the costs the negative terms.

The first income term is expressed in (3.2) this term represents the income provided from generating in the energy market which amounts to the energy generated from the parking lot to the grid multiplied by the market energy tariff.

$$\underset{P_{\omega,t}^{En,PL2G},P_{\omega,t}^{En,G2PL},P_{\omega,t}^{Res},P_{\omega,t}^{Res,Act},soc_{\omega,t}^{up},soc_{\omega,t}^{down}}{\text{Maximize}} \left\{profit^{PL}\right\} = \tag{3.1}$$

$$Max \sum_{\omega} \pi_{\omega} \sum_{t} \left\{ P_{\omega,t}^{En,PL2G}.\lambda_t^{En} + P_{\omega,t}^{Res}.\lambda_t^{Cap,Res} + P_{\omega,t}^{Res,Act}.\lambda_t^{En} \right.$$
$$+soc_{\omega,t}^{up}.\lambda_t^{Tariff,G2V} + n_{\omega,t}^{PL}.\lambda^{Tariff,stay} - P_{\omega,t}^{En,G2PL}.\lambda_t^{En}$$
$$-P_{\omega,t}^{Res,Act}.\Gamma^{Res}.\lambda_t^{En}.\pi^{unavail.} - P_{\omega,t}^{Res,Act}.\lambda_t^{Tariff,V2G}$$
$$\left. -soc_{\omega,t}^{down}.\lambda_t^{Tariff,V2G} - \left(P_{\omega,t}^{En,PL2G} + P_{\omega,t}^{Res,Act}\right).Cd \right\}$$

$$Income_1 = P_{\omega,t}^{En,PL2G}.\lambda_t^{En} \tag{3.2}$$

This second equation (3.3) is regarding the capacity payment of the reserve market, this capacity payment is given due to being available to selling power to the reserve market. Generally this capacity payment is given only in this market, but in some markets there can also be considered capacity payments for the regulation market. The equation is given by the power available to provide to the reserve market multiplied by the price of capacity payment.

$$Income_2 = P_{\omega,t}^{Res}.\lambda_t^{Cap,Res} \tag{3.3}$$

The following two equations (3.4) and (3.5) correspond to the payment to sell and buy power to the regulation down and up market respectively. These terms are calculated by multiplying the amount of available power that they can supply to the grid by the price of regulation. Although in this case the price also includes a probability factor because not everyone can be called to provide this type of service at the same time. Equation (3.6) works exactly the same although it regards the reserve market. Generally the probability of being called for reserve is much lower compared to the probability of being called for the regulation market.

$$Income_3 = P_{\omega,t}^{R-up}.\lambda_t^{R-up} \tag{3.4}$$

$$Income_4 = P_{\omega,t}^{R-down}.\lambda_t^{R-down} \tag{3.5}$$

$$Income_5 = P_{\omega,t}^{Res,Act}.\lambda_t^{En} \tag{3.6}$$

Equation (3.7) represents the incomes that are generated from the charging of the cars. This is given by the amount of charge that the cars get multiplied by the tariff defined by the PL for charging the cars.

$$Income_6 = soc_{\omega,t}^{up}.\lambda_t^{Tariff,G2V} \tag{3.7}$$

The last income presented in (3.8) is the amount of income that the parking lots from the time that the owners are in the parking lot which mean that for every hour they pay a tariff and the total income will amount to the number of cars times the tariff.

$$Income_7 = n_{\omega,t}^{PL}.\lambda^{Tariff,stay} \tag{3.8}$$

Now focusing towards costs, the first term of cost (3.9) expressed below represents the cost of buying energy to grid to provide to the PVs in order to charge. This is given by the power obtained from the grid multiplied by the energy price of the market.

$$Cost_1 = P_{\omega,t}^{En,G2PL}.\lambda_t^{En} \tag{3.9}$$

Cost equation (55) represented the costs of not being available to provide the energy necessary to the reserve and regulation up and down market. This being the power of reserve or regulation multiplied by the probability of not being available to participate in these markets all summed and then multiplied by the penalty of not being available.

$$Cost_2 = \begin{pmatrix} P_{\omega,t}^{Res,Act}.\Gamma^{Res} + P_{\omega,t}^{R-up}.\Gamma^{R-up} \\ +P_{\omega,t}^{R-down}.\Gamma^{R-down} \end{pmatrix}.\lambda_t^{En}.\pi^{unavail.} \tag{3.10}$$

Equation (3.11) represents the costs of generation due to participating in the reserve market. This being followed by equation (3.12) which represented the costs of paying to the owners due to discharging of their PEV's

$$Cost_3 = P_{\omega,t}^{Res,Act}.\lambda_t^{Tariff,V2G} \tag{3.11}$$

$$Cost_4 = soc_{\omega,t}^{down}.\lambda_t^{Tariff,V2G} \tag{3.12}$$

Finally the last 2 equations regarding costs are regarding battery degradation (3.13) and (3.14). 2 types of battery degradation have been considered deep discharge and shallow discharge. For deep discharge it is considered only providing energy in the reserve market and normal energy market. For Shallow discharge it is considered the other discharge condition which is regulation up market.

$$Cost_5 = \left(P_{\omega,t}^{En,PL2G} + P_{\omega,t}^{Res,Act}\right).Cd_{deep} \tag{3.13}$$

$$Cost_6 = P_{\omega,t}^{R-up}.Cd_{shallow} \tag{3.14}$$

3.1.2 Constraints

According to the rate of charge and discharge of EV batteries, the maximum power that can be injected to the parking lot or be injected back to the grid have been presented in (3.15) and (3.16), respectively.

$$P_{\omega,t}^{En,G2PL} + P_{\omega,t}^{R-down} \leq \gamma^{charge}.n_{\omega,t} \tag{3.15}$$

$$P_{\omega,t}^{En,PL2G} + P_{\omega,t}^{R-up} + P_{\omega,t}^{Res,Act} \leq \gamma^{discharge}.n_{\omega,t} \tag{3.16}$$

The SOC of parking lot in each hour depends on the SOC of parking lot from previous hour, the power traded with the grid, and the SOC of arrived or departed vehicles as presented in (3.17).

$$\begin{aligned} soc_{\omega,t} &= soc_{\omega,t-1} + soc_{\omega,t}^{arrival} - soc_{\omega,t}^{departure} \\ &+ \left(P_{\omega,t}^{En,G2PL} + P_{\omega,t}^{R-down}\right).\eta^{charge} - \frac{P_{\omega,t}^{En,PL2G} + P_{\omega,t}^{R-up} + P_{\omega,t}^{Res,Act}}{\eta^{discharge}} \end{aligned} \tag{3.17}$$

The SOC of arrived and departed PEVs are dependent to the number of stations and the supposed scenario for parking lot's SOC. The related equations are shown in (3.18) to (3.19).

$$soc_{\omega,t}^{arrival} = \begin{cases} 0 & SOC_{\omega,t}^{Scenario} \leq SOC_{\omega,t-1}^{Scenario} \\ SOC_{\omega,t}^{Scenario} - SOC_{\omega,t-1}^{Scenario} & SOC_{\omega,t-1}^{Scenario} < SOC_{\omega,t}^{Scenario} \end{cases} \tag{3.18}$$

$$soc_{\omega,t}^{departure} = \begin{cases} 0 & SOC_{\omega,t-1}^{Scenario} \leq SOC_{\omega,t}^{Scenario} \\ \dfrac{\left(SOC_{\omega,t-1}^{Scenario} - SOC_{\omega,t}^{Scenario}\right).soc_{\omega,t}}{SOC_{\omega,t}^{Scenario}} & SOC_{\omega,t}^{Scenario} < SOC_{\omega,t-1}^{Scenario} \end{cases} \tag{3.19}$$

where $SOC_{\omega,t}^{Scenario}$ denotes the stored energy in the parking lot obtained from the input scenarios and is calculated by (3.20).

$$SOC_{\omega,t}^{Scenario} = \sum Cap_{\omega,t}^{PEV}\ SOC_{\omega,t}^{EV} \tag{3.20}$$

In order to calculate the surplus SOC that remains in PEVs while their departure, we have:

$$soc_{\omega,t}^{up} = \begin{cases} 0 & soc_{\omega,t}^{departure} \leq SOC_{\omega,t}^{Scenario} - SOC_{\omega,t-1}^{Scenario} \\ soc_{\omega,t}^{departure} - SOC_{\omega,t}^{Scenario} - SOC_{\omega,t-1}^{Scenario} & Otherwise \end{cases} \tag{3.21}$$

$$soc_{\omega,t}^{down} = \begin{cases} 0 & SOC_{\omega,t}^{Scenario} - SOC_{\omega,t-1}^{Scenario} \leq soc_{\omega,t}^{departure} \\ soc_{\omega,t}^{departure} - SOC_{\omega,t}^{Scenario} - SOC_{\omega,t-1}^{Scenario} & Otherwise \end{cases} \tag{3.22}$$

The maximum and minimum values of SOC of parking lot can be formulated as (3.23).

$$\sum SOC^{EV,\min} \leq soc_{\omega,t} \leq \sum SOC^{EV,max} \tag{3.23}$$

3.2 Grid Model

A distribution network has been considered in where the proposed model is connected through the balance equations of the system testing to see if the system holds up. This is an important feature for real implementation that can be tested using real life grids in order to have an idea if the system can be implemented or not. So this has been introduced in the model and tested using a 14 node bus grid presented in figure 3.1.

So using this grid as a base for this study there have also been considered a lot of the features regarding the grid such as line losses, resistance values between nodes, and all the necessary features to determine the best position in the system to where the parking lot should be inserted in the grid. Following the equations considered in the model are presented.

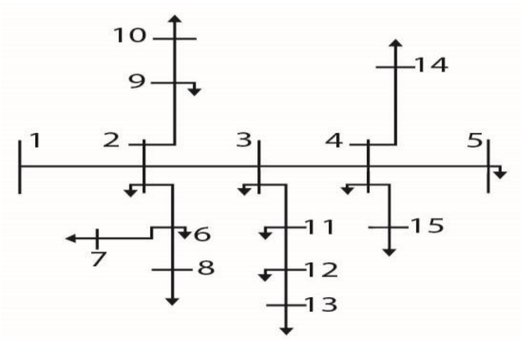

Fig 3.1. Distribution grid.

Equations (3.24) and (3.25) represent the balance equations for the active and reactive powers of the system, respectively.

$$P_{i,t,\omega}^{S} + P_{i,t,\omega}^{RN} - \sum_{j}\left[\left(P_{i,j,t,\omega}^{+} - P_{i,j,t,\omega}^{-}\right) + R_{i,j}.I2_{i,j,t,\omega}\right] + \sum_{j}\left(P_{j,i,t,\omega}^{+} - P_{j,i,t,\omega}^{-}\right) + P_{\omega,t}^{En,PL2G} = P_{i,t}^{D} + P_{\omega,t}^{En,G2PL} \quad (3.24)$$

$$Q_{i,t,\omega}^{S} + Q_{i,t,\omega}^{RN} - \sum_{j}\left[\left(Q_{i,j,t,\omega}^{+} - Q_{i,j,t,\omega}^{-}\right) + X_{i,j}.I2_{i,j,t,\omega}\right] + \sum_{j}\left(Q_{j,i,t,\omega}^{+} - Q_{j,i,t,\omega}^{-}\right) + P_{\omega,t}^{En,PL2G} = Q_{i,t}^{D} + P_{\omega,t}^{En,G2PL} \quad (3.25)$$

where $P_{i,j,t,\omega}^{+}$ and $P_{i,j,t,\omega}^{-}$ are the active powers of branch ij when going downstream and upstream, respectively. Similarly, $Q_{i,j,t,\omega}^{+}$ and $Q_{i,j,t,\omega}^{-}$ are the reactive powers of branch ij when going downstream and upstream, respectively.

Inequalities (3.26) and (3.27) represent the constraints of the active and reactive powers, respectively.

$$0 \le \left(P_{i,j,t,\omega}^{+} - P_{i,j,t,\omega}^{-}\right) \le V^{NOM}.I_{i,j}^{MAX} \quad (3.26)$$

$$0 \le \left(Q_{i,j,t,\omega}^{+} - Q_{i,j,t,\omega}^{-}\right) \le V^{NOM}.I_{i,j}^{MAX} \quad (3.27)$$

Equation (3.28) consists of the voltage balance in the system.

$$V2_{i,t,\omega} - V2_{j,t,\omega} - Z_{i,j}^{2}.I2_{i,j,t,\omega} - 2R_{i,j}\left(P_{i,j,t,\omega}^{+} - P_{i,j,t,\omega}^{-}\right) - 2X_{i,j}\left(Q_{i,j,t,\omega}^{+} - Q_{i,j,t,\omega}^{-}\right) = 0 \quad (3.28)$$

Constraints to linearize the power active and reactive present in (3.29).

$$V2_{i,t,\omega}^{NOM}.I2_{i,j,t,\omega} = \sum_{f}((2f-1)\Delta S_{i,j,f,t,\omega}.\Delta P_{i,j,f,t,\omega}) + \sum_{f}((2f-1)\Delta S_{i,j,f,t,\omega}.\Delta Q_{i,j,f,t,\omega}) \quad (3.29)$$

Piecewise linearization of the constraints is presented in (3.30)-(3.34).

$$\left(P_{i,j,t,\omega}^{+} - P_{i,j,t,\omega}^{-}\right) = \sum_{f}\Delta P_{i,j,f,t,\omega} \quad (3.30)$$

$$\left(Q^{+}_{i,j,t,\omega} - Q^{-}_{i,j,t,\omega}\right) = \sum_{f} \Delta Q_{i,j,f,t,\omega} \quad (3.31)$$

$$0 \le \Delta P_{i,j,f,t,\omega} \le \Delta S_{i,j,f,t,\omega} \quad (3.32)$$

$$0 \le \Delta Q_{i,j,f,t,\omega} \le \Delta S_{i,j,f,t,\omega} \quad (3.33)$$

$$\Delta S_{i,j,f,t,\omega} = V^{NOM}.I^{MAX}_{i,j} / F \quad (3.34)$$

Inequalities (3.35)-(3.36) represent power factor constrains where 0.95 is considered.

$$P^{RN}_{i,t,\omega}.\tan\left(\text{arcos}\left(-0.95\right)\right) \le Q^{RN}_{i,t,\omega} \le P^{RN}_{i,t,\omega}.\tan\left(\text{arcos}\left(0.95\right)\right) \quad (3.35)$$

$$P^{C}_{i,t,\omega}.\tan\left(\text{arcos}\left(-0.95\right)\right) \le Q^{C}_{i,t,\omega} \le P^{C}_{i,t,\omega}.\tan\left(\text{arcos}\left(0.95\right)\right) \quad (3.36)$$

3.3 Uncertainty Characterization

In order to make the model run there is a need to get data to be analyzed which is where the uncertainty characterization works. There are two important factors here to be considered for this characterization which is modeling the behavior of the vehicle. Arrival time, departure time and other factors. Also the battery capacity and the state of charge of the battery is something that needs to be tackled. Other factor to be modelled is the uncertainty of activated reserve which is also approached here.

3.3.1 Modeling the uncertainties of PEVs behavior

One of the main uncertainties of in a parking lot would be considered the behavior of the PEVs in the parking lot itself. This due to not having any data of information regarding these kind of subjects as it is a very recent subject, and there is little to no application.

In order to model the uncertainties of PEVs' behavior, truncated Gaussian distribution is widely employed for arrival and departure times and the SOC at arrival [57] and [58]. The details of PEV's probability distributions are expressed in table 3.1.

The capacity of each PEV depends on the PEV battery class. Ref. [59] has reported twenty four classes of PEV batteries, and in order to develop the distribution all of them have been considered. In order to model the uncertainties of different types of PEVs in the parking lot, the probability distribution of the battery capacities is employed as presented in figure 3.2.

Table 3.1. PEVs probability distribution

	Mean	Standard deviation	Min	Max
Initial PEV SOC	50	25	30	90
Arrival time	8	3	5	17
Departure time	16	3	11	24

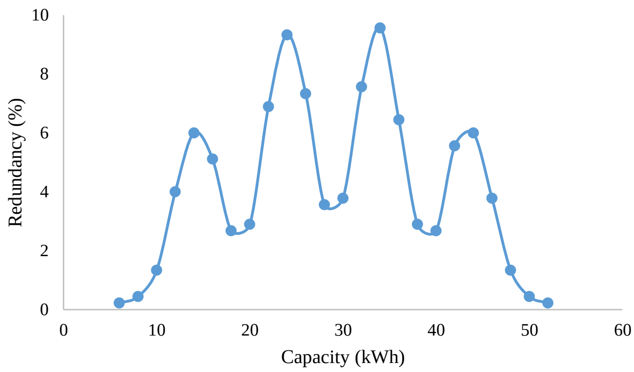

Fig 3.2. Distribution of different PEV battery classes.

3.3.2 Modeling the uncertainties of activated amount of reserve

The uncertain amount of activated reserve, $P_{\omega,t}^{Res,Act}$ is considered uniformly distributed between zero and PEV parking lot's offered quantity.

The probability distribution function of the amount of activated reserve is expressed as:

$$f(x) = \begin{cases} 1/P_{\omega,t}^{Res} & , \quad 0 \le x \le P_{\omega,t}^{Res} \\ 0 & , \quad Otherwise \end{cases} \tag{3.37}$$

In this subchapter a flow chart of the model will be presented by figure 3.3, in the flow chart it was tried to present all the functionality and the considerations that are made throughout the process of processing data. Starting on the data generation presenting the equations considered and finalizing by showing the data that is obtained from the model.

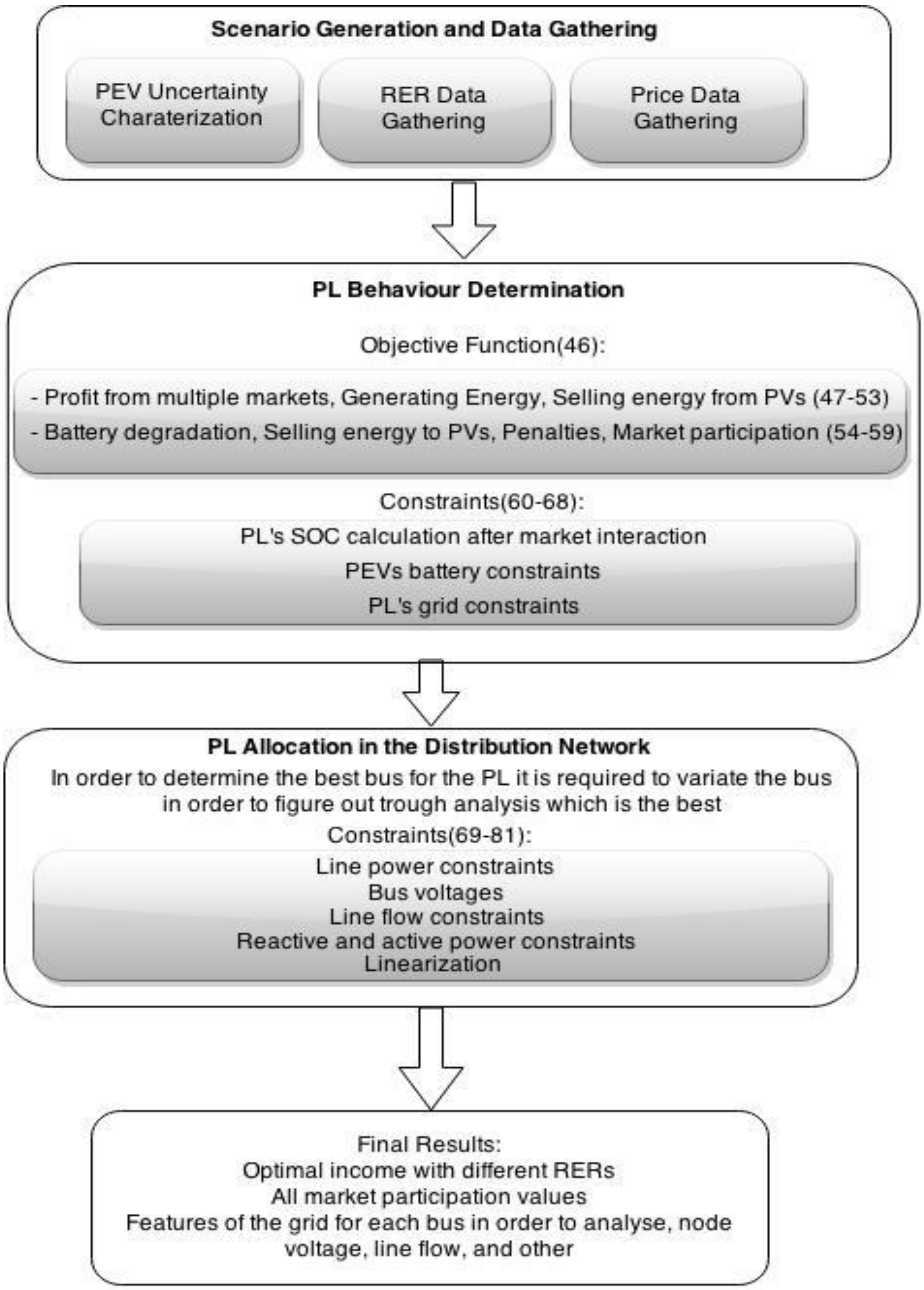

Fig 3.3. Flow Chart.

Chapter 4

Numerical Results

This section describes in detail the techniques used to create the proposed hybrid forecasting tool composed of the innovative combination of MI, WT, EPSO and ANFIS, advanced techniques applied in forecasting electricity market prices and wind power in the short-term.

4.1 Input Data

In order to indicate the effectiveness of the proposed model a PEV parking lot with the capacity of 1000 PEVs have been considered on the IEEE fourteen bus distribution network. The data of market prices, photovoltaic and wind generation have been utilized from the Spanish market, these tariffs have been extracted from [60]. In order to investigate the effect of different renewable energy resources, three different cases have been studied. Case I represents the base case that no renewable energy resource is modeled. In case II, a wind farm has been considered on the distribution network. Similarly, in case III, a solar farm has been taken into account. The RERs are located at node 12. In all mentioned cases, the PEV parking lot participates in the energy, reserve and regulation markets considering the uncertainties of PEV behavior. In order to tackle the uncertainties of renewable energy resources, ten scenarios have been generated for each wind and solar power production. The generated scenarios are illustrated in Fig. 4.1. In this figure, dots represent scenarios and lines denote the expected value.

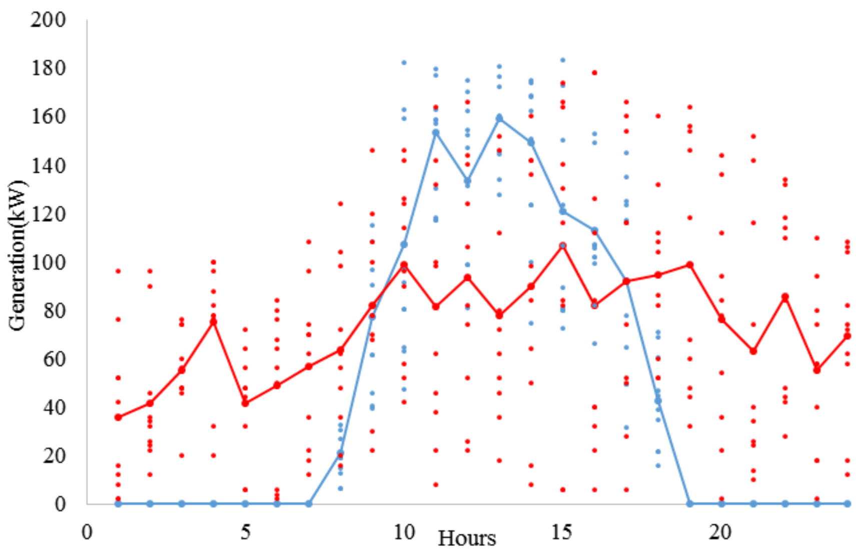

Fig. 4.1. Considered scenarios of wind farm (red) and PV farm (blue).

In order to fully analyze the market participation of the parking lot a distinct pattern between the prices of energy, reserve and regulation have been considered. To this end, the data obtained from November 2013 of the Spanish market have been employed. The expected amounts of market prices are presented in Fig. 4.2 and 4.3.

In order to provide a reasonable study of the overall working ability an analysis has to be made. This analysis will consist of three parts. First will be an analysis on the working capability of the system using the different renewable energies. In this first case a market analysis to determine in which and what times the PL participates followed by a grid analysis where the search for the best position of the PL is done.

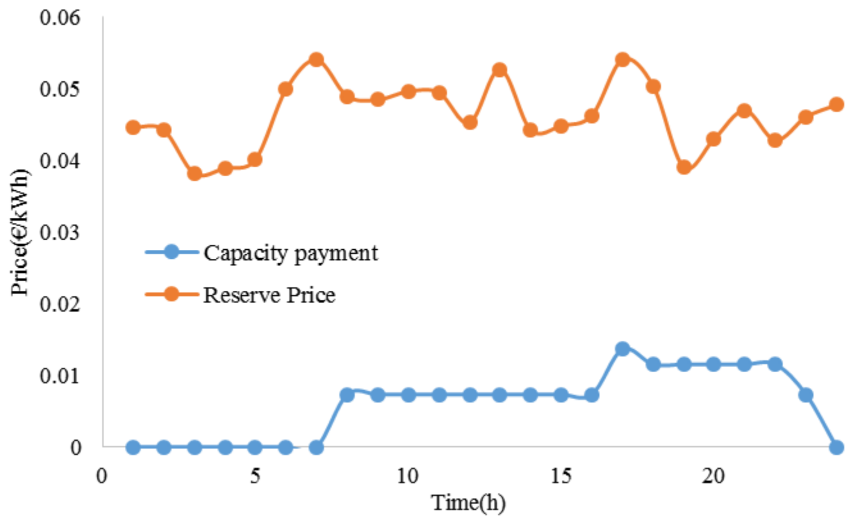

Fig. 4.2. Reserve market prices.

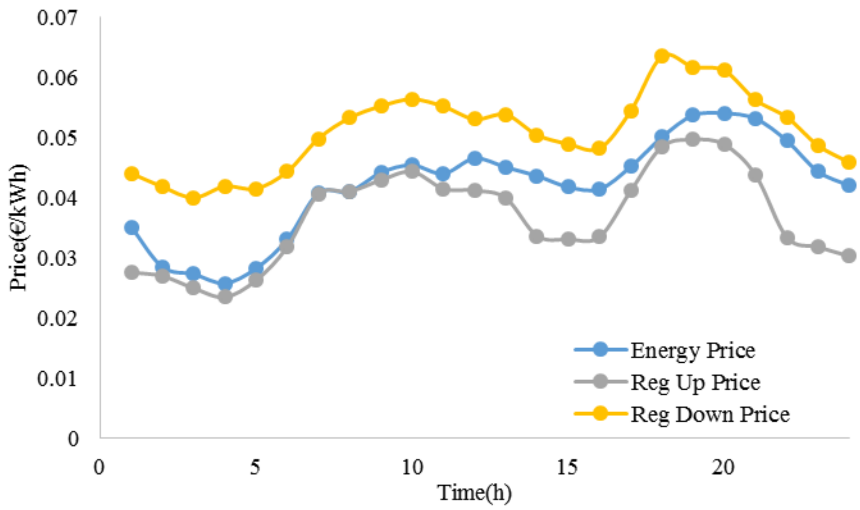

Fig. 4.3. Expected value of the considered prices.

Second analysis will be size influence of the renewable resources where multiple size farms will be employed in the system in order to see how it influences not only the market participation of the system but also obverse how that influences the grid overall.

Final case the limits of power which the substation can handle will be varied in order to determine also how that influences the market participation and also the grid which the system is included.

4.2 Analysis Between Different RER

4.2.1 Market analysis

In order to analyze the influence of different RERs, 3 scenarios have been tested for each individual case. The cases consist of no RER, this being case I, 200 kW windfarm case II and a 200 kW solar farm case III. In this market analysis the cases will be compared in all market participation.

This market participation will consist in an analysis, on the participation of the reserve market, normal energy market, and regulation market. An analysis on the SOC of the parking lot at all times will also be done in order to understand its influence on the market prices and the behavior. This will allow for a better comprehension how the different RER influence the behavior of the parking lot and also help determine which one is the best in terms of profit.

An overall analysis of the system has verified a couple of interactions of the PEV parking lot with the different markets due to the presence of the RERs. The reserve market is the only market that offers a capacity payment to the PEVs. The participation of the parking lot in the reserve market is illustrated in Fig. 4.4. As can be observed in Fig. 4.4, the capacity payment meaningfully influences the presence in the market.

Something that can be deducted from the results is that the parking lot only participates in the reserve market when the capacity payment is the highest. This means that the parking lot participates in the reserve market only in periods that the capacity payment can compensate the costs of operating in V2G mode due to high amount of degradation cost in deep discharging of the batteries.

Another point that can be observed is the hour 19 when there is no reserve participation because of the low amount of the reserve price in that hour. Therefore, the distinction in income does not come from the reserve market participation.

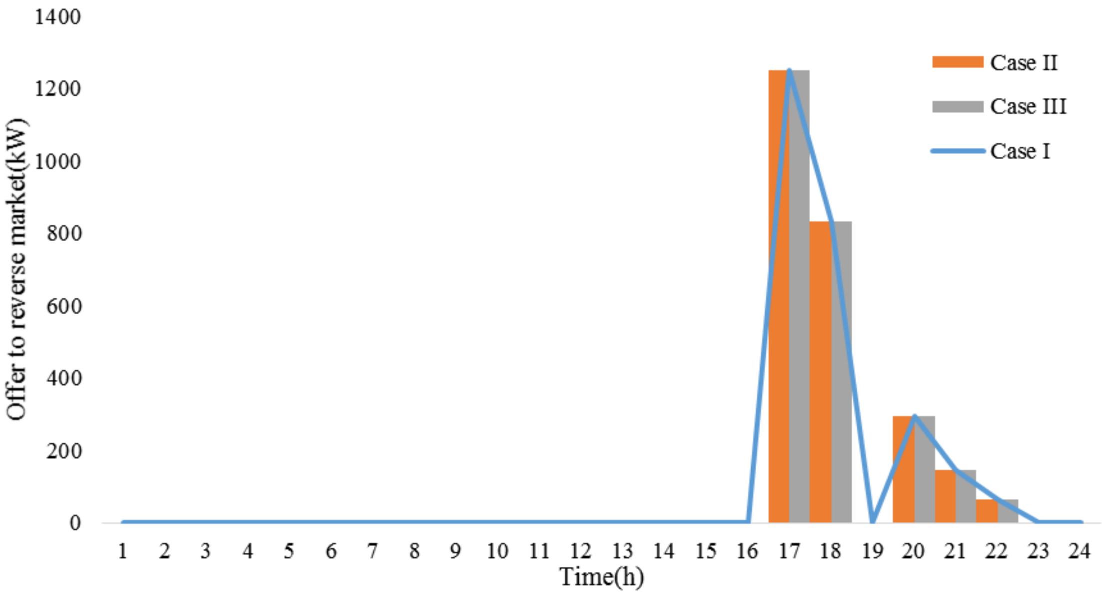

Fig. 4.4. Offer to reserve market

The traded energy between the parking lot and the grid has been illustrated in Figs. 4.5 and 4.6. As can be observed, being available more energy resources in the grid allows the PEV parking lot to buy higher amount of energy from the energy market.

This effect has more weight in case II that wind power generation is placed on the distribution network. Consequently, the amount of energy sold back to the grid is also higher. This reflects that the participation of this PEV parking lot in the energy market in case II is more than that in the case III.

The major distinction that can be observed from case I and case III is that the parking lot purchases more energy at hours that the extra power generation from the PV is available mainly from hours 9 to 18. According to case II, the parking lot can profit from the consistency of values along the day that surpass the profits of only daytime production.

Having a consistent load evenly allows a more distributed consumption and a better management leading through a higher profit. Another factor that influences the load that is bought from the energy market is the number of vehicles in the PL, as an example in the late hours there is no difference in the participation of the energy market between the three cases due to the low number of cars and consequently there is no influence by the RERs.

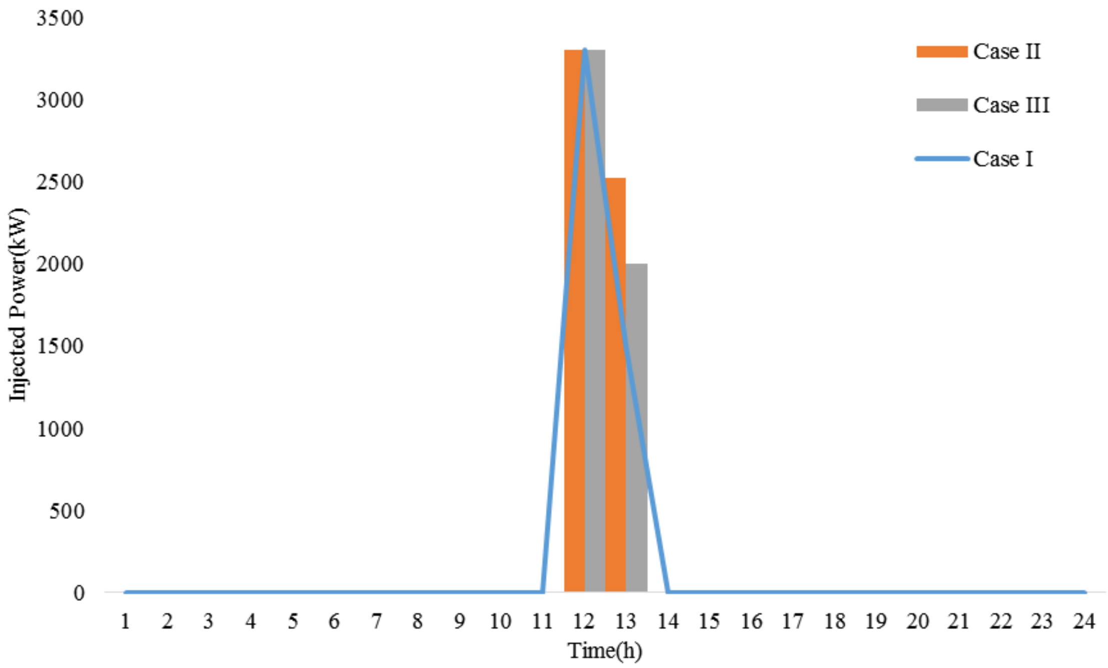

Fig. 4.5. Injected power

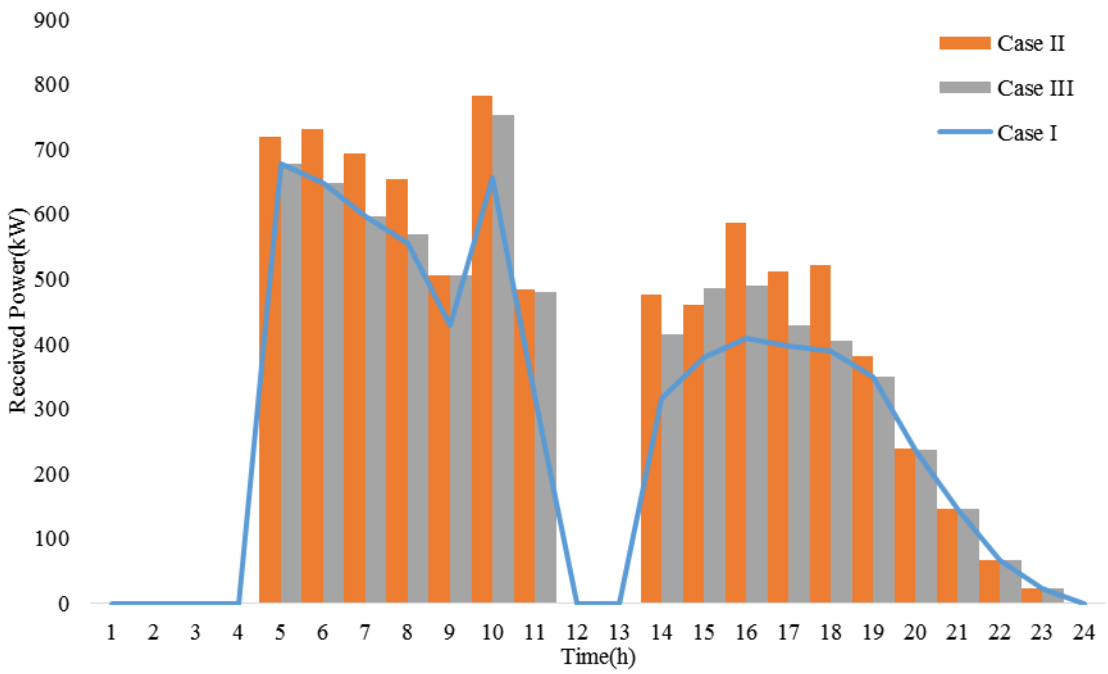

Fig. 4.6. Received power

Figs. 4.7 and 4.8 indicates the offer of parking lot in the regulation market. This value is not what the car really sells due to the probability of participation. The values presented in the offer are what the PL has available to sell but only a small percentage of that offer is bought.

By comparing Figs. 4.7 and 4.8 with Figs. 4.5 and 4.6 can be seen that, the PEV parking lot prefers to participate in the energy markets than in the regulation one. The reason is that the income from the regulation market is related to the probability of activated quantity of regulation, while there is no capacity payment for the regulation services. The combination of both these factors lead to a low participation in these markets compared to the normal energy markets.

AS it is stated in the name of the axis it is offer to the regulation up or down markets, meaning that this is not the actual value that is being sold to the market. This is the power which is available for that effect although only a percentage is sold. In this case the percentage considered was 15% which is a pretty common value.

Also from these two figures 9 and 10 can be concluded that cases III and case I tend to participate more on the regulation market has it has less available power from the RER compared to Case II leading to higher participation in regulation.

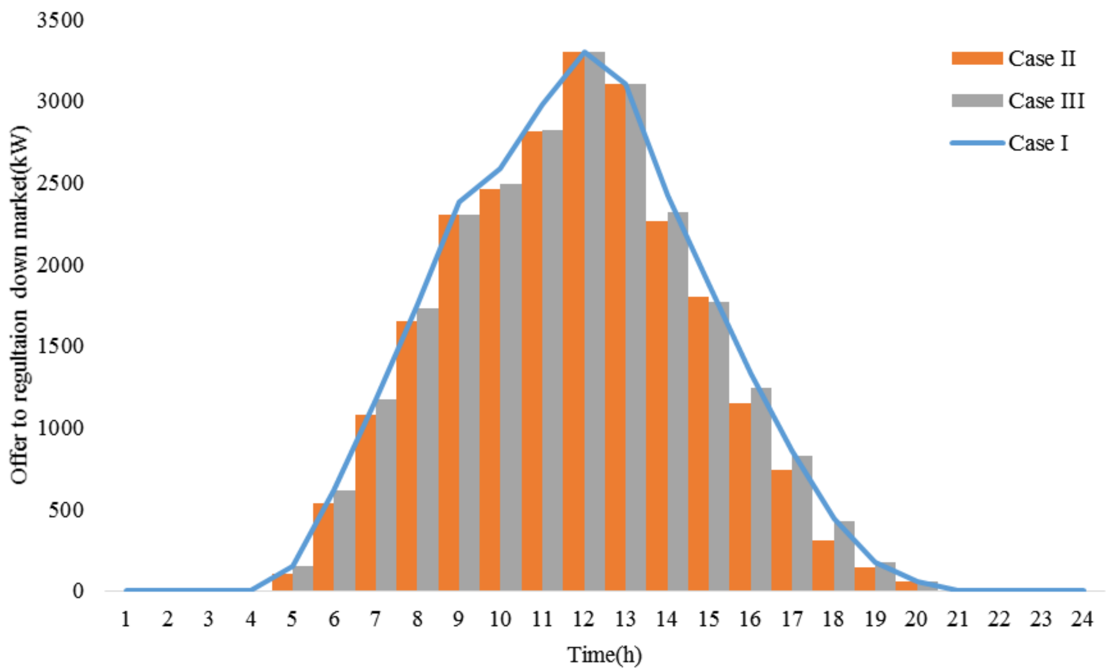

Fig. 4.7. Offer to regulation down market

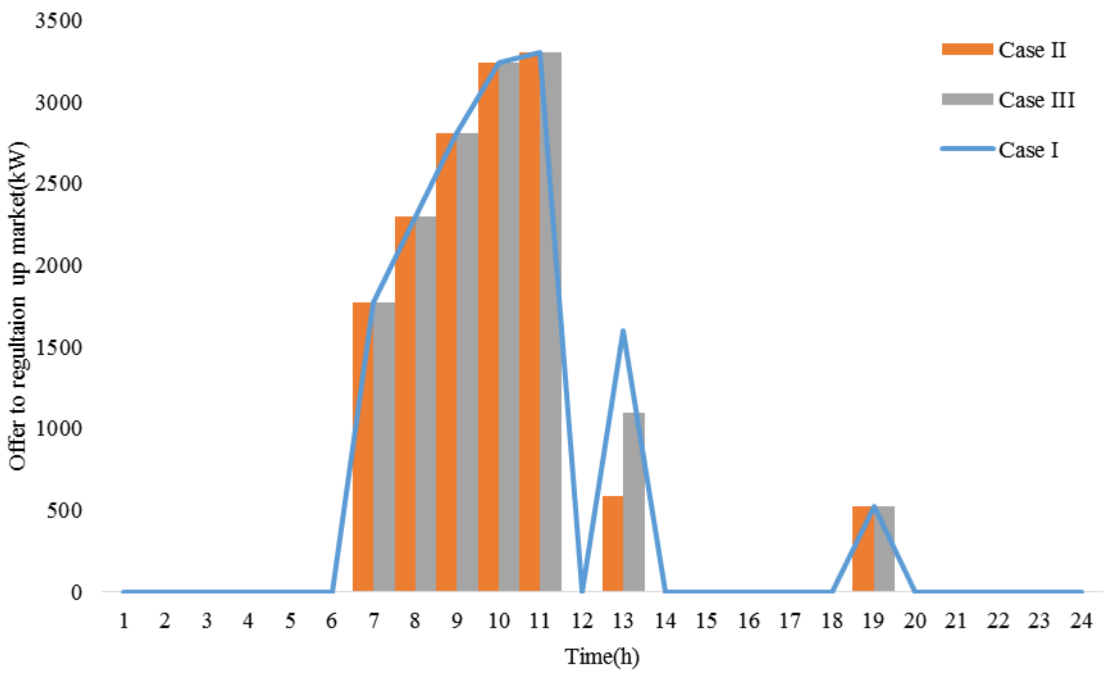

Fig. 4.8. Offer to regulation up market

The total SOC of parking lot is indicated in Fig. 4.9. As it can be seen, the highest amount of changing in the SOC happens between hours 11 and 13 when the parking lot sells energy back to the grid.

In addition, in case II the SOC of parking lot is higher than the other cases in most of the hours. This can show the PEVs have higher SOC when they departure and consequently the PEV owners can benefit from higher amount of the battery charge.

This figure of the SOC allows to understand fully how it all works and why Case II has the most profit overall. Due to the availability of more power due to the wind profile. It can be achieved a better management throughout the entire day.

This is a very important matter due to being always available to sell or buy at the best price possible. Although there is also a capacity limit for power being bought and this leads to further optimization with more cars or also with other scenarios generated. If the parking lot was more full throughout the day this would lead to higher profits due to being able to trade more energy.

The different terms of the PEV parking lot's profit are presented in Table 4.1. It can be observed that Case I is the one with the lowest profit overall as can be expected from a base case, followed by Case III and the most profitable is Case II.

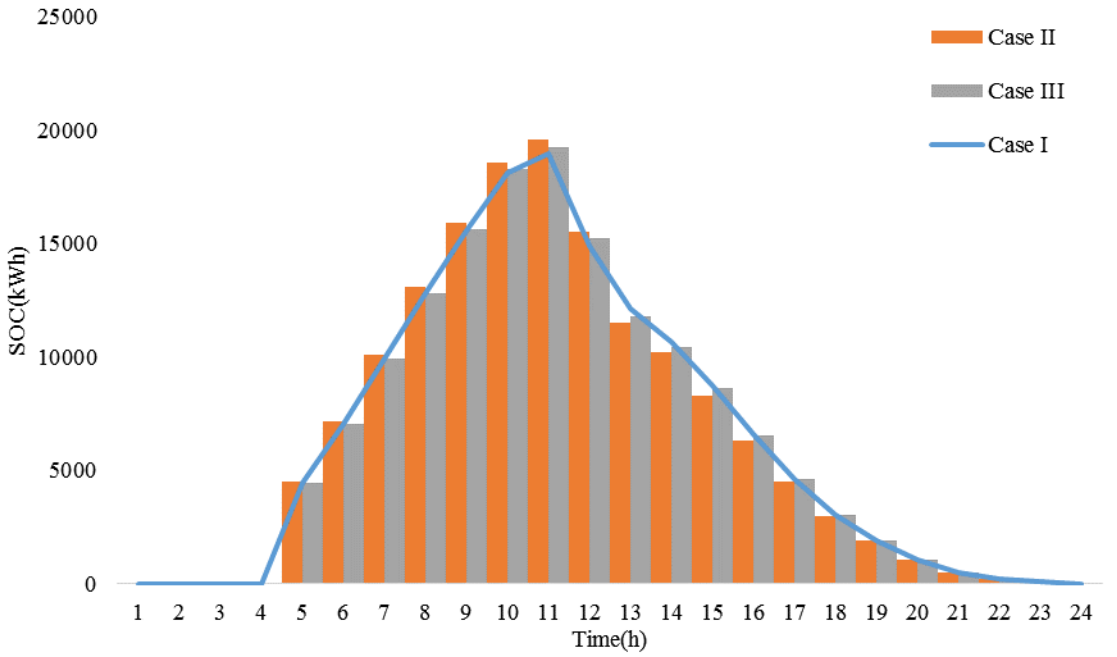

Fig. 4.9. SOC of the PL

Table 4.1. Incomes from different cases

	Case I	Case II	Case III
Regulation up income (€)	99	92	96
Regulation down income (€)	200	189	195
Reserve market income (€)	38	37	38
Energy market income (€)	221	267	244
Income from charging the PEVs (€)	1829	2215	2019
Payment cost to PEVs for discharge (€)	1362	1643	1500
Battery degradation costs (€)	177	188	182
Cost of buying energy (€)	278	338	308
Expected profit (€)	564	626	594

4.2.2 Grid analysis

Here a grid analysis has been employed in order to determine a couple of features of the system. A variation to the parking lot location between nodes of the system has been done in order to determine which location employs a less saturation from upstream network.

Following this it is also necessary to check the other nodes in order to determine if the rest of the system is working properly.

In order to analyze the impacts of the parking lot on the distribution grid, the placement of the parking lot on the 14-bus system has been changed, for three mentioned cases of wind, PV and without RER.

The considered grid is illustrated in the previous chapter witch was used to analyze the model, a few nodes have been selected to indicate the impact of parking lot placement. These nodes are 3, 4, 5 and 12. Moreover, the scenario which considers the 200kW farms is used for these analyses.

Figs. 4.10 to 4.13 represent the injection from the upstream network into the considered distribution network considering the parking lot on the different nodes. By comparing these figures, it can be observed that node 3 represents a node which needs the lowest amount of injected power from the upstream network. Moreover, the placement of the parking lot on the node 4 causes that the distribution system requires receiving more energy in case II compared to other cases.

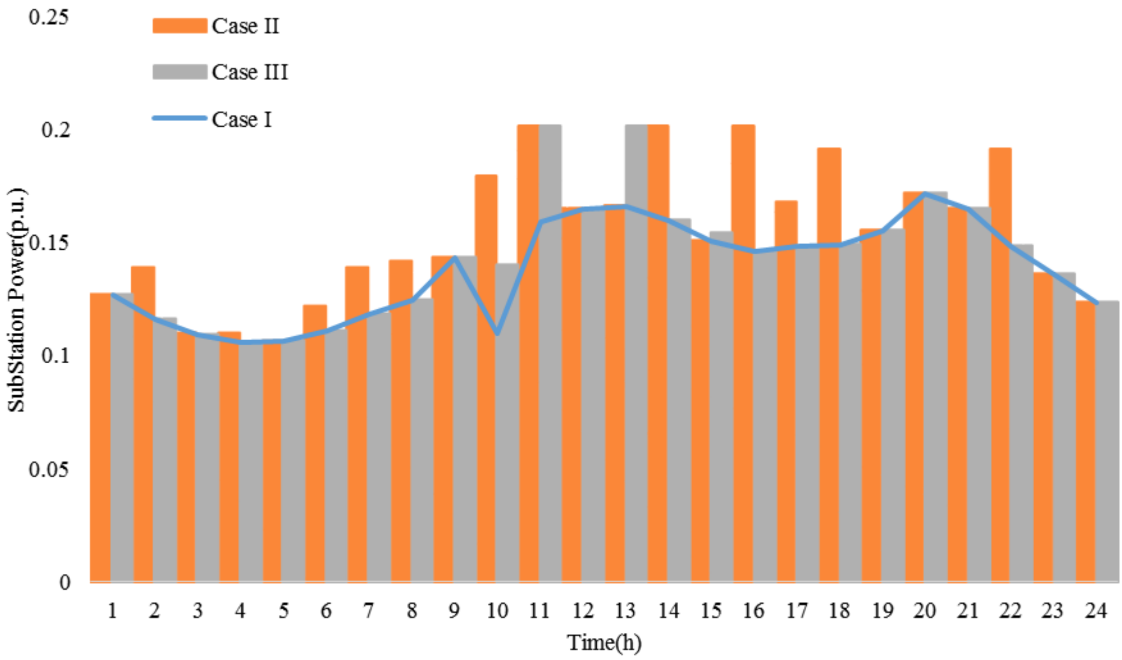

Fig. 4.10. Injected power from the upstream network (parking lot on node 3)

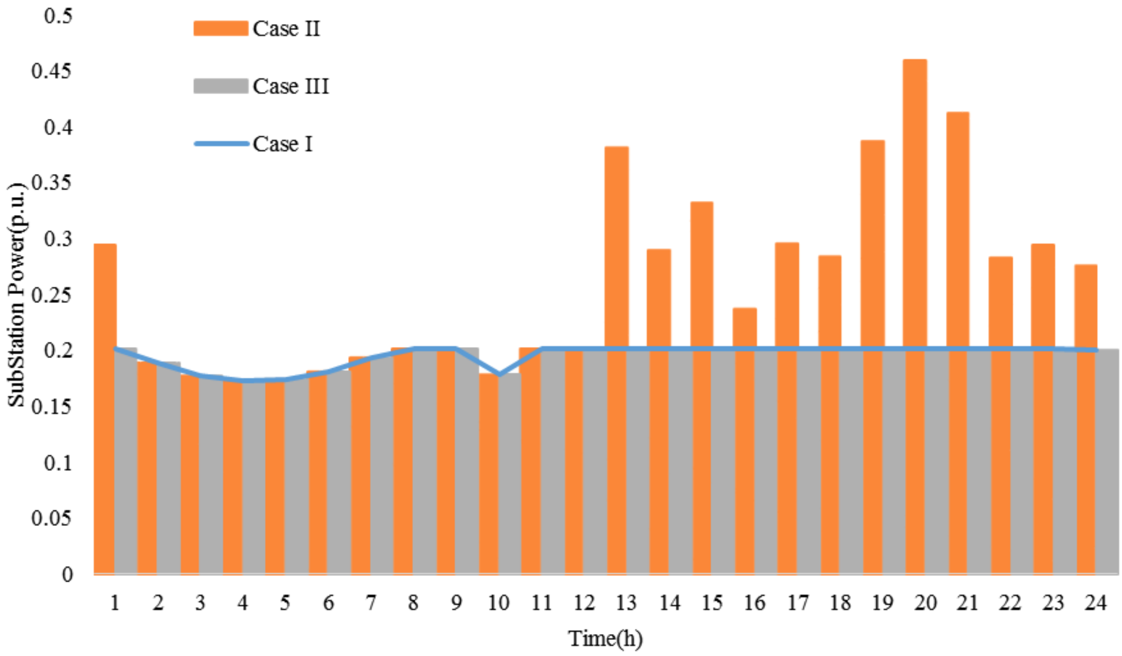

Fig. 4.11. Injected power from the upstream network (parking lot on node 4)

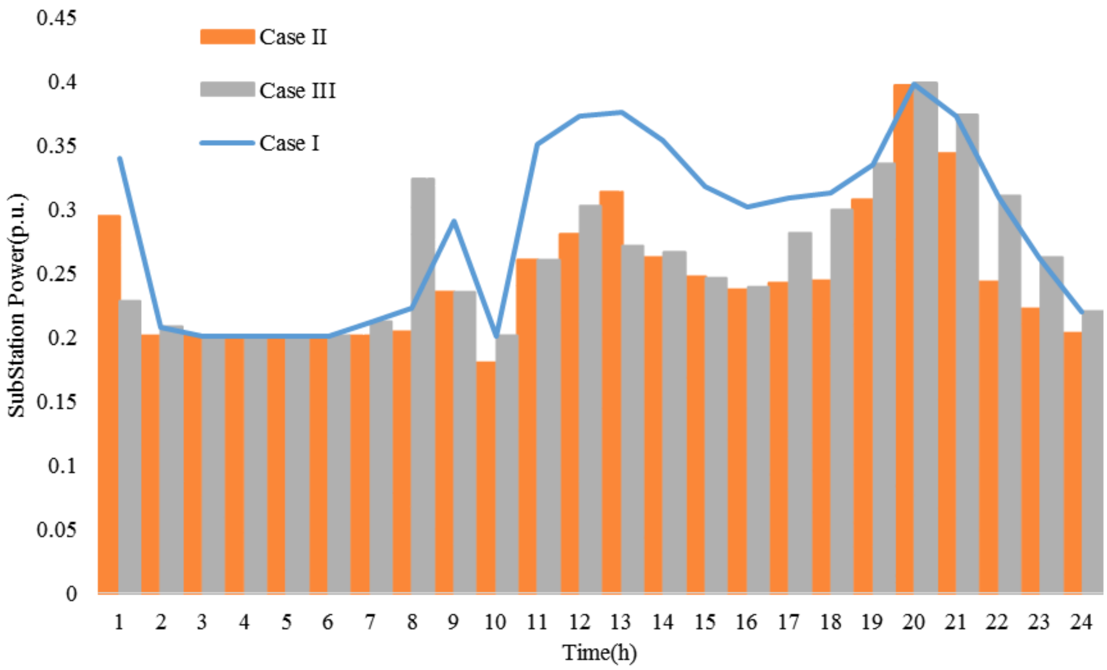

Fig. 4.12. Injected power from the upstream network (parking lot on node 5)

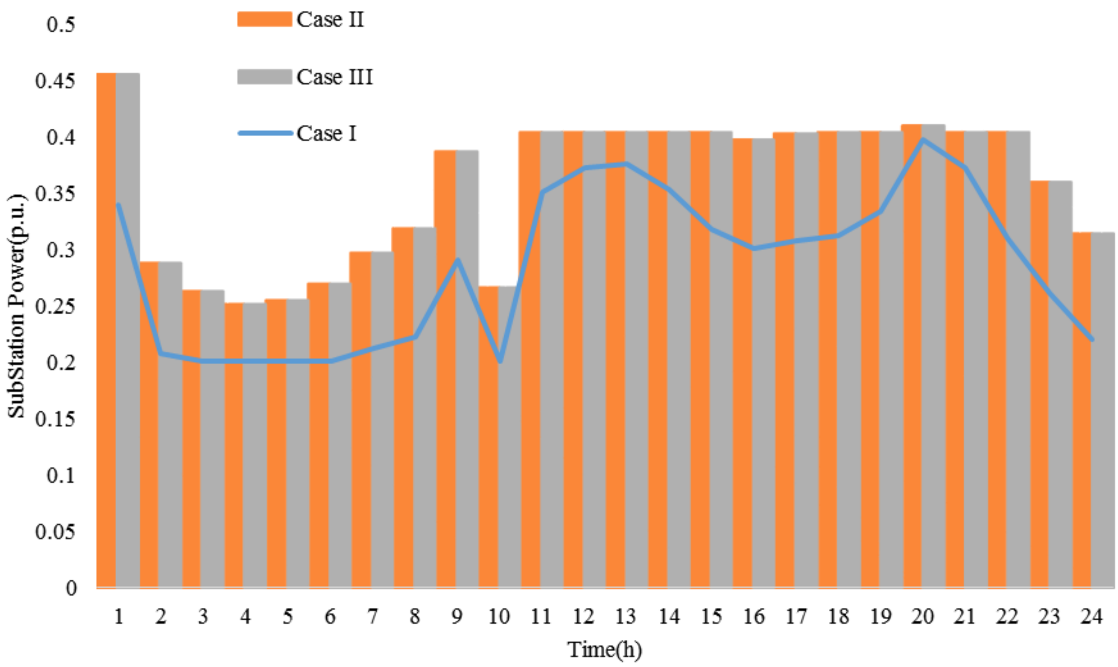

Fig. 4.13. Injected power from the upstream network (parking lot on node 12)

Figs. 4.14 and 4.15 indicate the hourly voltage of nodes 4 and 12, respectively. By comparing Figs. 4.14 and 4.15 are easily spotted the variation in the nodal voltage due to the RERs. For example peak hours for the PV can be seen from the nodal voltage peak in Fig.17.

On the other hand, in Fig. 16, it is shown that there is not any influenced place in the grid. This is due to the parking lot is located on node 3 and the RER is on node 12, which leads not to have a significant impact on voltage level. As would be expected from a node that is not in between supply and demand points of the grid.

According to case II, it can be seen that the distribution of nodal voltage is more smoothly distributed as it is expected from the wind scenario, just like the profile generated by Wind farms. According Case I, it can be observed that this case is more evenly distributed throughout the day with almost no variations, due to the consistency of no power being applied.

By comparing both nodes, the pattern is practically similar between nodes. There is just a higher impact on node 12 due to being the location of the renewable energy resources location.

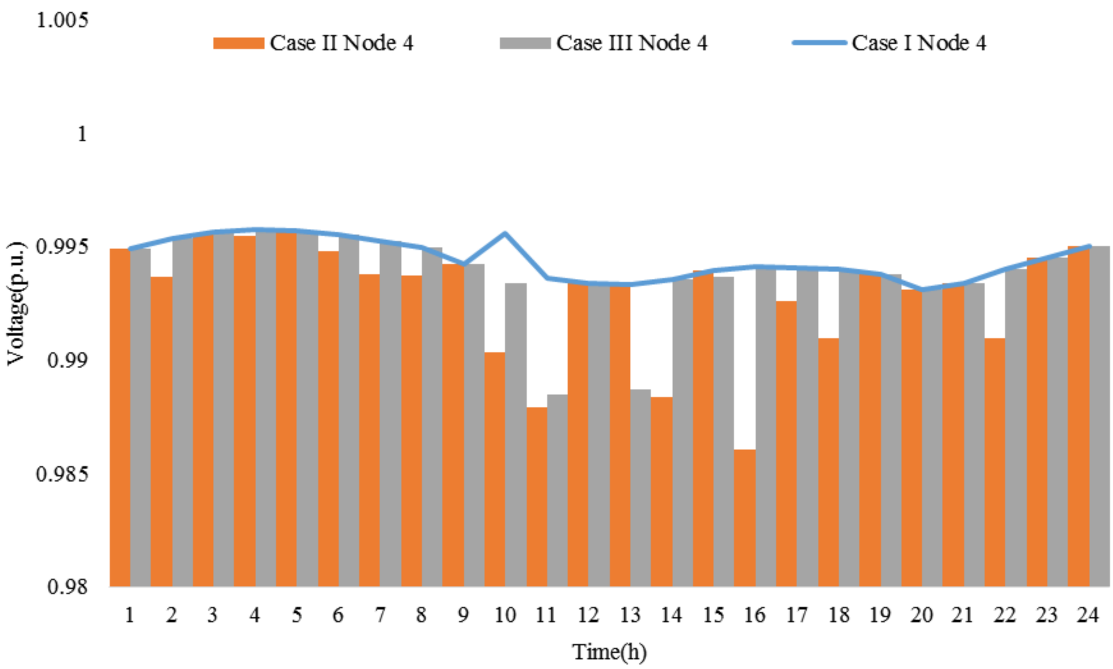

Fig. 4.14. Hourly voltage node 4

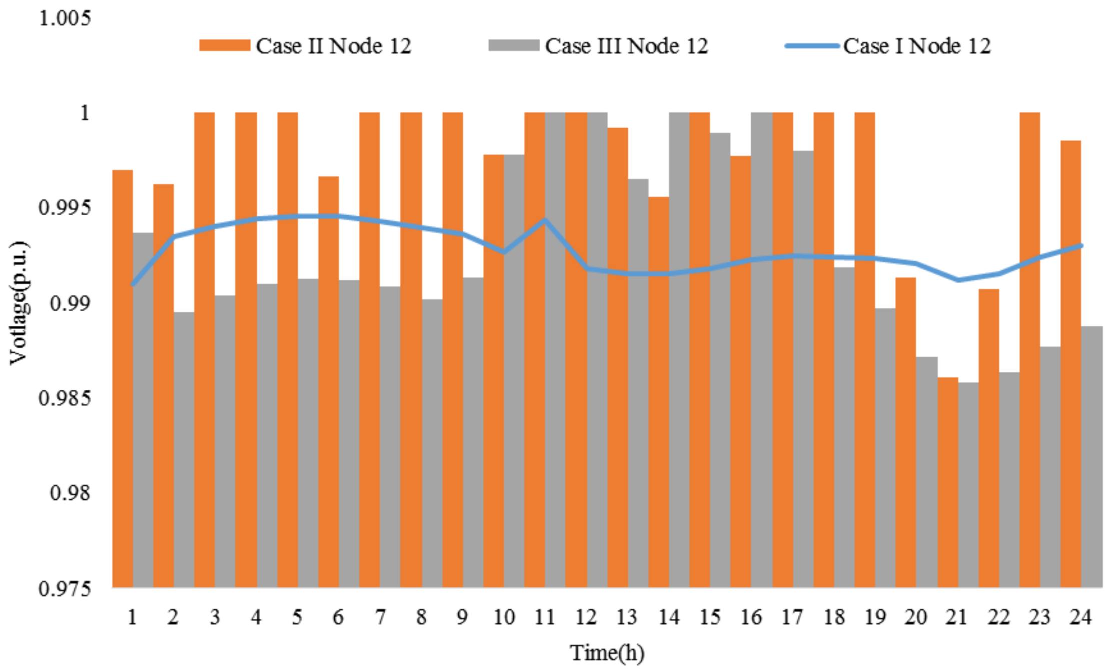

Fig. 4.15. Hourly voltage node 12

4.3 Analysis between Different Sizes of RER

4.3.1 Market analysis

In order to analyze the influence of the size of the RERs, 2 scenarios have been tested for each individual case, as the case with no RER is not influenced by size. This analysis will be made by varying the wind and solar farms from 200kW to 1000kW in even intervals of 200kW apart in order to provide a full analysis.

In this market analysis the cases will be compared in all market participation. This market participation will follow the same contents as the previous one. It will consider the reserve market, regulation market and normal energy market.

The intent of this study is to understand how size influences different the behavior of the parking lot and also help determine how the income grows versus size. And how the market participation in all of those specific markets varies with the same size growth.

The energy received the parking lot and the grid has been illustrated in Figs. 4.16 and 4.17. As can be observed, being available more energy resources in the grid allows the PEV parking lot to buy higher amount of energy from the energy market, just as previously mentioned.

Not only being available leads to buying higher amounts of energy but also with growth of the energy leads to more energy being bought. This effect has more weight in case II that wind power generation is placed on the distribution network. This reflects that the participation of this PEV parking lot in the energy market in case II is more than that in the case III.

All market will be compared from 200kW to 600kW in the figures in order to present a better picture in the figures so it won't be too saturated with data. Then a full analysis is provided further on in tables and with a growth versus size figure.

In Fig. 4.16 which denotes Case II what can be observed is that the power follows the profile expected from Wind throughout the day. But at the end of the day with the increase amount of power it for some hours it stops buying energy. This due to maybe having bought in excess previous hours and participate not in buying but selling as it doesn't need the power. Which we will see later on with analysis of the other markets.

In Fig. 4.17 it can also be observed that Case III has the profile of the PV's which means peak hours it buys energy and at the begging it buys all the same due to not being available extra power for being bought. The main influence are the values of the energy being bought in question which increase with the increase of the power.

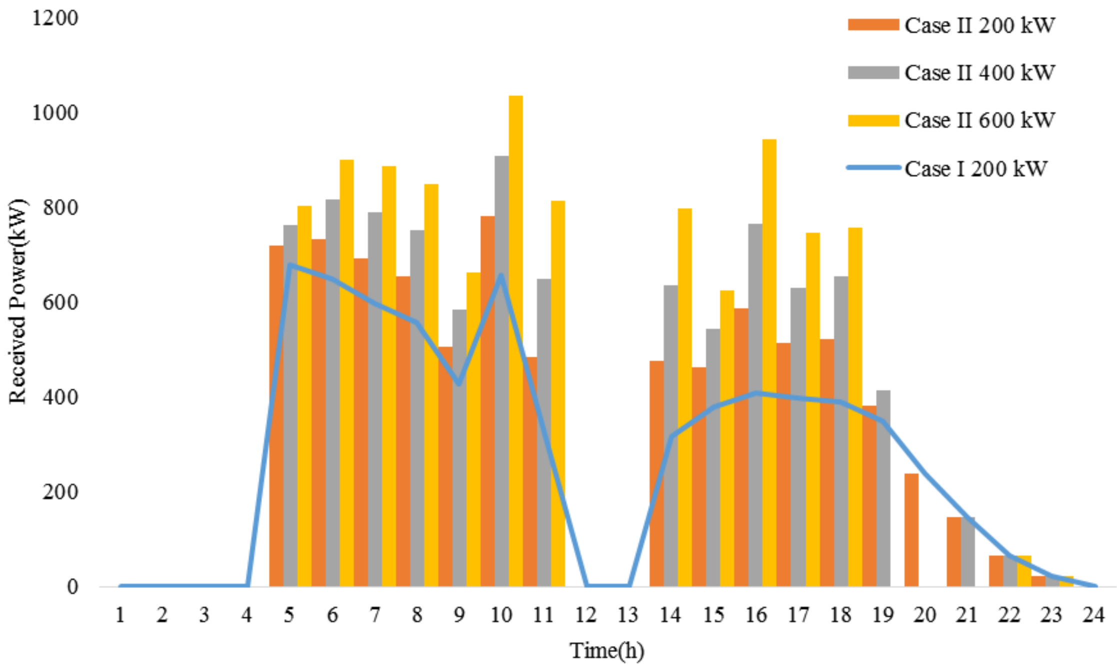

Fig. 4.16. Received power for Case II different sizes

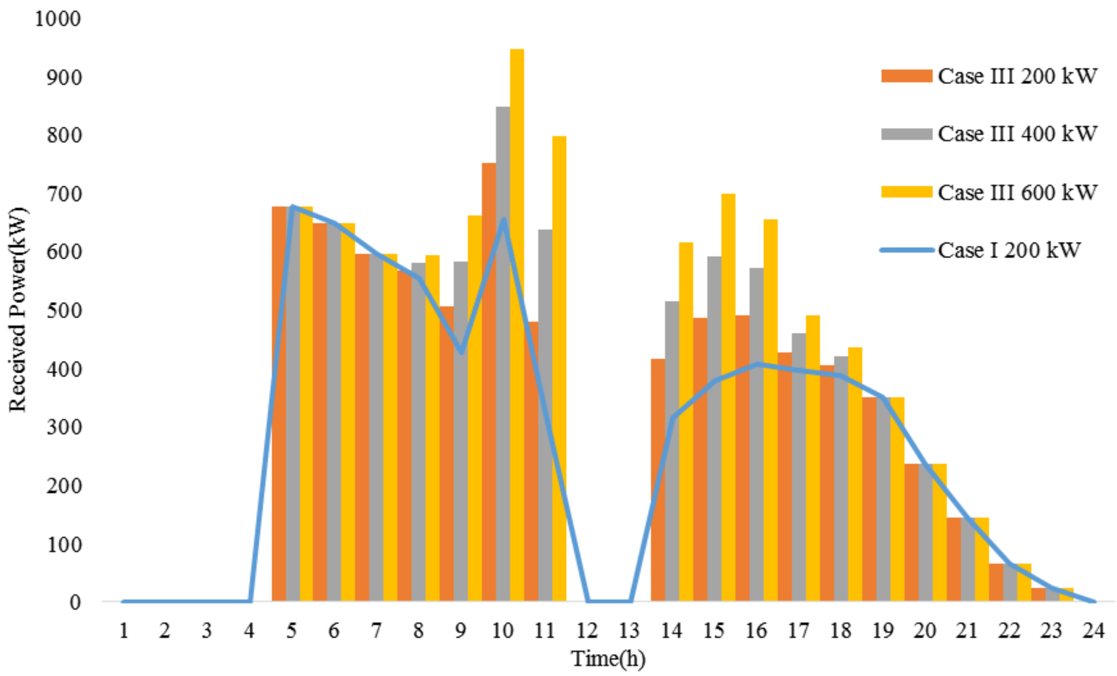

Fig. 4.17. Received power for Case III different sizes

From observing Fig. 4.18 some conclusions can be made to the tendency increase of the PL. First what can be observed is the value at 12, witch independently of the values of the RER the value that is sold is practically the same.

This shows that the maximum amount that can be sold at that time is being deployed, taking into consideration the car capacity and all those factors. Second thing that can be observed is the increasing of the sold power. Although from 400kW to 600kW some saturation is indicated due to the slowdown of the growth which suggests that for larger values the same saturation seen at time 12 will happen for 13.

For the third repair that can be observed in this scenarios is also the new selling hours, which show up with increasing power. This leads to conclude that due to the increase amount of energy captured at hours earlier in the day, it will induce the need to sell at those times of the day. Leading to an extra income of profit for those later times of the day.

From Fig. 4.19 conclusions are slightly different compared to what happens in Fig. 4.18. The saturation of selling quantities at time 12 hours is the same, as would be expected for the same cars and the same conditions which they are inserted only with the variation of the RER.

Other thing to note is also the noticeable increase of the selling power at time 13 although the possible saturation is not as foreseen as in case II due to lower values being sold, it will probably saturate at the same level. This saturation is due to one major factor which is the limit of cars at the time in the parking. Meaning that in order to sell more power there is a need to expand the parking lot over the 1000 PEV limit that is set as a basis.

There are no other new market participations for Case III at later hours as can be seen for Case II due to the conditions being different. This can be considered being inflicted by 2 main factors one being the power profile of the PV's as it is mainly peak focused and does not receive as much power as the other case. This mixed with the management can lead towards not having those peaks even with increased PV power.

For case II as the load is highly distributed throughout the day in this case is more of a peak load which means that for Case II there might have been more saved power, which could be sold later on while this does not happen for Case III.

This analysis already leads to noticeable differences between the effects of distinct renewable energy resources inserted in the system. And also it can be seen that the increase size has different effects on different renewable resources mainly due to the energies characteristics and profile.

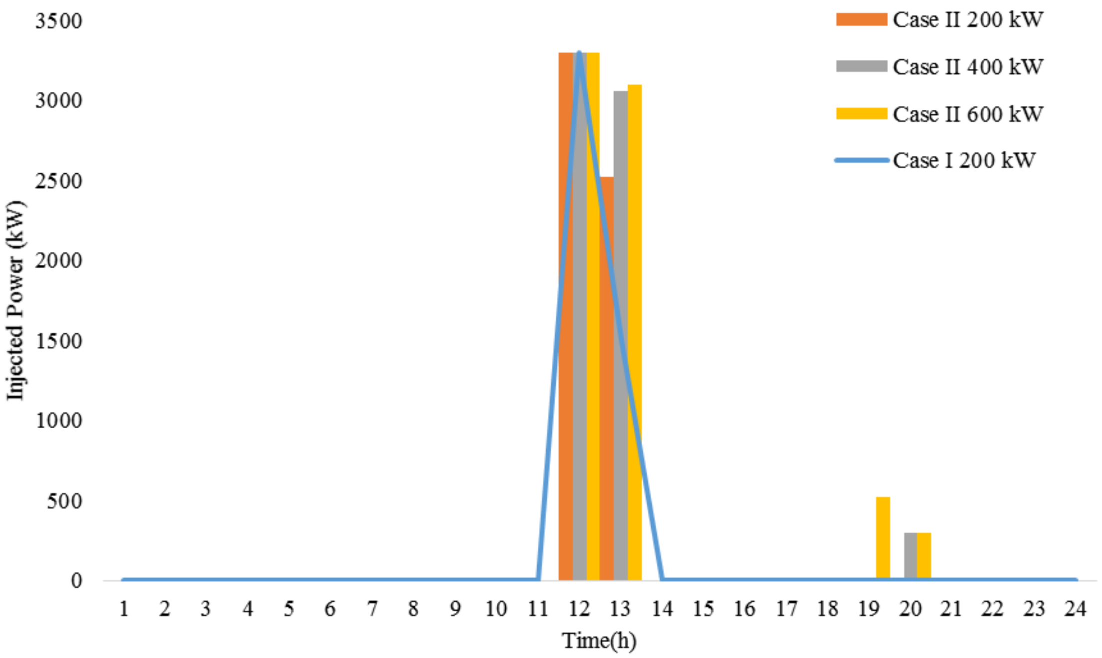

Fig. 4.18. Injected power for Case II different sizes

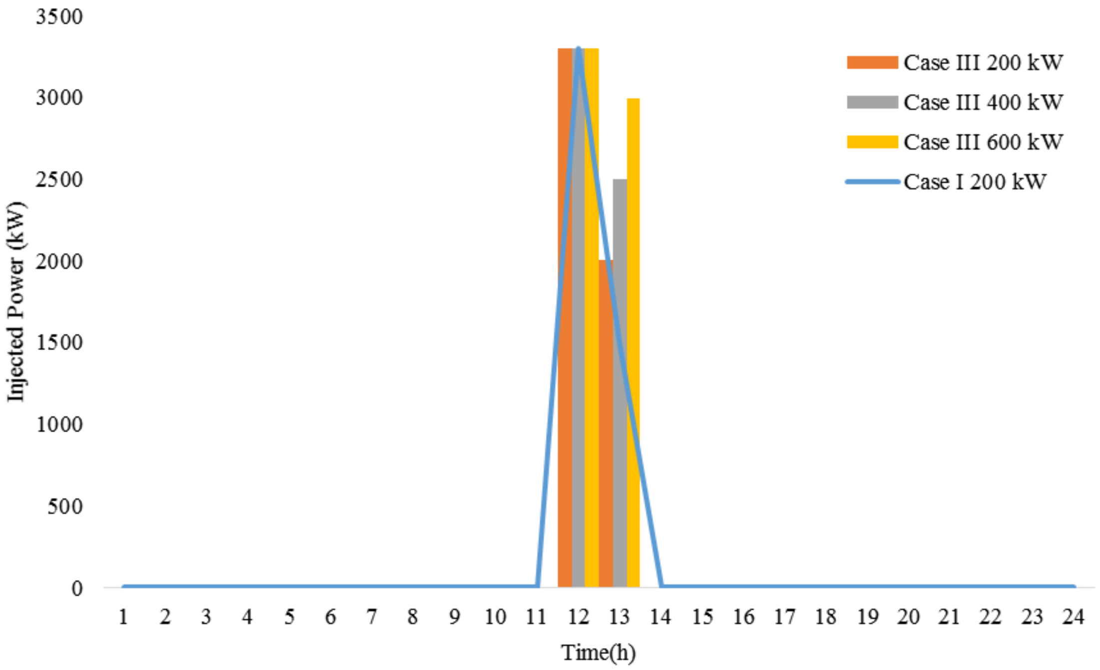

Fig. 4.19. Injected power for Case III different sizes

As can be observed in Figs. 4.20 and 4.21, with the increase of the increasing the power of the RER the values of reserve offer change, for Case II but not for Case III. This is explained the same way that the behavior of the energy market is explained, due to the energy obtained from higher values of power this leads to a change in behavior, and what time it is sold, and if there is power available for distribution at this hours or not.

In Case III the power obtained throughout the day is inferior so there is obviously more opportunity to maintain the profile while for Case II is different.

Figs. 4.22, 4.23, 4.24 and 4.25 indicates the offer of parking lot in the regulation market, first two regulation down followed by regulation up. This value is not what the car really sells due to the probability of participation. The values presented in the offer are what the PL has available to sell but only a small percentage of that offer is bought.

Comparing Regulation down it decreases expectedly with the increase of power as there is more power available from the normal energy market there is less necessity to buy from the regulation down market for both cases.

Difference is the changes for Case III correspond more to the PV profile as usual. There is also a difference in the regulation market for Case II for high values where it buys increasingly more energy this due to extra selling on the other markets it uses this to compensate.

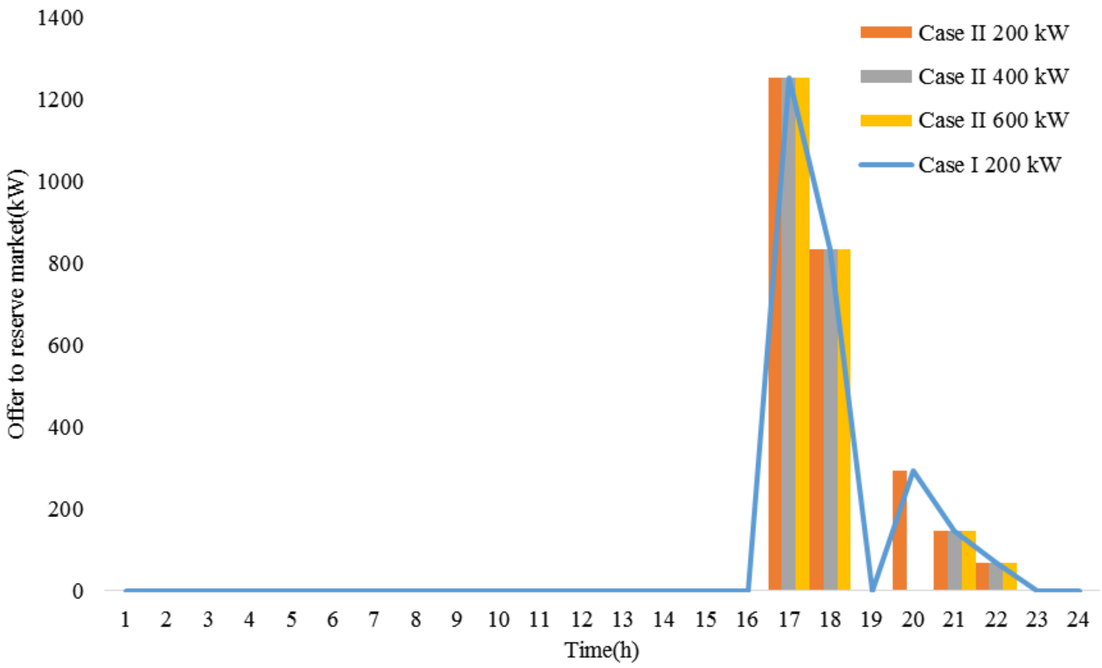

Fig. 4.20. Offer to reserve market for Case II different sizes

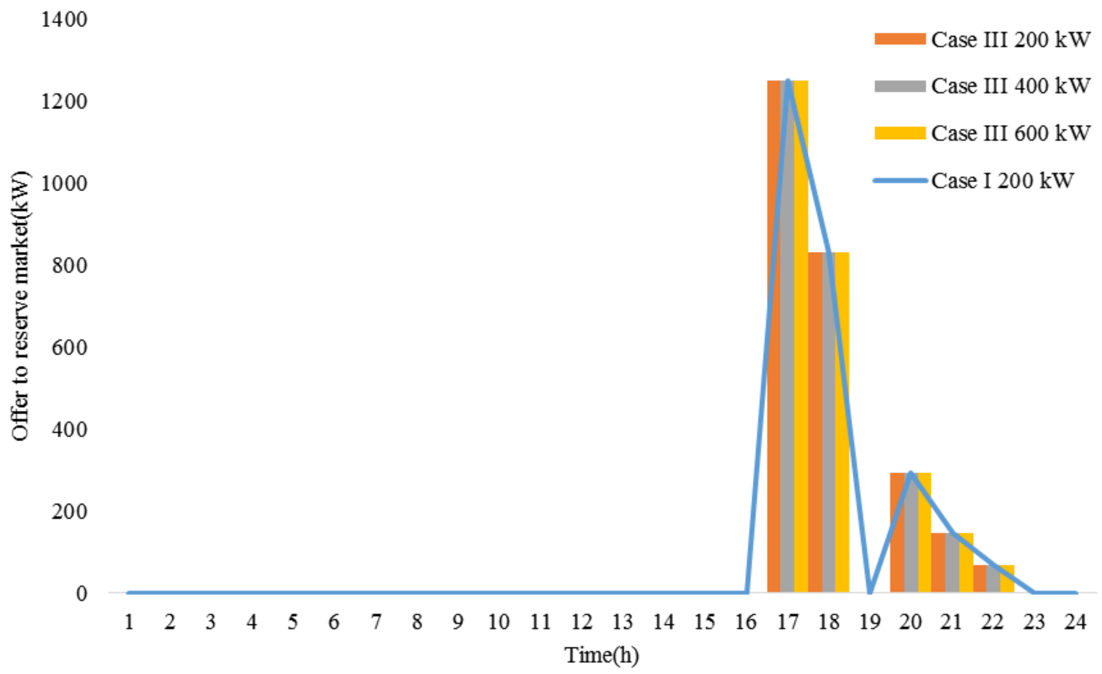

Fig. 4.21. Offer to reserve market for Case III different sizes

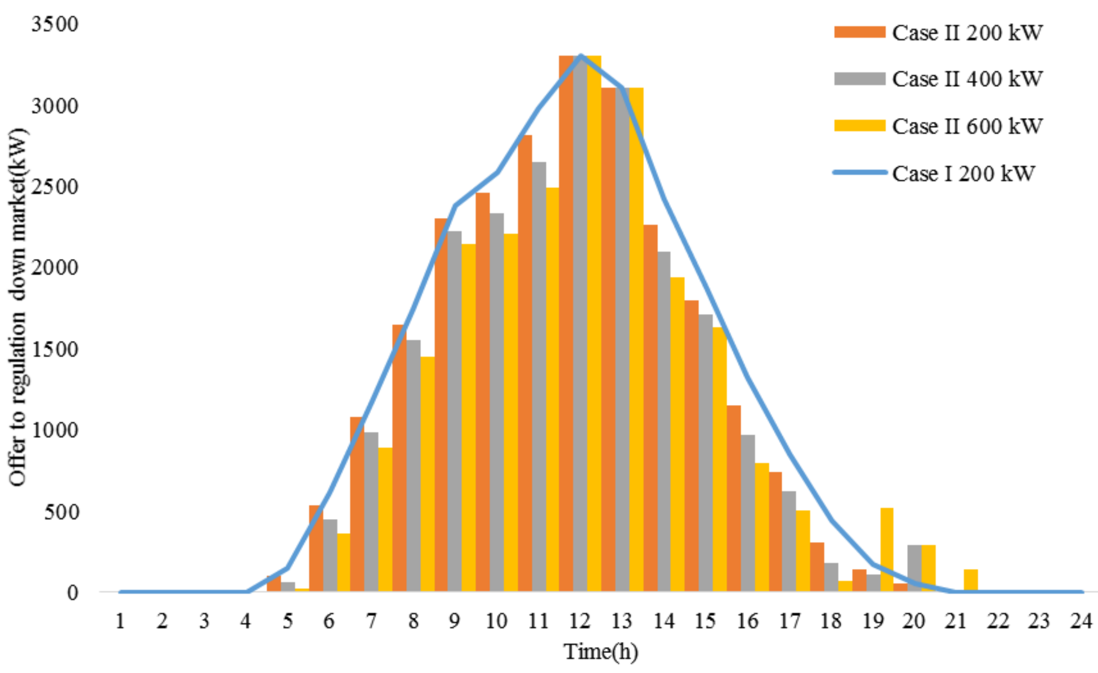

Fig. 4.22. Offer to regulation down market for Case II different sizes

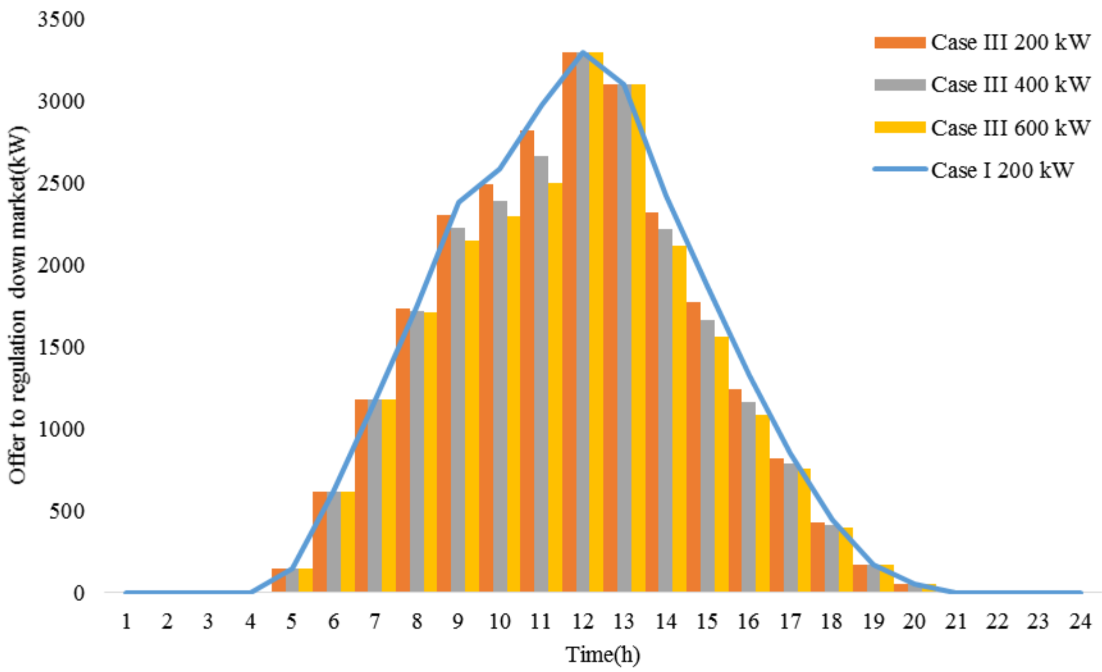

Fig. 4.23. Offer to regulation down market for Case III different sizes

For regulation up markets it is illustrated by Figs. 4.24 and 4.25. From here we can see for Case II there are some differences with the increase power. These differences can be observed for the late hours where it stops selling for 600 kW as for example for hour 19.

These will obviously be compensated and sold at a different market or save for other hours to sell at a better price. For Case III this can also be observed a decrease in sales for hour 13 with the growth of the PV Park. Although it is also noticeable that for the hour 19 in the other case it changed but for Case III it stays the same value maybe for higher value it will change.

The total SOC of parking lot is indicated in Figs. 4.26 and 4.27. As it can be seen, the highest amount of changing in the SOC happens between hours 11 and 13 when the parking lot sells energy back to the grid exactly as previously mentioned. In addition, in case II the SOC of parking lot is higher than the other cases in most of the hours.

The new factor which can be also noticed is that for Case II with the increasing of the power, there is also an increased SOC. While in Case III there are hours where the SOC of the highest power is lower than for the lowest power.

The difference in behavior is due to the market interactions and the power available between both cases. This leading obviously to different profits and participation in different hours at different markets.

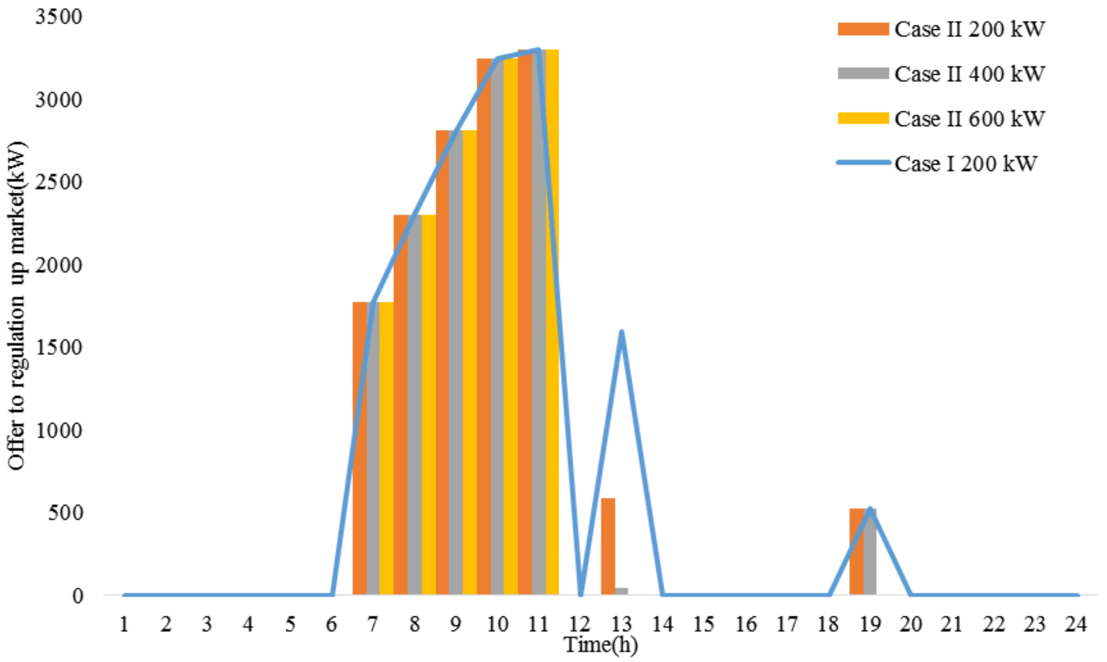

Fig. 4.24. Offer to regulation up market for Case II different sizes

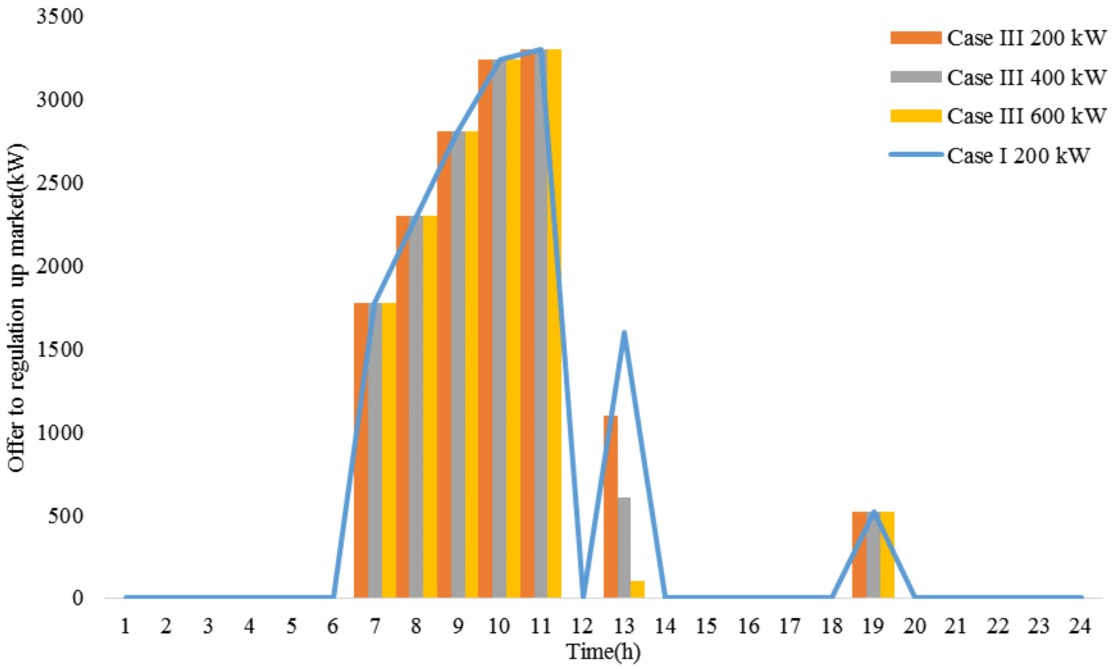

Fig. 4.25. Offer to regulation up market for Case III different sizes

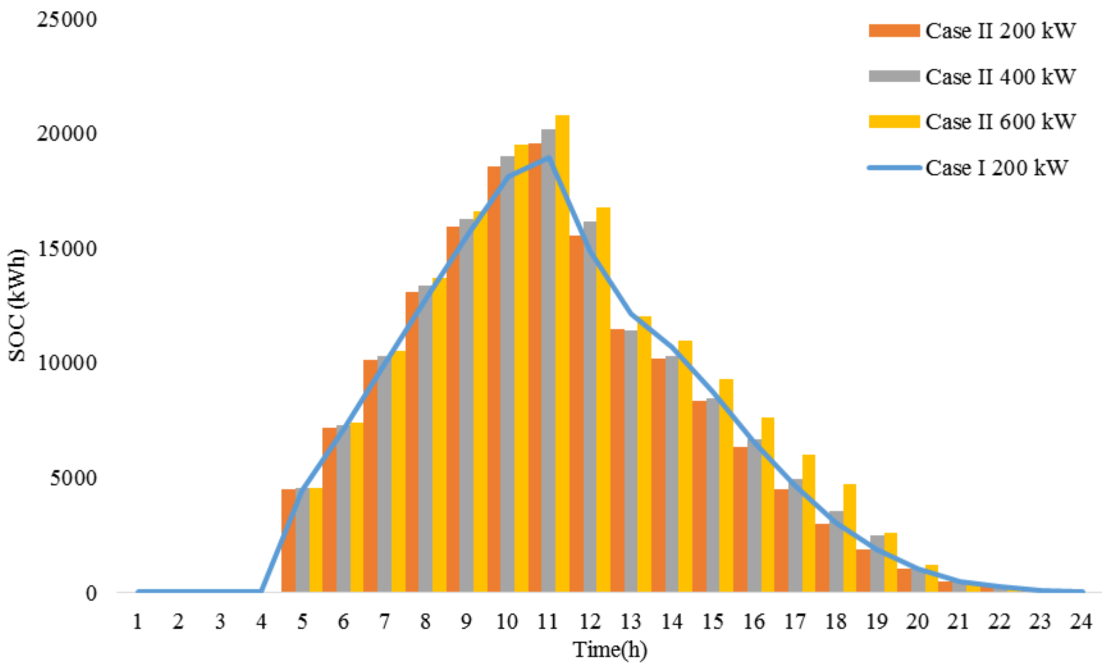

Fig. 4.26. SOC for Case II different sizes

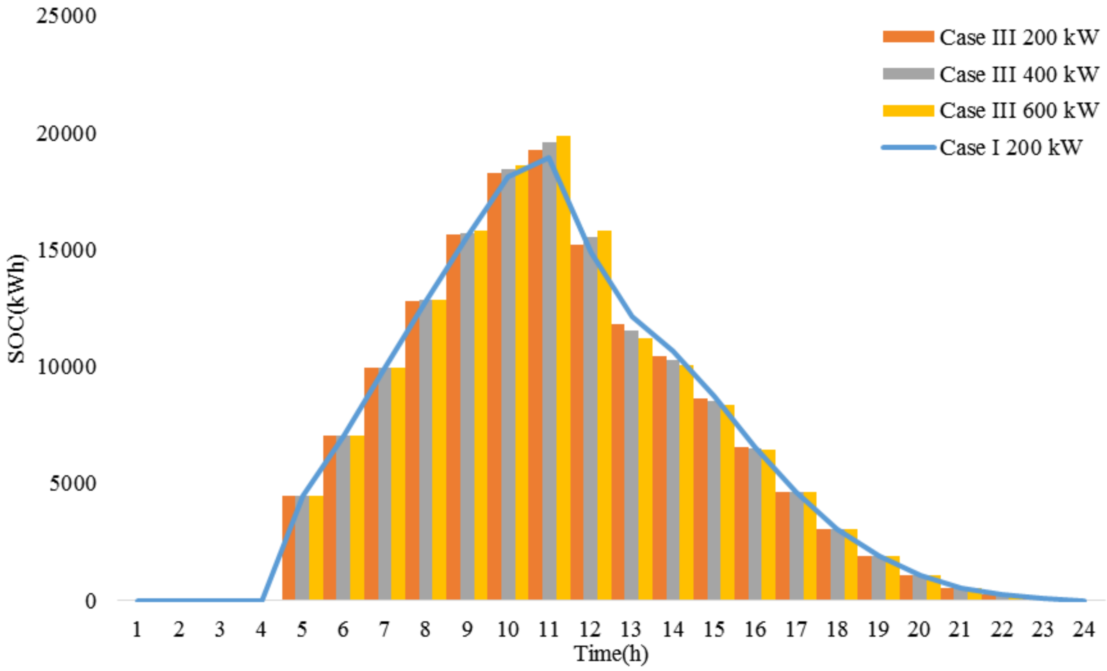

Fig. 4.27. SOC for Case III different sizes

From Fig. 4.28 it noticeable the difference between one case and the other. It can be observed with higher capacity for the RERs it also indicates a higher profit. Even though this is true it can also be overserved the declining tendency of the curve which means the higher the RER grows the profit grows slower. So there is a need to do a market analysis to see if getting a bigger farm pays out compared to the costs of implementation and maintenance. In tables 4.2 and 4.3 it is expressed all the values of the market participation for each individual case. As before Case II has a higher profit then the other cases.

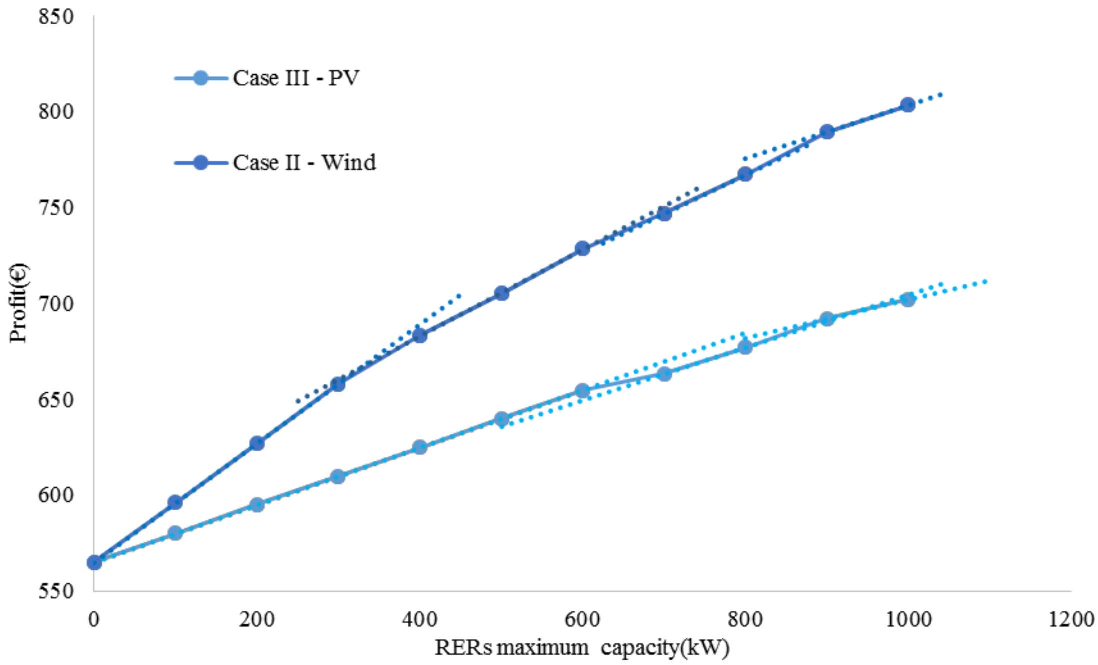

Fig. 4.28. Profit increase and growth curves

Table 4.2. Incomes for Case II for different RER sizes

	Case I	Case II 200 kW	Case II 400 kW	Case II 600 kW	Case II 800 kW	Case II 1000 kW
Regulation up income (€)	99	93	89	85	85	85
Regulation down income (€)	200	189	180	175	170	160
Reserve market income (€)	38	38	34	34	26	34
Energy market income (€)	221	267	307	337	364	392
Income from charging the PEVs (€)	1829	2215	2534	2747	2961	3251
Payment cost to PEVs for discharge (€)	1362	1643	1873	2028	2177	2396
Battery degradation costs (€)	177	188	200	206	216	229
Cost of buying energy (€)	278	338	384	410	441	490
Expected profit (€)	564	626	683	728	767	803

Table 4.3 Incomes for Case III for different RER sizes

	Case I	Case III 200 kW	Case III 400 kW	Case III 600 kW	Case III 800 kW	Case III 1000 kW
Regulation up income (€)	99	96	93	90	87	86
Regulation down income (€)	200	194	189	184	182	178
Reserve market income (€)	38	38	38	38	38	34
Energy market income (€)	221	244	266	289	304	321
Income from charging the PEVs (€)	1829	2019	2208	2397	2490	2636
Payment cost to PEVs for discharge (€)	1362	1500	1638	1776	1844	1947
Battery degradation costs (€)	177	182	188	194	197	203
Cost of buying energy (€)	278	308	337	367	378	398
Expected profit (€)	564	594	625	655	677	702

4.3.2 Grid analysis

A grid analysis has been employed in order to determine some features of the system. Having the proper node working conditions from the previous analysis here it is only required to do an analysis on how the system varies due to the influence of the size of the RER. To see if this variation in spite of the increasing income, has bad influences on the overall grid. In order to analyze the impacts of the parking lot on the distribution grid, the placement of the parking lot on the 14-bus system has been set to node number 3. This is due to figuring out that it was the best working node possible in the previous assessment. This analysis was done for three mentioned cases of wind, PV varying the values of the nodes from 200 to 1000kW.

Figs. 4.29 represent the injection from the upstream network into the considered distribution network considering the parking lot on node 3 for multiple sizes of RER. By comparing the multiple cases in the figure, it can be observed that with the growth of power for the smaller amount of powers there is not an influential growth in the upstream injection values. On the other hand for the values with the highest there is a tendency for the increased injection. This analysis was done for both PV and wind but it was found the pattern to be similar so it was only presented here the analysis of one of the cases.

Figs. 4.30 and 4.31 indicate the hourly voltage of nodes 4 and 12, respectively. By comparing Figs. 4.30 and 4.31 it is easily spotted the variation in the nodal voltage due to the differences in sizes of the RERs. For example it can be seen from the nodal voltage in Fig. 4.31 that with the increase of the size of the RER it is also highly increased the nodal voltage and the utilization of that node, also due to being the location of the RER's itself. On the other hand, in Fig. 4.30, previously it was shown that it was not an influenced place in the grid.

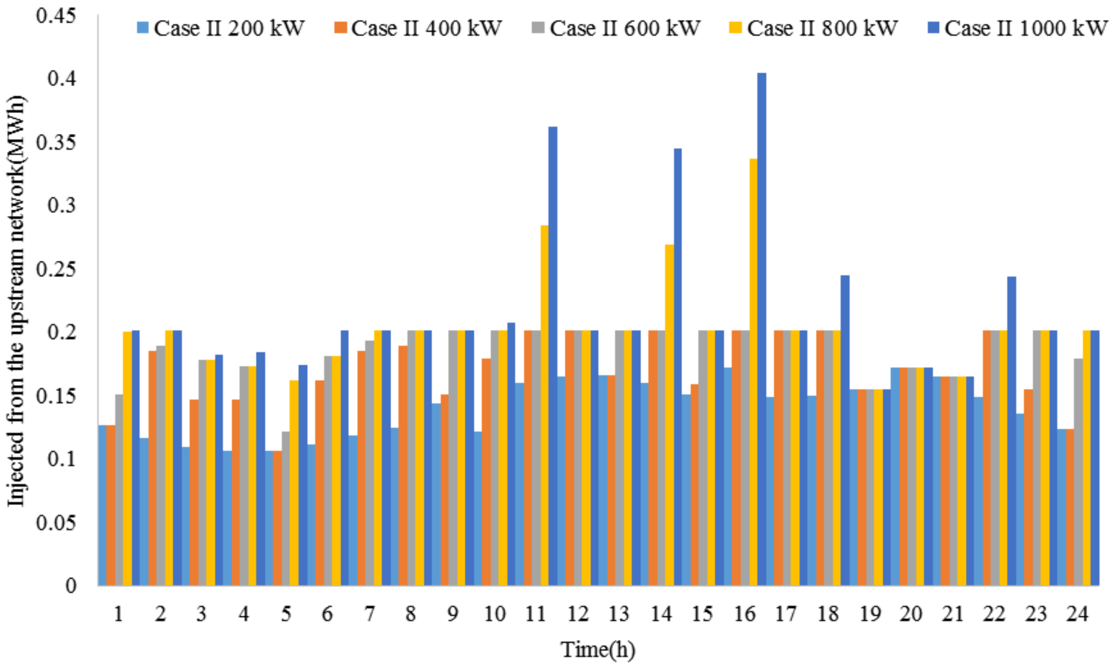

Fig. 4.29. Injected power from the upstream network (parking lot on node 3) for Case II different RER sizes

This is due to the parking lot is located on node 3 and the RER is on node 12, which leads not to have a significant impact on voltage level although in this case it is influence. This indicates that the increase RER leads to a less loading necessity on the non-influential nodes leading to a lesser nodal voltage.

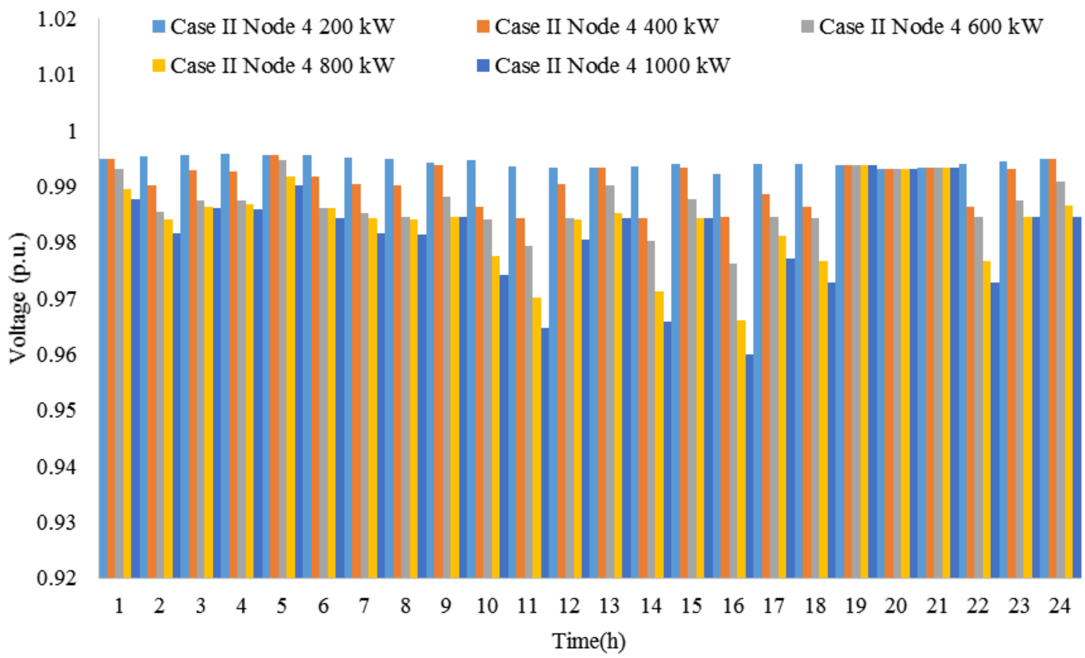

Fig. 4.30. Hourly voltage for Case II different RER sizes Node 4

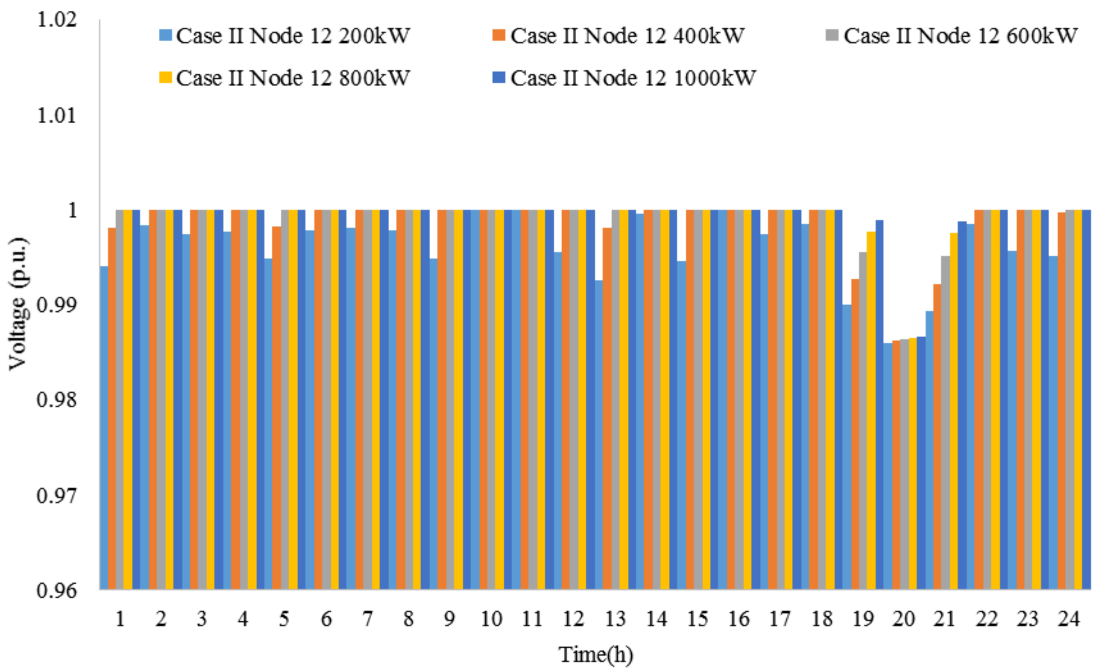

Fig. 4.31. Hourly voltage for Case II different RER sizes Node 12

4.4 Substation Limit Analysis

4.4.1 Market analysis

In order to analyze the influence of substation limits to the PL, the 3 scenarios have been tested for each individual case. The cases consist of no RER, 200 kW windfarm and a 200 kW solar farm, as the first analysis. In this market analysis the cases will be compared in all market participation, In order to understand how the change in substation limits can influence the behavior of the PL.

Observing Figs. 4.32, 4.33 and 4.34 it allows us to take a few notes on the effects of this change to the substation limits. The first thing to point out is obviously the effects it has on the amount of received power, which increases with the growth of the value.

One aspect to point out is for example at time 5 the values for 0.9 and 0.95 are the same, this because it reached the saturation power limit of the system due to the still low number of cars in the system which leads to a saturation of power received. Another aspect to denote is that the profile increase for Case I, II or III is the same so it will only be analyzed one of the 3 cases. The case analyzed here will be Case II due to being the most profitable overall.

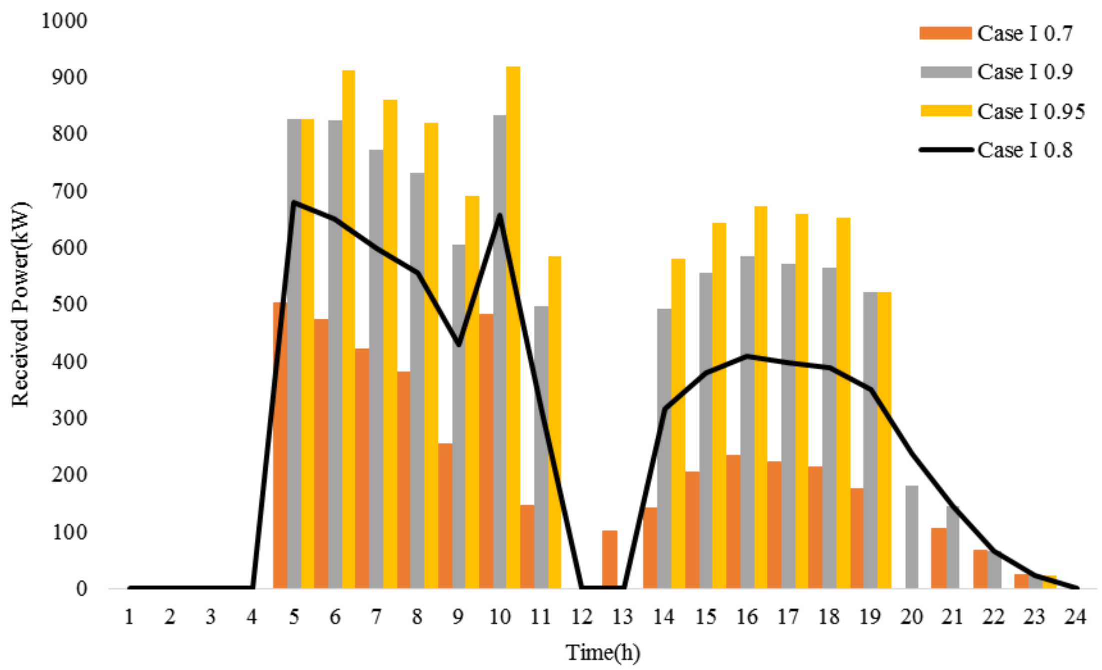

Fig. 4.32. Received power for Case I different Substation values

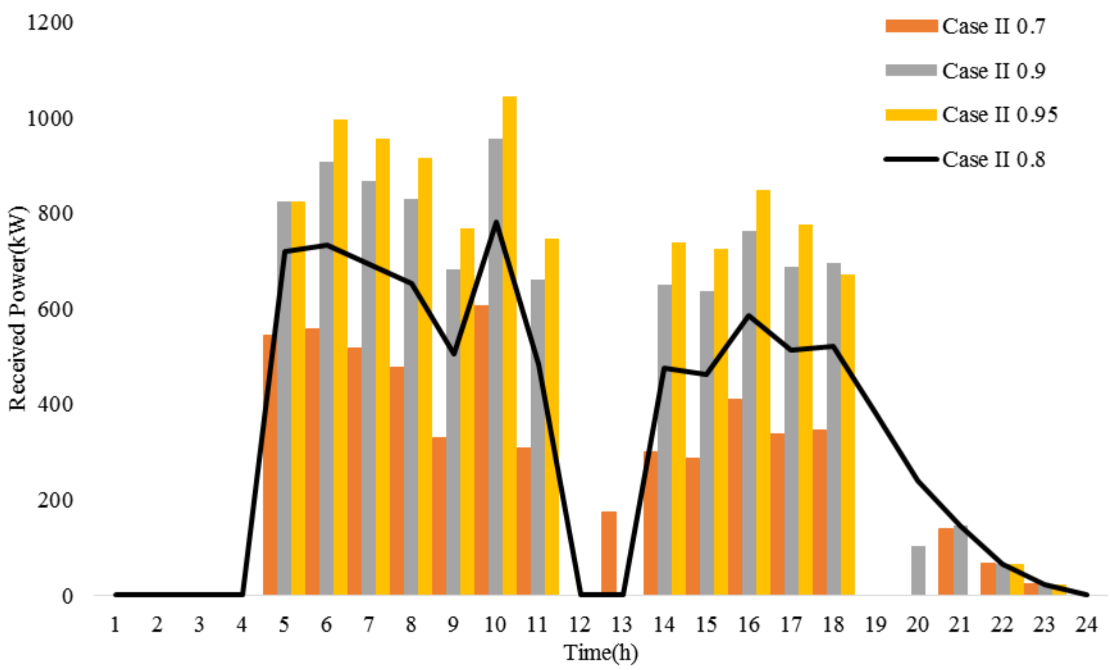

Fig. 4.33. Received power for Case II different Substation values

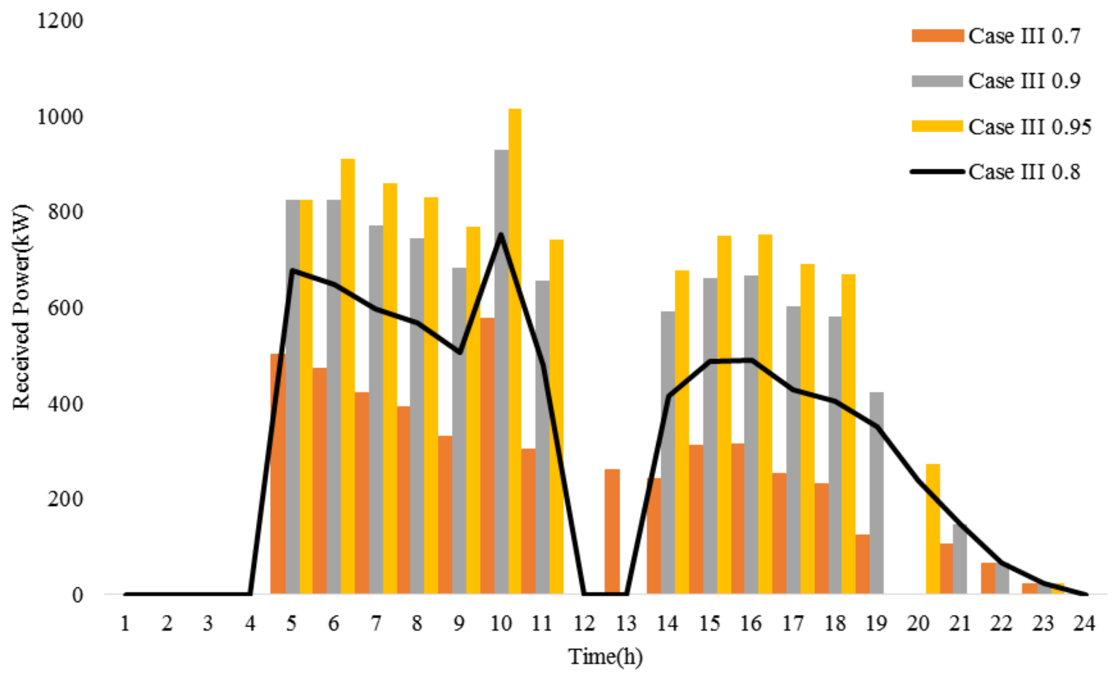

Fig. 4.34. Received power for Case III different Substation values

Fig. 4.35 represents the injection power, here we can observe a lot of differences between the values of the PSS limits. First being the participation in the later hour markets for 0.7 which is a consequence on the not participation on the 13th hour.

It is also noticeable the participation of the other 0.9 and 0.95 on the later hour market which is a consequence of the extra power which is obtained due to the increase obtained power.

Fig. 4.36 shows the reserve market offer. Which for the early hours all values are the same just only noticeable difference is for later hours. For the later hours changes can be seen mainly for 0.7 and 0.95 where they participate in less hours then the other.

Being the 0.7 probably due to the lack of power available and the 0.95 as for having extra power can sell in other markets for a better price or already sold earlier and has no power available.

This will be easily observed in later on in the SOC graphic where it is easily spotted the consumption of extra power from grid at earlier hours which lead to a high sell peak at that time of day. This is all justified from the early consumption of extra power showed in the received power graphic and as a result it is obtained this higher sold power.

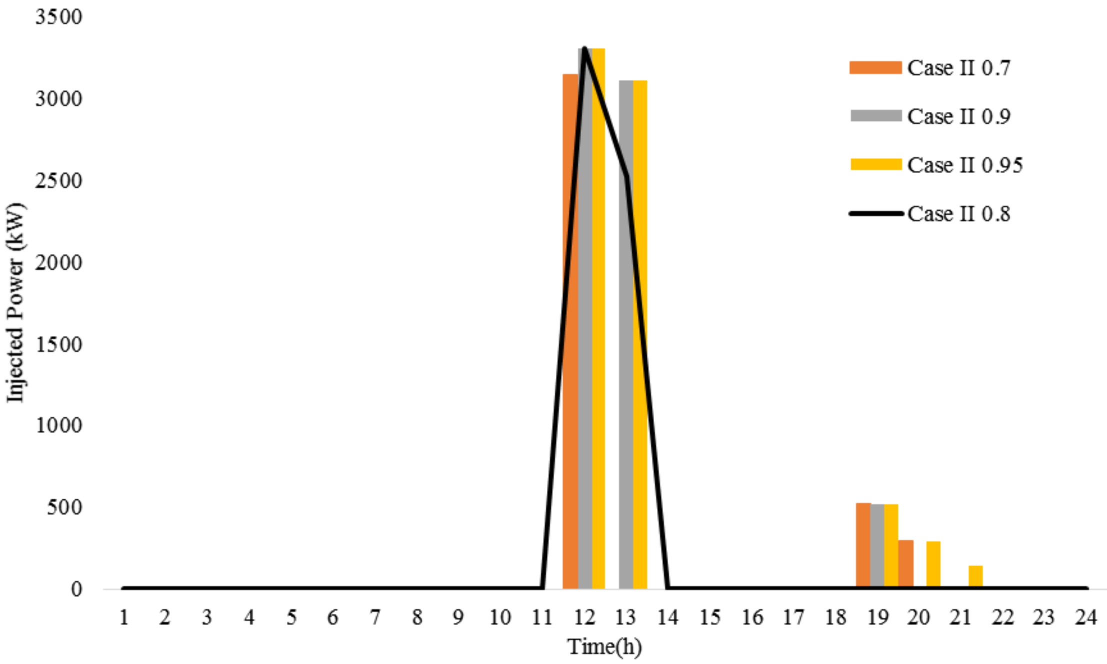

Fig. 4.35. Injected power for Case II different Substation values

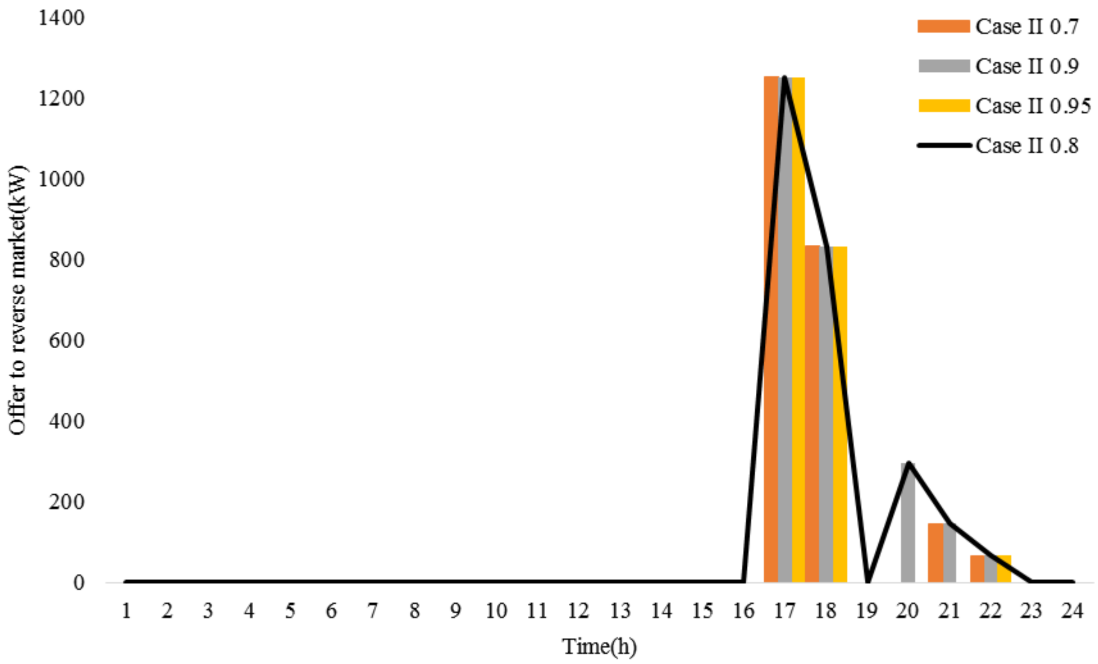

Fig. 4.36. Offer to reserve market for Case II different Substation values

Figs. 4.37 and 4.38 indicates the offer of parking lot in the regulation market, first two regulation down followed by regulation up. The values presented in the offer are what the PL has available to sell but only a small percentage of that offer is bought.

Comparing regulation down first, expectedly for 0.7 it will buy more due to buying less on the normal energy market, and buy less with the increase of the value of the substation limit value. Now comparing regulation up values.

The value is the same for hours until 12 then there is a peak for the 0.7 and a small bump for 0.8 while the other participate on the normal energy market this is explained by choice of participation due to the market iteration.

The total SOC of parking lot is presented in Fig. 4.39, as can be expected the SOC for the case where it has 0.95 for the substation limit is where the SOC of the PL will be the highest due to the extra available energy which corresponds in the graph.

The hours where it is the highest for all cases is the same which is the hours where it sells back the most energy. Just like it would be expected if more power can be obtained from the grid, more power will be consumed in order for a better management with the increase of the PSS value also the power is increased but then due to market interactions for later hours more power is sold at a certain time then others and the SOC for higher values is lower than for the lower ones due to selling more power at certain times.

The growth curve shows in Fig. 4.40 shows it can be concluded a couple of things. First being that profit increases in accordance to the PSS limit variation, higher values mean higher profit.

Following this idea it is also needed to denote the fact that the growth declines with the continuous increase of the value which mean that for higher values of PSS the growth declines. This leads to a necessity of a growth versus costs analysis, costs here being the impacts of the substation limits on the system, maintenance, life time.

Comparing tables 4.4, 4.5 and 4.6 it is easily seen that income increases with the PSS as there is more available power to be obtained with the increase of the limitation to the system. Here it is possible to see the multiple costs and benefits from the substation limit variations only thing that should also be considered here for determining the costs and income is the maintenance difference between all the cases.

But as it was mentioned previously in the state of the art this kind of considerations is only done in long term analysis, here it was only considered a short term analysis.

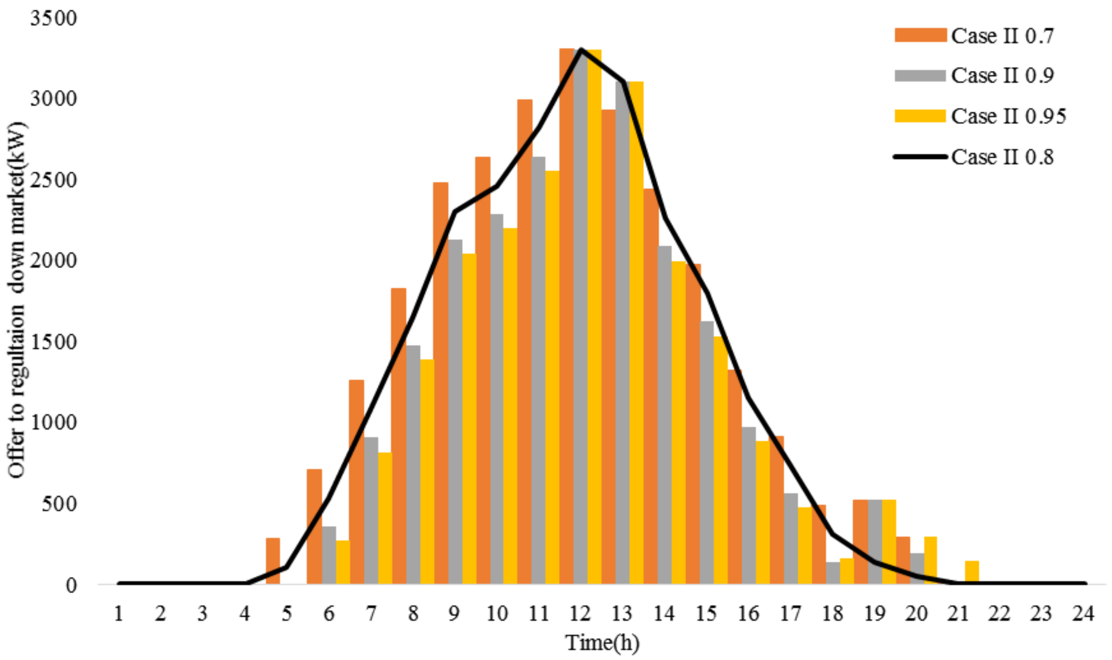

Fig. 4.37. Offer to regulation down market for Case II different Substation values

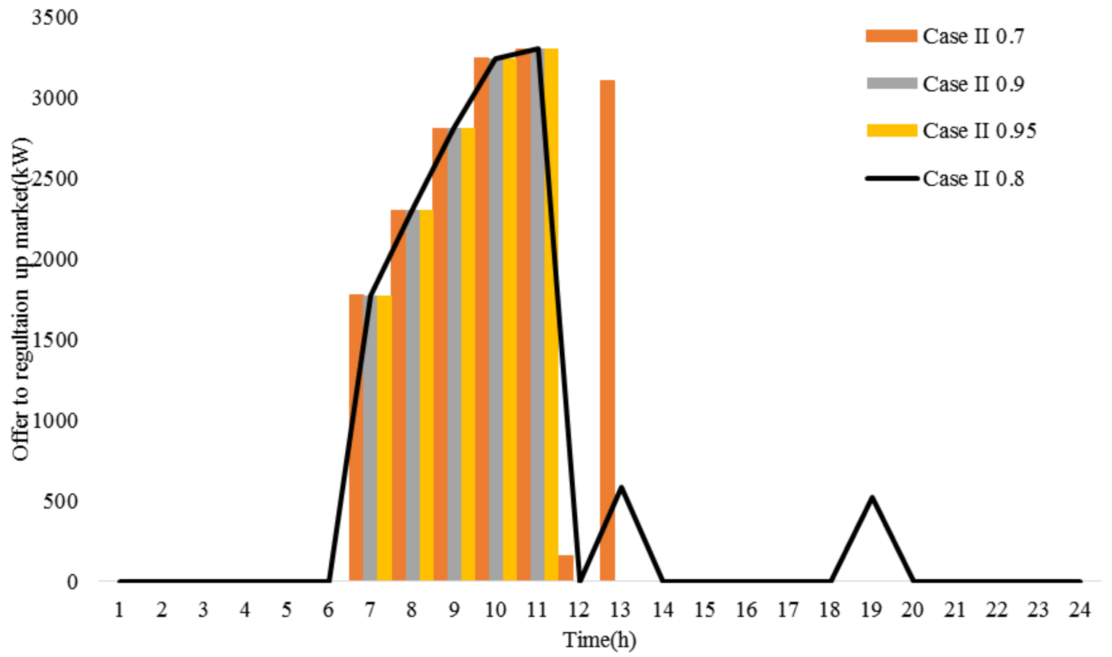

Fig. 4.38. Offer to regulation up market for Case II different Substation values

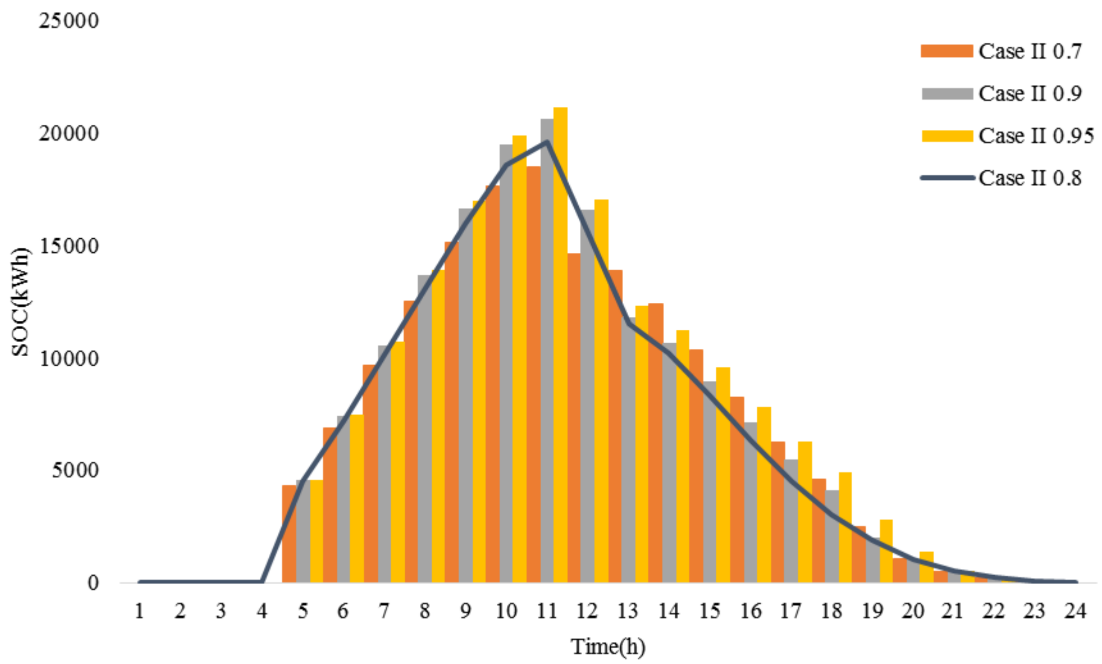

Fig. 4.39. SOC of the PL for Case II different Substation values

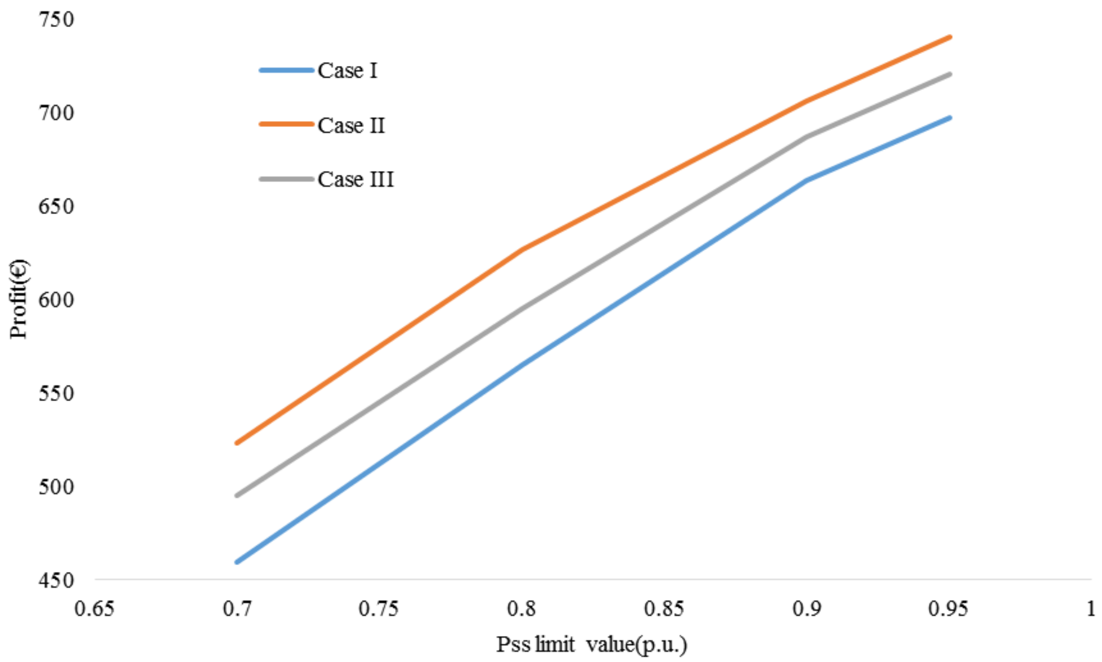

Fig. 4.40. Income Growth with PSS limit variation

Table 4.4. Incomes for Case I for different Substation values

	Case I 0.7 PSS	Case I 0.8 PSS	Case I 0.9 PSS	Case I 0.95 PSS
Regulation up income (€)	111	99	89	90
Regulation down income (€)	220	200	183	179
Reserve market income (€)	34	38	38	31
Energy market income (€)	143	221	293	316
Income from charging the PEVs (€)	1149	1829	2437	2595
Payment cost to PEVs for discharge (€)	863	1362	1805	1915
Battery degradation costs (€)	157	177	195	203
Cost of buying energy (€)	171	278	371	391
Expected profit (€)	459	565	664	697

Table 4.5. Incomes for Case II for different Substation values

	Case II 0.7 PSS	Case II 0.8 PSS	Case II 0.9 PSS	Case II 0.95 PSS
Regulation up income (€)	105	92	85	85
Regulation down income (€)	210	189	178	174
Reserve market income (€)	34	38	38	32
Energy market income (€)	190	267	321	345
Income from charging the PEVs (€)	1506	2215	2635	2803
Payment cost to PEVs for discharge (€)	1123	1643	1950	2067
Battery degradation costs (€)	168	188	201	209
Cost of buying energy (€)	224	338	395	417
Expected profit (€)	523	627	706	740

Table 4.6. Incomes for Case III for different Substation values

	Case III 0.7 PSS	Case III 0.8 PSS	Case III 0.9 PSS	Case III 0.95 PSS
Regulation up income (€)	108	96	89	85
Regulation down income (€)	214	195	180	176
Reserve market income (€)	34	38	34	35
Energy market income (€)	169	244	309	332
Income from charging the PEVs (€)	1368	2019	2549	2716
Payment cost to PEVs for discharge (€)	1023	1500	1884	2006
Battery degradation costs (€)	164	182	200	205
Cost of buying energy (€)	205	308	385	408
Expected profit (€)	495	595	687	720

4.4.2 Grid analysis

A grid analysis has been employed in order to determine how a couple of features of the system have been influence by the substation limits variations.

Having the proper node working conditions from the previous analysis here an analysis of how these changes have influence the system are needed.

What was observed here as it is represented in Fig. 4.41 is that the PSS values didn't influence in a significant way the analysis we did on the grid. As a result this was not pursued any further.

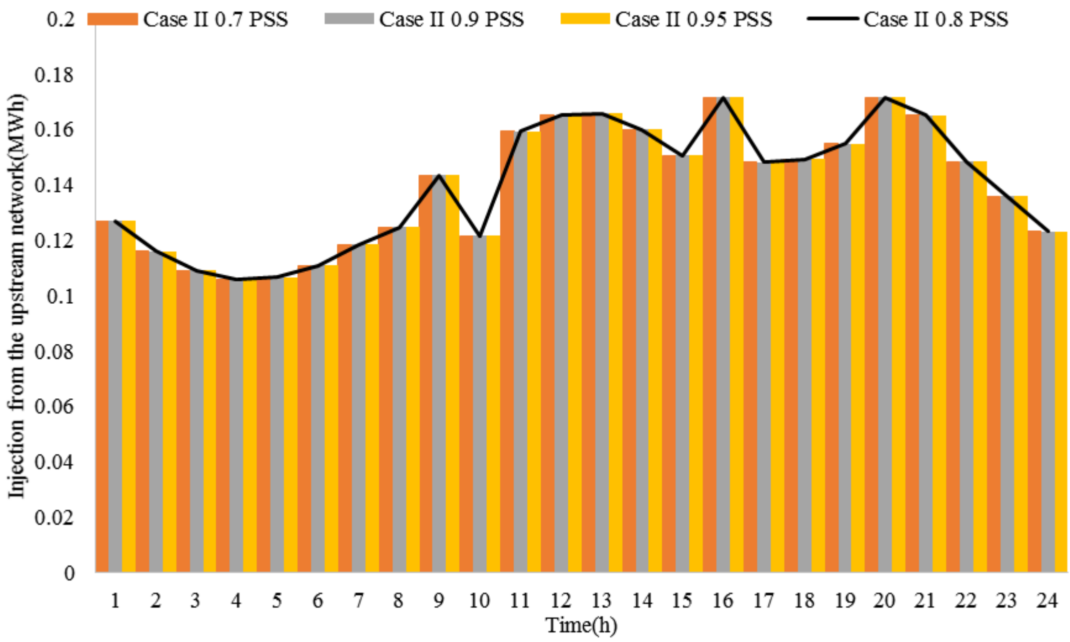

Fig. 4.41. Injected power from the upstream network (parking lot on node 3) for Case II different substation values

Chapter 5

Conclusion

This section describes in detail the techniques used to create the proposed hybrid forecasting tool composed of the innovative combination of MI, WT, EPSO and ANFIS, advanced techniques applied in forecasting electricity market prices and wind power in the short-term.

5.1. Main Conclusions

Here in this thesis a model was developed and presented with the objective of tackling the subject of managing a parking lot of plug-in electrical vehicles. This is not a problem right now as it is an emerging problem in the current society, so in order to predict and get ahead of the future problems and technologies this model has been developed.

For the first analysis of the problem it was done a study to reflect the impacts of different RERs on the profits and behavior of a PEV parking lot. The participation of the parking lot in multiple markets was modeled with considering PV and wind power resources, as well as the uncertainties of PEVs' behavior. The numerical results indicated that the behavior of parking lot in participating in the electricity markets changed by applying different RERs.

It was observed that the parking lot's profit was higher for the case that wind power generation was considered. It followed by PV and lastly the base-case that no RER was employed in the distribution system.

It was also noticed that the participation in the reserve market was mainly influenced by the price while the participation in the energy and regulation markets was influenced by the power availability.

The impacts of parking lot placement on distribution network were also analyzed and the best node to deploy the parking lot was found. In addition, the nodal voltage was analyzed and the variation of voltage because of different RERs could verify that the voltage followed the profile of the scenarios for the nodes that transmit the energy between the parking lot and the RERs.

Following the size impact of the different RER a need to study further is necessary so a size analysis followed it. The size analysis is a necessary as the energy profile is not always the same and it is also necessary to check if there are better sizes for functioning and maximizing the profit compared to others.

So in order to tackle this it was varied the PV and Wind farms from 200 kW to 1000kW. This enabled concluding multiple thing regarding the working ability of the system with bigger sized farms. The conclusion that were obtained are that the profit grows accordingly with the growth of the size of the farms whether it's PV or Wind.

Wind participates on different markets then the PV due to the different profile one being more peak centered while the other more evenly distributed.

Other conclusion is that with the growth there is a decay on the curvature of the growth meaning if we increased even more the profit would decay and probably stop increasing at some point. Only way this could be changed is by changing the size of the parking lot, so there is a need to optimize size of PL versus RER.

In terms of grid analysis what was determined what that grid behavior is in fact affected by the size of the RER leading to extra nodal voltage on the nodes which participate on the overall working ability of the parking lot and it decreases the nodal voltage of the other nodes around it.

Final analysis being the influence of imposed limitations in the system in this particular case the substation limit this limitation is limits the ability of power in the transformers at all times. The standard case that was first used was the 0.8 which was found to be a reasonable value.

In this case the value was varied between 0.7 and 0.95 in order to determine the impacts it has on the system. Here it was found what was expected which is that for lower values the system can get less power at a certain station which will lead to lower profits and vice versa. As far as impacts on the grid it was found that this has no impacts on the working ability of the grid.

For an overall workability of the system and for profit maximization it is needed to do a combination of all these factors, RER, size of the RER, and system limitations and versus this against costs of implementation and maintenance cost of the system on a long term analysis which is not what has been done here.

Overall the model shows a good working ability all the values are expected in the system and all changes with variations where expected which means it can be a model to implement in multiple case study scenarios. So the objective of building a good model for the implementation in real life case studies has been achieved, and hopefully will help do so in the future.

5.2. Research Contributions Resulting from this Work

This section presents the various publications in peer-reviewed journals, book chapters and conference proceedings resulting from the research work carried out in this thesis.

Papers in Conference Proceedings:

[PC1] F.A.S. Gil, M. Shafie-khah, A.W. Bizuayehu, J.P.S. Catalão, "Offering strategy of a plug-in electric vehicle parking lot in renewable-based distribution networks", in: Proceedings of the IEEE International Conference on Smart Energy Grid Engineering — SEGE'15, Oshawa, Canada, August 17-19, 2015 (accepted).

[PC2] F.A.S. Gil, M. Shafie-khah, A.W. Bizuayehu, J.P.S. Catalão, "Impacts of different renewable energy resources on optimal behavior of plug-in electric vehicle parking lots in energy and ancillary services markets", in: Proceedings of the IEEE Power Tech 2015 Conference, Eindhoven, Netherlands, 29 June - 2 July, 2015 (accepted).

[PC3] M. Shafie-khah, F.A.S. Gil, J.P.S. Catalão, J. Aghaei, M. Barani, "Impacts of participating in different demand response programs on operational behavior of plug-in electric vehicle parking lots", in: Proceedings of the 2015 International Symposium on Smart Electric Distribution Systems and Technologies — EDST 2015 (technically co-sponsored by IEEE), Vienna, Austria, September 8-11, 2015 (accepted).

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