Department of Mechanical and Aerospace Engineering

Project

Control of charging periods of electric cars and impacts in future low-carbon energy systems

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Abstract

Since the first design of an electric engine in 1815, the evolution of electric cars has remained slow and difficulties for the integration of this kind of clean transportation have stopped this technology being successful.

The integration of electric cars in the electrical network supposes an increase in the total amount of electricity per domestic dwelling involving risk of exceeding the maximum electrical peak and direct affection of the electrical profile. This project covers the analysis of the electricity system in terms of integration of electric cars. This document will be focused in domestic plug-in electric cars and how the electricity system can be alternated, parameters related to the electric cars and network can affect the whole system and which the consequences of modifying them may be.

The main objective of this project is the development of control software (with C++ and php languages) in which, employing data of consumption for domestic dwellings, a control system will be created, where different parameters and information from a determined period of time will be obtained.

Different strategies will be selected in order to develop a complete study of the integration electric car. The first strategy is developed for reducing the electricity cost, while the second one selects the periods of charging for the most reduced CO_2 emissions. Finally, the last strategy included in the software will be focused on the minimum impact in the network.

Additionally, a control software for regulating the periods of charge in order to reduce the impact in the network will be created. The option of selecting a renewable source as supplier of electricity will be introduced in the Control Software in other to analyze the effects of this integration in the grid in combination with electric cars. An analysis for long periods of time will be included for long time simulation.

The results show the benefits of selecting tariffs with reduced prices for off peaks periods in order to reduce bills and the impact of the charge of electric cars simultaneously. The almost invariable CO_2 emissions independently on the periods selected for charging was detected. The control software shows the high number of interruptions required during charging for long period of time and the small number of periods for discharging the car. When the renewable system is integrated,

the number of interruptions decreases considerably and the number of discharging processes increase for short periods of charge.

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Finally, the author would like to mention the important support that my family has supposed, economically and psychologically.

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Nomenclature

EV	Electric Vehicle
FCV	Fuel Cell Vehicles
g	Grams
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
ICE	Internal Combustion Engine
kW	kilowatts
KWh/d	kilowatts hour per day
km	Kilometres
Mpg	milles per gallon
Ofgem	Office for gas and electricity market
Ppl	Pence per litre
PV	Photovoltaic
UCS	Union of Concerned Scientists
W	Watts

Chapter 1

Introduction

Nowadays, the implementation of electric cars poses several doubts related to the electrical capacity of the current grid system and the viability of integration of EVs in the electric network. Question as: “How can the impact on the electric grid be reduced by controlling the domestic plug-in system for electric cars?” Or “How will renewable energies be combined with electric cars consumption in order to development a more stable base load grid?” are presented in this project and will be answered.

From the appearance of electric cars, thanks to Robert Anderson, who invented the first crude electric-powered carriage between 1832 and 1839 in Scotland (Ahmed, 2012), the evolution of this technology has been unhurried, due to several economical and industrial events. At the end of ninetieth century, electric vehicles competed with steam and gasoline-powered cars in the UK (Anderson & Anderson, 2010). By 1904, a third of the cars in New York, Boston and Chicago were electric (Anderson & Anderson, 2010). Nevertheless, this good beginning was stopped by the higher speed and level of independency of cars with motors of internal combustion. Although supporters of electric cars claimed for charging station in the decade of 10s (Anderson & Anderson, 2010), the low priced or almost “free” fuel (mainly in the USA due to the discovery of massive oil wells), the higher cost for manufacturing (for hybrid cars) in comparison to ICE cars and the difficulties for creating a electrical network outside urban areas dispelled the opportunities for the integration of electric cars in the early 20s (Westbrook, 2001).

During the wartime (First and second Word Wars) the use of electric cars continued dropping even though electric taxis around the word and vans for milk deliveries in the UK continued been employed (Høyer, June 2008). The reason for this sharp decline in the use of electric during these periods was the huge reservoirs of oil of some of the countries participating in the wars and the higher power developed by ICEs cars.

Due to the first oil crisis of 1973 (Chan et al., 2009), the transport sector (the largest energy sector and also the most important costumer of petroleum products) suffered the high prices of fuels and a new thought about the utilization of electric cars emerged. Fuel cell vehicles (FCVs), which use fuel cells to generate electricity from hydrogen and air to propel the vehicle, were studied during the next years and comments on 1974´s newspapers as “…high- density batteries are just around the corner…we look to the battery industry for a technology break thought" (Anon., 1974) were some of the facts that reveal the increasing interest in the electric car.

However, it is not till the beginning of the new century when the electric cars started having a space in the transportation market and a commercialization of electric cars started being considered viable. In 1999, the first hybrid car was launched by Honda (Høyer, June 2008) and the good results opened the path for hybrids cars and the investment in the study of electric cars. New batteries and reduced consumption of electric cars of new generation are improvements that allowed the quicker increment in popularity of this system of transportation last years.

Nevertheless, currently the market of electric cars is growing slower than predicted due to different factors and future implications of the technology. Rare or high-cost materials for batteries, lack of stations for electrical charging and the increase of electrical demand and accommodation in the electrical grid are the main challenges that electric cars are facing nowadays.

The development of new batteries has been studied and investments by big companies in this technology are continuous. The new battery could slash the price of electric vehicles by cutting the battery cost by half according to predictions of Envia (battery Manufacture Company). According to that information big automotive companies, as for example GM, are investing huge sums of money into this kind of companies (in January of 2011 they put $7 million into Envia (Krisher, 2012)) in order to achieve more efficient and independent electric cars.

While the word of batteries continues evolving, the lack of stations for electrical charging remains being a gap in the integration of EV. The current number of charging stations for electric cars is insufficient and does not allow the complete development of the technology in terms of independency of the technology. Several studies and practical experiments around the word have been carried out in order to develop a electrical model for charging electric cars. For example, the UCLA Smart Grid Energy Research Center is studying the possibility of wireless communication technology and smart charging stations for electric cars (Mok, 2012). However this technologies are far away from being implemented in reality.

In terms of impact in the network, the analysis of the effects that the electric car will have in the grid supposes a key point in terms of future development of the technology. As reported by some studies, the present intrusion of electric cars in the UK network is sufficient considering their management at off-peak periods due to the surplus capacity (Department for Business Enterprise and Regulatory Reform: Department for Transport, 2008). However, the random charging is not demonstrated to match the electric generation which means that the probability of saturation of the current electric system will be high if there is not a control system to regulate the charging for a penetration of a 30% of electric cars (Acha et al., 2010).

Estimations for future electrical consumptions as the study carried out by David JC MacKay in his book "Sustainable Energy - without the hot air" (MacKay, 2008), shows that for the plan of 2050, the required electricity supply will be increased from 18KWh/d to 48KWh/d per person which supposes a total increment of more than 160%. Analyzing the total electric demand for 2050 (see Figure 1), 18 of this 48 KWh/d per person, a 37.5%, is assumed to be due to consumption of electric cars.

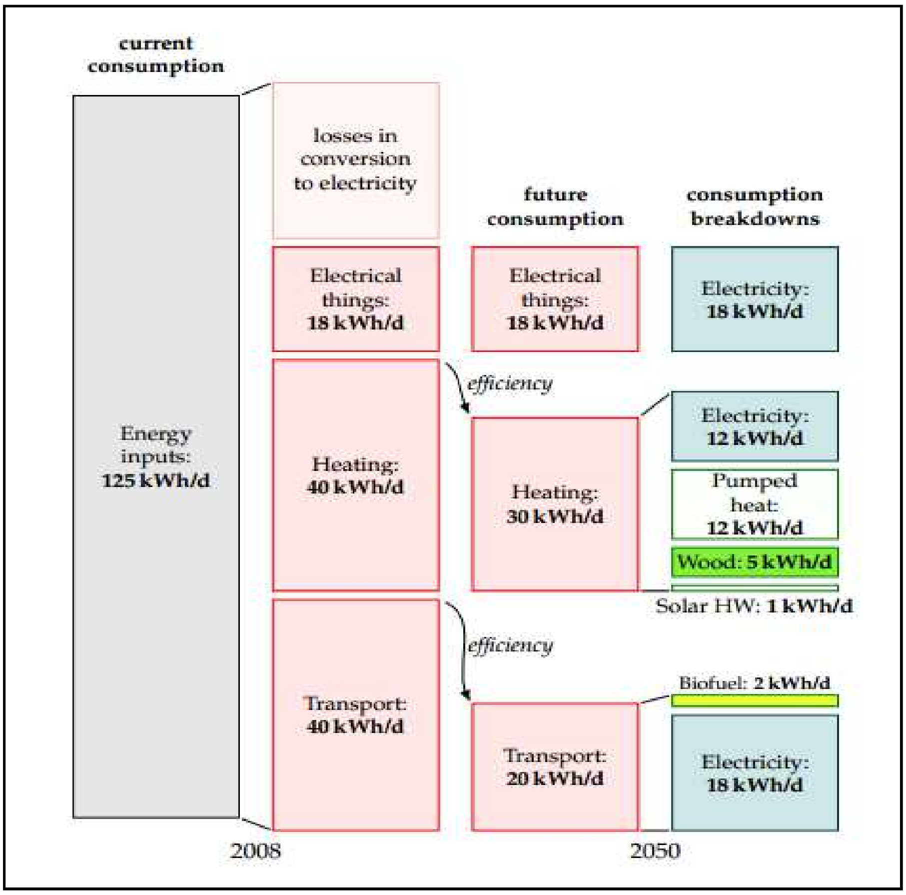


Figure 1. Consumption for 2008 and predicted consumption for 2050

This estimation shows the huge influence that electric cars will have in the future network and the necessity of an analysis for the accommodation of this technology. This project will be focus on the control of the domestic charging for EV in order to reduce the impact in the network. The analysis of parameters, as tariff or increment in the CO_2 emissions due to electrical generation will integrated in this project. Nevertheless, the changeable generation system predicted for next decades, due to the penetration of renewable energies, must be considered. As a result of this consideration the integration of renewable systems will be also a key point for this project.

Objectives and Activity Scope

The aim of this project is the development of software for controlling the charging periods of electric vehicles in order to reduce the impact that this technology has in the electrical network.

The main objectives of this project are summarized in the next bullet points:

-Identification of main parameters affecting integration of electric cars.

-Determination of main strategies affecting the development of the technology and the electricity network. Analysis of restrictions affecting these strategies is required to complete this objective.

-Identification of variable or statistics parameters and analysis of influence and importance of them in the current electrical system.

-Evaluation of the influence of renewable energies in the electrical network combined with electric cars.

The main scope of this project is the creation of control software that allows the analysis of multiple parameters affecting the integration of electric cars in the grid system.

The boundaries of this project are established following different directions:

-Data: the consumption and temperature data will be obtained per minute for UK locations.

-Tariffs: Three different tariffs will be selected for the developed program.

-Battery characteristics: A standard battery for electric cars will be selected and its characteristics will be fixed for the analysis.

-Strategies: Multiple strategies could be selected, nevertheless the lack of time impedes the study of all the possible options and only three strategies will be analyzed in the software.

-Sources of electricity: The analysis of the sources of electricity in order to determinate the CO_2 emissions per hour as being determine for UK standards and it is not extensible to other regions or countries of the world.

-Integration of renewable energies: A unique renewable sources will be selected for connecting to the electrical network of the dwelling. The technology selected will be photovoltaic panels.

Chapter 2

Methodology

The following diagram summarizes the complete methodology used for the development of this project.

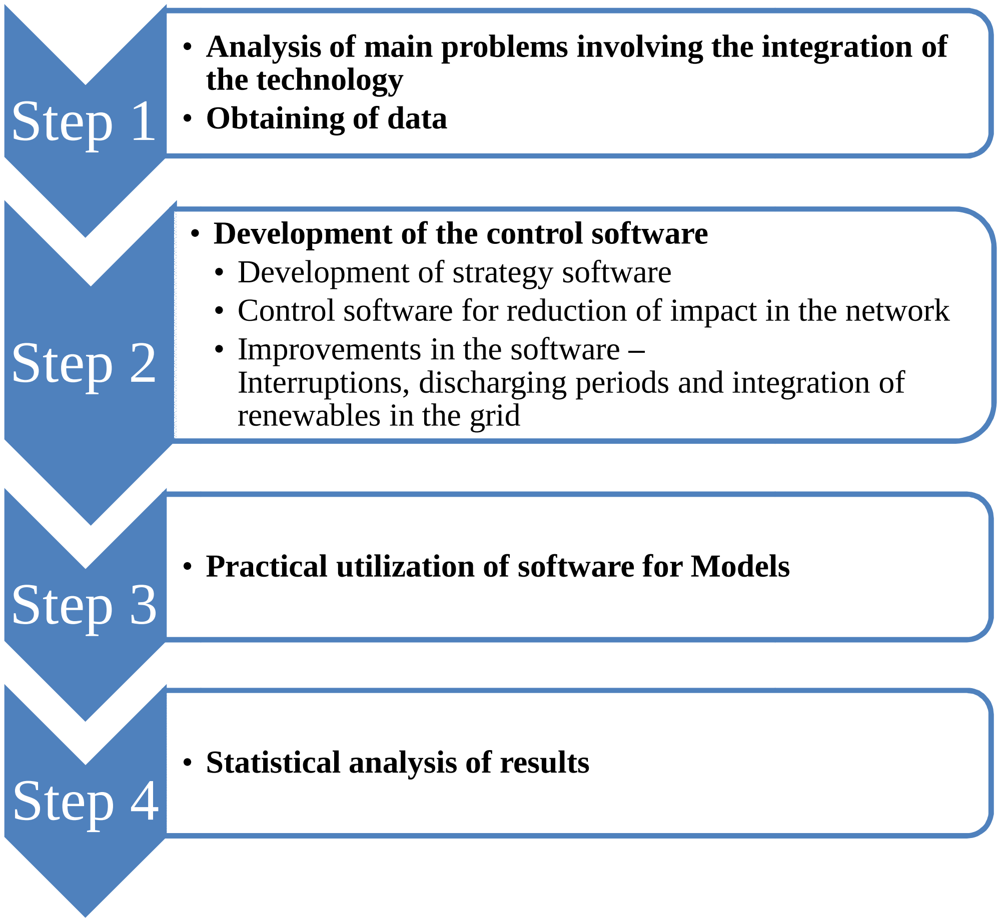


Figure 2. Diagram of methodology

A deep description of all the different parts of this methodology is included in the next paragraphs.

First step - Analysis of main problems involving the integration of the technology and obtaining of data:

The initial step for the development of this project was the determination of the main problems integrating the control of the electric car charging.

In order to focus on these problems a literature review was carried out. From the literature review the following ideas were obtained:

-An economical analysis was determined as a key point for the implementation of the technology. The analysis of the current tariffs in the UK was carried out in order to select the three main tariffs existing in the current electrical market. Data about tariffs and classification of periods according to the level of demand by electricity utilities were the central outputs of this research.

-The environmental impact was the second point of discussion. The CO_2 emissions generated during the production of electricity was considered the main environmental impact resulted from the integration of electric cars in the grid system. Data for the CO_2 emission depending on the technology used for the generation of electricity was obtained, additionally a research of data per hour for the amount of electricity generated by each kind of system of supply was selected.

-The main point of analysis, the impact in the network was interpreted. Data referring the current UK consumption and information about the maximum load admitted by the current grid system was obtained.

-An analysis of renewable disposals was carried out for the determination of the most probable renewable system implemented in the domestic electric grid. The integration of photovoltaic panels was selected as the adequate renewable disposal for this study. Data of energy produced by this technology was obtained.

-The last research step of this section was the determination of data for kilometres travelled in the UK and period of the day of occupancy of dwellings. This information was required to understand the discharge of the battery during travels and the possible period for pluging the EV.

Second step - Development of the control software:

The development of the control software starts with the design of an initial software for different strategies for charging the electric car. Followed for the creation of a software which allows a year analysis of the influence of the electric car technology in the grid.

For the programming of this softwares C++ and PHP were employed.

C++ is a basic programming language that allows the definition of different functions and classes. The C++ language will be used for the programming of the main body of the software.

PHP is other script language to utilize data as simple variables which allows an easier manipulation of the database required for the C++ software.

The software is linked to a website by using a web server, Apache and a Data Base Server MySQL. More information about how to use the software included in Appendix A.

The development of the software was carried out in three different parts. Detailed description about these sections of the software is specified in the following paragraphs:

Strategy software

The first step is the creation of the strategy software. Its main objective is the definition and calculation of results for tree strategies.

Additionally, this step allows the definition of the main parameters for the software, fixing some variables for an easiest programming. The main objective is to create first software able to calculate the results required for the determined strategies using the data provided. The input for this software is the period of time when the car is going to be charged, the state of charge of the car and the kind of strategy selected by the person that is going to control the charging. The output will depend on the kind of strategy selected.

The strategies are selected according to the different fields affected by the electric car implementation.

The first sector affected was the economical, as defined in the past step. The strategy selected facing this problem was the “minimum cost”. This strategy allows the calculation of the best tariff according to the hours for charging. The tariffs are three and data for the determination of the most common ones has been selected in the past step.

The strategy followed to determine how the environmental field was affected is the “minimum CO_2 emissions”. This strategy uses the data for CO_2 emissions of the past step to calculate the total emission depending on the period of the day and the consumption for that moment. The periods for charging with the minimum CO_2 emissions will be the output of this strategy.

The third selected strategy is related to the feasibility of the current electric network for the integration of electric car. It was called “minimum impact in the network” and analyzes the period for plugging of the car in a dwelling without generating a saturation of the grid. The output of this strategy will be the period for which the car can be charged generating the minimum impact on the grid.

This software allows having a clear idea of the main parameters affecting the technology.

Control software for reduction of impact in the network

According to the priority of this project, the analysis of the impact due to the electric car is required. Following this observation, the shape of the software was modified to accommodate the analysis of the impact in the network of the domestic plug-in in order to control the periods of charge.

The output of this software will be the period of charging for reducing the impact on the network. The probability of saturation of the grid is an important factor to consider. The integration of interruptions in the charging period is an improvement that allows the analysis of potential saturation. Information from studies of saturation grids were used to determine the level of load for considering an interruption on charging.

It must be taking into account that the period of charging could not be large enough for the complete charging of the car, in this case the state of charge of the car will be included into the results obtained.

In cases when the car can be charged completely during the period of it is at home, it is possible to discharge the car to balance the time of large consumption in the dwelling. The design of this application was integrated in the software by analyzing the consumption.

Improvements in the software –Integration of renewable energy system in the grid

The last step on the construction of the final software is the integration of renewable energy system which allows achieving one of the objectives of this project was the analysis of the renewable systems that can be integrated in the dwelling. The photovoltaic cells seem to be the most probable disposal for this integration. Using the data provided in the first step of this methodology description, the electrical production was integrated into the demand/supply analysis. The objective of this integration is to study the match of the electric car consumption and the generation of the PV panels.

Third step - Practical utilization of software for Models

In order to test the correct operation of the software and to apply it into real cases, five different models were selected.

These models were chosen considering the extreme possibilities of charging. The analysis covers the charging of the car for a period of two hours in order to estimate how short periods of charging affect the grid (Models 1 and 3).Periods of eight hours were then introduced (Models 2, 4 and 5).

The strategies were testing in Models 1 and 2 for short and long periods of time. With the purpose of analysing whether the software controls the interruptions and possible discharge periods, Model 3 and 4 were developed for short and long periods.

Additionally, the analysis of the renewable system (PV panels) is tested in the last model with the utilization of charging and discharging periods integrating the power generated by renewable energies (Model 5).

The models are analyzed in summer and winter periods with the purpose of detecting how the different consumptions will affect the integration of electric cars.

Forth step- Statistical analysis of results

For the analysis of results a descriptive statistics were be used. This methodology is focused on the description, visualization and summarizing of data obtained from the research done, in this case the different models results.

The utilization of graphics for the description of results and the comparison of parameters using this method allowed an easy and comprehensible understanding of the results of this project.

Literature Review

Introduction

Battery electric vehicles (BEVs) produce significant effects on the electrical energy system. These effects can be positive or negative depending on different parameters which will be explained in the next chapters.

This review document will analyze the current electric car and electric system fields to create a global idea about the overall implications of electric vehicles intrusion in the grid system.

In order to generate a useful background analysis about this topic, the current market of electric cars and the main difference related to conventional vehicles will be discussed. The evolution and main kinds of battery for electric vehicles will be introduced and the main technical and financial parameters affecting the evolution of this technology explained. In addition, an introduction to possible future situation related to the electric cars market will be discussed.

The electricity energy sector will be explained and the different factors upsetting positively and negatively the supply/demand profile will be exposed and examined.

The interaction between electric cars and the electrical system, including the impact of the renewable market, will be analyzed and the main factors relating both fields specified in order to understand all the implications of the effects of electric cars. The necessity of control system in the electrical grid will be justified.

Finally, a reflection about how the electrical system is affected by this technology and how this project can face this problem will be defined.

Electric car vs. ICE cars

Electric cars or Electric vehicles (EV) (Hybrid Cars, 2010) are defined as automobiles power-driven by electric motors. The electricity is stored using batteries or another kind of storage device. This thesis will be focused on battery electric cars, being excluded hybrid cars.

The main advantages of electric cars in comparison to the conventional cars (internal combustion automobiles) are:

Reduction in air pollution and GHGs

Reductions in GHGs emissions produced by direct use of the electric car have been clearly demonstrated. However, the indirect greenhouse gas emissions originate by the generation of electricity and manufacture of electric cars elements is a variable parameter and requires extensive analysis.

The UCS (Union of Concerned Scientists) (Stenquist, 2012), compared the emissions of EVs and ICE vehicles including the "wells-to-wheels" emissions, which account the emissions for the whole fuel cycle. They took into account not only the GHG emissions depending on the area where the car was going to be charged but also the moments when the emissions of power generation will be higher per region in the USA.

From this analysis it was proved that there were no areas where electric vehicles have higher global warming emissions than the average new gasoline vehicle. In addition, the 48% of the population lives in an area where EVs have lower global warming emissions than a 50 mpg gasoline-powered vehicle (Mahmassani, 2012).

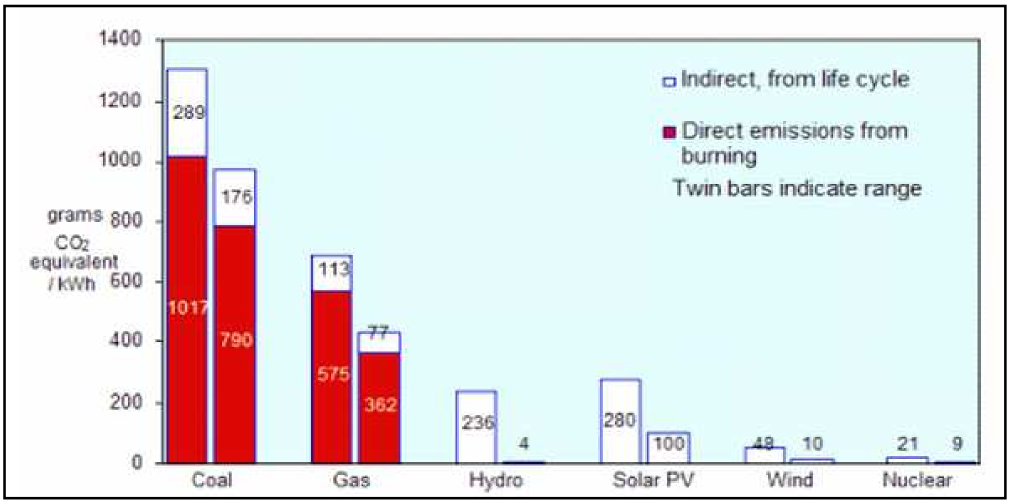


Figure 3. Green Gas Emissions from Electricity Production

According to this report (Mahmassani, 2012): "In a worst-case situation, with electric power generated from a high proportion of coal, an electric car will generate slightly more full-cycle global-warming emissions than the best gasoline-engine subcompact".

The chief executive of Nissan and Renault, Carlos Ghosn supports this perspective and go even further commenting that: "Even if you could use electricity only from coal, you're still better off using an electric car than using gasoline" taking into account the continuous environmental restrictions for coal powered plants (Stenquist, 2012).

The emissions generated during the manufacture of batteries are another point of discussion. Battery recycling methods require high quantity of energy and consequently they produce elevated GHGs emissions. According to some studies (Ricardo UK Ltd, 2011), the 43% of the emissions for standard mid-sized electric cars manufacture and recycling methods arise from the battery. The following graph gives a preliminary proportion of different kinds of cars where the proportion of GHG emissions generated from production varies from 18 to 24%.

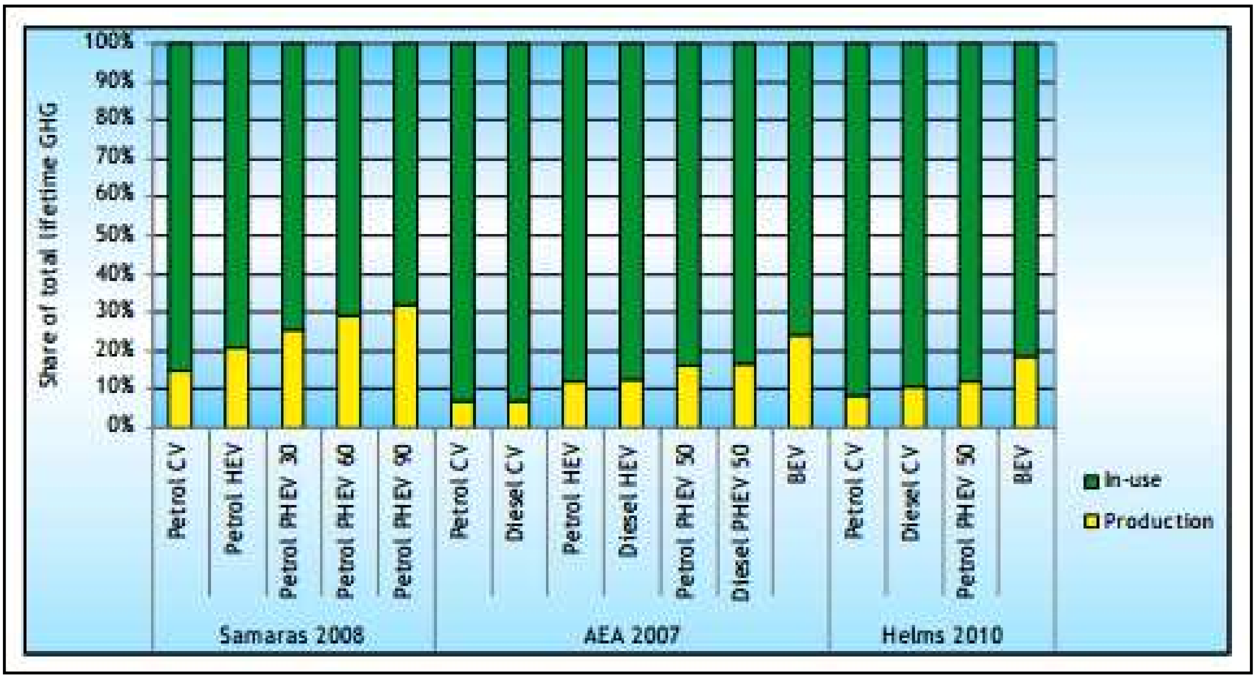


Figure 4. Estimated proportion of GHG emissions from production and usage phases for hybrids and EVs based on different literature sources(Samara,2008, SEI 2007 and Helms,2010) **(Gopalakrishnan et al., April 2011)**

Multiple factors, as the type of batteries, variability of charging and power plants emissions depending on the kind of use of the cars makes difficult to determine with accuracy the total emissions generated by electric cars. Additionally, the changeable future in terms of power generation and the improvements in storage systems generates a complicate prediction of future emissions. However, based on conservative studies, estimations for 2030 predict a reductions in the total emissions generated by electric cars. This decrement will be done by charging the electric cars without electricity from coal plants (Brouwer, February 2010).

Increment in the independence of fuel fuels

This advantage was one of the main causes of investigations about electric car during the fuel crisis of 1970´s (Castonguay, March 2009). However, the technology developed was not enough to compete with conventional vehicles. It might be though that in the future the improvements in the system of batteries could allow an easier commercialization. Nevertheless, the reduction in the fuel prices in the future due to the introduction of electric cars could have a rebound effect. According to several studies, the implementation of electric cars in Europe would generate a decrease in the fuel prices and the consumptions of it by developing countries and a highly possible increment in electrical tariffs (European Commission DG ENV, 26 April 2011).

Additionally, if the dependence from fuel materials decreases, the necessity of determined materials for the battery is another point of disruption. Although the quantity of main materials for manufacturing batteries is enough for the predicted demand and the possibility of continuous recycling of this material (20 tons of spent li-ion are transformed in 1 ton of Lithium) is possible (Talison Minerals, 2008), the high cost of this process implicates cheaper prices for lithium obtained directly from mining extraction. Furthermore, main countries where lithium can be found are Bolivia, Argentina, Chile, Australia, China and the USA (Mohr et al., 2012), which means a dependence on new material and a consequently price variability that cannot be controlled from Europe. This problem restricts again the independency on determined markets of the transportation field.

Reduction in total fuel costs

In order to compare the cost of fuel utilized for electric and conventional cars, the average price of fuel per kilometre was calculated in similar conditions for both cases.

If the current average electrical consumption i.e. for EV as Honda EV Plus is 3 km per kWh (Gopalakrishnan et al., April 2011) and the current electric tariff according to Ofgem data for 2011 (Ofgem, January 2011) is 0.129 £/KWh., the price of the "electric fuel" per kilometre would be 4.28 pence/km.

A similar operation is carried out taking into account data from January 2011 (Arval UK Ltd, 2011), 139.3pence per litre for diesel and average consumption of 11.065 l/100Km (Transport for London, n.d.). The average price per kilometre is 5.41 pence/Km for a common diesel car.

The results of these calculations show a considerable difference of price per distance travelled. However, the continuous increments in electric tariffs and energy policies, estimated as a 33% of increase from 2010 to 2020 in domestic energy bills (Department of Energy and Climate Change, 2011), generates a state of uncertainty that cannot be calmed with the increment in oil price prediction of more than a 50% for 2020 (Butter, 2010).

The main disadvantages are:

Shorter distance range without charging requirements

Current battery system for EV provides 100 to 120 km of travel in average for each deep cycle. The end-of-life for this systems is estimated arround150,000 and 240,000km (Gopalakrishnan et al., April 2011).

Comparing these values with the conventional car ones, the difference is that a deposit of 50 litres of an average diesel car allows to travel 451 Km (Butter, 2010) and the end-of-life for a diesel engine with these characteristics can reach 400,000 kilometers (van Setten et al., 2001), a 40% more than electric cars.

These differences are one of the main constraints for customers when they have to decide between the electric and ICE cars.

Longer time for recharging

Time for charging is a factor that determines the use of electric cars highly. The time required for charging is directly dependant to the number of hours and kind of route that is going to be travelled. The average number of hours required for charging a battery of 20 kWh is estimated on 6-8 hours (Success Charging, 2011). The comparison of this parameter with the few minutes necessary to refuel conventional cars is overwhelming. However, most of the EVs will likely be plugged almost every day; hence the charger time will be reduced to few hours per day.

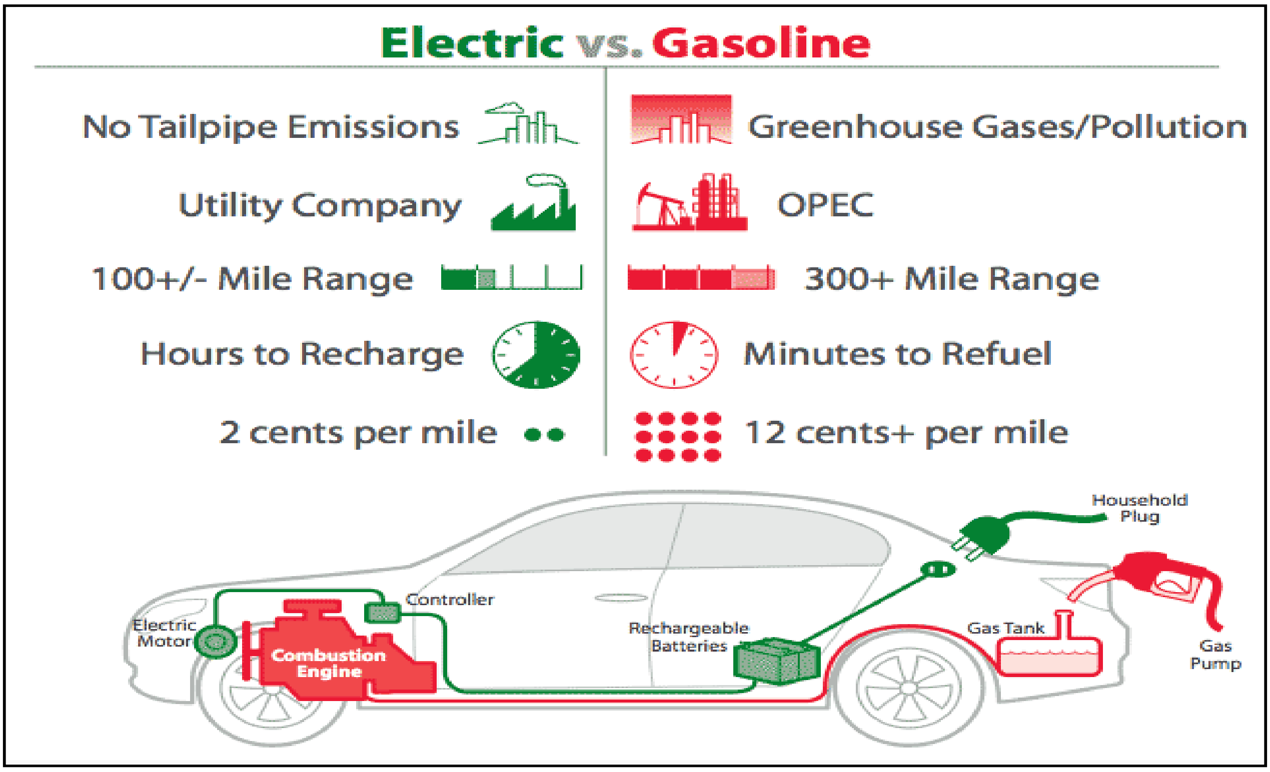


Figure 5. Main differences between Electric and ICE Cars in the USA **(Hybrid Cars, 2010)**

Main technical characteristics of electric cars

Robert Anderson invented the primitive electric carriage in Scotland (1832-1839) which used no rechargeable electric batteries for powering the machine. Improvements were carried out, however the lack of practical rechargeable batteries and the motors developed by the Belgian engineer Étienne Lenoir ICE vehicles in 1863, produced a decrement on the popularity of electric cars (Guarnieri, March 2011).

ICE Cars dominated the automobile sector until mid 2000´s when the evolution of hybrid cars opened the door to full electric cars vehicles. Currently, the technology is still not developed and disposals are trying to be improved for the batteries and the system for charging. Next paragraphs will give an overview of these two important parts of the electric car.

Batteries

Batteries are a storage disposal of electricity. They transform the stored chemical energy into electrical energy. The batteries are grouped depending on the kind of materials that composed them. The current types of battery integrated in electric cars are lead-acid**,** nickel metal hydride (NiMH) batteries and lithium-ion (Li-ion) batteries (Steinweg, 2011).

The high prices of the materials composing the battery is the main issue that it is trying to be solved. The energy density (Wh/kg) of the battery is one of the main parameters affecting the price of the batteries.

Next figure (Armand & Tarascon, 2008) shows the estimated evolution on price and capacity of batteries till 2030:

Battery type	Specific Energy density in Wh/kg	Cost to OEM*
2012 lithium Mn Spinel	105 ± 5	€ 200 per battery + € 620 per kWh
2020 Li Mn Spinel (Battery 1)	125 ± 5	€ 180 per battery + € 310 per kWh
2020 Silicon lithium (Battery 2)	160 ± 5	€ 200 per battery + € 350 per kWh
2025 Silicon lithium (Battery 1)	190 ± 10	€ 180 per battery + € 185 per kWh
2030 Silicon Li-S (Battery 2)	300 ± 20	€ 200 per battery + € 200 per kWh

Cost of 20 kWh battery in 2012 will be € 200 + € 620 per kWh * 20 kWh or € 12,600.
These are manufacturer costs, no retail prices.

Figure 6. Unsubsidised battery costs over time

The success on the evolution of the batteries will depend not only in the cross-interaction of different field to achieve better results. Biofuel cells and high-voltage liquid-electrolyte microbatteries inspired by electric eels have already been demonstrated (Armand & Tarascon, 2008).

Chargers

Currently, the market of chargers for electric vehicles is wide and they are divided in different groups according to the voltage and kind of electricity supplied. Four different kind of chargers for electric vehicles are defined by International Electrotechnical Commission (RTBOT, 2010):

Charger 1: slow charging from a regular electrical socket (1- or 3-phase)

Charger 2: slow charging from a regular socket but which equipped with some EV specific protection arrangement (e.g., the Park & Charge or the PARVE systems)

Charger 3: slow or fast charging using a specific EV multi-pin socket with control and protection functions (e.g., SAE J1772 and IEC 62196)

Charger 4: fast charging using some special charger technology such as CHAdeMO.

The main kind of charger used in the electric cars in the Charger two due to the low voltage required and the specific arrangement for EVs.

The low speed for charging of these chargers is trying to be improved. The investigation about the called “Wireless chargers”, often called power mats,(they use a technology called magnetic induction to transfer electrical energy from wall power sockets to electronic devices) might be a solution for quicker and simpler connection to the grid.

The market of the electricity

The electrical market is a sector where three different roles are presented: government, utility companies and customers. Different countries relates these three factors in different ways, in order to understand the operation of this relationships, the UK electrical system will be described.

The electricity legislation

The government defends the right of the customers but also has an important role sometimes as utility company. The government protects the customers from abusive tariffs imposing regulation systems. UK electrical system is regulated by Ofgem (Office of the Gas and Electricity Markets) governed by the Authority a group of non-executive and executive members. The main objectives of the Ofgem are firstly the protection of customers, regulating the monopoly of utility companies and promoting the competition for fair electrical tariffs. Secondly, promoting sustainable development related with gas and electricity utility companies and energy efficiency in general (Ofgem, 2007).

Additionally another important element in the UK system is Elexon the UK electricity balancing and settlement of the company which job is to identify the balances and unbalances and establish the price for these phenomenon according to the Balancing and Settlement Code (BSC) that can only be modified by the Ofgem (Elexon, n.d.).

The last service that must be mentioned to have a clear idea about how the electrical system works in UK is the Consumer Focus (Energywatch) that acts as an independent watchdog for the gas and electricity industries, advising customers about pricing bills and incidents with suppliers (Consumer Focus, n.d.).

In order to focus on the penetration of electric car in the electric system, the tariffs and policies related to energy generation and distribution play a fundamental role for accurate and efficient use of electricity. This topic will be analysed in deep in next chapters, however an introduction to main tariffs and policies is necessary for a correct understanding.

Tariffs in UK

The electricity tariffs in the UK have been suffering changes last decade. The variations in the electricity demand and the integration of renewable systems in the national network seems to be two main reasons for these changes.

Analysing the tariffs UK, it is easy to advertise that their number is directly proportional to the number of utility companies. The standard tariff is calculated has the average of the cost of the electricity consumed. However a similar patron is followed for all the companies.

The majority of the companies present a “fixed energy” tariff (Which?, 2012). This tariff is also called Standard and it is independent of the period of consumption. However, it is observed that the reduction in the consumption during night hours results in an easier accommodation of the demand during this period. The result of this observation is the tariff called “Economy 7” which offers lower cost electricity for a 7 hour period during the night. The electricity consumed during night hours is reduced by 3 or 4 times (depending on the company) compared to electricity you may use during the day (npower, 2012). “Economic 10” is another tariff that also reduced the cost of electricity for 10 hours per day included in the considered “off-peak” periods. These tariffs might be beneficial in the cases where the profile of electricity consumption matches the hours of reduced cost.

How has been shown the tariffs are directly related to the demand, hence the selection of the correct tariff could reduced highly the cost of the “fuel” for the electric car and boosts the popularity of this mean of transportation.

Interaction of electric cars and electricity system

Some studies point that with a 100% switch to EVs, the only way to be able to maintain the generation capacity at the same level is by introducing a controlled off-peak charging. If this process is not carried out, the distribution infrastructure can be exceeded. For example at 30% penetration rate of EV, without controlling the moment of charging, supposes a 54% of increment in household peak load. This peak is not able to be absorbed by the distribution network (Oscar van Vliet, 15 February 2011). At the same level of penetration, off-peak charging would produce an average increase in a 20% during low energy demand peaks and therefore it does not generate additional peaks and allows a stabilization of the base load.

However, the necessity of charging the EV might be a priority and the possibility of doing that during charging period is high. How to locate the periods for charging of electric cars for maintaining the peaks in low levels is a tricky question that control systems are trying to answer efficiently.

Conclusions

Comments as: “Electrification of the automobile is "gradual" but inevitable” of Bob Lutz Vice Chairman, General Motors, are currently heard in the automobile sector. The gradual integration of electric cars in the European automobile system is going to be more gradual and slower than predicted, due to ICE improvements and low price achieved that avoid the direct competition, the inefficient government involvement in the sector, dominated by private companies and the poor analysis of Utility Companies for the future distribution of chargers and generation profiles.

Deeper analysis of all these factors are carried out in the next bullets points

-Main problem of electric cars is that is not a government or an electricity company who is going to buy a technology; millions of customers must prefer this kind of car than the conventional one. The comparison of characteristics of electric cars and conventional cars is inevitable, and the most important factors for customers as are price and points of recharging are not clear in terms of future integration and facilities. The lack of real improvements and clear and good results generate uncertainty in the customers sector. Additionally, efficient consumption and the reduction of GHG emissions (which a consequent reduction in price) of ICE cars, maintain the conventional cars market two steps ahead of new electrical cars.

-Estimations can be correct but the energy market is so variable that changes can occur slower or quicker than predicted. For example the unexpected very rapid industrialization of China forced the investigation about Biofuels and synfuels but even with the emerging market the evolution is slower than originally predicted (Lovellette & Grant, July 2011).

- In order to attract the interest of customers, the necessary services for these technologies must be properly supplied. Reliability about the fuel supply is one of the most important parameter to buy an electric car. The government and utility companies, the interested organizations in the increment in the number of electric cars are failing the subject of chargers distribution. Home-charging is necessary but the additional integration of a considerable number of plug-in points in roads could be the real inflection point for this technology.

-The regulation system protects customers of electric cars from the more than probable abusive prices of utilities. Another interesting point is the analysis of tariffs and how they could improve the utilization of electric cars.

-The impact on the electrical system is another important parameter for integration of electric cars and its analysis poses relevant questions as: Is the grid available to manage the penetration of electric cars without disruptions in the supply? Are electric cars compatible with renewable energies in terms of creation of a standard base load? These questions will be tried to be solved and clarity and results will be exposed.

Chapter 3

Software Model

Different steps were necessary in order to program and define the final control software:

Establishment of software of selected strategies:

This first step is carried out for the determination of the main parameters affecting the electric car integration.

The software of strategies was kept as simple as possible. Whit this purpose, inlet parameters for the software were considered to be known and data was required for the electricity demand, current electrical tariff and CO_2 emission per generation source in the current market.

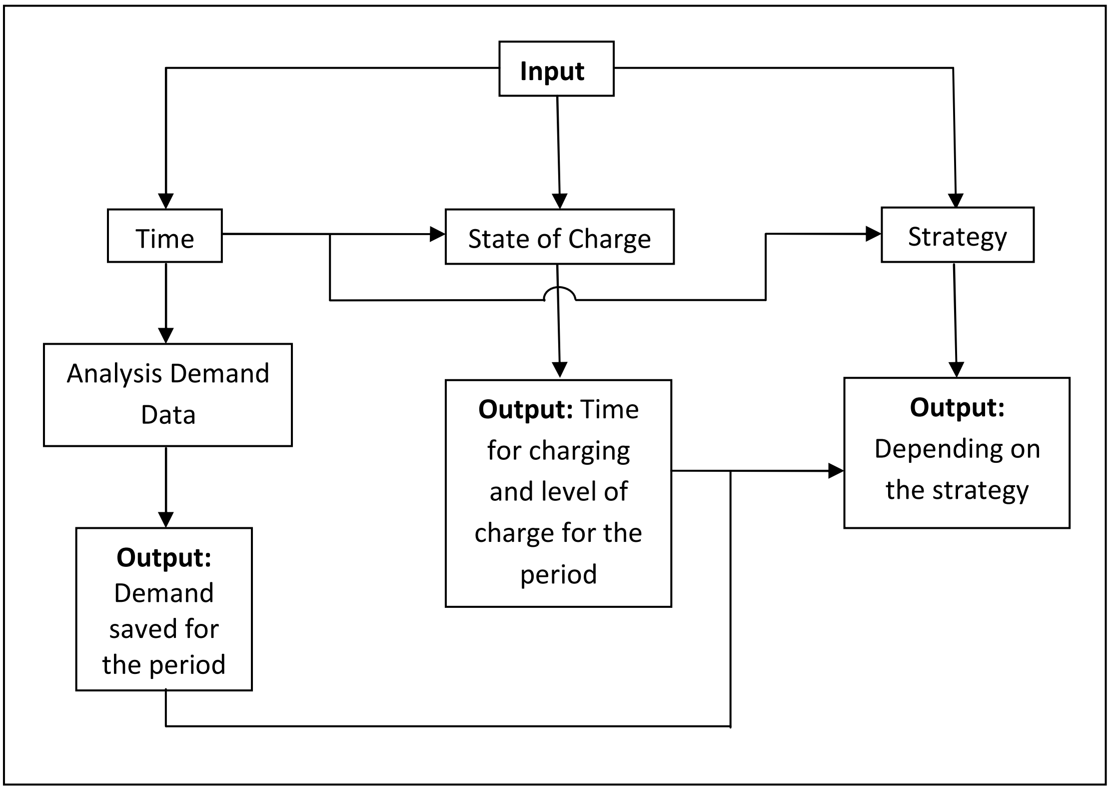


Figure 7. Structure of the initial software

The above chart represents the main structure of the software of strategies. The input parameters are the time for the analysis, the state of charge of the battery and the chosen strategy. The user of the software will select the time when the car is can be plugged, the state of charge of the car at the moment of starting charging and the strategy that will want to follow during the charging period. Data for the three different parts of this first software are required.

Following the main structure of the software, detailed charts for the different parts of the software are included in the next sections.

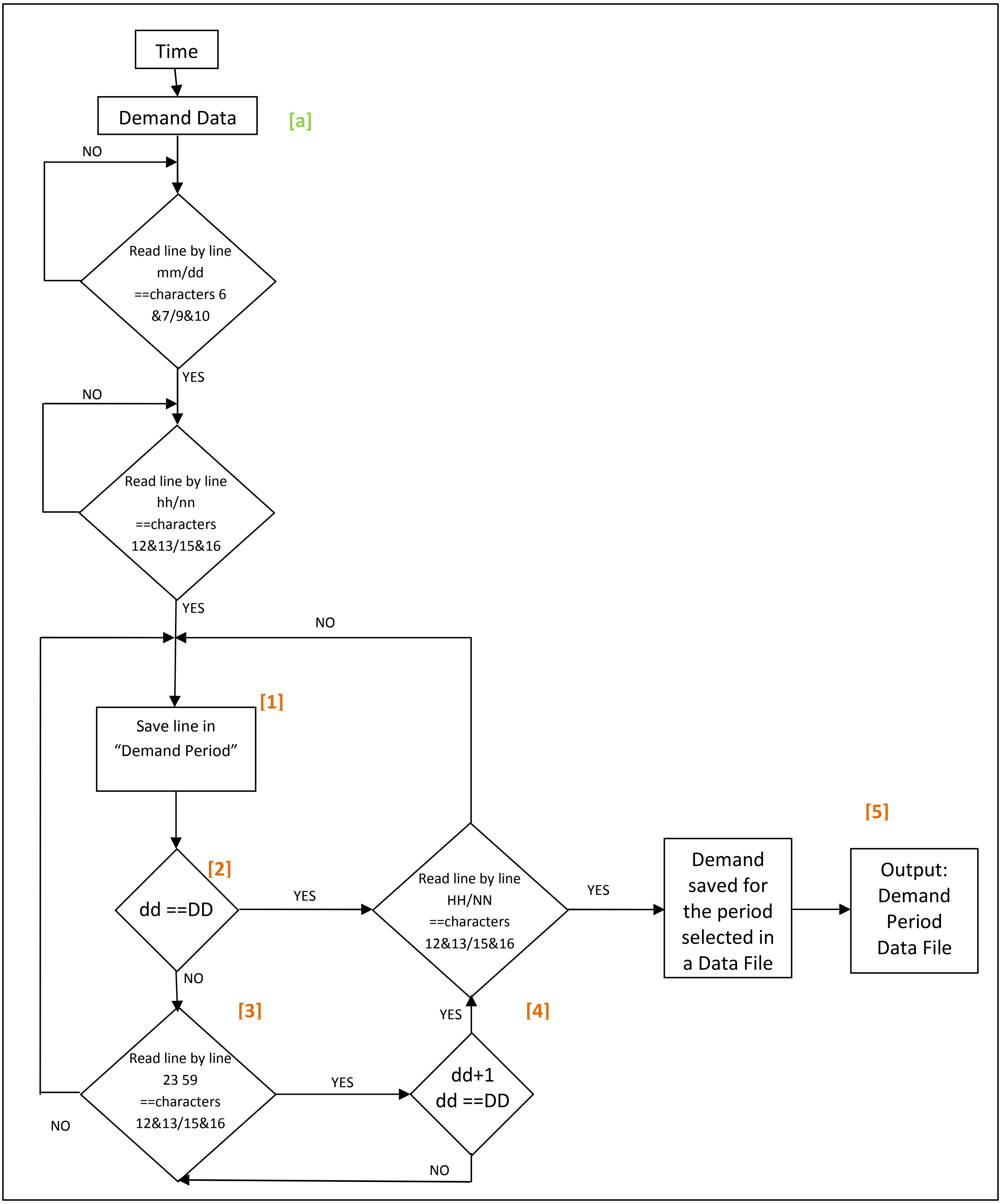


Figure 8. Function Time

Function Time

This function has the objective of selecting and saving as a different data file the period of time for the simulation. This output of this function will be employed in the rest of the software and also in the control software.

The following table summarizes the input variables that will save the values entered by keyboard.

Table 1. Input variables for function time

Input Variables	
dd	day for starting charging
mm	month for starting charging
DD	day for ending of charging
MM	month for ending of charging
hh	day for ending of charging
nn	minute for starting charging
HH	hour for starting charging
NN	minute for ending of charging

The software will read line by line the Demand Data File and find the values for mm/dd and hh/nn (starting date) and save this line in a new Data File called "Demand Period" [1].

Data definition:

*Before starting the data definition and data restriction for the battery characteristics must be added. The battery capacity, efficiency and total hours of charging for the battery will be fixed for this study as 20kWh (Hybrid Cars, 2010), 100% and 10 hours respectively (Ahmed, 2012). Variations for these values can be done, however in order to simplify the calculations these values are remained constant.

[a] **Data demand:**

This data has been obtained from a research of energy consumption in the UK called "Energy and fuel - Environment, conservation and land use". The study was carried out by the University of Loughborough (Richardson & Thomson, 2010). The data was obtained for 22 private dwellings situated in East Midlands,for the years 2008 and 2009 with a resolution of a minute.

The data contains the date and hour of the research and the true active power (taking proper account of the voltage) for the 22 houses and two years. For this purpose, each dwelling was fitted with a single meter covering electricity use of the whole dwelling.

For this software only one of the dwellings has been selected (model 1) and the study was carried out only for the year 2009. The model does not currently include central heating pumps or boiler fans. Most of the measured dwellings have oil or gas fired central heating. The only seasonal effect represented in the synthetic data is in the use of lighting, which is linked to natural daylight conditions. The power demanded by each dwelling was expressed in kW.

Description of the flow chart:

For determining the number of lines that must be saved, several processes can be carried out, i. e. summing the total minutes for the charging period and summing this value to the initial date or looking for the ending date of charging reading line by line. The second approach was selected **[2]**, firstly determining if the day of the saved line is the day of the end of the charging. For the case where the day is not the day of ending of the period, the software will read the lines and save them until the next day is starting (before 23:59 pm) **[3]**. When that happens, the software will compare the next day with the final day for the charging **[4]** and if it is not the process will be repeated saving the lines of the next day. When the days match, the software will detect the final hour saving the lines until that moment; therefore the demand for the period of study is saved in a new Data File**[5]**.

*The possibility of starting the analysis on 30th or 31st of a month and finishing it on the 1st of the next month has not been considered, wrong results can be achieved, hence avoid the selection of this days for the analysis.

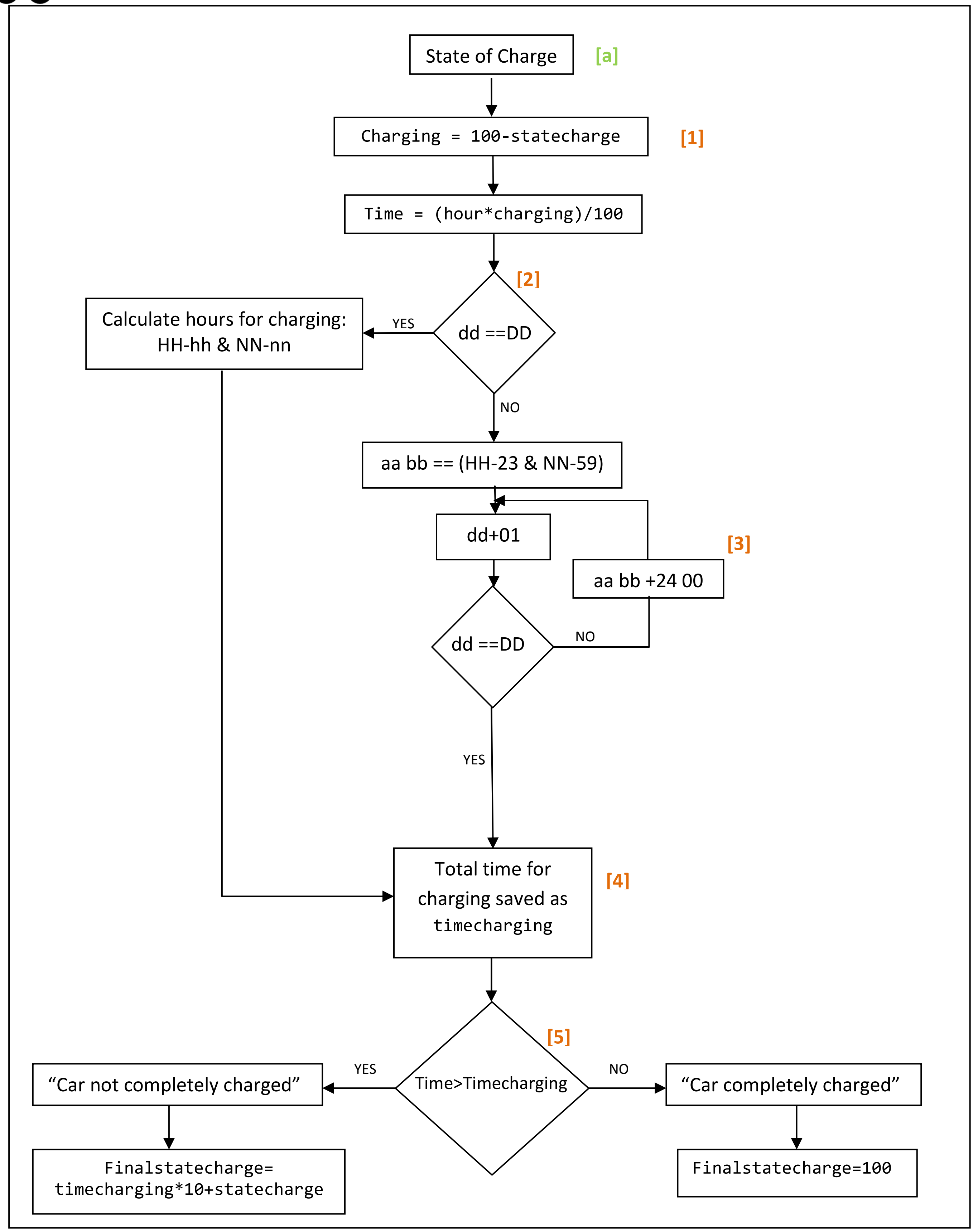


Figure 9. Function State of Charge

Function State of Charge

The objective of this function is to determine if the period selected by keyboard is long enough to cover the time needed for complete charging.

The input variables entered by keyboard are detailed in the next table:

Table 2 Input variables for function state of charge

Input Variables	
statecharge	level of charge determined by the user expressed as %
hour	number of hours for the complete charge of the car
mm	month for starting charging
hh	hour for starting charging
nn	minute for starting charging
MM	month for ending charging
HH	hour for ending charging
NN	minute for ending of charging

Additionally, there are some required variables that are defined in the following table:

Table 3. Required variables for function state of charge

Required Variables	
Charging	required charging to full the battery expressed as %
Time	Required time for completing the charging of the car
Timecharging	Total time the car is at home
Finalstatecharge	Final state of charge after charging period
aa bb	Structure that saves the total number of hours as

	aa (hours) and bb (minutes)

Data definition:

[a] **Data demand:**

The data used for this function has been defined in Function Time.

Description of the flow chart:

This function starts with the entering of the value statecharge. With this value the calculation of the variables Charging and Time can be realized [1]. The next step is the determination of the timecharging, the total time for charging the car. The process followed is similar to the one carried out for the determination of the Time Function [2]. For the case where the day is not the day of ending of the period, the software will recalculate the total number of hours for the analysis [3]. The total number of hours is saved as timecharging [4]. The total number of hours available for the charging is compared to the Time required for the complete charging of the car [5].

The output of this function is the determination of the final state of charge (Finalstatecharge), in case the car cannot be completed charged; or the confirmation of sufficient time for the complete charging. This information will be essential in next steps of the software design, taking into account that different processes will be required depending on the state of charging that can be achieved.

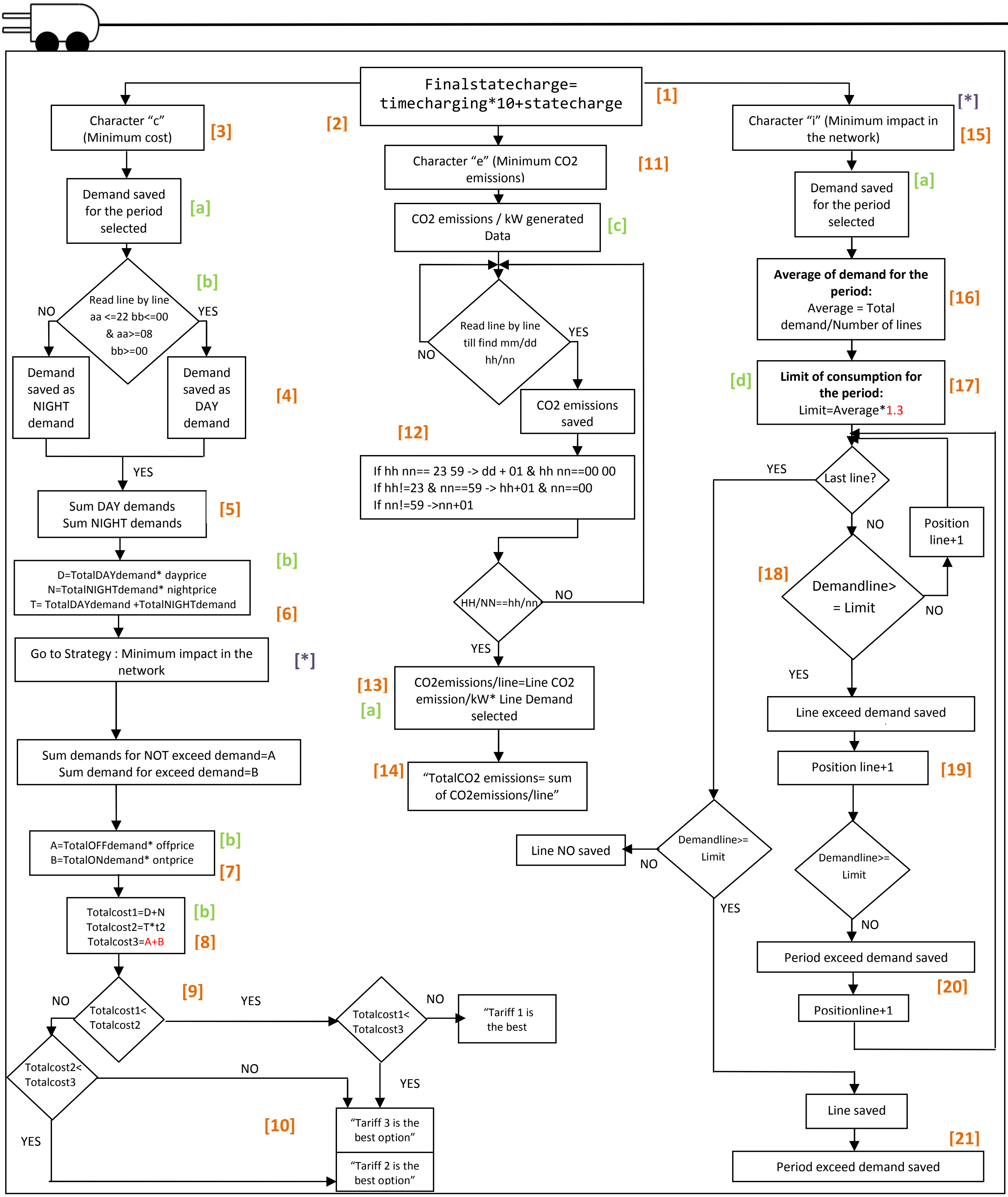


Figure 10. Function Strategies (not completed charging)

Function Strategies (not completed charging)

The strategies have been selected taking into account the most important parameters affecting the commercialization of electric cars related to the electrical network. According to this analysis, strategies defining electricity costs, environmental impact and impact in the grid due to electric cars have been selected.

Data definition:

Apart from the demand data **[a]** used in previous functions, there are data specifically required for the different strategies. The following section explained the considerations in order to obtain the data required for this software.

Data for Strategy of Minimum cost:

This strategy has the objective of determining the minimum cost for the integration of an electric cars during different ours of the day. With this purpose three different tariff where integrated in the software. The selection of the three tariffs was carried out according to the current tariff system, choosing the most common tariffs for the current utility companies.

The first tariff selected was the Economic 7 (npower, 2012). This tariff allows a reduction in the price of KWh for night hours. Concretely, the reduction is carried out during 7 hours (although there are company that can offer a wide number of hours) a day that can vary depending on the season. For example in the case of Scottish Power the period of reduce prize varies depending on the season being the period for this reduction from 22:00pm to 8:30am for winter periods and from 23:00pm to 9:30am for summer periods. This tariff could be very useful for these owners that only realized daily trips. In order to simplify a summary of both seasonal period has been selected. Therefore, the night period will cover from 22:00am to 8:00pm and the day period the rest of the day.

This tariff has been calculated by analyzing different Economic 7 tariffs of several UK operating utility companies. The average values for this tariff are 10.015 pence per kWh in the case of day consumption and 5.2 pence per kWh during the night periods. However, in order to consider the most restrictive case the tariff selected has been:

Table 4.. Tariff for Economic 7

Day Tariff (pence per kWh) from 8:00am to 22:00pm	Night Tariff (pence per kWh) from 22:00am to 8:00pm
14.39	0.0854

The second tariff called Standard Tariff has been calculated as an average of different standard tariff obtaining a value of 14.39 pence per kWh. This tariff is an average value of the majority of electric bills prices, obtained from a document provide by EDF (EDF, 2012). It does not take into account possible discounts during off peak hours or extra charge in case of exceeding determined consumption during peak hours.

The third tariff taken into account for this tariff does not link concrete hours to fixed prices. The objective of this tariff is to incentivize the consumption of electricity during off peaks. The hours which average consumption are priced at standard cost (14.39pence per kWh) however the periods of time when the consumption is produced during off peaks (when the demand is more than a 30 % lower than the average demand profile) is priced which a reduction of 50% of standard price, in the case of peak hours (when the consumption is over 30% of the average demand) is priced which an increment of 10% *(npower, 2012)*.

Table 5.Standard tariff

Day Tariff (pence per kWh) from 8:00am to 22:00pm	Night Tariff (pence per kWh) from 22:00am to 8:00pm
6.4755	15.829

Data for strategy of Minimum CO_2 emissions

The electricity generation follows some standards in terms of covering the total demand of the market. The base load is supplied by nuclear and coal plants due to the amount of hours necessary for activation of these technologies and also the lowest prices of these kinds of fuels. Due to that, there is always a base load that will generate CO_2 emissions; this base load is complemented by other kind of plants or technologies more flexible to switch it on or off.

This strategy allows the calculation of the periods of time when the car is going to generate the minimum quantity of CO_2 emissions.

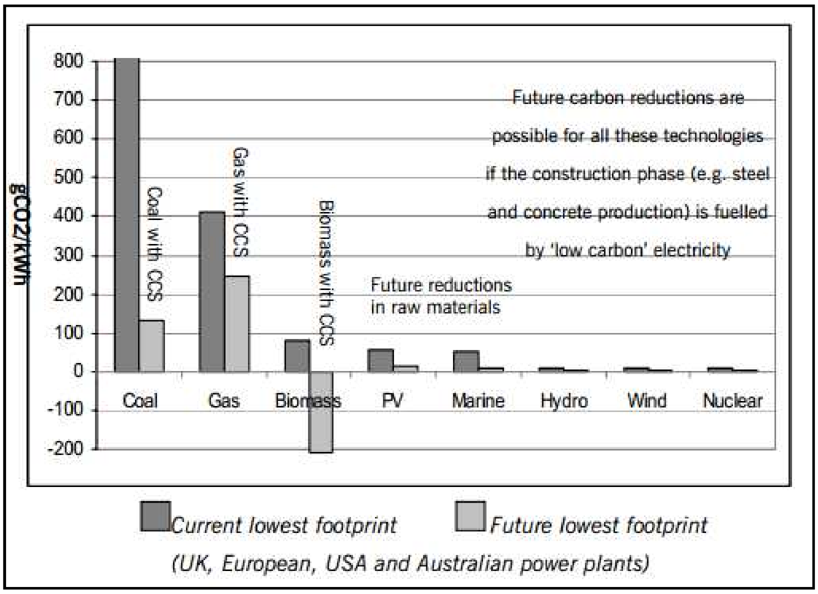


Figure 11. Grams of CO2 generated per kWh and generation technology **(Parliamentary Office of Science and Technology, 2009)**

Due to the difficulties for finding the data of g CO_2/kWh with a minute-resolution required for the the software, the creation of this data using a spreadsheet was necessary. The data used for this section of the software has been obtained from two different sources:

Data of g CO_2/kWh per generation technology was obtained from a report of the Parliamentary Office of Science and Technology, based in London (Parliamentary Office of Science and Technology, 2009).

Data for the proportion of energy generated by the different technologies was obtained for the year 2009. This data had an hour resolution. The value of the parameters was extended to every minute of the hour, due to that the data is not as accurate as it is required.

Knowing these proportions and using the demand data of last fucntions, the power generated by each technology per minute was obtained, this value was transformed into energy for the period selected and multiplied into the g eq. CO_2 generated by each technology.

Data for Strategy of minimum impact in the network

This is the most important strategy in terms of integration of electric cars. The large quantity of energy that these devices require must be integrated in the grid. The possibility of having a saturated grid is real if the car is plugged during periods when the demand of electricity is over 30% of the average demand (Kassakian & Schamalensee, 2011). Although this proportion could varies being smaller for period of high demand and bigger for periods of low demand and also the characteristics of the period vary the average value and consequently the consideration of on-peak demand periods, in order to simplify the software this considerations have not been taken into account.

Description of the flow chart:

This function was planned for the case of incomplete charging of the Function State of Charge **[1]**. From this point, the strategies **[2]** will be designed taking into account the time required for charging due to the limitation on the independency of the car that this parameter supposes.

The following steps describe the processes followed for obtaining the different output depending on the strategy selected by keyboard.

Strategy Minimum cost

The input variables entered by keyboard are detailed in the following table:

Table 6. Input variables for the strategy minimum cost

Input Variables	
Strategy	This character must be entered as "c" in order to select this strategy

Additionally, there are some required variables that are defined in the following table:

Table 7. Required variables for the strategy minimum cost

Required Variables	
TotalDAYdemand	Demand for day periods according to Economic 7 Tariff
TotalNIGHTdemand	Demand for night periods according to Economic 7 Tariff
TotalOFFdemand	Demand for off peak periods according to On-Off PeakTariff
TotalONdemand	Demand for on peak t periods according to On-Off PeakTariff
dayprice	Price for day periods according to Economic 7 Tariff
nightprice	Price for night periods according to Economic 7 Tariff
offprice	Price for off peak periods according to On-Off PeakTariff
onprice	Price for on peak periods according to On-Off PeakTariff
D	TotalDAYdemand* dayprice
N	TotalNIGHTdemand* nightprice
T	TotalDAYdemand +TotalNIGHTdemand
A	TotalOFFdemand* offprice
B	TotalONdemand* ontprice
Totalcost1	D+N
Totalcost2	T*t2(standard tariff)
Totalcost3	A+B

Starting with the demand data for the period of analysis[a], the software reads line by line the data and selects the period between 22:00 and 08:00 taking into account the information and data about

"Economic 7" tariffs [b]. The demand data file is saved as two different files depending on the "Night" or "Day" demand [4]. The next step is the calculation of the total demand during "Night" and "Day" periods[5], with these values the calculation of the total costs for the tariff Economic 7 is determined by multiplying the total demands for each period into their respective prices[b] [6]. For the calculation of the costs applying the tariff 2: Off-On peak, an estimation of off peak and on peak periods, as done for the strategy Minimum Impact in the Network, is required [*].Code from the strategy number three is employed for this strategy in order to achieve the total demand during off and on peaks[7]. In the case of the standard tariff there is not necessary to divide the total demand into different groups due to the only common cost independently on the period or characteristics of the demand [8].

The last step of this strategy is the comparison of the three different costs calculated for the different tariffs [9].The output of this strategy is the best tariff for the case study [10].

Strategy Minimum CO_2 emissions

The input variables entered by keyboard are detailed in the following table:

Table 8. Input variables for the strategy minimum CO_2 emissions

Input Variables	
Strategy	This character must be entered as "e" in order to select this strategy

Additionally, there are some required variables that are defined in the following table:

Table 9. Required variables for the strategy minimum CO_2 emissions

Required Variables	
CO_2emissions/line	It is the result of the multiplication of CO_2 emission/kW* KW for the minute selected
Total CO_2 emissions	Summarizes the total emissions for the period selected

In this case, the strategy consists in calculating the CO_2 emissions for the period selected [11]. Due to the fact that the time for the plug in is not sufficient to charge completely the battery, the reduction of CO_2 emissions is a second priority. For the calculation of the total CO_2 emissions for this period of time, the data CO_2 emission per KW is used[c]. The software reads line by line the data and selects the period for the analysis [12] following a similar scheme to the past flow charts. The result of this research is another data file that saves the CO_2emissions/ generated KW for the period selected, this data is multiplied into the demand for the same period [a] [13]. Therefore, the CO_2 emissions for the period selected is achieved and the output of this strategy, the total CO_2 emissions, is calculated by summing all the CO_2 emissions for the period [14].

Strategy Minimum impact in the network

The input variables entered by keyboard are detailed in the following table:

Table 10. Input variables for the strategy minimum impact in the network

Input Variables	
Strategy	This character must be entered as "i" in order to select this strategy

Additionally, there are some required variables that are defined in the following table:

Table 11. Required variables for the strategy minimum impact in the network

Required Variables	
Total demand	It is the sum of all the demands for the period selected
Number of lines	This variable saves the number of lines for the
Average	Total demand /Number of lines
Limit	This variable is the limit over which it is considered to have an on peak demand
Demand line	Demand for the line selected
Position line	Position of the line

This strategy is affected by the fact that the car cannot be completely charged for the period selected. Therefore the strategy will determinate how the charging during this period is going to influence the network, but no control of the period will be carried out in order to reduce the impact on the grid [15].

The demand data for the period of analysis will be used in this strategy[a] in order to calculate the average demand [16]. This value is calculated as the total demand for the period divided by the number of lines or minute (as each line saves the information for a minute). The data for the saturation of the grid [d] was used to determine the limit over which the demand is considered to saturate the network [17]. The next step is the determination of the periods of time that cover on peak demands [18]; this analysis is carried out taking into comparing the demand per line with the limit obtained from the data analysis. This comparison is done across all the lines of the demand period data [19]. A new data file is created in order to save the periods when the demand is going to saturate the grid [20].

The output of this strategy will be the period for on peak demand [21].

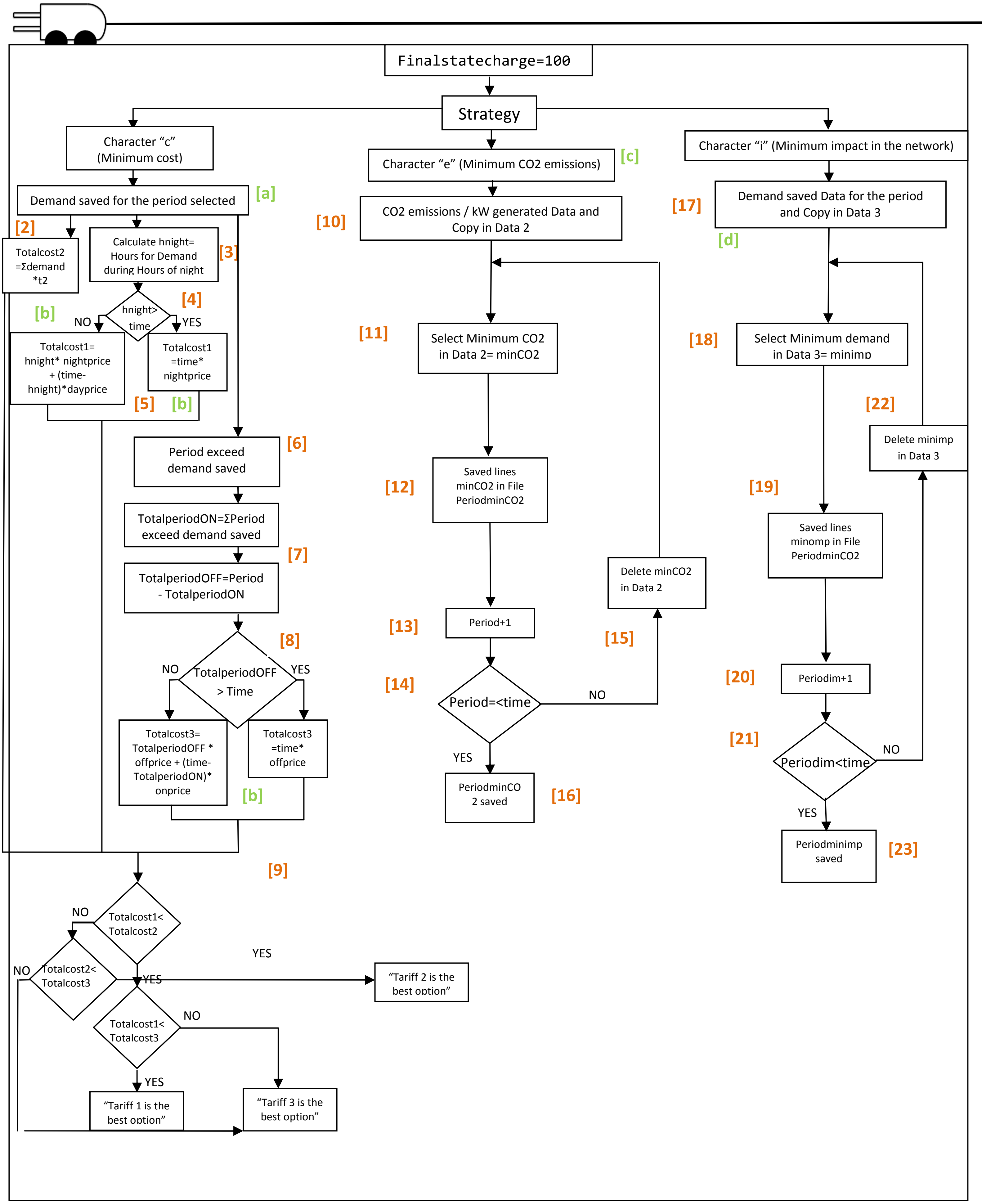


Figure 11. Function Strategies (completed charging)

Function Strategies (completed charging)

This function was created for analyzing different strategies for the car charging taking into account that the time required for the charge is sufficient for the completed charging (determined in function State of Charge) [1].

The strategies have similar objectives to the strategies of the Function Strategies (uncompleted charging).

Data definition:

The data used for this function is the same that has been used for the last function

[a]Data for the demand

[b] Data for different tariffs

[c] Data for CO_2 emission per KW per hour

[d] Data for saturation of the network

Description of the flow chart:

The function starts with the selection of one of the three strategies as it was done for the previous function.

Strategy Minimum cost

The input variables entered by keyboard are detailed in the following table:

Table 12. Input variables for function strategy minimum cost (completed charging)

Input Variables	
Strategy	This character must be entered as "c" in order to select this strategy

Additionally, there are some required variables that are defined in the following table:

Table 13. Required variables for function strategy minimum cost (completed charging)

Required Variables	
TotalperiodOFF	Demand for off peak periods according to On-Off PeakTariff
TotalperiodON	Demand for on peak t periods according to On-Off PeakTariff
TotalperiodON	TotalNIGHTdemand* nightprice
TotalperiodOFF	TotalDAYdemand +TotalNIGHTdemand

The strategy starts with the calculation of cost for the three different tariffs. The different with the same strategy for the case of uncompleted charge of the car in the period selected is that the fact of having extra time for charging the car might allow a reduction in electrical bills if the periods are selected for achieving minimum costs. With this purpose the three different costs depending on the tariff used for calculations are included in the function.

For the standard tariff, the period of time for charging the car does not affect the total cost of the consumed electricity; therefore the costs for this tariff are directly calculated multiplying the demand into the price per KWh **[2]**.

The Economic 7 tariff is influenced by the period of time the car will be charging **[3]**, hence the tactic for obtaining the minimum cost according to this tariff is by plugging the car during night period when the tariff is reduced. The function is programmed for selecting the night periods and comparing the total night period to the time required for charging the car **[4].** If the period for charging the car is covered by the night periods, the costs are calculated for night periods; otherwise the night periods will be used for the charging of the car but additionally day periods will be needed for achieving the 100% state of charge of the batteries, meaning and extra cost due to higher day tariff **[5].**

In order to achieve the minimum cost using the On-Off peak tariff, a similar process to the Economic 7 is developed. Using the same code that was used for the programming of the different parts of the Function Strategies (uncompleted charging) **[6]**, data files for off and on peak periods were created and the value of TotalperiodON and TotalperiodOFF are calculated as the sum of all the demand for these two period respectively [7]. The calculation of the cost is calculated considering the minimum total cost for the period and this kind of tariff, consequently the maximum hours of off peak will be selected. If the total number of off-peak hours is smaller than the time required for charging the car, the car can be plugged during off peaks hours reducing the costs according to this tariff and the total cost will be the result of the multiplication of the total off peak demand for charging the car into the tariff for this period; for the cases where the time required for the total charge, there is necessary to plug the car the extra time until completing the charging, and the total cost will be the sum of the costs during off peak and on peak **[8].**

Finally, the comparison of costs is carried out using a chain of evaluations relating the three different costs **[9].**

Strategy Minimum CO_2 emissions

The input variables entered by keyboard are detailed in the following table:

Table 14. Input variables for function strategies minimum CO_2 emissions (completed charging)

Input Variables	
Strategy	This character must be entered as "e" in order to select this strategy

Additionally, there are some required variables that are defined in the following table:

Table 15. Required variables for function strategies minimum CO_2 emissions (completed charging)

Required Variables	
minCO2	This variable saves the minimum CO_2 emissions of Data 2
Period	Counts the lines selected as minCO

This strategy commences with the utilization of the data for CO_2 emission [c] for the period of analysis. In order to understand how this software employs the data, next graphs show the utilization of the information. The modifications on Data 2 are explained as well as the selection of the minimum CO_2 emissions in each step of the software.

A copy of data of CO_2 emissions is saved as Data 2 [10]. In Data 2, the line of minimum CO_2 emissions is selected [11].

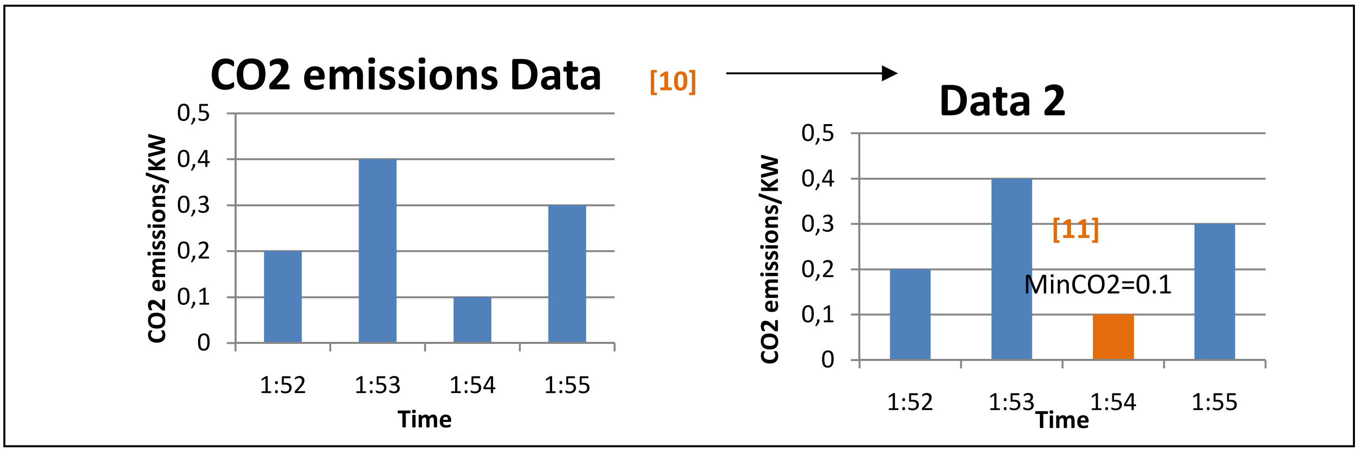


Figure 12. Example of selection of minimums CO_2

The minCO2 is then saved in the File PeriodminCO2 [12]. Additionally, the variable Period initialized as 0 sums 1 (one minute) [13] and it is compared to the total time for the completed charging of the car [14].

The following graphs represent the case when the variable period is still smaller than the variable time and the initial line minCO2 is deleted to allow the selection of the next minCO2 in Data 2[15].

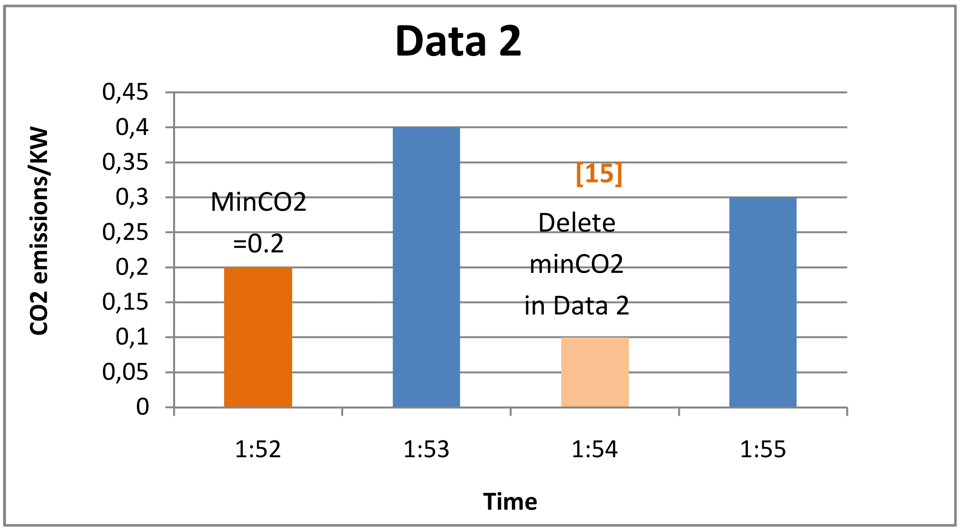


Figure 13. Example of selection of next minimum from Data 2

If the time for 100% state of the battery is equal to the variable period, the analysis is done and the period for charging the car considering minimum CO_2 emissions has been calculated [16].

Strategy Minimum impact in the network

The input variables entered by keyboard are detailed in the following table:

Table 16. Required variables for function strategy minimum impact in the network (completed charging)

Input Variables	
Strategy	This character must be entered as “i” in order to select this strategy

Additionally, there are some required variables that are defined in the following table:

Table 17. Required variables for function strategy minimum impact in the network (completed charging)

Required Variables	
minimp	This variable saves the minimum demand of Data 2
Periodimp	Counts the lines selected as minimp

The flow chart follows the same structure that was used for the strategy Minimum CO_2 emissions, but employing different data. In this section the software starts with the selection of the demand data file for the period of analysis [a]. The first step consists in copying the Data into another File called Data 3[17]. In Data 3, the line of minimum demand is selected [18] and saved as minimp and the line that contains this value is storage in the File Periodminimp [19].

Additionally, the variable called periodim initialized as 0 sums 1 (one minute) [20] and it is compared to the total time for the completed charging of the car [21].

For the case when the periodimp is smaller than the time required for the completed charging of the car, the minimum demand is deleted in Data 3; therefore the software resend the function into the research of the minimum demand for the period but in Data 3, hence the next minimum demand line is selected and saved[22]. This process will be repeated until the time for charging is equal to the variable periodimp and the period for the minimum impact on the network is saved into the file Periodminimp, the output for this strategy [23].

Design of control software for reduction of impact in the network

Due to the importance of the impact on the grid, specific software for the control of this parameter was created.

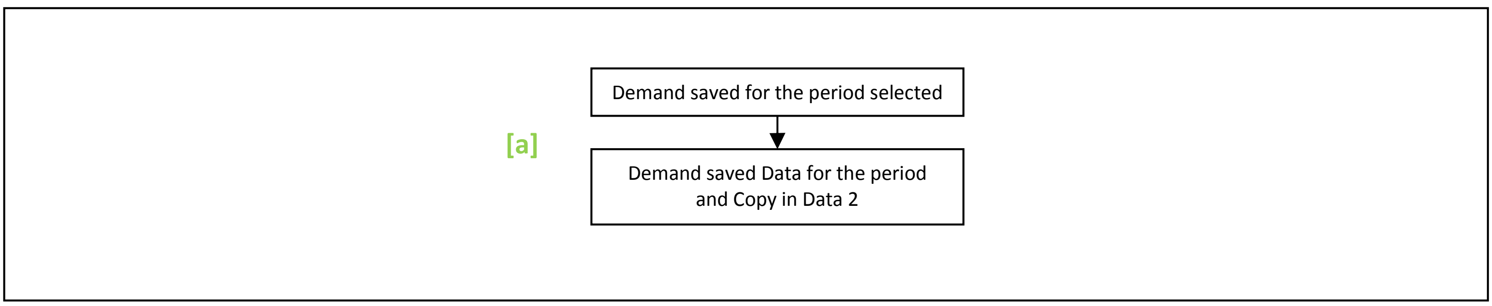
The software has two different versions. The first one has been designed for the calculation of the impact, as well as the minimum cost and CO_2 emissions strategies are included in this software as subsequent strategies. This software allows the analysis of a specific period of time and determined characteristics of the battery according to the models designed for the next section. The values of these parameters (period of analysis and state of the battery) are entered by keyboard.

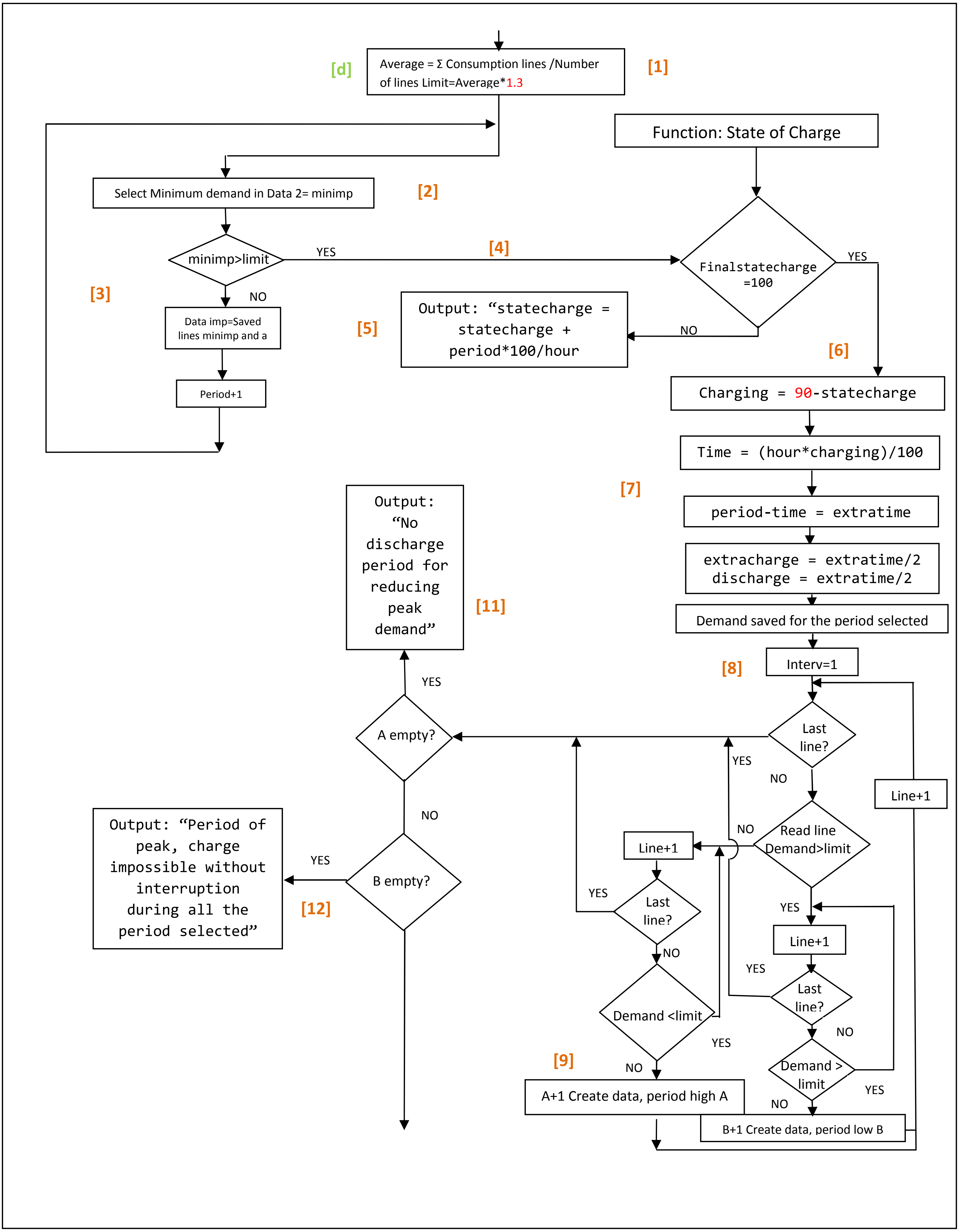
The second software is similar to the first one; however in this case the period of analysis is a whole year and random state of charge according to normal distribution for the number of miles travelled per day is developed. This software will draw a profile for the complete year taking into account the most probable state of charge and hours for the situation of the car inside the dwelling, and, at the same time, minimizing the impact on the network.

These softwares include the possibility of interrupting the charging of the car due to exceeded demand and consequently saturation of the grid. Additionally, there is another part of the control software that has been designed for discharging the car.

The final version of the control software will allow the determination of the periods of time the car can be plugged without generating saturation of the grid and at the same time balancing the load with the option of discharging the electric car when it is feasible.

The first chart flow showed in this section is the Control software that is used for the modelling analysis, the second flow chart is a summary of the Control software for a year, this software gives a general idea of how the electric car is affecting the network and to which level the charging/discharging control processes are able to reduce the impact of electric cars in the network.





[d]
Average = Σ Consumption lines /Number of lines Limit=Average*1.3
[1]
Function: State of Charge
Select Minimum demand in Data 2= minimp
[2]
minimp>limit
YES
[4]
Finalstatecharge =100
YES
[3]
NO
Data imp=Saved lines minimp and a
[5]
Output: "statecharge = statecharge + period*100/hour
NO
[6]
Period+1
Charging = 90-statecharge
Time = (hour*charging)/100
[7]
Output: "No discharge period for reducing peak demand"
period-time = extratime
extracharge = extratime/2
discharge = extratime/2
[11]
Demand saved for the period selected
Interv=1
[8]
YES
A empty?
Last line?
YES
NO
Line+1
NO
Output: "Period of peak, charge impossible without interruption during all the period selected"
NO
Read line Demand>limit
Line+1
YES
B empty?
YES
[12]
Last line?
YES
Line+1
NO
YES
Last line?
Demand <limit
NO
YES
[9]
NO
Demand > limit
YES
A+1 Create data, period high A
NO
B+1 Create data, period low B

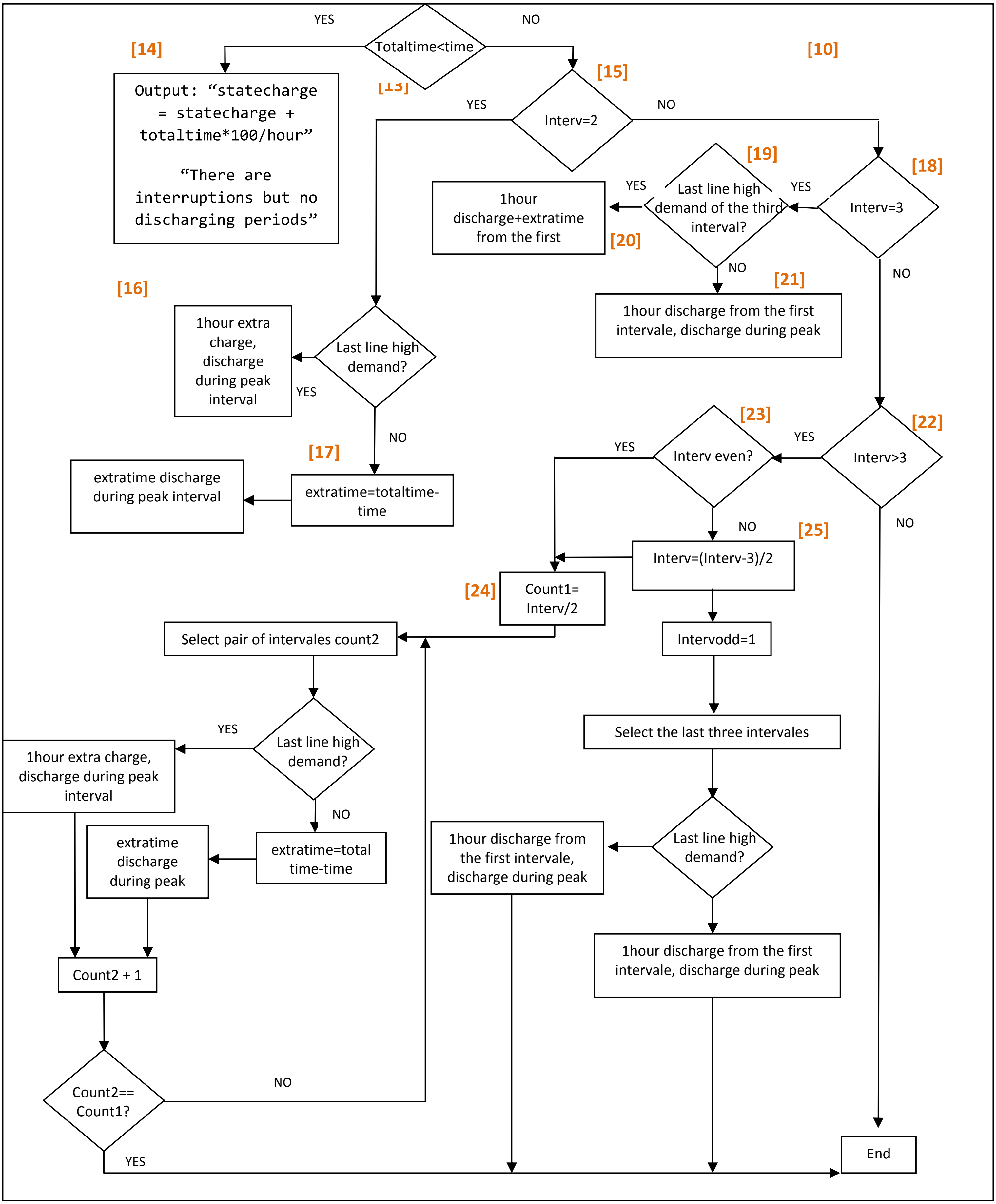


Figure 14. Control Software

Control Software

The objective of this function is to determine the optimum period of time in order to minimize the detrimental effects of electric cars in the grid. Interruptions and periods of discharge are included in order to achieve this objective.

The input and required variables are detailed in the next tables:

Table 18. Input variables for the function control software

Input Variables	
statecharge	level of charge determined by the user expressed as %
hour	number of hours for the complete charge of the car
mm	month for starting charging
hh	hour for starting charging
nn	minute for starting charging
MM	month for ending charging
HH	hour for ending charging
NN	minute for ending of charging

Table 19. Required variables for the function control software

Required Variables	
minimp	This variable saves the minimum demand of Data 2
Periodimp	Counts the lines selected as minimp
Interv	Saves the number of intervals for demands over and under the limit value
A	Saves the number of intervals which values are over the limit
B	Saves the number of intervals which values are under the limit

Data definition:

[a] Data for the demand

[d] Data for saturation of the network

Description of the flow chart:

The software starts with the utilization of the demand data [a] which is copied in a file called Data 2, for posterior modifications **[1]**. The average and the limit values are calculated in the same way they were determined for the past function[c] **[2]**. The amount of minutes that does not pass the limit is saved in the variable period **[3]**. This value is used for the determination of the maximum charging for the car when period of time entered by keyboard is not sufficient for the completed charging of the battery **[4]**. The total charge for this case is calculated taking into account the number of hours required for the total charging and the real period for charging with the interruptions considered by saturation of the grid **[5]**.

*No discharge periods are considered for these cases, due to the lack of time for charging the battery which avoid any possibility of discharging periods.

For cases where the time required for the charging the car is enough for achieving a 100% state of charge [6] the possibilities for combination of periods of charge boosts and with this increment the complexity of the software increases too. The first step of this section is the calculation of the variables of time required for charging and discharging, but in this case this variable will be considered to be the difference of a charge level of 90% and the initial state of charge [7]. This difference respect to the previous functions (where the maximum level of charge was 100%) is due to the fact that discharge periods might be introduced; hence the reduction in the level of charge of the battery gives more freedom in terms of periods for discharging.

The following table represents the demand for a period of ten hour during the 1st of January. As shown in this graph the peak period is happening around 9:20 am.

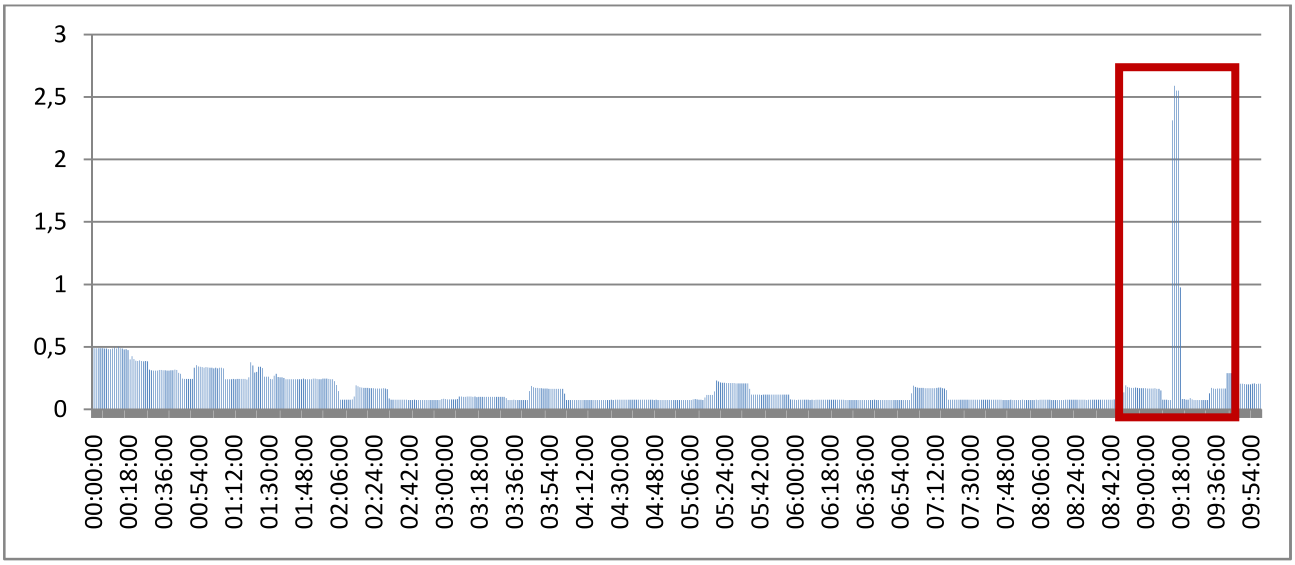


Figure 15. Example period of peak

If this period of time is analyzed separately and the limit is situated in order to avoid the saturation of the grid. According to the new graph, there is a period of time between 9:14 and 9:16 when the charging of the car should be stopped.

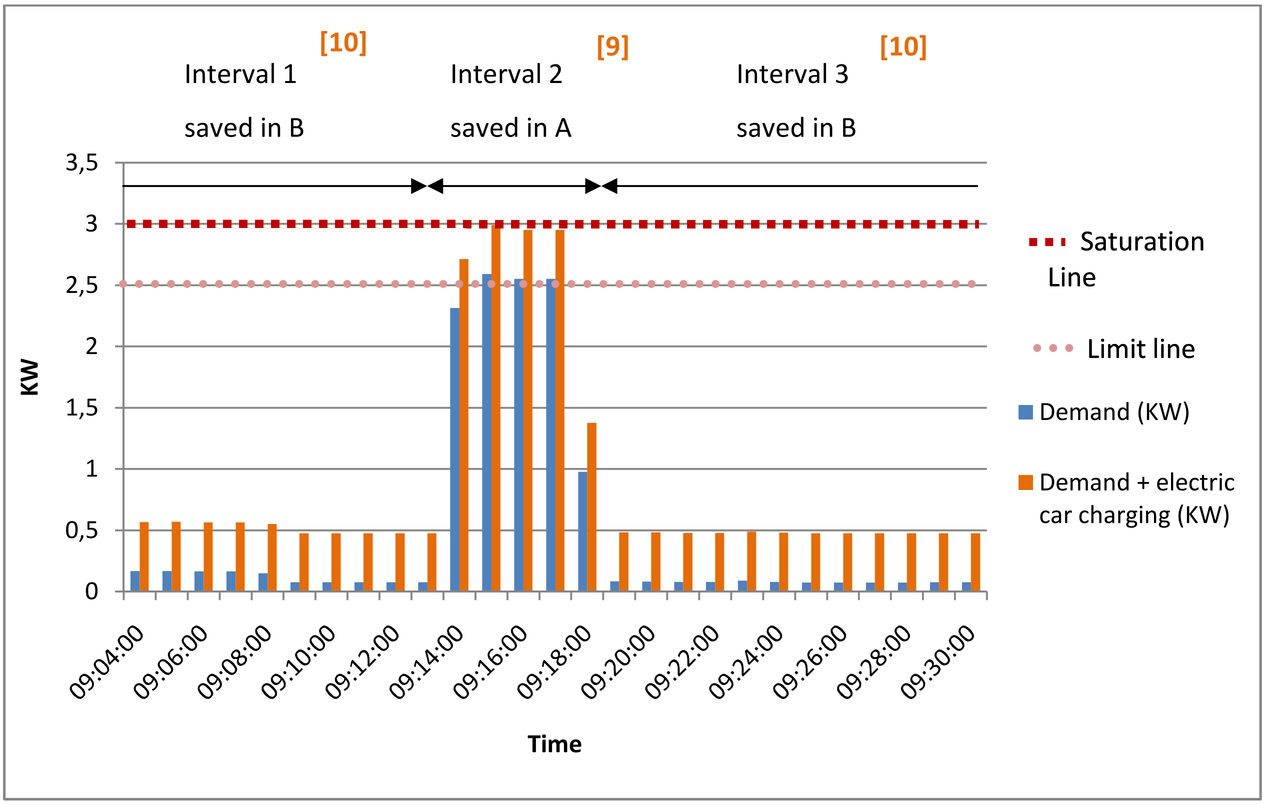


Figure 16. Example of analysis of intervals

In order to reject these on peak periods, the software will create to different data files A and B for the high and low demand period respectively, counting the intervals for each case as shown in the last graph [8]. The software uses the variable "interv" for saving the number of changes from period of off peak to on peak and vice versa and when these change is produced the data is saved in the respective Data File [9][10]. If there is not data in the file A, that means that there is not on-peak periods and consequently there is not necessary to relocate the charging period [11] in order to avoid them. For the case where there is data in the file A but there are not periods of off peak, the charge of the car for all the period results impossible [12]. For cases where A and B have information, it is possible to implement periods of charge and discharge if the sum of all the periods of low demand of B [13] is bigger than the time required for charging the car [14].

When that is not possible the message “There are interruptions but no discharging periods” appears at the screen and the final state of charge (inferior to 100%) will be calculated. If the total time for low periods is bigger than the time required for charging the car, the next step will be the analysis of the intervals for the period selected [15].

If the period has two different intervals, the analysis is addressed to two different options, an initial low interval followed by a high interval or vice versa [16]. For the first case, the charging process is completed until 100% at the first interval and then it is followed for a discharging period of one hour (10% of the battery) in order to finish the period with a 90% state of charge. For the other case [17], the difference between the 100% charge and the minimum level of charge, a 10% of the battery level (that is equal to one hour of charge for the specific characteristics of the selected battery) is used for reducing the demand during the first peak period, the discharging will be done commencing with the minute of highest demand. Additionally the extra time for charging during off peak periods can be used if the on peak period is not covered with the discharging of the battery for an hour.

If the intervals for the period are three, a similar process is carried out [18]. The determination of the nature of the last interval (high or low interval) is determinant for the determination of the kind of discharge [19]. If the last interval is a period of high demand, the discharging period covers an hour plus the extra time [20]. However, for the cases where the last interval is a low one, there is only a high demand period and the discharging must be calculated considering the 90% of charge necessary at the end of the period [21].

If the period is composed for more than three intervals [22], a division into smaller intervals is carried out. If the total number of intervals is even [23], the period will be divided into pairs of intervals that will be analysed following the process of a period of two intervals, adding a counting variable that will allow to go through all the pair of intervals[24].For the case of an odd number of intervals, the total intervals will be divided into pairs of intervals, except the last one that will be a period of three intervals **[25]**.Therefore, the intervals will be analysed as periods of two intervals except for the last one which will be a period with three intervals.

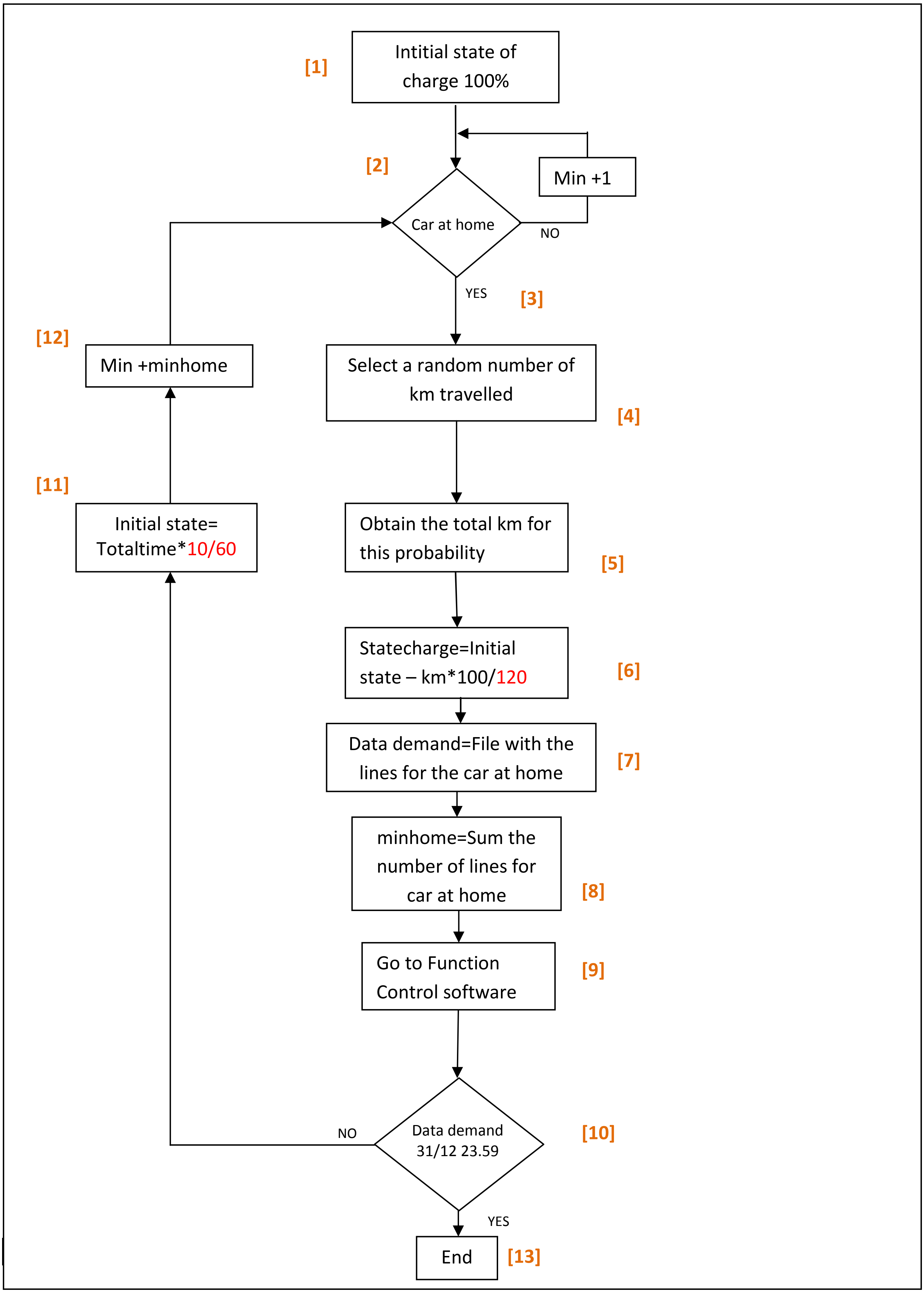


Figure 17. Control Software for long periods of time

Control Software for long periods of time

The objective of this software is the control of the impact on the grid of electric cars during a whole year. With this objective the control software has undergone several modifications related to the parameter for starting the operation of the programme.

The fist parameter modified was the period of time for the analysis. The software does not select the period for complete year. The starting date is predetermined as the 1st of January and the last day will be the 31st of December.

The required variables are defined in the following table:

Table 20. Required variables for the function control software for long periods of time

Required Variables	
minhome	Sum the number of lines for car at home
Initial state	State of charge when the car comes back home
Min	Saves the minutes for analysis

*No input variables are required for this process.

Description of the flow chart:

The first step of this software is the assignation of the value of 100% to the variable "initial state of charge" [1]. This value will be modified during the continuous charging and discharging for the electric car for the period of analysis.

The software will read the series of ones and zeros assigned to each minute of the year in order to determine whether the car is at home(it can be charged) or not. Different profiles are created for week and weekend days. The next graphs show the probabilities of the car been at home for week and weekend days:

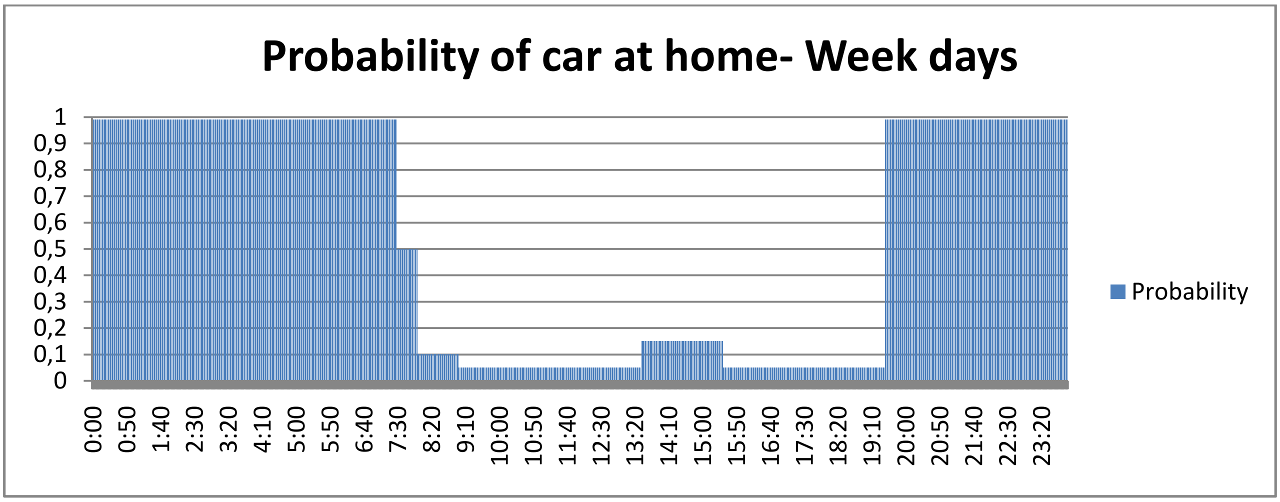


Figure 18. Probability of car at home during week days

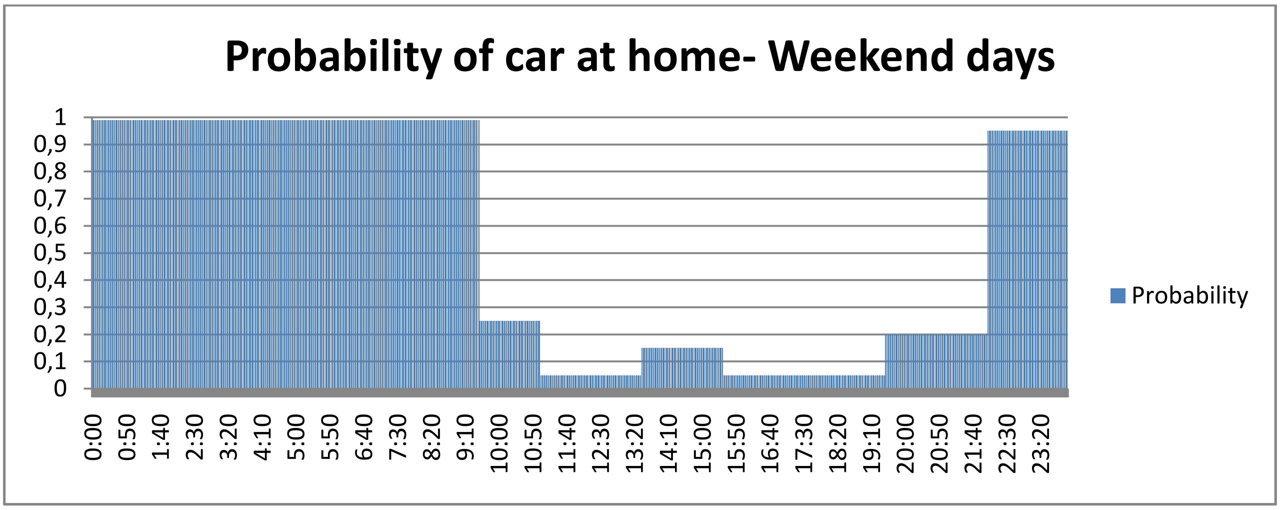


Figure 19. Probability of car at home during weekend days

These probabilities have been considered taking into account the habitual use of cars and information about traffic jams in the UK, accommodating in the profile a low probability for the car at home from 8.00am to 9.00am due to the peak on traffic during this period of time (INRIX, 2009) and also during the evening from 16.00pm to 17.00pm (Daily Mail Reporter, 2012).

Three different profiles have been created for following these probability profiles. The result of this calculation is three new different options in the software, the first when the car is at home the 50% of the time, the second, the 62% and the third the 70%. For one of the three options, the software reads the state of the car (0=car not at home, 1= car at home) until the car is at home [2], when that happens, the software starts the study of the state of charge of the car. The state of charge depends directly on number of km travelled; hence data that determines this parameter is required. (National Statistics, 2009). The next graph represents the state of charge for a random value for the kilometres travelled per day during 6 days and random period for charging.

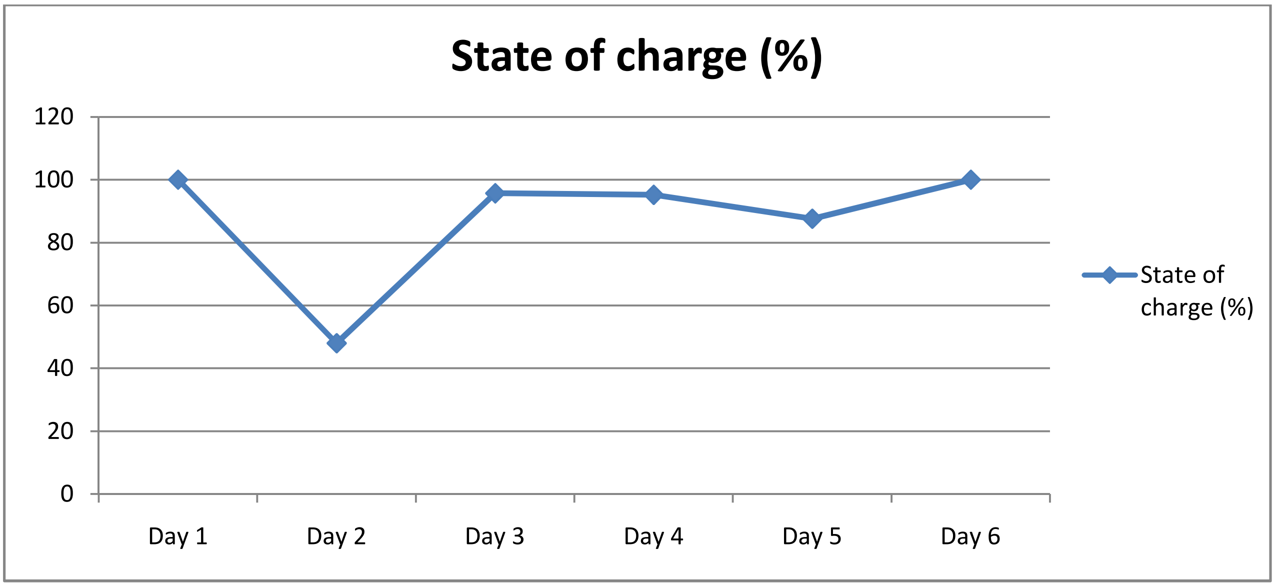


Figure 20. Example of states of charge for six days of analysis

According to the information provided by the data, the average miles travelled per person per year in Scotland are 5846 miles equivalent to 9408.225 km. Considering 365 days per year, the average number of kilometres travelled per day per person are 25.78 km. A random number will be selected between 20 and 40 km (in order to not to restrict the study to a unique initial state of charge when the car is at home).

Considering a 24KWh battery with an independency of 100Km, a relation between the number of km travelled and the decrement in the state of charge of the car can be calculated. The new state of charge will be saved in the variable "statecharge" **[6]**.

The software saves the lines for "the car at home" **[7]** and the number of minutes (number of lines of the period of the car at home) is saved in the variable "minhome" **[8]**. The software control is then used for the calculation of the real period for charging and the interruptions and discharging states, considering as the data for the demand of the dwelling the Data demand previously saved, and the state of charge of the car the stochastic value obtained from the normal distribution **[9]**.

At the end of the process it is necessary to know if this is the last line of the data demand; whether it is not the last line **[10]**, the software addresses the process to the question: Is the car at home? But before starting again the analysis, it is necessary to save as initial state for the next period the multiplication of the variable "totaltime" (obtained from the control software) into the state of charge per hour [11]and the variable “min” as the sum of the initial minute and the variable “minhome” [12]. The software finishes the process of analysis when the last minute of the year is raised [13].

Integration of renewable energies in the consumptions

For the analysis of the integration of renewable energies in the grid and the combination of electric car charging and renewable energies an additional code was added to the main software. The introduction of the renewable system to the software will allow a reduction in the total demand which will affect positively the integration of electric cars in the network.

The selected renewable system is Photovoltaic panels due to their easy integration for individual dwellings.

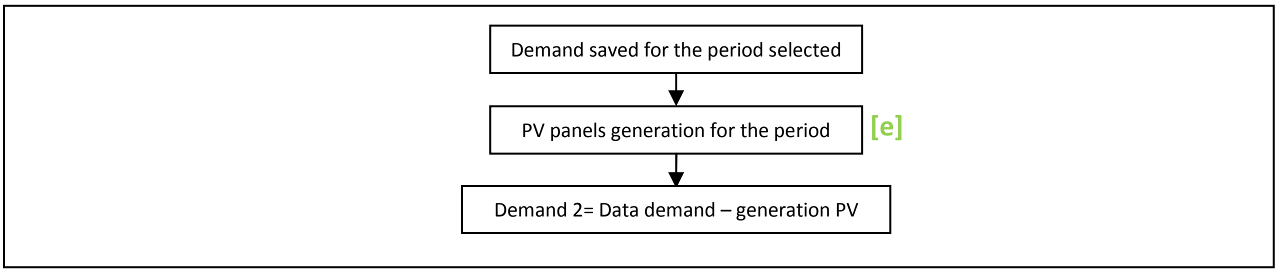


Figure 21. Renewable Integration

Data description:

[e] **PV Data**: The data selected for this software is not the most accurate. A similar problem to the CO_2 Data was detected. The impossibility of finding data with a minute resolution for a year imposed the necessity of creating it.

Data per day for the complete year of 2009 was obtained from the (A Note On Data and Graphs, 2012) for an average dwelling in the UK.

A part from this data, the average generation for a day with minute resolution was obtained from the calculation in the Spread Sheet “Integrated Domestic Electricity Demand and PV Micro-generation Model - Single Dwelling Simulation Example for 24 Hours” provided by the University of Loughborough (Richardson & Thomson, 2011).

The demand per minute is calculated as the total demand of each day multiplied into the proportion of power supplied by the panels per minute (taking into account the conversion of kWh into kW). The accurate is reduced due to the lack of time to do the calculations of the proportions of energy for the 365 days of a year. Hence, an average proportion was estimated.

Description of the flow chart:

This flow chart is only a part of the control program, and the main change incorporated by this addition is the creation of a new demand file that contents the difference of the demand and the energy generated by the PV panels. This new demand file will be the data used for the calculation of the periods of charge and discharge of the software.

Summary of different parts and final distribution of the software

Due to the complexity of the final softwares, it is not possible to develop a complete flow chart for each part of the final program. In order to condense the essential ideas and distribution of this program, the final distribution of the developed softwares is represented in the next flow charts:

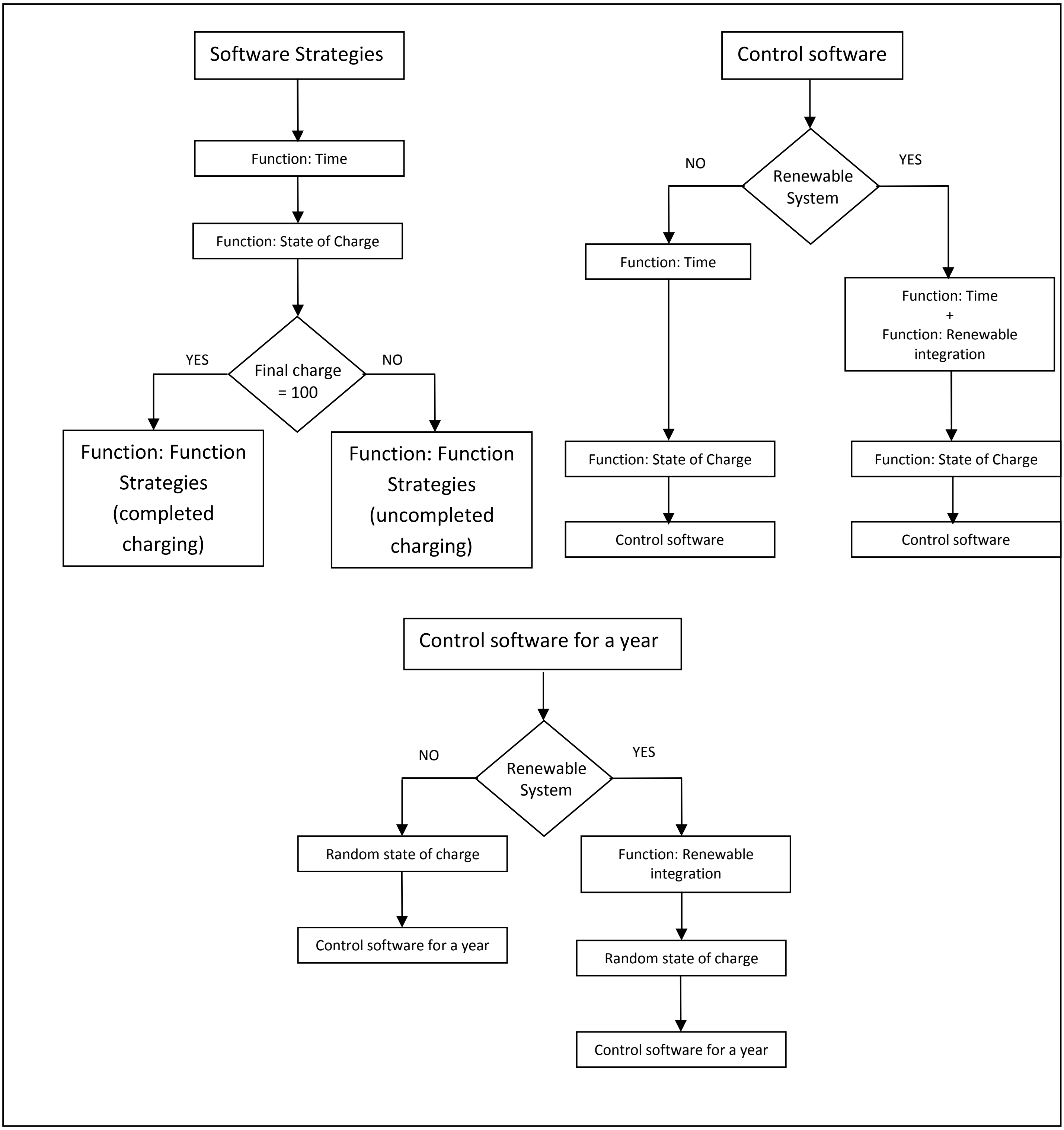


Figure 22. Total structure of the software

Three different softwares are included in the final design. They are necessary in order to measure different parameters and facts affecting the integration of electric cars in the network. They will be utilized for the analysis of several models in the next chapter.

The first part of the final software is the Software Strategies which compares the different strategies for several determined periods of time. The key objective of this software is the comparison of the different strategies in order to understand how the main factors attached to the integration of electric cars are related and affect each other.

The second part is the Control software which is the main software used for the model analysis section. Its main function is to determine the periods for the charge of the car taking into account the possible saturation of the grid and the possibility of discharging the battery during periods of peak demand with the purpose of reducing the impact of the electric cars in the electric network. This software also allows the analysis of integrating renewable energy into the grid showing how the demand profile accommodate both technologies and the grade of match between them.

The third software, the Control software for a year is the extension of the control software and it is used for the simulation of charging a car during a complete year. This software does not allow the selection of a period of time but it allows the selection of renewable energies into the system.

Chapter 4

Modelling Analysis

The modelling analysis will cover five different models which differences will depend on the number of hours for charging, the excess of the maximum load accepted by the electrical grid, the option of discharge of the battery of the car for balancing demand/supply profile and the possibility of charging due to the integration of renewable energy disposals.

The analysis will be carried out for two different seasonal periods, winter and summer, in order to analyse how the seasonal periods affect the integration of electric cars in the grid. The date selected for the winter period is the Monday 12th of January, and the date chosen for the summer period is the Wednesday 15th of July. These dates have been selected considering the high demand for these specific days of the week, which allow analyzing the most restrictive periods of time in terms of energy supply.

For the realization of a deep analysis day and night hours are selected with the purpose of determining how periods of low and high demand (night and day periods respectively) affect the technology.

Additionally, depending on the analysed model, two different initial states of charge will be selected. The main difference between the two systems is the grade of charge achieved after the period for the charging; completing the charging process or not depending on the number of hours for charging and the initial state of charge.

A brief explanation of the different models is shown below:

Model 1: Two Hours Charge Model

The car will be plugged during two hours for a period of winter and summer and night and day hours. The dates selected will be the ones specified in the introduction of this chapter: Monday 12th of January and Wednesday 15th of July. The hours of night will be from 00:00 am to 02:00 am and the day hours will be from 12:00 am to 14:00 pm, hence it might be observed how the strategies for the integration of the electric car are affected by the hours of the day.

For this model two different states of charge are selected. The reason for this division is that the strategy software is divided into two different functions, and the initial level of charge and the total time available for the charge of the battery are the factors that determine which function will be selected. In order to analyze both functions of the software the initial state of charge varies for each study between a 70% (in this case the software will address the strategies into the case “Car not completely charged”) and an 85% (the strategies will be addressed into the case “Car completely charged”).

Interruptions or discharge periods are not analysed due to the reduced time for the charge of the car. The objective of this model analysis is to determine how the different strategies are going to affect the charging of the car for short periods of charging. Therefore, the software Strategies will be used for this purpose. Comparisons of the results for winter and summer and day and night periods are carried out in the next chapter.

The next table summarizes the different simulations carried out for this model:

Table 21. Simulations for Model 1

		Winter period				Summer period			
		Day hours		Night Hours		Day hours		Night hours	
	State of charge	70%	85%	70%	85%	70%	85%	70%	85%
Software	Min cost strategy	*	*	*	*	*	*	*	*
	Min CO_2 emissions strategy	*	*	*	*	*	*	*	*
	Min impact strategy	*	*	*	*	*	*	*	*

Model 2: Eight Hours Charge Model

The car will be plugged during eight hours for a period of winter and summer and night and day hours. The dates selected will be the ones specified in the introduction of this chapter: Monday 12th of January and Wednesday 15th of July. The hours of night will be from 00:00 am to 08:00 am and the hours of day will cover from 12.00 am to 20.00 pm.

As explained for the Model 1, two different states of charge are selected. The first one in this case is 10% (for addressing the strategies into the case “Car not completely charged”) and 70% (in order to analyse the function “Car completely charged”).

The objective of this model is to compare how the strategies are affected by the different seasonal periods when the period of time is long enough for the charging of the battery. According to the objectives for these simulations, the software used for these periods of charge is the Strategy software. Due to the utilization of this software, the interruptions or discharge periods are not analysed for this model.

The next table summarizes the different simulations carried out for this model:

Table 22. Simulations for Model 2

		Winter period				Summer period			
		Day hours		Night Hours		Day hours		Night hours	
	State of charge	10%	70%	10%	70%	10%	70%	10%	70%
Software	Min cost strategy	*	*	*	*	*	*	*	*
	Min CO_2 emissions strategy	*	*	*	*	*	*	*	*
	Min impact strategy	*	*	*	*	*	*	*	*

Model 3: Two Hours Charge Model with Interruption

The car will be plugged during two hours for a period of winter and summer and night and day hours. The dates for the analysis continue being Monday 12th of January and Wednesday 15th of July. The hours of night, as well as for the Model 1, are from 00:00 am to 02:00 am and the day period will be from 12:00 am to 14:00 pm.

As explained for the Model 1, two different states of charge are required. In the case of models with two hours for charging the initial states of charge selected are 70% and 85%.

The objective of the simulation of this model is the analysis of the impact of the electric car in the network for short periods of time, considering the interruptions which might be necessary for reducing the saturation of the grid and the possibility of discharging the model for balancing the periods of off and on peak; hence the software used for this model will be the Control Software.

The next table summarizes the different simulations carried out for this model:

Table 23. Simulations for Model 3

		Winter period				Summer period			
		Day hours		Night Hours		Day hours		Night hours	
	State of charge	70%	85%	70%	85%	70%	85%	70%	85%
Software	Control software	*	*	*	*	*	*	*	*

Model 4: Eight Hours Charge with Interruption and Charge/Discharge Model

The car will be plugged during eight hours for a period of winter and summer and night and day hours for the dates: Monday 12th of January and Wednesday 15th of July. The hours of night, as for the previous model of eight hours, will be from 00:00 am to 08:00 am and the hours of day will cover from 12.00 am to 20.00 pm.

Two initial state of charge are again analysed, a 10% and 70%.

The objective of the simulation carried out for this model is to determine how the charging of electric cars affects the grid in terms of long periods of charge, the interruption periods and the discharging periods for reducing the impacts on the network are the main information obtained from this simulation. Therefore, the software used for this analysis is the Control Software.

The next table summarizes the different simulations carried out for this model:

Table 24.. Simulations for Model 4

		Winter period				Summer period			
		Day hours		Night Hours		Day hours		Night hours	
	State of charge	10%	70%	10%	70%	10%	70%	10%	70%
Software	Control software	*	*	*	*	*	*	*	*

Model 5: Eight Hours Charge with Interruption and Charge/Discharge with Renewable Energy Integrated Model

The car will be plugged during eight hours for a period of winter and summer and night and day hours; considering the possibility of interrupting the charging and also discharging the battery for reducing the impact of the electric car. The difference with the previous model is the integration of renewable disposal for the electric supply of the dwelling.

The objective of this model is to analyse the effect that renewable energies has into the integration of electric cars. Comparisons with the previous model will be carried out for determining the grade of relevancy that the integration of renewable energies has in combination with the use of electric car in order to reduce the impact of these vehicles in the electric grid; hence the software used for this model will be the Control software. The option Renewable Energy will be selected at the beginning of the simulation in order to include the energy supplied by photovoltaic panels into the electrical system.

The next table summarizes the different simulations carried out for this model:

Table 25. Simulations for Model 5

		Winter period				Summer period			
		Day hours		Night Hours		Day hours		Night hours	
	State of charge	10%	70%	10%	70%	10%	70%	10%	70%
Software	Control software + Integration of Renewable Source	*	*	*	*	*	*	*	*

Chapter 5

Results and Discussion

The following graphs summarize the results for the modelling analysis, explanation for the values obtained are then given. Additional information about this result and extended tables can be found in the Spread Sheet Folder.

Analysis of the strategy minimum costs

This first graph represents the total cost of the electricity consumed including the electric car for a period of two hours during day and night.

The lower electrical demand for summer period is clearly showed. The results do not proved the smaller demand during night periods due to checking the graph. It shows the high costs independently on the period of time selected for the standard tariff.

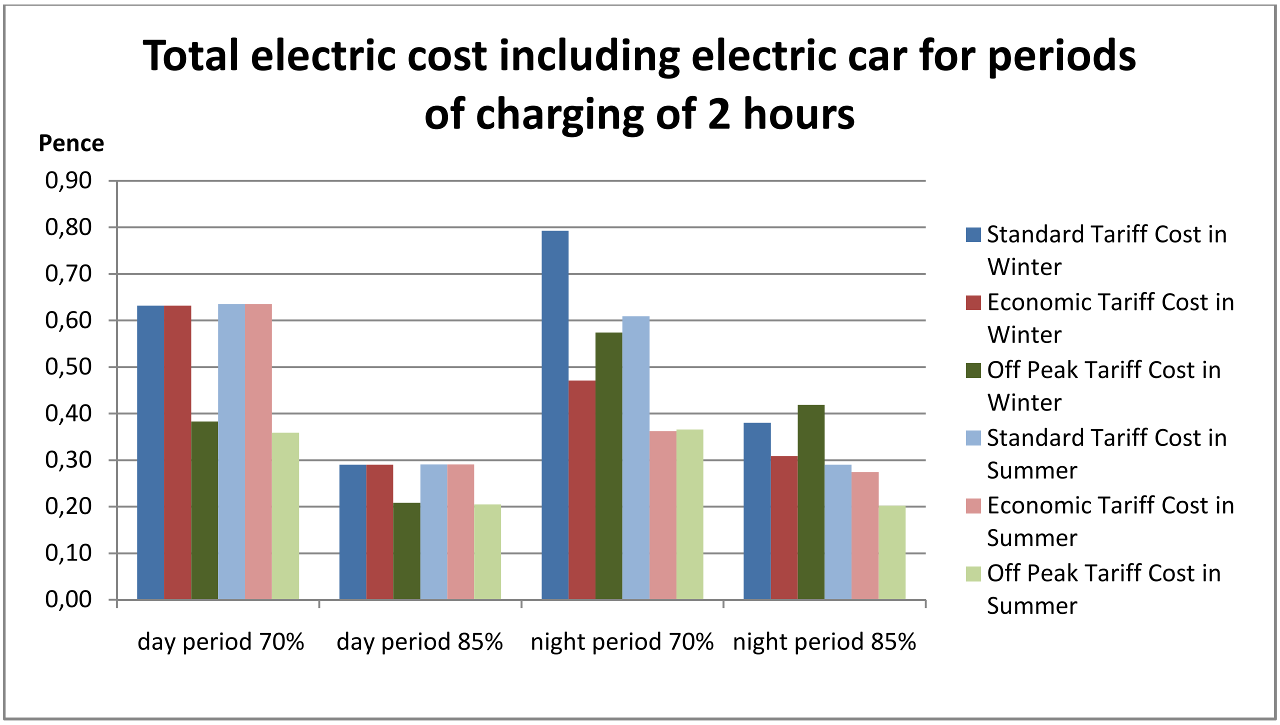


Figure 23. Total electric cost including electric car for periods of charging of 2 hours

The best tariff for all the possible options is the Off Peak tariff only. Only in the cases of the night periods the Economic tariff can have any possibility of comparison to the Off Peak tariff.

However, for cases where there is necessary to charge the car during the complete period selected (Table 24 night period 70% initial charge), the Off Peak Tariff has similar cost to the Economic 7.

This can be justify by the fact that the software allows to select the periods for lowest costs for each tariff only in cases where the total time for the simulation is more than the time required for charging the car to the 100%. In the case of 70% of charge, the software selects all the demands for the two hours of study, including the periods of high demand; therefore the cost for the off peak tariff can be increased rapidly.

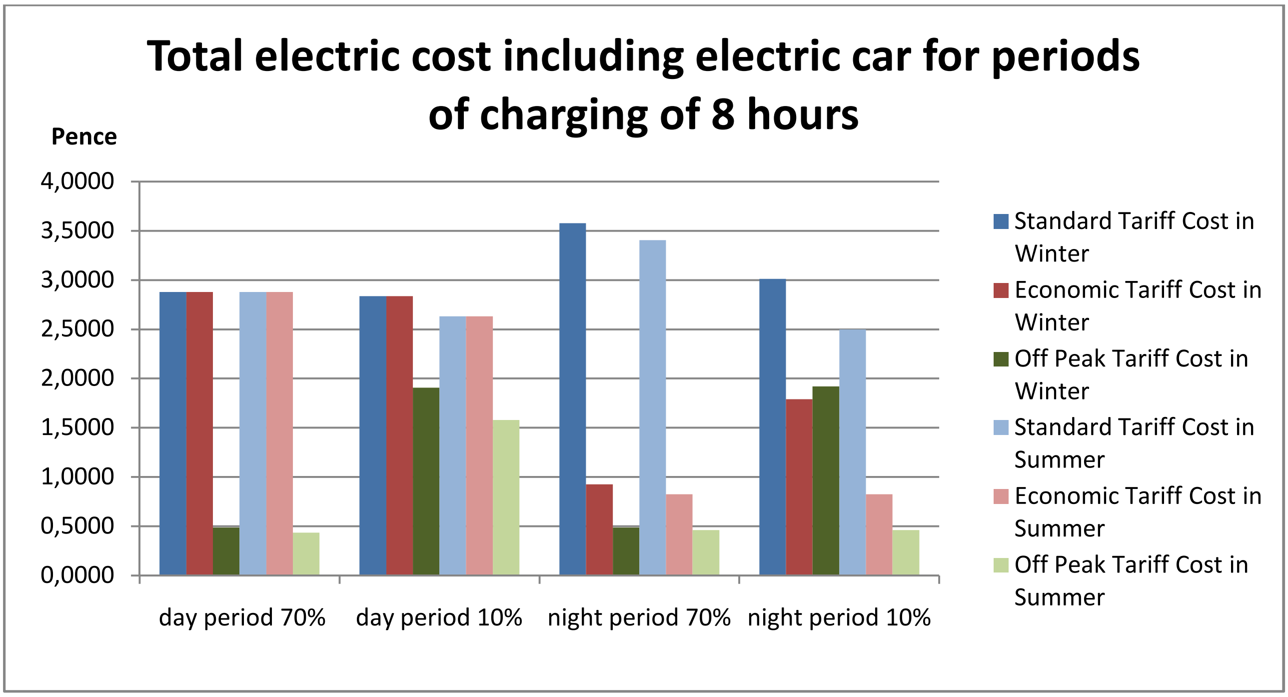


Figure 24. Total electric cost including electric car for periods of charging of 8 hours

The behaviour of the simulations are very similar for periods of eight hours, although it is significant the increment on the difference of cost respect to the standard tariff for the cases where the lowest demand can be selected (cases with initial state of charge of 70%).

The proportion of the total cost that is covered by the charging of the electric car is quite large; it varies in the cases of short periods of time from a 31% at the Standard Tariff to a 96% for the Off Peak Tariff. These results are logic in terms of the small quantity of demand generated during the off peak periods and the low price of this kind of demand. In the case of periods of eight hours, the quantity varies from a 62% for the Economic Tariff during nights and a 94% for Economic tariffs during day hours.

Analysis of strategy of minimum CO_2 emissions

In the cases of the analysis carried out for two hours during winter and summer periods, the results are showed in the following table:

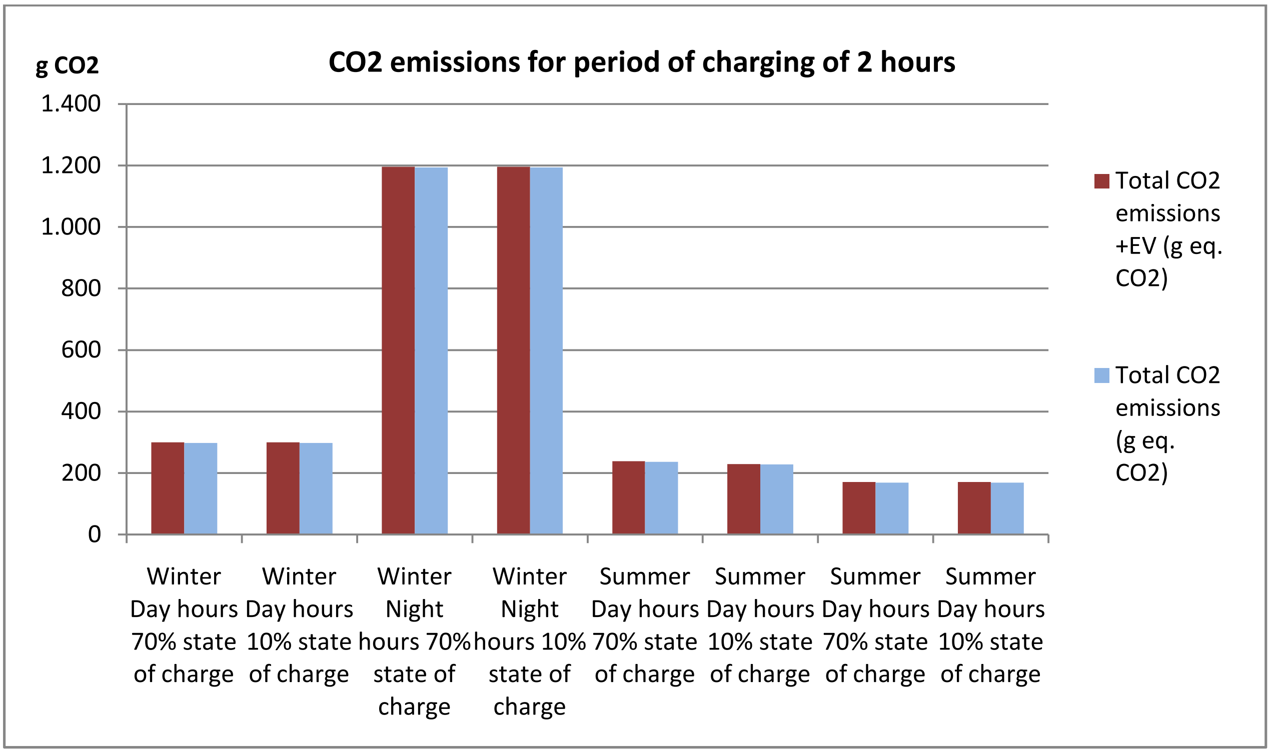


Figure 25. CO_2 emissions for period of charging of 2 hours

It is shown that the total g eq. of CO_2 generated by the utilization of electric cars increase only in a small portion the total CO_2 produced according to the results obtained.

The difference between the emissions produced during day and night periods is again due to the high demand that takes place during the night period, although it must be added that the demand required during night peak for this concrete day of winter presents a peak which increases its generation of CO_2 a 70%. In the rest of the cases the emissions are reduced.

The analysis of CO_2 emissions for long periods of eight hours are introduced in the following graph:

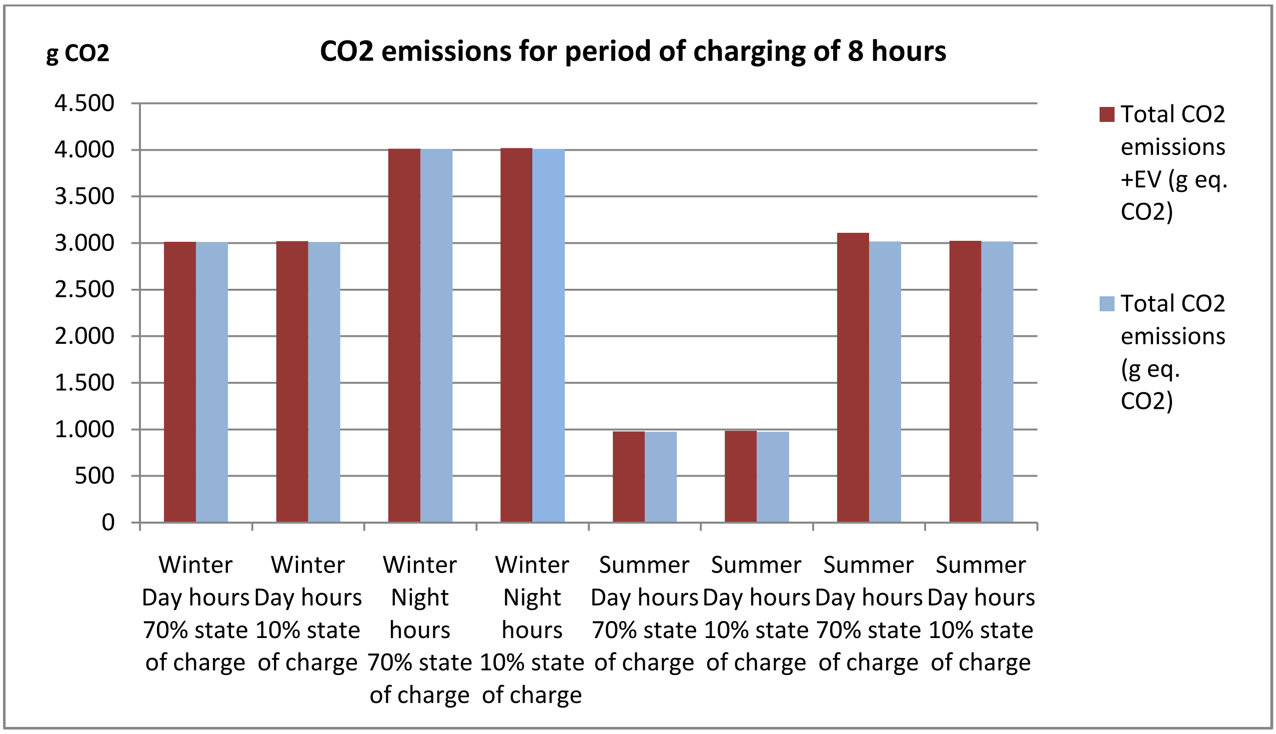


Figure 26. CO_2 emissions for period of charging of 8 hours

It is observed that during night periods in both cases, for winter and summer periods, the CO_2 emissions generated are higher than their respective emissions for the day. This is due to the high demand between 7am and 8am as well as the increase on the use of “dirtier” technologies for energy generation during those hours of the day.

The portion of CO_2 emissions produced by the electric car charging during these periods is again really small, even inappreciable in some cases. The average proportion of CO_2 emissions generated by the electric is only a 1.2% of the total CO_2 emissions caused by the generation of electricity demanded for the period that the car is plugged to the network (considering the selection of the period of charge of the car the one that most reduces the emissions of CO_2).

Analysis of strategy of minimum impact

The strategy of minimum impact in the network seems to work properly; the following table shows the demand during a period of time of two hours. The results show that in the case of initial charge of a 70% the car needs to be plugged for two hours in order to achieve the maximum charge that is available (a 20% for this kind of battery), hence its final state of charge at the end of the period will be a 90% and no extra time is obtained for avoiding the periods of time where the demand is higher.

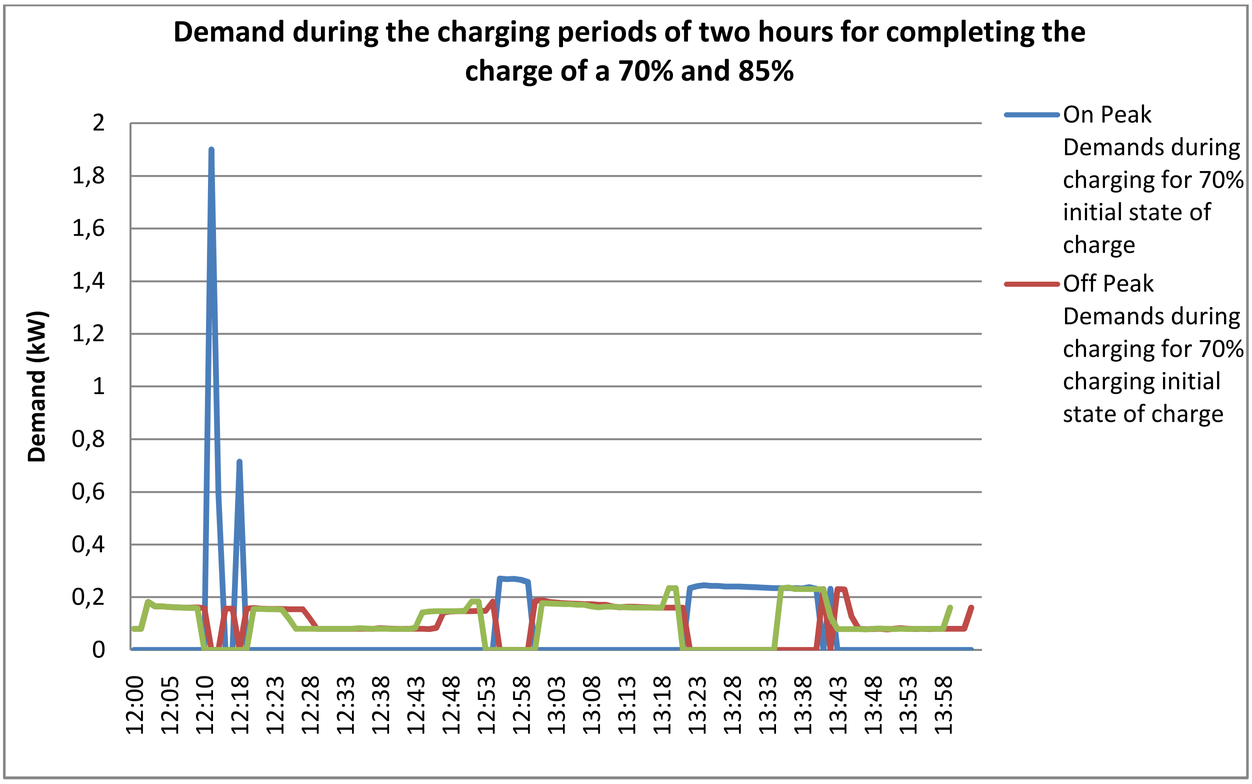


Figure 27. Demand during the charging periods of two hours for completing the charge of a 70% and 85%

However, for the case when extra time is available, the charge has been carried out by selecting the periods where the demand was lower (green line). In this way the total demand during the period of charge is reduced a 37%.

As shown in the following graph the charge control select the period of lower demand for charging the car.

The strategy for discharging the car during peak hours do not seems to work, however the real problem of this strategy is the restrictions selected for the charging. These restrictions must be changed in order to increment the possibilities of charging.

The next graph shows the demand for the charging periods for two different initial states of charge. In the case of the case of 70% for initial charge, the period of charging will be the total period being connected to the grid during peak periods (green line) in order to achieve a 90% of battery charge at the end of the period.

For the case of initial state of charge of 85%, there is extra time for the selecting the periods of lower demand and drop the highest demands. According to that, the red line of this graph represents the demand for the second initial state of charge.

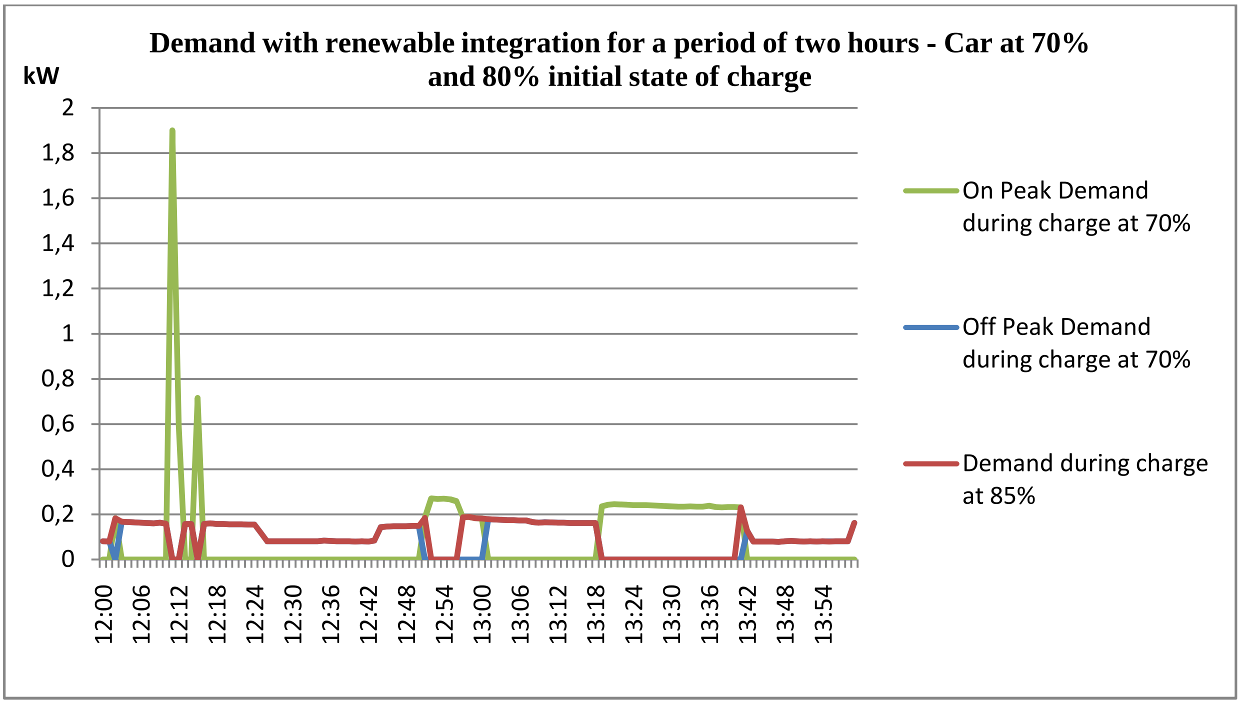


Figure 28. Comparison of demand for period of charging with the initial state of charge at the 70% and at 85%

During the period that the car is charging the minutes of peak demand are minimum. The total number of minutes for the charge of the car is 90 and the software avoids the higest demands when it is choosing the period of charge.

Analysis of control software with Renewable energies

The study was not carried out for night periods due to the generation of null total electricity by PV panels during this period of time. Comparing the result for two hours of day periods to the results of the impact in the network it is evident that the energy provided reduced the number of minutes charging during peaks when there is extra time for the charge of the car.

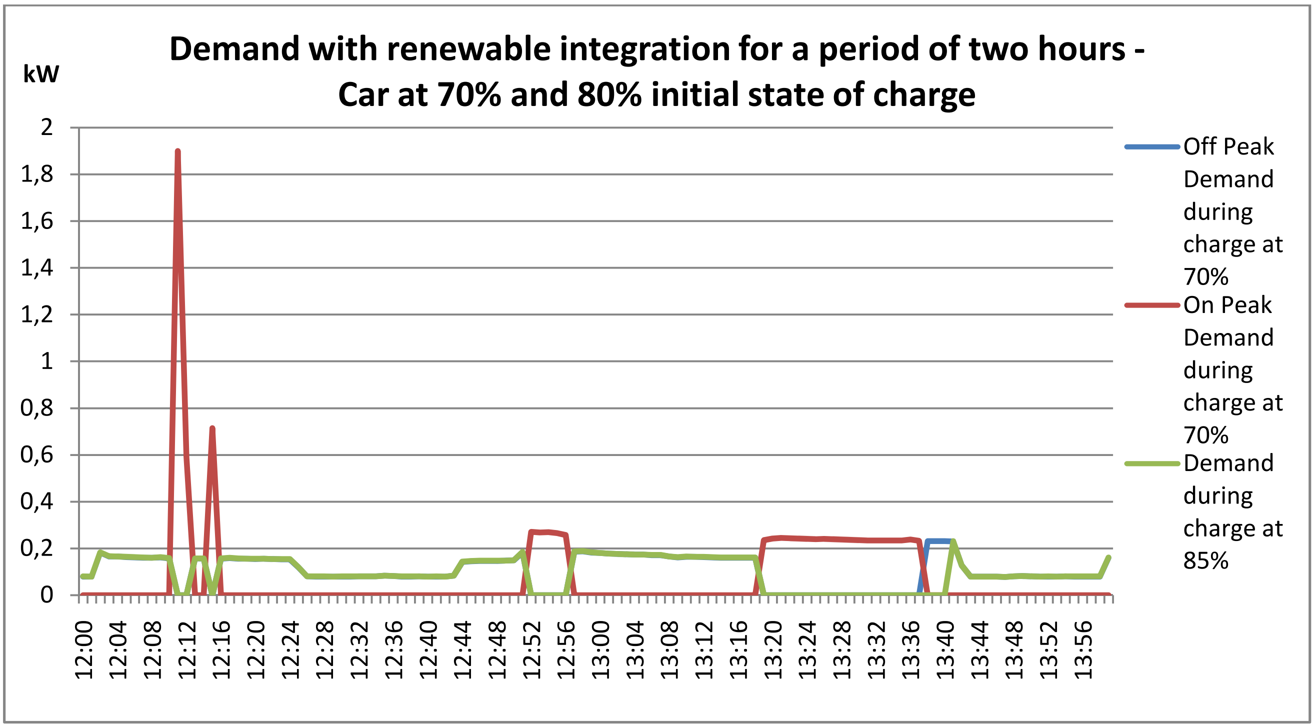


Figure 29. Comparison of demand with renewable integration for period of charging with the initial state of charge at the 70% and at 85%

If a comparison of the results for both cases (with renewable energies and without it), it is observed that for the case of renewable reducing the total demand the number of minutes of charging is 7, while for the same case but analysing the demand without the supply of renewable energy the minutes in on peak are 12. That demonstrates de reduction of the impact on the network for PV panels integrated with electric cars during days hours.

Chapter 6

Conclusions

Control software for the reduction of the impact in the electrical grid has been presented. It maps the electrical demand and the perturbations produced by the integration of electric cars. The software uses data from the UK for analyzing the different parameters affecting the charging of the electric car.

The main parameters affecting the charging of electric car and interactions, related to the connection of this technology to the electric grid, have been identified and three different strategies have been presented as result of this analysis. A part of the main software has been programmed in order to check the affects of variations in the parameters composing the strategies. The chosen strategies are the minimum cost of the electricity bills, an important parameter for the customer and also for the utility companies, the minimum CO_2 emissions, strategy selected for analysing how the periods low CO_2 emissions might match the periods of low electrical demand and the minimum impact in the grid, that avoids the saturation of the electrical transmission and distribution system. Results using this software were achieved for two different models.

As a result of the model analysis for the strategy of minimum cost carried out, the integration of electric cars technology in dwellings produced an average increase of an 81% in the total electric cost during the period that is charging. The tariff called Off Peak matches the best results in terms of reduction of cost.

From these results, it is observed that exits a direct relation between the lowest cost and the reduced impact in the network. This fact is mainly motivated by the electric tariffs proposed by the different utility companies. Although, there is infinity of tariffs, the electricity companies are tending to unify the tariffs into a common electricity cost in order to allocate the electric cars in the future and the integration of intermittent renewable sources in the electric market. The evolution of the tariff from 2009 to the present is focused on the balance of the supply/demand data and the results obtained for the modelling analysis corroborate the beneficial aspect that the new tariffs could have for the grid and the electric car.

The results for the modelling analysis following the strategy for obtaining the minimum CO_2 emissions show an average increase of the 1.2% in the grams of CO_2 equivalent due to the integration of electric cars in the network.

The analysis of the emissions of CO_2 developed in the second strategy of the software shows the apparent independency of this parameter respect to the impact in the network. The generation profile for the year 2009 remains conservative. It has been observed that a high quantity of energy generated for that year was produced in coal plants. Due to that fact, the CO_2 emissions remain high.

In order to carry out a deep analysis of the impact that electric cars have in the electric grid, an extension of the impact strategy has been presented. The Control Software not only detects the peak periods (and the consequently interruptions of the charging process) but also determine whether periods for discharging the battery can be allocated during the total time that the car is plugged.

The model carried out under this Control Software shows that for the assumptions of discharge specified for the model are not the ones which suits the requirement in the best way. The main issue is that the restriction for the first interval of each pair of intervals of high-low or low-high demand that must be able to cover the 90% of the necessary charging of the car. It means that i.e. for a period of 3 hours and a initial state of charge of 90% where there are four intervals (two of low demand and two of high demand) the first and third periods should be able to cover the 90% of the 10% of charging, that means a 9% (54 minutes for the type of battery selected) which is really difficult to achieve.

The only kind of period that could be analyze for obtaining discharge periods is a short periods of time (i.e. 30 minutes) and (i.e. 98% of initial charge) selecting at the same time an appropriate period of time. The results demonstrate the inefficacy of this method for discharging processes and suggest the reduction of the value of 90% to 50 or 40% in order to allow the possibility of finishing the total period that the car stayed at home with a 40% of charge instead of 90% as aforementioned.

The development of this software is still not finished and several mistakes must be corrected. However, the software provided many other possible applications and the authors have provided an open-source freely downloadable example of the program in the hope that it could be used as a guidance tool.

Further work

-More strategies: A possible extra strategy could be the increment in the total life of the battery, taking into account temperature and charge and discharge rates as main parameters for the calculations. This analysis result essential in order to carry out a deeper study of the benefits and inconveniences of short and long periods for charging, with the objective of optimizing the control software. The reductions of efficiency of the battery due to continuous charge and discharge of the car are a key point for the determination of the best period for charging. Interruptions in the charging period are directly affected by this parameter. The next step for continuing improving this control software might include the analysis of the periods of charging not only for reducing the impact on the network but also for extending the life of the battery.

-More tariffs: An extended study of the tariffs could suppose a decrease in the bills for costumers and a possible increment of clients for supplier companies. However, the huge number of tariffs depending on the supplier company and the lack of time avoid an exhaustive research.

-More renewable technologies: This study only covers the integration of PV panels and the data for the power generated by this technology is not trustful due to the variability of the energy generated depending on the days and hours selected. A deeper study related to the power produced by minute of this technology would improve the result for the simulation. Precise data per minute might allow an easier treatment of the data and the simulations for long periods of time.

Other kinds of renewable sources for the generation of electricity might be added to this analysis, as for example, wind power that might provide a completely different profile due to the generation of energy during night hours.

-More accurate data: The data selected for the demand is accurate; however the dates from the 7th of October to the 10th of November are not included in it. Additionally, the integration of data for different kinds of dwellings and buildings might be interesting. The information about saturated networks and the limit in demand for considering the grid saturated could be also extended to different cases depending on the period of the day and average demand for it. The data for CO_2 emissions is not accurate due to the difficulties to find data per minute, the data per hour was copied into the 60 min. Data per minute might improve the accuracy of this strategy considerably. In the case, of the data for the PV panels or, as it has been commented in the first point of this section, requires a deeper study. Furthermore, data from posterior years could help to better understand how the evolution of the profile of supply/demand in the future.

-Modification in the conditions for the process of charging and discharging: The restrictions applied to the discharge of the car, as for example the final state of charge required (90%) might be reduced for incrementing the possibilities of discharging during periods of peak. Moreover, the periods of maximum discharge period for determined of the cases of the Control Software might be increased in order to reduce the impact of the integration for electric cars.

-Stochastic analysis: The software does not provide an stochastic analysis for the hours of the car at home and the number of kilometres travelled per day, due to the difficulties that of integration of this information on the software. An interesting extra section could be the introduction of these data as normal distributions.

-Assumptions for the charge and discharge of the electric car: Some restrictions were required for the development of the discharging process. Different and less strict restrictions could be considered in order to amplify the periods of discharge for the car

-Integration of heating demand: The study of solar thermal panels, GSHP or possible district heating might introduce a reduction in terms of electricity consumption for heating and generate a different demand profile which might accommodate easily the domestic plug-in of electric cars.

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Appendix A. Use of the Software

Using XAMPP as a server for the data selected.

Save and unzip xampp in disc C:

In order to activate the software:

1. Execute: xampp-control
2. For Windows:

   Go to Apache(Web Server) / Actions and press Start (PIDS and PORTS values should appear on the software

   Go to MySQL(Data Base Server) / Actions and press Start (PIDS and PORTS values should appear on the software

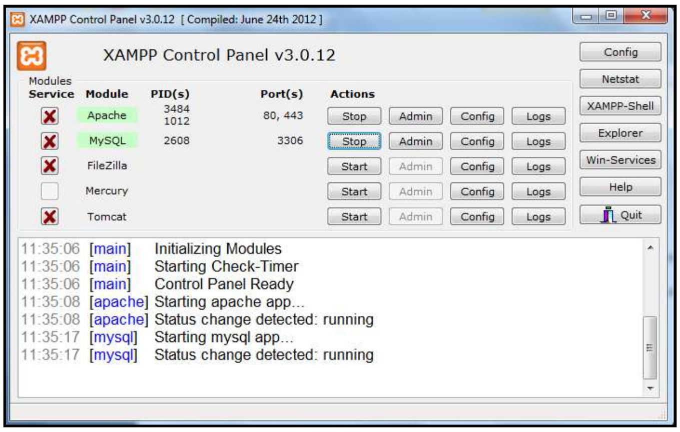

Figure 30. Apache(Web Server) and MySQL(Data Base Server)

3. Copy the link: http://localhost/simcharge/index.php

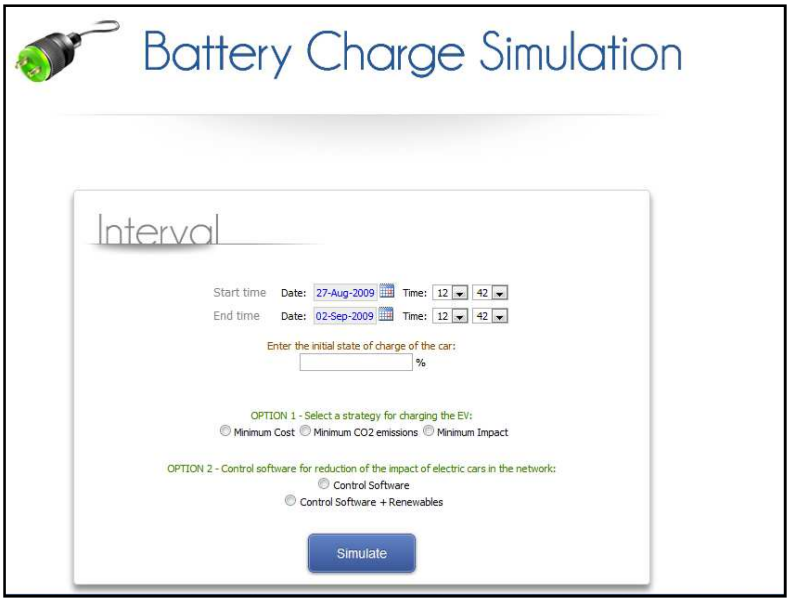

Figure 31. Image of the Index of the Software developed

4. Enter starting and ending dates and the hours for the simulation
5. Enter the initial state of charge
6. Select the strategy for the simulation

For checking the code and modifying fixed variables enter

Xampp>htdocs>simcharge>index

Xampp>htdocs>simcharge>mincost

Xampp>htdocs>simcharge>minCO2

Xampp>htdocs>simcharge> minim

Xampp>htdocs>simcharge> Control

Xampp>htdocs>simcharge> ControlR

Xampp>htdocs>simcharge> ControlL

For modifying the data introduced in the software:

1. Enter in the link: http://localhost/phpmyadmin/ (with the Apache and MySQL running)
2. Enter the next information:

   User: root

   Password: 1214
3. Enter in simcharge (left column)
4. Different options are introduced in this section: import, export, examine, etc.

*Applications with modifications of ports might affect the correct operation process of the system. It is recommended to close them.

*Data must be introduced as .sql file.

Appendix B. Examples of Data

Example Data Demand dwelling

Table 26. Example Data Demand dwelling

DATETIME	HOUR	KW
01/01/2009	0:00	0,18504
01/01/2009	0:01	0,18066
01/01/2009	0:02	0,18324
01/01/2009	0:03	0,18246
01/01/2009	0:04	0,18204
01/01/2009	0:05	0,18138
01/01/2009	0:06	0,18084
01/01/2009	0:07	0,18096
01/01/2009	0:08	0,18018
01/01/2009	0:09	0,17934
01/01/2009	0:10	0,18198
01/01/2009	0:11	0,17994
01/01/2009	0:12	0,18054
01/01/2009	0:13	0,18054
01/01/2009	0:14	0,18006
01/01/2009	0:15	0,17964
01/01/2009	0:16	0,1794
01/01/2009	0:17	0,17904
01/01/2009	0:18	0,17886
01/01/2009	0:19	0,1785
01/01/2009	0:20	0,17868
01/01/2009	0:21	0,17832
01/01/2009	0:22	0,1782
01/01/2009	0:23	0,17724
01/01/2009	0:24	0,1737
01/01/2009	0:25	0,17352
01/01/2009	0:26	0,17352
01/01/2009	0:27	0,1734
01/01/2009	0:28	0,17442
01/01/2009	0:29	0,17442
01/01/2009	0:30	0,17436

Example Data CO_2 Emissions

Table 27. Example of Data CO_2 Emissions

DATE	HOUR	gCO2 eq
01/01/2009	0:00	1,34516997
01/01/2009	0:01	1,31332904
01/01/2009	0:02	1,33208465
01/01/2009	0:03	1,32641435
01/01/2009	0:04	1,32336111
01/01/2009	0:05	1,31856317
01/01/2009	0:06	1,31463757
01/01/2009	0:07	1,31550993
01/01/2009	0:08	1,30983963
01/01/2009	0:09	1,30373315
01/01/2009	0:10	1,32292494
01/01/2009	0:11	1,30809492
01/01/2009	0:12	1,31245669
01/01/2009	0:13	1,31245669
01/01/2009	0:14	1,30896727
01/01/2009	0:15	1,30591403
01/01/2009	0:16	1,30416932
01/01/2009	0:17	1,30155226
01/01/2009	0:18	1,30024373
01/01/2009	0:19	1,29762667
01/01/2009	0:20	1,2989352

Example Data Photovoltaic Panels

Table 28. Example Data Photovoltaic Panels

DATE	KWh
01/01/2009	0,28
02/01/2009	0,47
03/01/2009	0,95
04/01/2009	0,5
05/01/2009	0,58
06/01/2009	1,08
07/01/2009	0,32
08/01/2009	0,94
09/01/2009	1,11
10/01/2009	0,26
11/01/2009	0,79
12/01/2009	0,13
13/01/2009	0,61
14/01/2009	0,36
15/01/2009	0,2
16/01/2009	0,3
17/01/2009	0,81
18/01/2009	1,36
19/01/2009	0,44
20/01/2009	0,64
21/01/2009	1,1
22/01/2009	0,81
23/01/2009	0,59
24/01/2009	1,2
25/01/2009	0,22
26/01/2009	1,1
27/01/2009	1,33
28/01/2009	0,24
29/01/2009	1,54
30/01/2009	1,36