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Optimization of Charging Time with Solar Panels for Electric Vehicles Using Fuzzy Logic

Cristhian Pineda, Robinson Jimenez Moreno and Olga Lucia Ramos
Faculty of Engineering, Nueva Granada Military University, Bogota, Colombia

Abstract: During the last decades, advances have been made to recharge vehicles with photovoltaic panels but because the energy supply of a panel depends on several environmental factors its contribution is minimal at the time of commissioning. For this reason, photovoltaic panels are used in electric vehicles that are currently marketed as electric charger for small electrical systems. In this study it is presented a methodology based on the fuzzy logic that allows to optimize the charging time with photovoltaic panels for electric vehicles in the rest hours of the vehicle. Given the fact that in urban areas, vehicles last most of the time at rest, since, their main function is to transport it is sought to take advantage of this time to minimize the charging time in the power grid and to reduce energy consumption of non-regenerative static sources and also the impact that will have the power grid, due to a massification of electric vehicles. This study provides as result an algorithm that optimizes the rest time of the electric vehicles to perform the charge, reducing the time of charging in the power grid and increasing the time of charging with photovoltaic panels.

Key words: Energy, fuzzy logic, optimization, photovoltaic panels, electric vehicles, power

INTRODUCTION

Since, the invention of the vehicle, the need to find energy sources necessary for its operation has been directly linked to its evolution. Due to the high demand of fossil fuels used by conventional vehicles, the tendency of this type of energy is to become scarce because of its non-renewable nature. Actually, the producers of vehicles worldwide have been developing electric vehicles, since, the source of energy for their operation as the name implies is electric which at the same time allows them to extract them from renewable energy sources such as: photovoltaic panels or KERS systems (Kinetic Energy Recovery System).

In similar works as the one presented by Tan *et al.* (2012) a model of a car park for hybrid vehicles is made in which photovoltaic panels located in the structure of the car park are in charge to charge the vehicles in order to minimize the negative impact to the networks, due to the massification of electric vehicles. The main difference is that in this work the charge is made without depending on a structure of photovoltaic panels located in the car park, otherwise the vehicle has photovoltaic panels adapted in the body to perform the charge.

By Dinis *et al.* (2012) the integration of a module of photovoltaic panels in a commercial vehicle Fiat Seicento Elettra is carried out in order to make a computational application that receives three parameters: type of panels, location and month of the year, providing as main output the scope in relation to the energy obtained by the photovoltaic panels.

One of the main problems to charge electric vehicles is the overload generated to the electric networks, this since, in the last years the sales of this type of vehicles have grown exponentially. By Tulpule *et al.* (2011) a photovoltaic panel structure is made in the parking lots of Columbia University and OH university in Los Angeles in order to reduce the overhead and emissions, analyzing three variables: impact of emissions, place-of-charge costs and vehicle owner costs, resulting in a significant reduction in the energy cost to be paid for both parking lots and owners as well as a reduction of CO_2 emissions in the environment. As the number of electric vehicles increases, the need to supply electric power increase by (Pires *et al.*, 2012) photovoltaic panels are used to support the electric networks in the charging of electric vehicles. Additionally when no charge is supplied to the vehicles, the energy collected by the photovoltaic panels is used as support, to compensate the reactive energy of the networks.

By Li *et al.* (2009) a method is designed to perform the energy supply in the charging stations using solar energy, taking as a point of comparison the cost of the

Corresponding Author: Cristhian Pineda, Faculty of Engineering, Nueva Granada Military University, Bogota, Colombia

recharge through the electric network, evidencing a positive impact on charging cost. In the end it is proposed to continue researching in the maximization of solar energy which in this article is developed, based on an algorithm of optimization of charging time and it can be implemented in the stations as long as the vehicle is parked by the user for a considerable time.

As there is a growing demand for photovoltaic panels to supply electrical systems it is necessary a way to simulate such systems before performing actual tests. By Dolan and Durago (2011) an emulator is done using LabView in which different variables that represent conditions of the environment can be changed.

Because the change in the environment is the main factor for obtaining energy with solar panels by Nakir *et al.* (2012); Al-Nabulsi and Dhaouadi (2012) a comparative study is carried out using a simulation on a mobile platform in real environmental conditions between three popular algorithms: P&O, IC and OC which are developed for the monitoring of the maximum power point. P&O is characterized by analyzing changes that disturb the operating voltage of the link between the photovoltaic panel and the power converter. If the DC voltage is incremental, the panel continues with the same direction, otherwise at the next voltage change the panel changes the direction. The algorithm IC incremental conductance algorithm is based on the slope of the voltage vs current curve, to make the decision to change the direction of the panel in case of decreasing the slope set. The OC algorithm is based on the current curve given by the photovoltaic panel to the converter to make decisions to change the position of the photovoltaic panel. As a result it was obtained that the IC algorithm obtained 5.536% more energy than the other algorithms being one of the best to implement in electric vehicles with photovoltaic panels.

By Papoutsidakis *et al.* (2013), it is implemented an adjustable mobile energy production system using photovoltaic panels which has a tracking method to find the highest solar radiation and through a mechanism is positioned to do an energy collection. Showing the avid interest in reducing the impact generated by the charging of electric vehicles to the electricity grids and the reduction of energy recharging costs for vehicle owners. For this reason, the purpose of this article is the development of an algorithm that allows to optimize the charging time in the hours of rest of the electric vehicle, contributing as a variant a control with fuzzy logic that evaluates the moment for the energy recharge. It starts evaluating the state of charge of the batteries by means of a fuzzy control. Following that, the user of the vehicle sends the number of hours that the vehicle will be at rest. With this information, an algorithm will optimize the charging time extending the charging time with photovoltaic panels to minimize the impact to the electric networks.

MATERIALS AND METHODS

Due to the fact of evidencing problems such as the negative impact to the electric networks and the over cost to the users for the use of these same ones it is necessary to implement methodologies that allow the use of other sources of renewable energy. In this research, we use photovoltaic panels that with the help of an algorithm that optimizes the charging time will reduce all the previously mentioned problems. For this, study A describes the operation mode of the fuzzy control which allows the algorithm to know the state of charge. In study B, the explanation of the algorithm and each of the phases. In study C, each of the materials needed for this work is described.

Charge fuzzy control: The fuzzy control section obeys to the need to know the state of charge of the batteries in an intelligent way, since, for the operation of the algorithm it is necessary to have an area of uncertainty that allows to identify the right moment to make the decision to charge besides to know the state of charge of the battery and in this way, carry out the execution of the algorithm of charge optimization.

Figure 1 illustrates the scheme of the control to be used. The variable sensed will be the voltage of the battery. The fuzzy controller input is determined by the difference between the maximum charge Voltage (V_d) and the battery Voltage sensed (V_s). This difference is called error.

The fuzzy input set is illustrated in Fig. 2 and is characterized as e = {High Voltage, Low Voltage} where e is in the range e = {0,...,13.5}. The low voltage element was identified between 0 and 1.75 because in this range

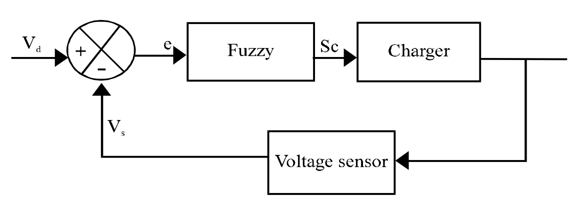

Fig. 1: Closed loop fuzzy control

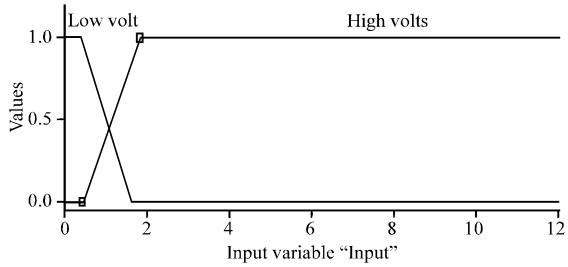

Fig. 2: Input fuzzy set

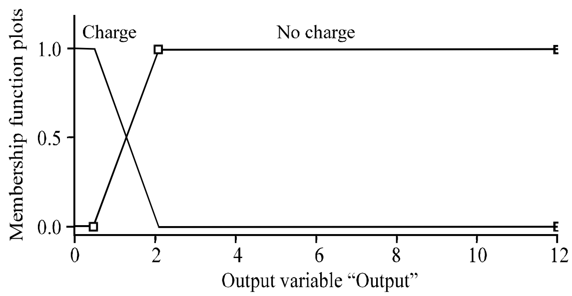

Fig. 3: Output fuzzy set

the battery decreases the load minimally and the high voltage element was identified between 1, 25 and 13, 5 as long as it has a membership greater than 40%, since, in this range the discharge intensifies.

Figure 3 shows the fuzzy output set which gives the control signal to charge or not the batteries and it is characterized as: Sc = {Charge, Not Charge} where Sc is in the range Sc = {0, 13.5}. The charge element was identified between 0 and 2.5 always and the not charge element was identified between 0.5 and 13.5 as long as the membership is >50%.

It is avoided the implementation of cooling air inlets in the first place because the vehicle will not have any radiator installed that required this and second because these inlets greatly affect the drag generated by varying the aerodynamic behavior. Following are 2 sub-sections in which are illustrated the parameters of the scenario of simulation for wind tunnel virtual test and the results of the simulation.

Optimization algorithm: The basic function of a vehicle is the displacement from one point to another, so, most of the time the vehicles remain in rest state in the parking lots. In general, to take advantage of the rest time by charging with renewable energy, advances have been made, e.g., smart buildings which use part of the photovoltaic panels to charge electric vehicles through solar energy.

Since, most of the buildings do not have solar energy technologies it is evident that the vehicles themselves could implement photovoltaic panels on all sides in order to increase the obtaining of solar energy and if necessary the lack of charge is obtained through the electric network.

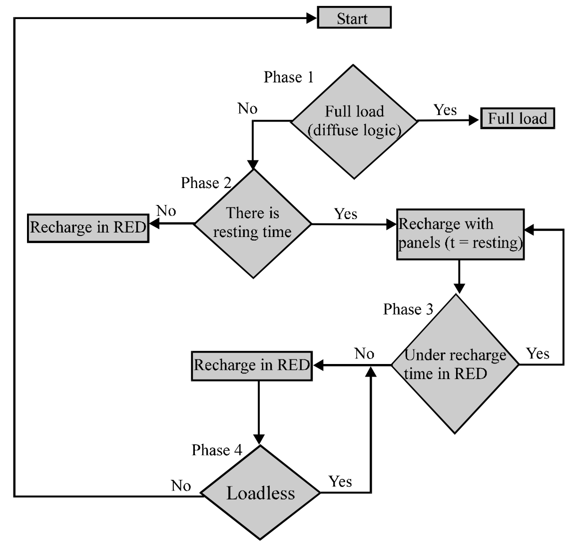

Fig. 4: Algorithm in phases

For the implementation of this system it is necessary to have an application that communicates with the user, this in order to know the time of rest, since, this data is vital for the optimization algorithm to calculate the charging time with photovoltaic panels and with the electric network. This application also allows to return the level of charge of the vehicle to the user.

Once the vehicle is parked and connected to a controlled electric network, a charge optimization algorithm is proposed. The main objective of the algorithm, illustrated in Fig. 4 is to increase the charging time with photovoltaic panels and propose the following phases.

In the first phase, the algorithm evaluates the charge level and makes a decision regarding the fuzzy response obtained. If the charge level is in the fuzzy set "Do not charge" the fuzzy algorithm gives said information to the user, therefore, the cycle of the algorithm will terminate.

For the case where the charge level belongs to the fuzzy set "Charge", the charge decision will be communicated to the user and will additionally ask how long the vehicle will remain at rest.

For phase two of the algorithm, the network and charging times with photovoltaic panels must be calculated.

The calculation of the times will be performed by an external clock in order to obtain accuracy and zero dependencies of the optimization algorithm:

$$T_{reposo} = T_{red} + T_{panel} \quad (1)$$

Equation 1 shows the equality to be met where T_{reposo} is obtained through the user, T_{red} is calculated by the time it takes the power grid tocharge the system in its entirety and T_{panel} is obtained by the difference between the two times mentioned above.

Charging time with electrical grid is variable due to the rate of power supply decreases when the battery charge level is reaching the maximum point.

To know the time it takes the ower grid to do a total charge, starting from a known level it is necessary to obtain an equation that represents the charging curve.

The charging curve of the battery is obtained through manufacturer's manuals or if necessary a sampling is done and depending on the shape of the curve a mathematical methodology is used to obtain the characteristic equation. The information provided by the user is vital for the algorithm since if the idle time is minimum or it is less than the network charging Time (TRed), the system will charge directly to the electrical grid.

When the charge is carried out through photovoltaic panels with TPanel duration, at the end of the time, phase three is done in which the algorithm evaluates the level of charge in the batteries in order to know the time that will take a new charge in the total network. This procedure is performed to know if the photovoltaic panels can continue with the charging process. To explain the procedure performed in phase 3 an example is made: the load level is 10 W, the rest time is 8 h and with the charging function in the network it is estimated that the change is done in 4 h. Consequently, the photovoltaic panels will have 4 h to charge. Because the environment is optimal for charging with panels they obtained 4 W in the 4 h. At this point, the algorithm evaluates the charge and finds that 6 W are missing. With the battery charging function it is estimated that the new charging time with electrical grid will be 3 h, so that, the panels will continue to charge the batteries constantly to the point that the remaining rest time is equal to the time that the grid takes to do a full charge or the photovoltaic panels do the total of the charge.

In the event that the charging time with photovoltaic panels (T_{panel}) is met and no significant change in the charge level has been made for environmental reasons, the algorithm will send a signal that will allow the switching the charge to be done by the electric network. This procedure is performed in order to ensure that in the rest Time (T_{reposo}), the total charge is done.

Phase 4 or final phase runs after the rest time has elapsed and the charge level is evaluated. If the charge is not complete the algorithm switches, so that, the charge is continued with the electrical grid until the charge is complete.

For this research was used an electric vehicle which is illustrated in Fig. 5 has dimensions 1 m long by 0.5 m wide and 0.2 m high and has incorporated a photovoltaic solar panel BP solar model: S×55 U with dimensions 1105×502×50 mm. The algorithm was implemented in an Arduino Mega 2560 card and a 128×16 LCD was used to visualize the charging state and the charging source used. The user will provide the rest time data through an application with serial communication using XBee transmitters.

In Fig. 6, the simulation of the control electrical system with each of its components is illustrated. In the central part of the Fig. 5 is a representative diagram of the Arduino Mega 2560 card, at the top is located a LCD screen responsible for displaying the level of charge of the batteries and which power supply is using. In the upper right side is the external clock in charge of carrying the time accurately for this case a DS1307 was used. In the right central side is the serial transmitter that communicates with an application allowing the user to know the time of rest. On the lower right side are the relays that allow switching between the two charging systems.

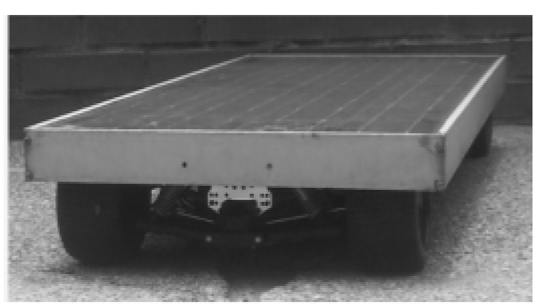

Fig. 5: Used elements in simulation

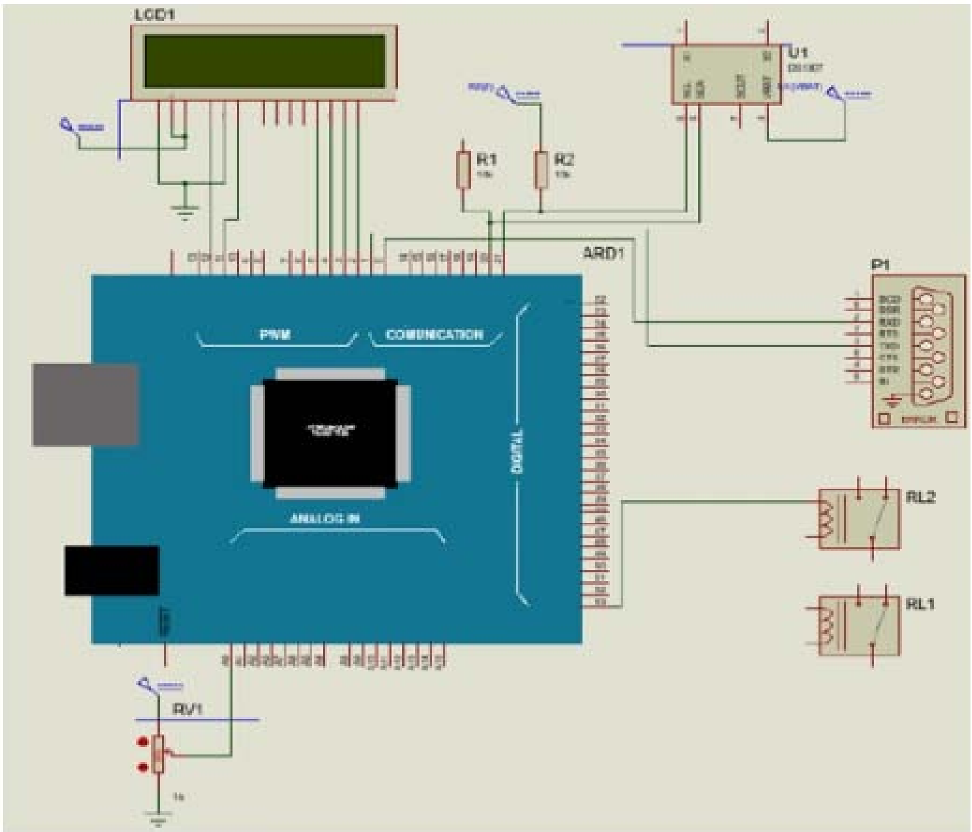

Fig. 6: Used elements in simulation

RESULTS AND DISCUSSION

Because the main objective of this research is to optimize the battery charging time by means of the energy supply by the electric network and by photovoltaic panels to reduce the negative impact to the networks by a massification of electric vehicles, the implementation and the type of panels are out of the interest of this work. Although, it is important to highlight that the efficiency of the algorithm depends on variables associated with photovoltaic panels such as location inclination, climate, month of the year and time.

Given the fact that the total charge time per electric network can vary, since, this is not linear it becomes necessary to obtain a characteristic equation of the charge of the battery which represents power over time this in order to know the time duration required to complete the maximum charge through the network, starting from any level.

Figure 7 illustrates the energy supply of the electric network to the battery for 360 min starting from a state of total discharge with a decreasing tendency as the increase in the charge level of the batteries, the energy transfer decreases. Deriving from the graphic, (Eq. 2 and 3).

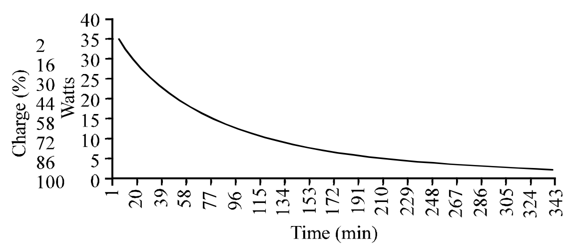

Fig. 7: Charging curve of the battery AGM 12 V, 5.5 Ah

In Eq. 2 and 3 are obtained by performing an exponential regression of the data obtained when charging the battery for 360 min with sampling time equal to 1 min, one as a function of time and the other as a function of power. These equations allow to know the duration of total net load if the initial load and the amount of power supplied by the network are known:

$$t[\text{time}] = 360-\left(\frac{-\frac{\text{In}(P(W))}{28.087}}{0.008}\right) \quad (2)$$

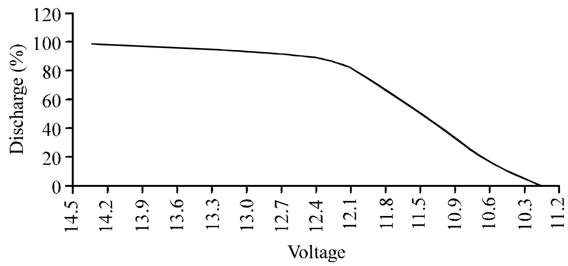

Fig. 8: Battery discharge

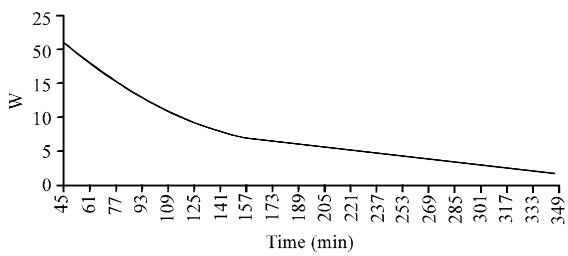

Fig. 9: Energy supply of the power grid

$$P(W) = 28.087e^{-0.008t(min)} \quad (3)$$

In order to know the efficiency of the proposed algorithm regarding the reduction of energy consumption of the electricity network, two tests are performed. The first test consists in supplying the battery viathe electrical grid, starting at a 40% charge level that is because for this AGM battery, the manufacturer's manual recommends a discharge of 60% in order to obtain a greater number of charging and discharging cycles. Figure 8 illustrates the battery discharge curve which is obtained from the manufacturer's manual and shows the percentage discharge of the battery.

In order to obtain the energy supply of the network from a 40% of charge of the battery it starts from Fig. 8 which characterizes the charge of the battery from a total discharge level. Figure 9 shows the energy supply of the power grid to the battery, from 21 W to the full charge.

The amount of energy supplied by the power grid is found by calculating the area under the curve of Fig. 10 which corresponds to integrating Eq. 4 in function of the time between t = 45 and t = 360. This calculation is performed in Eq 4.

$$\int_{45}^{360} p(W)\frac{dp}{dt} = \int_{45}^{360} 28.087e^{-0.008t}\frac{dp}{dt} \quad (4)$$

When solving the integral it results in an energy input from the grid of 2252.37 Wm which is equal to 37.539 Wh.

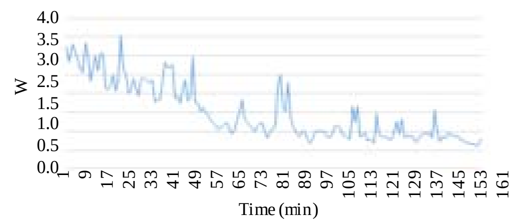

Fig. 10: Energy supply of the photovoltaic panels

The second test consists in implementing the algorithm of charging time optimization, starting from the same level of initial charge as the one used in the charge with power grid.

In the first phase, the algorithm by means of the implemented fuzzy control detects a 40% of charge and informs the user that should start charging.

In the second phase, the algorithm waits for the user to set the rest time which for this case is 8 h (480 min). Following that it is calculated the charging time with electric grid using Eq. 2, taking as main variable the level of power supplied by the electric network which for a level of 40% of battery charge is 21 W according to Fig. 8 and as a result it is obtained 318 min of charging trough electric grid. With the rest time and the charging time using the electric grid, the charging time with photovoltaic panels is calculated using Eq. 1 which is 162 min.

Figure 10 illustrates the energy input of the photovoltaic panel for 162 min starting from the same charge level of test one with a sampling time equal to 1 min.

To obtain energy with the photovoltaic panels, the average radiation is about 872.66 W/m^2 and there are peaks where the power increases due to the increase of radiation. For this case it is not possible to find a characteristic equation of the curve, since, it has no continuous forms, so, to know the amount of energy supplied which is equal to the area under the curve, the sum of the power samples must be performed from T = 0 to t = 165. This summation is represented in Eq. 5:

$$P(W)\sum_{t-0}^{162} \Delta P \quad (5)$$

Solving the summation from t = 0 to t = 162 results in an energy input from photovoltaic panels of 243.197 Wm which is equal to 4.053 Wh.

In phase 3, the algorithm again performs a charge level calculation using fuzzy control, to know if the charge can be continued with panels. For this test, the charge level increases to 45% which corresponds to 19 W

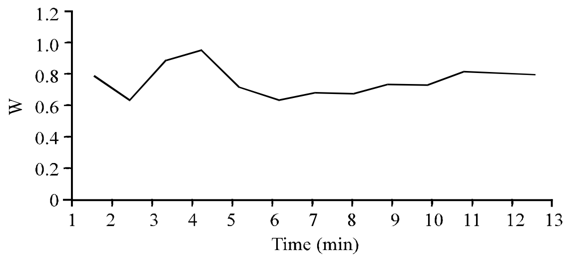

Fig. 11: Energy supply of the photovoltaic panels

supplied by the electric network to perform the charge, according to the characterization the battery charge illustrated in Fig. 8. Using E 2 it is obtained that the new charging time is 305 min using the electric network.

Due to the initial charging time using the power grid equals to 318 min with the new time, there are still 13 min which will be used to continue to obtain energy from the panels. Figure 11 illustrates the contribution of the panels for 10 min.

In order to find the amount of energy obtained during the 13 min, the sum of t = 0-t = 13 is obtained. The summation is represented in Eq. 6:

$$P(W)\sum_{t-0}^{13} \Delta P \tag{6}$$

Solving the sum from t = 0-t = 13 results in an energy input from photovoltaic panels of 9.945 Wm which is equal to 0.165 Wh.

After completion of the charging time with panels for the second time, the charge level is evaluated with the fuzzy control which indicates a 45% of charge, so, the energy input of the panels is not considerable and the algorithm proceeds to switch the charge to the power grid for 305 min to complete the total charge level. Figuer 12 shows the energy supply of the power grid.

The amount of energy supplied by the power grid is found by calculating the area under the curve showed in Fig. 13 which corresponds to integrating Eq. 4 in function of time, between t = 57 and t = 360, according to the characterization of Fig 8 for 45% of charge. This calculation is performed in Eq. 7:

$$\int_{57}^{360} P(W)\frac{dp}{dt} = \int_{57}^{360} 28.087e^{-0.008t}\frac{dp}{dt} \tag{7}$$

Solving the integral results in an energy input from the power grid of 2010.43Wm that is equal to 33.507.

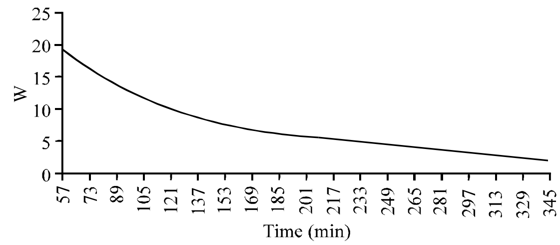

Fig. 12: Energy supply of the power grid

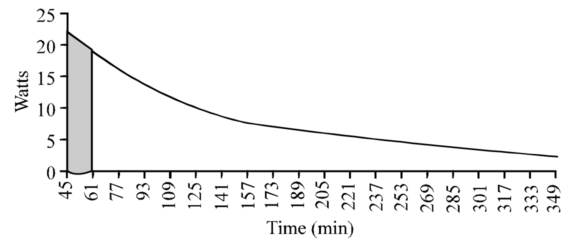

Fig. 13: Energy supplied decrease by the power grid due to the charge algorithm implementation

In Fig. 13, there is a red area which corresponds to the energy that stopped supplying the electricity grid, due to the implementation of the algorithm of time optimization of charge with photovoltaic panels.

The first test done shows an energy consumption by the grid of 2252.37 Wm and for the second test, 2010.43 Wm, therefore, the implementation of the algorithm for the case proposed in this study, decreases by 10.74% the electricity consumption of the grid

CONCLUSION

It is evident that the algorithm of charging time optimization reduces the power consumption of the electric network by 10.74% for the example proposed in this research.

The implementation of the algorithm proposed in this research, verifies that the negative impact of the electric networks can be reduced due to the massification of electric vehicles.

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