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Plug-in Hybrid EVES Optimizing with Power Converter

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Regular paper

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Plug-in Hybrid Electric Vehicles (PHEVs) are seen to be a step forward in vehicle electrification, to replace ICE based conventional vehicles. Using a PHEV implies that part of the vehicle energy comes from the grid or other sources, such as renewable energy, to charge the battery. However, renewable energy sources being intermittent sources, these new needs would only shift the problem by increasing the number of nuclear and coal power plants, and will not permit solving the problem of pollution or fossil fuel depletion. There is a need to optimize the way, in which the available resources are utilized, in order to reduce dependency on nuclear and coal power plants. This will achieve the overall goal of minimizing pollution, reducing the depletion rate of fossil fuels, as well as reduce the overall cost. This paper proposes a hybrid power system for house energy needs by utilization of renewable energy sources, grid, as well as the PHEV battery source. Emphasis of paper is on optimization of the overall cost of the system, by selecting the most cost effective and feasible option among the available options; namely, renewable energy sources, the grid and the battery of the PHEV. As a prerequisite to the implementation of this scheme, it is desirable to work out an approximate amount of available energy. For this, the efficiencies of the various power converters involved must be determined and taken into account to reduce the energy losses.

Keywords: Hybrid Electric Vehicle Energy System (HEVES), DC-DC Power Converter, Power Charging System.

1. Introduction

A hybrid integrated topology, fed by photovoltaic (PV) and fuel cell (FC) sources is proposed in this project. The proposed circuit is low cost, compact structure and highly reliable. It works as an uninterruptible power source that is able to feed a certain minimum amount of power into the grid under all conditions. PV is used as the primary source of power, with the FC section, acting as a current source, feeding only the deficit power. The DC power generated from the Photovoltaic and Fuel Cell is fed into the converter which is then converted into AC to load. The main objective of this project is to reduce Green House Gas (GHG) emissions from vehicles for global warming curtailment by using electric vehicles and the efficiencies of the various power converters involved must be determined and taken into account to reduce the energy losses. To reduce Green House Gas (GHG) emissions from vehicles for global warming curtailment a viable solution lies in using nonpolluting electric vehicles. New transportation penetration has affected energy production in a major way. Energy production is already reaching peaks. At the same time, load demand has drastically increased. Hence, it has become imperative to increase daily energy production. The challenge for the next few years is to reduce Green House Gas (GHG) emissions from vehicles for global warming curtailment. GHG emissions are mainly due to Internal Combustion Engines (ICE) used in transportation. To decrease this emission, a viable solution lies in using non-polluting electric vehicles. New transportation penetration has affected energy production in a major way. Energy production is already reaching peaks. At the same time, load demand has drastically increased. Hence, it has become imperative to increase daily energy production. It is well-known that world energy requirement is mainly catered by nuclear and thermal power plants which are not environment friendly. There is a need to go for renewable energy sources which are both environment friendly and cheap at the same time. This paper considers a control strategy including converter efficiencies, which consists of the local network, where the home is connected to renewable sources, in addition to the grid. The PHEV's battery can be connected to home, either to charge the battery, or to transfer its energy to the home (V2H), depending upon its state-of-charge (SoC) and the energy requirements of the home load. The concept of Grid-to-Vehicle (G2V) is the simplest process of integration of the EV batteries charging system with the power grid. It is not required any communication between both systems and only exists energy flow from the power grid to the EVs. Nowadays, this is the most common (and almost unique) batteries charging process for EVs and it will be the first approach to the massive integration of these vehicles. The concept of Vehicle-to-Home (V2H) is similar to the V2G concept; however it can avoid the grid infrastructure and the electricity tariff problems associated with V2G, because the bidirectional flux of energy is between the vehicle and the house. Thereby, V2H can be used to manage and regulate the profile of electricity demand in a house, controlling the use of the loads and the stored energy available in the vehicle. It also can be used out of the power grid in isolated electrical systems, and in conjunction with renewable energy sources, increasing their effectiveness. In recent years, a significant interest in hybrid electric vehicle (HEV) has arisen globally due to the pressing environmental concerns and skyrocketing price of oil. Representing a revolutionary change in vehicle design philosophy, hybrid vehicles surfaced in many different ways. However, they share the hybrid power train that combines multiple power sources of different nature, including conventional internal combustion engines (ICE), batteries, ultra capacitors, or hydrogen fuel cells (FC). These vehicles with on board energy storage devices and electric drives allows braking power to be recovered and ensures the ICE to operate only in the most efficient mode, thus improving fuel economy and reducing pollutants. As a product of advanced design philosophy and component technology, the maturing and commercialization of HEV technologies demand extensive research and developments. This research intends to address many key issues in the development of HEV.

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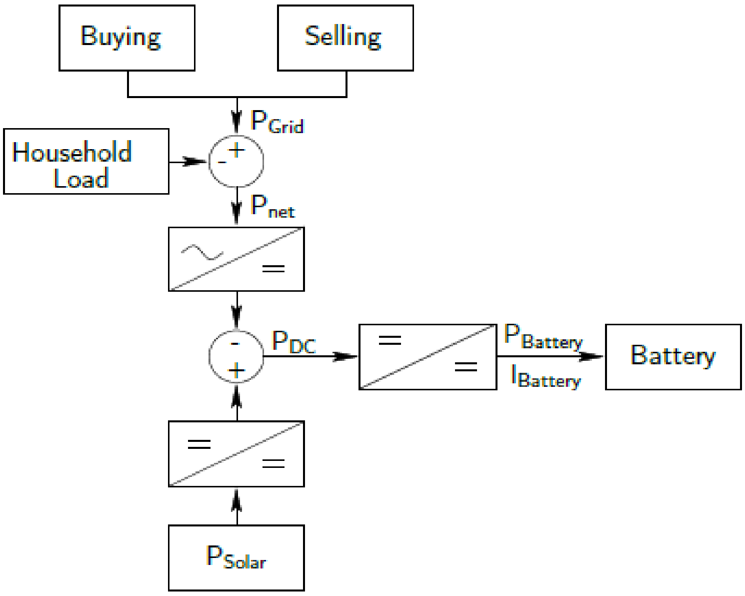


Fig. 1. General view of Electric Vehicle Batteries Charging System

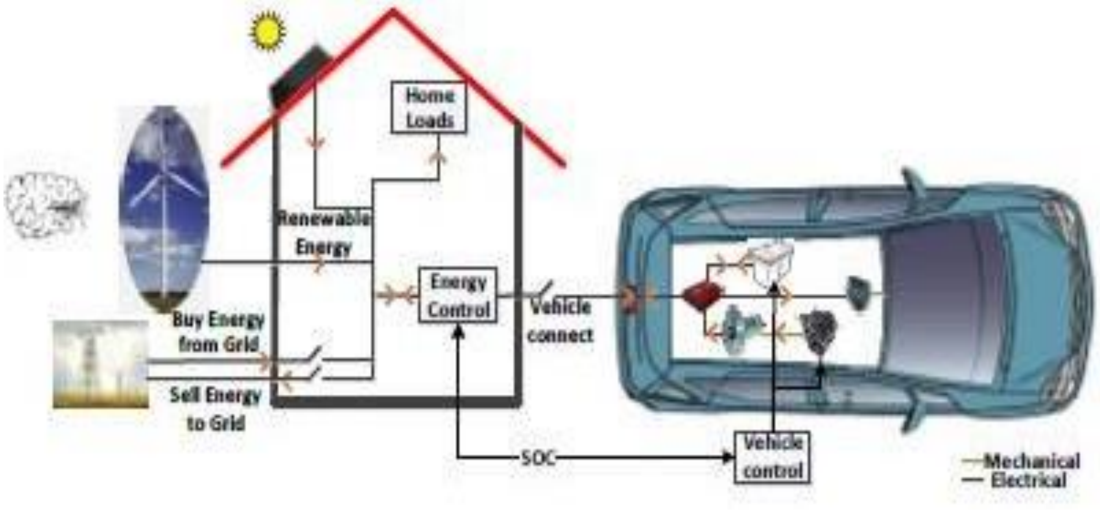


Fig. 2. Non-Conventional Energy Sources

The sources of energy which are being produced continuously in nature and are in exhaustible are called renewable sources of energy (or) non-conventional energy. With the power demand increasing consistently, a stage has come when these centralized power generation units can be stressed no further. As a result, the focus has shifted to generation (and consumption) of electric power "locally" leading to "distributed power generation systems". At the same time, increased awareness about the importance of a clean environment and the quickly vanishing fossil fuels have given impetus to the idea of local power generation using nonconventional energy (NCE) source (e.g., photovoltaic (PV) cells, fuel cells (FC), wind energy, etc.), which may suit a particular region and provide power at various load centers along the main power grid. Most of these sources are pollution-free and abundant. Unfortunately, they are not so reliable. For example, the PV source is not available during the nights or during cloudy conditions. Wind energy may or may not be available. Other sources, such as fuel cells may be more reliable, but have monetary issues associated with them. Because of this, two or more NCE sources are required to ensure a reliable and cost effective power solution. Such integration of different types of energy sources into a DG system is called a hybrid distributed generation system. Photo Voltaic (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include mono crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide or sulfide. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. Photovoltaic power capacity is measured as maximum power output under standardized test conditions. In this project, PV cell converts the solar radiation into electrical energy and does not cause any pollution. During low insolation period, even a small amount of power can be fed into the grid. Excess power is diverted for auxiliary functions like electrolysis, resulting in an optimal use of the energy sources.

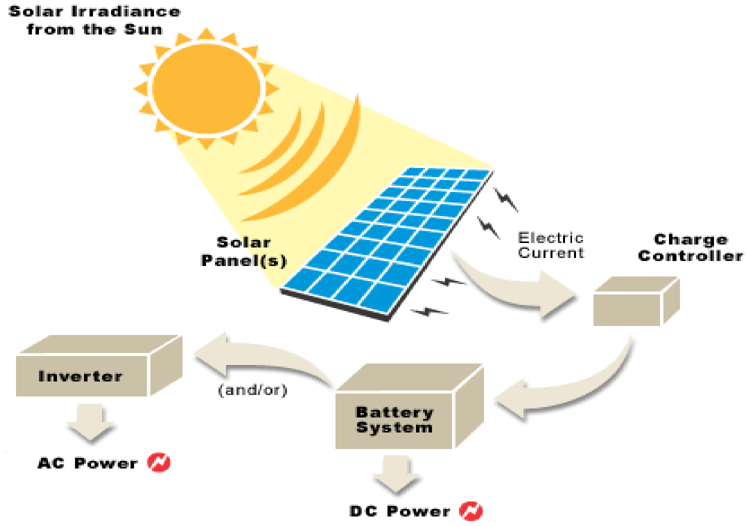


Fig. 3(a). Solar Energy

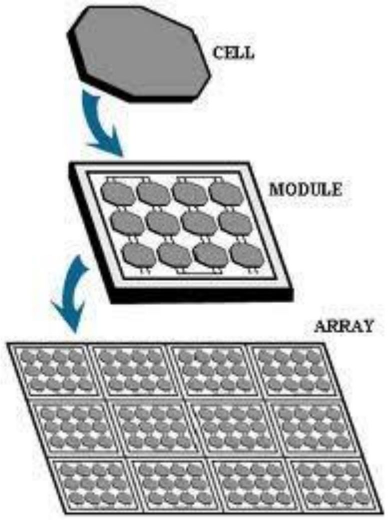


Fig. 3(b) Current Generation

Photovoltaic systems use cells to convert solar radiation into electricity. The cell consists of one or two layers of a semi-conducting material. When light shines on the cell, it creates an electric field across the layers, causing electricity to flow. The greater the intensity of the light, the greater the flow of electricity is. Photovoltaic is emerging as a major power source due to its numerous environmental and economic benefits and proven reliability. Fuel cells are self-contained power generation devices that are able to produce reliable electricity for residential, commercial, industrial and transportation applications. A fuel cell can convert hydrogen directly into electricity that can be used to power an electric car. Converter is used to process and control the flow of electric energy with the help of semiconductor device. The converter which has been used in this project is Z - source converter. An inverter is an electronic device that converts direct current to alternating current, the converted AC be at any required voltage and frequency with the use of appropriate transformers, switching and control circuits. A microcontroller is a small computer on a single integrated circuit containing a processor core, memory and programmable input/output peripherals. The microcontroller being used in this project is AT89C51. It has been used to send signals to the MOSFETs. A driver is an electrical circuit or other electronic component used to control another circuit or other component, such as a high-power transistor. They are usually used to regulate current flowing through a circuit or is used to control the other factors such as other components, some devices in the circuit. The driver circuit being used here is ULN2003. There are many situations where signals and data need to be transferred from one subsystem to another within a piece of electronics equipment, or from one piece of equipment to another, without making a direct ohmic electrical connection. These use a beam of light to transmit the signals or data across an electrical barrier, and achieve excellent isolation. In this study the converters are an unidirectional DC/DC converter, a bidirectional DC/DC converter (to provide for the charging and discharging modes of the battery) and an inverter were simulated and the efficiency curves were plotted with respect to frequency and input power. The bidirectional converter acts as a buck converter during the battery charging mode and as a boost converter during the battery discharging mode. The plot of efficiency v/s input power and frequency for each of the converters is presented in this section. Converter is used to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for the user loads. Since conversion and control of electrical power within a wide range varying from milli watts to giga watts is feasible with the help of semiconductor devices, they are finding increased attention. Hence, highly efficient power electronic technologies and reliable control strategies are needed to reduce the wastage of energy and to improve power quality. The switching characteristics of power semiconductor devices permit a power electronic converter to shape the input power of one form to output of some other form

2. DC/DC Converter

In this study basic DC/DC converters are used, a bidirectional converter with the topology as shown in Figure 4 and the other a buck converter with the topology as shown in Figure 5 Firstly, the efficiency is relating to the switching frequency. According to the following graph, for both buck and boost converters, the maximum efficiency is obtained when the switching frequency is 40 kHz.

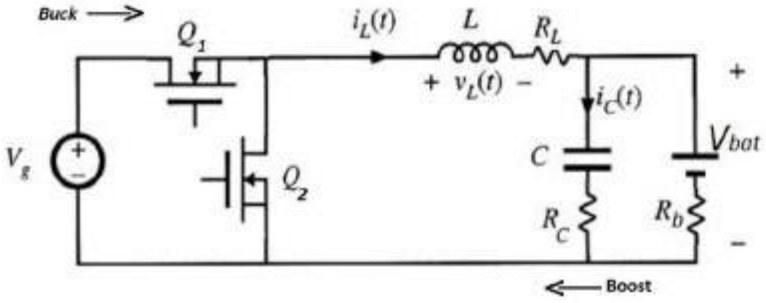


Fig. 4. Bidirectional DC/DC Converter

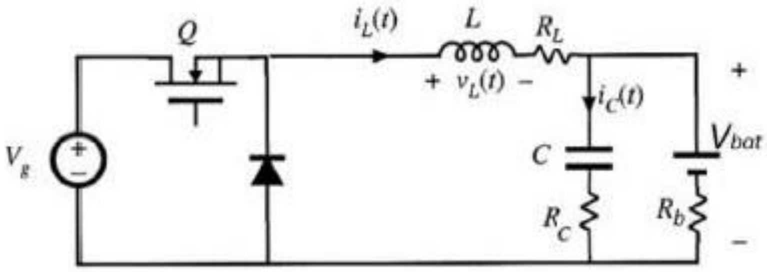
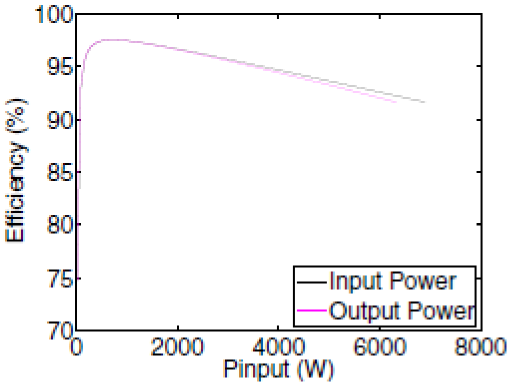
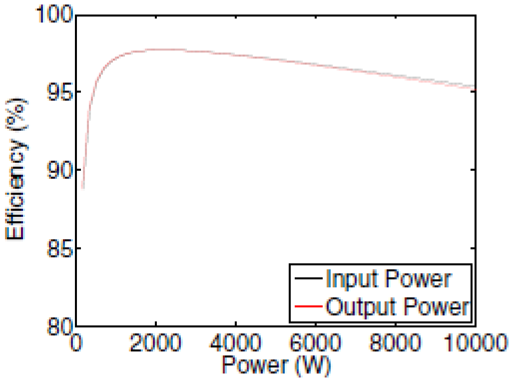


Fig. 5. Buck Converter

(Figure 7(b)) whereas the the buck mode between 1000 - 3000W (Figure 7(a)) to have the best efficiency.



(a) Boost efficiency characteristic



(b) Buck efficiency characteristic

Curve fitting has been done for the efficiency curve for boost operation and the equation for the same is given in (1) and similarly for buck operation the equation is as given in (2).

$$\eta_{\text{boost}} = -0.0006739 \cdot P_{\text{in}} + 97.12 \qquad \text{....................(1)}$$

$$\eta_{\text{buck}} = -0.001087 \cdot P_{\text{in}} + 89.83$$

....................(2)

The converter efficiency depends upon several factors including the components used and switching frequency. Converter losses include conduction, blocking, and switching losses [6], [7]. The converters in the case are a bidirectional DC/DC converter, a unidirectional DC/DC converter and an inverter. The conduction and switching losses in all the components are calculated separately and summed up to obtain the total losses. The efficiency is then calculated in (3)

$$\eta = \frac{Input\_Power - \sum(losses)}{Input\_Power}$$

..........................(3)

IGBT losses is divided in two categories, one is conduction losses and the second is switching losses.

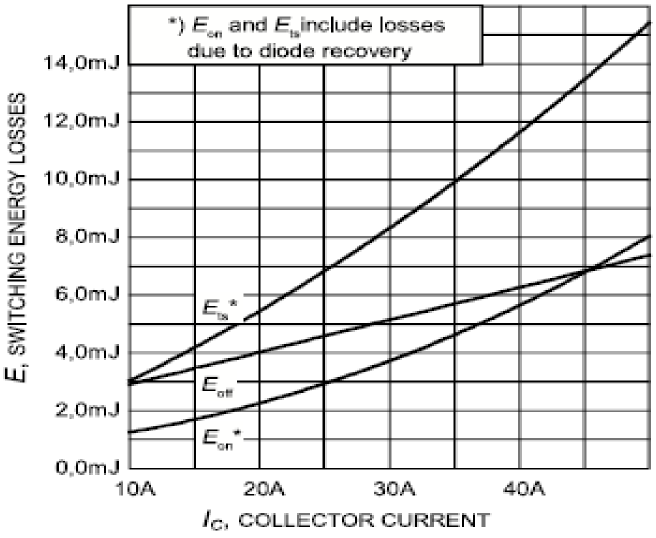
Conduction losses: The conduction losses is determinedby the equivalent IGBT diagram: voltage source in series with a resistance. The equation to calculate the conduction losses Pconduction is given in (4)

$$P_{\text{conduction}} = F_{\text{sw}} \cdot \int_{0}^{\frac{1}{F_{\text{sw}}}} (V_{\text{s}} + R_{\text{on}} \cdot I_{\text{c}}) \cdot I_{\text{c}} \cdot dt$$

...............(4)

where :
Vs : Forward voltage drop (V)
Ron : On state resistance (Ω)
Ic : Collector current (A)
Fsw : Switching frequency (Hz)

The switching losses can be calculated from the datasheet details as explained in [9]. First and foremost appropriate polynomial equation in Ic, for Eon, Eoff and Err are obtained from the graphs provided in the datasheets (Figure 3). This procedure includes noting down the values from the curves and then fitting a second order polynomial approximate equation by using a math tool, such as the Trendline tool in Microsoft Excel. Figure 3 shows the IGBT switching approximation Microsoft ExcelR . Figure 3 shows the IGBT switching approximation giving the turn-on (Eon) and turn-off (Eoff) IGBT energy and the diode reverse recovery energy Err plots. By using the Trendline tool, quadratuc equations approximating the loss curves Eon, Eoff and Err are obtained. For the IGBT [10] these equations are obtained as given below (3)



IGBT datasheet

$$E_{\text{on}} = 0.00218 \cdot I_{\text{c}}^2 + 0.041 \cdot I_{\text{c}} + 0.6105 \qquad (3a)$$

$$E_{\text{off}} = -8 \cdot 10^{-5} \cdot I_{\text{c}}^2 + 0.118 \cdot I_{\text{c}} + 1.7095 \qquad (3b)$$

$$E_{\text{rr}} = 0.0021 \cdot I_{\text{c}}^2 + 0.1659 \cdot I_{\text{c}} + 0.9329 \qquad (3c)$$

The switching losses fitted curves should be checked with the original curves to ensure they are close approximations. This checking is performed by placing the approximated curves obtained by mathematical tool on the same graph of the manufacturer datasheet.

B. Inductor losses

This study includes the copper losses in the inductor [6] Pinduc which is calculated as in (4).

$$P_{\text{induc}} = R_{\text{L}}(I^2 + \frac{\Delta I^2}{12}) \qquad (4)$$

where :

RL : Equivalent series inductor resistance ()

I : Current through the inductor (A)

_I : Ripple current

C. Diode losses

The diode conduction losses are calculated as in (5)

$$P_{\text{D}} = R_{\text{D}} \cdot I_{\text{on}}^2 + V_{\text{D}} \cdot I_{\text{on}} \qquad (5)$$

where :

PD : Diode conduction losses (W)

Ion : ON state diode current (A)

RD : On state diode resistance ()

VD : Diode voltage (V)

3. Battery Charging System

Nowadays, energy efficiency is a top priority, boosted by a major concern with climatic changes and by the soaring oil prices in countries that have a large dependency on imported fossil fuels. A great part of the oil consumption is currently allocated to the transportation sector and a large portion of that is used by road vehicles. According to the international energy outlook report, the transportation sector is going to increase its share in world's total oil consumption by up to 55% by 2030 [1]. Aiming an improvement of energy efficiency, a revolution in the transportation sector is being done. The bet is in the electric mobility, mostly supported by the technological developments in different areas, as power electronics, mechanics, and information systems. Different types of Electric Vehicles (EVs) are being developed nowadays as alternative to the Internal Combustion Engines (ICE) vehicles [2][3], namely, Battery Electric Vehicles (BEV),Plug-in Hybrid Electric Vehicles (PHEV), in its different configurations [3], and Fuel-Cell Electric Vehicles (FCEV). This chapter presents batteries charging systems for Electric and Plug-in Hybrid Electric Vehicles. To simplify the reading and to contribute to a simple understanding, from now on, in this chapter, it will be used the terminology of Electric Vehicle (EV) to define these two types of vehicles. It is predictable that in the near future, in a real full scale Smart Grid scenario, the power grid should meet the increasing demand of energy in a reliable and efficient way, maintaining the required stability and interfacing renewable energy resources, as a large network of micro grids. Figure 1 shows a draft of a scenario for a micro Smart Grid with: a micro generation power station with solar photovoltaic panels and micro wind turbines (which produce energy); some EVs with G2V and V2G capabilities (which can receive or provide electrical energy and Energy Storage Systems (which, like the EVs, can receive or provide electrical energy). Beyond the flow of energy between the parts, there is also the sharing of information, controlled by a Collaborative Broker [22]. In this figure are also shown the blocks of the Maximum Power Point Trackers (MPPTs) (for the micro solar photovoltaic panels and micro wind turbines), and the blocks of the AC-DC and DC-AC converters to adjust the levels of the voltages and the currents between both sides [23].

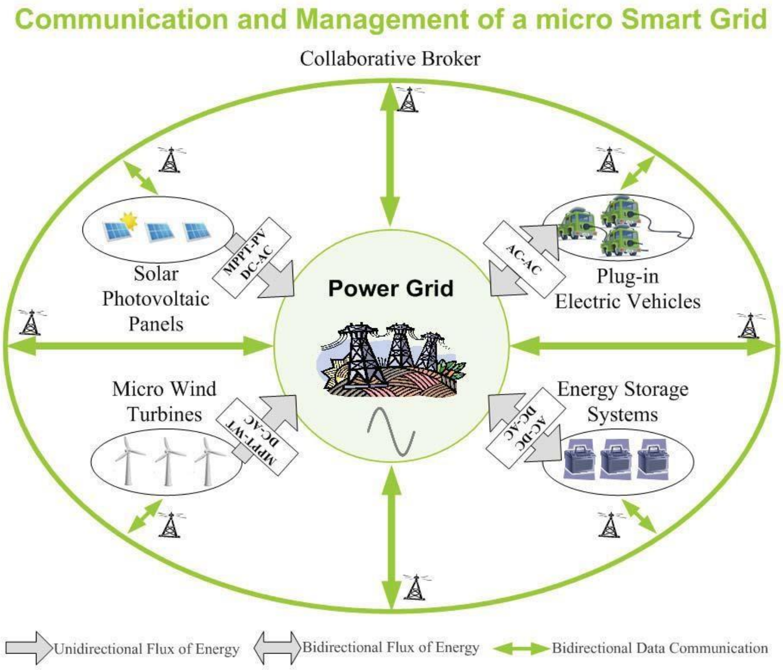


Figure 1. Scenario of a micro Smart Grid.

Such power grid scenario, with the EVs smart charging systems, will allow the communication of the vehicles with the local utilities to ensure that the batteries are charged when the electricity is cheapest and the impact of the charging systems on the grid is smallest. The use of computerized charging stations which constantly monitor the EV charging process, in order to optimize the charging rate, will be of extremely important to preserve the batteries lifespan. In Figure 2 is shown in detail the integration of EVs (in a typical charging park) with micro generation renewable energy sources (solar photovoltaic panels and micro wind turbines), and Energy Storage Systems (ESS), in a Smart Grid context.

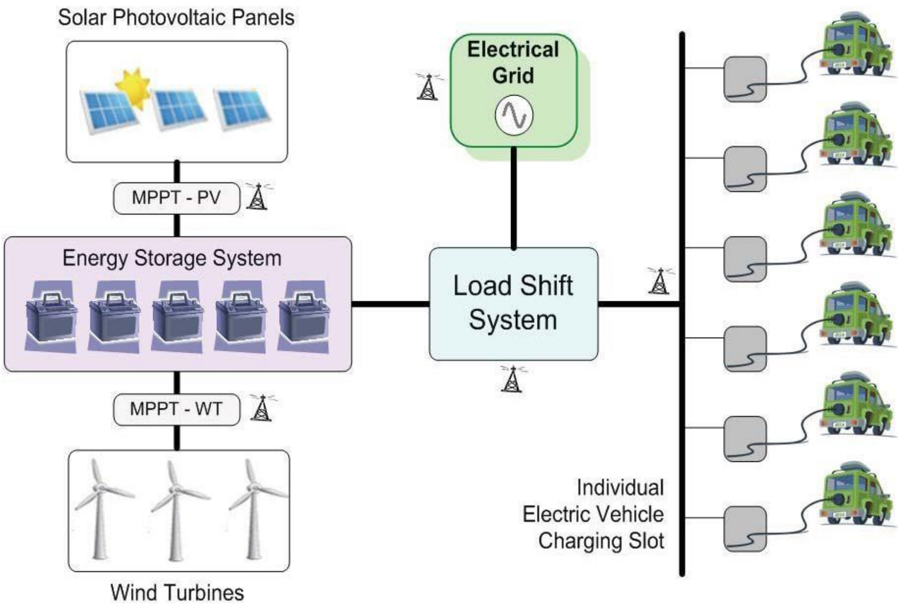


Figure 2. Integration of Electric Vehicles, renewable energy sources (solar photovoltaic panels and micro wind turbines), and Energy Storage Systems (ESS), in a Smart Grid context.

It was developed a laboratory prototype of a 3 kW batteries charging system that works with sinusoidal current consumption and unitary power factor, and that allows the charging of the batteries with different algorithms: constant-voltage, constant-current, and constant current followed by constant-voltage; in accordance with the State-of-Charge (SoC) level of the batteries and with their technology, namely, lithium, nickel, and lead-acid. Figure 13shows the schematic of the developed batteries charging system. This batteries charging system also allows bidirectional flow of energy between the power grid and the batteries, operating in both modes with sinusoidal current, and therefore, it can be considered as a smart charger. As illustrated in Figure 3, it is constituted by two main parts: the bidirectional power converter, which uses inductances, capacitors and IGBTs as switching power semiconductors; and the control system, that is constituted by the microcontroller, the signal conditioning circuit, the command drivers and the drivers.

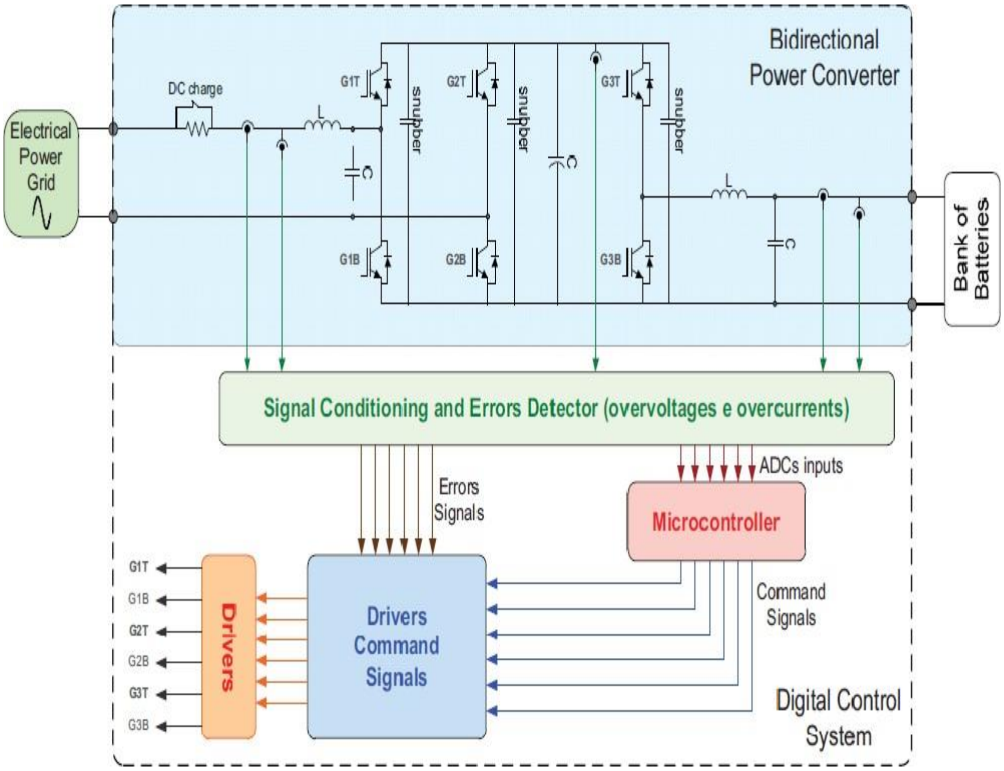
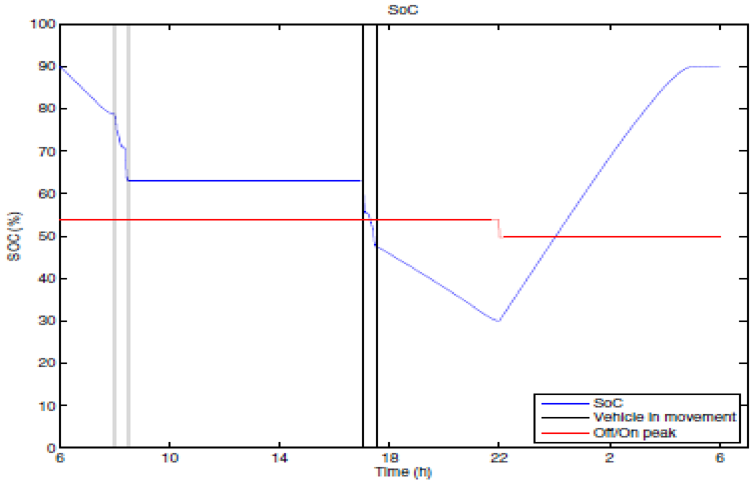


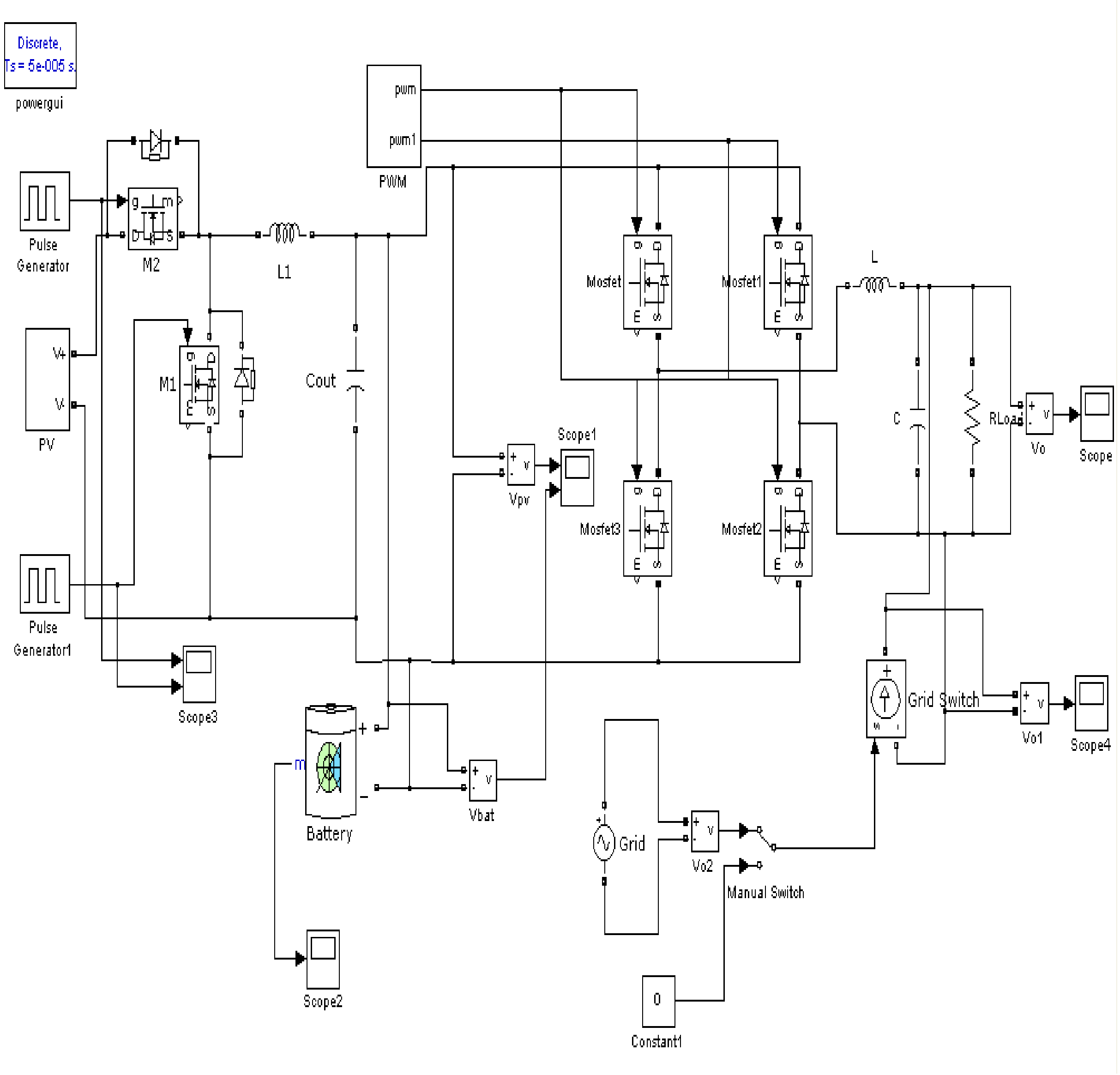
Fig.3. Schematic of the developed Electric Vehicle Batteries Charging System

As previously commented, and as demonstrated in [27], the load profile of the EVs batteries charging systems has high importance to the power grid management. Depending on the design of the electrical grid and the type of charging and discharging processes, EVs can be a problem or a benefit to the power grid. The batteries charging and discharging processes can be realized in two different ways: controlled and uncontrolled. In the controlled way, the batteries are charged or discharged in accordance to the capability and the needs of the power grid, and in accordance with the conveniences of the vehicle´s owner, which is the main figure in this process. In this scenario of real time control, several parameters should be taken into account, namely, energy price (to sell or to buy) and batteries State-of-Charge (SoC) and State-of-Health (SoH - reflects the batteries degradation along their lifetime). In [28] is proposed an autonomous distributed V2G control scheme, and in [29] is presented a coordinated charging scheme for multiple PHEVs in a residential distribution grid.

Some technical solutions for the integration of EVs in the electrical power grid can be found in [30].In the uncontrolled way, as the name suggests, there is no control over the charging system. The only control that exists from the moment in which the vehicle is plugged to the end of the process, is the decision if the process of charging or discharging can start immediately or after a fixed time delay (controlled by the vehicle´s owner in accordance with his convenience). Since there is no control over the charging systems, peaks of power consumption can occur in the electrical power grid, during some periods in which exist a large number of EVs simultaneously charging their batteries. These power peaks can bring overload problems to the power grid. Similar problems can occur when the energy stored in the batteries is delivered back to the electrical power grid. Despite these problems, nowadays, the uncontrolled way is the most common charging procedure. As predicted in [31], in Portugal, the smart charging (in controlled way) will be a necessity in midterm, in order to prevent a large demand of energy peaks over the power grid. The only difference of a PHEV from the HEV is its larger battery that allows energy to be charged from grid electricity. In addition to the power and energy demand of a HEV, additional ESS capacity requirement depends on its “all electric range” (AER). However, sizing the ESS for a PHEV is more complex for several reasons. First, in the AER, not only the energy but also the power is a concern, since the battery is the only source of power for most operations. Secondly, battery life is affected by the depths of charge and discharge. The depth of discharge on a PHEV is far more than that of a HEV with limited, shallow discharges. It is therefore more difficult to satisfy energy and power requirements with a reasonable life expectancy of the ESS. The focus of HEV design is mostly on power train efficiency. This efficiency depends on contributions from the engine, motor, battery, and mechanical transmissions. The peak efficiency of an ICE can be as high as 36% (based on 1998 Prius 1.5L Gasoline Engine), while the overall efficiency of its operation, on the other hand, is usually no more than 20%. Therefore, the objective of HEV design is to improve the overall vehicle efficiency by optimizing the sizes operations of its power train components. Although there is a great potential to improve the vehicle fuel economy and drive ability in principle, present control strategies based on engineering intuition frequently fail to capture these potentials. Due to the existence of multiple power sources on these vehicles, an overall fuel consumption and emission control strategy needed be developed. For different types of vehicle technology, the electrical energy storage system (ESS) is utilized differently. HEV are classified into three categories following the types of power source: electric vehicles (EV), hybrid electric vehicles (HEV), and plug in hybrid electric vehicles (PHEV). An EV uses ESS as the sole energy source. Technically an EV would not be considered as a HEV; it is discussed here in order to compare with the other two types. The ESS on an EV, usually a battery pack, is only charged from grid electricity except for during regenerative braking. The vehicle range with one charge is directly related to the energy capacity of the ESS. A HEV on the other hand, has more than one energy sources. The ICE or FC is usually hybridized with an ESS on a HEV. The ESS would be charged by the ICE or FC during the vehicle operation according to power demand, and no external power source is necessary to charge the ESS. A plug-in hybrid electric vehicle is also a HEV with its ESS being charged either by the on board power source, such as ICE and FC, or the stationary grid power. In HEVs, the size of the ESS is determined to provide sufficient energy storage (*kWh*) capacity and adequate peak power (*kW*) ability. In addition, appropriate cycle life and hardware cost have to be considered. The size requirement of ESS varies significantly depending on the characteristics of different vehicle’s power trains (EV, HEV and PHEV) [12]. This requirement can be obtained once the vehicle is specified and the performance target is established. However what is less straightforward and more challenging is to find an optimal ESS design that would satisfy the special characteristics of vehicle power requirements. Normally, energy storage units are primarily sized by either the energy or power capability. Charging-discharging efficiency is also considered. In this study, a comparison of the performance characteristics (*Wh*/*kg*, *Wh*/L, W/*kg* etc.) of various energy storage technologies for different vehicle power requirements is made to guide the ESS design. The batteries charging systems can be of two types: public chargers and residential chargers. Public chargers are an optimal solution to charge the batteries of the vehicles using energy from several sources of energy (as wind or sun) and can be deployed at strategic places around a town or city, like for example, at companies, public buildings and shopping centers parking lots. On the other hand, residential chargers are designed to deliver low power, in an efficient way, since in general they are used to make a complete charge of the batteries during long periods of time (slow charging). The main benefits of these two types of chargers are the comfort for the user, and the freedom of the user to charge the batteries when he wants, according with the best prices of energy. The main disadvantage is that, since each charging process is independent, the limit of overload of the electrical power grid can be easily reached. Currently, the majority of EVs are designed with on-board unidirectional batteries charging systems. Besides the on-board batteries charging systems, some vehicles allow the charge of their batteries with off-board chargers. An on-board batteries charging system refers to a charger implemented inside the vehicle. The user only has access to the input of the charging system. This type of charger is connected to the AC electrical grid voltage and is used to slowly charge the batteries – it is denominated as “slow charging”. On the other hand, an off-board batteries charging system is implemented outside the vehicle. It is given access to the DC voltage of the batteries and is used to charge the batteries as fast as possible – it is denominated as “fast charging”. Regarding the way that the charger can be connected to the vehicle, there are two different approaches: conductive or inductive. The conductive batteries charging system is made through a physical contact between the vehicle and the power grid. In counterpart, with the inductive batteries charging system there is no physical contact between the vehicle and the power grid. Independently of the charger type, the interaction between the EVs and the power grid should comply with regulatory standards, as the International Electro technical Commission (IEC) norms (IEC 62196 and IEC 61851). The battery behavior shown in Figure 13 describes the best behavior of a battery. Indeed, the battery discharges during the on-peak power, before the driver leaves home. Then, the battery continues to discharge from home to work; the vehicle does not use the ICE. Once the vehicle is parked there is no further changes in the battery state. In this study the battery charging at business place is not considered. At the end of the business day, the driver comes back home and the battery is only used to propel the vehicle to home. Once back at home, the battery helps the grid to supply the household load until the off-peak hours start. During this time the battery is charged to prepare the next day. To prepare the next day, a constraint has been implemented in the optimization algorithm, that is the initial SoC has to be the same as the final SoC. This constraint allows to have a repeatable system. From 10 PM to 6 AM, the grid energy is greater than the household consumption and the battery will be charged since it is off-peak power

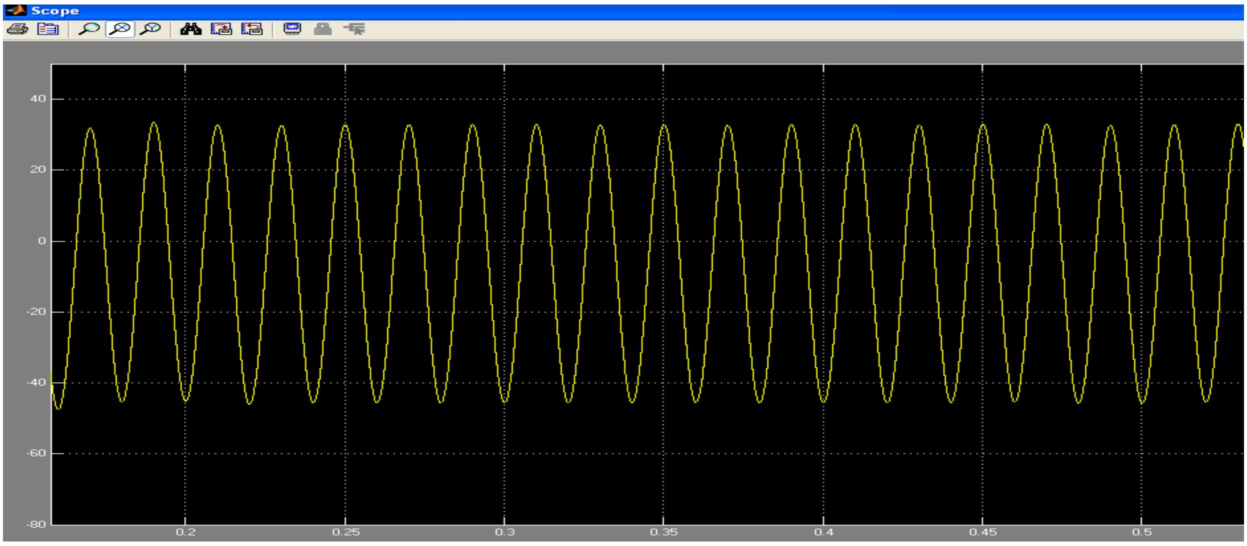


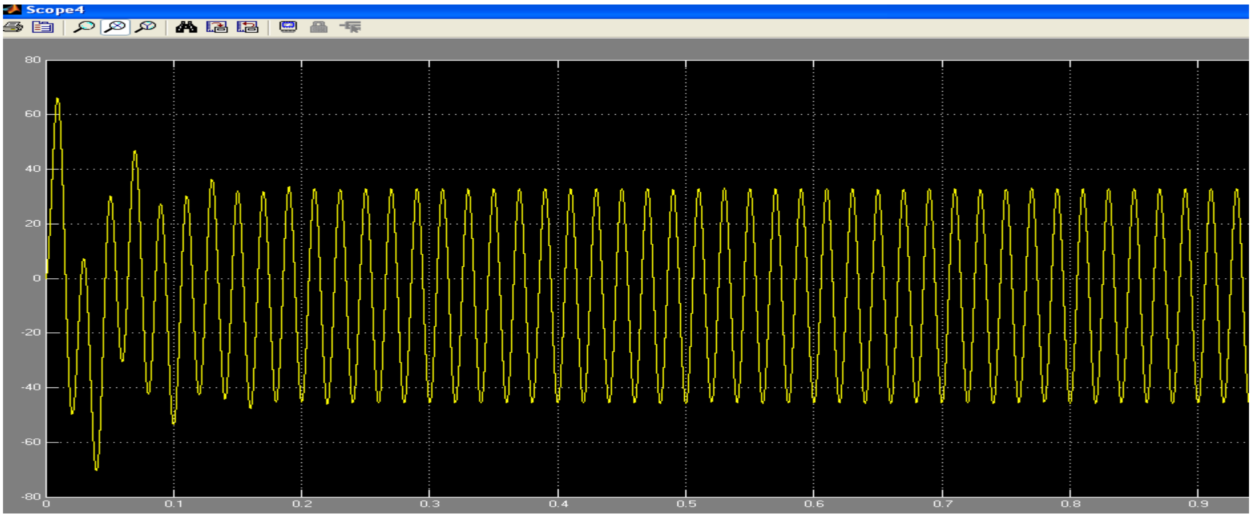
Battery State of Charge

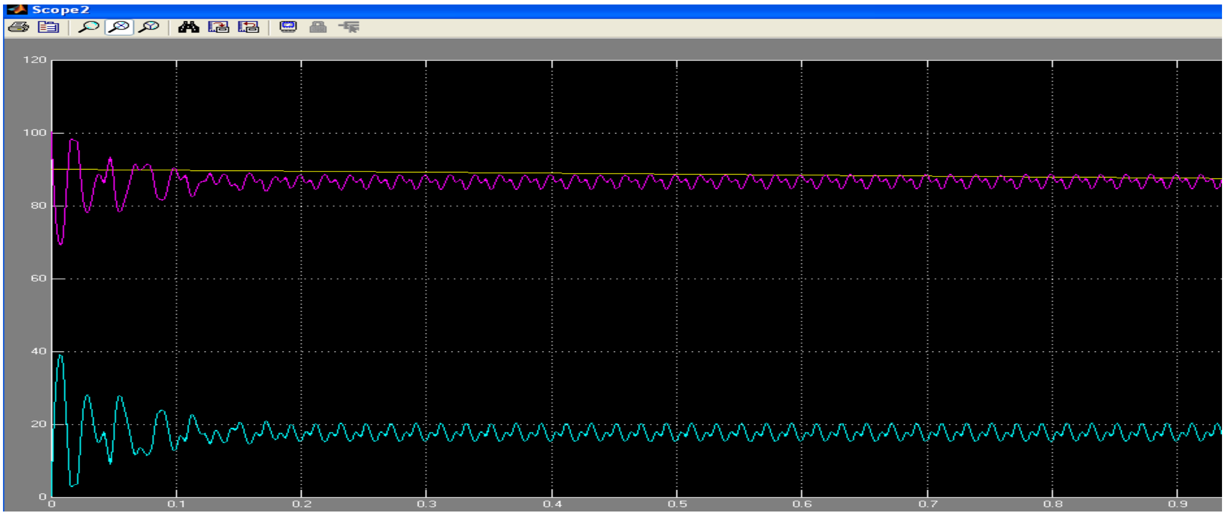


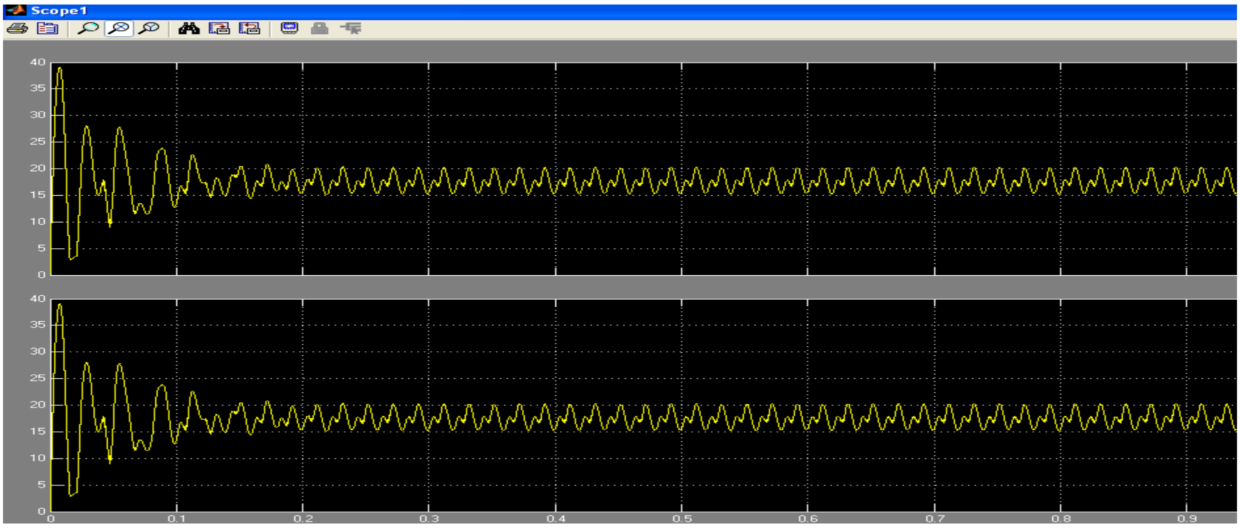
Simulink diagram for Electric Vehicle Batteries Charging System

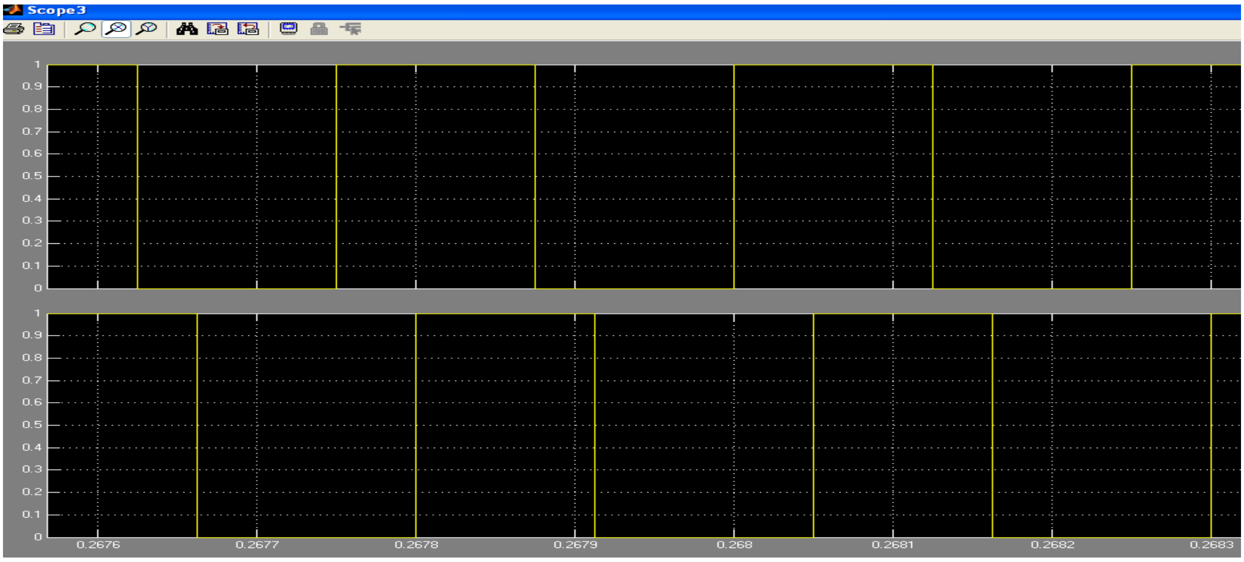
4. Simulation Outputs











Conclusion

The converter efficiency plays an important role in determining the exact amount of power available to the user. The efficiencies of various converters have been estimated by taking into consideration the non-idealities of the components of the respective converter. This graphs and plots presented in this paper corresponds to basic converters. But the procedure can be adapted to any converter once the converter is chosen since the losses calculation procedure or approach for each component of the converter remains the same. More, to implement converter losses allow the grid power to be smooth and then uses a significant amount of energy from the electric grid. This system has more losses than the regular system because of the step conversion. However the losses are less compared to the gain of reducing the peak power during the evening, when the vehicle helps the grid to supply household load.

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