Journal of Advances and Scholarly Researches in Allied Education
Vol. 16, Issue No. 3, (Special Issue) March-2019, ISSN 2230-7540

Simulation of Solar Powered Charging Station Interface for Electric Vehicles

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Abstract – Public charging networks for Electrical Vehicles (EV) is on the rise, with more than 1 million EV deployed worldwide. Whether for economic benefits (higher price per KWh for a faster charging) or for the sole purpose of priority, it has become a point of interest to set a strategy on how to prioritize EVs charging from a single network, especially if the power source is limited as in the case of renewable energy. In this paper a strategy will be proposed for EV charging station to give priority to certain EV to charge faster and prevent the SOC from being the main drive in case of limited power source. The aim of this paper is to design and evaluate a charging algorithm that will prioritize EV and fill some faster than others. This approach can be utilized by private businesses to categorize and lower the fees for charging, making EVs more attractive economically. The scenario considered for this paper is an office building parking lot that is shaded by solar photovoltaic (PV) panels. This paper discussed Time-multiplexing method, a strategy to charge EV from solar energy.

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INTRODUCTION

The necessity for a better fuel economy and further reduction in greenhouse gas emissions is pushing automotive industry to go through a comprehensive restructuring to electrify the vehicles and introduce plug-in hybrid electric vehicles (PHEV) and electric vehicles, cumulatively called plug-in electric vehicle (PEV). The electrical powertrain of current and upcoming PEVs is composed of an energy storage system connected to propulsion machine through an inverter. In addition, an add-on battery charger is inevitable part of vehicle powertrain.

In majority of PEV, a bidirectional dc/dc converter is deployed between the battery and propulsion machine inverter. This converter is responsible to boost the battery voltage and efficiently control the delivered or absorbed power during cruising and acceleration or regenerative braking, respectively. In this conventional structure, the bidirectional dc/dc converter is only operated during propulsion and an individual ac/dc converter is utilized to charge the battery. Regardless of the converter topologies, this architecture consists of two individual power electronic converters for two independent operation modes. An efficient solution to make the system more compact, lighter, and cost efficient would be integrating the add-on charger unit with the bidirectional dc/dc converter, which is used during cruising and acceleration.

The basic power electronic interfaces rendering volume and weight of electric and plug-in hybrid electric vehicles are an inverter, an on-board charger, and a bidirectional dc/dc converter. This paper proposes an innovative integrated bidirectional converter with a single-stage on-board charger to reduce the number of switches, size, and weight of the power electronic interfaces. The analyses show that 266 cm^3 and 1.1 kg can be saved due to the elimination of the inductor core used for power factor correction in charging mode, in addition to the reduction achieved through removal of inductor winding, power switches, diodes, and additional heat sink of the conventional structures. A proof-of-concept prototype with power limits of 8.4 kW in charging and 20 kW in propulsion modes has been designed and validated at various power levels. The peak efficiencies for propulsion and regenerative braking operations are measured as 96.6% and 94.1%, respectively. The power factor is recorded as 0.995 at 1.8 kW charging power, where crest factor and peak efficiency are recorded as 1.49 and 91.6%, respectively. The overall electric powertrain with a single integrated power electronic converter is illustrated in Fig. 1. In this structure, the charger and the bidirectional dc/dc converter share the same power stage as charging and propelling do not happen at the same time. As a result, overall cost, weight, and volume of the power electronic converter can be reduced effectively through reducing the number of switches, sensors, and large volume energy storage elements such as inductors.

PROPOSED APPROACH

In this regard, this paper proposes a new integrated single-stage charger topology for PEV, which can also be used in retrofit conversion of an HEV to a PHEV. The proposed converter uses minimum circuit components offering a further cost-effective solution in comparison to the other integrated charger topologies presented in the literature review. With the boost charging capability, it enables operating with wide single-phase charging voltage ranges including 120/220/240 VAC, considering the battery voltage is between 300–400 V, which is the case in Chevy Volt. In addition, it is capable of stepping up and stepping down the voltage in both power flow directions during cruising and acceleration, as well as regenerative braking.

This paper is organized as follows:-

- The advantages and motivation of using an integrated charger and a bidirectional dc/dc converter in the powertrain.
- The proposed integrated topology is introduced and operation modes are explained in detail.
- The proposed converter is compared with other possible basic single-stage charger topologies.
- In addition, detailed analyses on size reduction, loss, and reliability are presented in this section.
- The overall control scheme developed for controlling each essential operation mode is explained in detail.

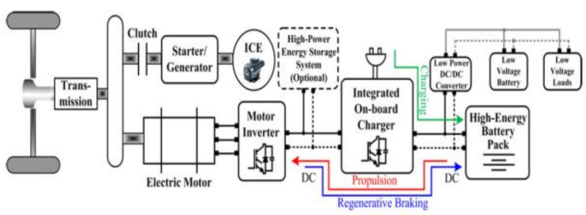

Fig. 1 System level structure of a parallel powertrain PHEV with on-board integrated battery charger

HYBRID ELECTRICAL VEHICLE

A plug-in hybrid electric vehicle (PHEV) is a vehicle powered by a combination of an internal combustion engine and an electric motor with a battery pack. The battery pack can be charged by plugging the vehicle into the electric grid and from using excess engine power. A PHEV allows for all electric operation for limited distances, while having the operation and range of a conventional hybrid electric vehicle on longer trips. The purpose of this study was to develop a methodology for optimizing a PHEV design using minimum drivetrain cost as a figure of merit and determines the optimum designs for an all-electric range (AER) of 10, 20, and 40 miles. Design parameters, electric motor size, engine size, battery type, and battery capacity, are optimized to determine the least cost design that meets a fixed set of vehicle performance constraints.

The performance constraints are: 0-60 miles per hour (mph) acceleration time, 50-70 mph acceleration time, 0-30 mph acceleration time in electric only operation, top speed, and grade ability. The design optimization was carried out for three different levels of all electric range between 10 and 40 miles. A plug-in hybrid electric vehicle (PHEV) is a vehicle powered by a combination of an internal combustion engine and an electric motor with a battery pack. The battery pack can be charged by plugging the vehicle into the grid and from using excess engine power. A PHEV allows for all electric operation for limited distances, while having the operation and range of a conventional hybrid electric vehicle on longer trips. PHEVs have significant potential to reduce oil consumption and greenhouse gas (GHG) emissions. Using energy off the grid as a substitute for burning gasoline, PHEVs increase coal, natural gas, and nuclear energy use in power plants, but also increase our energy independence from oil. There are an increasing number of prototype vehicles being developed. However, most of the prototype designs have been designed with the intent to prove the technology. There have also been many examples of converting hybrid electric vehicles (HEVs) to PHEVs. However, a methodical design optimization has not yet been published.

OPTIMIZATION CONSIDERATIONS

A vehicle design optimization presents many complexities. A vehicle presents a system of many components working together in very intricate ways. The powertrain of a hybrid electric vehicle (HEV) is a link of an internal combustion (IC) engine, electric motor, transmission, wheels and axles, and battery pack. Each component has several parameters and possible designs. For example, a battery pack can have different capacities, chemistries, and voltages. Varying a single parameter typically has an effect on the whole system design. Also, compatibility between different components with varying parameters must be checked. For example, it must be ensured that the battery pack has enough available power to supply the peak electric motor power and there must be a check to see if the transmission can withstand the torque from the motor and engine. Also, there must be a way of evaluating the effectiveness of any given design. The vehicle design must adhere to a set of performance constraints, such as 0-60 mile per hour (mph) acceleration time and grade-ability constraints. Also, the vehicle design must be evaluated for cost to determine the minimum cost design. There could be many other figures of merit besides lowest cost, such as minimum gasoline consumption, minimum weight, or best performance.

PURPOSE

The purpose of this study is to determine an optimum least cost PHEV design with base vehicle characteristics that meets a set of performance constraints. Knowledge of this optimum design will allow for better accuracy when using PHEV characteristics in estimating future energy consumption, emissions, and social impacts. The vehicle design parameters engine size, electric motor size, battery pack capacity and battery types are optimized. A base vehicle platform resembling the characteristics of a mid-sized sedan is used. The least cost design that meets a set of performance parameters including 0-60 mph acceleration time, 50-70 mph acceleration time, 0-30 mph all electric acceleration time, sustained grade ability, and top speed, is determined for different values of all electric range. The social impact of the optimum designs are evaluated in terms of reduced carbon emissions and gasoline consumption. The optimization construction and methodology is developed. The resulting methodology can be adapted for different vehicle technologies and performance constraints.

OVERVIEW OF A HYBRID ELECTRIC VEHICLE

A hybrid electric vehicle (HEV) uses both an internal combustion (IC) engine and an electric motor in the powertrain, and also uses a bank of batteries to recapture and store energy from braking. This combination of an electric motor and an IC engine is more efficient from a system viewpoint than a conventional powertrain. There are many different configurations of hybrid electric systems, including series, parallel, and power-split platforms. All PHEVs in this study have a parallel hybrid configuration with a pre-transmission motor location and a continuously variable transmission (CVT). This configuration is shown in Figure 3.1. The addition of HEV technology to a vehicle design improves efficiency primarily by four ways. First, the addition of the electric system allows the IC engine to operate in a more efficient range a greater amount of time. Typically, IC engines are more efficient at a higher load near wide open throttle. In a conventional vehicle, power requirements at cruising and idling are so low that the engine is forced to run at a lower than optimum loading. However, with a hybrid configuration, the IC engine can run at the most efficient load most of the time, using the excess power to charge the batteries. If the batteries are charged, the electric motor can provide the small amount of power required to propel the vehicle while the engine remains off.

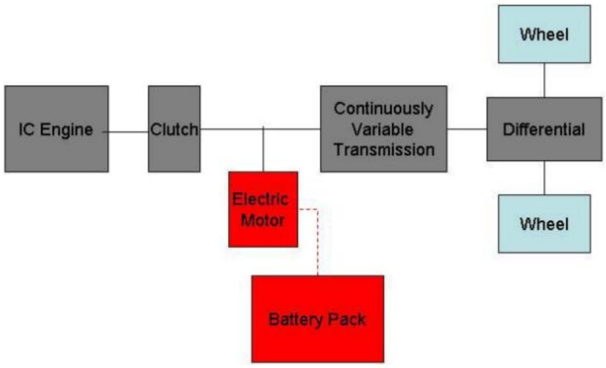

Figure 3.1 PHEV Parallel Pre-Transmission Configurations with CVT

Second, having the power of an electric motor at hand, it makes it possible to downsize the engine. Electric motors have higher torque at low rpm range while IC engines typically have high torque at high rpm range. This makes using an electric motor combined with an engine during acceleration, a time when the highest torque is needed, more efficient that using a larger equivalent torque IC engine. Also, having a smaller engine reduces the engine braking load, leaving more energy available to be recovered by regenerative braking. Thirdly, having an electric motor allows the IC engine to completely shutoff instead of idling. The electric motor can simultaneously start the car moving and start the engine. Not having the engine idling while sitting at a traffic light significantly increases fuel economy in city driving. The Chevrolet Silverado incorporates this mild form of hybridization, and by simply eliminating engine idling, it has shown a 13% fuel economy increase in city driving. Finally, the electric system allows for extensive recapture of the energy of braking. In conventional vehicles, deceleration is accomplished by friction between brake pads and rotors. The kinetic energy is dissipated in the form of heat. However, it is possible to recover a lot of this energy in useable form. By using the electric motor in reverse as a generator, the resistance created by the generation of electricity can be used to decelerate the vehicle and the electricity generated is used to charge the battery. Some estimates show it is possible to get almost 60% of the energy of braking back into useful electricity.

MODELLING AND SIMULATION

Modelling and Results of Solar-PV System: -

A 30 KW panel is considered as consisting of 24,080 solar cells arranged in 344X70 combinations. The solar array consists of number of panels connected in series-parallel configuration and a panel consists of number of cells. The power characteristics of the solar cell are formulated using its equivalent circuit. The equivalent circuit of the cell is presented as a current source in parallel with diode and a parallel resistance with a series resistance.

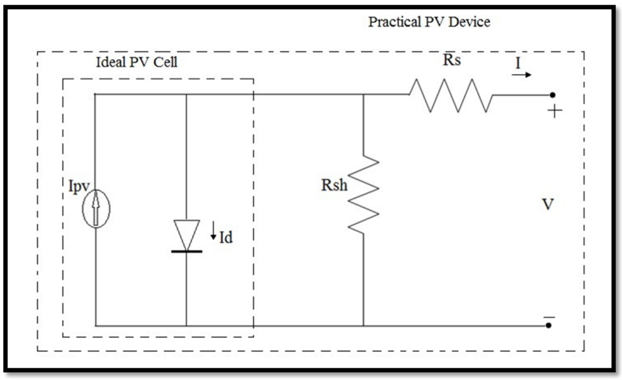

Figure-4.1 Equivalent circuit of a practical PV device

The output current can be measured by subtracting the diode currents and current through resistance from the light generated current. From this circuit, the output current of the cell is expressed as,

$$I = Ipv - Id - I_{Rsh} \qquad (4.1)$$

$$I = Ipv - I_0\left[\exp\left(\frac{V+IRs}{a}\right) - 1\right] - \left(\frac{V+IRs}{Rp}\right) \qquad (4.2)$$

Where,

$$a = \frac{NS.A.K.Tc}{q} = Ns.A.V_T$$

$$= \frac{Isc + Kv * dT}{\exp\left(\frac{Voc + Kv * dT}{a * V}\right) - 1}$$

Where, ns are numbers of cells connected in series. The output current of the solar panel is I. The light generated current is Ipv. Saturation currents through diodes are I_0. The voltage at output of panel is V Series resistance of cell is Rs which represents the internal resistance of cell and it is considered as 0.55 Ω. The Boltzmann's constant is K (1.38 X 10^{-23} J/K). Ambient temperature (in Kelvin) is T and charge constant is q (1.607 X 10^{-19}C). A 30 KW solar-PV array is realized considering 24,080 cells (344×70 dimensions) using (4.1) - (4.2). A Matlab model for the same is developed.

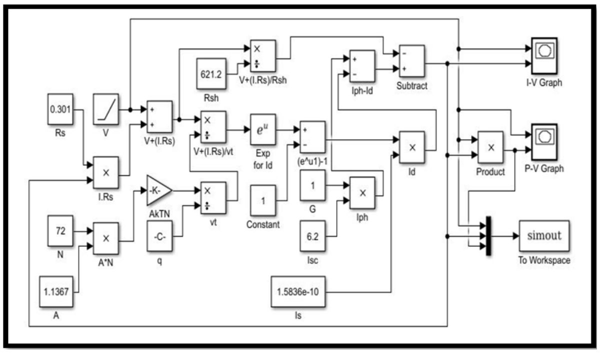

Fig 4.2 Solar PV MATLAB Modelling

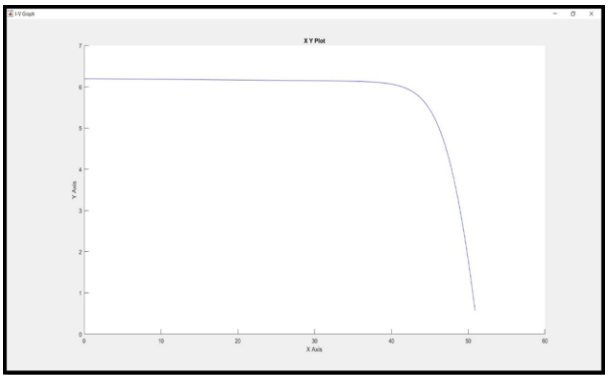

Fig 4.3 Solar Cell I-V Characteristics

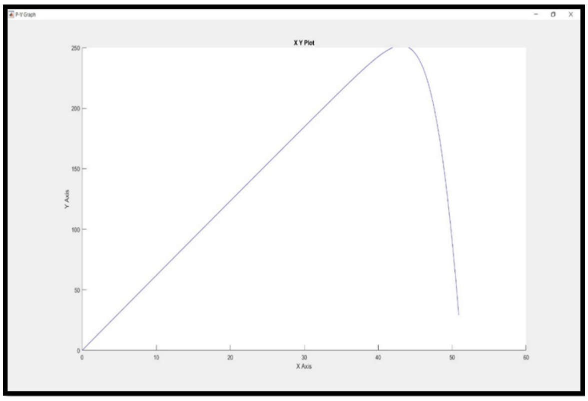

Fig 4.4 Solar Cell P-V Characteristics

Electrical Vehicle Charging System

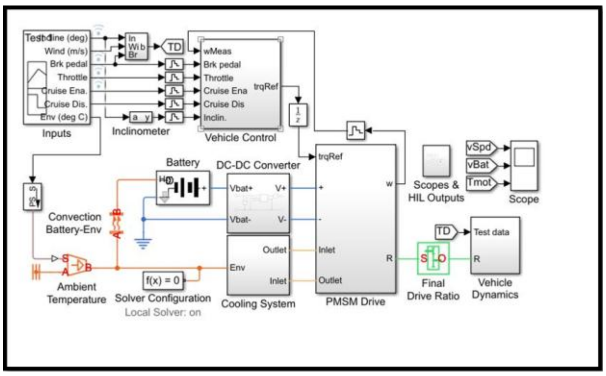

Fig 4.5 Electrical Vehicle Charging System

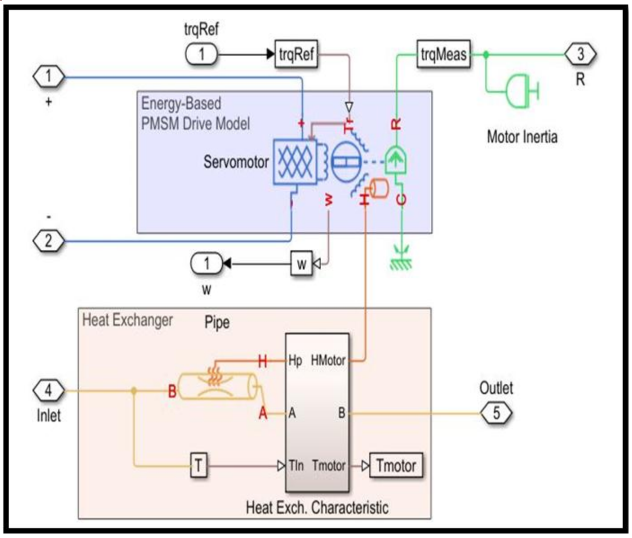

Fig 4.6 PMSM Drive Subsystem

Simulation Results

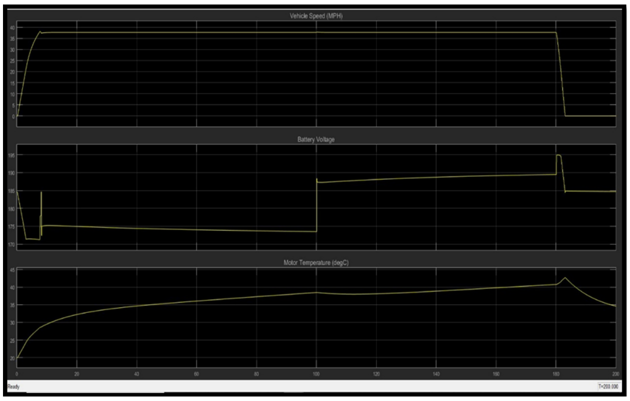

Fig 4.7 Electrical Vehicle output system

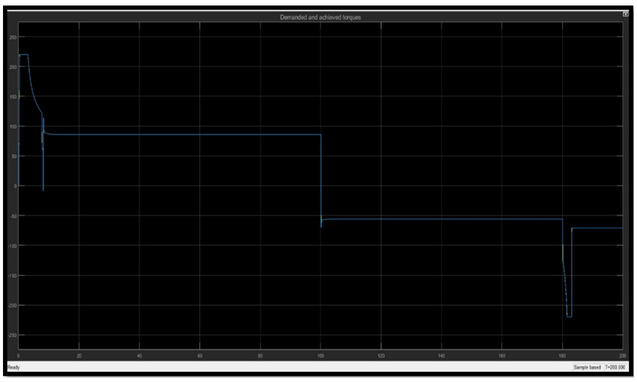

Fig 4.8 Torque Variation after controlling

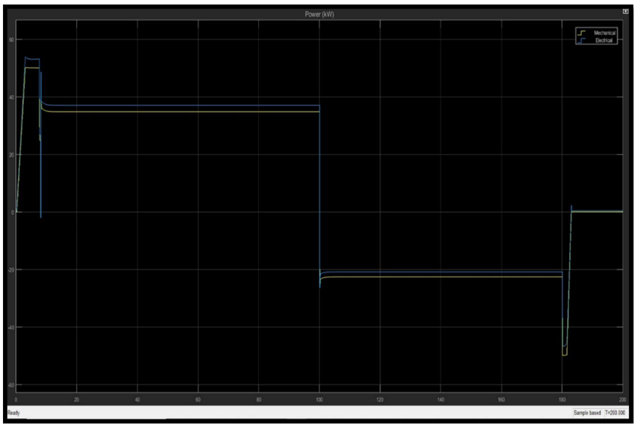

Fig 4.9 Mechanical and Electrical Power Variation

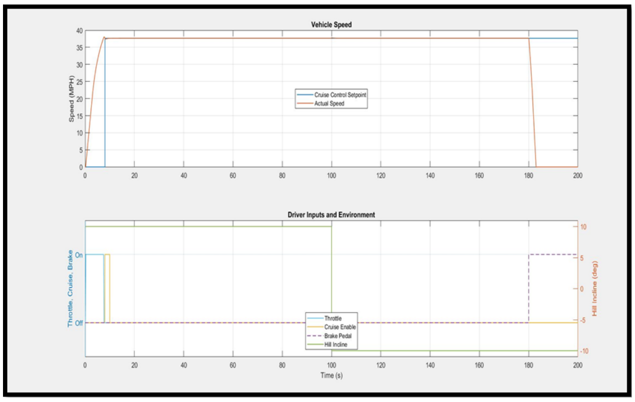

Fig 4.10 Vehicle Parameters

Matlab Simulation of Solar Based Charging Station

In this section we have develop the Matlab simulation of Charging station for electrical vehicles, which consists different multiples sources for electricity including Solar PV, Fuel Cell, and main Grid utility supply system. Due to that kind of configuration the continuous power supply 24*7 is available from the charging station.

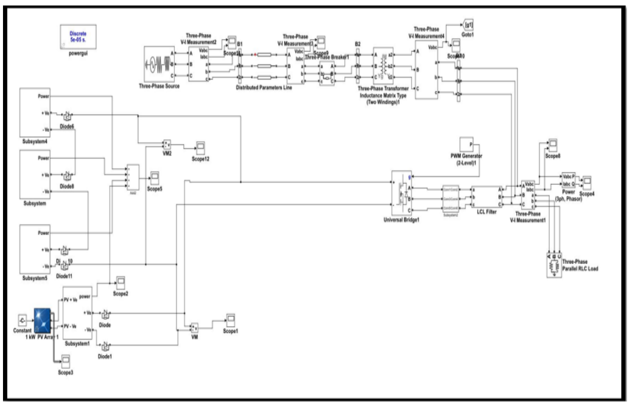

Fig 4.11 Proposed Charging station System Matlab Simulation

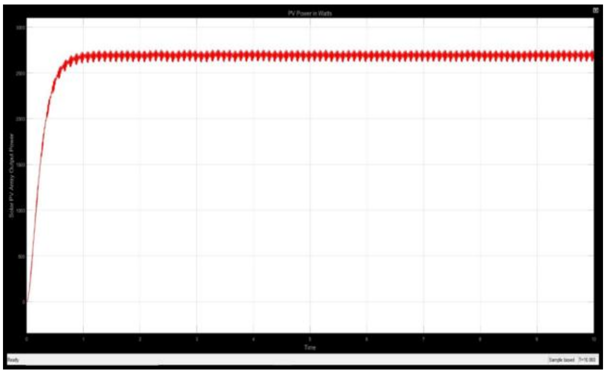

Fig 4.12 Solar PV output Power

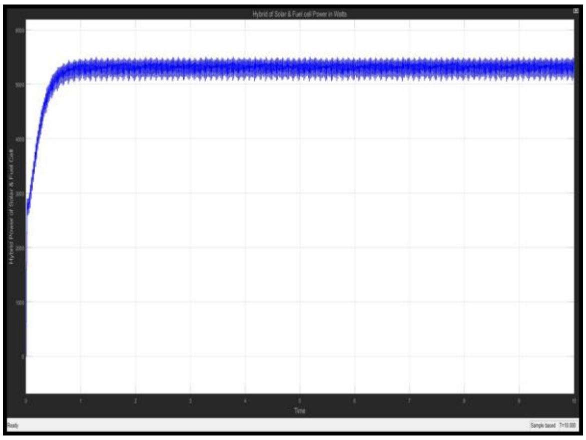

Fig 4.13 Hybrid Power output of Solar PV and Fuel cell configuration

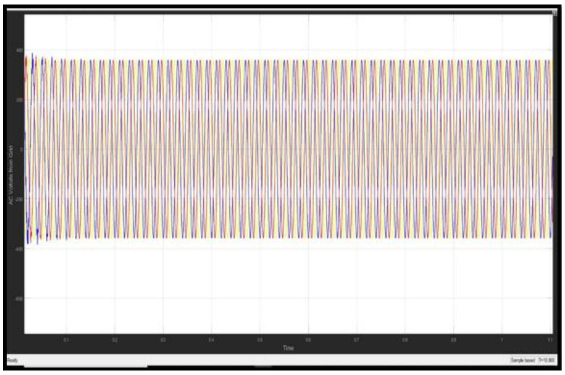

Fig 4.14 Main Grid AC Supply voltage

Fig 4.15 Receiving end Output AC voltage and Current

CONCLUSION

This paper discussed Time-multiplexing method, a strategy to charge EV from solar energy. This method proved to be successful by simulation and experiment in charging EV different amount of energy based on priority. Further investigation of this method can be carried to reduce the charging cycle time, and study the effect of constant switching on the battery lifetime. This Paper also highlights the future developments, which have the potential to increase the economic attractiveness of such systems and their acceptance by the user. This Paper also represents the modelling and Simulation of Solar PV System using MATLAB-SIMULINK software. The Simulation results show the ideal I-V and P-V characteristics of the solar PV system. The Matlab Simulation of Electrical Vehicle Charging station based on Solar PV is succefully developed with multiple sources of Fuel cell and Main utility grid supply.

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