Modeling and Simulating a battery management system for an Electric Vehicle Applications

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ABSTRACT

Greener transportation is the motivation to shift from conventional vehicles to electrical vehicles (EV). EV's being the present technology, charging of the EV's battery with best charger in secured environment is the challenge. The EV's fast charging DC has advantages in reducing charge time, but maintaining the optimal temperature for the battery and availability of charging stations have benefited on-board charging (through AC supply). The constant current constant voltage (CCCV) battery charger has reduced the peaking currents during initial stages and promotes charging of cells with different capacities at the final stage. The environment to charge must be safe, so as the battery never damages. In onboard charging, due to fault currents inducing in the supply might damage the battery, so an intelligent controller is required to detect theses faults and can open the circuit breaker associated with it. The idea of this work is to charge the EV's battery with CCCV battery charger through on-board charging system where the supply is derived from grid and solar. The supply system has intelligent controllers operating to detect the faults and to work respectively. The backup generator has been provided during faults in grid. The intelligent controller used to generate the control signals for circuit breakers is Arduino Uno. The solar has been converted to AC by using a three-level neutral point clamped based State Vector Pulse Width Modulated (SVPWM) inverter. To generate the control signals from Arduino Uno, the Proteus Professional software has been utilized and to simulate the present work, MATLAB/Simulink software has been used respectively.

Keywords: Electric vehicle (EV), solar array, on-board charging, constant current constant voltage (CCCV) technique, state vector pulse width modulation (SVPWM), circuit breakers, Arduino Uno, current sensor etc.

1. INTRODUCTION

Electric vehicles (EVs) have taken a significant leap forward by advances in motor drives, power converters, batteries, and energy management systems [1]–[4]. However, due to the limitation of current battery technologies, the drivingmiles are relatively short that restricts the wide application of EVs [5]–[7]. In terms of motor drives, high-performance permanent-magnet (PM) machines are widely used while rare-earth materials are needed in large quantities, limiting the wide application of EVs [8], [9].

In order to overcome these issues, a photovoltaic (PV) panel and a switched reluctance motor (SRM) are introduced to pro-vide power supply and motor drive, respectively. First, by adding the PV panel on top of the EV, a sustainable energy source is achieved. Nowadays, a typical passenger car has a sur-face enough to install a 250-W PV panel [10]. Second, a SRM needs no rare-earth PMs and is also robust so that it receives increasing attention in EV applications [11]–[16]. While PV panels have low-power density for traction drives, they can be used to charge batteries most of time.

Generally, the PV-fed EV has a similar structure to the hybrid electrical vehicle (HEV), whose internal combustion engine (ICE) is replaced by the PV panel. The PV-fed EV system is illustrated in Fig. 1. Its key components include an off-board charging station, a PV, batteries, and power converters [17]–[19]. In order to decrease the energy conversion processes, one approach is to redesign the motor to include some onboard charging functions [20]–[22]. For instance, paper [22] designs a 20-kW split-phase PM motor for EV charging, but it suffers from high harmonic contents in the back electromotive force (EMF).

Another solution is based on a traditional SRM. Paper [23] achieves onboard charging and power factor correction in a 2.3-kW SRM by employing machine windings as the input filter inductor. The concept of modular structure of driving topol-ogy is proposed in paper [24]. Based on the intelligent power modules (IPMs), a four-phase half bridge converter is employed to achieve driving and grid-charging. Although modularization supports mass production, the use of half/full bridge topol-ogy reduces the system reliability (e.g., shoot-through issues). Paper [25] develops a simple topology for plug-in HEV that supports flexible energy flow. But for grid-charging, the grid should be connected to the generator rectifier that increases the energy conversion process and decreases the charging effi-ciency. Nonetheless, an effective topology and control strategy for PV-fed EVs is not yet developed. Because the PV has differ-ent characteristics to ICEs, the maximum power point tracking (MPPT) and solar energy utilization are the unique factors for the PV-fed EVs. In order to achieve low-cost and flexible energy flow modes, a low-cost tri-port converter is proposed in this paper to coor-dinate the PV panel, SRM, and battery. Six operational modes are developed to support flexible control of energy flow.

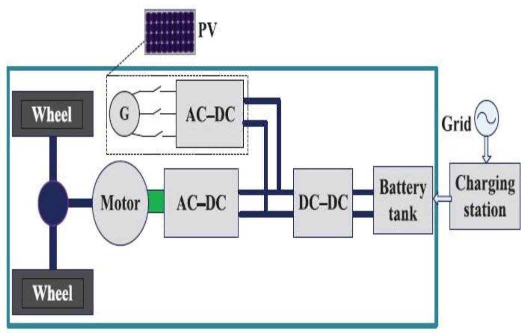

Figure 1:PV-fed HEV.

The drastic decline in the fossil fuels [1], brings out the term E for Electric in place of Engine. Electric vehicles have become a vital coinage in Auto mobile industry. The heart of this vehicles [2] are motor and the power supply to the motor(battery). Various charging paradigms have paved their way for fast and efficient charging. One among them is off-board charging (DC charging), which has a capability of charging 80% of Battery within 19minutes with greater limitations. The less availability of DC stations and temperature management in the battery pave the way to shift again to on-board [3] charging stations (AC charging). There is a great demand for efficient way of charging and fault isolation. At present power grid system are solely following the conventional methods, where the integration [4] studies are highly required to adopt new generation units and consumers. In this context, the studies for integration of a solar to existing power grid is realized with the dynamic loading sequences at charging station. The charging station which is equipped with roof mounted photovoltaic panels is integrated with peak time solar power generation data [5]. The dynamic response of the grid is under the surveillance of micro controller to ensure the fault levels generated at the transmission lines and to simulate a response accordingly. This discourse, discusses the way to integrate power from the grid and the PV array [6] to charge a battery and also to isolate the system during the fault generation [7]. Battery controller [8] (CCCV) maintains the current level during the initial raise in voltage and maintains the voltage level when it reaches its desired value.

In Simulink, the voltage and current values of power grid for on board charging are observed. Then three phase faults like double line to ground fault are imposed at a specified section with a particular time period to identify the changes in the system parameters. Immediately the intelligent control system incorporates the circuit breaker [9] action preventing the system from any failure. The novelty in parallel scaling down and sensing out the fault current to isolate the system with the help of circuit breaker is achieved using the current sensor and Arduino micro controller [10] simulated in Proteus professional.

The paper has been organized into four sections. Section 2, describes the system and specifications of the proposed system. Section 3, discuss about methodology of proposed system, here the MATLAB simulated system and its results along with system simulated in Proteus have been discussed. Through section 4 paper gets concluded.

2. ELECTRICAL VEHICLES

Global warming, carbon footprint, environmental pollution and shortage of fossil energy hasled to the wide application of Electric Vehicles in many countries. With the rapid developmentof the EV industry, planning of ways to charge EVs is gaining widespread attention [1].Moreover, apart from private vehicles, modes of public transport like Auto-Rickshaw are alsobeing developed using PV in developing countries [2]. Charging of an EV plays a veryimportant role in the EV industry. We use EV to decrease the carbon footprint due to vehiclesrun by petroleum products. But charging of an EV also needs electricity.

There's no meaningof using an EV if the charging of EV is done altogether by conventional power plants that usefossil fuels or nuclear energy for producing electricity. Anticipation is to make future chargingstations powered by on-site PV systems [3]. But due to intermittency of solar power, we needto connect it with grid as well to create a reliable supply source. Charging deadlines are the keydeterminant of the overall carbon footprint of the charging service. The later the deadlines are,the more solar energy would be available for EV charging, reducing the use of conventionalenergy and the associated carbon footprint. This method can be used to charge an EV to travelfor longer distances but with charging wait time associated with it. To further reduce the waittime, the concept of PV-based Battery Switch Stations was proposed [4].

In the BSS, theautomated switch platform will replace the depleted batteries with fully charged batteries. Thiscan be done in a very short duration of time as compared to charging the battery. Unfortunately,no charging technology is available until now that can charge the battery in less than half anhour. Thus, BSS can be useful in charging of an EV with minimum wait time. Furthermore,workplaces like office buildings, factories and industrial area are the ideal places to providesolar EV charging where the building rooftop and car parking lots can be mounted with PVpanels [5]. A grid connection will be necessary here too to ensure reliable power supply butlarge charging durations (6-9 workplace hours) will result in low power requirements whichcan be met by the PV panels in most cases.

Powering public EV charging stations at workplaceusing local solar generation is a very promising application as solar power peaks at almost thesame time when utilization of this station peaks, creating an opportunity for maximum solarenergy utilization and thus, reducing the carbon footprint of EV charging. Lastly, the conceptof solar hat was proposed to utilize car rooftop for charging of the EV [6]. Until now, theefficiency of PV panels and the size of the car rooftop where it can be mounted doesn't allowfor complete dependence of energy consumed by EV to be produced by solar hat. But this doesnot mean we cannot use it. Most vehicles draw some power even when the key is switched off. This sleep mode current discharges the battery. If the vehicle is kept idle for a long time, even then the battery will be discharged.

A battery drain of 30% will cause problems to crank thevehicle due to inductive loads. Hence, even though we cannot power an EV with rooftop PV,we can make sure the battery do not drain due to sleep mode current. This can be used for bothEVs as well as traditional internal combustion engine vehicles to avoid battery discharge dueto sleep mode currents.

In [1], algorithm for determining where a PV farm or solar charging station needs to be kept isproposed. The charging demand is divided into three types: slow, regular and urgent chargingdemands. The slow charging demand is met during long-time parking by slow charging piles,which are located at residential buildings and office parking lots. The regular demand is metby regular charging piles, which are usually located at commercial parking lots, with a higherrated power than that of slow charging piles. The urgent demand is met by fast charging stationsbuilt along the roads, in case of an EV needs urgent charging. Calculation of charging demand,planning of charging piles and planning of fast-charging stations are the factors depending onwhich, where a solar station must be situated is decided. Currently, slow and regular demandcan be met easily with the existing technology but to meet urgent charging demands (preferablyless than 30 minutes charging time) much work needs to be done. This PV farms/Solar stationscan use various concepts of designing EVSE, V2V, V2G, Reactive Power Compensation, etc.along with location algorithms to provide best charging facilities to an EV.

3. SYSTEM & SPECIFICATIONS

The proposed system's block diagram has been shown in Fig. 2. It can be seen that the power from grid has been integrated with solar power and together charging the battery of an EV with CCCV on-board charger. The integrated solar power has been converted from its natural DC into AC with the help of a neutral point clamped three-level inverter respectively. This inverter [11] has been controlled through the PWM pulses generated from SVPWM. It can be observed that the input current to the charger is continuously monitored by the current sensor. The current sensor has been integrated to a microcontroller (Arduino Uno), which generate control signals to monitor the safe supply. The backup generator has been supplied for backup.

The VI-characteristics and maximum power point [12] (MPP) curve of the solar array used has been shown in Fig. 3. It can be observed that the plot has been plotted for irradiance of 1000wm-2 and working temperature of 25oC respectively. The maximum power (25kW) can be tracked when solar operates at 415V. The short-circuit current and open-circuit voltage are 72A and 415V respectively. Table 1 shows the parameter values of the solar array used in the simulation. The Fig. 4 shows the battery discharging characteristics. From the plot it can be inferred that the exponential voltage being 456V and the pink area shaded in the plot corresponds to the exponential voltage drop. The discharge curve has been drawn at 0.4347C rating. It can be observed that the nominal voltage is 400V and the battery drains completely at 2.3 hrs. with discharging current 43.47A (0.4347*Irated). The discharging curves have been even plotted for 0.065C, 0.13C and 0.325C ratings. It can be seen that battery drains completely at 15.8, 7.2, 3.1 hrs. respectively. The battery parameter values have been depicted in Table 1.

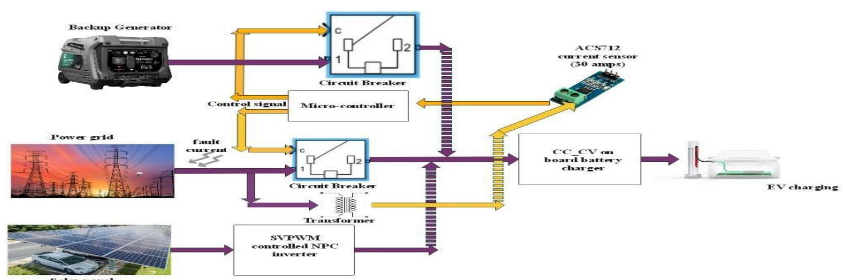

Figure 2. Block Diagram of the proposed system.

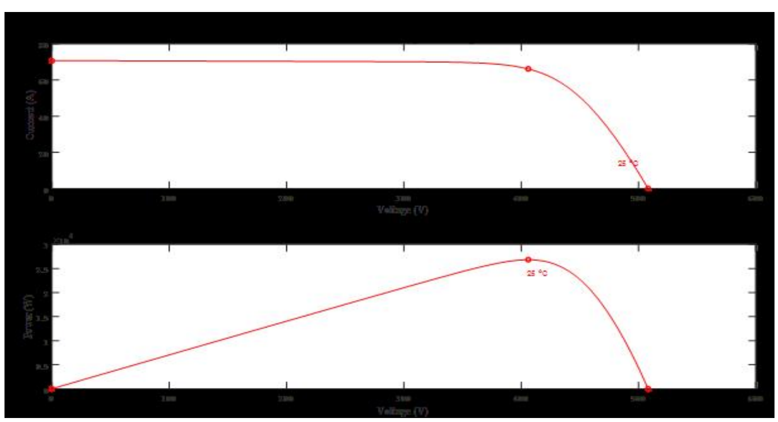

Figure 3. V-I characteristics and MPP curve of Solar array simulated

The battery charger input parameter curves along with the harmonics in input current have been shown in Fig. 5. The charger efficiency, power factor and THD of battery charger has been plotted with respect to the usage factor for the polynomial curve. The specified along with simulated curves have been shown. The specified being the darker. At 0.7 usage factor, the battery charger efficiency is observed as 82% and input power factor as 0.79 and the THD being 0.24 respectively. It can be seen that the dominating harmonic is 5th harmonic with frequency is 250Hz (5*50) with amplitude 0.9. The parameter values of the battery charger circuit used in simulation has been shown in the Table 2.

Table (1). Specifications and parameters of solar array and battery.

Solar Array		Battery	
Parameter	Value	Parameter	Value
Short-circuit current I_{sc}(A)	7.84	Maximum/Rated capacity(Ah)	100
Open circuit voltage V_{oc}(V)	36.3	Nominal voltage(V)	400
Irradiance (Wm^{-2})	1000	Initial State -of –charge(%)	2
Maximum power(W)	213.15	cutoff voltage(V)	300
Series and parallel connected module per string	14,9	Fully charged voltage	465.5949
Current and Voltage at maximum power point I_{mp}(A), V_{mp}(V)	7.35,29	Normal discharge current and Internal resistance(ohms)	43.4783 0.04

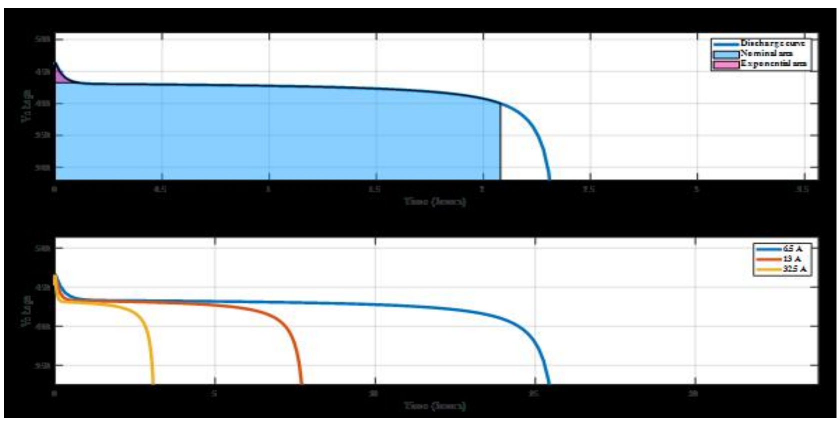

Figure 4. Battery discharging characteristics.

Table (2). Specifications and parameters of Battery charger

Parameter	Value
Nominal power(W).	40000
Effective voltage(V)	400
Frequency(Hz)	50
Bulk current(A)	100
Float voltage(V)	400
Fully charged voltage(V)	465.5949

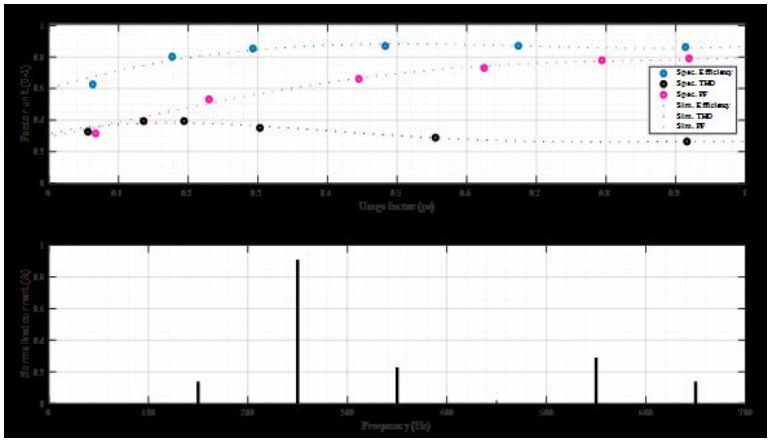

Figure 5. Battery charger parameter curves and Input current harmonics

The nominal voltage of current sensor ACS712ELC-30A is 5V and it measures the between 30A and -30A with the scaling factor of 66mV per Amp.

4. SIMULATION RESULTS

The simulation model of the proposed system has been shown in Fig. 6. For simulating the specifications of Hyundai Kona vehicle has been selected. The lithium ion battery of the vehicle is 40kW with terminal voltage of 320V-400V respectively. For powering the battery of 40kW, a (√3*40) 69.28kW of AC power has been chosen. Among which the solar is providing a 25kW of power and remaining being fed from grid respectively. The line rms voltage at which the system operating is 400V respectively. The DC power of solar has been converted to AC for integrating it with grid power to provide on-board charging which has been shown in Fig. 7. The conversion has been done by utilizing a neutral point clamped (NPC) based three-level inverter. To achieve the desired output, the state vector pulse width modulation technique has been used for generating the gate pulses of the inverter. The state vector method converts the three-dimensional vectors into two-dimensional space. The inputs to SVPWM generator are the reference AC voltage waveforms, the positive and negative clamped DC link voltages along with the input dc current. The states for the respective block are generated by utilizing the XOR logic. The state variables being A, B, C and states being PNN, PPN, NPN, NPP, NNP, PNP respectively. This block generates the twelve pulses which are fed to the inverter.

The LC filter has been used after the output of the inverter to filter the harmonics. This integrated power is transferred to battery through CCCV battery charger which have inputs as constant voltage, constant current and three phases of AC input supply. The constant current and voltage are specified as 100A and 400V. This on-board charge converts the AC into DC and charges battery at constant current till the terminal voltage reached its specified value and once reached then battery charges at constant voltage respectively. The circuit breakers (CB) have been connected to the grid before integration to safeguard the equipment. These circuit breakers command signal will be generated according to the faults induced in the system. During fault conditions, the MATLAB function block generates low signal to open CB of grid and to close CB of the backup generators to supply the battery without any interruption. Due to limitations of MATLAB the logic utilized to generate control signals from Arduino Uno has been imported to the MATLAB function block and generated the command signals required for the CB's of the system. The generation of control signals during faults through Arduino Uno have been shown in the Proteus Professional software as the continuation of this model.

The simulation figure shown in Fig. 6 has been simulated and its respective results have been depicted from Fig. 8 to Fig. 15 respectively.

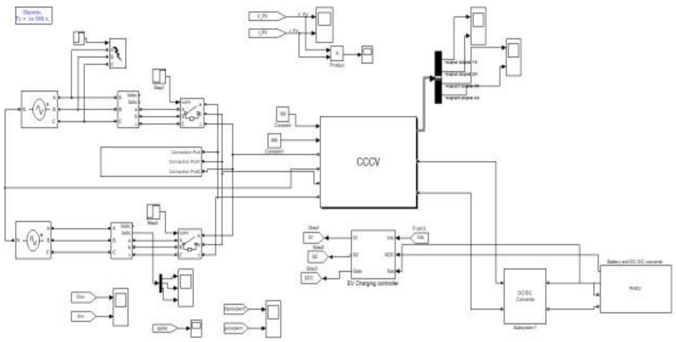

Figure 6. Overall simulation figure of the proposed system

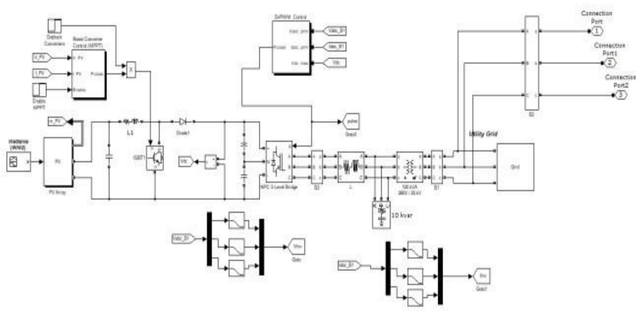

Figure 7. Solar (SVPWM 3level Inverter) subsystem simulation figure

From Fig. 8 it can be inferred that the overall DC link voltage or solar voltage is maintained at 460V and the solar current is observed to maintain at 42A respectively. The Fig. 8 shows the gate pulses generated by SVPWM. It can be seen that the twelve pulses are multiplexed and fed to the NPC based three-level inverter. The Fig. 9 shows the output voltage and current waveforms of the inverter. It can be seen that 320V peak voltage (i.e., 400Vrms line) has been generated and current of 51A peak (36Arms) respectively. It can be seen that the required (√3*400*36) 25kW power has been generated from solar subsystem.

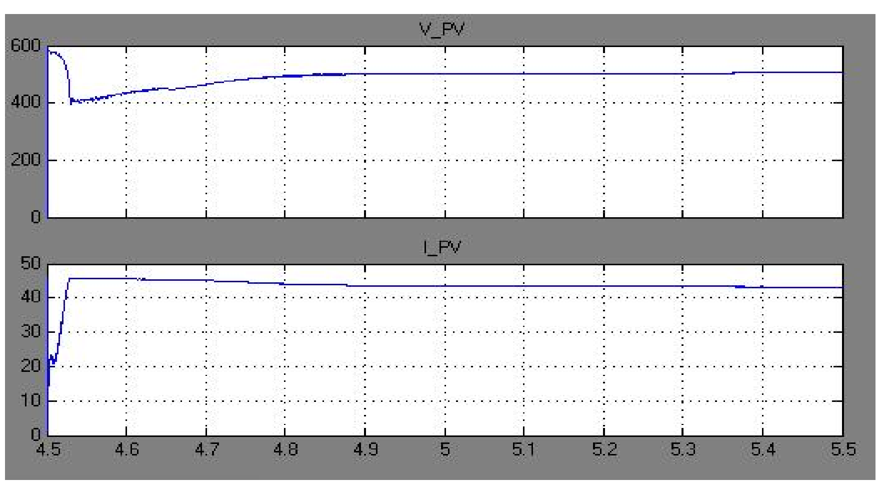

Figure 8. Solar array voltage in volts and solar array current in amps

The Fig. 11 shows the voltage and current waveforms of input of the battery charger. It can be seen from the respective figure that the integrated voltage can be observed to be maintained at 320V peak and current maintained at 140A peak respectively. The fault has been introduced into the system at t=5sec and the fault currents into the system have been introduced in phase A, B respectively with respect to ground and phase C is free of fault current. The fault currents in fault generator before and after transition have been shown in Fig. 12. It can infer that the currents in phase A and B after transition have been peaked to 30kA respectively and phase C current in fault generator being zero before and after transition. The corresponding response of the output has been shown in Fig. 13. Fig. 11 is the zoomed version of Fig. 13 after transition. It can be seen that the during fault currents at 5sec the CB of the main system have been opened and after 0.4 sec the backup along with solar have been charging the battery. It can be inferred that the fault currents haven't been introduced into the battery.

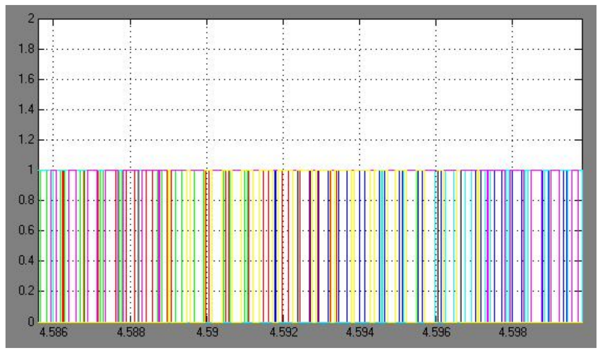

Figure 9. Gate pulses generated from SVPWM

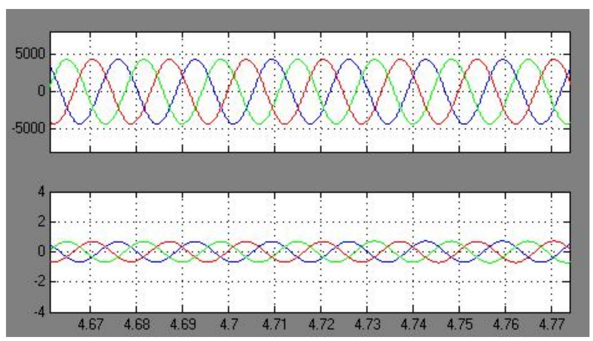

Figure 10. Inverter output voltage in volts and inverter output current in amps

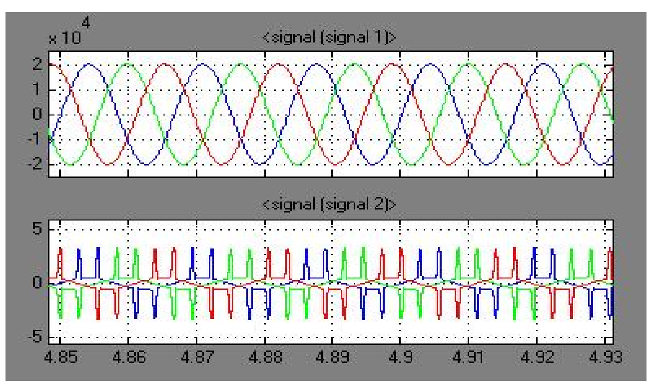

Figure 11. Battery charger input voltage (volts) and current (amps).

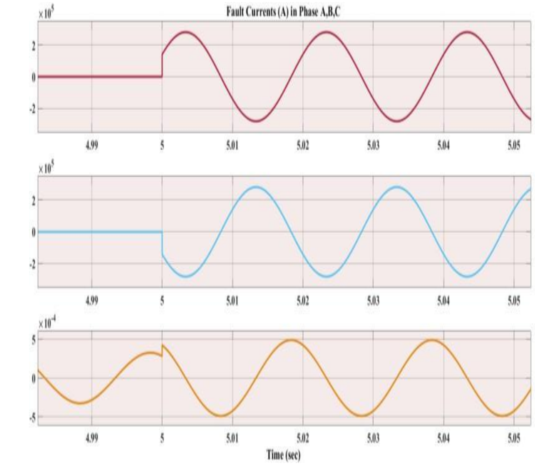

Figure 12. Phase currents (amps) of Fault generator during the transition

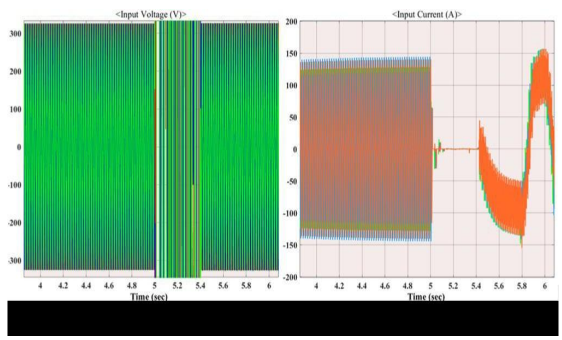

Figure 13. Battery charger input voltage (volts) and current (amps) during the transition

The Fig. 13 shows the voltage and current waveforms of the battery. It can be inferred that battery is getting charged at constant current of 100A till 70sec. After 70sec the battery reaches its nominal voltage 400V, then mode of charging has been shifted to constant voltage. The Fig. 14 shows the state of charging of battery. It can be seen that the initial State of Charge (SOC) of 2% has been increased to 4.6% in 100sec of simulation.

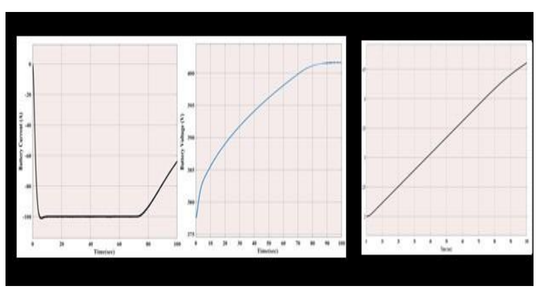

Figure 14. Battery voltage (volts),current (amps) and SOC %

5. CONCLUSION

The sole aim of the proposed system is to have an efficient, safer and consistent way of on board charging with the power sharing from both grid and the solar is illustrated using MATLAB Simulink and Proteus Professional. The Solar array of maximum 25kW has been selected to meet the demands of load along with the losses. The corresponding open-circuit and short-circuit test values have been considered to plot V-I characteristics and MPP curve respectively. DC power of solar is converted into Ac using NPC 3 level inverter with SVPWM technique to maintain the voltage and current at 400V, 42A.Using CC_CV battery controller, battery is allowed to charge efficiently with constant current(100A) until it reaches the rated voltage(400v) and thereafter with constant voltage. The double line to ground fault at the grid transmission lines are been detected and isolated the fault by activating circuit breaker using the MATLAB function which mimics the functionality of micro controller. It is also seen that when fault occurs, the voltage and current values deviates from their normalized values. Opening of Circuit breaker during fault instantly protected the on board battery blast out. Small prototype of fault analysis is simulated in Proteus. The command signal to energize the coil in relay has been generated from the Arduino Uno during the detection of faults. Current sensor plays a vital role in sensing the fault currents. The consistency can be obtained by providing backup generator during isolation. It can be inferred that proposed system has the best results and the whole control system is energy efficient as the input power has been parallely shared by solar and grid.

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