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SIMULATION ANALYSIS OF SMART GRID OPERATED SOLAR BASED EV CHARGING STATION

[1]Mr. Sanjay Soni, [2]Mr. Vipul Patel,[3]Mr. Sunil Chauhan, [4]Mr. Bhavesh Makwana,[5]Mr. Nilesh Patel
[1, 2, 3, 4]P.G Scholar, Electrical Engineering Department, Sankalchand Patel University, Visnagar, Gujarat, India
[5]Assistant Professor, Electrical Engineering Department, Sankalchand Patel University, Visnagar, Gujarat, India

Abstract
Nations across the world face the challenge of increasing power production while reducing the carbon emission. They need to minimize power loss and downtime, harness alternative power sources, and so on. The numerous challenges facing them have one solution – smart grids.The use of EVs will also focus on development of EV charging stations with several new technologies based on Renewable Energy Resources (RERs). Among all the different types of RERs the Solar energy is one of most prominent and popular source of energy for long term use. Thus, the renewable energy based EV charging station provides immense potential for EV charging & controlling. There are several innovative advance technologies also developed in upcoming future. The integration of Energy storage system with solar energy must require for continuous power generation and effective source for Charging Station (CS). In this paper we discuss on Grid Integrated solar powered EV station with Battery Energy Storage System (BESS). The proposed concept is developed using Matlab Simulink and tested with different case studies of EV charging station. The energy management of Grid and RERs is also carried out in this paper with BESS. The MPPT and PID controlling is developed for the proposed configuration in Matlab-Simulink.
Keywords-PID, EV, RER, SG, Converter, MPPT, etc.

I. INTRODUCTION
In electrical grid network the only key objective is to maintain the balance between load demand and power generation. Smart grid provides two way communication between power supplier and consumer through digital control. SG infrastructures includes Information communication control, Automation, Computers and information control. The smart grid provides control over power supply as per the demand variation quickly through new technology and digital control. The smart grid concept provides new technology development, dependability, availableness, and new opportunities for electricity market. The key benefits of development of SG over power grid are explained below.

The advantages related to the Smart Grid include:
- More economical transmission of electricity to consumers
- Quicker restoration of electricity when power disturbances occurs

- Reduced operations and management prices for utilities, and ultimately lower power prices for customers
- Reduced peak demand, which can conjointly facilitate lower electricity rates
- Increased integration of large-scale renewable energy systems
- Better integration of customer-owner power generation systems, together with renewable energy systems
- Improved security

"A smart grid is an electricity network with digital technology use to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control and communication within the supply chain to improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain.''Smart grid was introduced with the aim of overcoming the weaknesses of conventional electrical grids by using smart net meters.In electrical grid network the only key objective is to maintain the balance between load demand and power generation. Nations across the world face the challenge of increasing power production while reducing the carbon footprint. They need to minimize power loss and downtime, harness alternative power sources, and so on.The numerous challenges facing them have alternative solution – i. e. smart grids.

This paper examines the recent EV charging station based on solar PV panels. Recently three different levels of EV charging stations research is undergoing in US as shown in the fig 1. In these three categories charging stations are classified according to their power charging rates. These three are classified as given below:-

1. First EV Charging which takes place overnight with slow charging rate of 1.5-2.5 kW with convenient output voltage level of 120 V.
2. Second level Charging technology are which requires 240V outlet with power charging rate of 4-6.5 kW very fast. These level-2 charging can fully charge the batteries of EV within 3-6 hours.
3. Third technology of charging level are undergoing of research is requires very high power rating of 50-75 kW. For this level-3 charging system three phase power systems are used with off board chargers. This level-3 charging system is also known as DC Fast charger.

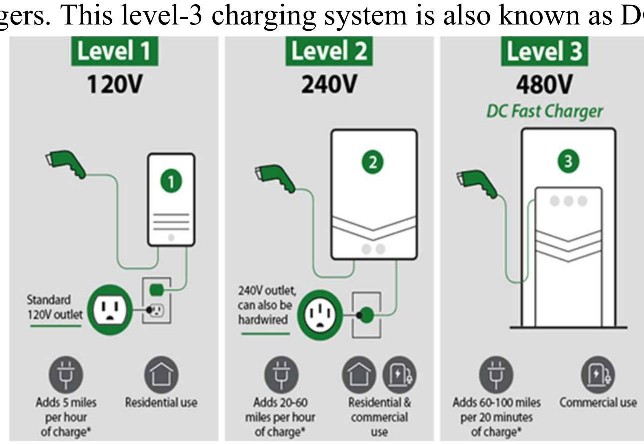

Fig 1- Three levels of chargers for EV charging stations

In this paper different charging topologies and their energy management system are reviewed in the literature papers. Different researchers have represents various kind of control strategies for solar powered EV charging stations. Solar powered charging station operation and role of BESS is discussed in [2] with Buck-Boost converter topology. For constant power management grid integrated charging station concept is explained in [3] for number of EVs charging with solar PV source. The grid integrated solar powered charging station provides multiple benefits for charging of number of EVs at same time with different operating modes. Prioritizing the EVs charging from thelimited available solar energy is given in [4]. Feasibility ofdifferent types of PV and BESS charging for commercial,home and business has been explained in [5] Shows thesolar powered e-bike charging station that provides AC, DCand contactless charging of e-bikes. The charging station hasan integrated battery storage that gives both grid-connectedand off-grid function. In paper [6], it shows the model of agrid connected rapid electric vehicle charging station ensuringpower quality with reduced harmonics. The control of eachvehicle charging is centralized and individual control is givento transfer energy from AC grid to the DC bus.In the proposed work, an optimal approach for designand power management of Electric Vehicle charging stationpowered by solar PV and a Battery Energy Storage System(BESS) with AC grid is explained. The unreliability of solarand dynamic charging requirements of EVs are considered forthe power flow strategy.

Solar PV acts as the primary source tocharge all the connected EVs in the charging place. Since thepower from PV at night is not there, a battery as an energystorage device is provided to charge the EVs connected inthe charging station. Whenever there is a deficiency in thepower output of solar or BESS to charge the EVs, requiredamount of power will be taken from the AC grid ensuringcontinuous operation of charging station throughout the day.The proposed system is formulated, designed and validatedusing MATLAB/Simulink.

II. SMART GRID OPERATIONS

The Smart Grid has revolution in the existing grid network operation by replacing the sensor devise, Smart Metering Devices, interline power flow control, power flow network with balance conditions with information flow & power flow use. In the below diagram of fig.2 shows the power generated from different energy sources of conventional & RERs both kinds. The power from the generating units are transmitted through the transmission line to substation units. The distribution line & feeder line network with MV & LV network are operated for local power distribution to load side. The power flow is unidirectional from generation to distribution network. While the load consumer and distribution is bidirectional for power management with information flow network through communication networks. The network operations are very helpful for smart grid operation from sending end to load side.

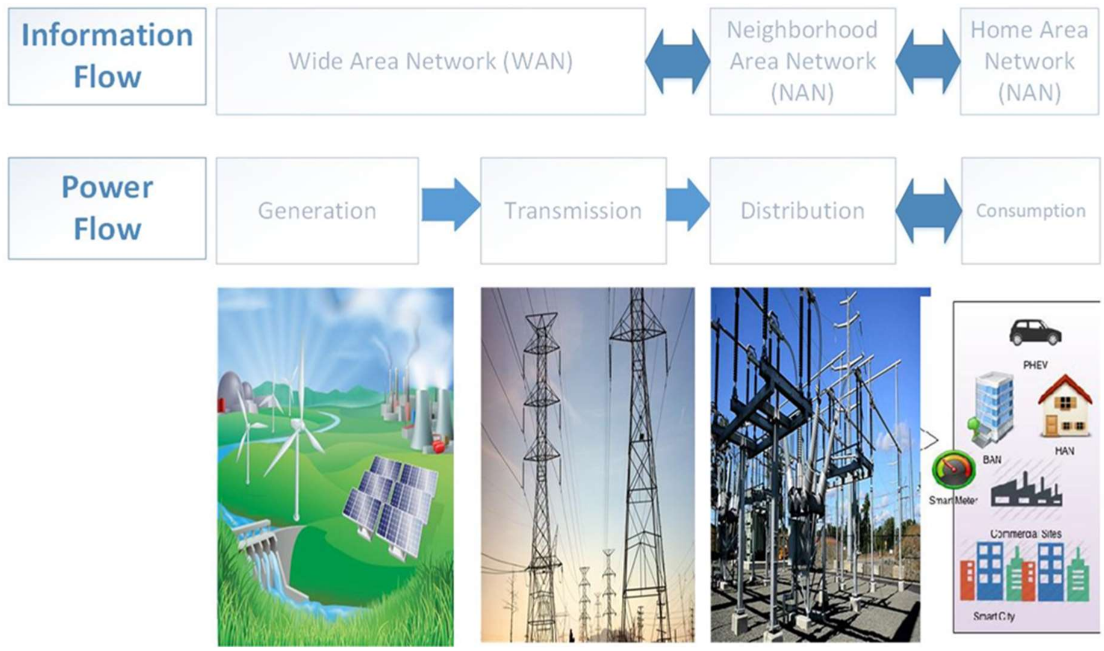

Fig.2. Architecture of Smart grid (SG) with power flow indication

In the smart grid development with the electrical loads are added with EV unit for the charging facilities. The EV operations are derived with different operating modes like V2G, V2V, and V2H with different metering devices. The SMI devices are very important to manage load distribution to all the electrical loads in electrical network.

- V2G EV: - In V2G EV the electrical vehicle is connected with the power grid. In this configuration, it will obtain energy form grid as well as inject the back to the grid.
- V2V EV: - In V2V EV the electrical vehicle is connected with other EV. The energy is distributed among other EV. In this configuration, the EV first charged through local grid supply and then using controller distributes that energy among other EVs.
- V2H EV: - In V2H EV the electrical vehicle is connected with home supply. The vehicle charges from Home appliances during the night condition to reduce the cost level.

Smart Grid Architecture Components

To understand the SG operation multiple devices are useful like SMI, network domains, closed loop network configuration, distribution for power to loads. The operational mechanism of SG is shown in below fig.3 to understand the smart grid device with management of power flow from send end to load side. The power supplier, power distribution units, network units are studied with SG architecture. The use of SCADA plays an important role in smart grid operation with bidirectional power flow management.

- Smart meters
- Consumer domain (HAN (Home Area Network) consists of smart appliances and more)
- Grid domain (Operations include bulk generation, distribution, transmission)
- Communication network (Connects smart meters with consumers and electricity company for energy monitoring and control operations, include various wireless

technologies such as Zigbee, Wi-Fi, Home Plug, cellular (GSM, GPRS, 3G, 4G-LTE) etc.

- Third party Service providers (system vendors, operators, web companies etc.)

In this project work I have investigated the effect of PV systems in low-voltage and medium-voltage (MV) distribution systems in this paper, and suitable online strategies to alleviate these problems were presented. In this regard, extensive. LV and MV distribution network modelling and analysis have been completed.

As a result, proper PV system allocation in the network will be possible. Using the approach described above, PV networks for medium-voltage three-wire systems and low-voltage four-wire systems with Y-D transformers and ground impedance can be modelled. PV system modelling will be performed using temperature and ambient radiation data, inverter efficiency, PV panel parameters, and the V-I feature.

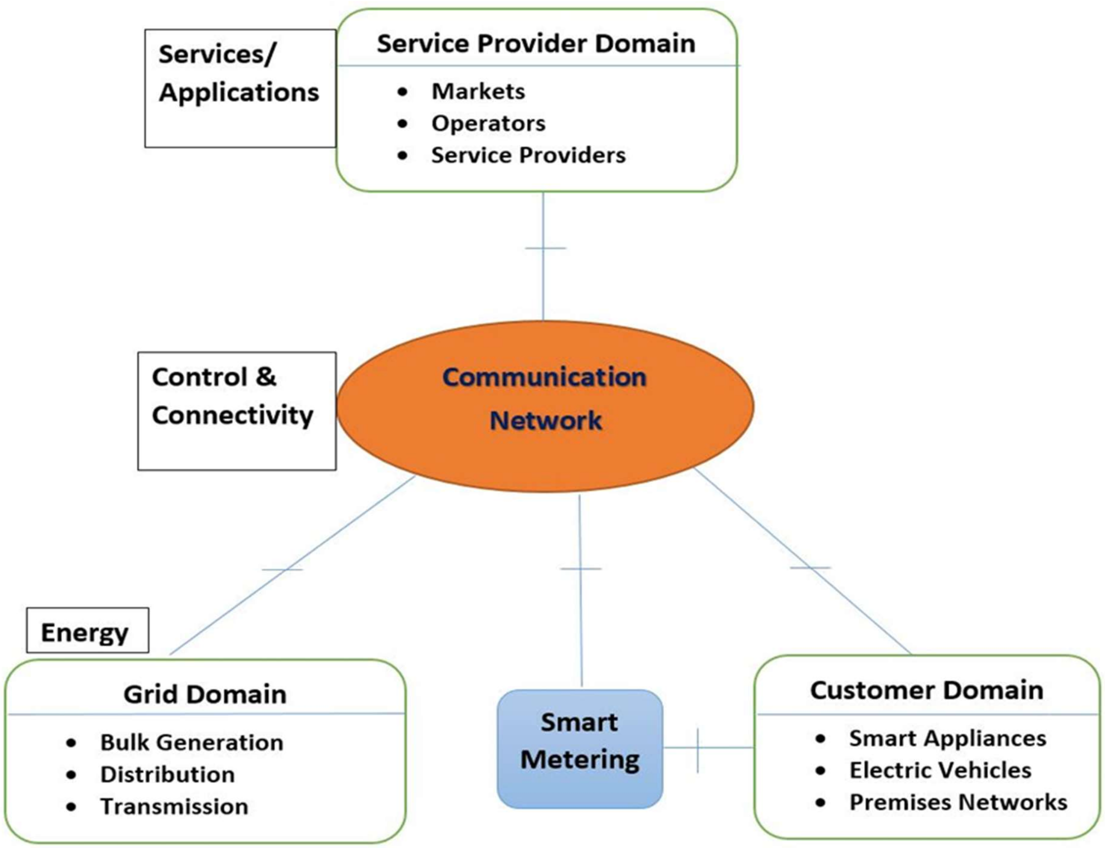

Fig.3- Smart Grid Architecture with components

III. SOLAR PV CHARGING STATION

Design Calculation of Solar PV system for Charging Station

Total connected load to PV panel system: 300 KWh/day

Total KWh rating of the system

= Total connected load (KW) × Operating hours = 156 × 6 = 1800 KWh

Actual power output of a PV panel = Selected module Wp× operating factor

= 305 × 0.75 = 228.75 watt

The operating factor‟ is used to estimate the actual output from a PV module.

[The operating factor between 0.60 and 0.90 (implying the output power is 60 to 80% lower than rated output power) in normal operating conditions, depending on temperature, dust on module, etc.]

The power used at the end use is less (due to lower efficiency of the system

= Actual power output of a panel × combined efficiency

= 228.75 × 0.81 = 184.68 □ 185 W

Energy produced by one 305 Wp panel in a day

= Actual power output × 8 hours/day (peak equivalent)

= 185 × 8 = 1480 = 1.48 KWh/module

Number of solar modules required to satisfy given estimated daily load:

= (Total KWh rating (daily load)/ (Daily energy produced by a panel)

=1800/1.48 = 1216.21 □ 1217

Design Calculation of BESS for Charging Station

The SOC Estimation of energy storage unit is adopted from □7,8]

$$SOC(t) = SOC(t-1).(1-\delta_{bat}(t)) + \left(\frac{p_B(t)}{V_{bus}}\right)\eta_{bat}.\Delta t ----(1)$$

$$\begin{aligned} &Where: \\ &\delta_{bat}(t) = \text{Hourly self discharge rate (Practically it considered 0)} \\ &p_B(t) = \text{Charging or discharging power} \\ &V_{bus} = \text{Common DC bus voltage} \\ &\eta_{bat} = \text{Charging and discharging efficiency} \\ &\Delta t = \text{Hourly time step} \end{aligned}$$

The required BESS power is the minimum amount of power in KW that increase the SOC from initial. On other side the available ESU power is the maximum amount of power in KW, which BESS can supply in time step □t before its SOC reaches minimum limit. It is referred as;

$$\text{Req\_P}_{\text{ESU}}(\text{t}) = \frac{SOC_{\max} - SOC(t) \times C_b.N_b}{\Delta t} \quad ----(2)$$

$$\text{Avl\_P}_{\text{ESU}}(\text{t}) = \frac{(\text{SOC(t)-SOC}_{\min}) \times \text{C}_\text{b}.\text{N}_\text{b}}{\Delta \text{t}} \quad ----(3)$$

$$\begin{aligned} &Where: \\ &C_b = \text{rated capacity of single battery} \\ &N_b = \text{Total no. of batteries in ESU} \end{aligned}$$

SOC set minimum 10% and 90% maximum.

The battery model contains a nonlinear voltage source and it models open circuit voltage, series resistance. Hence the output voltage is dependent on both current and the SoC, where SoC is a function of time as a nonlinear.

Battery voltage and SoC can be described as follows;

$$V_b = V_0 - R_b I_b - K\frac{Q}{Q-\int I_b dt} + A.\exp(-B\int i_b dt ----(1)$$

The internal resistance of the battery is Rb, open circuit voltage potential (v) is Vo, charging and discharging current of the battery is ib and K is the polarization voltage, A is the exponential voltage and B is the exponential capacity.

$$SOC(\%) = SOC_0(\%) - 100\left[\frac{\int I_{bat}.dt}{Q}\right]----(2)$$

Calculation of EV Load Demand for Charging Station

For the modeling of EV power demand, mainly three parameters are considered;

1) Rated battery capacity (KWh)
2) Plug in time (Hrs)
3) Initial SOC (%) and Final SOC (%)

In proposed EV charging model, it is assumed that at departure time, the SOC of the EV batteries should be 80% of its full load capacity and to avoid over- discharging EV charging should be stop at 10% of rated capacity. Therefore, maximum demand of an individual EV is the 70% of its rated battery capacity.Calculation of power demand of single EV at a time t is referred based on work in [10, 11].

The required EV Power can be found as;

$$P_{EV.req.} = \left(SOC_{max} - SOC_{min}\right) \times C_{bat}$$

For multi connected Evs, the total EV power demand can be expressed as

$$EV_{S}\_demand_{total} = \left\{\sum_{n=1}^{N} p^{n}_{EV.t,(t=9,10,...22)}\right.$$

Since proposed EMS is designed for day hours 9:00 am to 10:00 pm.

IV. SIMULATION AND RESULTS

Network Modelling

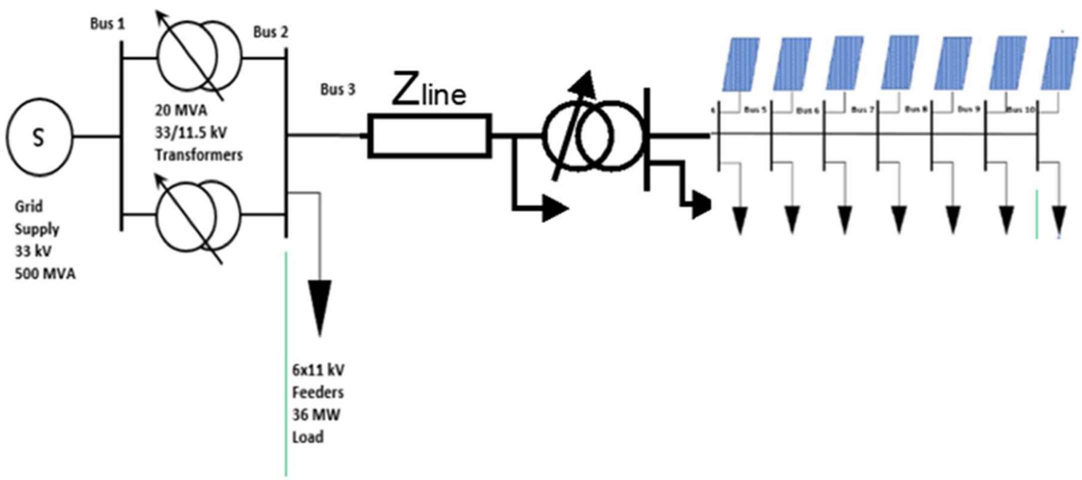

Fig 4- Line Diagram for Network Modelling

The distribution system to be considered in this assignment is described below.

Existing system

- It is made up of a 33 kV three-phase source that represents the grid supply and ensures a constant (slack bus) voltage of 1.0 per unit.
- The 33/11 kV substation is made up of two 20 MVA delta star transformers with on-load tap changers. The substation has six 11 kV outgoing feeders, each with a 6 MW load and a power factor of 0.95. These feeders and their associated loads are represented as a lumped load connected to the main 11 kV busbar (bus 2).
- One 11 kV outgoing feeder connects to a local 11kV bus by a 3 km of overhead line (185 mm2 3-core XLPE Cu cable). This local bus connects to a Low Voltage (LV) 11/0.4 kV substation
- The LV substation supplies 300 customers, at 400 V spread evenly across three phases.
- There is also a school, some shops (2) and some light industry (3 units) on the local bus. Model them as extra 3 phase loads on the LV bus at 400V.

The Below section presents the work which I have performed in the IPSA software for DG unit integration for manage performance of load distribution. The overload conditions can be monitored with the indication on transformer ratings. As shown in below fig.5 the grid supply is connected with two transformers devices with two busbar which connected with load-1 for local distribution.

The transmission line is provided between busbar-2 and busbar-3 for power transmission of main grid supply to local distribution units. The busbar-4 is worked as a distribution feeder line to provide connections for local loads in the proposed system.

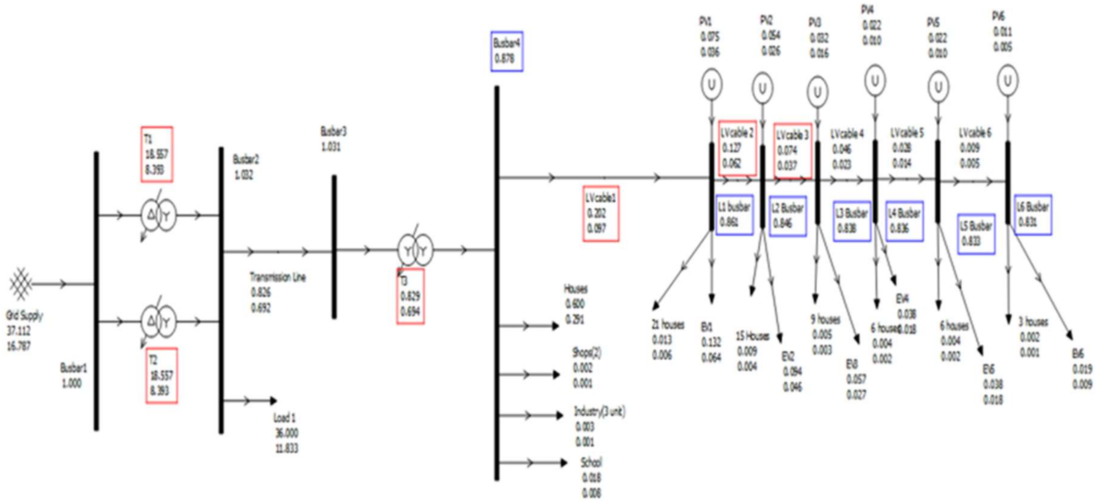

Fig 5- Proposed Grid Network Low Daytime Load with PV unit

Fig.5 shows the load variation and effects in proposed grid network with indicating effects on transformer and busbar. The red tags indicates the overload conditions of respective transformer while blue tags of busbar indicates very less voltage level then defined values of busbar voltage.

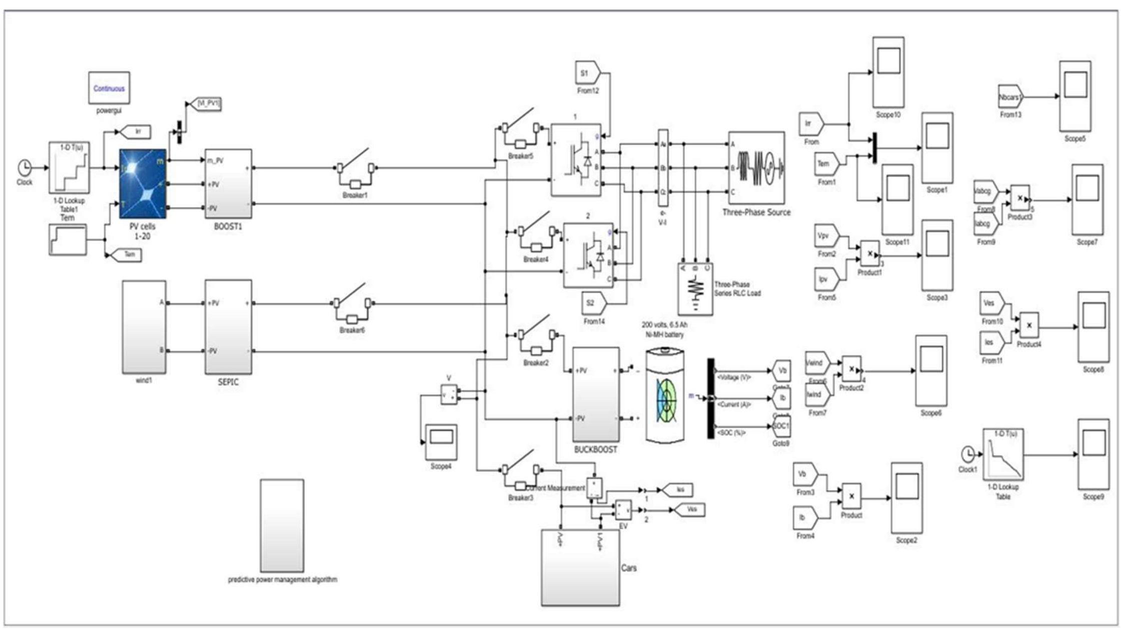

Fig 6- Simulation of EVs Charging with Solar-Wind- BSB system

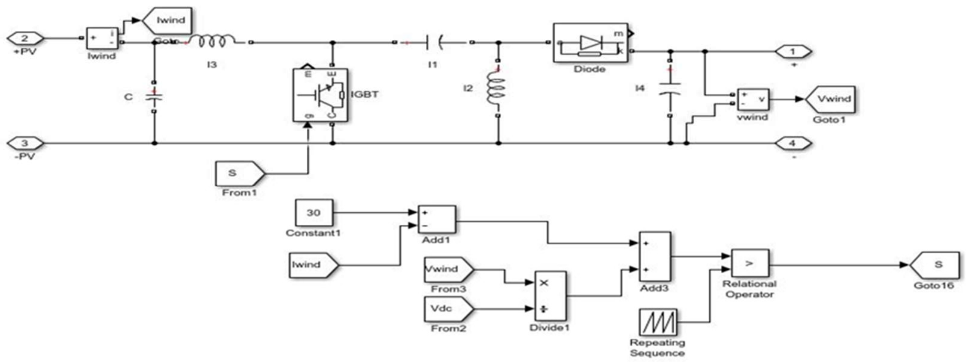

Fig 7- Simulation of SEPIC Converter for Wind Power Plant

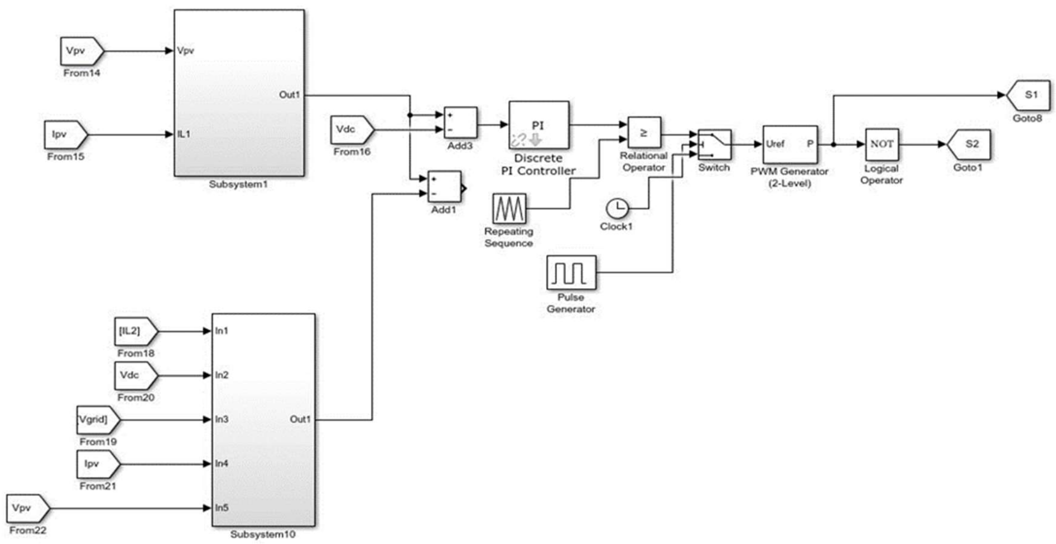

Fig 8-Simulation Design of Predictive Model Control algorithm

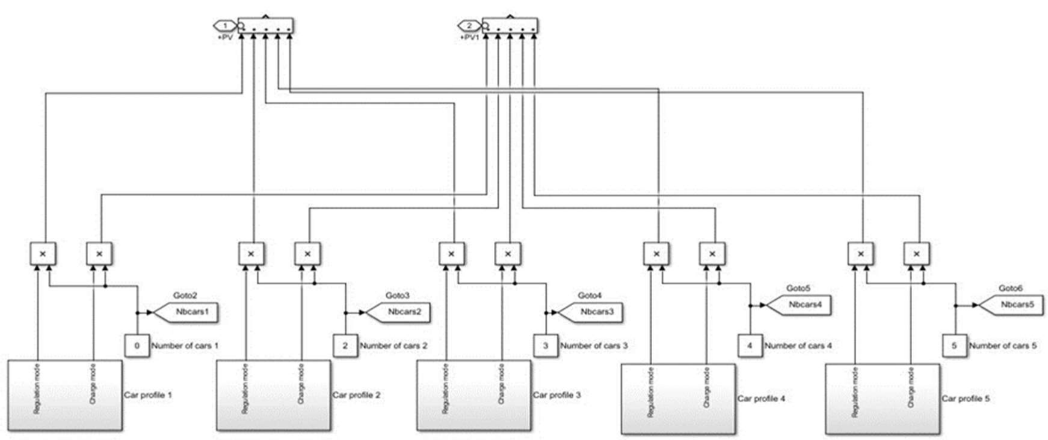

Fig 9- Simulation Model of 5 EVs Car Profiles

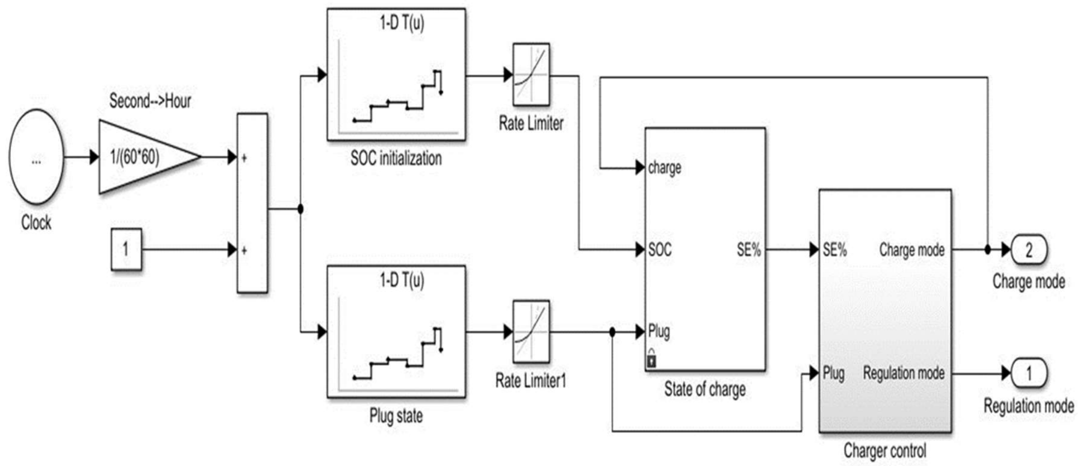

Fig 10- Simulation Modelling of EV Car Profile

Simulation Results

In this the results are carried out for time duration of t=0 to t=1.5 hours. It will be clearly indicates the zero EV power demands and EV vehicles charging.

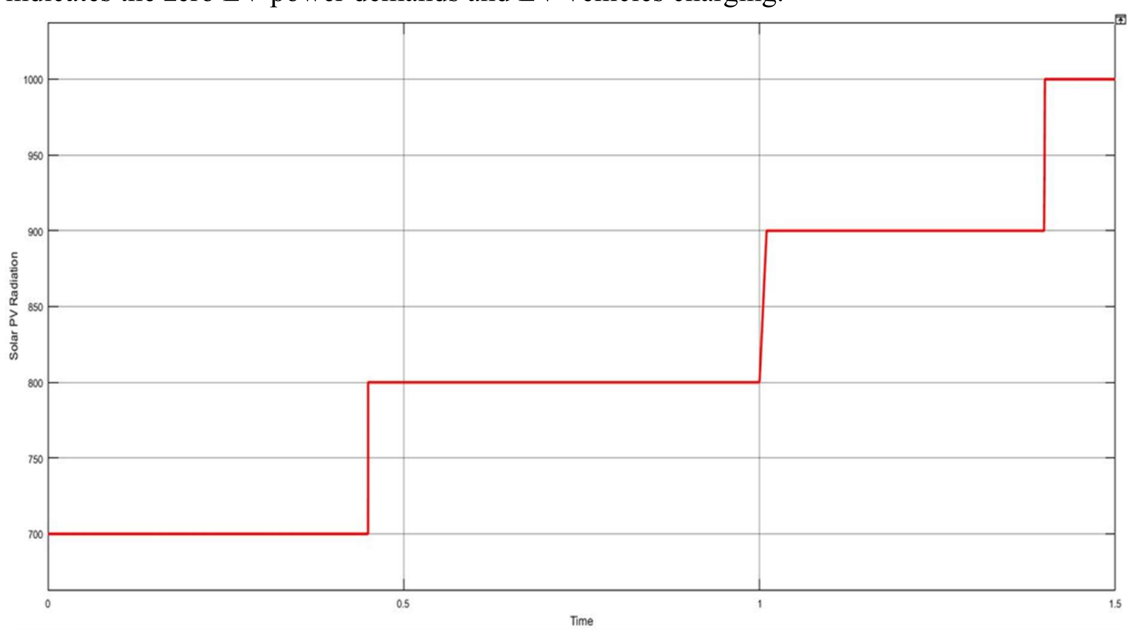

Fig 11- Solar PV Radiation Level

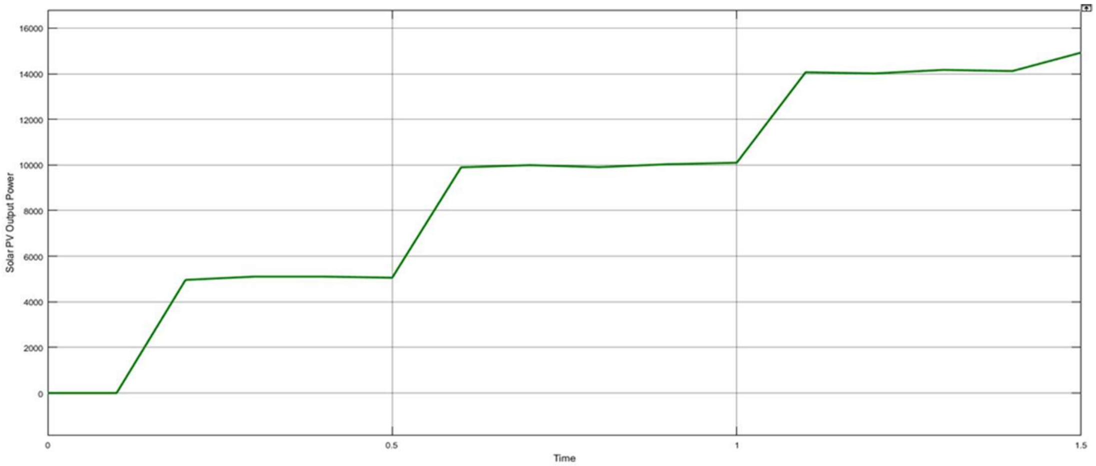

Fig 12- Solar PV Array Output Power

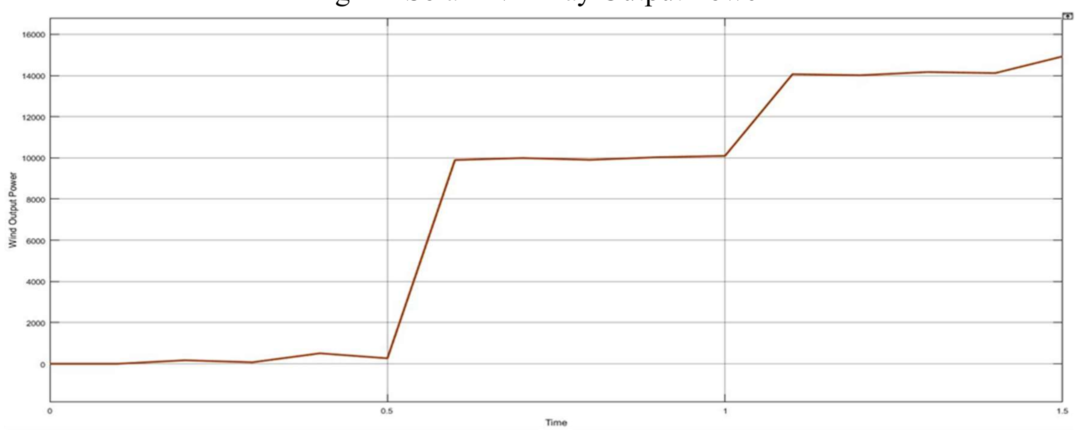

Fig 13- Wind Power Plant Output Power

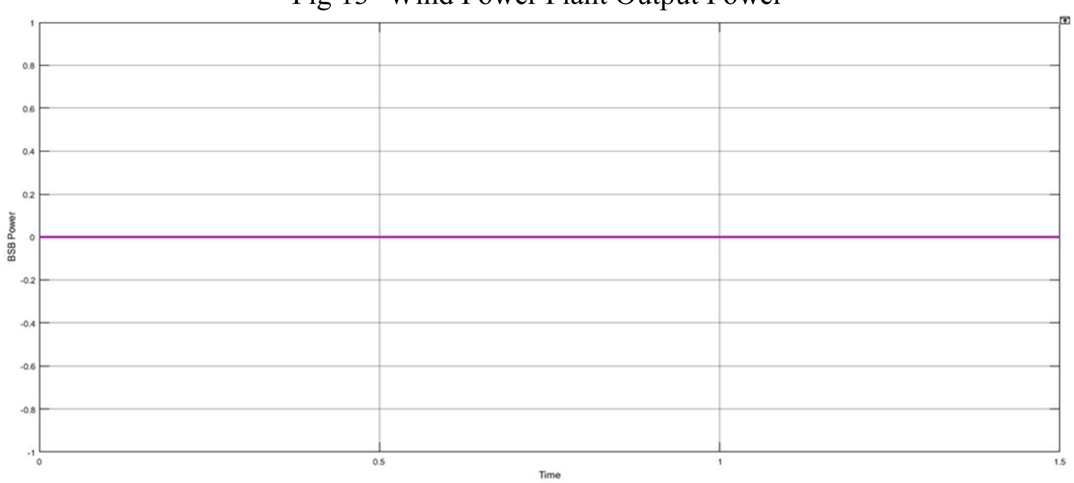

Fig 14- Battery Storage Power

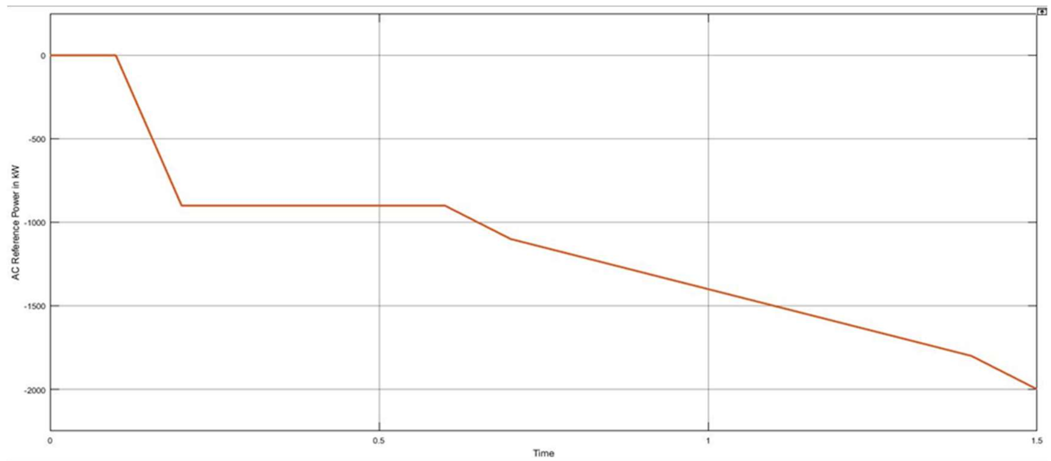

Fig 15- AC Reference Power of Charging

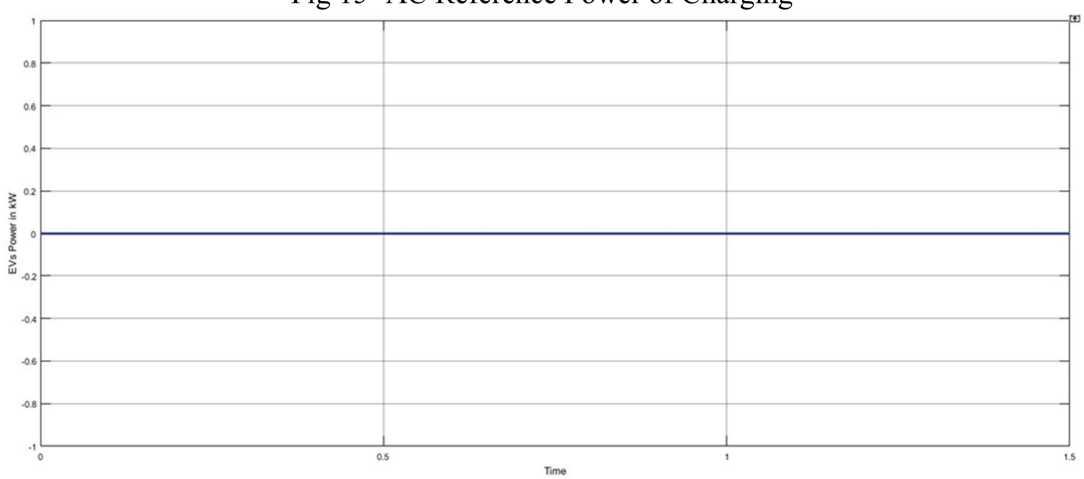

Fig 16-EV Output Power

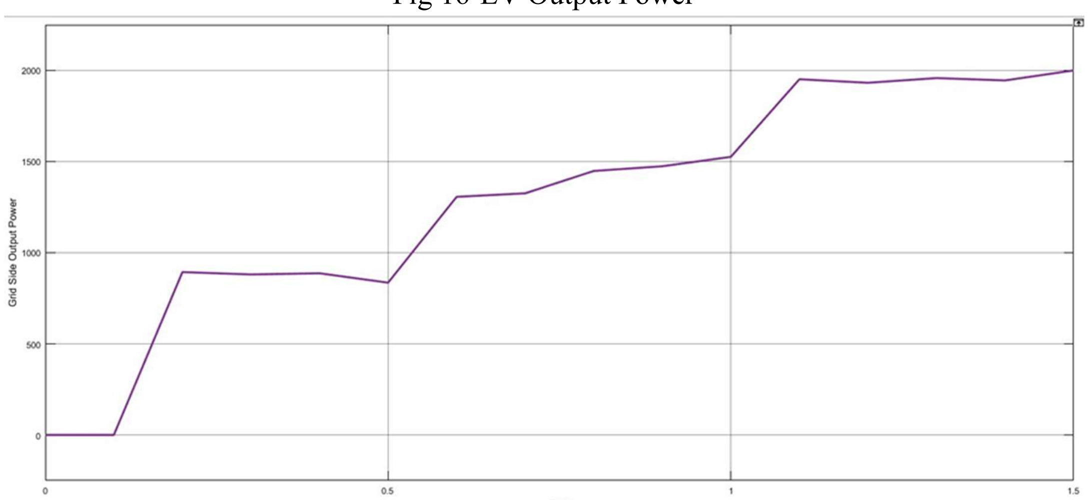

Fig 17- Grid Side Output Power

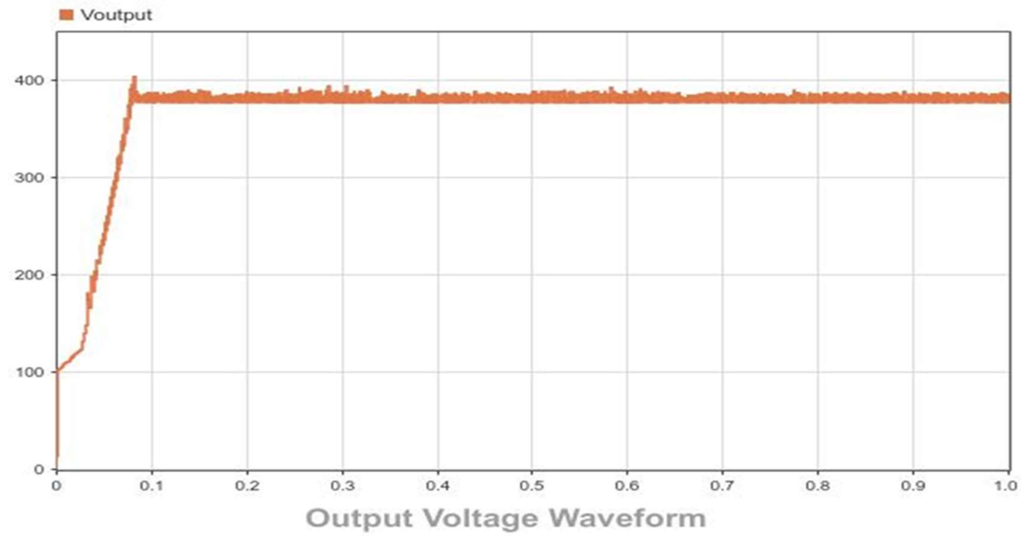

Fig 18- Simulation Waveform of Output Voltage for Proposed Converter with Closed Loop Controlling

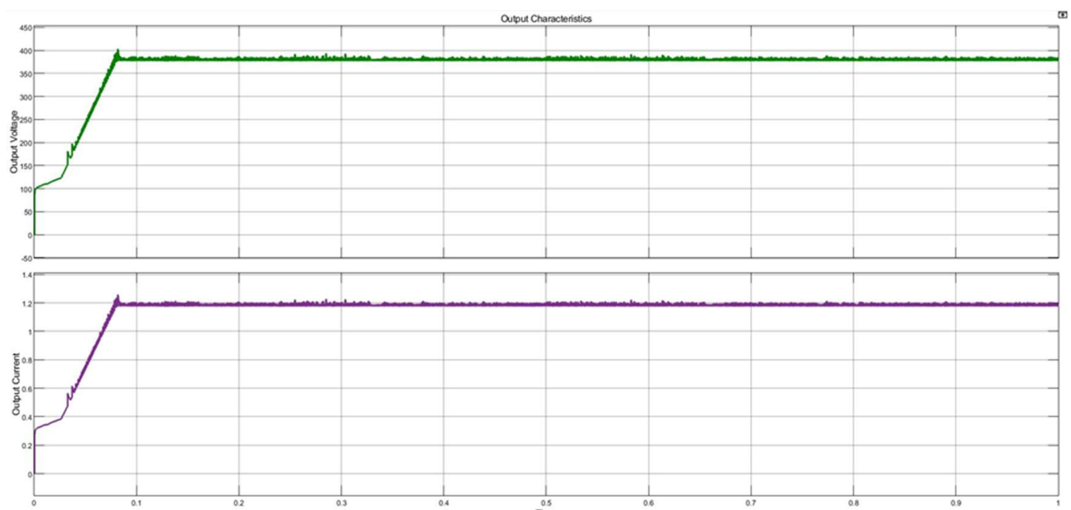

Fig 19- Simulation Results of Output Voltage and Current for Proposed Converter with Closed Loop Controlling

V. CONCLUSION

As discussed in this paper we can say that the cyber-attack in SG has several effects on grid parameters magnitudes variation. The review on SG architecture, SG security and vulnerability analysis are discussed. In this project a predictive model is presented in detail to forecast EVs power demand and to maintain a high level of accuracy and stability of the charging station by securing an effective real time monitoring of each partincluding the grid. The reliability and the flexibility of the hybrid power sources are achieved via seven operating phases by which a large scale of power for any EV charging mode is fulfilled. The proposed optimization algorithm has been validated by simulation results performed in Matlab/Simulink. However, the analysis of data is established by the HCP in order to feed the PPMS with the required load flow specifications of EVs, so that it can calculate the total power demand and monitor the available energy in the CS. In terms of decreasing the charging cost from over-relying on the grid and for a smooth integration of RES, the PPMS would set the optimal charging scenario from the RES battery and grid, based on a smart scheduling of power.

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