A Project Report

On

Charging Electric Vehicles with Energy from Wind, Photovoltaics and Hybrid Energy Storage System

BY

GROUP NUMBER-4

STUDENT NAME	ID NO
AAKANKSHA SINGH	2018A3PS0354H
ARASANAPALAI SRIKANTH NAVYA SRI	2018A3PS0134H
AROONDHATI BHURE	2018A3PS0528H
ERANKI VENKATA JHAHNAVI	2018A3PS0154H
PRAGYA SINHA	2017B1A31749H
THAMBABATHULA OMANA	2018A3PS0553H
VYSHNAVI S K	2018A3PS0619H

Under the supervision of

Dr. Sudha Radhika

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BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE PILANI (RAJASTHAN)

HYDERABAD CAMPUS

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ABSTRACT

The recent decades have seen a significant rise in both population and pollution and depletion of natural resources. Hence, Hybrid Renewable Energy Systems which allow eco-friendly optimization of electrical power generation are the need of the hour. This paper presents a methodology for integrating Hybrid Energy Storage Systems with PV-based solar power and wind power to charge a three-phase load. Hybrid Energy Storage System (ESS), acting as a buffer for the generated energy, will provide energy to the load in case of emergencies. The aim is to maximize the delivered power of Renewable Energy resources like wind and solar energy to the grid while still having a reliable power supply, an Energy Storage System(ESS). This power source absorbs energy when renewable sources produce excess power and supplies when they produce less. The modelling and simulation of various components of the charging station like wind, solar photovoltaic, and Energy Storage Systems with their corresponding control functions and algorithms are applied and presented. Furthermore, ESS advantages are observed by measuring the voltage, current and the state of charge (SOC).

KEYWORDS: Electric Vehicles (EVs), DC Micro-grid, Hybrid Energy Storage Systems (ESS), Solar energy, Wind energy, MPPT algorithm, rectifier, inverter, chopper

CONTENTS

1. INTRODUCTION

Air contamination is one of the dangerous consequences of conventional automobiles which utilize non-renewable energy sources like petroleum, Diesel. It has been found that it has become preferable to use renewable energy sources for charging Electric Vehicles because of varying reasons ranging from environmental concerns to energy costs. It has thus become the need of the hour and essential to make electrical energy storage components perform better with respect to their energy density, cost, power density, cycle efficiency, lifetime, size and in order to acquire higher storage performance. Hybrid combinations of 2 or more power generation technologies, cumulated along with storage can be used to improve system performance, since the availability of renewable resources is limited. Hybrid Renewable Energy System (HRES) merges a minimum of 2 feasible energy resources with some traditional source (diesel or petrol generator) along with storage, to fulfill the interest of an area. Other examples of storage systems include: flywheel, compressed air energy storage, supercapacitor, pumped hydroelectric storage, superconducting magnetic energy storage, solar fuels and hydrogen. The capital expense of battery storage technologies has decreased largely because of the number in ESS which made batteries more preferable than others.

This project presents a viable low cost energy storage solution which solves the limited availability of resources like solar and wind by integrating second–life EV batteries. New challenges to the stability, integrity and reliability of the utility grid arise because of the limited resources which comprise an increasing percentage of system generation capacity as compared to the traditional hydraulic and thermal synchronous generation. These adverse effects on the utility grids can be reduced by combining energy storage with renewable sources . Hybrid and hybrid electric technologies are performing a key role in increasing the fuel efficiency and declining the outflows of new EVs. In all these technologies, energy storage systems are an integral part. Because of their relatively long lifetime, high energy, fast response, less cost and high power densities, Li-ion batteries have become the most desirable storage systems. These traits make these batteries an expense compelling possibility for the integration of renewable energy and automotive applications. The proposed system is a combination of photovoltaic solar power, wind power and Li–Ion battery energy storage into a DC microgrid–based charging station for EVs. For corporate sites or car parks, these charging stations are appropriate with connections to the public transport. When combined with PV and wind sources, EVs will be able to deliver the energy.

2.METHODOLOGY

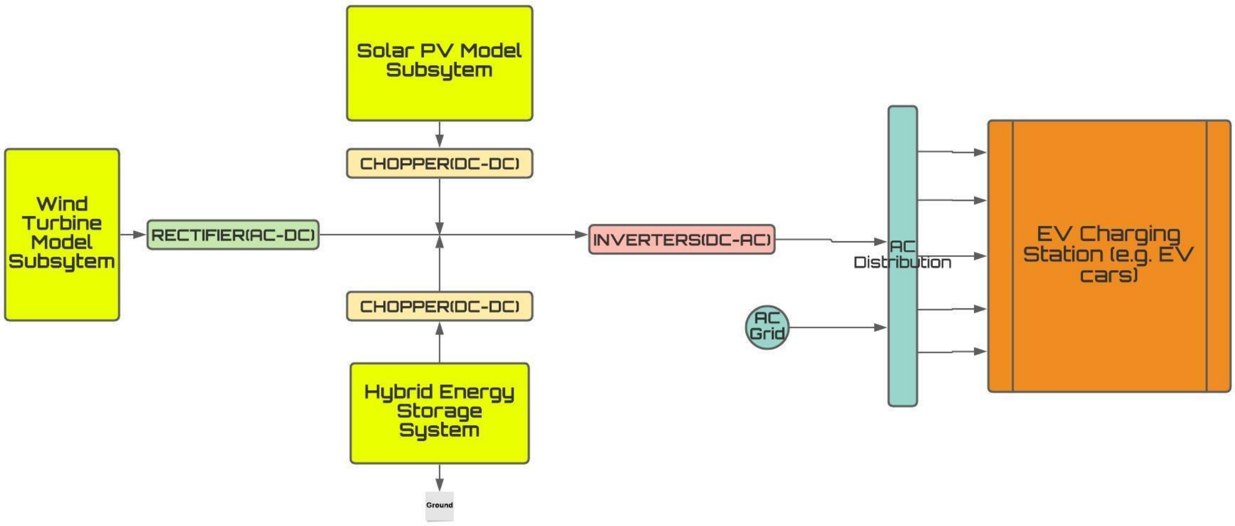

Fig. 1. EV Charging Station block diagram

Figure 1 shown above, proposes a DC microgrid system topology with the integration of a PV solar array and a wind turbine as the renewable sources integrated with a Hybrid Energy Storage System (HESS) that provides the EV charging station with energy.[1,2] The grid-connected charging station has permitted the import/export of energy under supervision and instruction of the inbuilt control systems. The primary objectives are to supply power to the EV Charging facility via renewable sources and provide the deficit energy via a buffer, Hybrid Energy Storage Systems (HESS). Capturing the greatest possible renewable energy from natural resources like wind, sunlight etc, while the maintenance of a stable grid output power is the focus's control objective. The excess power generated and stored in HESS is further delivered to the grid and EV batteries and also used to act as a backup for charging the EV batteries in unfortunate unforeseeable shortages.

2.1 Wind Energy Model:

Wind energy is harvested via a combination of turbine and generator. Typically, a wind turbine has 3 blades. The three blades move because of wind. Factors such as performance coefficient of turbine, density of air, tip speed ratio, blade pitch angle (beta), and velocity of wind affect the entire power generator. For safe mode of operation, the system is operated when the wind speed lies between cut-in and cut-out speeds. Speed of wind higher that cut out speed can damage the system. That speed lower than cut in speed may lead to inefficient operation.

PMSG (Permanent magnet synchronous generator) is another kind of synchronous generator which is based on Faraday's law of electromagnetic induction. Their self-excitation allows them to be operated at higher power factor and efficiency. There is a magnetic field on the rotor that rotates and a stationary stator of multiple windings that carry out induced voltage and sets up the current. The rotors excitation here is provided by a permanent magnet.

The amount of power captured by the wind turbine (power delivered by the rotor) is given by

$$P_t = 0.5\rho A C_p(\lambda, \beta) \times (v_w)^3 = 0.5\rho A C_p \times \left(\frac{\omega_m R}{\lambda}\right)^3$$

where ρ is the air density (kilograms per cubic meter), Vω is the wind speed in meters per second, A is the blades' swept area, and Cp is the turbine-rotor-power coefficient, which is

a function of the tip-speed ratio (λ) and pitch angle (β). ωm = rotational speed of turbine rotor in mechanical radians per second, and R = radius of the turbine.The target optimum torque is be given by the following equation.

$$T_{m\_\mathrm{opt}} = K_{\mathrm{opt}} \left(\omega_{m\_\mathrm{opt}}\right)^2$$

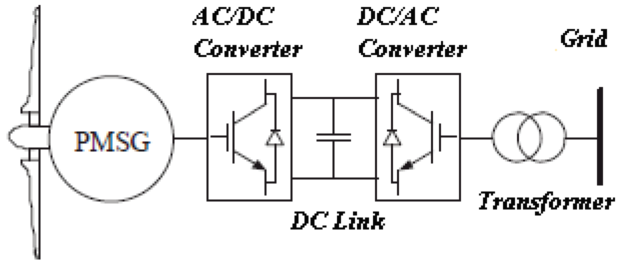

Fig. 2. Schematic of grid connected to a system powered by wind [2]

2.2 PV Model:

The MATLAB Simulink model consists of a DC to DC converter, PhotoVoltaic array, Maximum Power Point Tracker (MPPT) controller, and a load (Fig 3). The model is implemented at varying irradiances and constant standard temperature. PV array includes modules in series and parallel. Implementation is done for varying conditions, as in daily conditions, we won't be having constant irradiance or temperature. For daily application, diversified conditions are taken. Chopper acts as an interface between the load and the PV array for transferring the power. The PV array has a point where the power is maximum. If we can operate at that point, we can have the maximum efficiency possible. So the MPPT controller is introduced to track the maximum point and tune the chopper's duty cycle for tracking the real time maximum power point and also to operate the load at that point. There are different algorithms to implement the MPPT controller. In this model, the Perturbation and Observation (P&O) algorithm is being implemented.

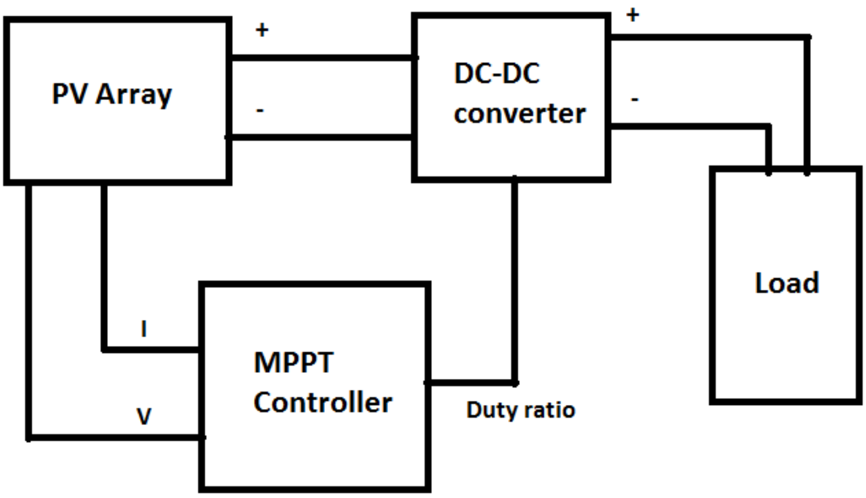

Fig. 3. PV solar model

Perturb & Observe Algorithm:

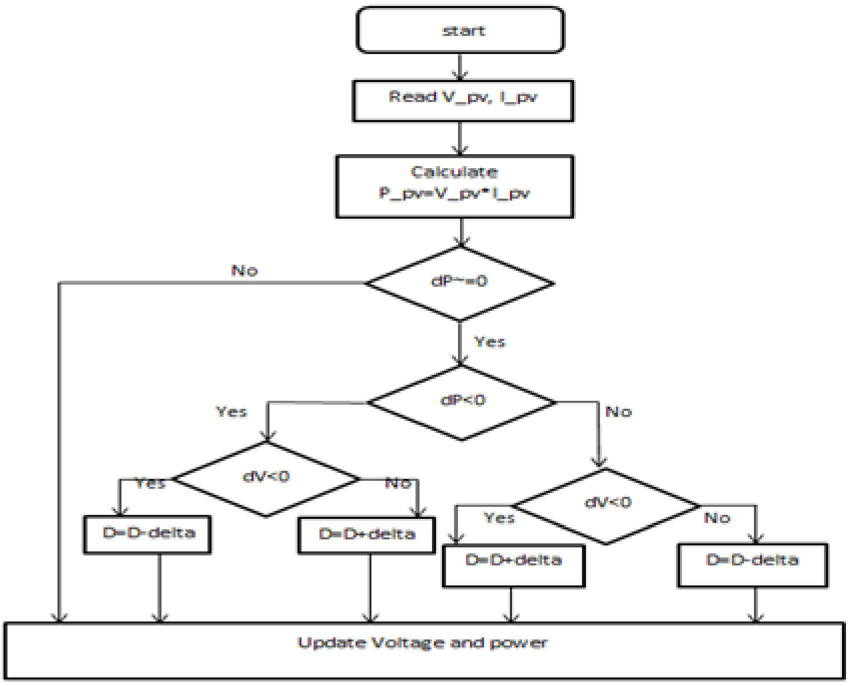

Fig. 4 P & O Algorithm

In this algorithm, the Photovoltaic modules output voltage and current will be passed to the MPPT algorithm block. After reading the values, power will be calculated. According to the change in values of power and voltage, delta will get adjusted till it reaches the maximum point. So the corresponding duty cycle will be sent as output of the MPPT block. This duty cycle is used to generate pulses for the switch that is being used in the circuit. In this way, the Perturb & Observe algorithm works for MPPT controllers.

2.3 Hybrid Energy Storage System:

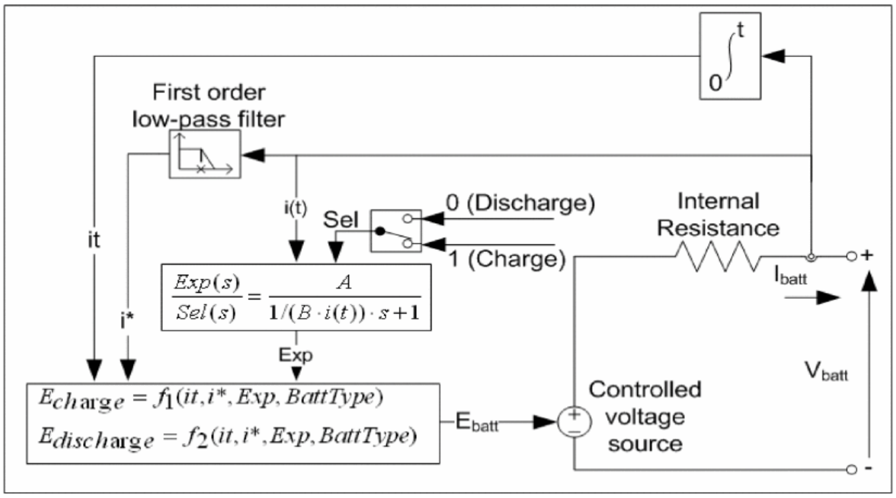

Fig. 5. Equivalent battery circuit [1]

A Hybrid energy storage system (Hybrid ESS or HESS) can be described as integration of two or more energy storage systems (ESS) in an application where these ESS have nearly similar properties and characteristics with the motivation of achieving best of both worlds to rectify the drawbacks of individual ESS with each other's advantages and reduce the cost by maximizing their individual performances. For example, an ESS with quick charge and high power capabilities can be paired with an ESS having longer and stable power supply properties to achieve synergy and create a better supply system.

In previously conducted researches, it was found that battery is one of the most up and coming storage technology able to give promising results for both long and short term storage along with rapid charge and discharge cycle making it suitable for many applications like load levelling, voltage sag, bulk power application, voltage regulation, frequency control and regulation, black start, uninterruptible power supply (UPS), spinning reserve etc. [10,11] Which led us to select a two battery HESS, with NiMH (Nickel Metal hydride) batteries as our goal is to improve the lifecycle of the system and sustain the output power delivered to load as the main source starts to discharge and becomes less and less efficient in delivering power. This has been shown to improve the battery's life cycle and delivers a continuous power load.

Mathematical modelling of HESS:

1) SOC:

   It is formulated as the current capacity of the battery divided by the nominal capacity of the battery. Nominal capacity is the maximum charge that the battery can hold.

$$SOC(\%) = 100(\left(1 - \frac{1}{Q}\int_0^t i(t) \ \ dt).\right)$$

2) NiMH charging and discharging model:

   The mathematical model of charging for NiMH batteries is given by:

$$f_1(it, i_f, i, Exp) = E_0 - K \cdot \frac{Q}{Q - |it|} \cdot i_f - K \cdot \frac{Q}{Q - it} \cdot it + \text{Laplace}^{-1}\left(\frac{Exp\ (s)}{Sel\ (s)} \cdot 0\right)$$

   Which is very similar to that of Lead Acid batteries. NiMH also shares similarity with the discharging model:

$$f_2(it, i_f, i, Exp) = E_0 - K \cdot \frac{Q}{|it| + 0.1 \cdot Q} \cdot i - K \cdot \frac{Q}{Q - it} \cdot it + \text{Laplace}^{-1}\left(\frac{Exp\ (s)}{Sel\ (s)} \cdot \frac{1}{s}\right)$$

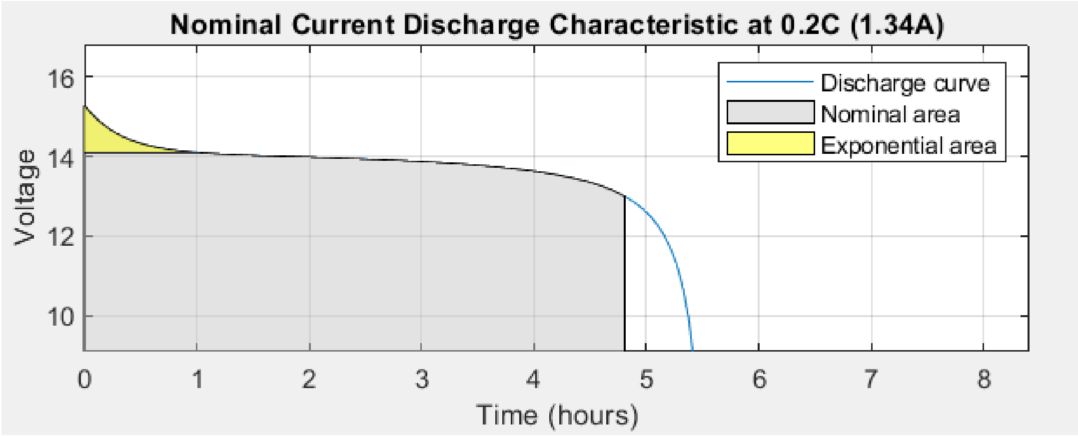

Fig 6: Discharge Plot

Here, there are three regions, the exponential area which shows an exponential drop in the voltage as the battery starts to charge, the nominal area which shows the total charge stored in battery that can be delivered until the voltage becomes lower than the nominal value, and the discharge area which shows a sharp drop in voltage as the battery starts discharging.

In our HESS model, when the source battery reaches its minimum State-of-charge then the secondary storage acts like a backup by supplying the remaining power to charge the source battery. The idea behind the same is to avoid a sudden/massive drop of SOC of the source supply to its lowest level. The HESS is connected to the DC link through a boost converter. The purpose of the converter is to increase the terminal voltage to the magnitude of DC bus voltage. The system will be implemented in MATLAB Simulink.

3. MODELLING AND SIMULATION

The simulation software used in the project is Simulink/MATLAB.

3.1 Wind Energy Harvesting:

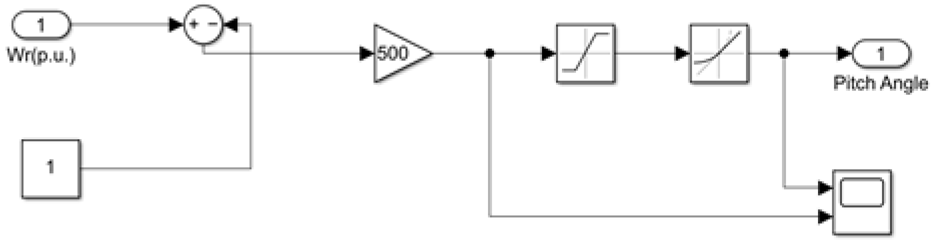

Fig. 7. Pitch Controller

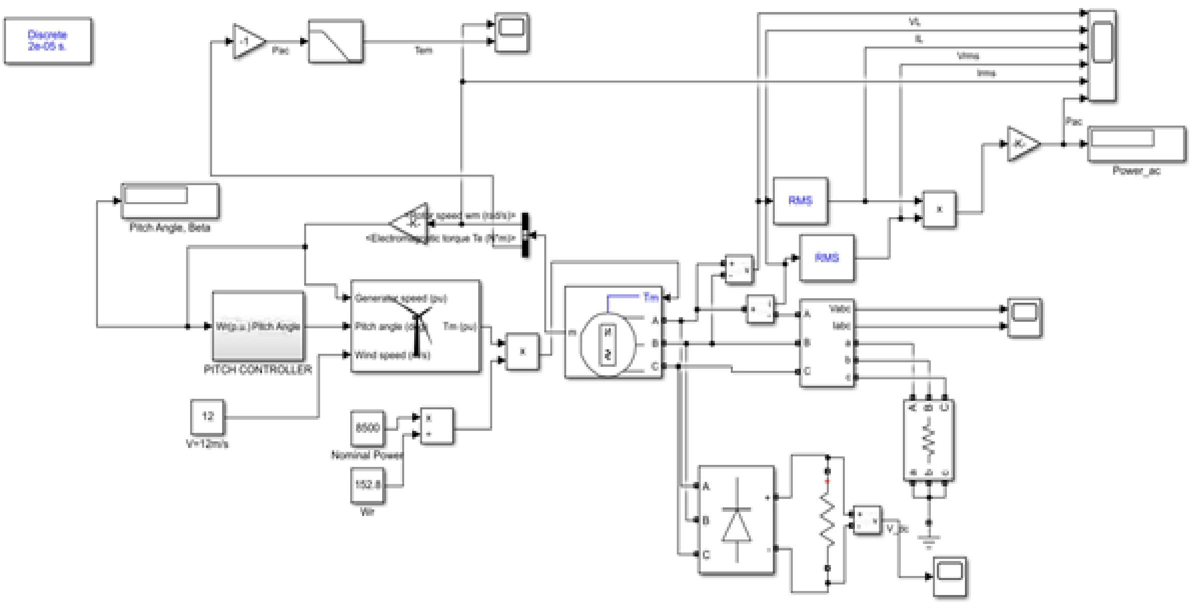

Fig.8. Wind energy harvesting

The conversion from wind energy to electrical energy is facilitated by wind mill, turbine, PMSG (permanent magnet synchronous generator) generator and rectifier. The entire system is modelled in discrete simulation type with 20*10-6 as step time. Thus the parameters of the power gui block are modified. To the turbine, a constant wind speed of 12m/s is supplied. The nominal mechanical output power is taken as 8500 W. The pitch angle is controlled by a subsystem called pitch controller. Inside it, the rotor speed is subtracted from a constant. It’s then subjected to a gain of

500. The saturation block ensures that this value doesn't go above 45. The rise and fall of the signal is controlled by a rate limiter. It has a rising slew rate of 2 and a falling slew rate of -2.

We have assumed, the torque generated from the turbine is the same received by the generator's shaft. Hence, modelling of two mass drive trains was not needed. The computed beta via pitch control is expected to be very small for optimal performance.. The PMSG's rotor speed is fed to the generator speed of the turbine. Using a gain block, the appropriate constants are converted. Below are the characteristics of the turbine used. Maximum power can be obtained by having turbine speed at a point where peaks of the graphs are observed for any given wind speed. Here, MPPT algorithm can be deployed to find the peak power conditions.

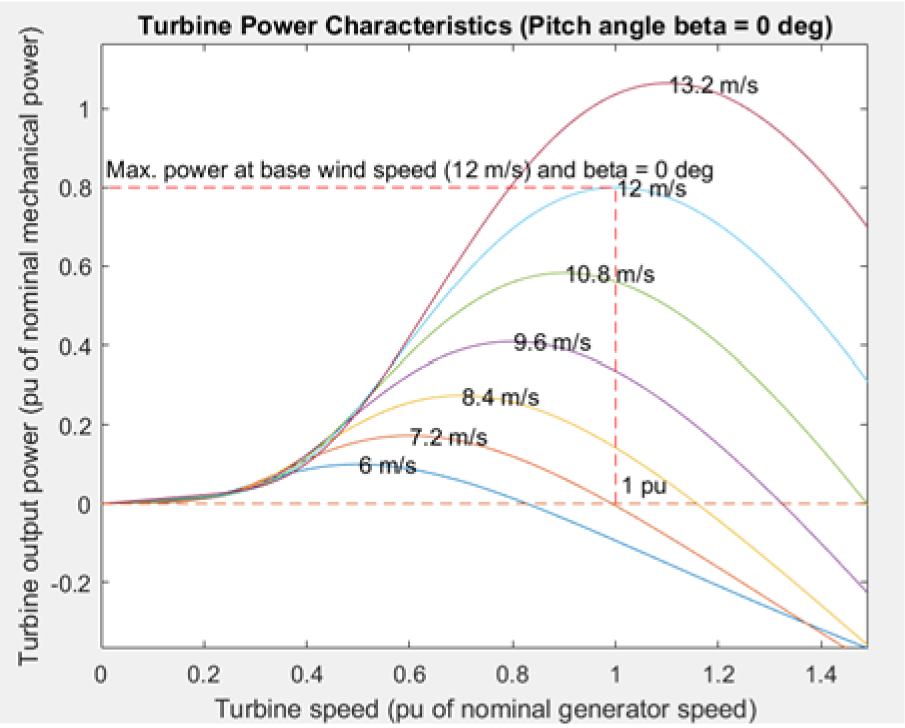

Fig.9. Turbine Characteristics

The torque after multiplying with required constant is fed to a three phase PMSG Generator. According to MATLAB, the stator windings are connected in wye to an internal neutral point. The output of this machine is three phase voltage. Electromagnetic torque produced is put through a LPF. It is then observed by a scope. A load of 25 Ohms three phase-star connected is used. The three phase voltage generated can be observed via a scope. RMS current and voltages are computed and multiplied to AC power value. The 3 phase voltage output is also given to a universal bridge. Diodes are used for rectification purposes. The rectified output is observed through the scope. The DC output can be boosted to a higher DC voltage using boost or buck-boost converter. The following is a diagram of a generic boost converter. The input voltage can be connected to the output of the above system.

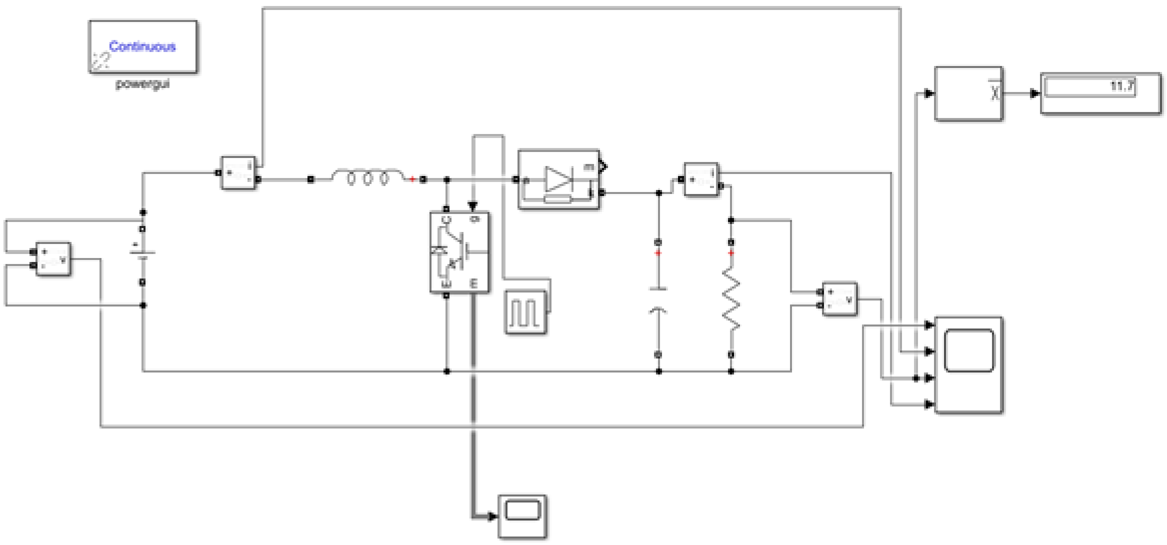

Fig.10. Boost Converter

3.2 Solar Array:

A solar cell is the basic photo voltaic component. Since the current generated by a single photo voltaic cell is small, huge numbers of solar cells are connected in series and parallel connections and are connected to a string monitoring box. In this project 264 modules are connected in parallel and 7 modules in series. For the simulation of the controllers, solar array block is taken. The temperature of the array is 25 degree Celsius and variable irradiance which varies for 5 sec. In Fig. 1 the varying irradiance plot is attached. In such a manner the irradiance is varied and the later part is the DC-DC converter and MPPT controller.

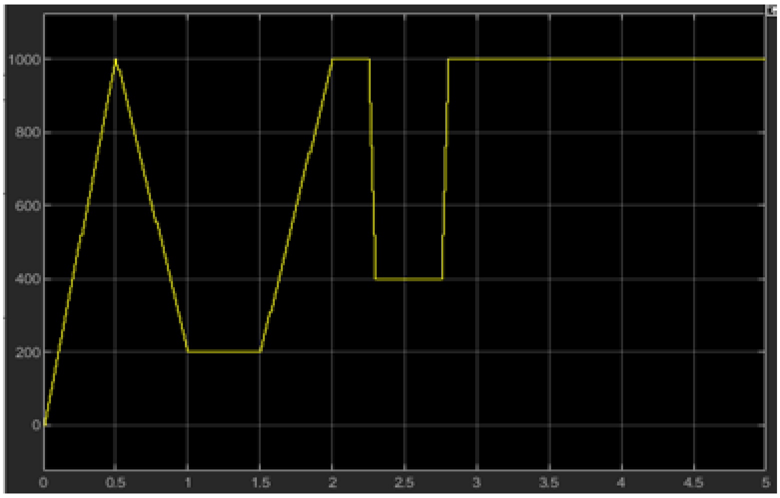

Fig.11. Irradiance variation

Generally a chopper acts as an interface between the PV modules and the load for transferring the power. The PV modules can be used for direct charging purposes but it can damage those batteries and reduce their lifespan due to the variations in current and voltage. There are variations in current and voltage due to changes in the surrounding conditions. To serve the purpose of transferring the power from the PV modules to the utility grid DC-DC converters are used in between them. Here the usage of DC-DC converter became compulsory due to the demand it has received to resolve the issues. . The output voltage of the photovoltaic array is low and the load rating can be different. Basically all these converters consist of a diode, switch, inductor, capacitor and a resistor (load). In place of switch fully controlled devices like MOSFET, IGBT are used.

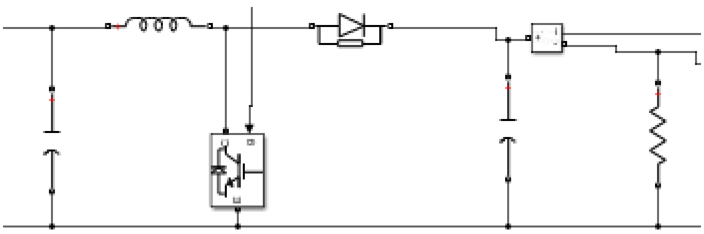

Fig.12. 2 DC-DC converter

For the solar array to work at the MPP, it should see that corresponding impedance in the circuit. MPPT controller basically control the duty cycle of the DC-DC convertor to make sure of this. The algorithm or the network is designed such that the voltage and current in the solar cell at which MPP occurs, which changes continuously due to various factors, is found and duty cycle of the DC-DC convertor is hence found and is fed to it. The DC-DC convertor that is used in the project is a boost convertor. The MPP algorithm used is Perturb & Observe Algorithm.

The MPPT algorithm is implemented because that for each value of irradiance and temperature there will be a value at which the power will be maximum. So through this model we will be trying to operate the load the maximum power possible for the given conditions.

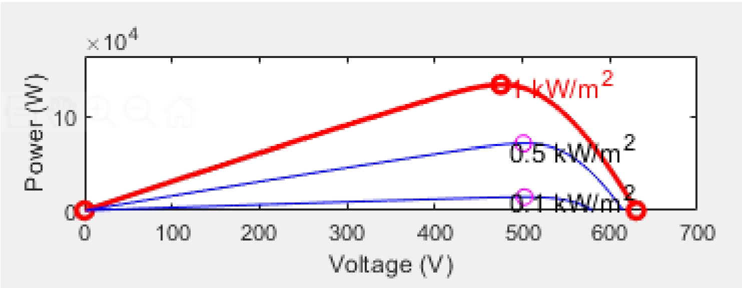

fig.13. P-V characteristics of PV array

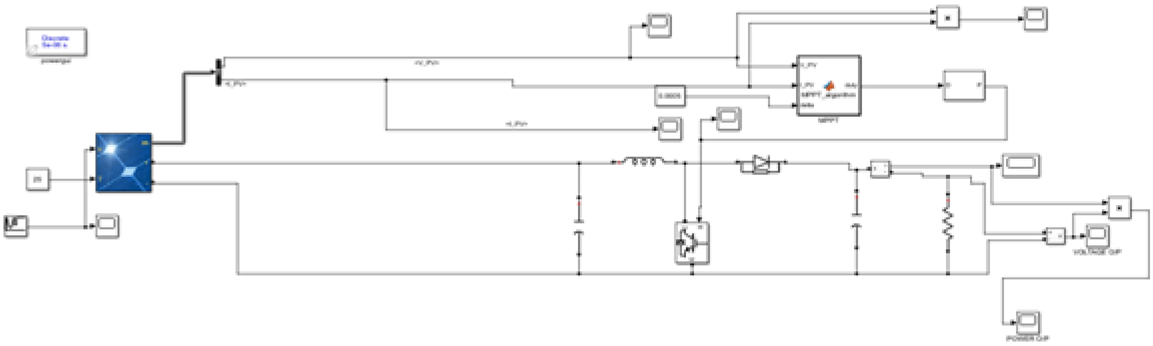

Fig.14. Simulink Model of PV system

The fig. 3 is the integrated model of the PV module, DC-DC converter and the MPPT controller. In place of the MPPT controller, MATLAB function block is used to perform the MPPT algorithm. The controller is designed based on the P & O algorithm mentioned in the MPPT controller section. The inputs of the MPPT controller are PV system voltage, current and delta (0.001). Delta is the value used to change the duty cycle. The value shouldn't be too big or too small. It should be in range such that we can reach the maximum point. The issues with too small or too big is when we have big value we may miss out the maximum point as we go across the curve of P-V characteristics.

3.3 Hybrid Energy Storage System:

In this model, we have a load connected to a source battery, B1, which supplies it constant power. When B1 reaches SOC = 40%, B2 is connected to B1 and charges it till it reaches 100% all the while B1 is still supplying power to load. The circuit is shown below:

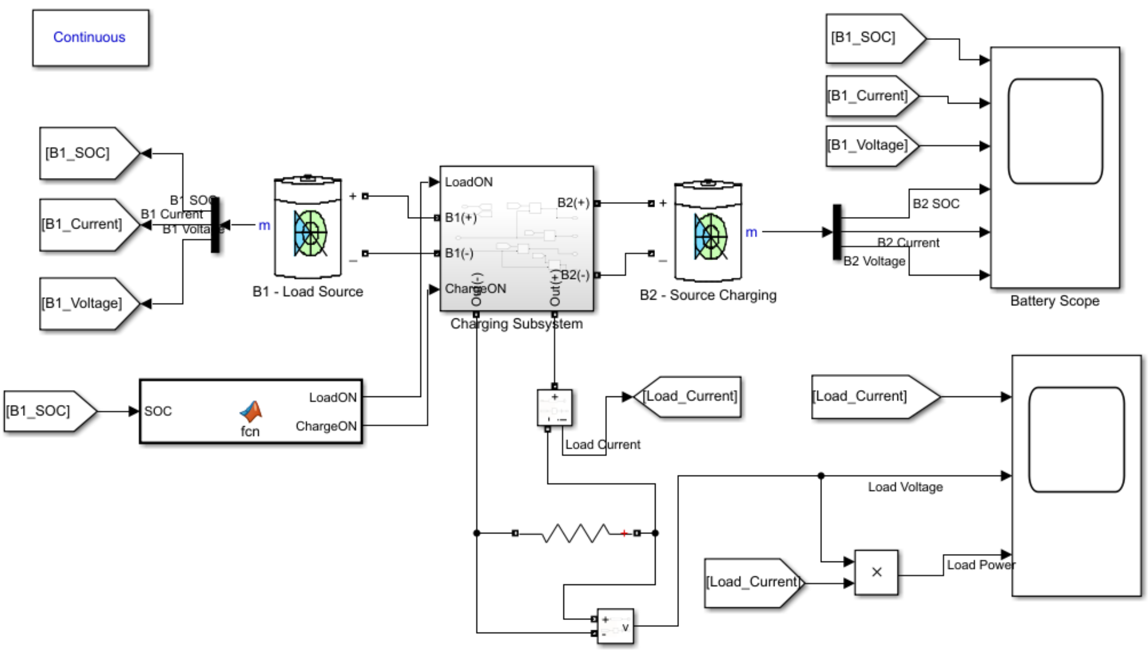

Fig.15. Simulink Model of HESS

Matlab Function that was used to control the switches in the circuit:

Editor - Block: hybrid_ESS/MATLAB Function*

MATLAB Function*

```
function [LoadON, ChargeON] = fcn(SOC)
ChargeON = 0; %Initially battery doesn't need to be charged
LoadON = 1; % The supply to load will always be on
    if SOC <= 40 % Efficient power supply SOC Threshold
        ChargeON = 1;  %Setting Control variable to close the circuit breaker
    elseif ChargeON == 1 && SOC > 40 %If circuit is already Charging, charge till B1 is full
        ChargeON = 1;
    elseif ChargeON == 1 && SOC == 100 %if B1 has charged fully, break the circuit
        ChargeON = 0;
    elseif SOC == 0   %Disconnect once system (i.e B1 and B2) has completely discharged
        LoadON = 0;
    end
```

Fig.16. Switching circuit MATLAB function

This gives two outputs, LoadON and ChargeON, which dictate whether load should be connected to source and whether source should be charging, respectively. Simulation time was given to be 10000s (As it takes at least 3200s for battery to discharge)

3.4 Integrated Model:

The simplified simulation circuit is given below

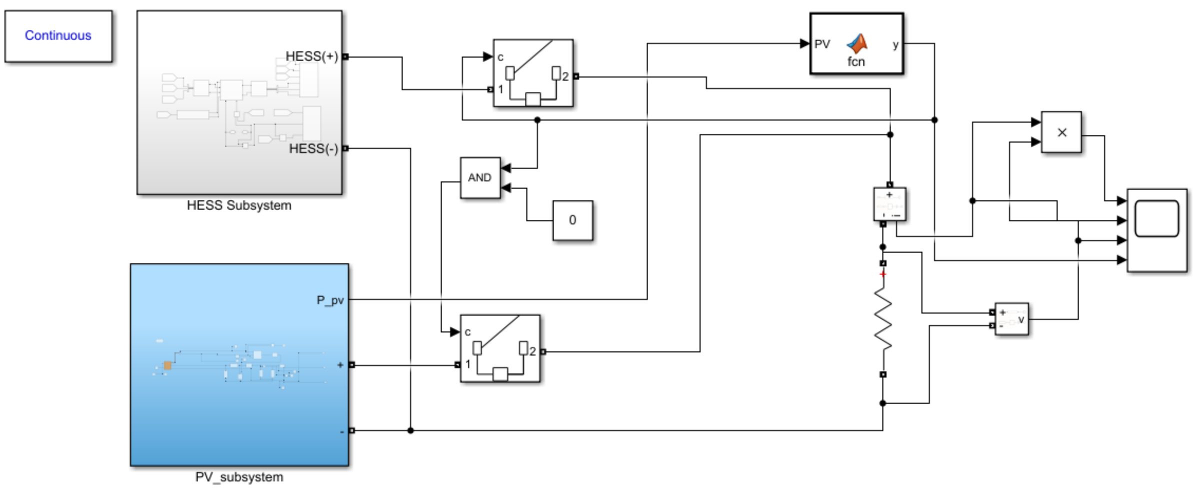

Fig.17: Integrated circuit in SIMULINK

In this circuit, we have approximated EV charging stations to a resistive load in this simplified circuit. We set the threshold power delivery by PV subsystem at 50MW, if the power delivered drops below this value, HESS is connected and PV subsystem is disconnected from the EV charging which maintains the power until PV's output capacity is restored, then it is connected again. In a similar way we can integrate the wind turbine subsystem to the grid and use HSS for storing excess power and delivering power when other sources fail to work.

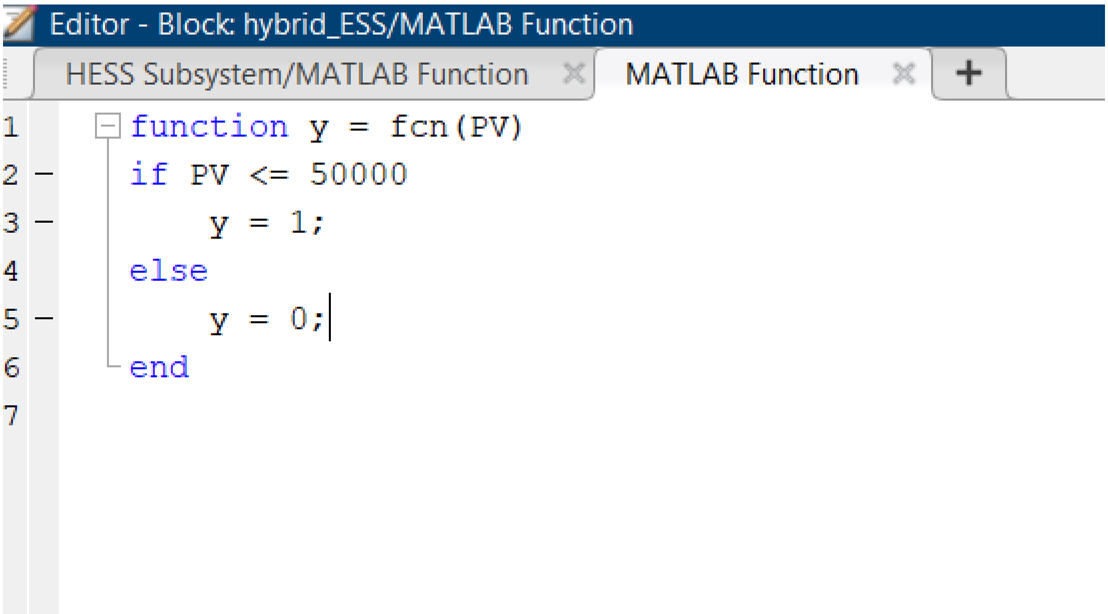

Fig 18: Matlab function to control switching between subsystems

4. RESULTS:

4.1. Wind Energy:

1. The pitch angle varies between 0.035 to 0.04. The same can be seen from the plot below. The after gain plot is the rotor speed of PMSG amplified that is used in the pitch controller.

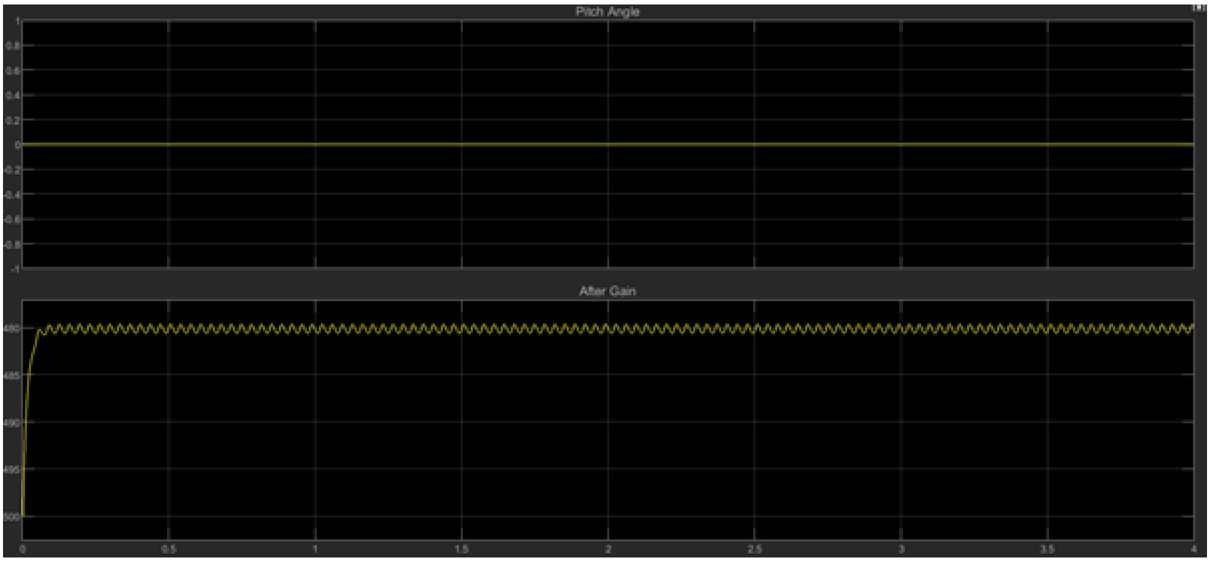

Fig.19

2. The rotor speed and the electromagnetic torque of the PMSG Generator as shown below.

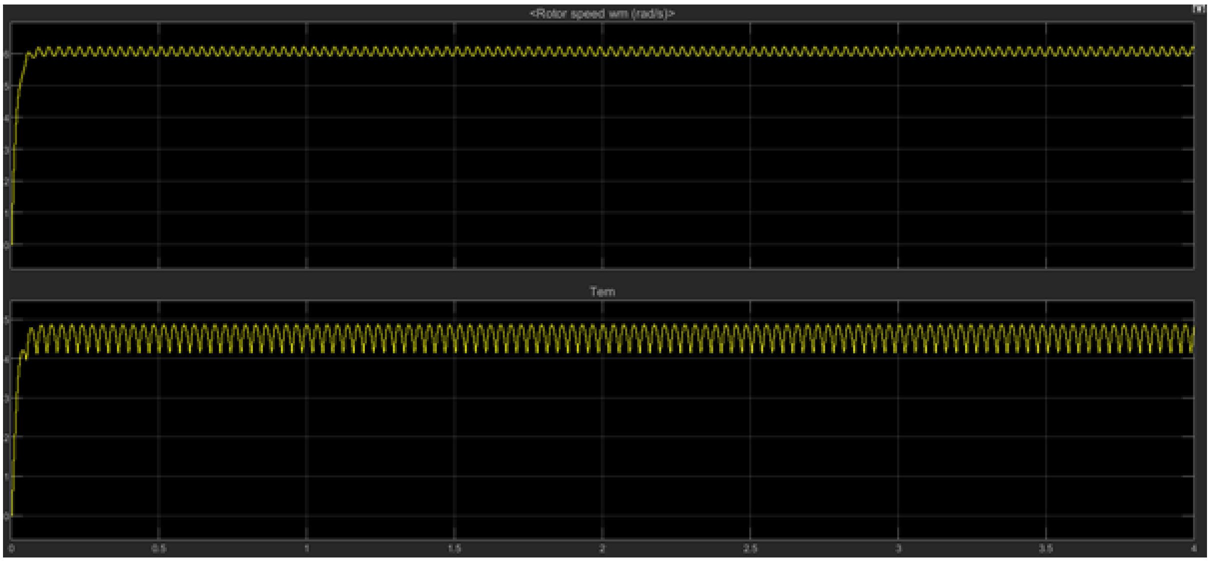

Fig.20

3. The three phase output voltages and currents produced as shown below.

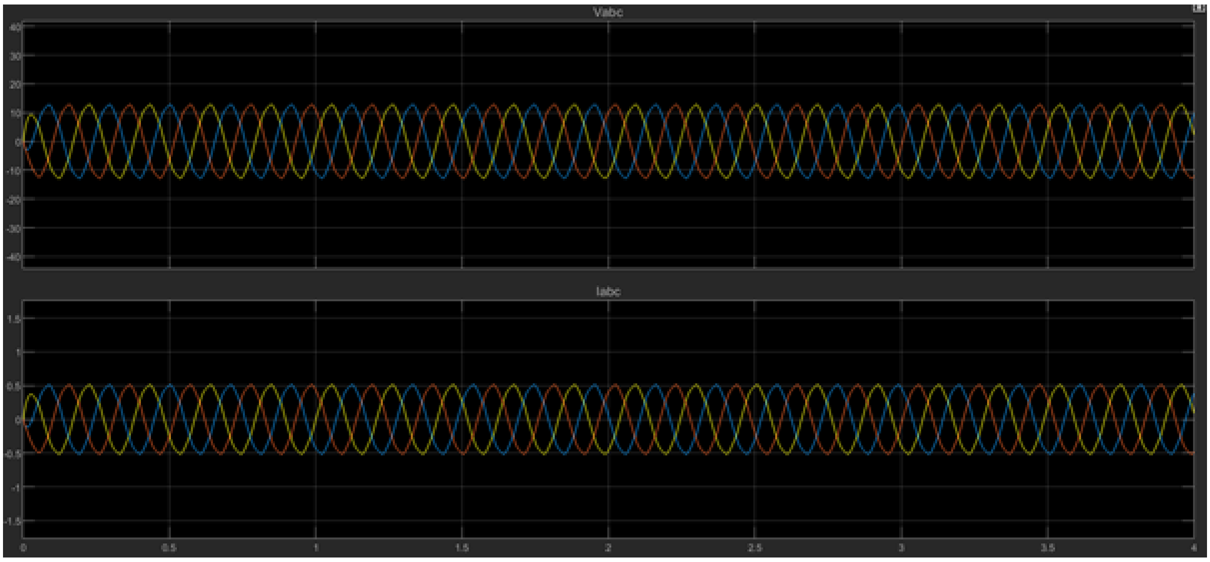

Fig 21.

4. The line voltages, currents and their rms values are shown below. The resultant Pac is also plotted.

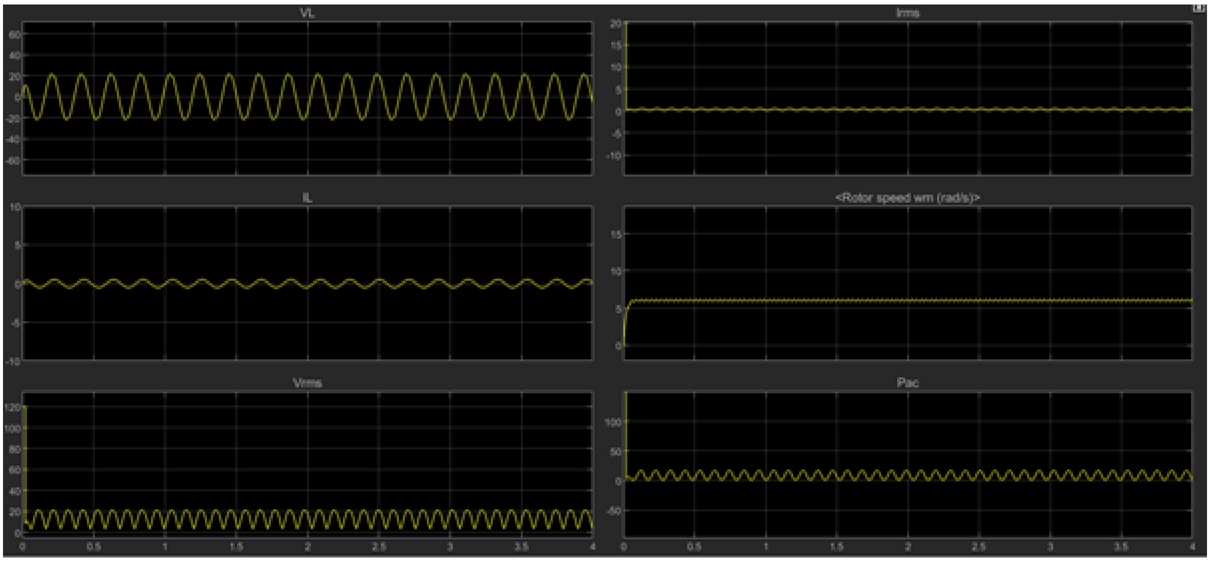

Fig.22

5. After rectification of these 3 phase voltages, the following voltage graph is observed.

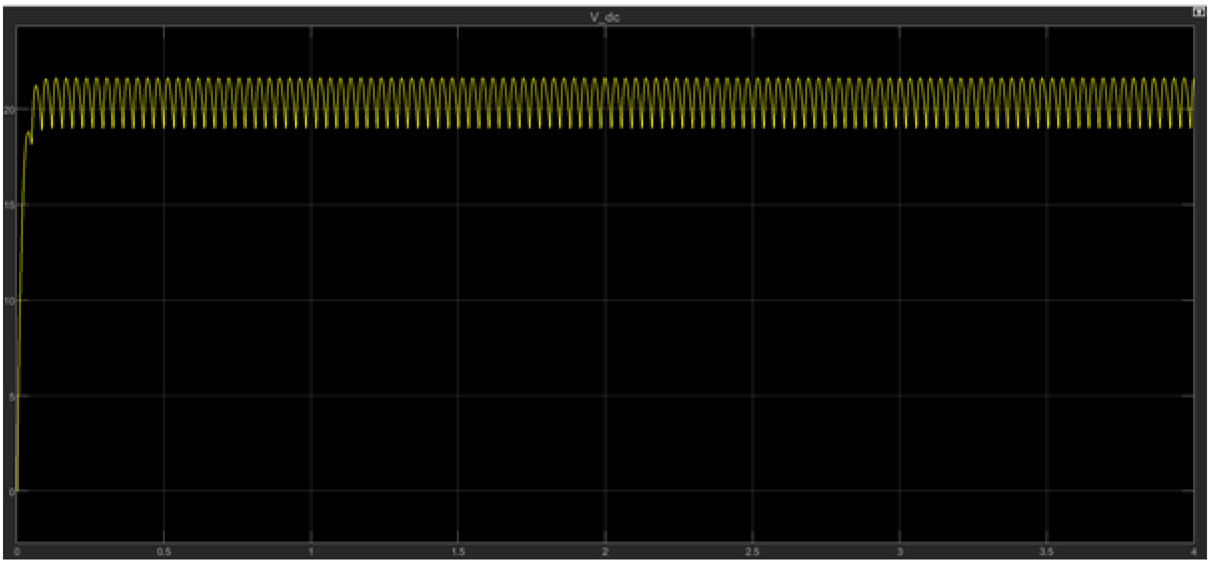

Fig.23

6. Sample output currents and voltages of a boost converter for 10V input.

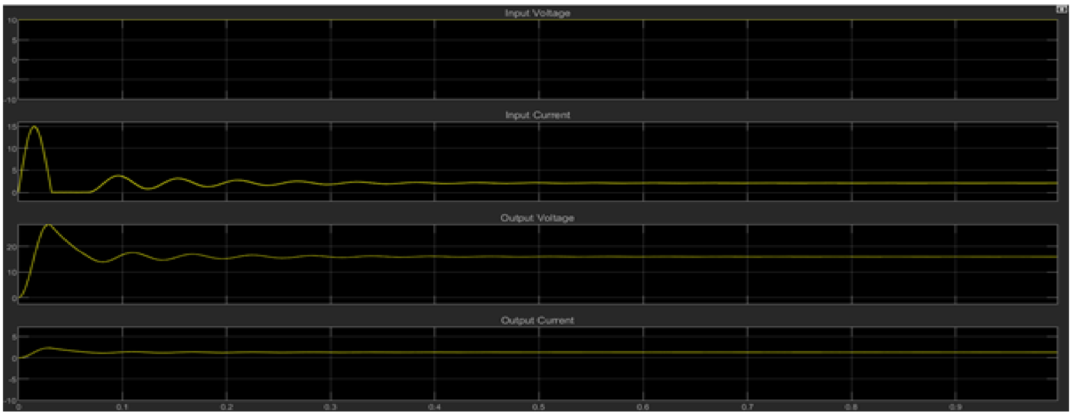

Fig. 24

Whenever the irradiance is changed the system tries to attain the maximum for those environmental conditions. So here we observe that the power follows the irradiance graph. We can say that the load is trying to maintain at the maximum power possible and the voltage gets adjusted according to the load.

4.2. PV Solar Cell:

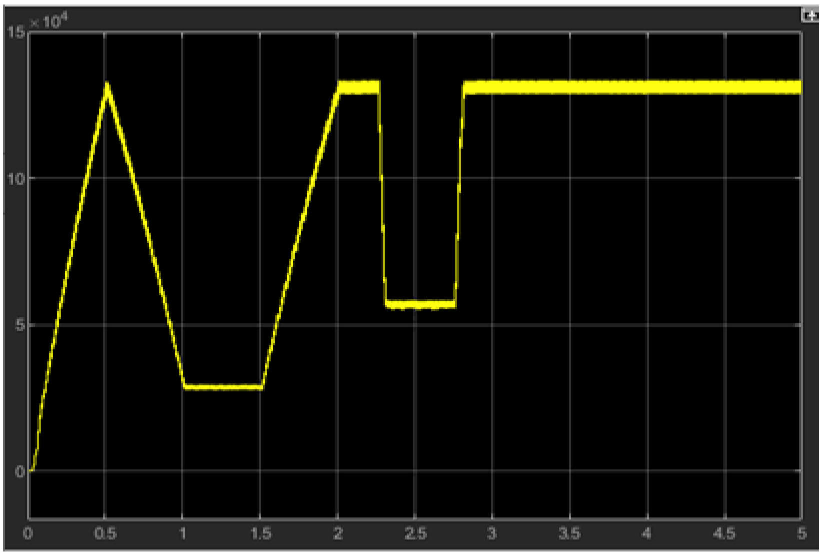

Fig 25: Output Power

Whenever the irradiance is changed the system tries to attain the maximum for those environmental conditions. So here we observe that the power follows the irradiance graph. We can say that the load is trying to maintain at the maximum power possible and the voltage gets adjusted according to the load.

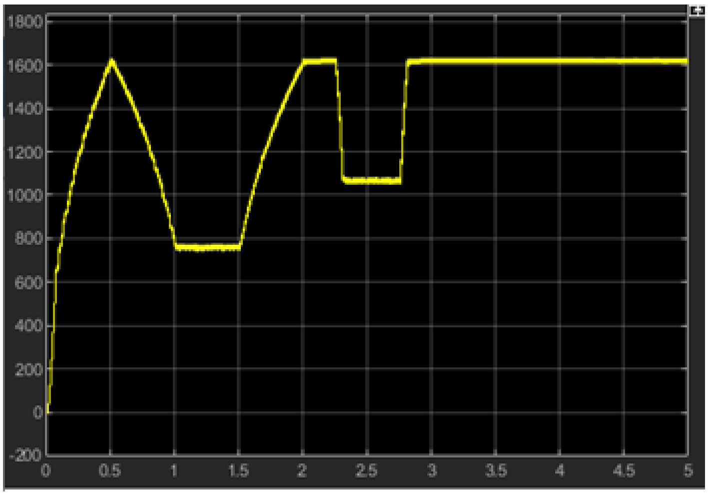

Fig 26 :output voltage

4.3. HESS:

We first ran simulation with Initial SOC of B1 at 100%, but soon after the 7600s mark, the simulation barely progressed, therefore we ran the simulation again with B1 initial SOC at 50% to plot the charge - discharge cycle completely.

1) Power Delivered to Load:

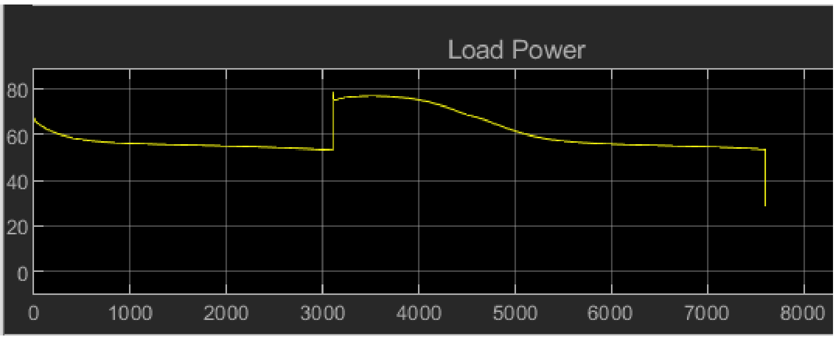

Fig.27

2) B1and B2 characteristics:

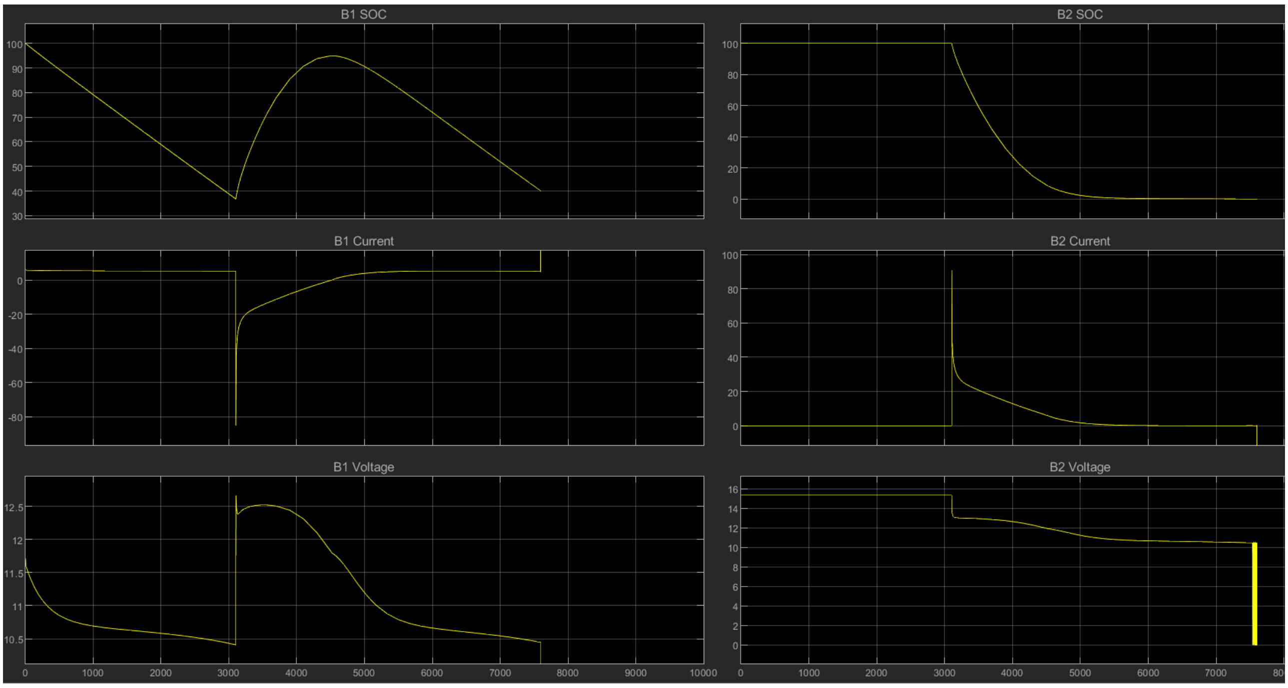

Fig.28

From the B1 and B2 SOC graphs in (2), we see that, at first B1 is only delivering power to load, hence it's decrease in charge is linear (as load is purely resistive), once SOC reaches 40%, B1 starts charging from B2 and the B2 SOC starts dropping while still delivering power to load. After B1 gets charged to its max possible SOC and B2 is discharged to 0%, B1 continues discharging while delivering power to the load.

From the graph showing power delivered to load in (1), we see that the power delivered doesn't drop (there is a power surge as there is an increase in B1 voltage when it starts charging initially). Therefore, we are maintaining the minimum power we deliver to the load for a longer amount of time while also increasing the lifecycle of the batteries. After both the batteries are discharged, the load disconnects from the source.

4.4. Integrated Circuit:

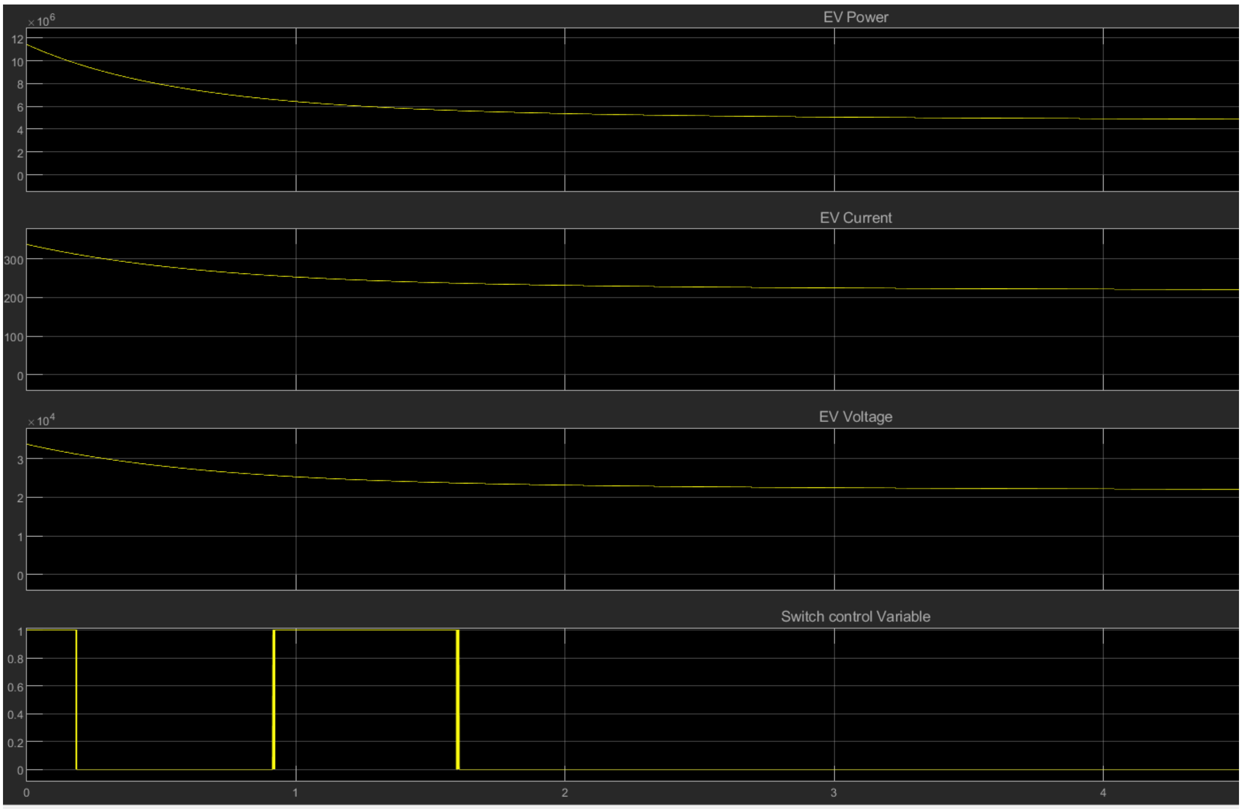

Fig. 29

In this graph, we can see that the EV power is maintained and there are no abrupt changes due to change in power delivered by PV Subsystem as the HESS kicks in to maintain the load supplied and let it decline steadily, As simulation progresses PV output generation is steady and so the HESS remains disconnected. The power threshold was set at 50MW based on Fig.25 of PV Subsystem.

CONCLUSION

Hybrid Renewable Energy Systems offer an eco-friendly optimization of electrical power generation. This study proposes a hybridization of the traditional fossil-fuel based power generation systems by integrating them with renewable energy resources like wind and solar power, thereby providing a simple and cost-efficient solution to the problem of energy shortage. The excess power generated by these sources is stored in a hybrid battery storage system to ensure continuity of power supply to the load in case of emergencies. The aim is to maximize the delivered power of Renewable Energy resources like wind and solar energy to the grid while still having a reliable power supply, an Energy Storage System(ESS). When the renewable energy sources produce excess power, it is stored in the hybrid batteries and when they fall short of the energy demand, energy is supplied to the load by the power stored in the hybrid batteries.We integrated HESS with the PV subsystem and found out that the load delivered to the EV charging station was steady and continuous. Using this application, we can still supply power to the grid in situations of failure in one of the sources by compensating with power from the other sources. The design and comprehensive modelling and simulation results of various components of the Hybrid Renewable Energy System like wind, solar photovoltaic, and Energy Storage Systems with their corresponding control functions and algorithms have been described and presented in detail.

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