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Implementation and Control of Hybrid Solar PV and Wind System for Standalone Microgrid

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Abstract: As the fossil fuels are non-renewable sources of energy and depleting with time, the focus moves towards the renewable sources of energy like solar and wind energy. The renewable sources of energy do not deplete with time and fulfill the increasing demand of energy. In this paper hybrid solar PV system and wind generation systems are implemented using MATLAB/SIMULINK with battery storage in a microgrid, to supply the power demand, at remote locations. Battery storage system is used due to the intermittent nature of the solar and wind energy and thus making this generation system more reliable. The implemented model consists of solar PV, wind turbine connected to a permanent magnet synchronous generator and the output of both the systems is connected to a common DC link through a BOOST converter. A PWM inverter is used for converting the output of boost converter to provide a 3- phase power to the load. In this system Maximum Power Point Tracking (MPPT) is used for both wind and solar PV system. The simulation results of the implemented system are presented in this paper for different environmental conditions.

Keyword: Solar PV system, Wind system, MPPT, BESS, Microgrid

I. INTRODUCTION

Fossil fuels like coal, crude oil and natural gas are supplying most of the energy. Energy demand is increasing day by day with increase in population. But as fossil fuels are depleting in nature and also produce greenhouse gases that lead to the global warming therefore there is a need to focus on the renewable sources of energy like solar energy, wind energy, geothermal energy etc. Several hybrid models are used by either combining them with the grid or as a standalone system. Hybrid models are used due to the fluctuating nature of renewable sources of energy and in hybrid system of two sources if one source is not available then the other source will supply the energy. In this paper a standalone hybrid system composed of solar and wind is proposed and the hybrid system is implemented using MATLAB/SIMULINK. The solar PV system output is connected to a DC Boost converter to enhance the voltage, wind system using PMSG generator is implemented. The output of both the sources is connected to a common dc link where a battery storage system is also connected which will charge through the output of these sources during the excess generation and battery will discharge and supply the load during the insufficient generation due to the fluctuating nature of these sources. The output from dc source is inverted into ac through PWM inverters. MPPT (Maximum Power Point Tracking Techniques) is used in both solar PV and wind systems to track the maximum power from solar under different solar radiations and from wind under different wind speeds.

II. SOLAR PHOTOVOLTAIC SYSTEM

Photovoltaic system is a system used to supply electrical energy by converting the solar energy into electrical energy. Photovoltaic system comprises of solar PV panels, dc-dc boost converter, inverters to change the DC output of the solar PV panels into AC etc. MPPT is used to obtain the maximum power under different environmental conditions.

A. Solar PV modules/ arrays

The basic building block of Solar PV module is solar cell. The PV modules comprise of such several solar cells by connecting them either in parallel or series [3].

Solar cells are p-n junction semiconductor diode made up of thin layer of p-type silicon semiconductor fabricated over a thick layer of n-type semiconductor [1]. Solar cells work on the principle of converting solar radiations into electrical energy using photovoltaic effect. When solar radiations fall on the p-n junction of solar cells then the photons with energy greater than the band gap energy creates the electron-hole pairs at the junction. Then the free electrons move towards the n-region and holes toward the p-region and thus creating a potential difference at the junction. When an external load is connected at the output of the solar cell an electric current start flowing through the load.

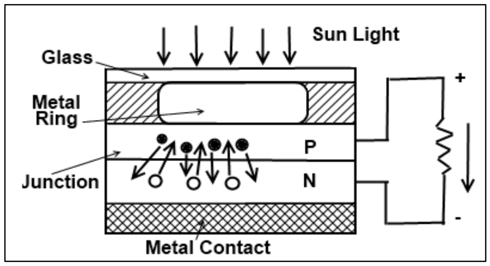

Fig 1- Solar cell

B. Mathematical Modelling of Solar cells and Solar Arrays

Solar cell is equivalent to current source connected to a p-n junction diode and resistors connected in series that describes the internal resistance and in parallel for describing leakage current [2]. The characteristic equation for photovoltaic cell is given by

$$I=I_{Ph}-I_0*(\exp(q*(V+I*R_S)/(A*k*T_r))-1) \quad (1)$$

$$V=V_{SH}-I*R_S \quad (2)$$

$$I=N_P*I_{Ph}-N_P*I_d \quad (6)$$

$$I_{Ph}=(G/G_r)*I_{SC(T_r)}*(1+\alpha_{I_{SC}}(T-T_r)) \quad (3)$$

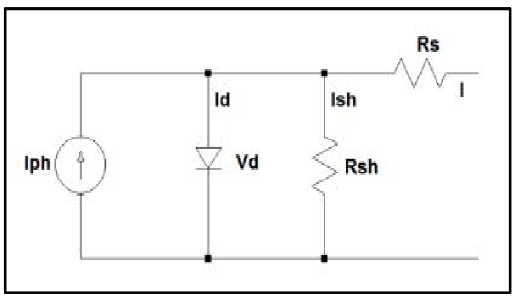

Fig 2- Equivalent circuit of Solar cell

$$I_0=I_{0(T_r)}*(T/T_r)^3*\exp(((q*V_g)/(A*k))*((1/T_r)-(1/T))) \quad (4)$$

$$I_{0(T_r)}=I_{SC(T_r)}*(\exp((q*V_{OC(Tr)})/(A*k*T))-1) \quad (5)$$

Where,

I_0 and V_0 = Cell output current and voltage,

I_{sc}= short circuit current at rated temperature (A/^{0}C),

T = Cell Temperature in Kelvin,

A=Ideality factor,

k= Boltzmann's constant; 1.38*10^ (-23) J/K,

q = electron charge; 1.6*10^ (-19)C,

α_{ISC}= short circuit current temperature coefficient,

G = solar radiation (W/m^2),

G_r= solar radiation at STC (W/m^2)

I_{scr} = short circuit current at 25°C,

I_{ph} = light generated current,

V_g= band gap energy,

T_r= reference temperature,

R_{sh}= shunt resistance,

R_s= series resistance,

As the solar cells produce less power and voltage therefore they are connected in series or parallel on a module for generating high voltage and power.

Solar arrays are a group of several PV modules which are connected in series and parallel to obtain the required voltage and current.

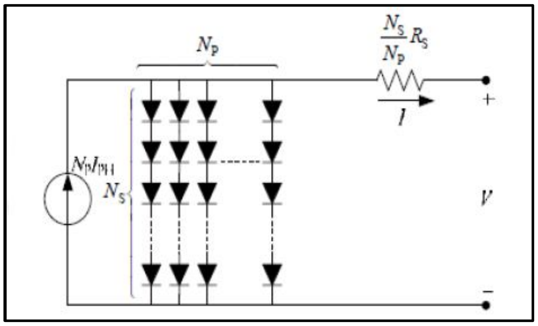

Fig 3- Equivalent circuit of PV module

For a PV array with equivalent circuit shown in figure 3, the equation for output current is given by

$$I_d = I_0 * (\exp((q*(V+I*R_S))/(A*k*T_r*N_S))\text{-}1) \quad (7)$$

$$I_0 = I_{0(Tr)} * (T/T_r)^3 * (\exp(((q*V_g)/(A*k)) * ((1/T_r) - (1/T)))) \quad (8)$$

$$I_{0(T_r)} = I_{SC(T_r)} * (\exp((q*V_{OC(Tr)})/(A*k*T*N_S)) - 1) \quad (9)$$

Where,

N_s = number of cells connected in series,

N_p = number of cells connected in parallel.

The model of solar array used in solar PV system is modelled in MATLAB/SIMULINK using these equations for any number of modules connected in series or parallel for providing the required output voltage and power [4]. A direct block of solar PV array can also be used from the SIMULINK library.

III. WIND SYSTEM

The wind system converts the wind energy by capturing it on wind turbine as kinetic energy and converting it into mechanical energy for driving a generator. The generator then uses this energy to generate electrical power. The wind system consists of wind turbines, PMSG generator, rectifier, inverter and LC filter. For the control of rotor speed and for obtaining the high output power, the power electronics equipment is used [7] [8].

The power generated by the turbine is given by

$$P = \frac{1}{2}\rho A v^3 C_P \quad (10)$$

Where

P=power output of the turbine input to the generator,

ρ = air density,

A= area swept bythe rotor

v =wind speed

Cp=power coefficient which depends up on the tip speed ratio(λ) and pitch angle (β)

And

$$\lambda = \frac{2\pi NR}{v} \quad (11)$$

Where,

N= speed of rotor in revolutions per minute,
R= radius of rotor blade in meter,
The actual torque acting on the rotor is given by

$$T=\frac{1}{2}\rho A v^2 C_T \qquad (12)$$

$$C_T = C_P / \lambda \qquad (13)$$

.Where, C_T = torque coefficient

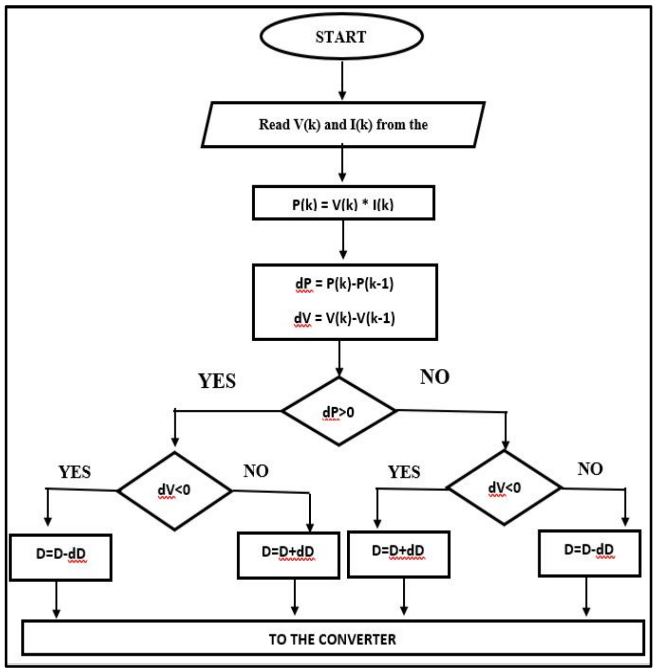

Fig.4 Block diagram of wind energy conversion using PMSG

A. Permanent Magnet Synchronous Generator (PMSG)

In a permanent synchronous generator, the permanent magnet is mounted on the surface of the rotor and the excitation field in the air gap is created by permanent magnet rotor [9]. For the maximum efficiency the air gap between the rotor and stator is kept small. The PMSG provides better efficiency and lesser maintenance due to the absence of dc excitation applied to the rotor
The PMSG's shaft is connected mechanically to the shaft of turbine. The output of the PM
SG is converted to dc through dc rectifier. The block diagram of WECS is shown in fig 4.

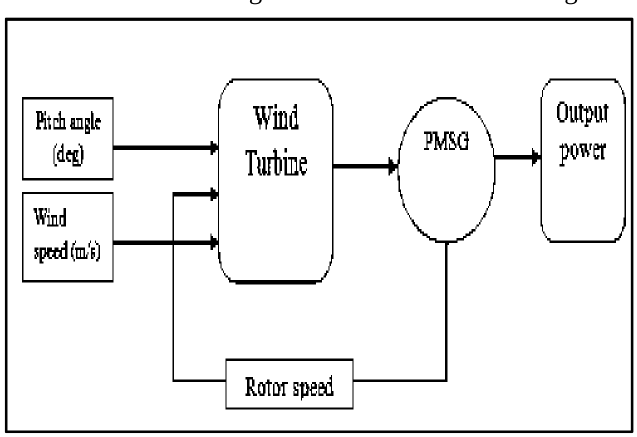

Fig 5. Flow chart of P&O MPPT

IV. MAXIMUM POWER POINT TECHNIQUES

Maximum power point technique is used with wind and solar PV system to extract the maximum power at different conditions.

A. MPPT for Solar PV System

The efficiency of overall solar PV system is very low due to the varying nature of solar energy. Therefore, to increase the efficiency of the solar PV system maximum power point technique is used. The MPPT is used to extract maximum power from the system for different operating conditions.

There are several MPPT techniques used with solar PV system such as Perturb and Observe (P&O), Incremental Inductance, short circuit current method, open circuit voltage method etc [5],[6].

In this paper we use perturb and observe method of maximum power point tracking techniques and the flow chart of P&O technique is shown in fig 5. In this technique the voltage is observed at each instant and power is then calculated. Then at each instant the power is compared with the previous one. And then the perturbation is done in the voltage by perturbing the duty cycle of the converter to obtain the maximum power.

If the change in power is negative then the voltage is increased or decreased with respect to the maximum power point that is if the voltage is in the left of MPP then it should be increased and if it is on the right of MPP then it should be decreased. And for positive change in power, voltage is perturbed in the same direction of change in voltage that is if change in voltage is positive then voltage is increased otherwise it is decreased.

The voltage is increased or decreased by perturbing the duty cycle of boost converter. The relationship between the duty cycle and output voltage of the converter is given by

$$V_{out} = \frac{V_{in}}{1-D} \qquad (14)$$

Where,

V_{out} = The output voltage of the converter,

V_{in} = The output voltage of the solar PV system,

D = Duty cycle

B. MPPT for Wind system

Due to the unpredictable nature of wind input, methods are adopted to obtain the optimal operating point where the maximum power can be obtained. There are Maximum Power Point (MPP) techniques for tracking the optimal operating point for variable speed wind energy conversion system like Tip speed ratio control, Optimal torque control, Power signal feedback control etc.

In this paper optimal torque control method is used. In this method the torque of the PMSG generator is adjusted according to the reference torque of wind turbine which is adjusted to obtain the maximum power under variable wind speed.

The wind turbines are designed to operate at a specific value of tip speed ratio which is an optimal value to obtain optimal torque under different speeds.

If $\lambda_{opt}$is the optimal value of the tip speed ratio then the power coefficient is maximum $C_{pmax}$for this tip speed ratio. The power obtained under these values is optimal power P_{opt} and torque obtained is optimal torque T_{opt}.

$$P_{Opt} = \frac{1}{2}\frac{\rho A \omega_m^3 R^3 C_{Pmax}}{\lambda_{opt}^3} \qquad (15)$$

$$T_{Opt} = \frac{\frac{1}{2}\rho A \omega_m^2 C_{Pmax} R^3}{\lambda_{opt}^3} \qquad (16)$$

Where,ω_m= angular velocity of the rotor (rad/sec)

$$T_{Opt} = K_{Opt}\omega_m^2 \qquad (17)$$

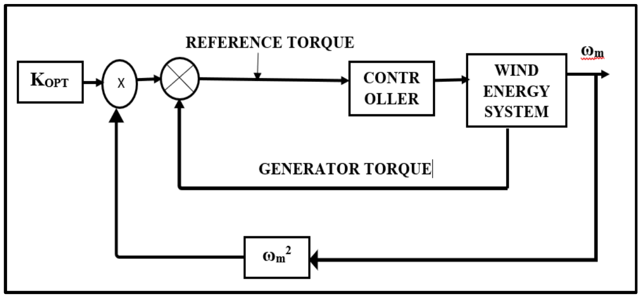

Fig 6. Block diagram of MPPT used in wind energy conversion system

The optimal torque is given to the controller as reference torque where the generator torque is compared and adjust with respect to the reference torque as given in fig 6 [10].

V. BATTERY ENERGY STORAGE SYSTEM

Storage system is an important part of this system and it is composed of batteries, bidirectional converters and controllers. There are two modes of operation of battery, in one mode it is charged if there is an excess power from the hybrid sources and in another mode it discharges or supply the voltage to the load during the deficiency of supply from sources.

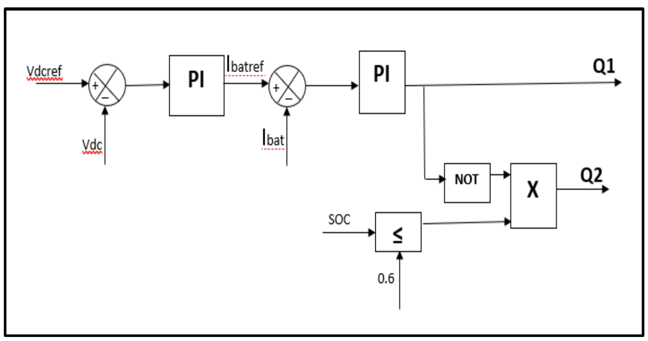

Fig 7. Controlling of converter connected to battery

The charging and discharging of battery is carried out with the help of bi-directional converter (Buck-Boost converter) as shown in fig 8 which is connected to the common dc bus and maintain the common dc voltage at the bus.
When the dc voltage at common dc link (V_{dc}) is greater than the battery voltage (V_{bat}) and the state of charge (SOC) is less than 60% then the bidirectional converter operates in buck mode that is battery starts charging and if $V_{dc}$is less than V_{bat}then the converter operates in a boost mode that is the battery starts discharging through the load [11]. The controlling is explained through the block diagram given in fig. 7.

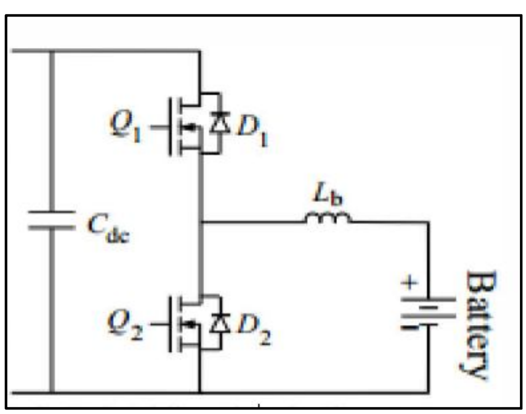

Fig 8. Bidirectional converter

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VI. PROPOSED HYBRID SOLAR PV AND WIND SYSTEM

A hybrid Solar PV and Wind system is suggested in this paper which is implemented using MATLAB/Simulink as shown in fig.-9. It consists of a solar PV array with MPPT control and dc-dc boost converter, wind turbine operating at variable wind speeds with MPPT control and ac-dc rectifier, dc battery for storage of electrical energy with proper management of energy supplied or absorbed by battery. All the output from these sources and battery are dc in nature and connected to a common dc bus. The dc bus output is then applied to a SPWM three phase inverter for obtaining ac output to supply ac loads [12] [13].

VII. SIMULATION RESULTS

The simulation presented in this paper consist of the wind energy conversion system operated at varying wind speeds (10,11,12)m/sec, solar PV system at the input of which there is varying solar irradiation (1000,800,700,600) W/m^2 connected to the common dc bus through converters and the Simulink model of battery with its control is also connected to the common dc bus. The dc voltage of the dc bus is then converted to three phase ac by using PWM inverters and LC filters to compensate the harmonics. The ac supply obtained is used to supply the static load of 15KW connected at t=0sec and dynamic loads of 2.5KW connected at t=0.5sec to t=1sec and 4KW connected to the single phase of the inverted three phase system output between t=2sec to t=2.5 sec.

Solar photovoltaic system simulated in this paper comprises of photovoltaic array, MPPT control and boost converter. The voltage generated by the PV array is 319.7volts which is increased by using boost converter and thus the PV system generates the electrical dc voltage of 636.5volts and dc output current of 9.725amperes. Solar PV system generates an average power of 6221Watts.The PV system output results are shown in fig 10.

The simulated wind energy conversion system comprises of wind turbine, PMSG, MPPT control generates an ac voltage and current of 398volts and 12.61amperes respectively. The rectifier is used to convert the ac output into dc. The power generated by WECS is 7906watts.The dc output from the wind system is connected to the common dc bus. The output of WECS is as shown in fig 11.

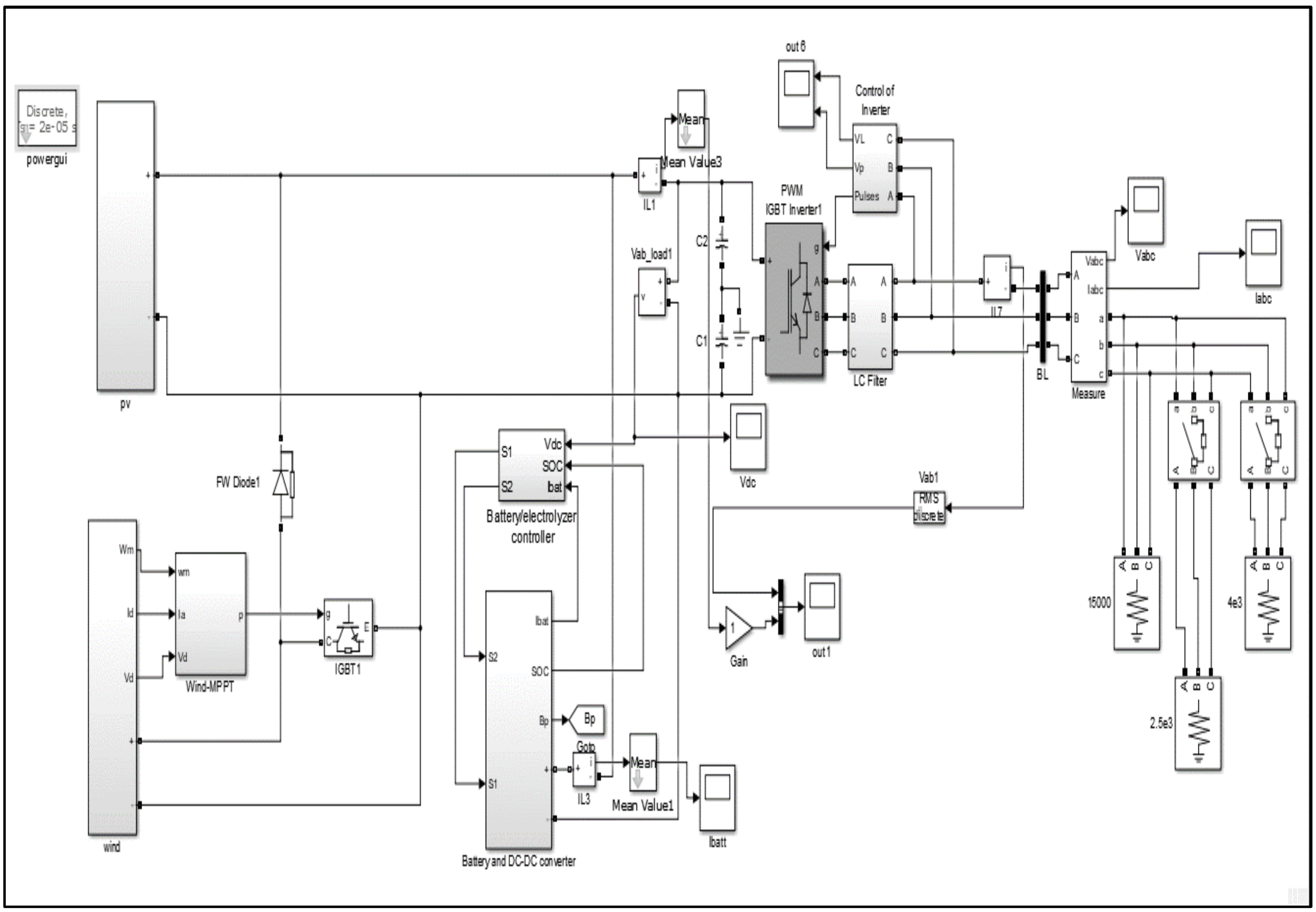

Fig 9 Implementation Model of Hybrid System

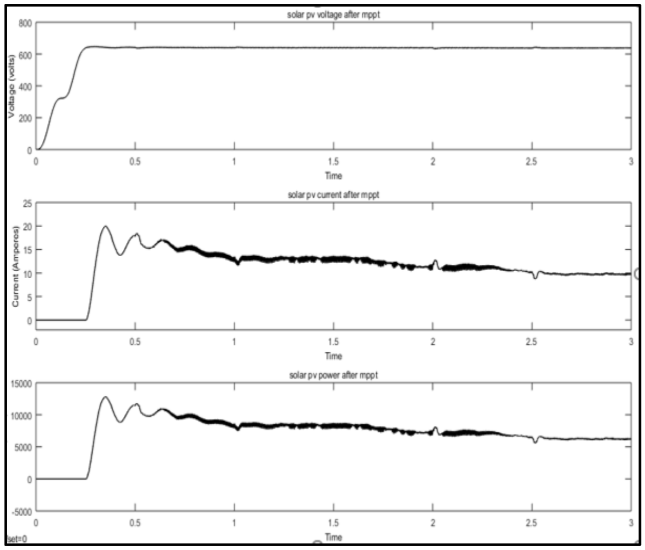

Fig 10 Solar PV output

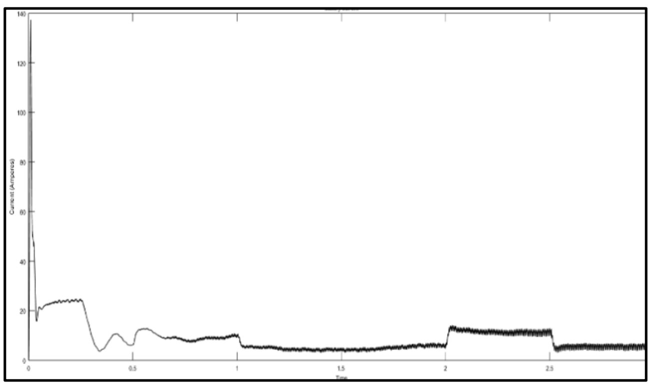

Fig 11 WECS output

The battery used in the simulation is of capacity 6.5Ah and 200volts. It charges and discharges according to the need of the system through the bi-directional converters. The voltage at the common dc bus (V_{dc}) is 640 volts. The battery output is also connected to thecommon dc bus. The Vdc voltage is shown in fig 12.

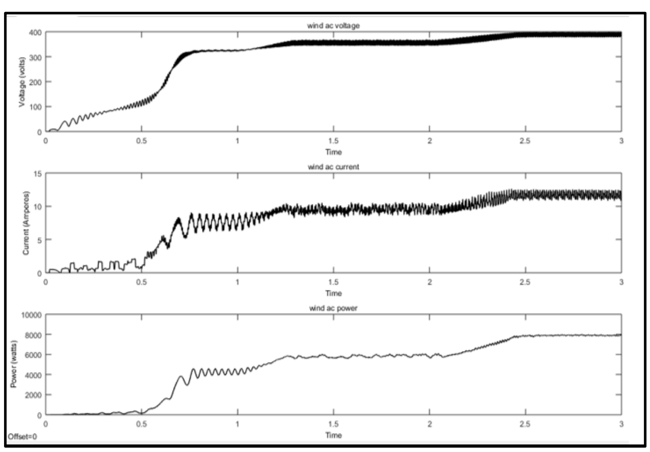

Fig 12 Battery current

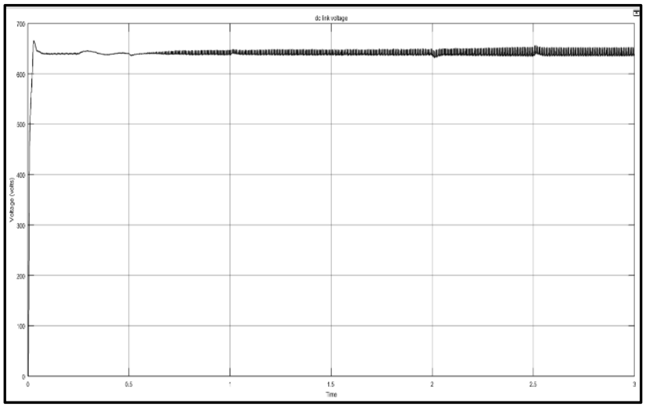

Fig 12 DC bus voltage

The dc output is converted to three phase ac output by using SPWM inverter. The three-phase ac output voltage and current from the inverter to supply the load is shown in fig 13 and fig 14.The system supplies the increased current during the addition of dynamic load at t=0.5 to t=1sec and at t=2 to 2.5 sec. The power supplied by the hybrid system and the load demand is shown in fig 15.

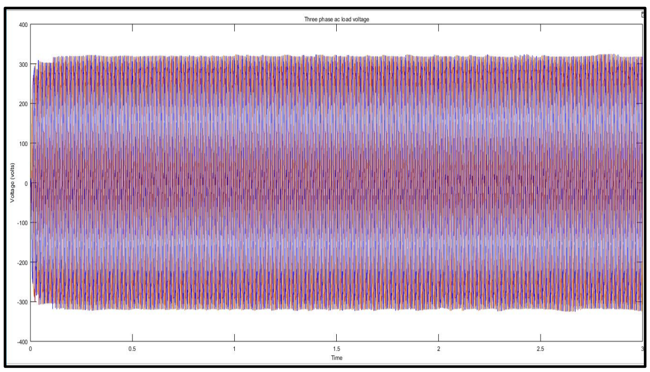

Fig 13 Ac output voltage

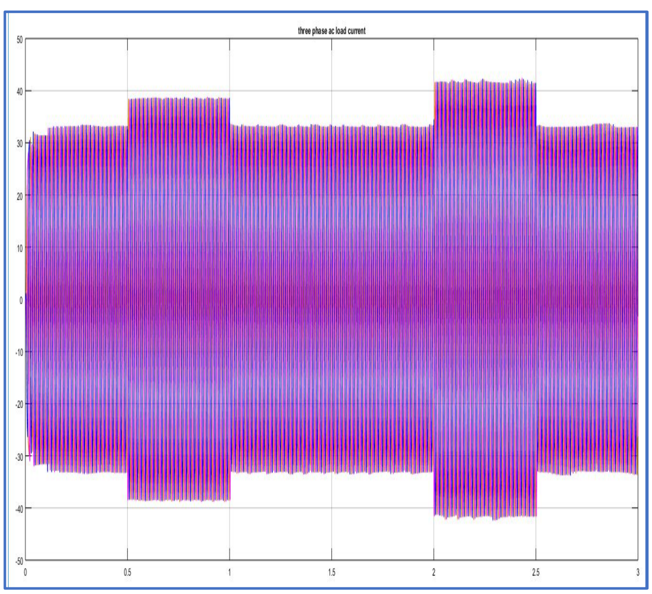

Fig 14 Ac output current

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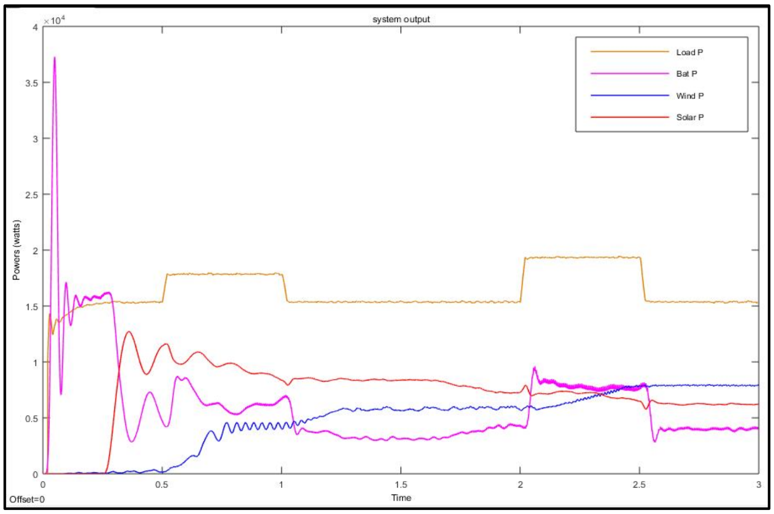

Fig 15 System power and load demand

VIII. CONCLUSIONS

The paper discusses and analysed the hybrid system with several controls like MPPT control for solar PV system, MPPT control with WECS, control of battery and the control of inverter using PWM technique. The major concern is about the dc voltage at the common dc bus which should be maintained constant. The future work is to reduce the fluctuations in the dc bus voltage.

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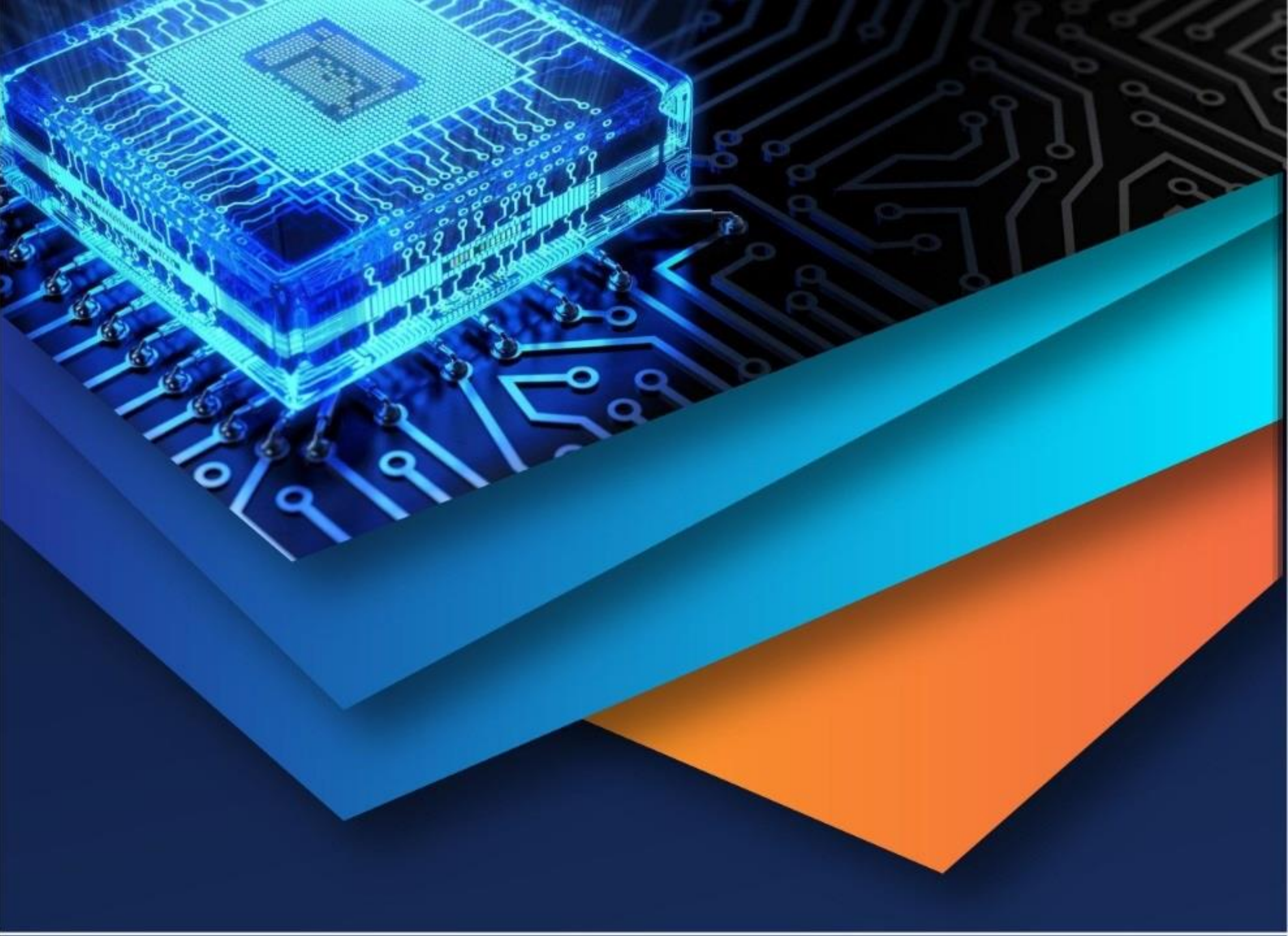

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