Using Point of Common Coupling (PCC) for Power Shaving in Grid Connected Hybridized Network

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Abstract: A network that connects all components together is referred to as a grid. A study has been conducted over hybrid system which is a self-sustainable grid. The hybrid system is connected with the grid at Point of Common Coupling (PCC). The aim of this paper is to focus on the behavior of different intermittent energy sources, which are complementary to each other or not. For this purpose, research papers related to different intermittent energy sources are considered, and the behavior of renewable sources in different regions are discussed. Integration of solar, wind and battery sources to main grid, and a suitable control system for the PCC is presented that provides uninterrupted power flow from the hybrid system to load and the main power grid. The current and voltage regulator on PCC are optimized by Particle swarm optimization (PSO) algorithm. The hybrid system in this paper contains multiple power generator sources that include photovoltaic cells (PV), wind turbine and battery. Negative impact on main power grid by changing power through PCC are also examined.

Keywords Point of Common Coupling (PCC), Power Shaving, Particle swarm optimization (PSO) algorithm, Photovoltaic cells (PV), Wind turbine, Battery Energy Storage System, Induction Generator, Grid Connected Hybridized Network, MATLAB/SIMULINK software.

1. INTRODUCTION

Electric power systems are the fundamental infrastructure of modern society. All are aware of the current situation of fossil fuels in the world. The world has made great industrial progress. This industrial revolution has been a major factor in the rapid increase in environmental pollution. Also, with the passage of time, these fossil fuels are decreasing day by day leading to a rapid increase in its prices. The demand, due to the industrial revolution and increasing population, is also increasing day by day. It has become very difficult to keep a balanced relationship between supply and demand of fossil fuels [1].

Global warming has led to an increase in research towards renewable energy sources for electricity generation and integration in main power grid. Green energy sources are a good option to tackle the ever-rising problems of climate changes.

One of the main causes of global warming, rising greenhouse gas emissions in the atmosphere, can be attributed to increased usage of fossil fuels [2]. According to the International Panel for Climate Change (IPCC), net zero CO2 emissions must be reached by 2050 in order to keep warming to 1.5 °C, as the average world temperature is expected to rise by about 3 °C during the following few decades [3].

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Renewable energy is generated from natural processes includes solar, hydro, geothermal heat, tides, water, and various forms of biomass. This energy cannot be exhausted and is always renewed. There are three main qualities of renewable energy sources *i.e*. abundance, allowance of modular technology and pollution free. These sources are a viable alternative, and the world is already turning towards new, clean, sustainable energy sources [1].

In Europe, Solar and Wind energy are the most common and carbon free renewable source. The use of solar power to generate electricity is rising sharply all around the world. The total amount of capacity was 178.9TWh and the amount of wind power generated in Europe was about 510.1 TWh by the end of 2020 [4]. It is estimated that by the year 2035 the installed capacity of wind energy will be about 1102GW while the yearly wind power generation will be around 2073TWh. Europe at the top position in the generation of wind energy, and integration of wind power to grid will be the good sign in the future [19].

With European countries having such a big potential in wind and solar power, an integration system capable of integrating wind and solar power to the main grid will be a good solution for utilizing these sources in technical as well as economical aspects. This solution allows providing excess solar and wind power to grid or Battery Energy Storage System (BESS). BESS could be a good option as a backup power system. Solar-wind hybrid system with battery storage capabilities can be a part of the distributed generation system.

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Grid integration of renewable resources has many advantages as follows [20]:

- Increased reliability.
- Reduced power losses.
- Decreased carbon dioxide emission.
- Low environmental issues
- Cost savings energy.
- Power quality enhancement.

In this current scenario, there is a need to utilize the naturally occurring energy around us. This can be in the form of sunlight (solar energy), wind energy etc. In short, utilization of renewable energy is the cheapest and the easiest solution to all of our existing problems.

With the recent development in science, it has becoming much easier to utilize these different sources. But there are a few limitations to these sources. For example, there will be no sunlight on a rainy day. Therefore, generation from solar energy might fail. There isn't a fixed speed of wind so there will be fluctuations when wind energy is used for the generation.

The solution to these problems is hybridization. Hybridization is becoming very common these days. Hybridization of different energy sources means combining the different renewable energy sources in order to get an output. The hybrid renewable energy system (HRES) invariably includes battery storage to meet the demand when solar, wind energy sources is not available. This is the main benefit of hybridization of different renewable energy sources.

This research introduces a novel strategy for integrating hybrid renewable energy sources solar, wind, and battery storage into the primary grid through current and voltage regulation optimization at the Point of Common Coupling (PCC) with Particle Swarm Optimization (PSO). Unlike earlier work that necessarily considers standalone renewable sources, the given research explores the complementary nature of variable energy sources such that there are stable and consistent flows of power to reduce grid reliance [48]. PSO application is more grid stabilizing as it reduces voltage and frequency variation due to oscillating renewable power [49]. Practically, the hybrid system under consideration has immense potential for application in microgrids and distributed energy systems. For example, Germany's Energiewende initiative has shown that hybrid microgrids can provide improved energy reliability with lower carbon emissions [50]. Through grid resilience improvement and ease of large-scale penetration of renewable energy, this research contributes towards improved sustainable energy transition and decentralized power generation.

1.1. Methodology

This section discusses the procedure used in this study for hybridization of different energy sources. In this paper, quantitative research methods are implemented. This is performed by mathematical modelling of all the different sources of power, such as, wind, battery, and PV cells. Each of these kinds of sources operate in accordance with physical laws that are described through mathematical equations. The important variables and factors that drive these sources are analyzed and described by use of different models for each of the different source of energy. The popular control algorithm of PI controller is also discussed. For solar panel, the simple parallel diode and resistance model is described. It is a good approximate model for most applications. For the wind turbine, key expressions of mechanical energy are used to express the power that can be obtained through wind energy. Finally, battery is used to store the surplus power from solar and wind system. Also, it will deliver the power to the load when the power is required.

In order to facilitate this research, books and research papers relevant to the subject of energy generation through hybrid system. Furthermore, the findings included in different journal articles and books can be reviewed, allowing to analyze the results and how the methodologies used by those authors to obtain these results. Their findings facts as a guide line and helping tools during research, and take clues from their methodologies and techniques to achieve the results that are aimed in this paper.

2. MATHEMATICAL MODELLING OF HYBRID SYSTEM

2.1. Mathematical Modelling of Solar PV

PV cells are semiconductor devices that convert sunlight into electricity. The basic model of a PV cell is shown Figure **1**.

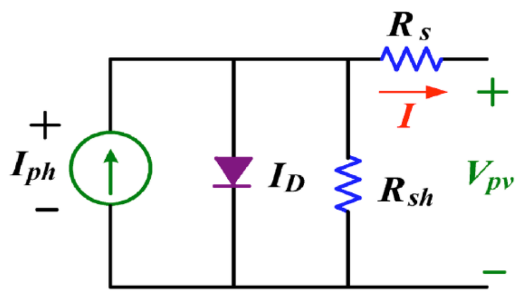


Figure 1: PV cell equivalent circuit diagram [11].

In this model, the solar cell acts as a current source in parallel with a diode and a small resistance (shunt resistance).

By using Kirchhoff's Current law the output current of the non-ideal PV cell is,

$$I_{pv} = I_{ph} - I_D - I_{sh} \tag{1}$$

Where I_{ph} is the current source represents the cell photocurrent, I_D is the current through the diode, R_S and R_{sh} are the series and shunt resistance of the cell [6].

The PV panel equations are shown mathematically in [6-10].

Based on Figure **1**, Photo - current module is given as,

$$I_{ph} = [\, I_{scr} + K_i(T - 298)]\,\frac{\lambda}{1000} \tag{2}$$

Reverse saturation current module I_{rs} is expressed as,

$$I_{rs} = \frac{I_{scr}}{e^{\frac{(qV_{OC})-1}{N_S kAT}}} \tag{3}$$

So, Saturation current module I_D differs with cell temperature is defined by,

$$I_D = I_{rs}[\frac{T}{T_r}]^3 \exp\,[\frac{q*E_{go}}{Bk(\frac{1}{T_r}-\frac{1}{T})}] \tag{4}$$

The shunt resistor current calculated as,

$$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{V_{pv}+I_{pv}\,R_S}{R_{sh}} \tag{5}$$

Hence, the output current of the PV module is,

$$I_{pv} = N_p[\, I_{ph} - I_D\left[exp\left\{\frac{q(V_{pv}+I_{pv}R_S)}{N_S AkT}\right\} - 1\right] - \frac{N_p V_{pv}+N_S I_{pv} R_S}{N_S R_{sh}} \tag{6}$$

The value of R_S is very low and R_{sh} is very high, so due to the simplicity of the modeling they can be neglected. Then the output current can be written as follows,

$$I_{pv} = N_p[\, I_{ph} - I_D\left[\exp\left\{\frac{q(V_{pv}+I_{pv}R_S)}{N_S AkT}\right\} - 1\right] \tag{7}$$

From the equation of I_{pv} the PV voltage can be given as,

$$V_{pv} = \frac{N_S AkT}{q}\ln\left(\frac{N_p I_{ph}+N_p I_D - I_{pv}}{N_p I_D}\right) - \frac{N_S}{N_p} I_{pv} R_S \tag{8}$$

Table 1: Solar Panel Parameters

PV Array Module Name Sunpower SPR-305E-WHT-D	
Maximum power (W)	305.226
Cells per module (Ncell)	96
Parallel strings	66
Series connected modules per string	5
Open circuit voltage V_{oc}(v)	64.2
Short circuit current I_{sc}(A)	5.96
Voltage at maximum power point V_{mp}(V)	54.7
Current at maximum power point I_{mp} (A)	5.58
Irradiances $\frac{w}{m^2}$	1000, 250
Temperature ℃	25, 50

A PV array is connected with 66 parallel strings and 5 in series and its maximum power is 305.226 W. Hence, the total power production from PV array is 100.724 KW.

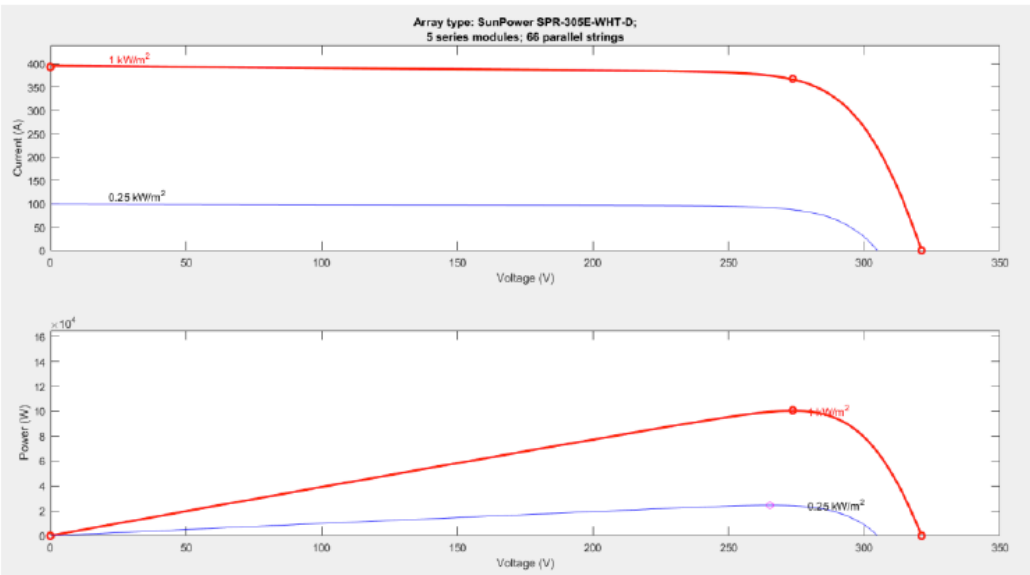


Figure 2: PV and VI curve for PV panel.

2.2. Maximum Power Point Tracking

MPPT stands for Maximum Power Point Tracking. It is an optimization method used for solar panels. An MPPT controller is typically a buck or boost converter connected between the solar cell and the load, and attempts to match the impedance between the source and the load so that maximum available power can be delivered at all times. Solar panels are devices that are dependent on external environmental and atmospheric conditions, so the power being generated by them is fluctuating in response. The function of the MPPT is to keep these fluctuations to a minimum, and keep cell operating at a point where maximum power can be delivered. This provides control and stability to the solar panel.

In this paper Perturb and Observe algorithm is used to track the MPPT of PV module

Perturb and Observe Algorithm

Maximum Power Point Tracking algorithm has its advantages and disadvantages. Due to simplicity of Perturb and observe (P&O) method is generally used. P&O method adjusts the operating voltage of PV cell, the important purpose of MPPT technique is to attain the maximum power point voltage to make sure that the maximum voltage of PV will be delivered to the converter and also control the duty cycle of the dc-dc converter.

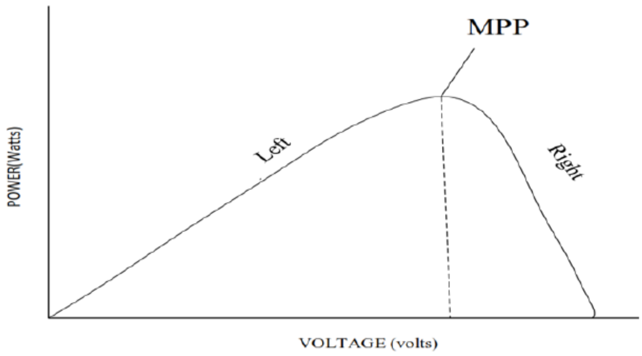


Figure 3: P-V characteristics curve (P & O) [10, 16].

The p-v characteristics curve of a PV system as shown in Figure **3**, from the PV curve the maximum point moves left or right to achieve the maximum power and always monitor the voltage of PV then delivered the maximum power. On right side of Maximum Power Point as the power increases when the voltage decreases. While on left side of MPP increasing voltage will increase power. This is the main idea behind the P&O algorithm to track the MPP [11].

The flow chart of P&O algorithm is shown in Figure **4**.

2.3. DC / DC Converter

DC / DC converter used to deliver the maximum power from the PV cells to the load. It coupled between the solar cell and the load. By changing the duty cycle,

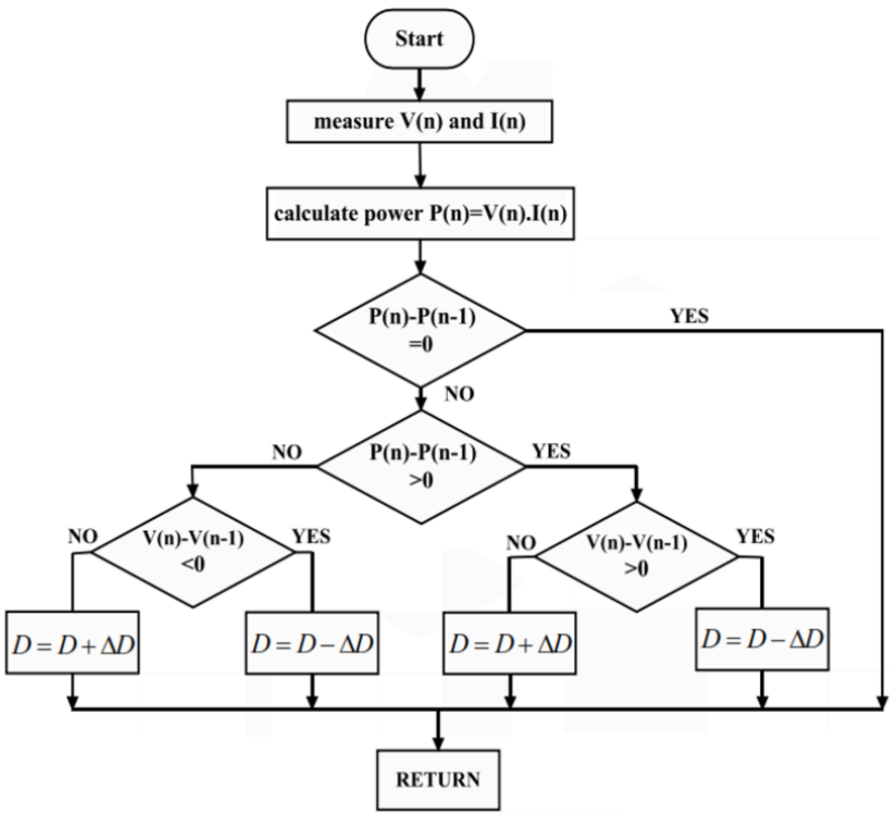


Figure 4: Flow chart of P&O algorithm for MPPT [16].

it changed the impedance of the load, so able to deliver the maximum power [12].

Types of DC / DC converters;

- Buck converter (step down).
- Boost converter (step up).
- Buck-Boost converter.

In present work, need to draw maximum voltage from the solar panel. Hence, boost converter has been selected for this purpose.

2.3.1. Boost Converter

- The output of boost converter is higher than input. Hence, using Boost converter PV system directly connected to the load and DC grid. For AC-grid it is connected through inverter.
- Boost converter has high efficiency, easy to control, and reduce oscillation. Block diagram of boost converter as shown in Figure **5**.

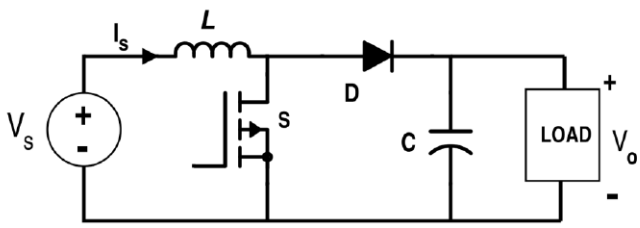


Figure 5: Boost converter [17].

Boost converter commonly used for increasing the voltage and delivered the power. Hence, output voltage of DC/DC boost converter can be given as,

$$V_o = \frac{V_s}{1-D} \tag{9}$$

Where V_s is the input voltage and D is the duty-cycle.

2.4. Inverter

The key purpose of the inverter is conversion of DC power into AC, or if connected to a stiff grid , control the flow of active and reactive power. The important characteristics of a wind, PV inverter are its reliability and its efficiency. The inverters are designed to operate approximately at the maximum power of the system. Normally, inverter efficiencies are fluctuating between 90% to 96% at full load.

The inverter generates the active power and delivered to the ac load and local grid and also control the reactive power. Some of the inverters have ability to absorb or produce reactive power, if needed. Its depend on the q axis current. In this hybrid system q axis current is zero. Therefore, reactive power will be zero. So, Inverter are designed to perform at unity power factor. Therefore, the inverter power flow equations are given as follows [13].

$$P = \frac{V_{inv} * V \sin(\delta_{inv})}{X_t} \tag{10}$$

$$Q = \frac{V(V_{inv} * \cos(\delta_{inv}) - V)}{X_t} \tag{11}$$

Where,

X_t Is reactance between line and the transformer.

2.5. Modelling of Wind Turbine

Wind turbine rotates by the kinetic energy of the wind, which is given as,

$$E = \frac{1}{2} m v^2 \tag{12}$$

Hence, the wind power can be given as,

$$P_w = \frac{dE}{dt} = \frac{1}{2} \left(\frac{d_m}{d_t}\right) v^2 \tag{13}$$

Where m is the mass, $\frac{d_m}{d_t} = \rho A v^2$ is the flow rate, ρ is the density of air, $A = \pi R^2$ is area through which the air flows.

The mechanical power established through wind turbine can be given as,

$$P_w = \frac{1}{2} \rho \pi R^2 v^3 C_p(\lambda, \beta) \tag{14}$$

Where, P_w is the mechanical power from wind turbine, R is the length of blade, v is the wind speed, $C_p(\lambda, \beta)$ is the power coefficients.

The equation of tip-speed ratio depends on the mechanical speed of wind turbine rotor ω_t, and is as given below,

$$\lambda = \frac{\omega_t R}{v} \tag{15}$$

$$\omega_t = \frac{d\theta_t}{dt} \tag{16}$$

Wind turbine efficiency based on the turbine modelling characteristics can be obtained through following equation,

$$C_p(\lambda, \beta) = c_1 \left(\frac{c_2}{\lambda_i} - c_3 \beta - c_4\right) e^{\frac{-c_5}{\lambda_i}} + c_6 \lambda \tag{17}$$

$$\lambda_i = \frac{1}{\frac{1}{\lambda + 0{,}08\beta} - \frac{0{,}035}{\beta^3 + 1}} \tag{18}$$

Where coefficients c_1-c_6 for this model are: c_1=0.5176; c_2=116; c_3=0.4; c_4=5; c_5=21; c_6=0.0068. Wind turbine will be delivered the maximum output

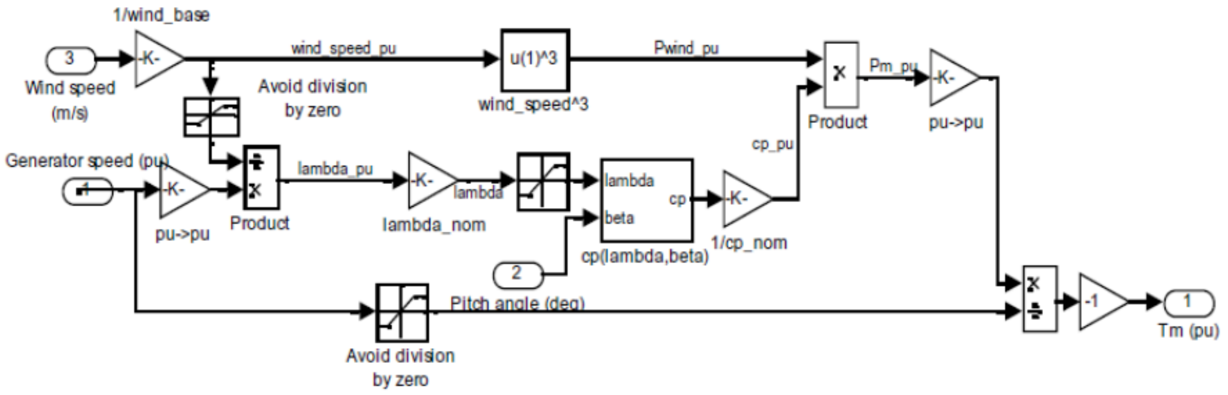


Figure 6: Wind turbine block in Matlab /Simulink.

power when maximum value of C_p and the pitch angle β will be to zero. In this project for extract the maximum power from wind turbine keep the value of β will be zero [14].

The wind turbine torque equation is,

$$T_t(t) = J_t \frac{d^2\theta_t}{dt^2} + T_r \quad (19)$$

Where, J_t is the inertia of the turbine rotor and T_r is the reaction torque.

Electromechanical Torque equation from generator side is shown as,

$$-T_e = J_g \frac{d^2\theta_g}{dt^2} + T_g \quad (20)$$

Where, θ_g is the rotational angle of the induction generator while J_g is the rotor inertia of the IG and T_g is the reaction torque [15].

Wind turbine block model as shown in Figure **6**.

Above is a model of wind turbine established in MATLAB Simulink.

Modelling of Induction Generator

The d-q equivalent circuit diagram of the 3-phase squirrel-cage induction generator as shown in Figure **7**,

From this diagram, the d-q axis equations of the stator and rotor voltages are,

$$V_{ds} = R_s i_{ds} + \frac{d\varphi_{ds}}{dt} - \omega\varphi_{qs} \quad (21)$$

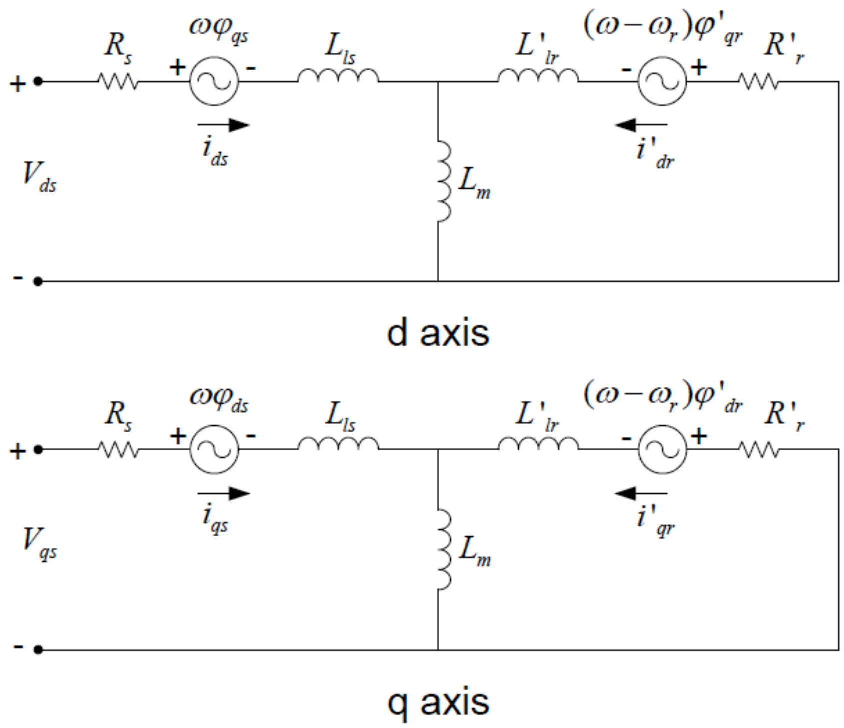


Figure 7: **d**-**q** equivalent circuit of the squirrel-cage induction generator.

$$V_{qs} = R_s i_{qs} + \frac{d\varphi_{qs}}{dt} + \omega\varphi_{ds} \quad (22)$$

$$0 = R'_r i'_{dr} + \frac{d\varphi'_{dr}}{dt} - (\omega - \omega_r)\varphi'_{qr} \quad (23)$$

$$0 = R'_r i'_{qr} + \frac{d\varphi'_{qr}}{dt} + (\omega - \omega_r)\varphi'_{dr} \quad (24)$$

Here, ω is the reference frame angular velocity and ω_r is the electrical angular velocity. Flux linkages from the set (21) – (24) described as:

$$\varphi_{ds} = L_s i_{ds} + L_m i'_{dr} \quad (25)$$

$$\varphi_{qs} = L_s i_{qs} + L_m i'_{qr} \quad (26)$$

$$\varphi'_{dr} = L'_r i'_{dr} + L_m i_{ds} \quad (27)$$

$$\varphi'_{qr} = L'_r i'_{qr} + L_m i_{qs} \quad (28)$$

Where,

$$L_s = L_{ls} + L_m \quad (29)$$

$$L'_r = L'_{lr} + L_m \quad (30)$$

Then the electromechanical torque equation will be,

$$T_e = \frac{3}{2}\frac{p}{2}(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}) \quad (31)$$

Here, p is number of poles of the machine [16].

Table 2: Wind Turbine Parameters

Wind Turbine	
Nominal mechanical output power (KW)	100
Base power of the electrical generator (KVA)	100/0.9
Base wind speed (m/s)	12
Maximum power at base wind speed (p.u. of nominal mechanical power)	0.73
Base rotational speed (p.u.)	1
Pitch angle (deg)	0
Induction Generator	
Nominal power (KVA)	100/0.9
Nominal voltage (V)	500
Nominal frequency (Hz)	60
Stator resistance (p.u.)	0.01965
Stator inductance (p.u.)	0.0397
Rotor resistance (p.u.)	0.01909
Rotor inductance (p.u.)	0.0397
Mutual inductance (p.u.)	1
Inertia constant (s)	0.09526
Friction factor (p.u.)	0.05
Pole pairs	2
Initial conditions 1,0 0.4,0.4,0,0,0	

2.6. Modelling of Battery Energy Storage System

Lead acid battery invented in 1859. It is a type of rechargeable battery. Lead acid battery can be discharge at a very high rate. In this project Lead-Acid battery is used for storing the power. Battery block from Sim Power Systems library. Battery will supply power to the load when PV generation is constant or variation in generation and wind is not working. PV and wind generation is 162KW when both are operating together, so the storage capacity for 2 hours should be,

$$E = P * t(h) = 150^3 * 2 = 300\ KW \quad (32)$$

Where P is the load power assumed for modelling the battery. Since the battery voltage is 435 V, the total ampere hour required is,

$$Q = \frac{E}{V_{dc}} = \frac{300\ k}{435} = 690\ \text{Ah} \quad (33)$$

Hence, capacity of the battery should be 690 Ah [17]. According to modelling it is able to deliver the power to the load till two hours but taking very long time for charging. So, here assumed the capacity 50 Ah for analyse the behaviour of battery when fully charged. Equivalent circuit of the battery is as shown in Figure **8**.

Mathematical model of discharging state ($i^*<0$) is given in (34) and charging state ($i^*>0$) is described by equation (35).

Lead – Acid Model

$$f_2(it, i^*, i, Exp) = E_0 - K\frac{Q}{|it|+0.1Q}i^* - \frac{Q}{Q-it}it + Laplace^{-1}\left(\frac{Exp(s)}{Sel(s)}\frac{1}{s}\right) \quad (34)$$

$$f_1(it, i^*, i, Exp) = E_0 - K\frac{Q}{Q-it}i^* - \frac{Q}{Q-it}it + Laplace^{-1}\left(\frac{Exp(s)}{Sel(s)}0\right) \quad (35)$$

Where,

E_0	Constant voltage (V)
E_{batt}	Nonlinear voltage (V)
K	Polarization constant (Ah^{-1})
i^*	Low frequency current dynamics (A)
I	Battery current (A)
It	Extracted capacity (Ah)
Q	Maximum battery capacity (Ah)
Exp(s)	Exponential zone dynamics (A)
Sel(s)	Battery mode (*Sel(s)=0:* discharge state, *Sel(s)=1:* charge state)
A	Exponential voltage (V)
B	Exponential capacity (Ah^{-1}) [5, 18].

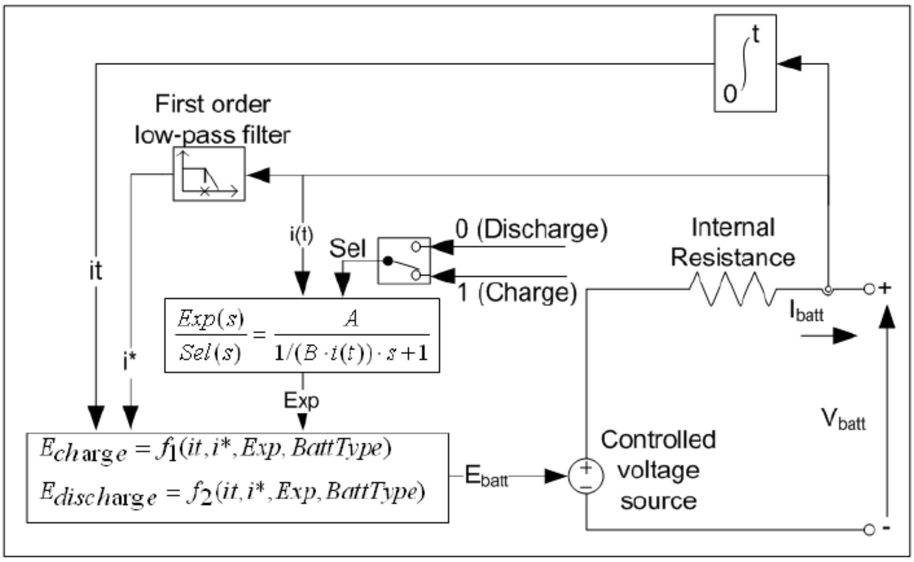


Figure 8: Equivalent circuit of the battery [10].

Table 3: Battery Parameters

Lead-Acid Battery	
Nominal voltage (V)	435
Rated capacity (Ah)	690
Initial state-of-charge (%)	60

2.7. Controlled Current Source

Controlled Current Source (CCS) as shown in Figure **9** is used to convert the input signal into a constant current output. Battery is provided with a constant current to get charge. Direction of an arrow in the icon of the CCS shows the direction of the flow of current. Maximum amplitude of the current can also be set in it. As constant current will be delivered to the battery during its charging period. According to the load, different amplitude of current is delivered at different time.

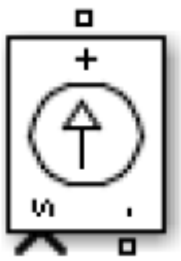


Figure 9: Controlled current source.

2.8. Need for Complementary Energy Sources

One of the major drawbacks of utilizing solar power is the uneven distribution of sunlight throughout the world. These intermittency results in reduced efficiency of solar sources for power generation. Another major drawback of solar power is the availability of sunlight is weather dependent. Rain, fog, frost and cloudy weather could significantly reduce the amount of power generated by solar panels. Majority of these factors are predictable which makes power generation through solar sources effective. Although, if a storage element is not used then solar sources are ineffective as they cannot produce power at nights or during bad weathers [41].

The next source of energy considered for this study is the wind-generated power. It is a reliable option for power generation as the power through wind can be produced at any time. Although, the production of power through wind depends on multiple external factors. These factors are both controllable and uncontrollable. The controllable but necessary to cover factors are the characteristics of a wind turbine, its size and adaptability. Whereas, the uncontrollable factors are the natural factor that includes the air speed, which must not be too slow or too fast. In the case of too slow wind speed the power could not be generated and in the case of too fast wind speed the turbine needs to be shut down due to the threat of damage to the turbine. The wind speed that is considered too slow is 2.5mps and that considered too fast is 25mps. Another uncontrollable factor is the density present in wind; it is known that colder air is denser. The output generated through wind turbines varies as the speed of wind differs geographically. Erecting multiple wind turbines in an aligned manner may generate power more effectively. The seasonal effect creates an impact on the power production in wind turbines because of the unpredictable nature of wind [21].

Due to intermittent characteristics, Solar and wind sources cannot produce a continuous and secure power, except combined with storage capacity like battery, flywheel etc. The characteristics of the solar and wind vary with the climate. The relation between the solar and wind power in different locations for example, Tromsø (69.65° N), Pasvik (69.45° N), Sortland (68.64° N) is different. Sortland and Tromsø are located on the coast, while Pasvik is situated inland and have slightly different climate. Throughout the year large variation is seen in the solar energy as these locations are north of the Arctic Circle where there is midnight sun in the summer and polar night in the winter. In Tromsø and Pasvik the polar night lasts from 27th November to 16th January, while in Sortland 3rd December to 9th January. So, the sun is absent during a mid-winter period, alternative source is required to the solar power such as wind because it is present in the whole period during midnight sun and polar night [22].

In Serbia, the maximum amount of wind energy production naturally occurs in winter while in summer generation through solar energy is higher. In contrast of this, during winter the demand of electricity are much higher than summer because of increase in consumption. Solar and wind both are highly intermittent energy source and its nature depends on the weather. Figure **10**, shows yearly distribution of solar and wind energy density (kwh/m2) according to measurements taken at the Metrological department (Zeleno Brdo) in Belgrade. According to the European Union (EU) standard methodology (CEC, 1989), wind energy is measured as per square meter of rotor area (vertical area swept by the turbine blade) while the solar energy is measured per square meter of horizontal surface. The ratio of solar power from December to July is 1:6.1 and between July and March (or November) the ratio of wind energy is nearly 1:2.75. The combine ratio between solar and wind energy over the period August-September and that over the period March- April is 1:1.8.

In other word, by adding wind energy the relative fluctuation of solar energy can be compensated. So, reducing the ratio from 1:6.1 to 1:1.8. The complementarity effects are even more dramatic in the absence of solar radiation or bad weather conditions [23].

The solar energy decreases between July and December while wind energy increasing from July till November. On the other hand, from March to July (or November) wind energy is falling sharply. While, solar energy increases gradually.

Thus, it could be concluded that due to the change in availability of these renewable energy sources, the combination of all these energy sources in a grid could be more effective as the accessibility and storage of power will be more frequent and available even with the effect of one source being absent. These result shows that all these sources act complementary to each other. Hence, using a hybrid local network of the wind, solar energy with battery system is the best solution to overcome these effects.

2.9. Hybrid System

The proposed hybrid system should consist of following components:

- Solar Panel
- Wind Turbine
- Induction Generator
- Bridge Rectifier
- Boost Converter
- Capacitor Bank
- Voltage Source Inverter

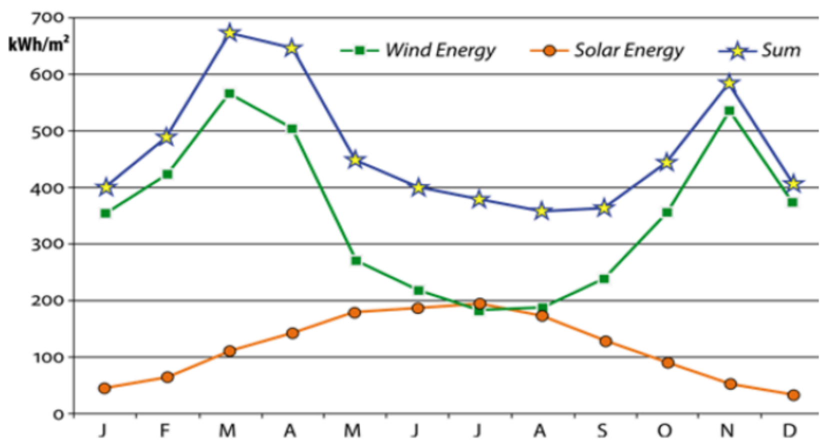


Figure10: Annual of average (by month) course of solar, wind energy in Belgrade from 1961 to1990 [23].

- Electrical Grid
- Battery Energy Storage System
- 162-kVA 260V/25kV three-phase coupling transformer.

Solar panel produce DC voltage and DC to DC boost converter directly connected to the solar panel. Boost converter boost the output voltage of solar panel and the duty cycle is controlled by perturb & observe technique. Also, it is used for tracking the maximum power from the solar panel. The production from solar is 100 KW at $1000\, w/m^2$ and 25℃. The Production depends on sun radiance and temperature. Change in radiance mean change in power production. At different radiance and temperature checked the response the solar panel.

Wind turbine is coupled with self-excited induction generator and produce AC voltage. AC voltage is converted to DC voltage through bridge rectifier. The generation is depended on wind speed and at 12m/s the production is about 62 KW [21].

Battery is used as a backup power supply in this system. When solar, wind working together battery will be charged and could also provide power to the load when solar power is decreased, if wind generator stops working, battery will start to discharge and delivered power to the load. Charging and discharging of battery is controlled by using MATLAB function and a constant current controlled source is used.

These three sources are combined at common DC bus bar and a 30 KW DC resistive load is also connected to the same bus bar. The surplus power is fed to the AC load and main grid through DC to AC (VSC) converter. Gain value of PI controller K_p and K_i for Current and voltage regulator are optimized by particle swarm technique. While the total production from solar and wind of 162 KW is connected to electrical grid through three phase voltage source converter (VSC).

2.10. PI Controller

Different types of controllers are being used by different industries and one of the most common controllers in industrial application is the Proportional Integral controller (PI). In this study, PI controller is chosen for current and voltage control regulator. Because it eliminates the error of steady state from the controller variable and the system is stable to fast uncertainty.

The output of PI controller is in time domain and it is defined by the following equation,

$$u(t) = K_p(t) + K_i \int_0^t e(t).dt$$

2.11. Particle Swarm Optimization Technique for PI Controller

Particle swarm optimization technique (PSO) is used to obtain the gain of PI controller k_p, k_i for voltage and current regulator. In present work, a program for PSO is developed in MATLAB. Further, the Simulink model of the given system is linked to the MATLAB program (PSO program) for tuning of PI controller gains.

The main objective of PSO is to reduce the error between PI controllers input and the given reference value for the input, such that output of the PI controller quickly reaches to a steady state.

2.11.1. Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a robust stochastic evolutionary computation technique based on the movement and intelligence of swarms, introduced by Kennedy and Eber hart in 1995 [24]. PSO algorithm is inspired by the optimal swarm behavior of animals such as fishes, birds and insects like bees.

PSO is Initialized with a random group of particles (solution) and then searches for best-case scenario by updating generations. Each particle in search space has a certain speed, and there is a result by means of the objective function to adjust the value in each iteration, each particle is updated by following "best" two values. This value is identified as $(pbest_{ij}(t))$. The other "best" value is traced through the particle swarm optimizer is the best value, attained so far via any particle in the population. This best value is a global best and named $(gbest_{ij}(t))$. After searching the two best values, to adjust its position $(x_{ij}(t))$ and speed $\left(V_{ij}(t)\right)$.

The updated equations are presented in formulas (36) and (37), used to find the value, and the particle update process is shown in Figure **11**.

$$V_{ij}(t+1) = w\ V_{ij}(t) + c_1 r_1 (pbest_{ij}(t) - (x_{ij}(t)) + c_2 r_2 (gbest_{ij}(t) - (x_{ij}(t)) \quad (36)$$

$$x_{ij}(t+1) = V_{ij}(t+1) + x_{ij}(t) \quad (37)$$

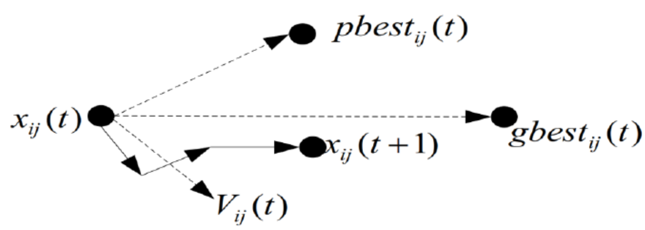


Figure 11: Particle update process [25].

Where,

$\left(V_{ij}(t)\right)$ is the speed of particles.

Vmax is the limit of the maximum speed.

ω is inertia weight.

c_1 and c_2 are acceleration constants.

r_1 and r_2 are random number which are uniformly distributed.

$pbest_{ij}(t)$ is the optimal location of the individual history of the particles.

$gbest_{ij}(t)$ is the optimal position of the history of the particle groups.

$x_{ij}(t)$ is the position of particles.

i is the number of particles.

t is the generation(iteration) of particles.

j denotes the j dimension of the particles [25].

Influence of Parameter Selection in PSO Algorithm

The effectiveness of the Particle Swarm Optimization algorithm almost entirely hinges on configuring its parameter values correctly. Such as the inertia weight (ω) and acceleration constants (c_1, c_2) since they directly affect convergence velocity, accuracy, and the ability of the algorithm to find the global optimum

1. Inertia Weight (ω)

The previous velocity of a particle will be given a fraction of that value. This parameter balances the respective roles of the particle's best-known position and its previous best-known position.

- When set to a large value (above 1.0), it leads to much stronger global exploration because then, the particles cover much larger parts of the search space. However, sometimes such strong exploration would slow down convergence among the particles to the best optimal solutions.
- When set to a small value (below 1.0), strong exploitation at the acceleration phase can be ensured thus reducing the probability of getting trapped in local optima.
- Decreasing Inertia: A common practice is to decrease inertia weight linearly. For example, the value is set to start with ω = 0.9 and ω = 0.4 to start with an exploration phase and gradually move towards an exploitation phase [43].

2. Acceleration Constants (c_1, c_2)

These two define the relative contributions of personal experience (c_1, cognitive construction) and social experience (c_2, social component) in the movement of a particle.

- **Cognitive Constant (C_1):** Controls the tendency of the particle to move toward its own best-found position.
  - High values of c_1 (> 2.0): This implies overmuch individual exploration that damages the cooperation of the whole swarm.
  - Low values of c_1 (< 1.0): This reduces diversity and might perceptibly decelerate convergence.
- **Social Constant (C_2):** This parameter indicates how much the individual particle is also attracted to the global best solution.
  - c_2 Higher (>2.0): It promotes information sharing, which has the disadvantage of precipitating premature convergence.
  - c_2 Lower (<1.0): It limits the information-sharing facility and convergence proceeds at a slower pace.

Our Recommended values: $c_1 = c_2 = 2.0$ (default setting) but some studies recommend $c_1 = 1.5$, $c_2 = 2.5$ to enhance the performance of the model in complex problems [44-45].

3. Velocity Clamping (Vmax)

- Large Vmax: Velocity overshoots; instability.
- Small Vmax: Limits movement of particles; only exploration.

4. Population Size (Swarm Size)

- Larger swarm: More exploration but needs more computations.
- Smaller swarm: Quicker convergence but may face local optima [47].

2.11.2. Flow Chart of PSO

Flow chart of PSO as shown in Figure **12**

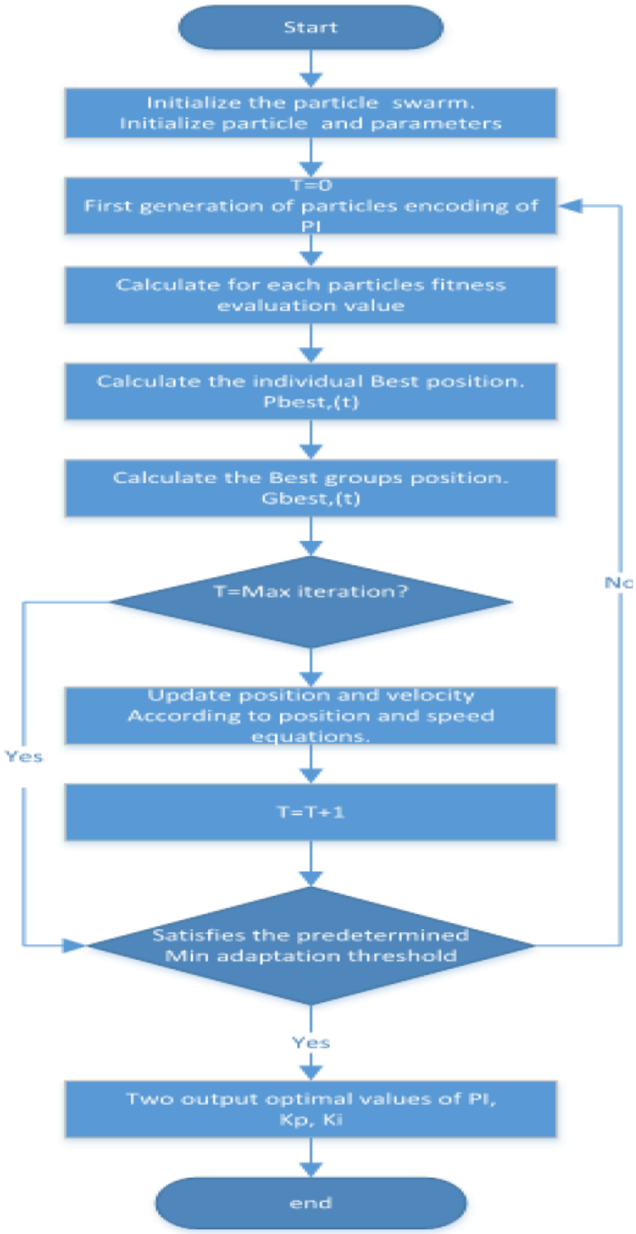


Figure12: Flow chart of PSO [25].

2.11.3. Results by using PSO Algorithm

The optimized controller results tuned by the PSO algorithm in MATLAB are,

K_p for voltage regulator = 699.0365

K_i for voltage regulator = 1

K_p for current regulator = 0.616

K_i for regulator = 0.1

The best cost obtained is 34607.6808 and the plot between best cost and iteration is shown in Figure **13**.

2.12. Controlling of Point of Common Coupling (PCC)

At the point of common coupling (PCC) the voltage and frequency of renewable energy sources is determined by the grid. The distributed generation sources are non-renewable and renewable for example wind turbine generate AC voltage and convert it to DC voltage through bridge rectifier and DC converter. While photovoltaic cells produce DC voltage. DC to AC voltage source converter (VSC) involves their interconnection with grid. Synchronization with the grid the AC voltage and control of injected current into the grid to keep the unity power factor at the point of common coupling (PCC) to achieve the IEEE standard 1547 for Distributed Generation [26]. The grid synchronization using Phase locked loop (PLL) and control current of the renewable energy based grid connected system in synchronous rotating d-q reference frame.

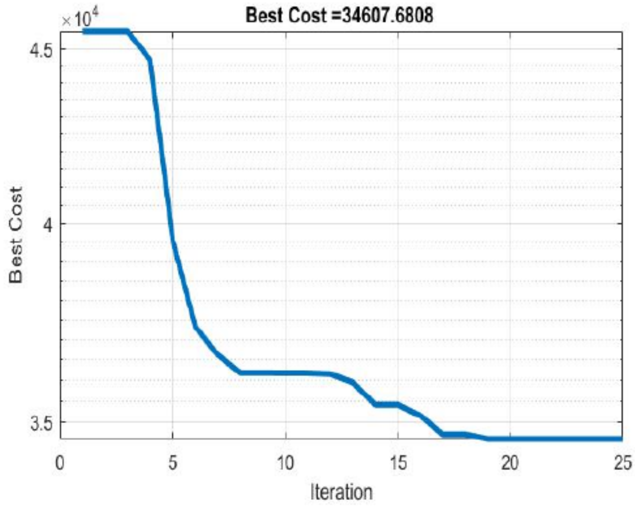


Figure 13: Best cost vs Iteration.

2.12.1. Control Strategy of Inverter

Inverter output current is controlled by grid side current controller. The DC voltage kept at constant level to the input of the Voltage Source Inverter/ converter (VSC). The DC voltage can be generated by battery, PV array, or rectified output of wind turbine, input DC voltage convert into AC voltage through converter. The control signal controls the inverter parameters so the output of VSC completely synchronized with grid. The modulation signal is responsible for the inverter output voltage synchronized with grid in terms of phase and frequency. This modulating signal for inverter is the output of current control loop. The synchronous dq rotating frame controlled the current and the grid three phase voltage and current is transformed into two phase dq quantities using park transformation. So, the transformation of grid values into dc values become much easier to control [27-29]. The PI controller control the inverter current and it gives better performance during controlling the DC quantities and realizes no steady-state errors in the control loop [27, 30, 31]. The active and reactive power independently controlled by d and q axis current because of Voltage Oriented Control in which the grid voltage vector is aligned with d axis. Due to coupling between d and q axis current, decoupling terms are necessary to attain independent control of active and reactive power. Furthermore, the frequency and phase angle of grid voltage rotating in the synchronous frame. While the grid angle is required to do the Park transformation by using the Phase locked loop.

2.12.2. Phase Locked Loop

According to the IEEE standard 1547. To attain the unity power factor of Distribution generation at Point of common coupling (PCC) [26]. The inverter injected current should be synchronized with the grid. So, the phase angle, frequency and voltage of grid are playing the vital role to synchronize the system with grid and control the active and reactive power [32]. Therefor phase locked loop are used to detect the grid voltage and angle. So, the dq rotating frame are controlling the grid angle for this instance grid voltage vector to carry out the transformation. Therefor the PLL topology based on dq reference framing is used. Here the phase angle is determined by using rotating frame with grid voltage vector [33]. V_d moves synchronously with grid voltage vector by putting V_q equal to zero and then voltage oriented control is applied also. The PI controller is kept to $V_q$equal to zero. The PI controller output is the frequency of grid which is synchronize to the angle of grid voltage then the feedback to the abc transformation to dq quantities and then lock the dq reference frame with the grid voltage [27, 32, 34]. K_p and K_i is the proportional and integral gain of PI controller and then transfer function of PLL in dq quantities is given in equation (38) [36].

$$G(S) = \frac{K_p S + K_i}{S^{2+} K_p S + K_i} \tag{38}$$

The response of PLL is fast and protect the system from the distortions and noise present in the grid and also detect the system transients. The block diagram of PLL is illustrated in Figure **14**.

2.12.3. Current Control

The d axis is aligned with the grid voltage through dq rotating frame. The grid voltage vector aligned with the d axis current due to control technique. So, the grid voltage vector is known as voltage oriented control (VOC) [35, 36]. By controlling the individual axis of inverter current it is easily to control the active and reactive power of inverter. The reference current for d-axis (I_d*) control the inverter output active power. While the reference of q axis current (I_q*) control the output reactive power of inverter through voltage oriented control. The input side of dc link voltage to keep constant by the reference of d axis current is established by the voltage control loop. To maintain the unity power factor of the distributed generation (DG) the q-axis reference current is set to zero [26]. The two PI controllers is controlling the d and q axis inverter then the inverter and grid quantities are transformed in dq axis. The PI controller minimize the steady state error to zero between the actual inverter current (I_d and I_q) and reference current (I_d* and I_q*). According to the mathematical modelling of grid connected inverter. The inverter output voltage is given by [31, 37].

$$\begin{bmatrix} U_d \\ U_q \end{bmatrix} = L\frac{d}{d_t}\begin{bmatrix} I_d \\ I_q \end{bmatrix} + R\begin{bmatrix} I_d \\ I_q \end{bmatrix} + \omega_l \begin{bmatrix} -I_q \\ I_d \end{bmatrix} + \begin{bmatrix} e_d \\ e_q \end{bmatrix} \tag{39}$$

$$U_d = L\frac{di_d}{d_t} + RI_d - \omega_l I_q + e_d \tag{40}$$

$$U_q = L\frac{di_q}{d_t} + RI_q + \omega_l I_d + e_q \tag{41}$$

The dq quantities from the Park transformation are the output of inverter voltages U_d and U_q. While e_d and e_q are the dq quantities of the grid voltages. The

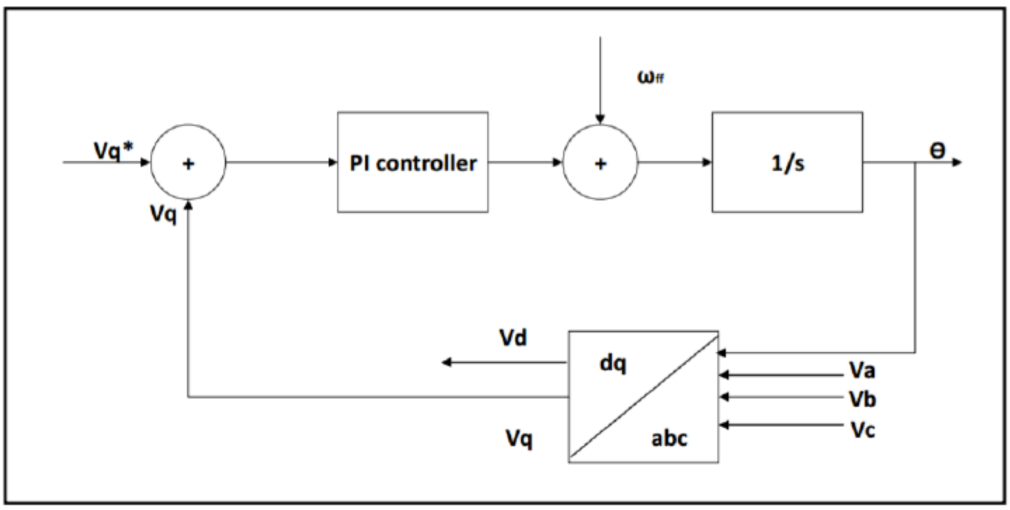


Figure 14: Block diagram of PLL [29].

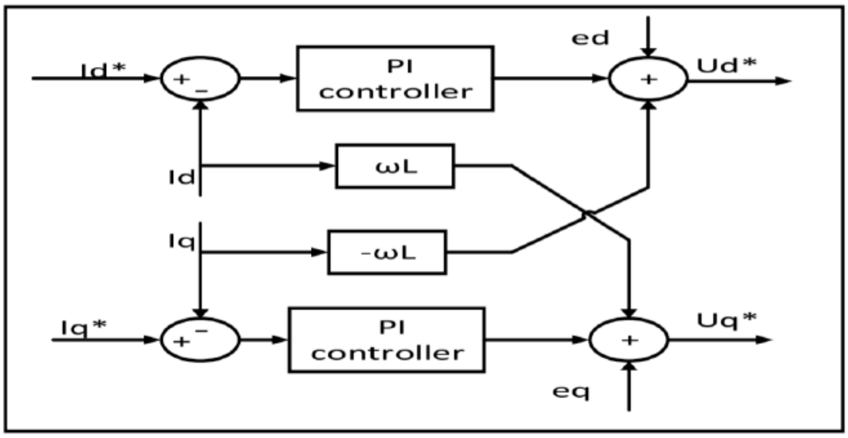


Figure 15: Controller d and q axis current [31].

cross-coupling elements are necessary to decouple the d and q axis because there is a strong coupling between these two axes. Similarly, feed forward voltage is usually used to improve the PI controller performance [27]. The controller of d and q axis current is shown in Figure **15** [31].

Current Control Loop

The controlling of d and q axis current loop have similar stability because both loops are decoupled and feed forward voltage [38]. By the current control algorithm, calculated the three -phase reference voltages U^*_a, U^*_b, U^*_c .The pulses for inverter are generated through PWM algorithm. Then the inverter required voltage is generated.

2.13. Impact on Main Grid Due to Changing Power Through PCC

Due to the intermittent nature of the renewable resources like solar, wind. Its weather dependent energy sources. Change in weather means change in Power production. For this instance, power will continuously change by the variation in solar radiance and wind fluctuation. So, the power flow through PCC will always change. For this act of PCC, it creates an adverse effect on main grid.

2.13.1. Technical Issues of Grid Connected PV Wind Hybrid System

Grid connected hybrid system can create undesirable impacts on the main grid, because of variation in solar radiance and fluctuation in wind speeds daily, hourly and short interval of time.

The negative impact includes variations in voltage at Point of common coupling (PCC), voltage rise and reverse power flow, voltage and current harmonics generated by the inverters, output power fluctuation, variations in frequency in small power systems, and low power factor of operation of the distribution transformer.

Fluctuation in Voltage and Regulation

Fluctuation in voltage means change in voltages and can create the problem if it goes out of the defined ranges. While the voltage over the defined values causes damage sensitive electronic equipment and also decrease the life of equipment also voltage below the range cause the dimming the light.

Voltage regulation are not only affected by voltage fluctuation that occur on the grid. Fluctuation in voltages can lead the voltage imbalance, output power fluctuation and increase in voltage causes to reverse power flow. When there is a certain amount of wind and PV power penetration in the distribution feeder, the Power flow starts in the reverse direction, especially during maximum wind and peak sunshine hours. That the voltage will increase at PCC. When PV and Wind system connected along a feeder, the voltage along the distribution feeder from the transformer is increasing. Hence, needed actions should be taken to avoid voltage violations at PCC against the regulations.

Fluctuation in Output power

Fluctuation in Output power is the most common problem for DG depend on renewable energy sources like wind, solar. Short interval fluctuation in second can lead problem with quality of power (voltage and power factor). While fluctuation in long term need backup power to provide constant power like battery, diesel generator etc. Short interval problem can be resolve by power factor correction and tap changer to maintain the quality of power. On the other hand, by using battery storages system or other backup sources can minimize the effect of such fluctuations.

Storages system

There are many types of storage such as battery, super conducting magnetic energy storage (SMES), flywheels can be used to utilize the power fluctuation. Storages can deliver the power supply when the increase the voltage on the feeders and also used for peak shaving, power failure protection, load shifting and balancing the load demand.

Power factor Correction

Due to poor power factor on the grid leads the line losses and more problematic for voltage regulator. Mostly inverters have ability to maintain unity power factor. In the voltage regulating mode of inverter provide current that is out of phase with the grid voltage and provide power factor correction. Power factor is automatically controlled or by simple fixed.

Variation in Frequency and Regulation

Frequency is the most key factors in power quality and must be unchanged throughout grid connected system. Variation in generation due to intermittent nature of renewable sources lead to frequency fluctuation. Frequency regulation is usually controlled by control loops. It is very difficult to control the frequency with the high penetration of solar and wind. In the grid connected hybrid systems increases the problems of frequency fluctuation will become more noticeable.

Inverter can control the frequency because it is faster than conventional generation and can control the frequency in milliseconds. Inverter can only able to control the frequency of system when injecting the power in to the grid (network) when system is in operating mode [39].

Voltage and Current Harmonics

Grid connected inverter cannot generate the pure sinusoidal wave it contains harmonics in current and voltages. The distortion current reflected through the distribution impedance causes a harmonic voltage distortion or voltage drop.

The three-phase harmonics distortion on the circuit can create many problems for the main distribution grid system, Harmonics can lead to power system inefficiency. Some of the negative impacts that harmonics may affect the grid equipment are listed below:

1. Generator

The harmonic in voltage and current increase causes the iron and copper losses in machine due to overheating. Because current and voltage are dependent on frequency.

2. Transformer

Stray flux losses in transformer causes increased copper and iron losses in transformer windings because of overheating. While there is multiple zero crossing in the current wave form which lead the harmonic voltage, distortion causes instability operation.

3. Capacitor

Due to harmonic effects which lead the heat increases. Due to this act capacitor life will be reduced and causes losses in power. Also, dielectric failure due to over voltage on the capacitor.

4. Fuses and Circuit Breaker

Harmonics can lead the wrong actions, damaging the components without any apparent reason [40].

5. Impact of skin effect on equipment Performance

Power and energy dissipation of active equipment, mostly their effect on temperature rise. Harmonics increase the power losses due to the skin effect; the current flow is concentrated nearer to the surface of the conductor at higher frequencies, thus raising the AC resistance. The present research enhances the traditional methods, like the 'Kskin' factor, toward a more accurate knowledge of harmonic-induced losses and their impact on equipment performance and efficiency [42].

2.13.2. Advantages of Battery Storage System

Distribution network contain harmonics because of that a typical load is non -linear, due to large use of power electronic devices. This can be solved by connecting a battery energy storage system (BESS) at the PCC and by supplying power through an inverter, having the right phase shift when generation is low and incapable to meet the demand. Also, BESS can compensate for voltage deviations and imbalance that is within a distribution system.

Block Diagram

Block Diagram of Solar- wind with battery grid connected Hybrid system as shown in Figure **16**

Solar- wind with battery grid connected Hybrid system Simulink model

Solar- wind with battery grid connected hybrid system Simulink model as shown in Figure **17**.

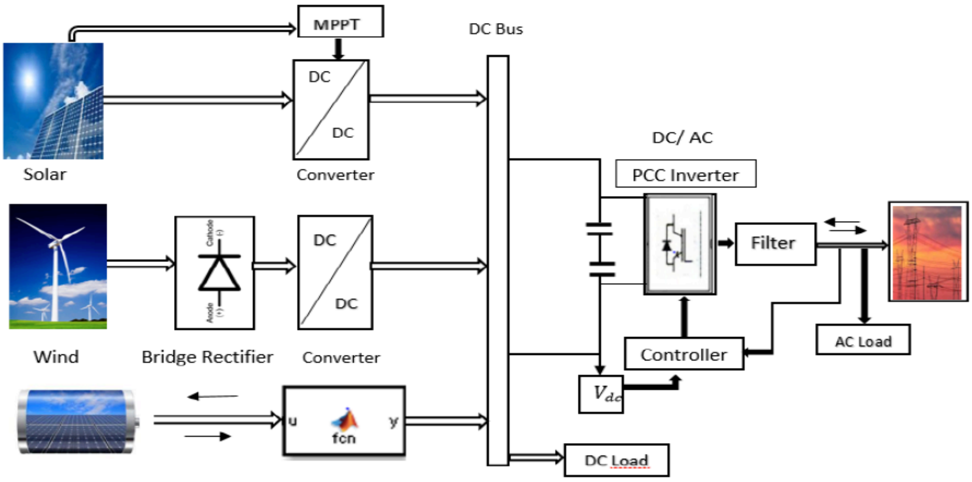


Figure 16: Block Diagram of Solar- wind with battery grid connected Hybrid system.

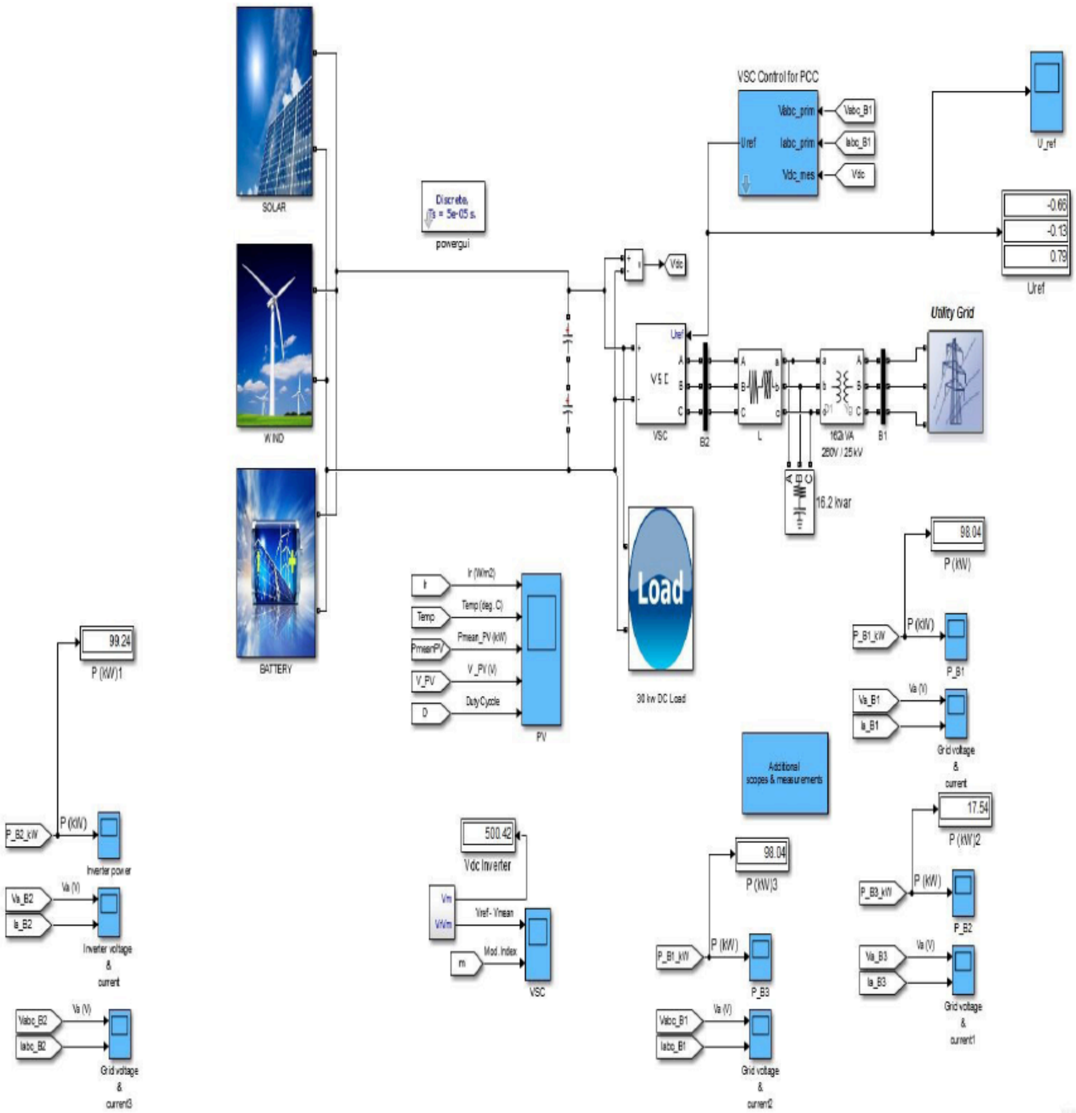


Figure 17: Solar- wind with battery grid connected Hybrid system Simulink model.

3. RESULTS AND DISCUSSIONS

3.1. Simulation Results of PV Module

Figure **18** shows the effect of irradiance, temperature on the power generation from the PV array. Generation from the PV array highly dependent on the solar irradiance and temperature. Boost converter duty cycle is fixed on D = 0.5 as shown in figure at t=0 till t=0.3 the PV voltage and output Power is 252.2 V and

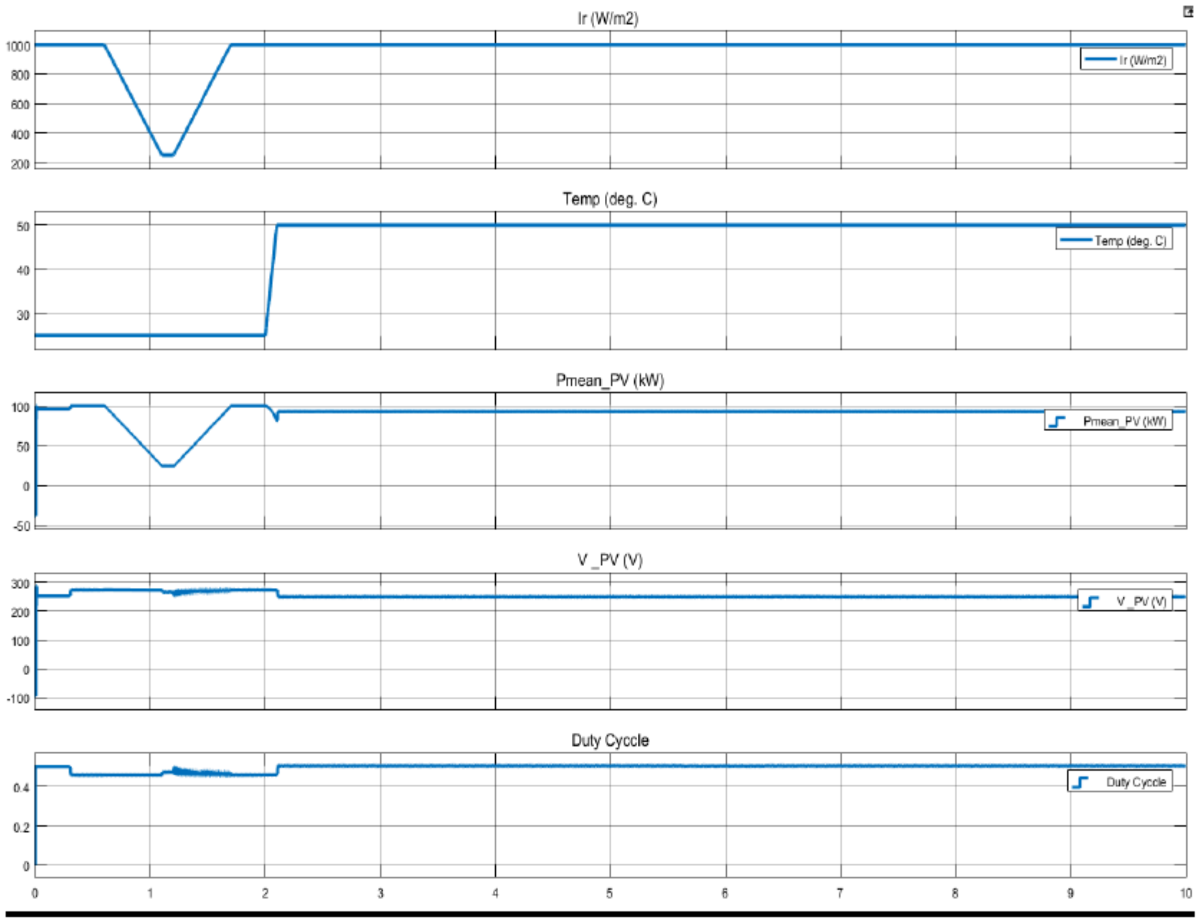


Figure 18: PV System: Voltage, Current, Power.

96.1 KW. While the maximum power of PV array is 100KW at 1000 $\frac{w}{m^2}$. For extracting the maximum power from the PV array MPPT regulator is enabled after 3sec. MPPT regulator changed the PV voltage by changing the duty cycle and obtained the max power at D = 0.456.

The PV array working on normal condition at 1000 $\frac{w}{m^2}$, 25℃ between 0.3s and 0.6s while duty cycle varying from 0.456 to 0.459 PV array delivered the max power at 274 V. When the solar irradiance is decreased from 1000 $\frac{w}{m^2}$ till 250 $\frac{w}{m^2}$ after 0.6s to 1.1s MPPT controller extract the max power at constant irradiance.

Solar irradiance constant at 250 $\frac{w}{m^2}$ between time t=1.1 and 1.2s variation in duty cycle from 0.4668 to 0.49 started again for extracting the max power at that point PV array produced 24.38KW.

After time t=1.2s to onward the solar irradiance increased and back to 1000 $\frac{w}{m^2}$ at 25℃. But in contrast of this, temperature is increased from 25℃ till 50℃ increased in temperature effected the PV output power and the power decreased from 100kw to 92.948 KW. So, the temperature also effected the production of PV array. While the temperature increased there is some transient from t=2s till 2.1s output power reduced between 92.948KW and 78 KW than restore its actual power.

3.2. Simulation Results of Wind Power System

Wind generator started after 2.14sec because of self-excited process. Due to self-excited process of the induction generator initial voltage buildup stage is observed in Figures **19** and **20**. Initially the stator voltage buildup slowly and reached a steady state while the magnetization current initially started from zero to a stable steady state condition. When once the machines core is saturated a stable output, voltage obtained. After 2.14s induction generator current and power is stabled with in few of seconds and generator is working on steady state condition also delivered the constant output power because of wind speed is fixed.

3.3. Simulation Results of Charging/ Discharging of Battery

Battery charging and discharging shown in. Figure **21** Battery and PV system provided the power to the load until wind generator is not started. PV production is varying due to change in solar irradiance and temperature. When the PV production is 100KW battery is discharged slowly and fulfill the load demand and also provide the power to grid. While the PV power

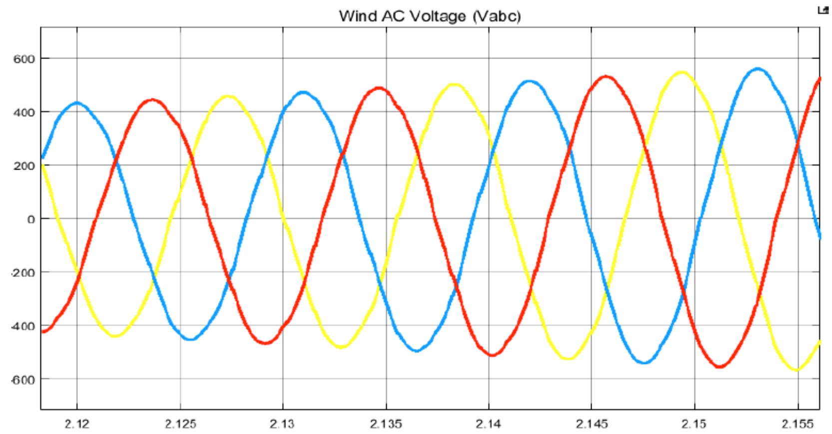


Figure19: Wind System: AC Voltage (Vabc).

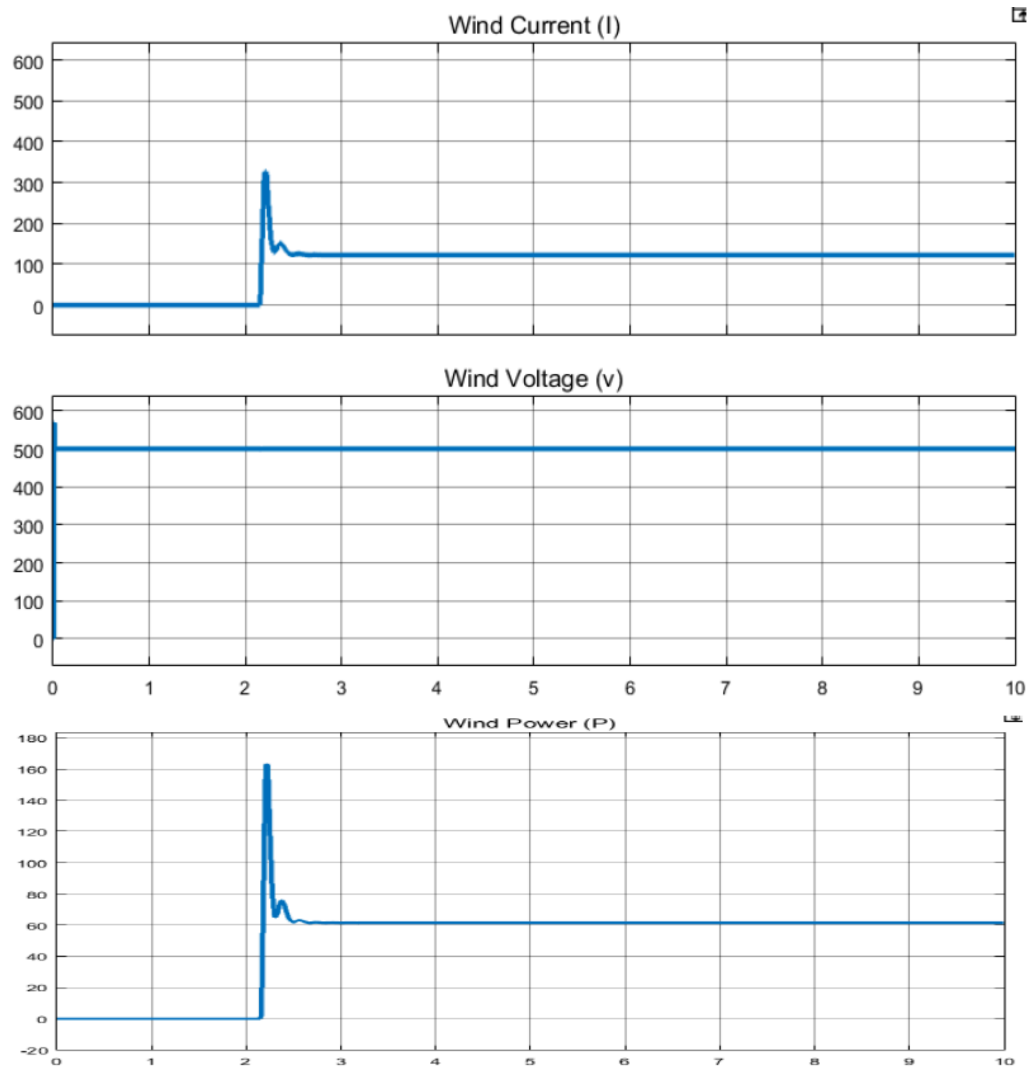


Figure 20: Wind System: Current, Voltage, Power.

is decreased till 24.34 KW at 250 $\frac{w}{m^2}$ but load is fixed than battery start to be discharged rapidly with large current 273A in this duration battery voltage declined sharply until PV production reached its actual power. At t=1.8s battery voltage is increased again and current decreased due to the PV generation increased. On the other hand, after 2.14s wind turbine start to produce power and according to the condition when both generators working together battery charged with 48.8A current. When battery SOC reached 99.99% charging current is zero and voltage decrease to its fully charged condition as shown in Figure **22** than charging stopped for the protection of battery.

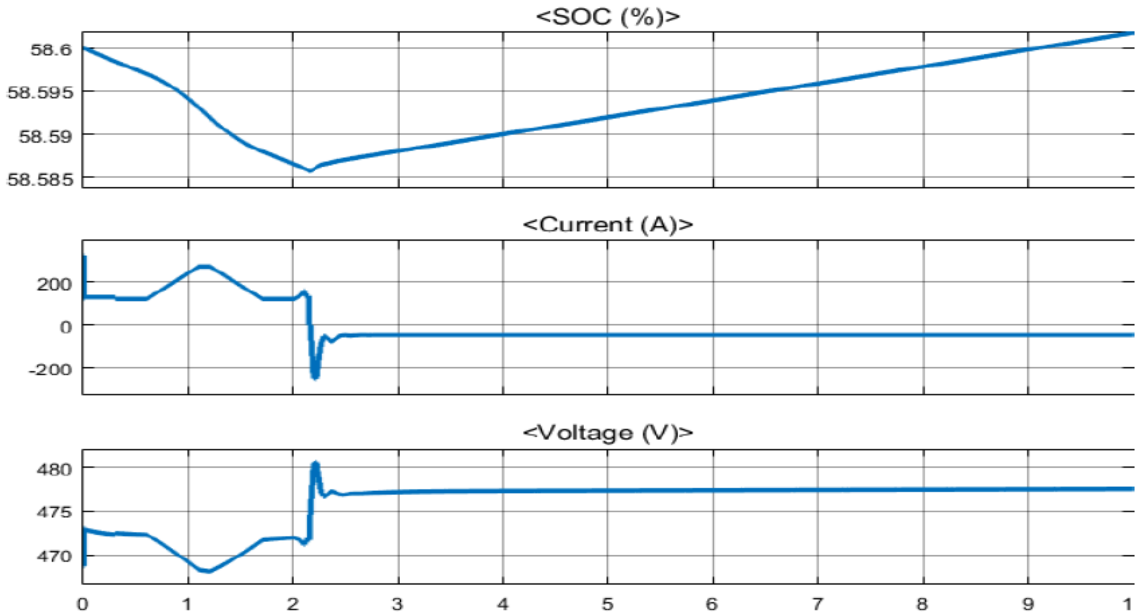


Figure 21: Charging Discharging of Battery.

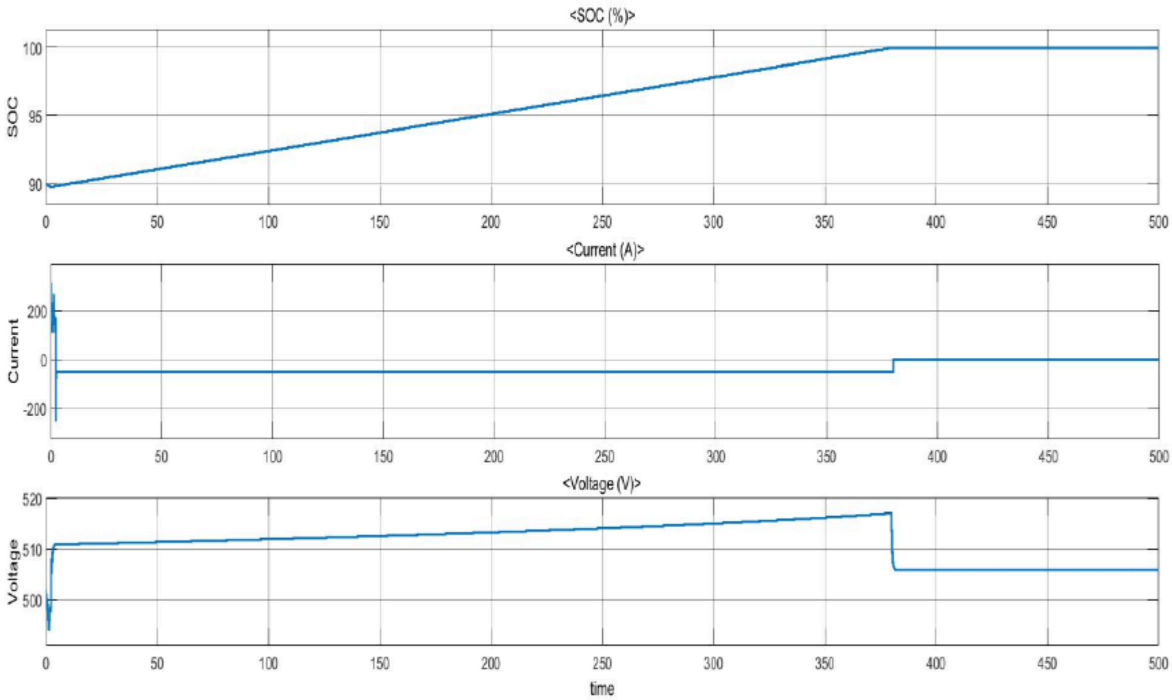
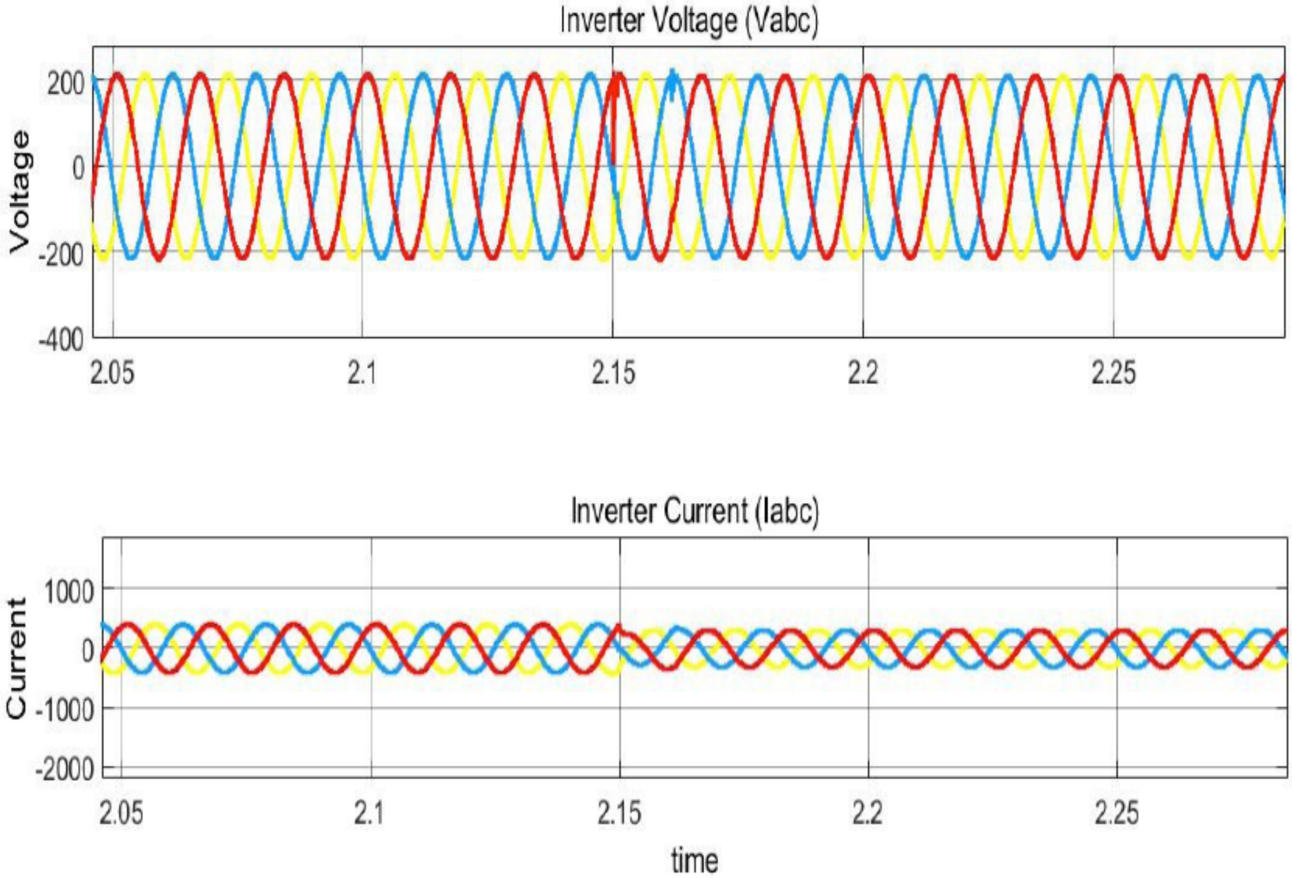


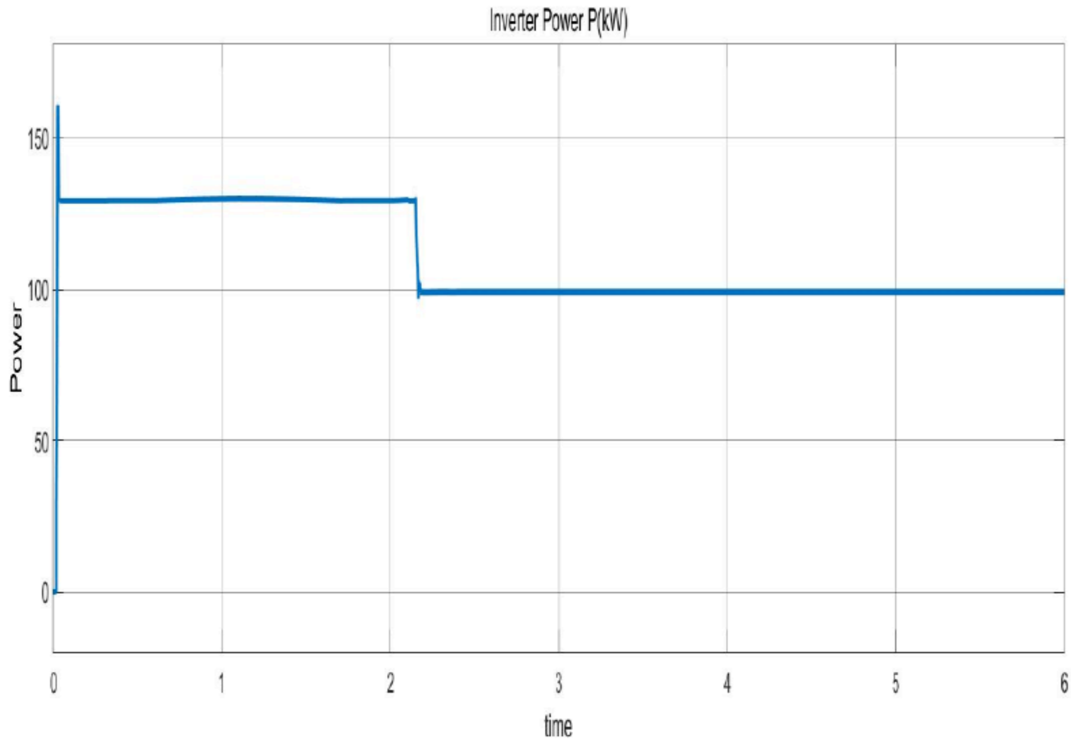
Figure 22: Charging of Battery.

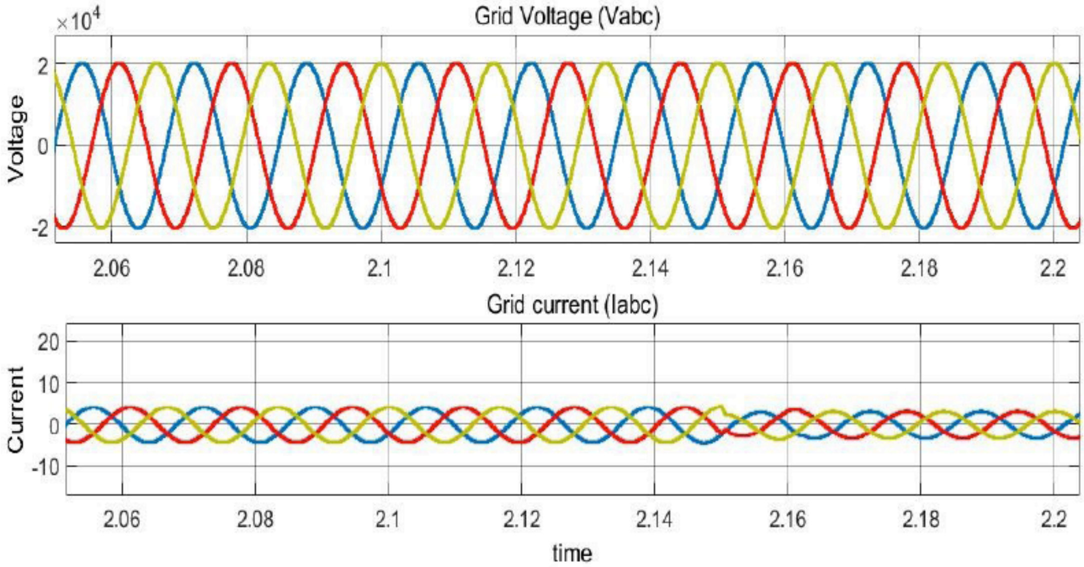
Comparing the Results of PCC Inverter with Grid

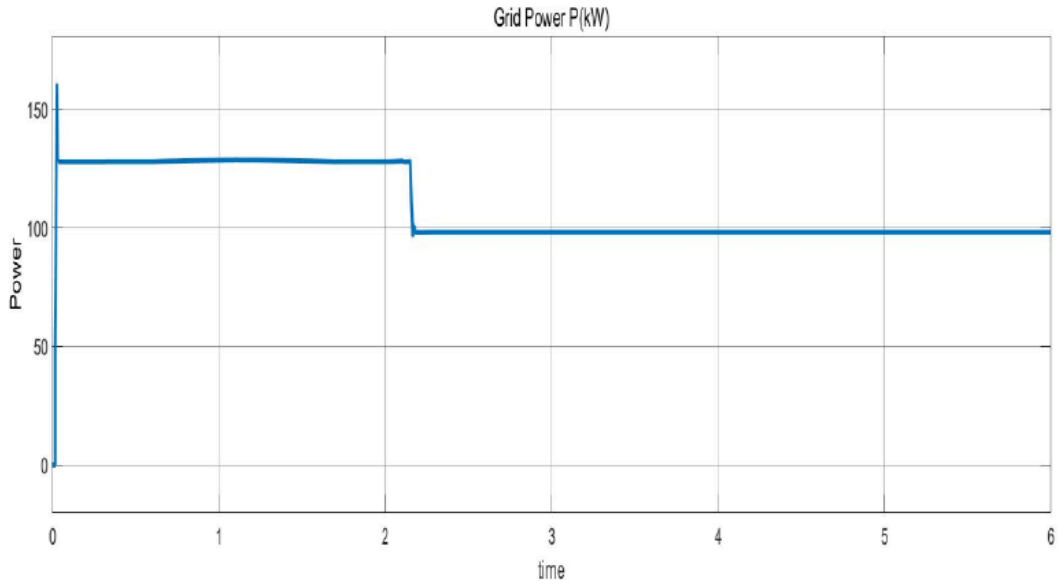
Figure **23** shows that the waveform of PCC inverter such as voltage, current, power of the inverter and grid are properly synchronized due to implementation of PLL and PI controller which ensure grid synchronization thus the system voltage, phase sequence and frequency are same. The PI controller controlled the inverter current in d and q axis. Due to the tracking ability of PLL and PI controller the inverter output current is in phase with grid voltage when the q axis reference current is set to zero.

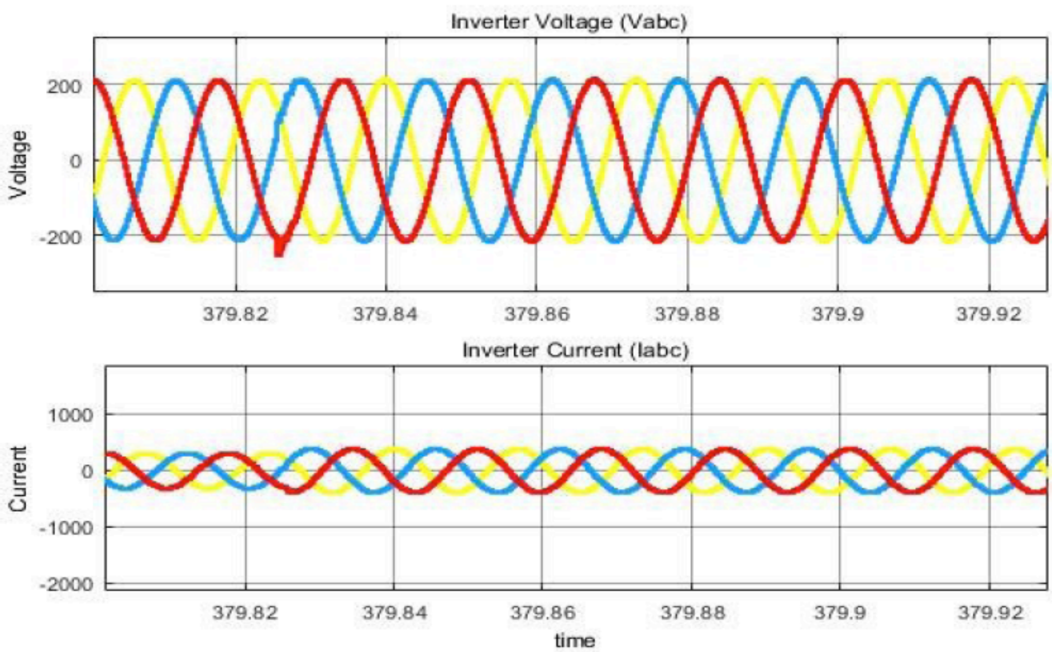
In Figure **23** at t=2.146 to t=2.16s there is some transient in inverter voltage, current and grid current because at that point wind turbine is connected in the system and battery charging started. When the battery is charging mode current amplitude and power is declined till the fully battery charged. After t=379.82s battery charged and system restore its actual condition and again power and current increased and excess power feed to grid.


Inverter Voltage (Vabc)
Voltage
200
0
-200
-400
2.05
2.1
2.15
2.2
2.25
Inverter Current (Iabc)
Current
1000
0
-1000
-2000
2.05
2.1
2.15
2.2
2.25
time


Inverter Power P(kW)
Power
150
100
50
0
0
1
2
3
4
5
6
time


Grid Voltage (Vabc)
×10^4
Voltage
2
0
-2
2.06
2.08
2.1
2.12
2.14
2.16
2.18
2.2
Grid current (Iabc)
Current
20
10
0
-10
2.06
2.08
2.1
2.12
2.14
2.16
2.18
2.2
time


Grid Power P(kW)
Power
150
100
50
0
0
1
2
3
4
5
6
time


Inverter Voltage (Vabc)
Voltage
200
0
-200
379.82
379.84
379.86
379.88
379.9
379.92
Inverter Current (Iabc)
Current
1000
0
-1000
-2000
379.82
379.84
379.86
379.88
379.9
379.92
time

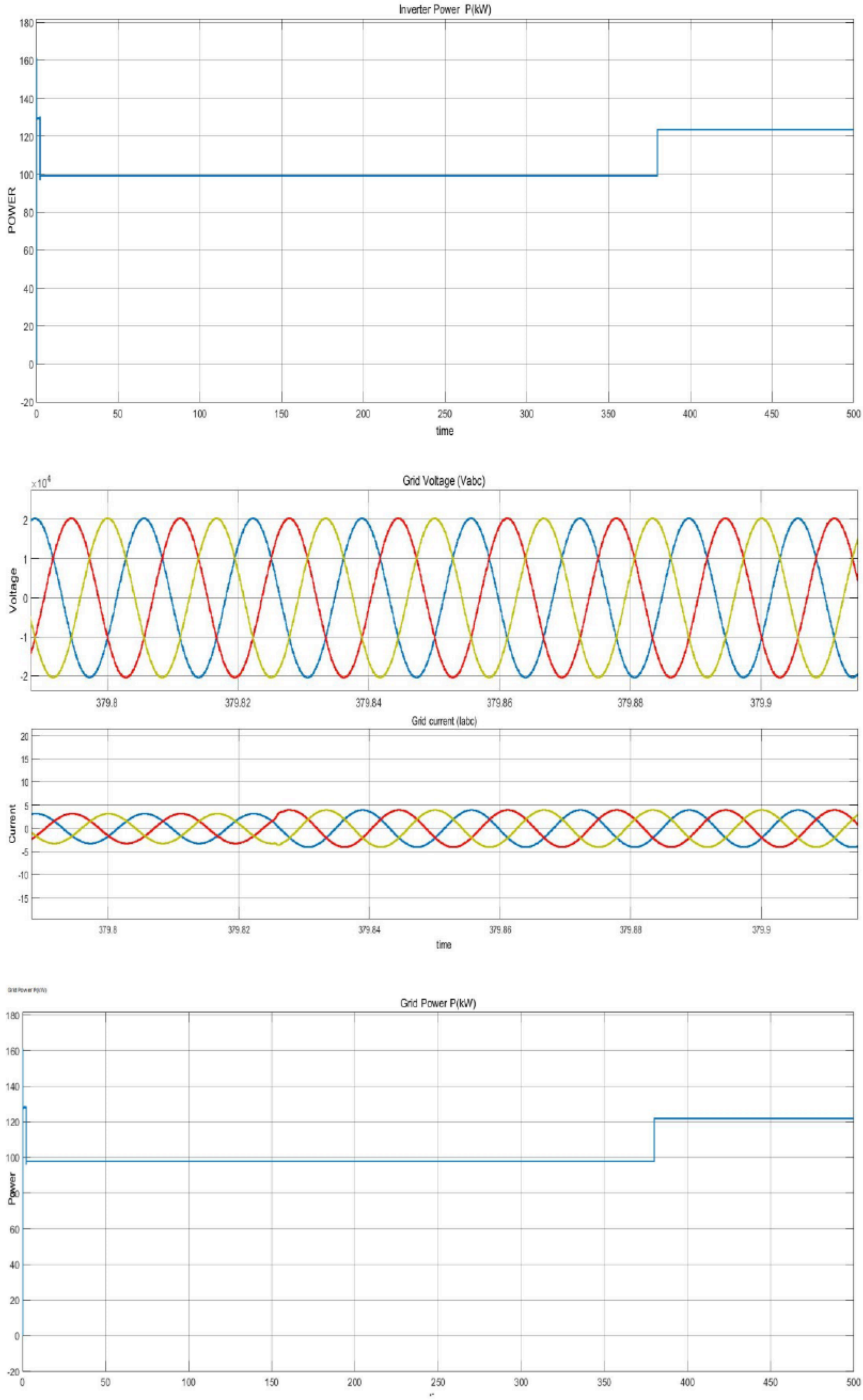


Figure 23: PCC inverter and grid voltage, current, power.

4. CONCLUSION

In this paper, hybrid solar wind power system with battery energy storage system (BESS) is analyzed and advantages of BESS to compensate power flow and its technical significance, nature of renewable energy sources such as solar or wind and effects on main grid by varying power through PCC is discussed. While the

Simulink modelling of the hybrid system and its dynamic responses of real power flow of the system to be considered. The power flow through PCC inverter and its response is simulated when constant power flow, variation in power due to change in solar irradiance, charging and discharging behavior of battery is tested. Also, the gain parameters of PI controller Kp and Ki for voltage and current regulator is tuned with the help of Particle swarm optimization technique (PSO). Simulink results are presented and discussed. On the other hand, Battery has an ability to control active power flow. The performance of hybrid system is improved by Battery energy storage system (BESS).

ABBREVIATIONS

BESS	Battery Energy Storage System
AC	Alternating Current
DC	Direct Current
IG	Induction Generator
SEIG	Self - Excited Induction Generator
VSC	Voltage Source Converter
PV	Photovoltaic
PI	Proportional Integral
P & O	Perturb and Observe
PSO	Particle Swarm Optimization
MPPT	Maximum Power Point Tracking
PCC	Point of Common Coupling
CCS	Controlled Current Source
HRES	Hybrid Renewable Energy Source
DG	Distribution Generator

CONFLICTS OF INTEREST

The author declared no conflicts of interest.

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