Modeling and Simulation of Hybrid Microgrid with Renewable Energy Sources in Grid-Connected Mode

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Abstract*: Presently, RES plays a vital role in Microgrid application. Microgrid is proposed to produce accessible power for all area network. The Microgrid is an assembly of various source & loads that conduct as a controllable governed structure to supply power to the modest areas. A hybrid grid comprises AC as well as DC grid associated with a bidirectional converter. AC power supply sources & loads are a couple to AC networks and DC supply and the loads are coupled to the DC networks. Energy storage systems (batteries) can be lumped together into AC or DC network. This paper represents a hybrid structure of microgrid performing in grid-connected mode comprise of solar, wind, and battery. This system is designed to reduce the procedure of multiplex conversion with control methods and result analysis. To exchange power smoothly between AC & DC grid, for different resource conditions, the power electronic (PE) converters are implemented with various controller designs. It has the potential to operate for easy soft exchange of power in AC and DC grid and several control systems are executed for PE converters for stable operation under different source environments. A small-scale hybrid grid has been designed and simulated using MATLAB/ Simulink software.

Keywords: **Hybrid Micro-Grid, Solar Cell, Wind Power, Battery, Converter, Grid Connected.**

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I. INTRODUCTION

In recent years, the electrical power system is implemented with a three-phase AC power network owing to different cases like systematic, efficient & ease in step-up/ step-down of the voltage level at different stages, for large transmission line and for immanent characteristics of non-renewable fuel source which drives rotating machine for power generations. As per the safety and security concerns, the power generation of non-renewable sources like coal, crude oil, gasoline, and natural gas the power station is located far away from load center and local areas. The power generation from these sources and transmission over a long distance is quite difficult and this leads to high losses in transmission line and intricacy of the system get increases. Also, pollution, emission of carbon gas and the environmental effect is very high due to non-renewable energy source. As a result due to the increase in awareness of renewable energy sources (RES), the implementation of a microgrid in hybrid power systems is growing in popularity. As awareness of environmental issues, the renewable energy source is one of the most promising clean and green resources. The maximum power demand of RES such as solar, wind, hydropower, hydrogen, biomass, geothermal energy, has been universally studied today. RES is one of the most seek areas in the region of electrical and electronics engineering. Due to the exhaustion of fossil fuel and growing, energy demand RES fulfilled abundant attention. RES is used in many different areas of a microgrid. A microgrid is the best antidote for the implementation of different types of a generator with conventional grids.

Nowadays a modern power system is experiencing significant modifications since more no. of non-conventional energy power conversion systems are coupled to low voltage distribution system due to system reliability and environmental free in nature. However power generation from DC microgrid is emerging as a better alternative but for DC sources and electrical load, it's a concoction of AC and DC loads. Thus an individual DC microgrid can't banish the losses and it requires multiple-stage conversions. DC loads like a refrigerator, mobiles, batteries, E-vehicles (EVs), LED lights to improve to preserve electric energy and to mitigate the emissions. Owing to that DC loads are highly preferable in a residential, industrial, and commercial buildings. The power system load become more dominant towards DC and most of the industries prefer DC load for a speed control purpose, but when these loads are delivered to AC grid then it needed more no of AC/DC or DC/AC converters for the supply of DC voltages[2]-[3].

AC microgrid is proposed to existing AC grid technology but the power generation from distributed generation (DG_S) such as PV array, batteries is DC power which is again converted back into AC through power electronics devices for the connection of AC utility grids. But a present existing system AC power sources are supplies as a load with the help of power electronics converters. It requires an additional converter further this might get increased the cost of the system. It is less efficient and more no. of power losses are occurred in the process of conversion. Again the stability issue, synchronization problem are occurred in the AC grid [4-7].

Thus, in a particular AC microgrid and DC microgrid it requires more no of multiple conversion stages and due to this more losses are eliminate besides this reactive power requirement are inherent demerits.

Thus, the combination of AC and DC microgrid is a better alternative solution to minimize the conversion losses. A hybrid AC/DC microgrid is more beneficial than independent AC or DC grid [8]. The combination of solar, wind has become a more catchy solution to the hybrid grid. This combination of two renewable sources gives better system reliability and this system becomes more efficient, cost-effective to run since the flaw deficiency of one system can be a strength of the other one. The combination of a hybrid system with a grid helps to develop the economy, reliability, and accuracy of power generation for supplied to load. Various configurations of hybrid microgrid systems are available, variation in all of these hybrid microgrid structures are found in their control mechanism, their types of coupling, circuitry for power electronics devices [9]. We can design various types of systems such as AC-coupled, DC-coupled, or hybrid-coupled system while generating hybrid structures with RES. The suggested model, of a hybrid system are somewhat difficult than the individual grid. A variety of control techniques for controlling the converter and managing the stability of the structure in grid-connected mode are elucidated as follows.

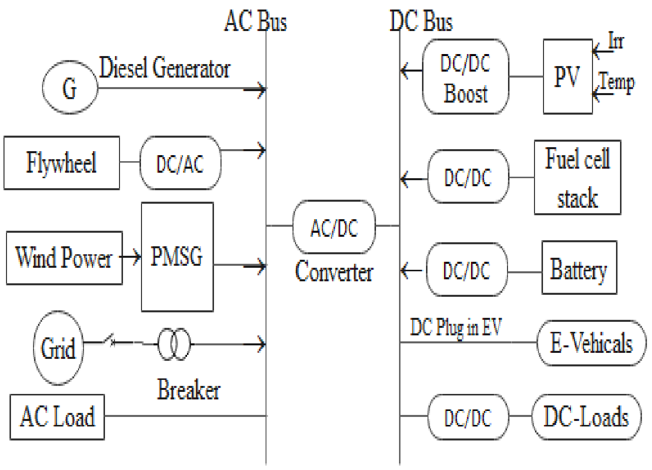


Fig. 1. Hybrid AC/DC microgrid structure

The simple architecture of hybrid AC/DC microgrid as illustrated in Fig.1. The architecture of hybrid AC/DC microgrid contains correlation of AC and DC microgrid through the medium of the three-phase bidirectional converter with the help of a transformer. The electrical connection of the AC grid with utility grid is done with the help of transformer and circuit breakers. AC sources are coupled with the AC grid side such as wind power, diesel generator, and tidal plant whereas DC sources are coupled with the DC grid side such as solar, battery, flywheel, electric vehicles, and fuel cell. All AC sources and loads are coupled with the AC grid side and all DC sources and loads are coupled along with the DC grid side.

II. Configuration of Hybrid Microgrid

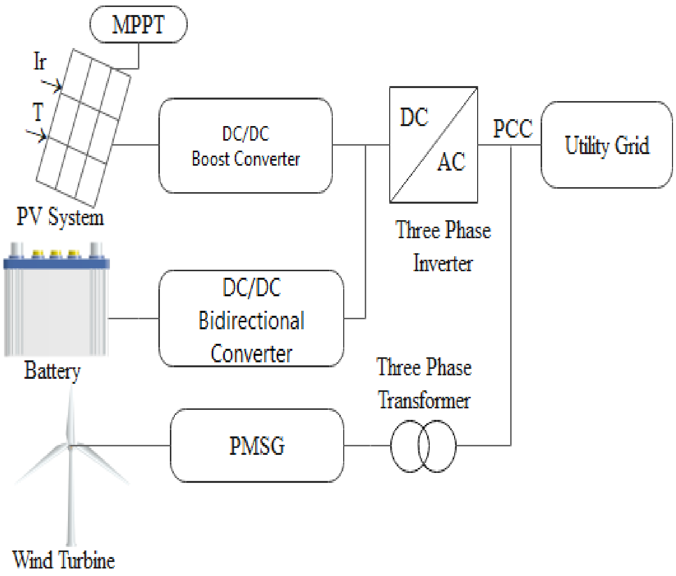


Fig. 2. Functional block diagram of hybrid micro-grid with solar, wind, and battery.

The proposed system, a hybrid combination of permanent magnet synchronous generator (PMSG) and Photovoltaic (PV) cell which are intermittent and complementary in nature as mentioned in Fig.2. Where a solar PV array is coupled with a boost converter to produced constant DC voltage with MPPT control techniques to find out the maximum power. The battery is linked with DC/DC Bidirectional buck-boost converter which is coupled with the utility grid through a bi-directional DC/AC three-phase inverter. Again the system is connected through PMSG which is driven by a wind turbine with a generator side & grid side controller. Wind turbine with PMSG is directly coupled with utility grid through a point of coupling (PCC) with three-phase transformer where the load is connected.

A. Modeling of Solar Cell

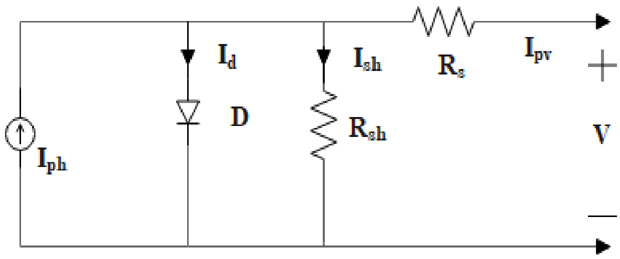


Fig. 3. Identical structure of Single-diode PV cell.

Fig.3 represents the elementary configuration of a single-diode solar cell in which a nonlinear diode D, shunt resistance R_{sh}, series resistance R_s are used. In this PV panel shows by a current source in parallel combination of diode [10]. The mathematical modeling for current and voltages are given by,

$$I_L = I_{PH} - I_O\left\{e^{\left[\frac{q(V+IR_S)}{KT}\right]} - 1\right\} - \left(\frac{V+IR_S}{R_{SH}}\right) \quad (1)$$

$$I_L = I_{PH} - I_O\{e^{38.9(V+IR_S)} - 1\} - \frac{1}{R_{SH}}(V + IR_S) \quad (2)$$

Where,
Sun Power SPR-305E-WHT-D solar module is used with a maximum output power of solar module is 305W,
No of cell per module = 96
Parallel String =55
Series connected module per string =10

B. Control mechanism of Boost Converter with MPPT

To achieve voltage, current, and power at a maximum point on the IV & PV curve, MPPT techniques are used, so that tracking of maximal power from the solar cell is possible. Fig.4. Shows the DC/DC (Boost) converter through MPPT technique which helps to produce the maximum power from the solar panel.

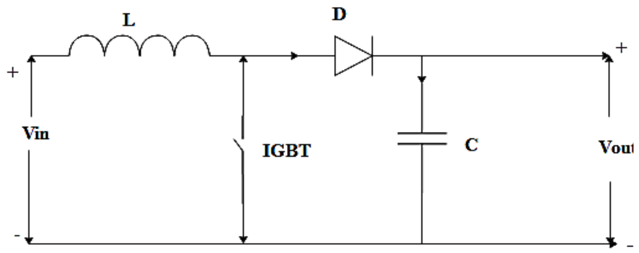


Fig. 4. DC/DC Boost Converter

There are two methods to reach the maximum point voltage level in DC/DC boost converter. Out of that, the perturbation and observe (P&O) techniques are adopted to collect the power from the output voltage and current of solar panel. The value of voltage and power are calculated in iteration form and (P_n) is stored and again the value is calculated in $(n + 1)^{th}$ iteration i.e. $P(n + 1)$ and again calculate the difference of two power equation iteration i.e. (ΔP). If (ΔP) is positive then the converter increases the output voltage of the solar cell, or else vice versa, which will regulate the duty cycle of the solar panel. When the value of (ΔP) is approximately zero then the solar panel reaches its maximum point. Fig.5. explained the algorithm of the P&O method.

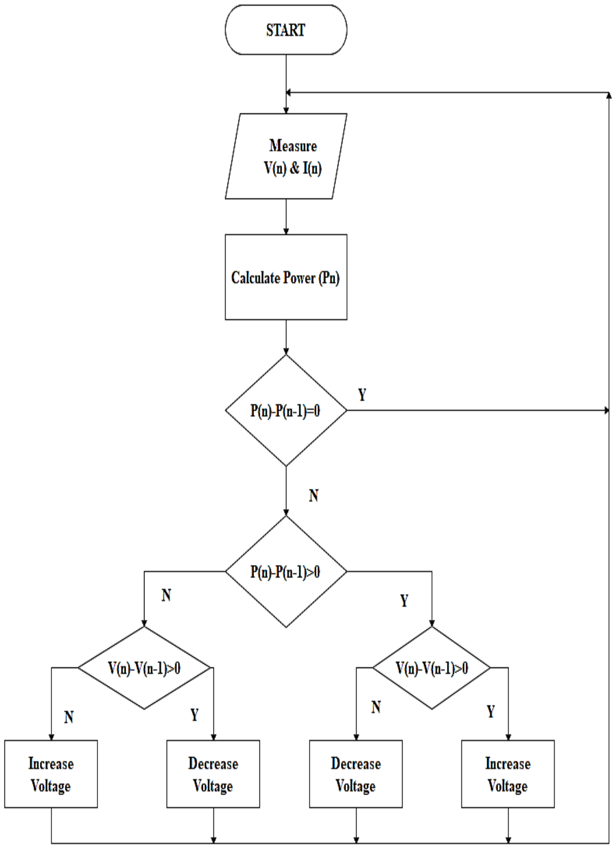


Fig. 5. Algorithm of P&O scheme.

TABLE1: SOLAR PANNEL PARAMETER

Symbol	Description	Value
V_{oc}	Rated open circuit voltage	$64.2V$
I_{PH}	Phase current	$5.96A$
I_o	Reverse saturation current	$1.1753\times 10^{-8}A$
q	Charge of electron	$1.1602\times 10^{-19}C$
A	Ideal factor	1.50
k	Boltzmann constant	$1.38\times 10^{-23}J/K$
R_S	Series resistance	0.037152Ω
R_{SH}	Parallel resistance	269.5934Ω
I_{SC}	Short circuit current	$5.96A$
Ki	Temperature coefficient of SC current	1.7×10^{-3}
Tr	Reference temperature	$301.18\ K$
I_{rr}	Reverse saturation current at Tr	$2.0793\times 10^{-6}A$
E_{gap}	Energy bandgap(silicon)	$1.1eV$
n_p	No.of parallel cell	528
n_s	No.of series cells	480
S	Solar radiation level	$0\sim 1000W/m^2$
T	Surface temperature of PV	$350K$

C. Wind Turbine Generator Modeling

The wind turbine creates kinetic energy which will be converted into mechanical energy at the rotor side through the turbine, then the mechanical energy is transfer to electrical energy through the generator. The mechanical power of wind turbine is derived in equation (3). Presently the research progress enables the utilization of variable speed wind turbine and it has higher energy and lower power fluctuations.

Basically, PMSG and Double Feed Induction Generator (DFIG) are implement in variable speed drive Wind Turbine Generator (WTG). Fig.6. shows the Schematic diagram of PMSG connected to back to back converters. The PMSG has more no. of advantages such as, has a property of self-excitation and it has higher energy production due to permanent magnet excitation which obliterates losses related to rotor winding [11]. It has a low maintenance cost, small size. A two-phase synchronous rotating reference frame (SRRF) is adopted to run the system of PMSG.

The mechanical power of a wind turbine is as follows;

$$P_{mech} = \frac{1}{2}\rho A_t C_p V^3{}_w \quad (3)$$

The Power Coefficient is:

$$C_p = \frac{2P_{wind}}{\lambda S V^3{}_{wind}} \quad (4)$$

$$T_{wind} = T_{mec} = \frac{1}{2}\frac{C_p \lambda \rho R S V^2{}_{wind}}{\lambda} \quad (5)$$

Where,
P_{mech} is the mechanical power, ρ is the density of air $\left({kg}/{m^3}\right)$ C_p is the coefficient of power, V_w is the upstream wind speed of the rotor $[{m}/{s}]$ and A is the rotor area $[m^2]$ $(A = \pi r^2)$ being R is the blade radius $[m]$.

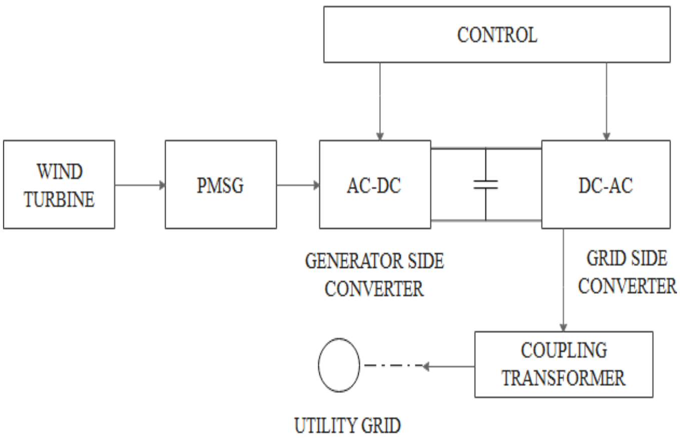


Fig. 6. Schematic diagram of PMSG connected to back to back converters

D. PMSG Model

Fig.7 & Fig.8. display the equivalent circuitry of PMSG on q-axis and d-axis. The electrical model equation of PMSG is represented by:

$$\frac{di_q}{d_t} = \frac{1}{L_q}\left[V_q - p\omega_g\left(L_d i_d + M i_f\right) - R_q i_q\right] \quad (6)$$

$$\frac{di_d}{d_t} = \frac{1}{L_d}\left[V_d + p\omega_g L_q i_q - R_d i_d\right] \quad (7)$$

The electrical rotating speed of the generator is ω_e which is expressed as;

$$w_e = p \times w_g \quad (8)$$

Where;
i_d&i_q are the stator current, v_d & v_q are the stator voltage, p is the no. of pole pair of a generator, R_d& R_q are the stator resistance, ω_g is the rotor angular speed, L_d&L_q are inductances of d and q axis, $M$is the mutual inductance, i_f equivalent rotor current.

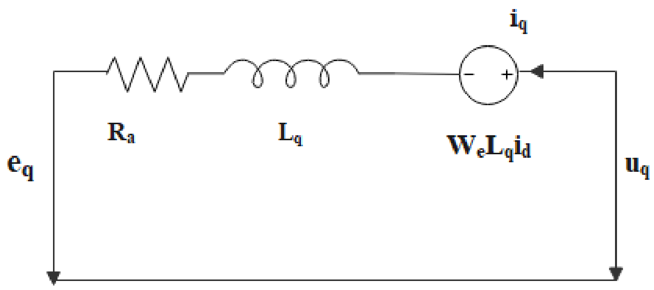


Fig. 7. Equivalent circuitry of PMSG on q-axis

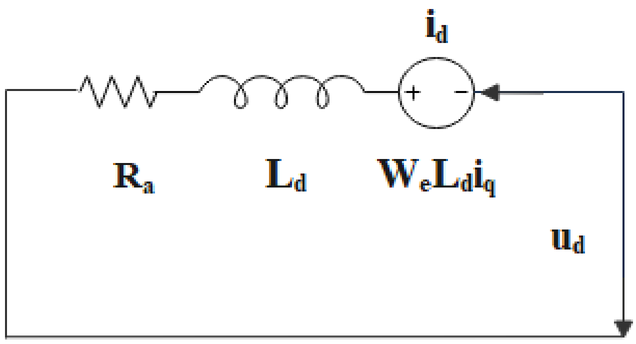


Fig. 8. Equivalent circuitry of PMSG on d-axis

E. MODELING OF BATTERY

Fig.9. display the control strategies of battery for bi-directional DC/DC converter [12]. The energy storage system includes battery with bi-directional DC-DC converter. Control strategies which can operate and synchronize the flow of power in both direction, the converter can operate in charging and discharging mode where it depends upon the energy requirements to stabilize DC bus voltage and PCC [13].

State of Charge (SOC) limitation will decide the current limits of charging and discharging mode of battery.

Charging Time: Whenever S_1 is ON, it will operate as Boost converter and then battery gets charged.

Discharging Time: Whenever S_2 is ON, it will operate as Buck converter and then battery gets discharged

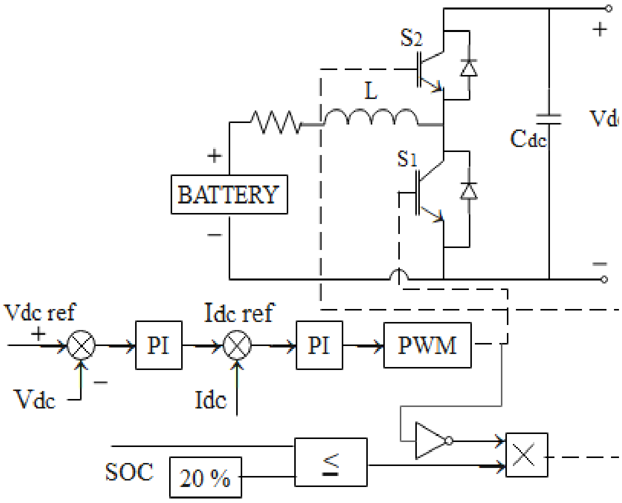


Fig. 9. Control Strategies of Battery

III. OPERATION AND CONTROL OF GRID

Two types of operation is involved in the Microgrid:

1. Grid-tied mode
2. Islanded (Autonomous) mode

Grid-connected mode is studied and simulated for the modified system with MATLAB/Simulink software. For reliable operation under different resource conditions, there are five types of the converter are used in the hybrid system. The co-ordinately controlling capability enables the grid to transfer safe and stable power in both AC and DC grid. The grid side converter and generator side converter in the WTG are used to balance, control, and extract the maximum power from the AC grid. Again the AC grid side is coupled to utility grid [14]-[15]. If any surplus of power on-grid side or DC side then excessive power will transfer from one side to another side. In this situation, the basic converter will act as an inverter mode. The performance of the bidirectional converter is, it reduces the multiple energy conversion techniques, losses, enhances the overall functionality and efficiency of the system, maintain the smooth exchange of power in AC and DC grid is possible. For controlling the main converter PQ control scheme is used. For the calculation of active current (i_d) and reactive current $(i_q)$from line current, Clarke and Park conversion methods are used. The overall performance of the hybrid microgrid, principal of operation, and control mechanism of WTG, batteries, PV array are studied.

IV. PERFORMANCE ANALYSIS

The proposed method of a hybrid microgrid is simulated. The dynamic outcomes of the suggested model under different cases is showing better results not only in steady-state but also in transient response by changing solar irradiance and wind speed respectively. The proposed model is verified and validated through MATLAB/Simulink Software.

A. Steady-State Analysis

In steady-state, DG units are run at their nominal point and are driven on the load and grid sides. The solar system and wind power generation can provide adequate power to the load and grid side. Fig.10 represents the results which are evident that all DG units achieve steady-state performance after a short period and all active power of five loads shows that two DG units have ample power to supply local loads.

B. Transient State Analysis

Case1 (when time (t) = 0 to 1Sec, wind speed = 12m/s, and solar irradiance = 1000 $W/_{m^2}$ **)**

During this period, power acquired from the wind farm is about 55kW and injected power to the grid is 100 kW and power from the grid side 50 kW is achieved. It is identified as, energy storage element (Battery) is not at all deliver energy and operated in inactive mode i.e. Neither charging nor discharging.

Case2 (when time (t) = 1 to 2 Sec, wind speed = 12m/s, and solar irradiance = 500$W/_{m^2}$**)**

During this period, power acquired from a wind farm is about 55 kW and injected power is 50 kW and power from the grid side 100 kW is achieved. The battery will operates in active mode when the power from a solar panel enables to deliver power to the grid side.

Case3 (when time (t) = 2 to 3 Sec, wind speed = 5m/s, and solar irradiance = 500 $W/_{m^2}$)

During this period, power acquired from a wind farm is about 30 kW and injected power is 50 kW and power from the grid side 200 kW is achieved. From the observed result, it is concluded that the load of 200 kW is completely fulfilled by all the energy supplying sources for various conditions.

Fig.10. shows the output voltage across solar cell including a charge of solar radiation and boosted up to 900V with the help of a boost converter and compatible output waveforms are shown. Fig.11 shows the sink electrical power across the wind. Fig.12. displays the Active voltage and current across the main converter. Fig.13. displays the active power across the main converter Fig.14 & Fig.15 displays the active Power on the Load side and source side respectively.

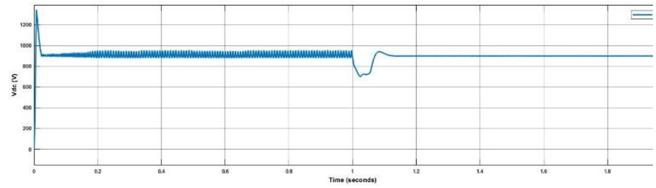
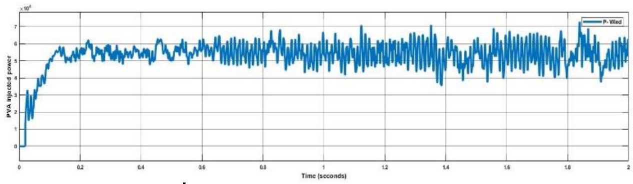


Fig. 10. Output Voltage across PV cell



Output Power across Wind

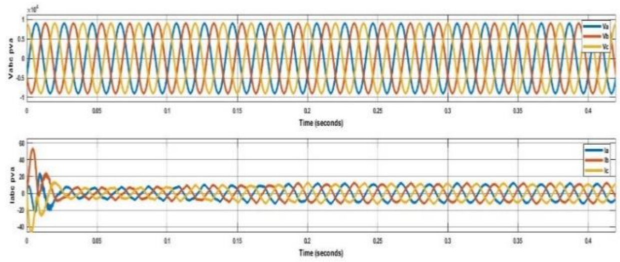


Fig. 11. Active Voltage and Current across the main converter

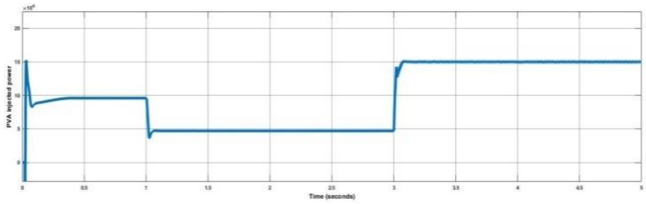


Fig. 12. Active power on the main Converter.

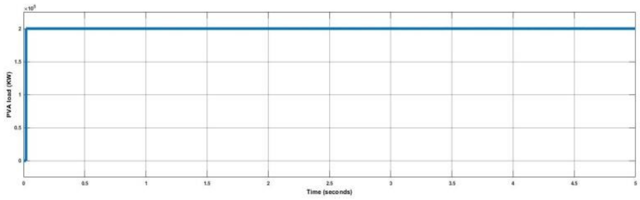


Fig. 13. Active Power on the Load side.

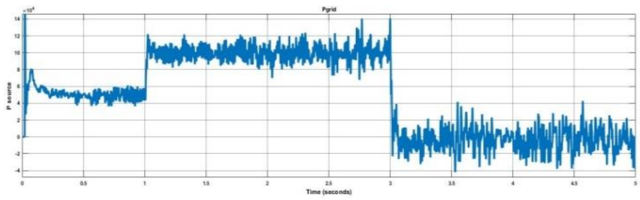


Fig. 14. Active power across the source side.

V. CONCLUSION

In this paper, Modelling and Simulation of Hybrid Microgrid with Renewable Energy Source in Grid-Connected Mode is elucidated. It reduces the losses associated with multiple energy conversion techniques unlike in individual AC or DC microgrid. The different control strategies and dynamic modeling of the system are analyzed. For different cases, short-term transient simulations are simulated and the following conclusion is achieved.

(1) At steady-state, all DGs unit works in stable conditions and power supply to the loads. This unit helps to mitigate the voltage sag and also provides the required power to the local loads.
(2) Wind speed fluctuation generates a similar PMSG transient. The pitch control system adjusts the pitch blade and extracts the wind power, if the wind speed is lesser than the normal value. The output power decreases, if the wind velocity is greater than the nominal value.
(3) As if solar radiance is changed, the corresponding changes will take place in the PV output generation. When PV cell and wind power are inadequate to meet the load demand then at that time energy storage system (battery) will help to fulfill the power demand and to keep DC bus voltage during a transient period. Hence improvement in the performance of the system can takes place. Due to the variation in solar irradiance, it causes a change in solar PV generation, but it tracks the maximum power for each generation.

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