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Performance analysis of protection technique for AC microgrid from symmetrical faults

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Abstract
The research paper is presenting an implementation of Microgrid which assumes lots of loads & sources operated under a one controllable unit system providing power to the localized area. A microgrid model is built integrating wind energy, solar energy, diesel generator and residential load model and analyzing the impact of Renewable Energy Sources with microgrid on various quantities like active power, reactive power, current & voltage as shown and presented in the research paper during normal and fault condition. The various factors on which production of energy depends are PV farm's size & it's efficiency and speed of wind for Wind farm. The load is residential which has a consumption profile at given power factor. Highest solar intensity is during mid-day. The development of model is aimed to provide a sustainable energy supply to load without affecting the nature and compromising the needs of the future generation. In our research work we have used high-speed tripping protection technique for symmetrical faults.

Keywords: Micro-grid, solar energy, wind energy, diesel engine, renewable energy systems, distributed energy resources (DERs), distributed generation (DGs), matlab simulink, solar farm, wind farm, integrated energy systems, modeling, simulation, etc

1. Introduction
The concept of microgrid uses the distributed energy generation concept which support weak grids, improves the power quality, etc. Using the renewable energy sources as distributed energy sources has reduced the usage of conventional sources of energy as the emission of greenhouse gases are reduced which is also beneficial for the environment. During grid-connected mode, power can flow in both directions. Under the failure condition of power grid microgrid get detached from main grid and convert into islanded mode for protection and islanding control, and supply power for important load. Once the problem of grid failure is resolved, grid-connected mode is activated again & microgrid gets connected back to distribution grid. Many challenges are faced in microgrid implementation [1-3]. Major issues are listed as below,

a. Microgrid methodology & its Planning.
b. Distribution & protection of microgrid.
c. Microgrid simulation & analysis.
d. Economic Operation and Energy Optimal Management of Microgrid

Many problems are faced by traditional power grid like instable centralized mode of control, environmental pollution due to use of conventional sources of energy (like coal, etc) & energy crisis. Even when the supply & demand balance is maintained by the power grid yet above mentioned problems are still can't be solved. Due to this, many researchers has opted microgrid as a possible viable solution. The key driver for establishing the microgrid is renewable distributed energy sources. But it is still a big challenge to integrate them properly [14-20]. Microgrid has great potential for wide application. At present, some of the major countries of the world, such as the US, EU, Japan and China, have carried out research on microgrid. India should also adopt the concept of microgrid at major level as soon as possible [6]. The sources used for integration with microgrid have major benefits like they do not contribute in change of climate or any type of pollution, enormous & infinite fuel sources (solar), reliable, no toxic, no moving parts, silent operation, reliable, accessible. Hence, clean & best technology as eco-friendly. So it motivated me to analyze the model of microgrid integrated with renewable energy sources [4-7].

1.1 Microgrid: Needs and Requirement

It is highly necessary to develop microgrid technology rapidly based on the current situations of power system. With situations all around the world, it is important to develop microgrid technology with increasing technical development in power system characteristics [8-15].

1. In situation like blackout of large area due to accident, the power supply is guaranteed to important loads due to dispersed & flexible characteristics. It compensates for the vulnerability of main grid in stability & stability and losses caused due to natural disaster.
2. Industry’s development is promoted by improving microgrid’s utilization rate, absorption of micro sources. Comprehended, flexible energy is provided according to the need of the user by distributed energy. It cooperates with users as much as possible. Microgrid is economical as losses due to transmission & distribution is almost nil as compared to the cost of transmission & distribution caused in distance transmission.
3. Improve reliability & power quality is provided by microgrid to fulfill electricity requirements. Power electronic devices are used as interfaces between grid and distributed energy sources which provide flexible active as well as reactive power & voltage output of generation thus increasing grid’s reliability.
4. Microgrid contribution to economic developments of various remote areas of country where it is not feasible, possible or unsuitable to develop power grid by using distributed energy sources.

2. Literature Review

The world has now faced a new challenge of depletion of conventional energy sources and is trying to become less dependent on the energy sources based on the fossil fuels. Using renewable energy sources is the best solution of the problem. It is expected that fossil fuels will be totally replaced by the renewable energies because of the many reasons like they are inexhaustible, cleaner and produce lesser CO2 emission [16-25].

It is very important to increase the efficiency of these clean energy sources but at the same time a proper connection between the renewable energy generation source and the main grid is also highly necessary. The different models are needed to be made for the enhanced working of micro-grid connected with different loads. When these models are made there simulation speed is needed to be accelerated. When the PV panels are in operation during day time, they supplies power to the grid supported by the power generated and transferred to the micro-grid by wind farm & Diesel engine generator [26-38].

Micro-grid is a discrete energy system consisting many sources of energy, storage systems to store the energy generated, operating independently or simultaneously with main grid. It was earlier aimed to design, model and to simulate a small scale micro-grid using phasor solution constituting renewable energy generation source [39-48]. Now the integration of renewable energy sources like wind & solar with the microgrid is achieved [49-54]. With the help of two sources, more power is can be supplied to different type of loads for a longer duration of time. A microgrid architecture is shown in figure 1 where multiple energy source are connected to the microgrid like Fuel Cell, Solar, Wind, Hydro, Storage unit. Various types of loads like Domestic households load, Commercial load, Industrial Load, Agriculture/ Irrigation load, etc. are also connected to the microgrid. The loads get the supply of power from the microgrid while the sources provides the power to the microgrid. The microgrid is not connected to the main grid. When no connected to the main grid, the grid operates in the islanded mode. When the microgrid is connected to the main grid, it is in grid-connected mode of operation. In figure 1, it can be seen that energy storage units are attached to microgrids as well so that when the sources provide the supply the energy storage system gets charges for the times when the sources of supply couldn’t provide necessary power to the loads. In that case, energy storage units discharges to provide the supply to loads [55-60].

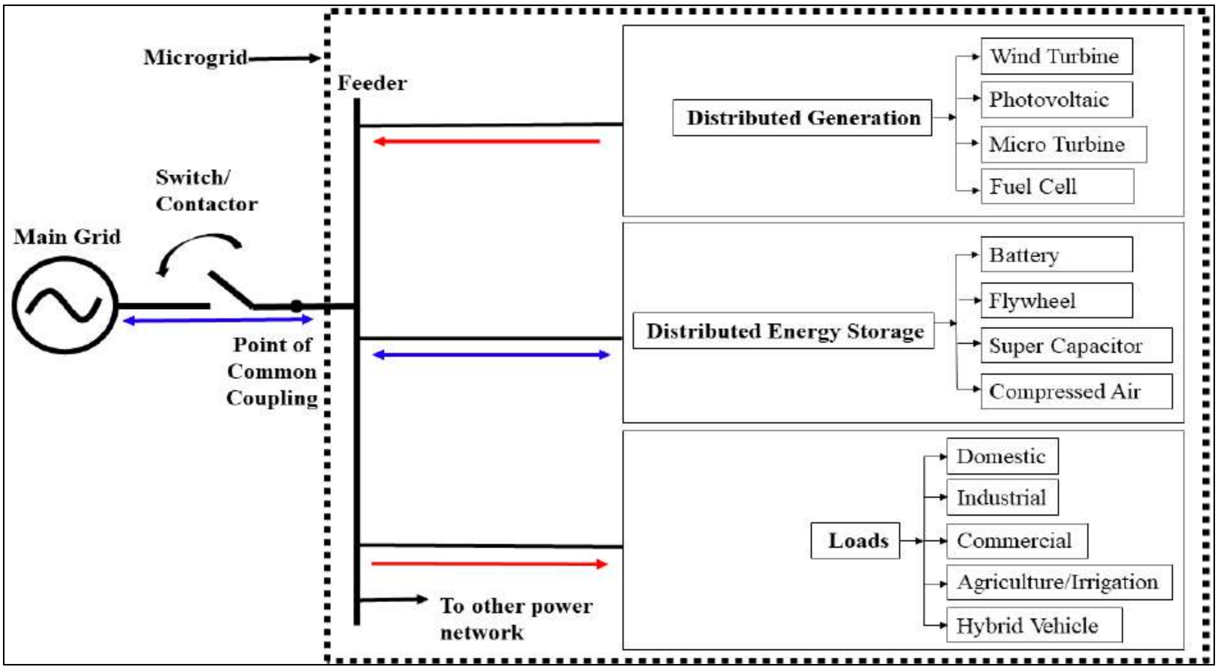


Fig 1: Microgrid Architecture

It is very important that an electrical distribution utility supplies voltage within specified limits to its customers. To supply the required voltage in specified limits to the customers several distribution circuits & techniques are developed to determine the necessary design & expense [61].

3. Proposed Models and Mathematical Modeling

For the development of a microgrid, it is necessary to do mathematical modeling before developing the simulation model in MATLAB Simulink. In the following section, the modelling of diesel engines, solar PV modules, and wind turbines is done.

3.1 Diesel Engine

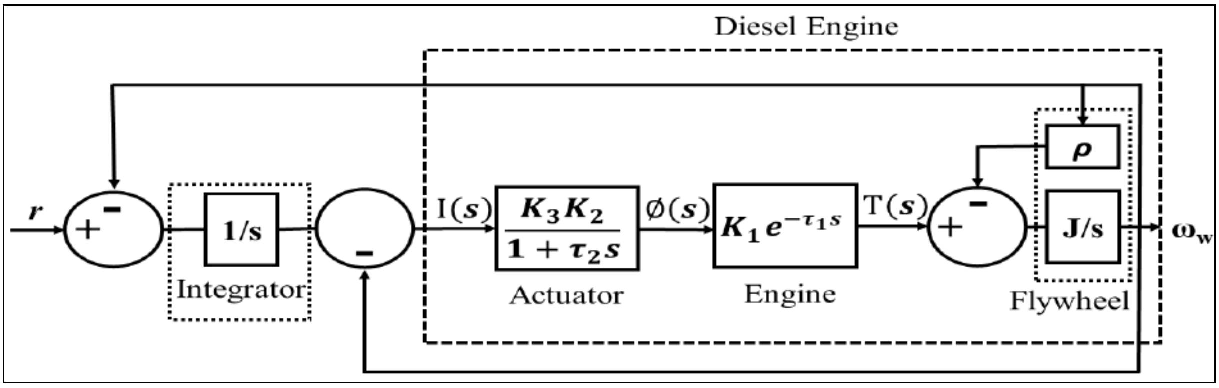


Fig 2(a.): Block Diagram of the Diesel Engine System

There are many methods of Diesel Engine modelling. A diesel engine is a type of speed feedback system considering control theory. Once the speed command is given by operator by adjusting the setting of governor, the fuel supply is regulated to have an engine speed within range [62]. The fuel actuator system's structure is shown by the model below along with its equation.

$$\emptyset(s) = \frac{K_3K_2}{1+\tau_2 s} I(s) \tag{1}$$

$$T(s) = \emptyset(s)K_1e^{-\tau_1 s} \tag{2}$$

Where, $\emptyset(s)$ = Fuel-flow, $I(s)$ = Input current, τ_1 = Time delay, τ_2 = Time constant, K_1 = Engine torque constant, K_2 = Gain, K_3 = Current driver constant, $T(s)$ = Mechanical Torque.

3.2 Solar Power

As the most widely used renewable source of energy is solar energy as in many areas solar irradiation is available in plenty but electricity is not available. Hence, the best option to supply electricity is using the solar energy. Research organizations across the world have tried to integrate the solar energy into power grid & microgrid. Efforts are made by policy makers & energy industries. Solar energy is can be harnessed by concentrating solar power, by solar thermal & PV generation. Hence, solar energy is quickly integrated with the power grid and is highly encouraged across the world. The solar panels efficiency varies with type of material used, its surrounding, intensity of sun rays, weather conditions, geographical conditions, etc. With increasing research, it is focused that efficiency of the solar panels should increase in the future and used world widely [63-64].

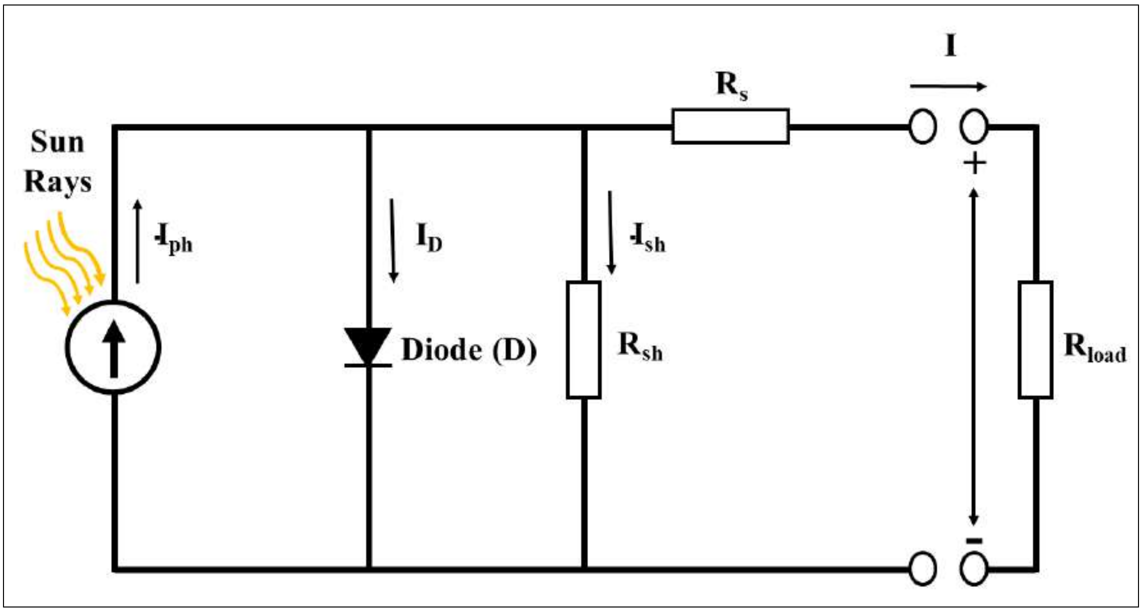


Fig 3: Equivalent circuit of a PV module

The various equations involved in modelling of the PV cell are shown below.

$$I = I_{ph} - I_D - I_{sh} \quad (3)$$

$$U_{OC} = U + IR_s \quad (4)$$

$$I_D = I_d \left[\frac{qU_{OC}}{A_{cf} K_B T} - 1\right] \quad (5)$$

$$I = I_{ph} - I_{os}\left\{exp\left[\frac{qU_{oc}}{AKT}\right] - 1\right\} - \frac{U_{OC}}{R_{sh}} \quad (6)$$

$$I_{ph} = \frac{G}{100}[I_{SCR} + K_I(T - 25)] \quad (7)$$

$$I_{os} = I_{or}\left(\frac{T}{T_r}\right)^3 exp\left[\frac{qE_{GO}}{BK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \quad (8)$$

Where,

I = Output-terminal current, I_{ph} = Generated current, I_D = Diode current, I_{sh} = Shunt-leakage current, I = Cell output current, V= Cell output voltage, I_{os}= Cell reverse saturation current, q = electron charge=1.6*10−19 Coulombs, A,B = p-n junction ideality factor, K = Boltzmann constant, T = Cell temperature [◦C], KI = Short circuit current temperature coefficient at ISCR,KI= 0.0017 A/◦C, G = Solar irradiation in W/m^2, ISCR = Short circuit current at 25◦C and 1000W/m^2, EGO = Band gap for silicon, T_r = Reference temperature, T_r = 301.18◦K, I_{or} = Cell saturation current at T_r, R_{sh} = Shunt resistance, U = Terminal voltage of the cell, U_{oc} = Open circuit voltage.

3.3 Wind Power

Wind Power is also one of the mostly used renewable energy source. To generate power from the wind, a minimum wind speed of 3m/sec is required. Blowing winds have sufficient amount of potential energy which gives kinetic energy to the wind turbine to generate electricity [64-65].

The power output of wind turbine is proportional to cubic relation with the wind speed, air density & the area swept by the rotor. It can be summarized in a mathematical expression 9 & 10.

$$P = \frac{1}{2}\rho A V^3 \quad (9)$$

$$Pmean = \frac{1}{2}kCA\rho V^3 \quad (10)$$

Kinetic Energy is extracted using wind turbine from the wind passed through its rotor. The wind turbine's developed power is given by (11). The amount of wind energy extracted by the wind turbine is measured by the power coefficient C_p *in* (12) that is the function of tip speed ratio λ in (13)

$$P = {}^1/_2\, C_p \rho V_w^3 A \quad (11)$$

$$C_p(\lambda, \beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{\frac{-21}{\lambda_i}} + 0.0068\lambda \quad (12)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (13)$$

Where, P = Power output of wind turbine (Watts), Pmean = Output power of wind turbine including coefficient of performance, ρ = Density of air (1.225 kg/m^3), A = Swept area (m^2), V_W^3 = Velocity of wind (m/s), C_p = Power coefficient, β = Pitch angle.

The importance of high-speed triggering protection techniques for symmetrical defects in preserving the safety and dependability of power systems These techniques seek to promptly detect and isolate defective sections of an electrical network in order to minimise damage and maintain its stability. Let's examine in depth the essential features of high-speed trip protection techniques for symmetrical faults.

1. **Symmetrical Faults:** Symmetrical faults are electrical defects that occur simultaneously in all three phases of a power system. Typically, apparatus failure, insulation failure, or external factors such as lightning strikes cause these defects. Symmetrical faults are distinguished by fault currents that are balanced in all three phases.
2. **Rapid Fault Detection:** High-speed triggering protection techniques use a variety of techniques to rapidly detect symmetrical faults. One common method uses overcurrent relays. These relays are linked to current transformers (CTs) that monitor the passage of current throughout the electrical system. When a symmetrical fault occurs, the fault current exceeds a preset threshold, activating the overcurrent relay and initiating the tripping procedure.
3. **Zone Selective Interlocking:** ZSI is a method for coordinating the operation of protective relays in various zones of a power system. It ensures that the relay closest to the malfunction is the first to operate, isolating the faulty section without influencing the remainder of the system. ZSI is dependent on the protective relays' ability to exchange information regarding malfunction locations and alarm signals. Using ZSI substantially reduces the time necessary to isolate a defective section, thereby minimising the impact on the entire power system.
4. **Distance Protection:** Protection by a Distance Protection at a distance is another crucial technique for high-speed trips. It employs impedance-based measurements to estimate the distance to a power system fault location. When a symmetrical fault occurs, the relay's impedance changes, allowing the distance relay to ascertain the approximate location of the fault. The relay then initiates the tripping procedure in the afflicted zone, isolating the malfunctioning section.
5. **Pilot Protection:** Pilot protection, also known as differential protection, monitors the currents at both extremities of a protected zone using communication-based relays. These relays exchange data continuously to ensure that the currents entering and exiting the protected zone are balanced. If a symmetrical fault occurs within the zone, the currents will become unbalanced, causing the pilot protection relay to

activate and trip the circuit breakers, isolating the faulted section.

6. **High-Speed Communication:** High-speed communication systems are required for rapid fault detection and triggering. These systems facilitate the exchange of data between protective relays and control centres in real time. Fibre-optic cables, Ethernet, and other high-speed communication protocols are frequently used to transmit data quickly and reliably.
7. **Adaptive Settings:** High-speed tripping protection techniques frequently include adaptive settings to modify the operational characteristics of the relay based on the conditions of the power system. These adaptive parameters take system impedance, fault current magnitude, and power system dynamics into account. By dynamically adjusting the relay settings, the protection system can effectively adapt to system changes, thereby enhancing defect detection's reliability and sensitivity. In conclusion, high-speed triggering protection techniques for symmetrical faults entail rapid detection and isolation of defective power system sections. Utilising overcurrent relays, ZSI, distance protection, pilot protection, high-speed communication, and adaptive settings, these methods ensure the safety, reliability, and stability of the electrical network by minimising damage and rapidly isolating faults.

High-speed tripping protection aims to rapidly detect and isolate faulted section of the power system to minimize potential damage and ensure the safety and reliability of the electrical network. Thus, we have successfully implemented this protection scheme in our research work.

4. Implementation Procedure and Simulink Model

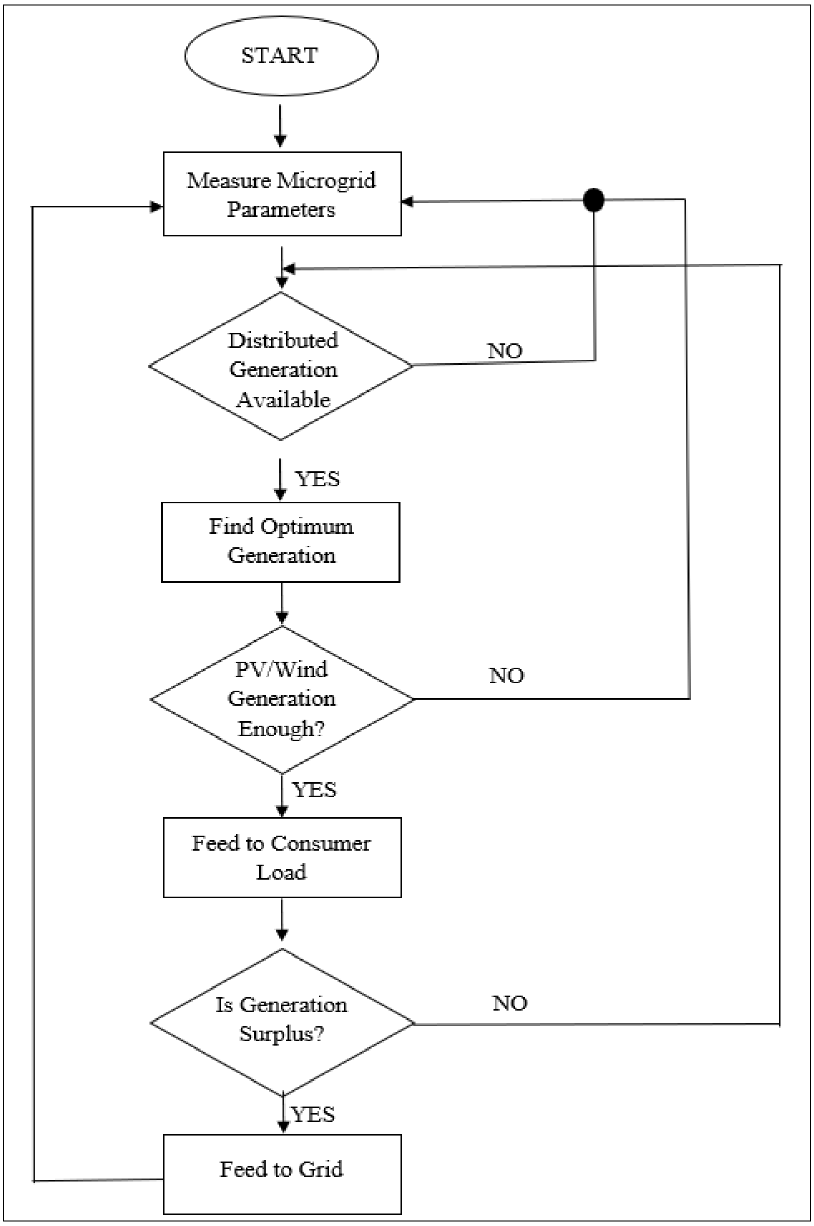


Fig 4: Flowchart for Implementation of Microgrid

Initially all the parameters of grid are to be calculated by using appropriate techniques & formulas. Few practical known assumptions are taken like frequency is can be taken at 50 Hz or 60 Hz. For practical purpose and considering nationwide scenario, 50 Hz frequency is taken for input in the model. Once all the parameters like active power, reactive power, apparent power, power generated by generating units, power consumed by loads is known, the desired MATLAB based simulation model is can be built with the help of the parameters given in appendix [66].

Flowchart for implementation of microgrid is shown in figure 4. It is needed to confirm that whether microgrid has generating units connected with it or not. Models of Wind Turbine, PV Farm & Diesel generator are connected to the microgrid. Once it is confirmed that microgrid has generation sources available and connected properly, then optimum generation of energy using these generating units is required. Once the generation units are optimized, look whether the PV & Wind farm generated electricity is sufficient or not. If Yes then there is no need to generate electricity from diesel generator. If No, then generator is can be used to generate the electricity. Then the energy is can be fed to loads. If the generated amount of energy is in surplus such that all the loads get sufficient amount of energy and still there is energy available, then it can be fed to the grid under the grid-connected mode. Repetition of the process is done again and again to fulfil the requirement of load. The microgrid model proposed in the research paper contains the PV & Wind farm which generates renewable energy but diesel generator generate non-renewable energy so it used to provide the energy only when the Solar & Wind Farm does not provide sufficient amount of energy [67-68].

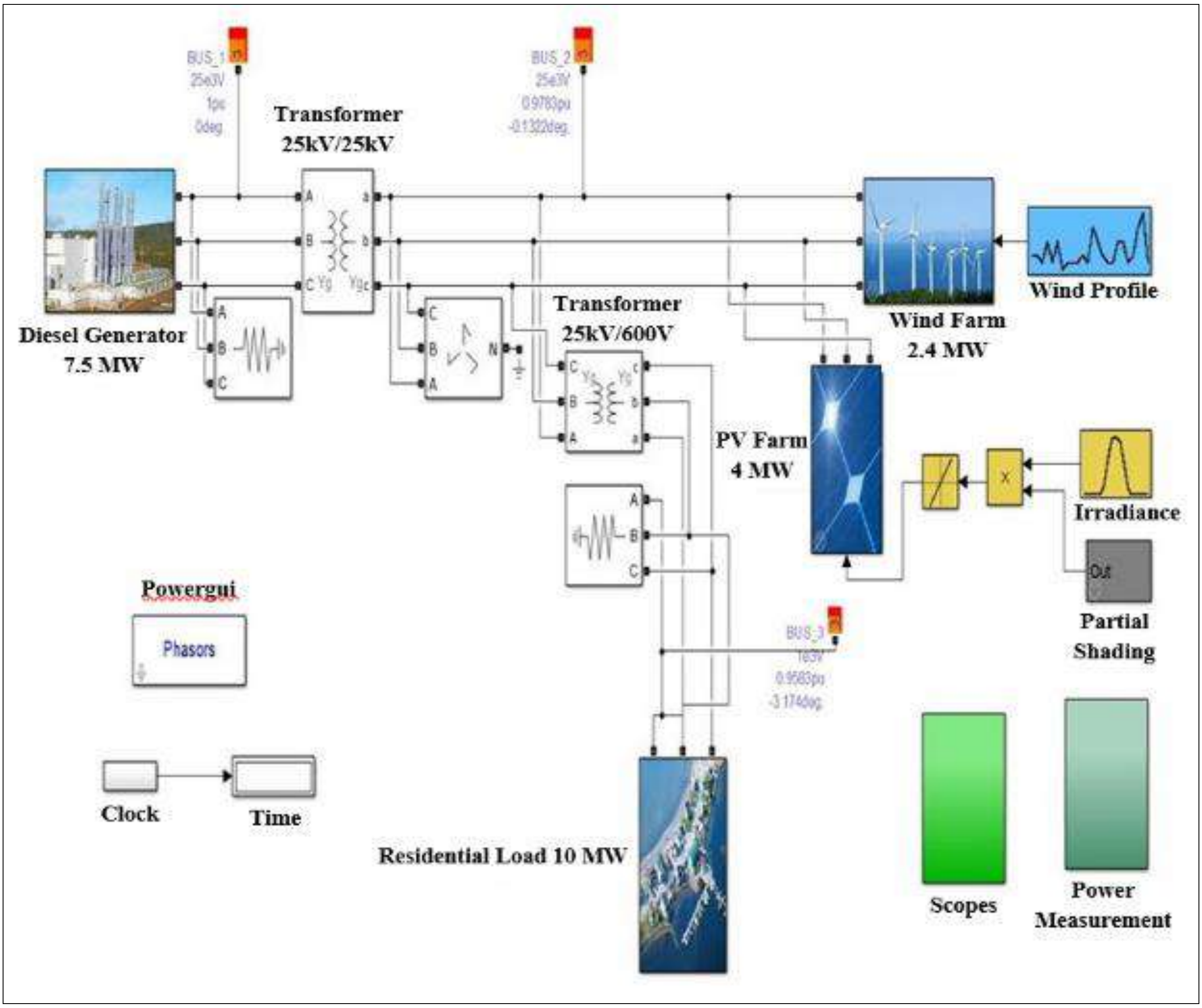


Fig 5(a.): Microgrid model using MATLAB Simulink

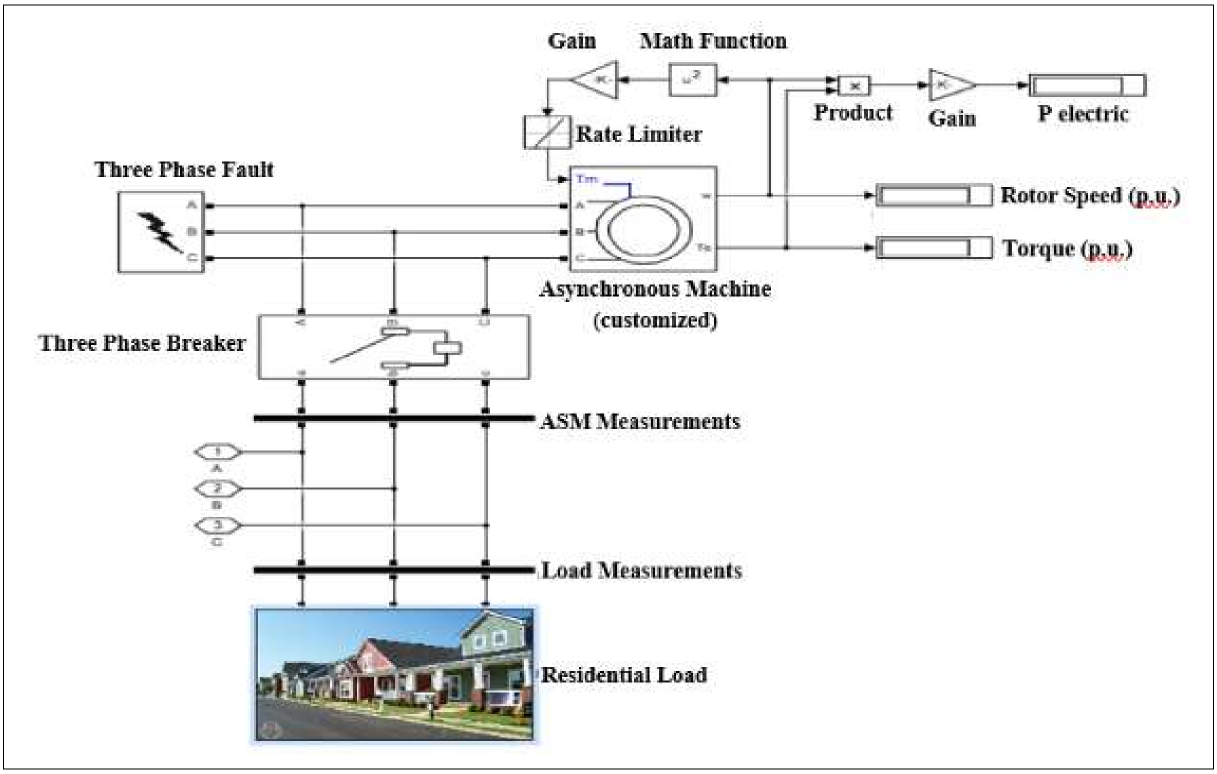


Fig 5(b.): Residential Load Model with Three Phase Fault

5. Results and Discussion of Microgrid

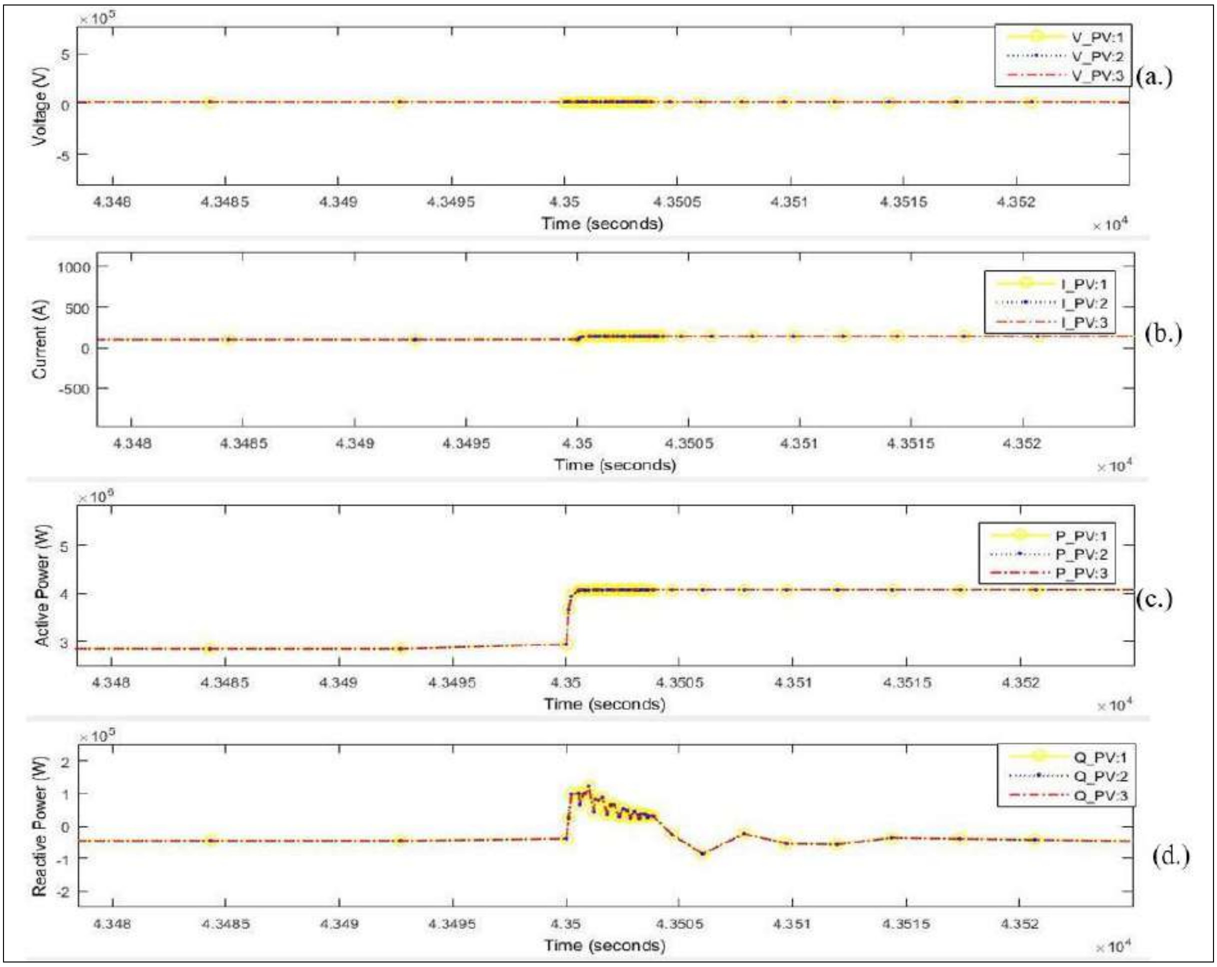


Fig 6: Time Series Plots of Voltage v/s Time for (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM

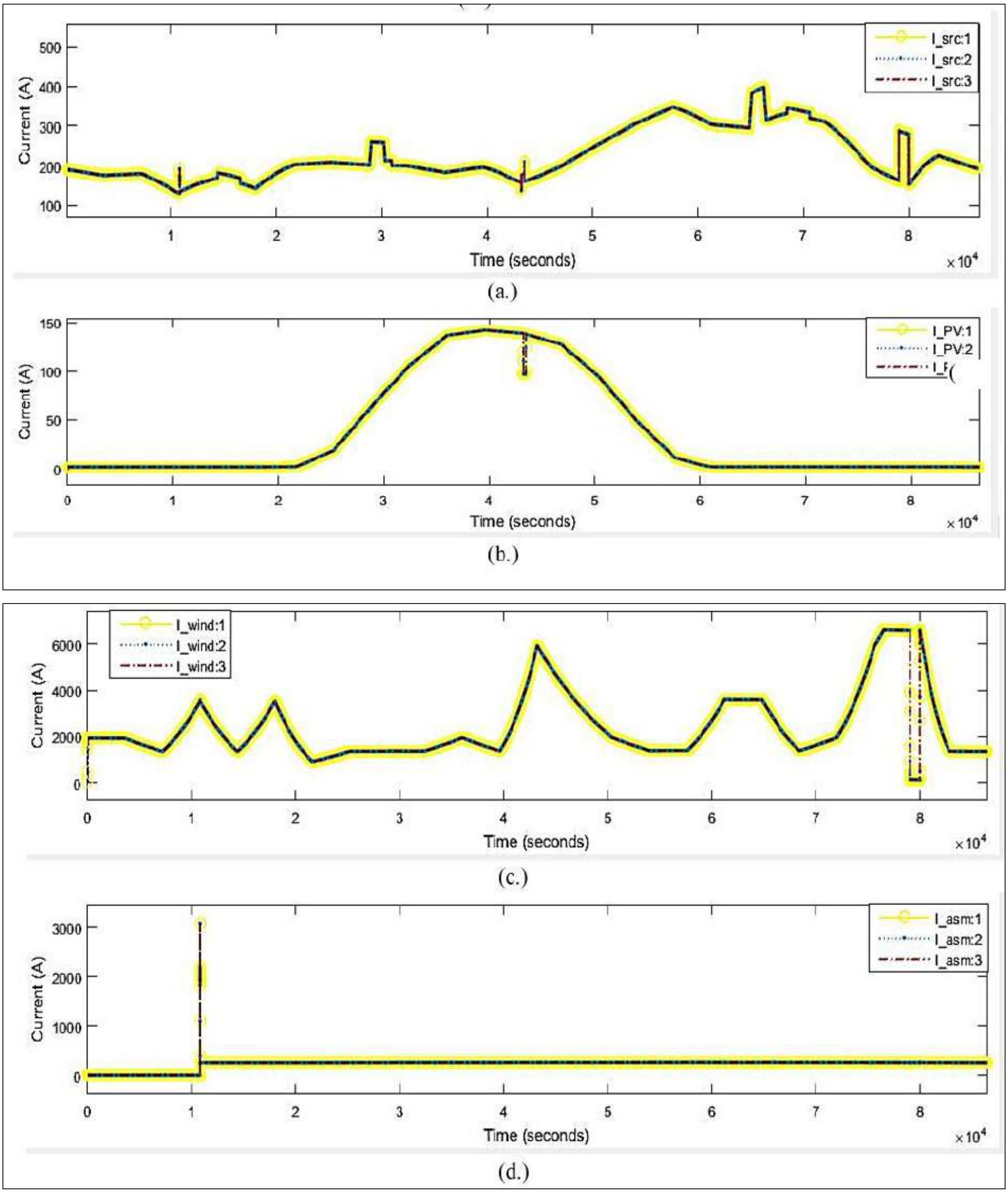
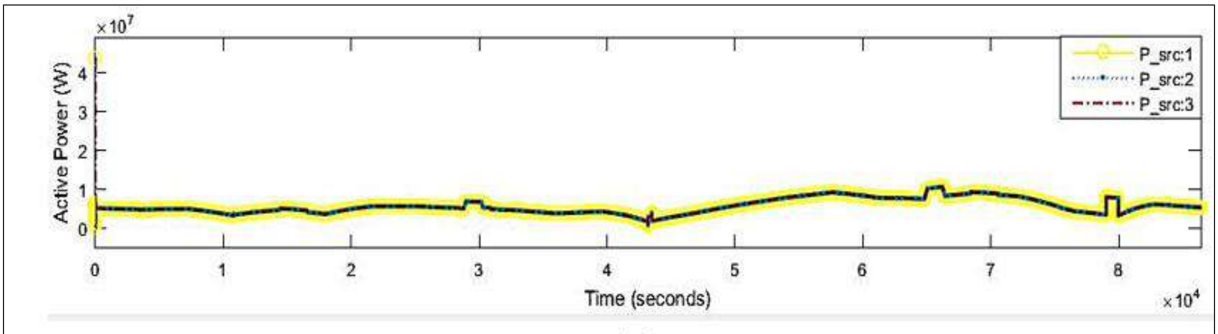


Fig 7: Time Series Plots of Current v/s Time for (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM



(a.)

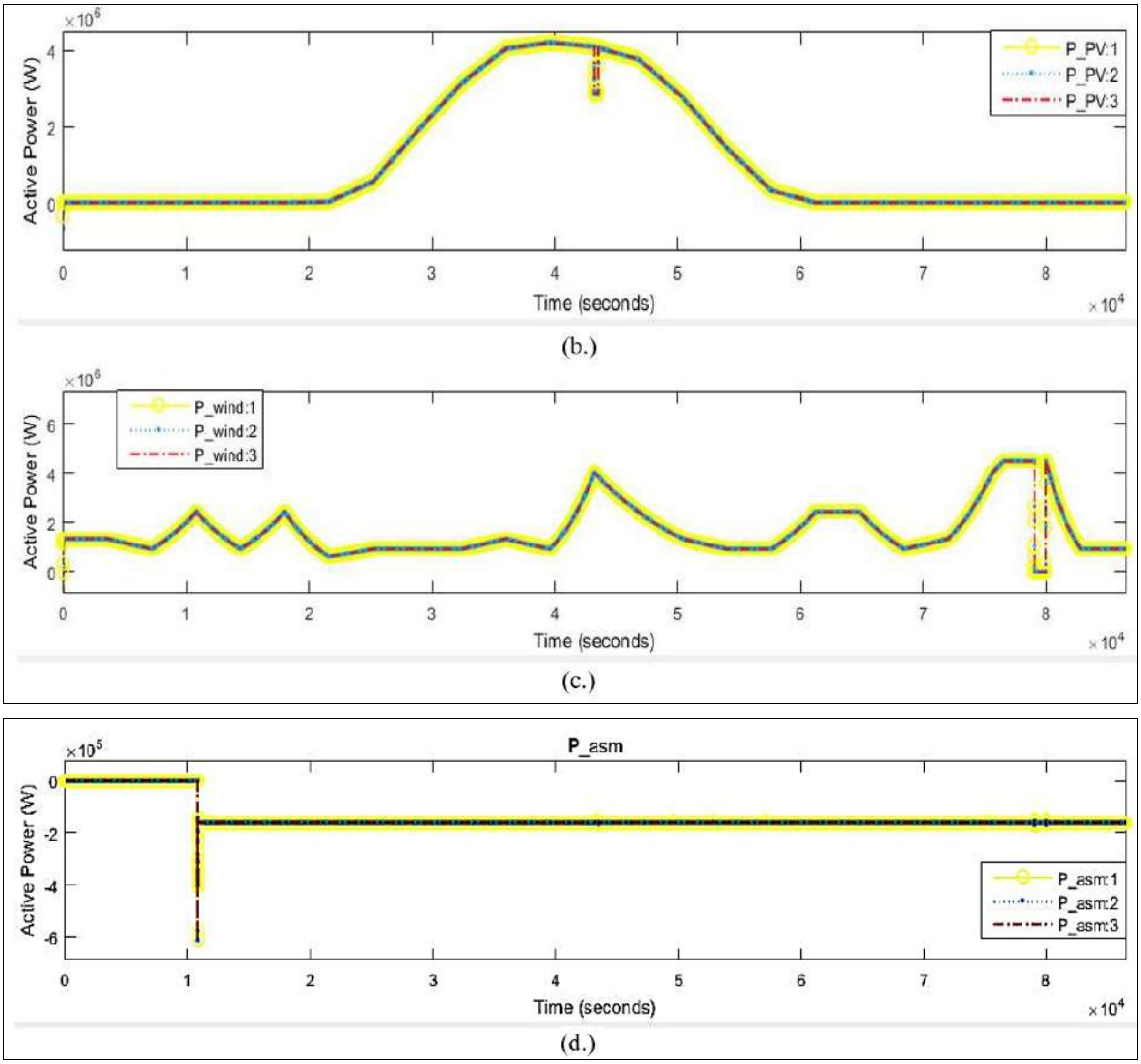
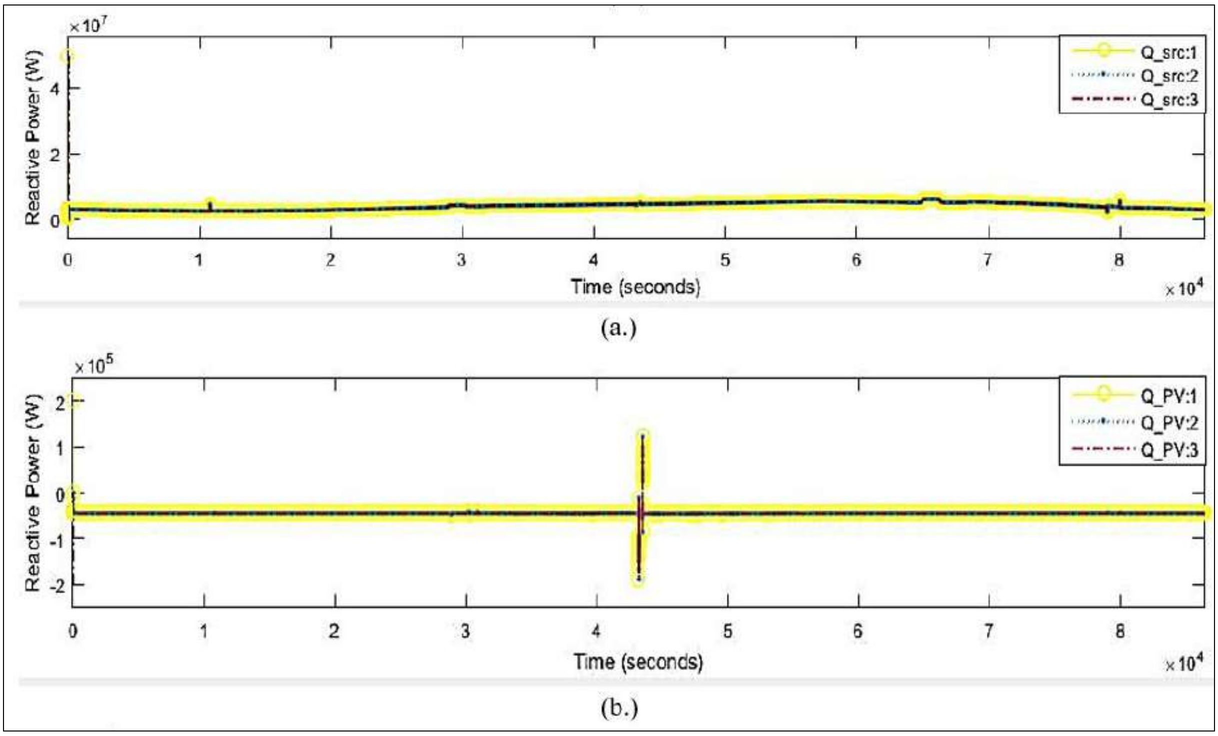


Fig 8: Time Series Plots of Active Power v/s Time for (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM



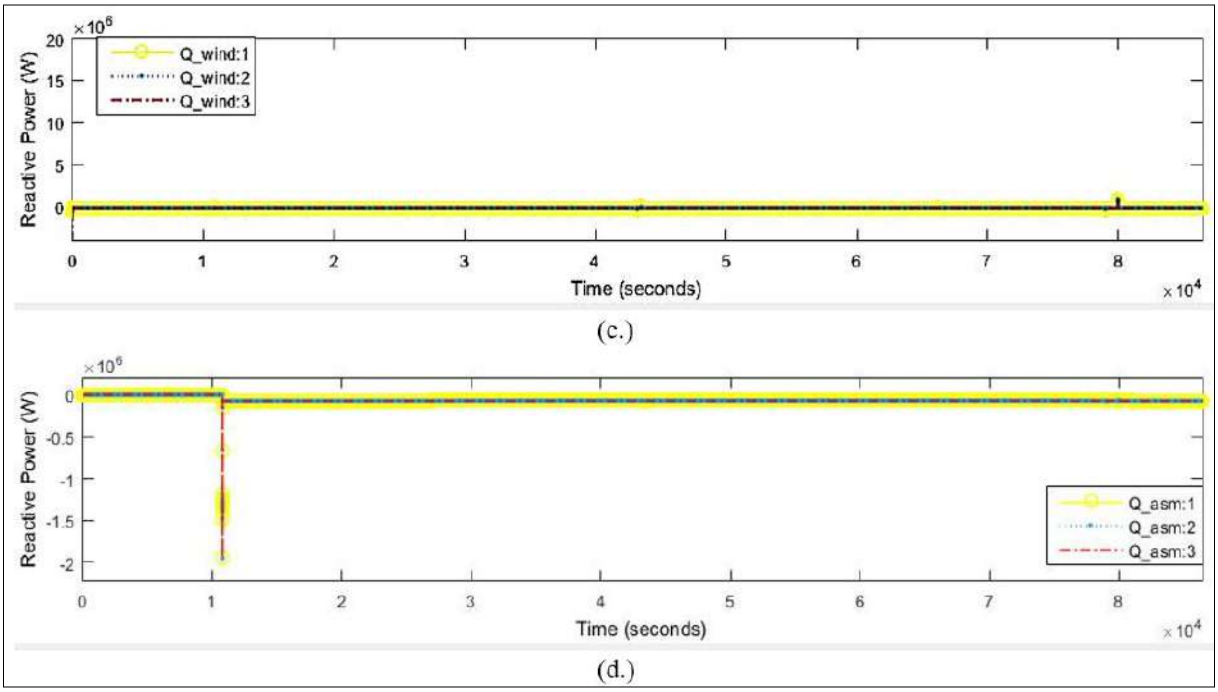


Fig 9: Time Series Plots of Reactive Power v/s Time for (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM

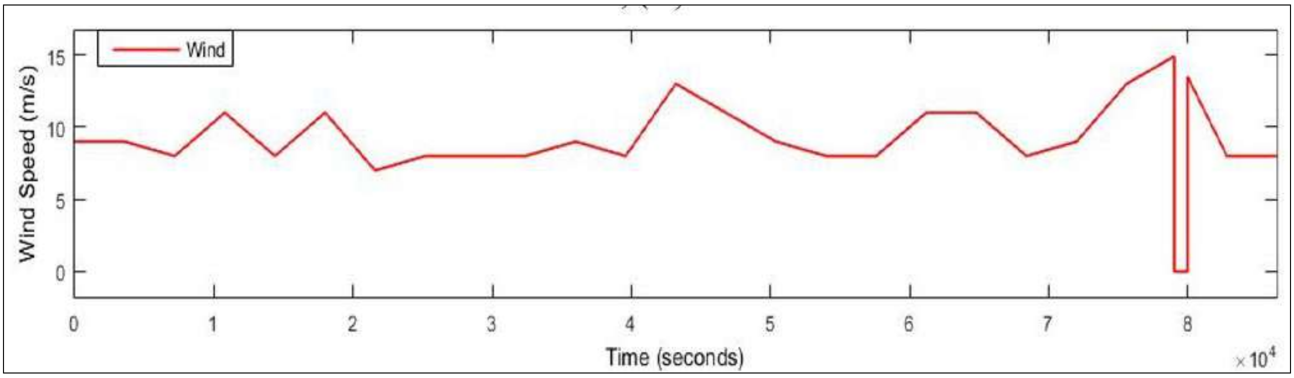
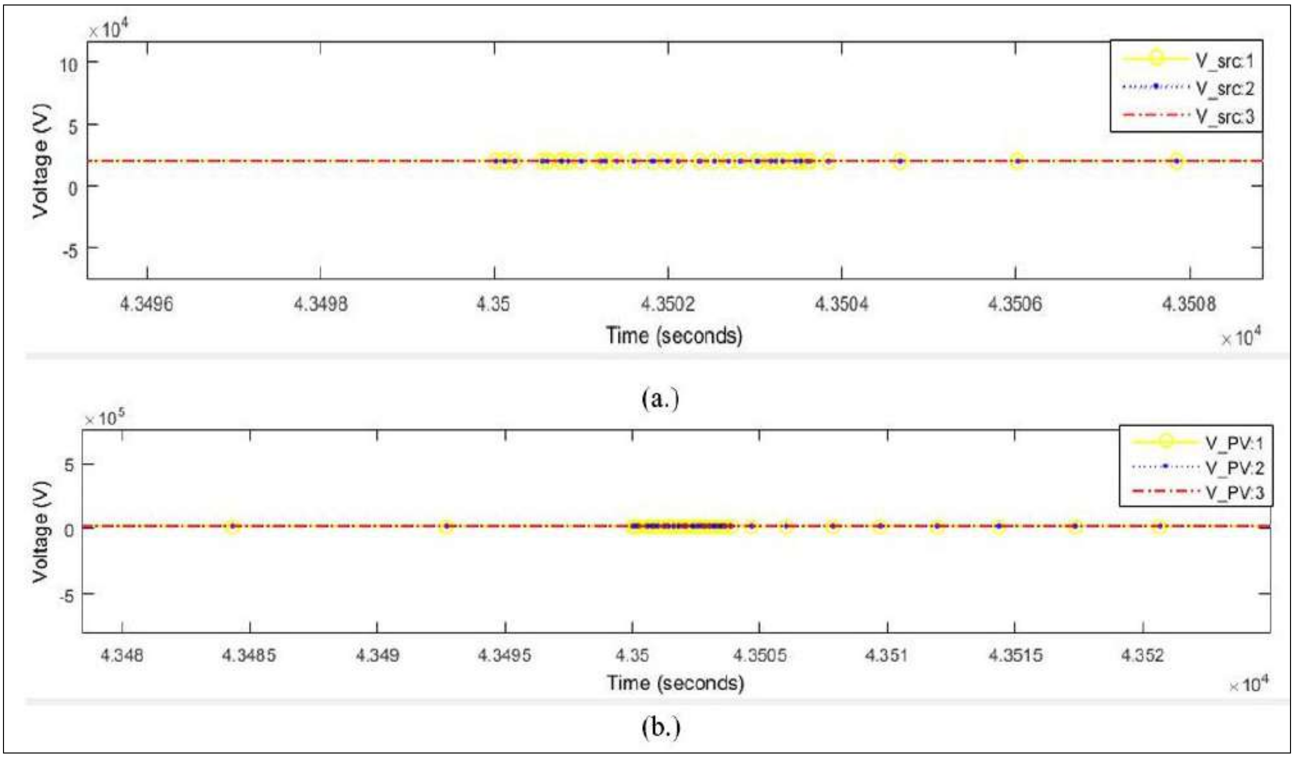
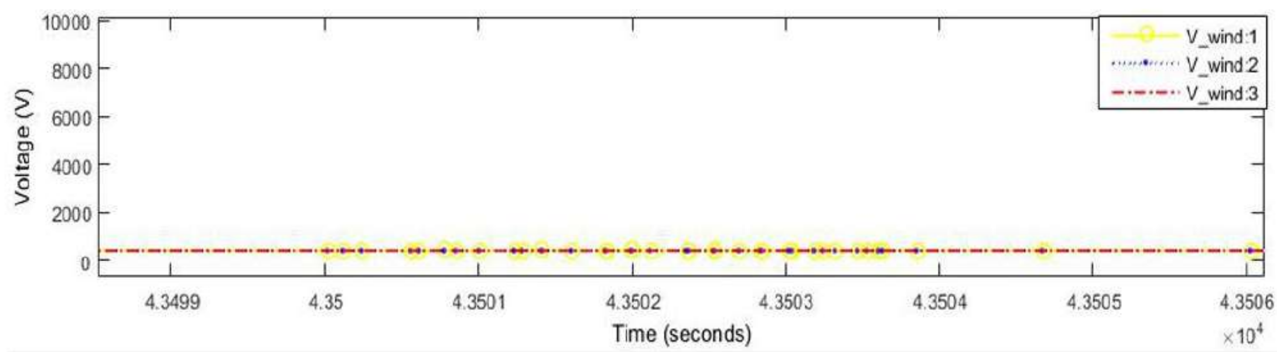


Fig 10: Time Series Plots of Speed variation v/s Time for Source, PV Farm, Wind Farm, ASM





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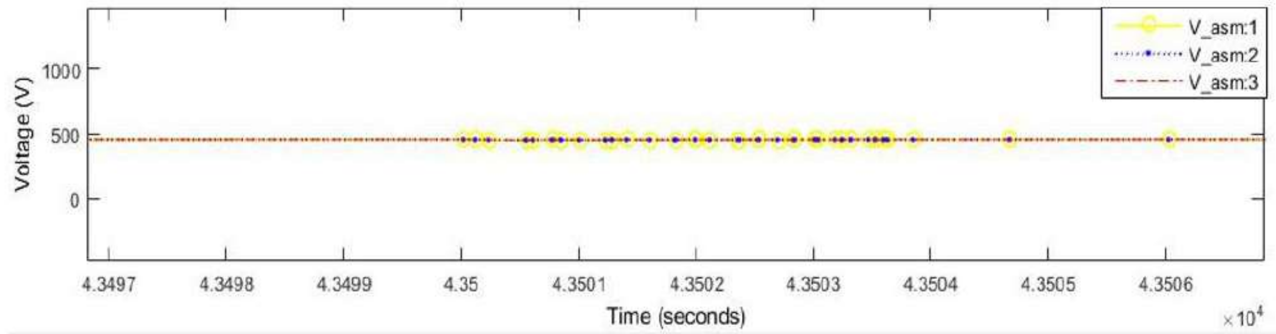
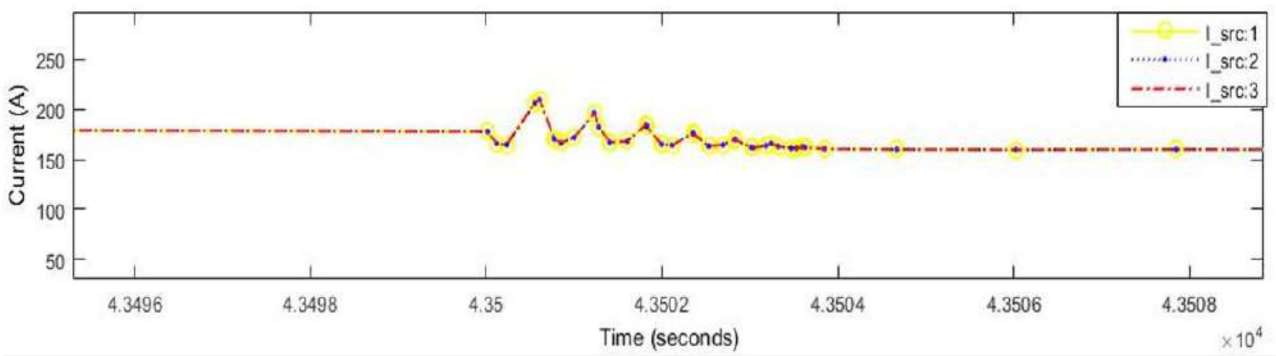
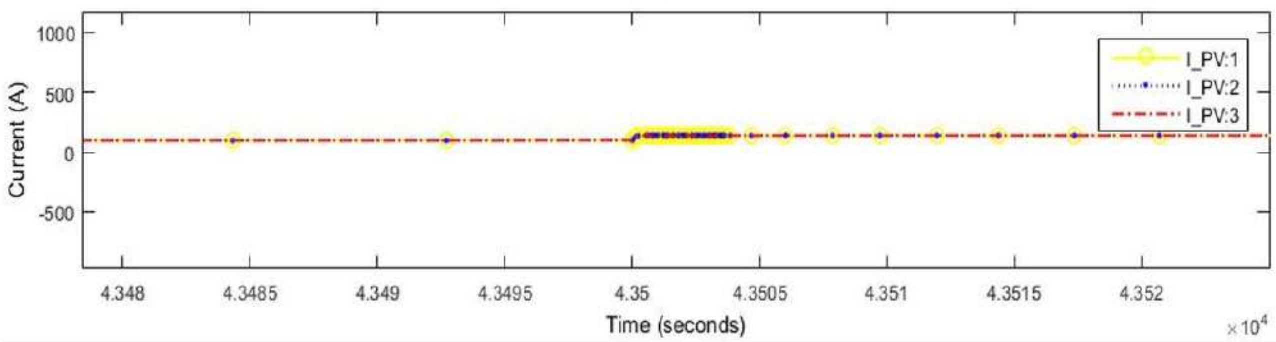


(d.)

Fig 11: Time Series Plots of Voltage v/s Time during and after Fault Stablization of (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM



(a.)



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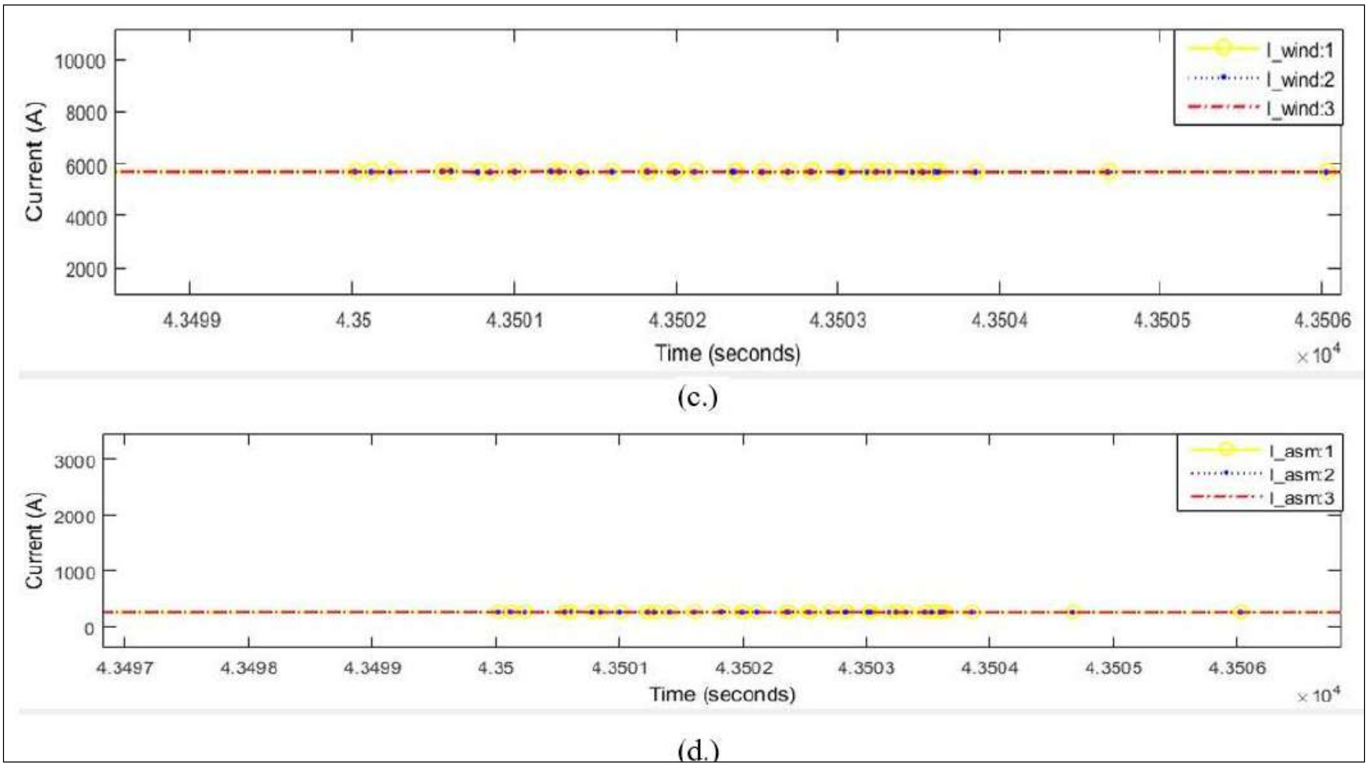
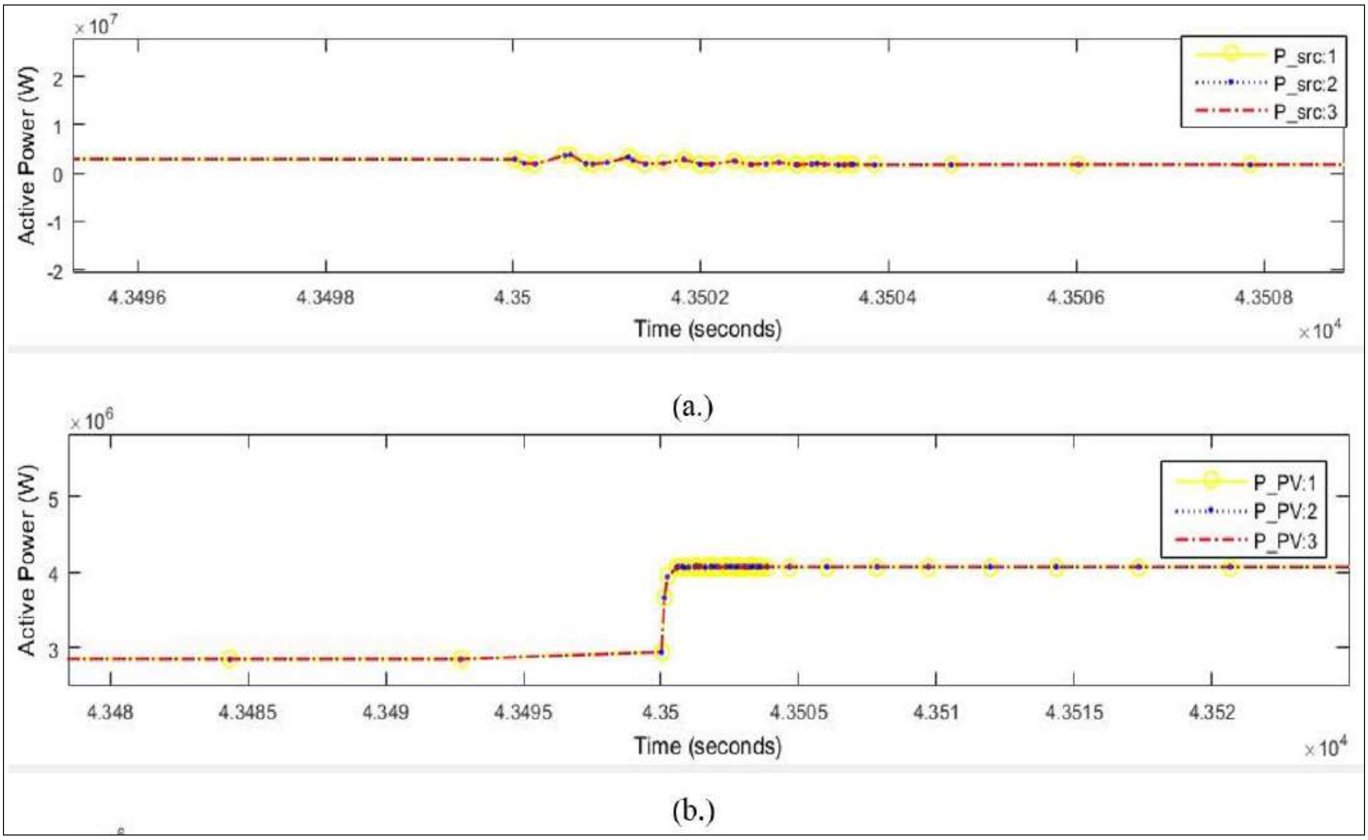
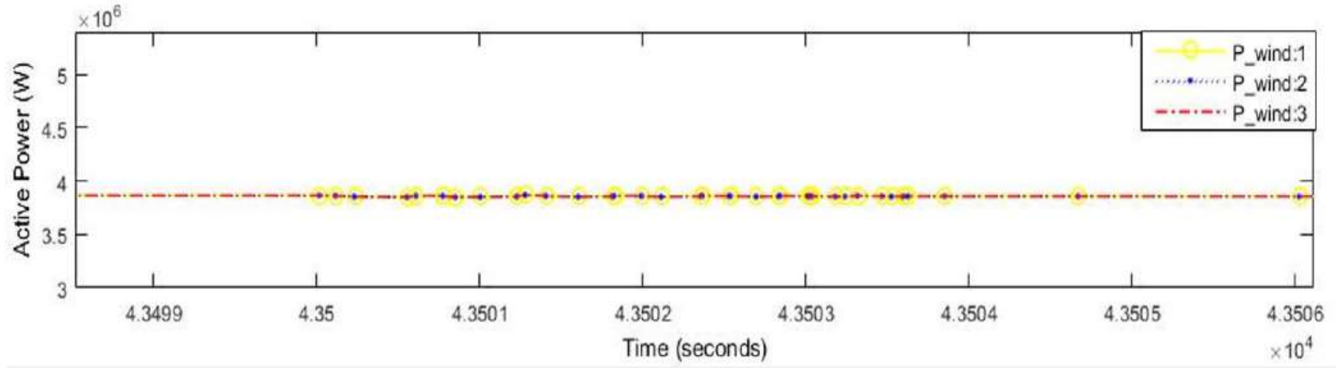


Fig 12: Time Series Plots of Current v/s Time during and after Fault Stablization of (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM





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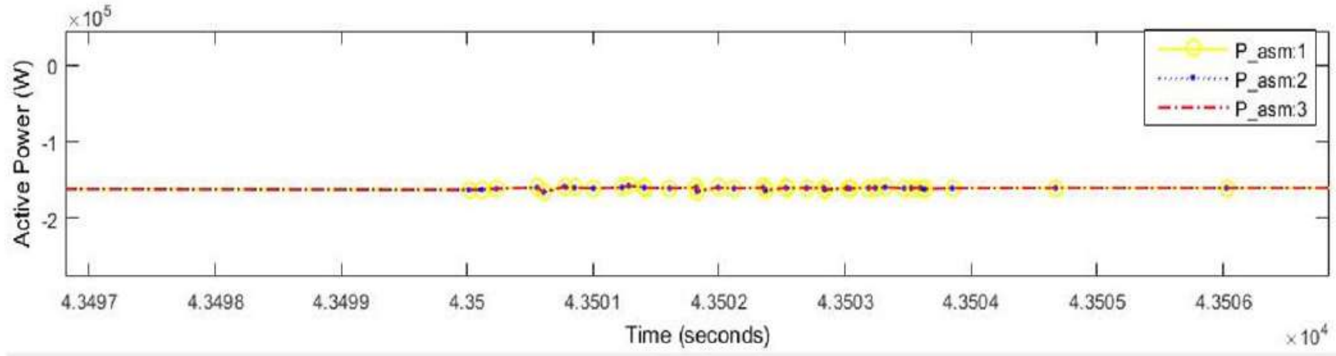
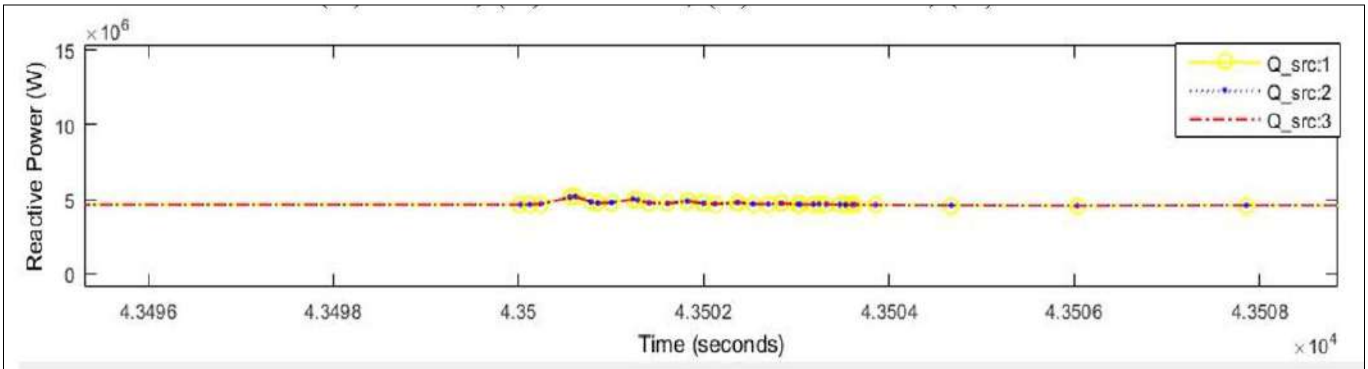


(d.)

Fig 13: Time Series Plots of Active Power v/s Time during and after Fault Stablization of (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM



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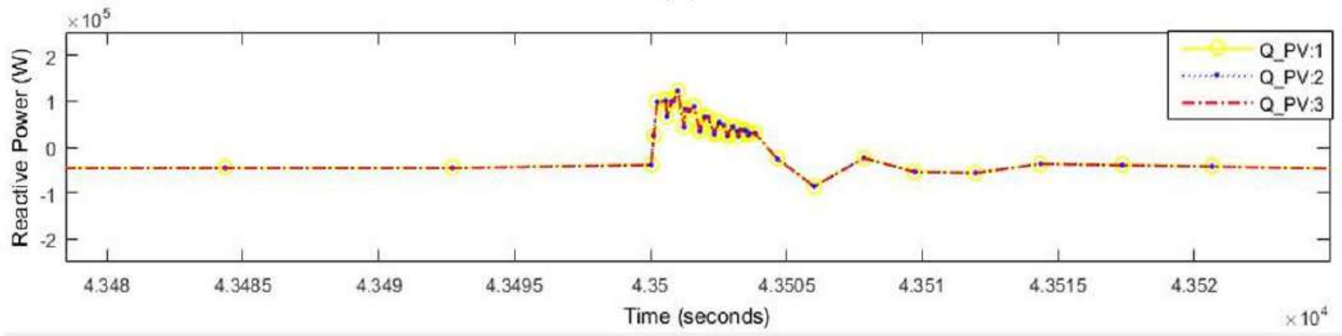

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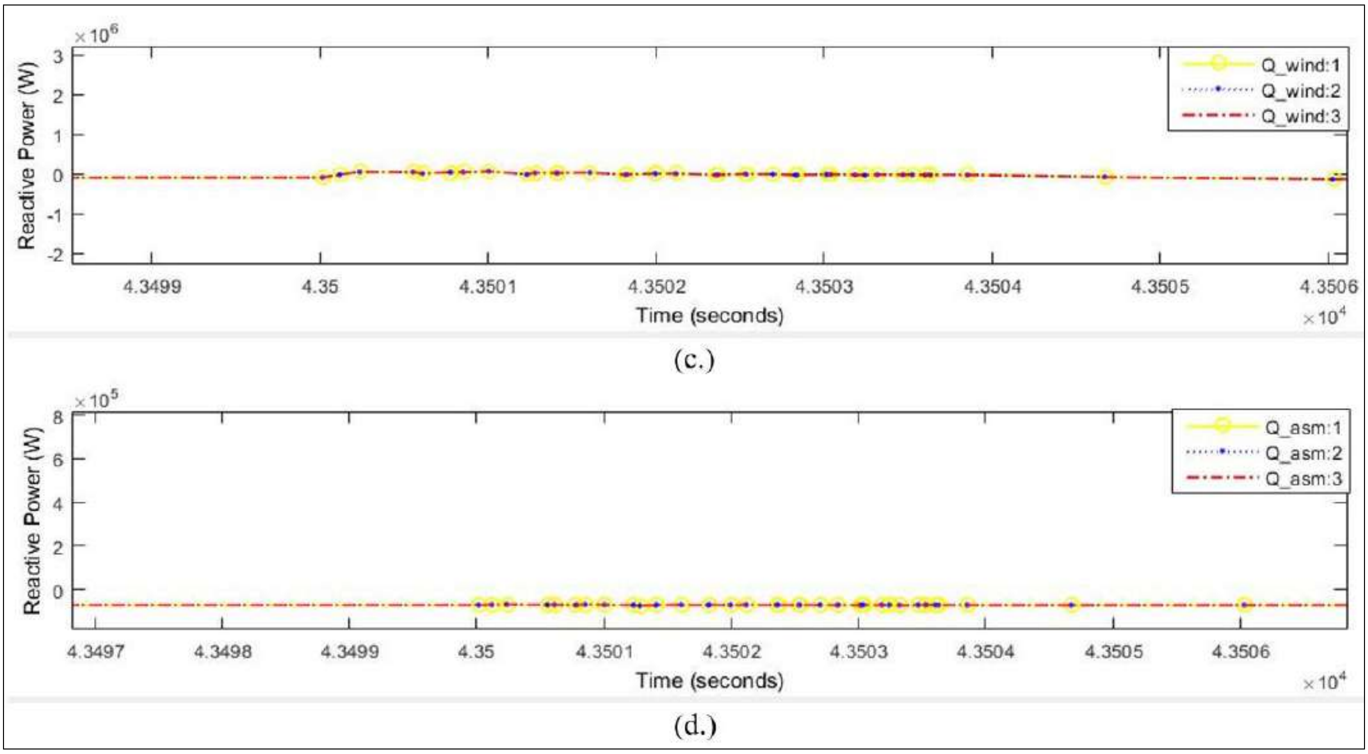

Fig 14: Time Series Plots of Reactive Power v/s Time during and after Fault Stablization of (a.) Source, (b.) PV Farm, (c.) Wind Farm, (d.) ASM

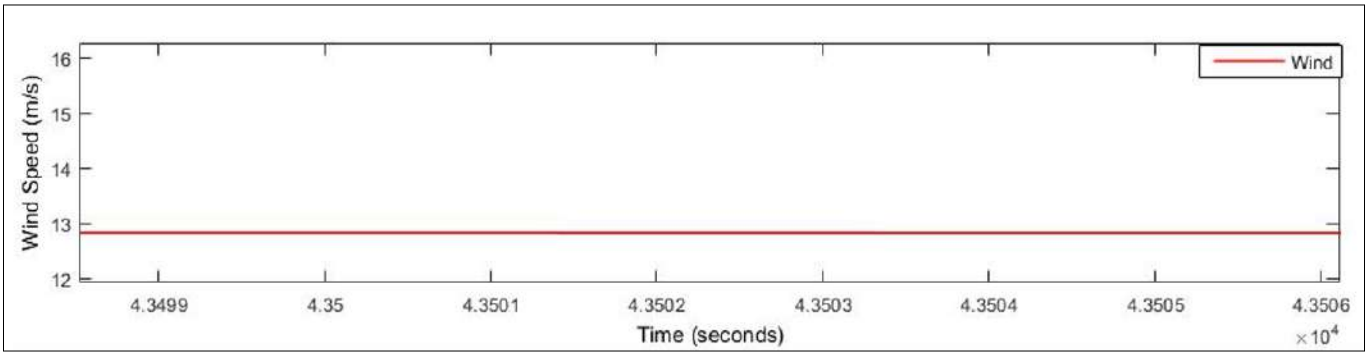

Fig 15: Time Series Plots of Wind Speed v/s Time during and after Fault Stabilization of Wind Farm

The rated values of diesel engine generator, solar PV farm, wind farm and residential load models are 7.5 MW. 4 MW, 2.4 MW and 10 MW. Solar PV panel's power at different periods of time was observed. The normal distribution curve was followed by solar intensity. At midday, the solar intensity is highest. Throughout the day, the speed of the wind varies greatly & had multiple peaks & lows. Just like a normal consumption of a household, similar pattern is followed by the residential load. Usually the consumption of energy is low during day time as people do out for work during day time. Only few people remain at home. The consumption increases with passage of time and reaches a peak during the evening when everyone return back to home and all household work start. Grid frequency will be affected during day time due to few events like partial shading at noon which affects the solar power production and when wind exceeds the maximum allowed wind power, the wind farm trips at 10 PM at night. Solar Power generation varies throughout the day depending upon the conditions and circumstances. The condition & circumstances include various factors like type of Solar Panels used for generation i.e. monocrystalline, polycrystalline, thin film & concentrated type PV cell's and there orientation on the basis of position of sun i.e. azimuth or zenith orientation and the type of solar cell used. The secondary source used here is the Wind Farm. Diesel Generator generates electricity at different hours of day & night according to the working of Solar Panels and load on the micro-grid is can be seen in the output. Power consumed by load at different times of day is displayed. It was observed that load consumption during peak hours is high and both sources work efficiently. After running the microgrid model (fig. 5 a.) the power profiles of both consumption & generation for an entire day were observed.

6. Conclusion

There are four part into which microgrid is divided: A Diesel Generator, PV Farm, Wind Farm & Loads. Base power is provided by the diesel generator to maintain the least amount of power in the microgrid. PV farm & Wind farm provides the renewable energy. This microgrid is basically considered for a thousand households in a community on the day of less utilization of electricity whether in spring season or falls season. This is maybe a possible future scenario. It can be safely assumed that voltage generated by each source is stable with a constant profile. The Diesel generator used in the simulation is used to balance between the power which is consumed by the load & the power produced by RES. The frequency deviation of the grid is determined through the observation of the rotor speed of the synchronous machine. The two RES used in the microgrid generates electricity based on many factors. The PV farm is dependent on three main factors i.e. the size of area of PV farm, the irradiance data & the efficiency of solar panels.

Electrical power produced by the wind farm follows a linear relationship with the wind. After simulation is performed, it is observed that solar panels do not generate any power from 8 PM to 4 AM i.e. after sunset and before sunrise. After that, power generated by the solar panels increases slowly with increase in intensity of the sun rays. From 2 PM to 3 PM, when the intensity of the sun rays is maximum then maximum amount of power is generated. The load connected is residential load and 0.15 given power factor, it follows consumption profile. In the loads connected, different assumptions are made i.e. the energy consumed by them at different times of the day changes according to the use of different equipment at different periods of day & night. During peak hour in the morning at around 9 AM and in the evening at around 7 PM & 10 PM at night, energy consumed is highest. From 6 PM to 12 PM of the next day, the solar panel does not produce the maximum electricity as the intensity of sun rays during this period is lesser or even negligible during night time. This operation is performed with the help of the battery controller.

Hence, we have successfully developed an AC Microgrid in which PQ control scheme and V/f control schemes are combined for implementation under grid connected and islanded mode of operation to have a better control on output parameters such as voltage, frequency, power etc. so that fault is can be avoided initially. However artificial fault analysis is done to check the stability of the system whether the developed microgrid system attains stability or not when symmetrical faults and unsymmetrical faults occur at grid side of grid connected AC microgrid. The aim is to separate the critical and non-critical load during the undesired islanding when a fault has occurred. But this work of separating the critical and non-critical loads is currently in progress along with the literature review.

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