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A Study on Modeling and Simulation of Hybrid Solar-Wind System under Variable Load Condition

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Abstract: - Energy demand is increasing with speed of rocket and the resources of conventional energy sources basically fossil fuels (coal, gas, oil) are decreasing rapidly. The renewable energy is free of cost and abundantly found anywhere. It is also carbon free so does not impact on global warming or climate change. If we increase the burning of fossil fuel the earth will not be an inhabitable for living beings. One of the major worldwide tasks is to reduce the emission from the traditional power plants by using renewable energy and reduce the cost of supplying electricity to remote areas. Power generation and energy needs always be uneven. However, these energy sources (renewable) are based on weather condition and poses inherited intermittent nature, which hinders stable supply. Combining multiple renewable energy sources can be a possible solution to overcome defects and to optimized the global efficiency of the process. Hybrid energy sources not only provide reliable power but also leads to reduction in the required storage capacity. An oversized hybrid system satisfies the load demand but not economical. An under sized system can't meet the load demand. The optimal sizing of the renewable energy power depends on the mathematical model of system components. Main objective of this paper to study on the various load conditions for achieving this goal. As a whole this paper summarizes the mathematical modeling of various renewable energy system in the MATLAB platform.

Keywords: Solar Power system, Wind power system, Mathematical Modelling, Critical load, Hybrid Model

I. INTRODUCTION

From our inception, whole world has been aware that the Sun is the ultimate energy source. However, the Sun provides us with alternatives derived from its energy that are both sustainable and convenient for our use. Furthermore, these alternatives are cost-free and environmentally friendly. Energy consumption is a fundamental aspect of our daily lives, beginning from the early hours of the day until the late hours. Nowadays, life without energy is unimaginable for people. As humanity progresses year after year, the global population continues to increase. Consequently, the overall energy demand is also growing exponentially, keeping pace with the rapid advancements of society and population growth. According to a survey, primary energy demand is increasing at a rate of 1.5% per year, and by 2030, the total energy demand will reach 16,800Mtoe, representing a 40% overall increase. On the other hand, a significant challenge with electrical energy arises when providing power to rural areas far from commercial distribution networks. While this infrastructure offers comfort, supplying electricity continuously can be challenging. Therefore, this study aims to establish a mathematical model as a reference for developments in this field. One major drawback of solar energy compared to other energy sources is its dependence on daylight hours. To overcome this limitation, this paper proposes the combination of two renewable energy systems to achieve maximum efficiency. This combined system, known as a Hybrid system, enhances the reliability of the overall energy system while remaining cost-effective. A Hybrid Renewable Energy System (HRES) can either operate as a standalone system or be connected to the grid. Standalone systems require sufficient generation and storage capacity to handle the load. In grid-connected systems, the storage device can be relatively smaller since power deficits can be supplemented from the grid. A grid-connected HRES can supply electricity to both the load and the grid. However, proper power electronic controllers are necessary to regulate voltage, frequency, harmonic regulations, and load sharing when connected to the grid. Based on the type of HRES, its operating mode can be classified into island mode (local consumption of generated electricity) or grid-connected mode (connection to the grid as a renewable energy source). In this paper, the hybrid renewable energy system comprises solar PV, wind, and diesel systems, all interconnected with a grid. Various loads are connected to the system, and the results are analysed by modifying the load conditions.

II. LITERATURE REVIEW

Diego et al. conducted a study on power efficiency in a hybrid system using wind and solar power. Authors found that DC Micro-Grids showed superior energy efficiency and reliability in low-scale applications like lighting

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[Diego A *et,al* 2022]. The modeling of a system, as discussed by Vivek and Prof. Chellamuthu, encompasses a combination of a wind energy source, photovoltaic cells, an industrial load on the load side, and solar power cells for the domestic load on the source side. The wind is considered an unregulated energy source, while the diesel generator acts as a regulated energy source, and the domestic load functions as an uncontrolled energy recipient. During load variations, the voltage and frequency of the system experience marginal changes. Notably, when the load is modified, the power drawn from the diesel generator substantially increases, while the other sources provide relatively less power [Vivek Venkoba Rao *et.al* 2007]. Haitao et al. designed a bidirectional DC/DC converter for energy storage in a 5KW wind-solar hybrid system. Author tested its feasibility using a MATLAB/Simulink model. The converter uses the Ampere-Hour method for accurate battery charge detection and an adaptive control algorithm for stable energy conversion, achieving efficiency [Haitao Hu *et.al* 2017]. Gangadharayya et al.'s study focuses on integrating solar and wind power into the power grid to improve flexibility, reliability, security, and efficiency. They propose a hybrid system that incorporates solar, wind, and pumped hydro storage systems (PHSS), addressing voltage and frequency regulation challenges. The technology is effective, cost-free, and efficient, making it an ideal fit for renewable energy growth [Gangadharayya Salimath *et.al*. 2017]. Zhongfei et al. highlight the growing importance of renewable energy sources like solar and wind, which can meet electricity needs in remote areas and improve the environment. This paper simulates a 500kW wind-solar complementary microgrid system, focusing on maximum power tracking. It provides an in-depth understanding of renewable energy development, microgrids, and wind-solar energy resource distribution in China [Zhongfei Gao *et.al* 2020]. Sungwoo and Alexis studied a resilient microgrid powered by solar and wind energy, using a direct-driven permanent magnet synchronous wind generator and variable speed control method. They examined the 30-KW wind/solar hybrid power system dynamic model and its performance under various conditions [Sungwoo Bae *et.al.* 2012]. Shiyas and colleagues developed a dc/dc converter with a fuzzy controller for integrating renewable energy sources, ensuring stable output voltage and seamless integration of intermittent primary energy sources [Shiyas P.R *et.al*. 2012]. Akshay et al. discuss India's growing electricity demand and propose hybrid solar and wind energy systems as alternatives. They simulate and develop a hardware model for a single-phase system, using mathematical simulation software to analyze factors like sag, swell, voltage, current, and THD. A seven-level inverter converts DC solar power into AC, improving overall power quality. The model is then developed for a single-phase power system [Akshay B. Zadel *et.al.*2017]. Swapnil and colleagues present a renewable energy hybrid power system that combines photovoltaic and wind sources, using a Cuk DC-DC converter, three-phase inverter, and LC filter. The system is environmentally friendly and widely available in India, but can cause fluctuating output voltage. The authors model the system using MATLAB Simulink, demonstrating enhanced reliability and mitigation of output voltage fluctuations [Swapnil B. Mohod *et.al* 2016]. Daniel et al. study the energy conversion equations for a hybrid PV and wind turbine system for electrical power generation. They develop a numerical model and compare it with experimental data, aiming to optimize and design the system. The study also conducts stability analysis, aiming for future large-scale utilization. The study highlights the importance of considering solar radiation and ambient temperatures in PV panel design [Daniel *et al* 2017].

Soro et al. study a hybrid power system (HPS) that combines wind energy conversion, solar photovoltaic, biodiesel generator, and storage battery. The system aims to ensure reliable power supply under various weather conditions. The model includes wind turbines, photovoltaic panels, a permanent magnet synchronous generator, power converters, and maximum power point tracking controllers. The dynamic behavior of the HPS is evaluated under different conditions, considering wind speed and solar radiation variations. The simulation model, implemented in MATLAB/Simulink software, accurately represents the system's performance under specified conditions [Soro S. Martin *et. al.* 2017].

B. Kanagasakthivel and Dr. D. Devaraj present a hybrid energy system that combines solar photovoltaic (PV) and wind power for isolated areas. The system is interconnected through a DC/DC Boost converter. The model is modeled and simulationd using MATLAB/SIMULINK, and its performance is evaluated under varying wind speeds and irradiation levels. The simulation model is validated by testing with diverse input data, confirming its accuracy and adaptability. The model can be easily adapted to accommodate different parameters [B.Kanagasakthivel *et. al* 2015]. Zainab et al. studied hybrid renewable energy systems that combine solar panels, wind turbines, and battery storage to power various DC loads. They examined energy conversion, transmission, and harmonization based on solar and wind energy potentials and consumer requirements. They developed simulation models for solar and wind energy sources, photovoltaic cells, and battery storage. The model was tested with diverse input data, confirming its accuracy and ability to accurately represent the system's behavior. The study used MATLAB/Simulink software for modeling and comparative analysis [Zainab Sh. Abdulridha *et al* 2020]. Sangay D orji et al. conducted a research to compare power quality and reliability between isolated and integrated mode operation of a power system in Samdrup Jongkhar, Bhutan. The study used MATLAB simulation and collected data from satellite records, NASA, and SolarGIS, to understand the advantages and disadvantages of each approach [Sangay Dorji *et. al.* 2021].

III. PROBLEM FORMULATION

After analyzing various research papers, authors have designed a grid-connected hybrid system consisting of a PV solar system, a PMSG wind system, and a diesel generator. The system is connected to various loads, and by manipulating the loads, authors observe the power distribution to the loads and the grid and also analyze how changing the load values impacts on the system and the grid.

IV. MATHEMATICAL MODELLING

A. PV System:

- **PV Potential Assessment:**

PV cell are made of semiconductors material, which are specially treated to form an electric field, positive and negative side. The model of the solar cell can be realized by an equivalent circuit that consists of a current source in parallel with a diode. The current source represents the current generated by photons (often denoted as Iph or IL), and its output is constant under constant temperature and constant incident radiation of light. Rs and Rsh components can be neglected for the ideal model. Power output of a PV array is based on solar irradiance and ambient temperature. The power output in this model is calculated as

$$P_{pv} = \eta_{pvg} A_{pvg} G_t \quad (1)$$

where η_{pvg} is PV generation efficiency, A_{pvg} is PV generator area (m^2), and G_t is solar irradiation in tilted module plane (W/m^2). η_{pvg} is further defined as

$$\eta_{pvg} = \eta_r \eta_{pc} [1- \beta (T_c - T_{c\,ref})] \quad (2)$$

where η_{pc} is power conditioning efficiency which is equal to one when MPPT is used, and β is temperature coefficient ((0.004-0.006) per ^{0}C), and η_r is the reference module efficiency, and $T_{c\,ref}$ is reference cell temperature in ^{0}C. Reference temperature ($T_{c\,ref}$) can be obtained by relation

$$T_{cref} = T_a + \left(\frac{NOCT-20}{800}\right) G_t \quad (3)$$

where T_a is ambient temperature in ^{0} C, *NOCT* is nominal operating cell temperature in ^{0}C, and G_t is solar irradiation in tilted module plane (W/m^2). The total radiation in the solar cell considering normal and diffuse solar radiation can be estimated as

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad (4)$$

- **System Modelling**

Solar cell, the building block of the solar array, is basically a P-N junction semiconductor capable of producing electricity due to photovoltaic effect. PV cells are interconnected in series-parallel configuration to form a PV array Using ideal single diode as shown in Fig. 1, for an array with N_s series connected cells and N_p parallel connected cells, the array current may be related to the array voltage as

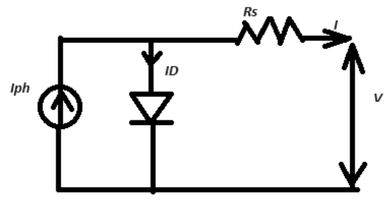

Fig 1. Ideal single diode PV cell model(proposed)

$$I = N_P [I_{ph} - I_{rs} [\exp\left(\frac{q(V+IR_S)}{AKTN_S}\right) - 1] \quad (5)$$

Where

$$I_{rs}=I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\left[\frac{E_G}{AK}\left(\frac{1}{T_R}-\frac{1}{T}\right)\right] \quad (6)$$

and q is the electron charge (1.6 × 10-9C), K is Boltzmann's constant, A is the diode ideality factor, T is the cell temperature (K). I_{rs} is the cell reverse saturation current at T, T_r is the cell referred temperature, I_{rr} is the reverse saturation current at T_r, E_G is the band gap energy of the semiconductor used in the cell. The photo current I_{ph} varies with the cell's temperature and radiation as follows

$$I_{ph}=\left[I_{SCR}+k_i\,(T-\mathrm{Tr})\frac{S}{100}\right] \quad (7)$$

where I_{SCR} is cell short circuit current at reference temperature and radiation, k_i is the short circuit current temperature coefficient and S is the solar radiation in (mW/cm^2)

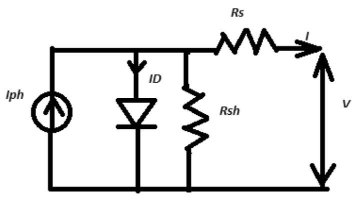

Fig 2. Single diode PV cell model(proposed)

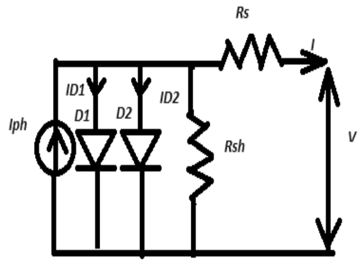

Fig 3. Double Diode PV model(proposed)

Solar cells are generally modelled as single diode in Fig. 2 and double diode circuit model in Fig. 3.
Single diode model uses an additional shunt resistance in parallel to ideal shunt diode model. I-V characteristics of PV cell can be derived using single diode model, as follows

$$I = I_{ph} - I_D \quad (8)$$

$$I=I_{ph}-I_0\left[exp\left(\frac{q(V+R_sI)}{AKT}-1\right)-\frac{V+R_sI}{R_{sh}}\right] \quad (9)$$

where I_{ph} is photo current (A), I_D is the diode current (A), I_0 is the technology specific-related dimensionless coefficient, and γ is the factor considering all the non-linear temperature-voltage effects.

where I_{ph} is photo current (A), I_D is the diode current (A), I_0 is the inverse saturation current (A), A is the diode constant, q is the charge of the electron (1.6 × 10^{-9} C), K is Boltzmann's constant, T is the cell temperature (^{0}C), R_s is the series resistance (ohm), R_{sh} is shunt resistance (Ohm), I is the cell current (A), and V is cell voltage (V). Output current of the PV cell using two diode model can be described as

$$I=I_{PV}-I_{D1}-I_{D2}-\left(\frac{V+IR_s}{R_{SH}}\right) \quad (10)$$

$$\text{Where,}\ I_{D1}=I_{01}\left[exp\left(\frac{V+IR_s}{a_1V_{T1}}\right)-1\right] \quad (11)$$

$$I_{D2}=I_{02}\left[exp\left(\frac{V+IR_s}{a_2V_{T2}}\right)-1\right] \quad (12)$$

I_{01} and I_{02} are reverse saturation current of diode 1 and diode 2, V_{T1} and V_{T2} are thermal voltage of respective diode. a_1 and a_2 represent the diode ideality constants.
Simplified model for PV system modeling is presented below:

$$V_{OC}=\frac{V_{oc}}{cK\,T/q} \quad (13)$$

$$P_{max}=\frac{\frac{V_{oc}}{cK\,T/q}-ln\left(\frac{V_{oc}}{cK\,T/q}+0.72\right)}{\left(1+\frac{V_{oc}}{nK\,T/q}\right)}\left(1-\frac{R_s}{V_{oc}/I_{sc}}\right)\left(\frac{V_{oco}}{1+\beta ln\frac{G_0}{G}}\right)\left(\frac{T_o}{T}\right)^{\gamma} I_{sco}\left(\frac{G}{G_0}\right)^{\alpha} \quad (14)$$

where v_{oc} is normalized value of the open-circuit voltage V_{oc} with respect to the thermal voltage
Vt = nkT/q, n is the ideality factor (1 < n < 2), K is the Boltzmann constant, T is the PV module temperature in kelvin, q is the electron charge, α is the factor responsible for all the non-linear effects that the photocurrent depends on, β is a PV module technology specific-related dimensionless coefficient, and γ is the factor considering all the non-linear temperature-voltage effects.
Equation (14) represents the maximum power output of a single PV module. A real system consists of the number of PV modules connected in series and parallel. The total power output for an array with N_s series connected cells and N_p parallel-connected cells with P_M power of each module will be

$$P_{array} = N_S N_P P_M \quad (15)$$

B. Wind Power System:

- **Wind Potential Assessment:**

The fundamental equation governing the mechanical power of the wind turbine is given by

$$P_w = \frac{1}{2} C_P(\lambda, \beta)\rho A V^3 \quad (16)$$

where ρ is air density (kg/m^3), Cp is power coefficient, A is intercepting area of the rotor blades (m^2), V is average wind speed (m/s), λ is tip speed ratio. The theoretical maximum value of the power coefficient Cp is 0.593, also known as Betz's coefficient

The Tip Speed Ratio (TSR) for wind turbine is defined as the ratio of rotational speed of the tip of a blade to the wind velocity. Mathematically,

$$\lambda = \frac{R\,\omega}{V} \quad (17)$$

where R is radius of turbine (m), ω is angular speed (rad/s), V is average wind speed (m/s).

The energy generated by wind can be obtained by

$$Q_w = P \times (Time)[kWh] \quad (18)$$

Sometimes because of various factors the velocity of wind at any particular height cannot be obtained by direct measurement. In that case the data at any reference height can be interpolated or extrapolated to find the wind speed at any particular height. The wind velocity is measured at a lower height can be error prone due to vegetation, shading and obstacles in the vicinity.

$$v(z)\ln\left(\frac{z_r}{z_o}\right) = v(z_r)\ln\left(\frac{z}{z_o}\right) \quad (19)$$

where Z_r is reference height (m), Z is the height where wind speed is to be determined, Z_0 is the measure of surface roughness (0.1-0.25 for crop land), v(z) is wind speed at height z (m/s), and v(z_r) is wind speed at reference height z (m/s).

The optimum rotor speed is given by:

$$\omega_{opt} = \frac{\lambda_{opt}}{R} V_{wn} \quad (20)$$

which gives

$$V_{wn} = \frac{R\omega_{opt}}{\lambda_{opt}} \quad (21)$$

where ω_{opt} is optimum rotor angular speed in rad/s, λ_{opt} is optimum tip speed ratio, R is radius of turbine in meters and V_{wn} is wind speed in m/s.

V. PROPOSED MODEL

Authors have designed a solar PV-wind-diesel hybrid system in MATLAB simulation in Fig 4. The system consists of several components such as the main grid, transformer, diesel generator, solar PV array, wind turbine, and various critical and non-critical loads.

The power rating of the main grid is 154 MW with a voltage rating of 34.5 KV. The grid is connected to a 34.5/0.4 transformer. The hybrid system, which includes the solar PV array, wind turbine, and diesel generator, is connected to a 400 V line.

One of the non-critical loads is connected to the 400 V line, while the other two non-critical loads are connected to the solar PV array and the PSMG wind turbine. The critical load is connected to the diesel generator.

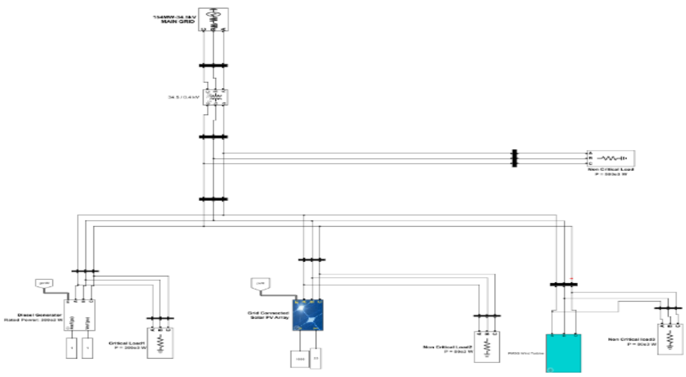

Fig 4. Solar PV_Wind_Diesel Hybrid Model

In Fig 5, the power rating of the PV system is 41 kW (sometime it has been changed to 2 MW, 800 kW, 200kW) and it operates at the grid frequency of 50 Hz. The solar irradiation considered is 1000 W/m², and the temperature is 25°C. By incorporating DC link, inverter control, and grid inverter into the PV model, authors can simulate the behaviour of the PV system, analyze its performance under different conditions, and study the power generation and interaction with the grid in this hybrid power system.

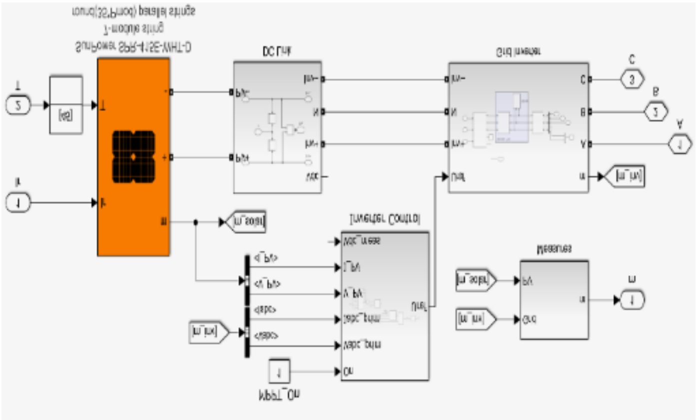

Fig 5. Solar PV Array Model

It seems that the PSMG wind turbine system in this design has a rated power of 1.5 MW and operates at a rated frequency of 50 Hz. The voltage of the system is 400 V in a L-L (line-to-line) connection. For simulation, we have assumed a constant wind speed of 12 m/s.
The wind turbine model includes various components and controls. These typically consist of the Permanent Magnet Synchronous Generator (PMSG) on the rotor side, grid-side control, a speed regulator, and pitch control. The PMSG is responsible for converting the mechanical energy from the wind into electrical energy. The grid-side control is used to ensure the proper connection and synchronization of the wind turbine system with the main grid. The speed regulator helps maintain the desired rotational speed of the wind turbine, while the pitch control adjusts the angle of the turbine blades to optimize power generation based on wind conditions. By incorporating these components and controls into the simulation, authors can analyze and optimize the performance of the wind turbine system within the hybrid power system we have designed.

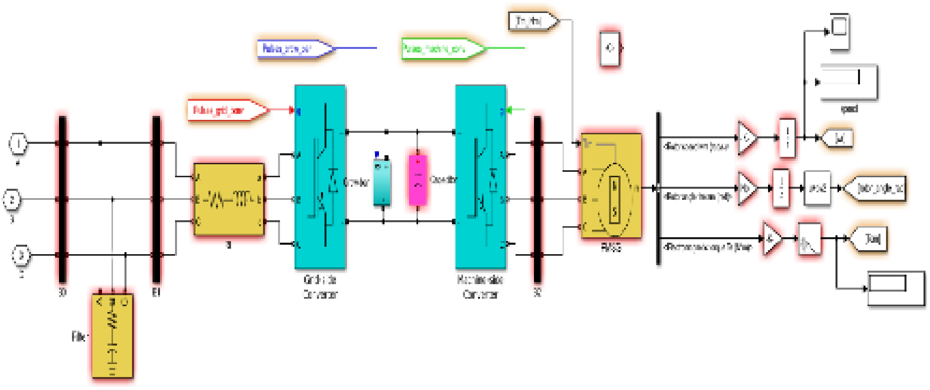

Fig 6. PMSG Wind Turbine Model

The Diesel Generator block consists of a synchronous generator with a rated power of 430 kW. The generator operates at a rated voltage of 400 V and a rated frequency of 50 Hz.
The synchronous generator in the Diesel Generator block is responsible for converting the mechanical power from the diesel engine into electrical power. It operates at a fixed speed that is synchronized with the grid frequency (50 Hz in this case) to ensure proper power generation and distribution.

By incorporating the Diesel Generator block into your simulation, we can model the behaviour and performance of the generator within the hybrid power system we have designed.

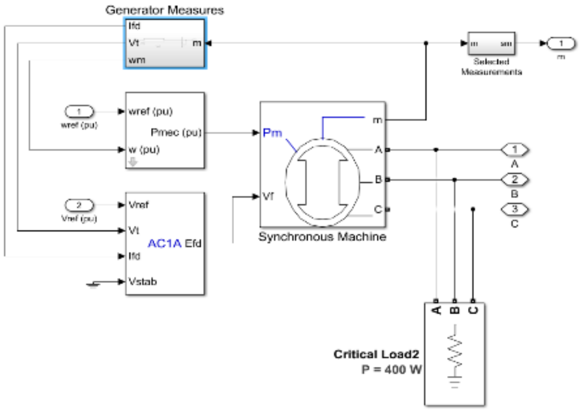

Fig 7 Diesel Generator Model

VI. Result and Discussion

Case Study :1

When, a 500 kW Non-Critical Load is connected with the 400 V line. A 450 kW Critical Load is connected with the Diesel Generator. An 80 kW Non-Critical Load is connected with the PV Array. A 100 kW Non-Critical Load is connected with the PMSG Wind Turbine.

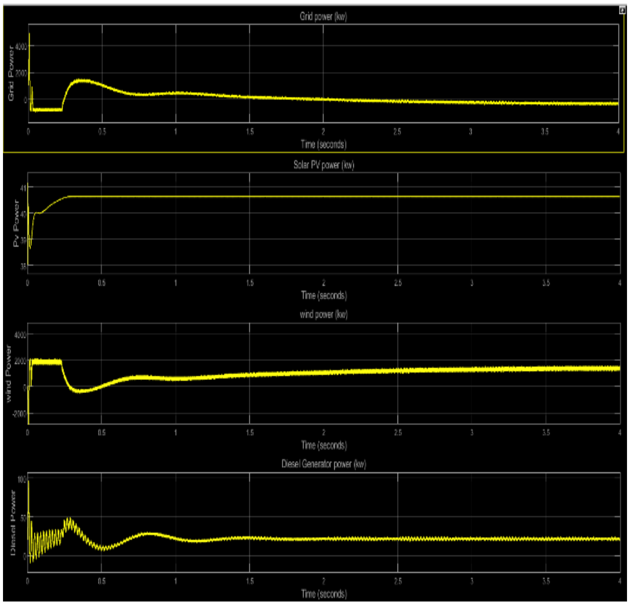

Fig. 8.1 Grid Power, PV Power, Wind Power, Diesel Power Vs Time Graph

From the fig 8.1 one can easily observe:

Fluctuation and Transient: From 0 to 0.5 seconds on the graph, there is a fluctuation in the power values. This is likely caused by transient effects, which can occur due to various factors such as switching on or off of equipment, sudden changes in load, or disturbances in the power supply. These fluctuations indicate an unstable power supply during this period.

Unstability: Even after 0.5 seconds, there is still some fluctuation and instability in the graph up to 2.5 seconds. This suggests that the power supply is not yet fully stable during this period.

Stability: After 0.5 seconds, the graphs show a decrease in fluctuations, indicating a more stable power supply. The power values become relatively constant, suggesting a steady power output.

Up to 2.5 seconds on the graph, the power values are positive in the Grid Power vs Time graph. This indicates that the hybrid system is no longer generating excess power, but instead, it is drawing power from the grid. This can happen when the demand for electricity exceeds the hybrid system's generation capacity, requiring additional power from the grid to meet the load.

After 2.5 seconds, the power values on the graph enter the negative region in the Grid Power vs Time Graph. This means that during this period, the hybrid system is generating excess power that is being supplied to the grid. This could occur when the hybrid system (which combines multiple power sources, such as renewable energy and conventional generators) generates more power than what is being consumed. The hybrid system generates total 1.841 MW and the total load connected is 1.13MW.

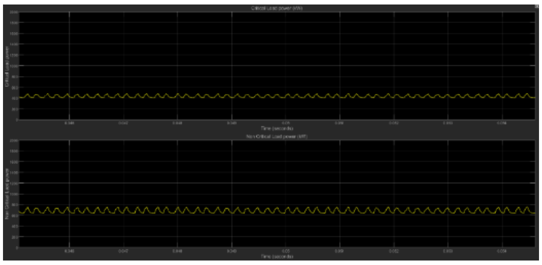

Fig 8.2 Critical and Non-Critical Load Vs Time Graph (Before the Transformer Connection)

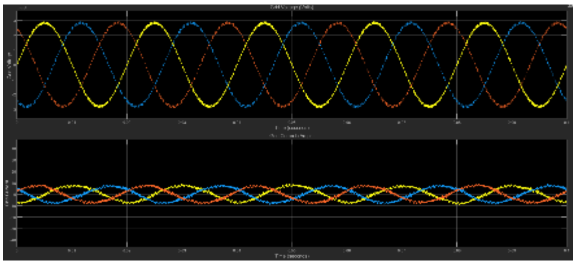

Fig 8.3 Grid Voltage and Current Vs Time Graph

The critical load power is 450 kW and the non-critical load power is 600kW. Which is represented on the graph. The Grid voltage is 34.5 kV and Grid current is 9 amperes almost.

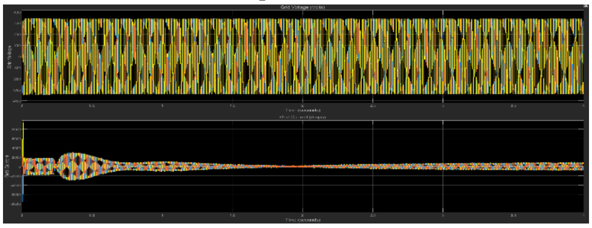

Fig 8.4 Grid Voltage and Current Vs Time Graph (After the Transformer Connection, basically LV side)

Here we can see the voltage is almost same but the current fluctuates due transient effects, which is basically occur due to various factor such as switching effect and sudden change in loads.

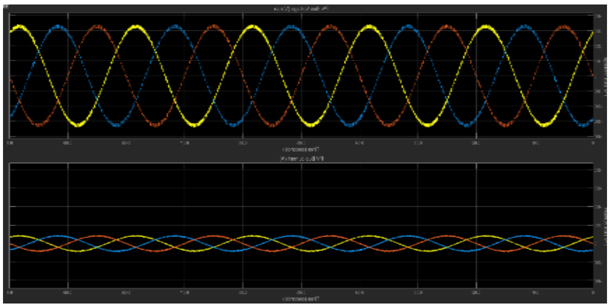

Fig 8.5 PV Bus Voltage and Current Vs Time Graph

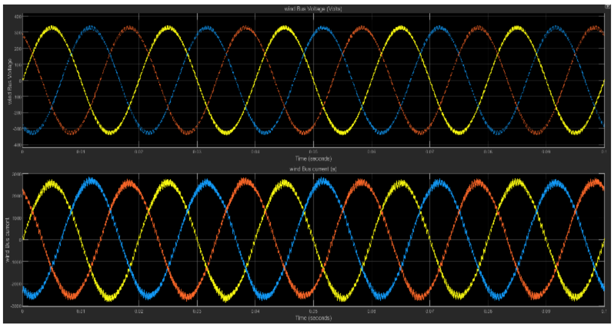

Fig 8.6 Wind Bus Voltage and Current Vs Time Graph

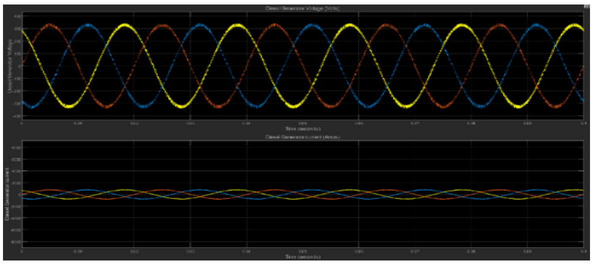

Fig 8.7 Diesel Generator Bus Voltage and VS Time Graph

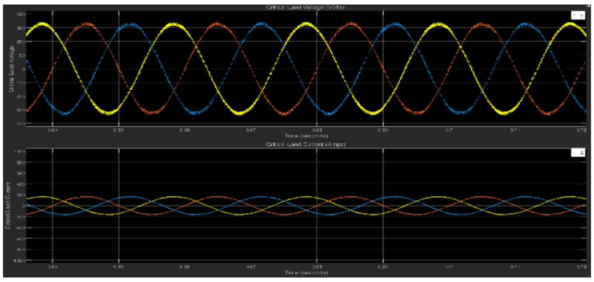

Fig 8.8 Non-Critical Load Voltage and Current (Which is connected with PV system)

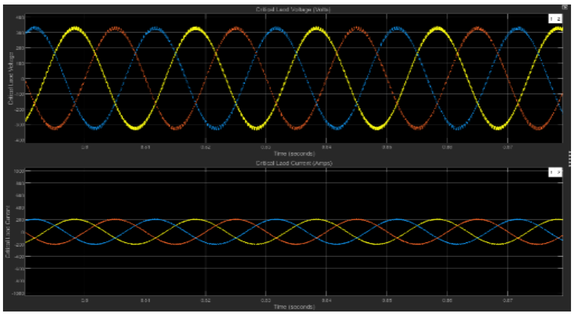

Fig 8.9 Non-Critical Load Voltage and Current (Which is connected with Wind system)

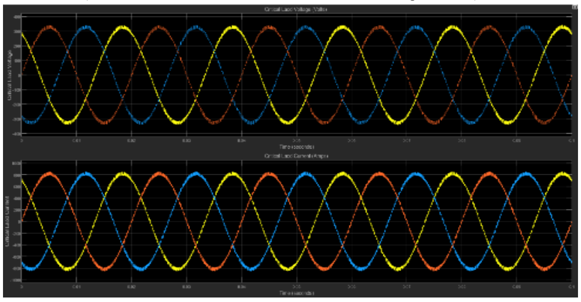

Fig 8.10 Critical Load Voltage and Current (Which is connected with Diesel Generator)

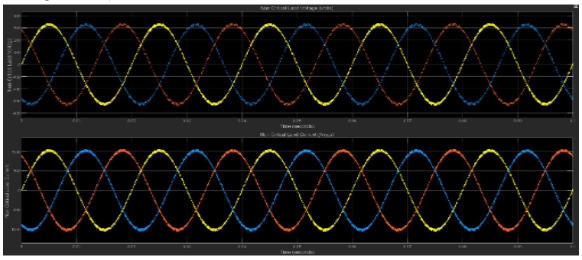

Fig 8.11 Non-Critical Load Voltage and Current (Which is connected with Grid 400 V Line)

Case Study 2:

When, a 500 kW Non-Critical Load is connected with the 400 V line. A 300 kW Critical Load is connected with the Diesel Generator. An 80 kW Non-Critical Load is connected with the PV Array. An 80 kW Non-Critical Load is connected with the PMSG Wind Turbine.

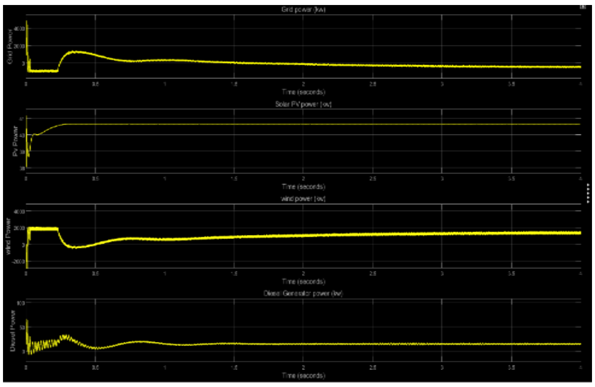

Fig 9.1 Grid Power, PV Power, Wind Power, Diesel Power Vs Time Graph

Comparing graph 8.1 with the current graph, the conclusion is that the nature of the graphs is almost the same. However, there is a change in the loads. In the previous experiment, the total load connected was 1.13 MW, whereas in the current experiment, the total load connected is 960 kW. It's worth noting that the generating capacity remains the same at 1.841 MW.

Upon observation, the notable point is that the grid power graph reaches the negative power axis in approximately 2 seconds, whereas in the previous graph, it took more than 2 seconds. Based on this, we can conclude that when the load is increased without a corresponding increase in the generating capacity, the load consumes more power, resulting in less power being supplied to the grid.
Upon comparison, the conclusion is that the PV Power, Wind Power, and Diesel Power graphs are exactly the same as in the previous one because their values remain unchanged.

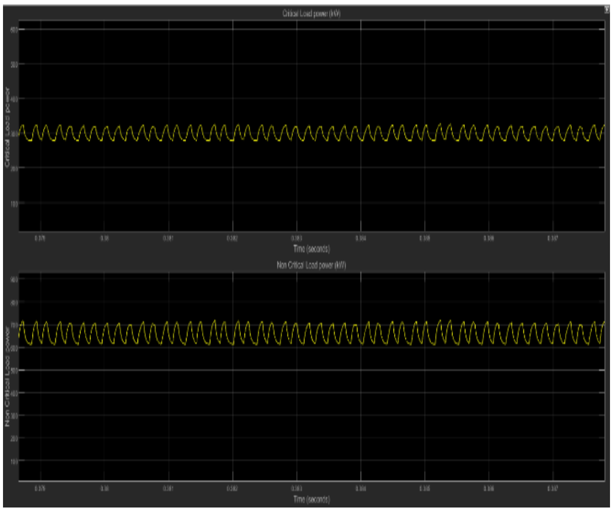

Fig 9.2 Critical and Non-Critical Load Vs Time Graph

By comparing this graph 9.2 with the graph 8.2, the conclusion is that the current graph represents both critical and non-critical loads connected to the system. Specifically, it shows a connection of 300 kW critical load and 660 kW non-critical load.

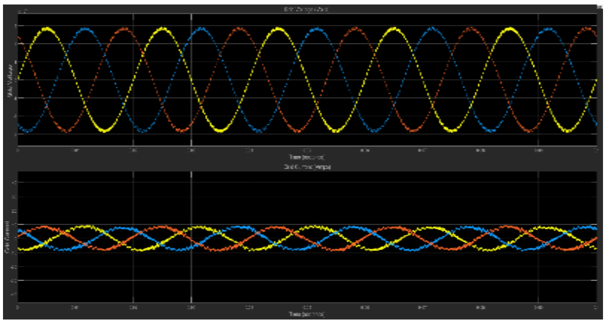

Fig 9.3 Grid Voltage and Current Vs Time Graph (Before the Transformer Connection)
Comparing graph 9.3 with graph 8.3, the conclusion is that they are mostly the same. This is because both graphs depict the same grid hybrid system connected to the grid, and the loads connected to the system are almost identical differing only by a small amount.

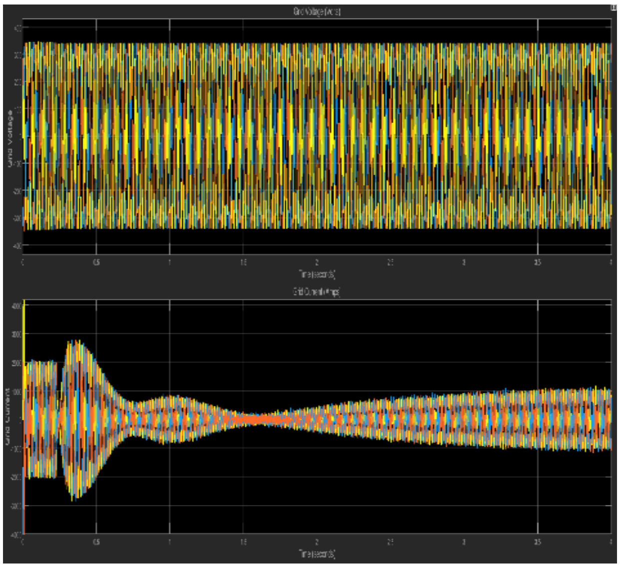

Fig 9.4 Grid Voltage and Current Vs Time Graph (After the Transformer Connection, basically LV side)

Upon comparing this graph with the graph 8.4, the conclusion is that the voltage profile remains the same. However, there are changes in the current profile due to the variation in load. Despite the changes, the nature of the current remains approximately the same.

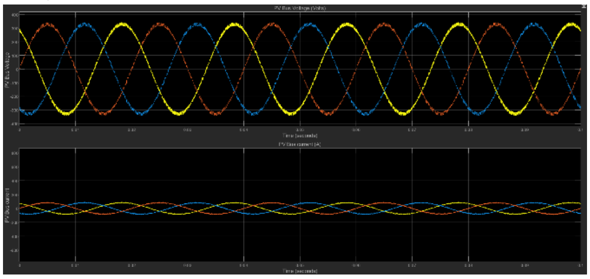

Fig 9.5 PV Bus Voltage and Current Vs Time Graph

Upon comparison, the conclusion is that the upper graph (9.5) is exactly the same as graph 8.5. This is because there have been no changes in the generation power (41 kW) of the PV system, the load connected to the system remains the same at 80 kW, and the input to the system remains constant (temperature, irradiance).

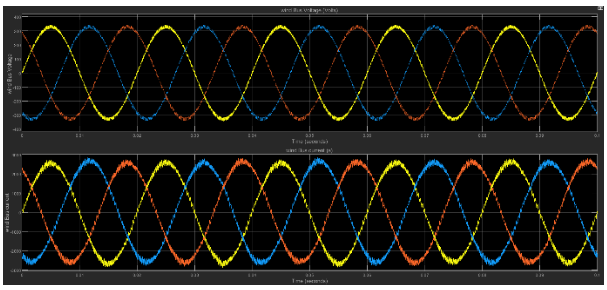

Fig 9.6 Wind Bus Voltage and Current Vs Time Graph

Upon comparison, the conclusion is that the upper graph is exactly the same as the graph 8.6. This is because there have been no changes in the generation power (1.5 MW) of the PMSG Wind System, and the input remains constant. The load connected with the Wind System is 80kW, so the load is fully supplied power by the Wind PMSG generator so the graph is same. In the previous experiment the load connected was 100kW which was fully supplied by the Wind PMSG System. In both the cases the load does not exceed the generation value and the connected load is same so the graph remains same.

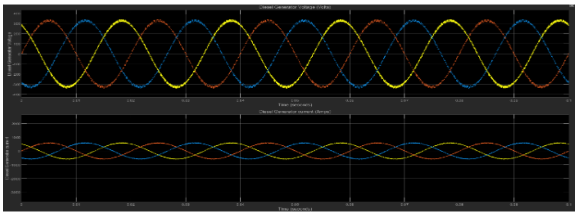

Fig 9.7 Diesel Generator Bus Voltage and Current Vs Time Graph

Upon comparing graph 9.7 with graph 8.7, the conclusion is that the voltage profile remains the same. However, the current profile has changed in accordance with the load connected to the system. In graph 9.7, the load connected to the system is 300 kW, and the generation capacity of the Diesel Generator (DG) system is also 300 kW. Since the DG system is capable of fully meeting the load demand, the load is not drawing power from the grid.

In the previous experiment (graph 8.7), the load connected to the DG system was 450 kW, while the generating capacity remained at 300 kW. In order to meet the higher demand, the load was drawing power from the grid, resulting in a higher current profile compared to the current profile in graph 9.7. This is why the current profile in the DG Bus is different between the two graphs, 8.7 and 9.7.

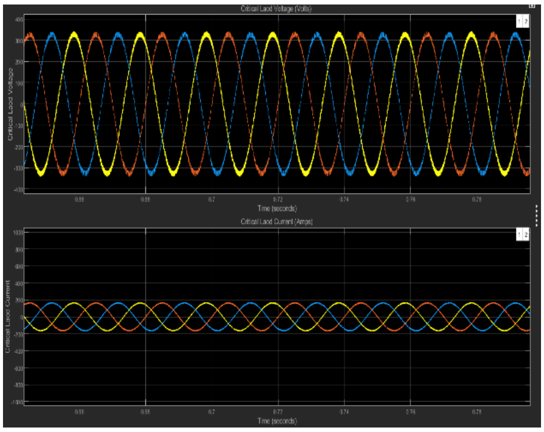

Fig 9.8 Non-Critical Load Voltage and Current (Which is connected with PV system)

Upon comparison, the conclusion is that this graph is exactly the same as graph 8.8. This is because we have connected the same load (80 kW) to the PV system in both cases.

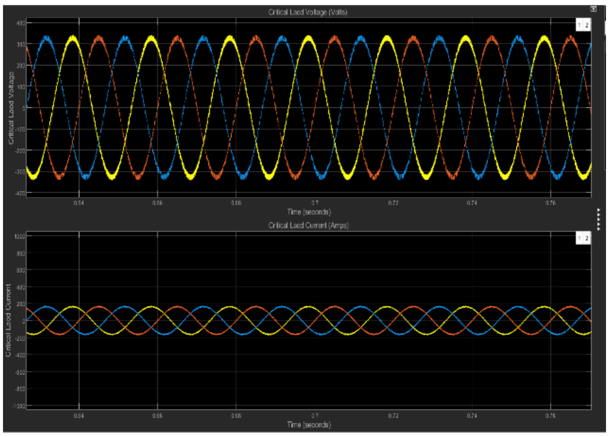

Fig 9.9 Non-Critical Load Voltage and Current (Which is connected with Wind system)

By comparing graph 9.9 with graph 8.9, the conclusion is that the Voltage vs. Time graph is the same. However, the Current vs. Time graph has changed due to a decrease in load from 100 kW to 80 kW. As a result, the current values have decreased accordingly.

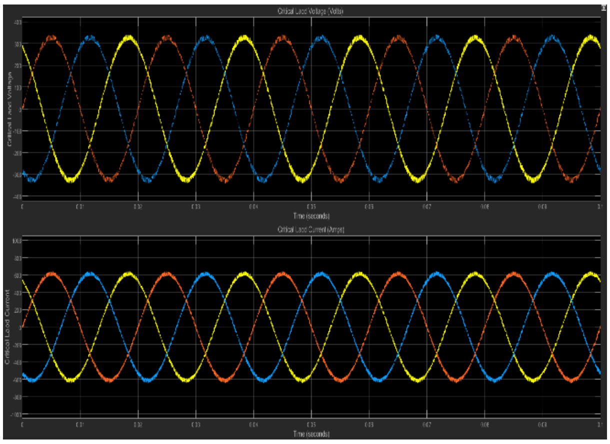

Fig 9.10 Critical Load Voltage and Current (Which is connected with Diesel Generator system)

By comparing graph 9.10 with graph 8.10, the conclusion is that the Voltage vs. Time graph is the same. However, the Current vs. Time graph has changed due to a decrease in load from 450 kW to 300 kW. As a result, the current values have decreased accordingly.

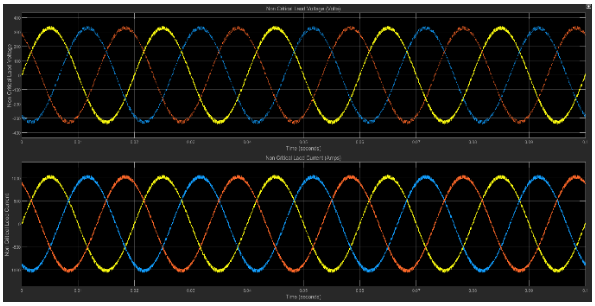

Fig 9.11 Non-Critical Load Voltage and Current (Which is connected with Grid 400 V Line)

Upon comparison, the conclusion is that this graph is exactly the same as graph 8.11. This is because we have connected the same load (500 kW) to the Grid 400 V Line in both cases.

VI. CONCLUSION

The primary focus of this paper has been on analyzing the system's performance under various loads by modifying them. The experiment shows that as the load changes, the current values also change accordingly. However, there are no changes observed in the voltage values. Although time constraints limited the scope of this work, there is tremendous potential for further investigation and improvement.

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