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Modeling and Simulation of Grid Connected Hybrid Power System Integrated with Solar PV/Wind and Controlled by Voltage Regulator

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Abstract: *This study investigates the growing attention towards non-conventional sources of energy due to the increase in prices of conventional energy sources. The focus of this research is on a hybrid solar-wind energy system that is connected to the grid. The hybrid system incorporates both wind and solar sources, along with AC loads. In the solar component, the DC output is enhanced using a boost converter, while the maximum power point tracking (MPPT) technique is employed to optimize the solar system's output. The wind subsystem consists of a permanent magnet synchronous generator, rectifier, and boost converter to maximize the wind energy output. A voltage regulator is utilized to control the hybrid solar-wind system. The modeling of the hybrid PV (photovoltaic) and wind turbine, which is regulated by the voltage regulator, is explained. The aim is to enhance reliability and reduce reliance on a single energy source by combining these two systems. The Solar-Wind hybrid power system described in this study effectively harnesses renewable energy from the sun and wind to generate electricity. The system control primarily relies on a microcontroller, ensuring the optimal utilization of resources and improving efficiency compared to individual modes of generation. Additionally, it increases reliability and decreases dependence on a single energy source. This hybrid solar-wind power generation system is suitable for both industrial and domestic applications. To ensure the originality of the content, it is essential to conduct a thorough literature review and properly cite any referenced sources.*

Keywords: hybrid solar-wind energy system, grid-connected, wind, solar, AC loads, boost converter, MPPT technique, permanent magnet synchronous generator, rectifier, voltage regulator, etc

I. INTRODUCTION

Over the past few years, there has been a growing emphasis on non-conventional sources of energy due to the increasing cost of fossil fuels, depletion of non-renewable energy, and environmental concerns [1]. Renewable energy sources, such as solar, wind, and hydro power, have become essential worldwide. Their utilization helps meet electricity demands while reducing pollution [1].

Hybrid power systems combine two or more renewable energy sources, such as PV-fuel cell, PV-biomass, and wind-PV systems [16]. These hybrid systems are cost-effective, environmentally friendly, and suitable for rural areas. The combination of PV and wind power provides an effective energy solution with improved reliability and power characteristics [3, 4]. The aim of this paper is to model a hybrid solar PV/wind power system, optimizing its main parameters and analyzing its performance. The model includes a PV array, wind conversion system, DC/DC converter, battery, and voltage regulator [16, 17]. The voltage regulator is used to control the hybrid system, and Matlab/Simulink is employed for simulation [16].

Hybrid power systems, which combine multiple renewable energy sources such as PV-fuel cell, PV-biomass, and wind-PV, have gained traction due to their environmental benefits and cost-effectiveness in rural areas [16]. Among these combinations, the integration of PV and wind power offers an efficient and reliable energy solution with improved power characteristics [3,4]. This study focuses on modeling a hybrid solar PV/wind power system, optimizing key parameters and evaluating its performance. The system components include a PV array, wind conversion system, DC/DC converter, battery, and voltage regulator [16,17]. The voltage regulator plays a crucial role in controlling the hybrid system, and simulation is carried out using Matlab/Simulink [16].

Energy consumption has seen a steady increase due to global development and population growth. Forecasts indicate a 1.5% annual rise in primary energy demand, reaching 16,800 Mtoe by 2030, representing a 40% overall increase [1]. The BP Statistical Review of World Energy reports a 2.5% growth in global energy consumption in 2011, aligned with historical trends [2]. Fig.1 illustrates the upward trajectory of Gross Domestic Product (GDP) from 1970 to 2010, with a projected increase beyond 2030.

II. LITERATURE REVIEW

In [2017] Dr. Swapnil B. Mohod, Vikramsingh R. Parihar, presents a renewable energy hybrid power system based on photovoltaic (PV) and wind, and equipped with Cuk DC-DC converter, three phase inverter and LC filter. The wind and PV energy are suitable for hybrid system because they are environmental friendly and widely available in India. However, the hybrid power system that solely depends on the intermittent renewable energy sources generates a fluctuating output voltage that leads to damage to the machines operating on a stable supply. The modeling of the hybrid system with Cuk converter, three phase inverter and LC filter are done using MATLAB Simulink.

In [2002] Manwell, Mc Gowan & Rogers,, Most Renewable energy systems require less maintenance and also have low operating costs compared to coal fired power stations. Individually, renewable energy sources are not reliable but on hybrid mode the reliability is significantly improved.

In [2015] Prachi P. Chintawar, M. R. Bachwad, It is an accepted fact that coal and oil reserves are declining; however human society's dependence on these fossil fuel resources is still on the incline due to high load growth and high rate of industrialization and economic development. Thus the need for cleaner, sustainable and viable sources of electrical energy are of utmost importance in order to ensure that the next generation enjoys the same economic development.

In [2016] Mubashar Yaqoob Zargar, Mairaj-ud-din Mufti, proposes on the development of Stand Alone hybrid Wind-Solar Photovoltaic system where energy storage device is used for voltage control. The system is modelled considering dynamic wind speed and solar irradiance level. Both wind and solar grids are connected at dc link where energy storage system is installed for voltage control. Wind power is harnessed by Permanent magnet synchronous generator(PMSG). Maximum power point tracking(MPPT) used increases the efficiency of solar photovoltaic(SPV) system. The simulation of MPPT algorithm to track maximum power is also presented where pulses are supplied to boost converter using perturb and observe methodology. LC filter is used to filter ripples

Simulation experiments are carried out to demonstrate the effectiveness of the overall system.

In [2017]N. Mendalek and K. Al-Haddad, This paper presents the modeling and simulation of a photovoltaic (PV) system. The equations governing the operation of the one-diode equivalent model are developed and the identification of the model parameters is performed through MATLAB script. The system studied encompasses a commercial PV panel, a dc-dc boost power converter, a battery and a dc load. The boost converter is controlled using voltage error PID compensator which has an input reference voltage computed by perturb-and-observe (P&O) maximum power point tracking (MPPT) technique. The system is simulated in MATLAB/Simulink environment for different irradiation levels and PV module temperature values. The control strategy is also validated in presence of rapidly varying irradiation conditions.

III. METHODOLOGY AND ALGORITHM

Mathematical Model for proposed PV Panel

The equivalent circuit of single solar cell is shown in Fig. 2.1. The solar panel for the required power rating is obtained by connecting number of solar cells in series and parallel. The equivalent circuit of the solar panel with Ns number of series connected cells and Np number of parallel combination of series string is shown in Fig. 2.2.

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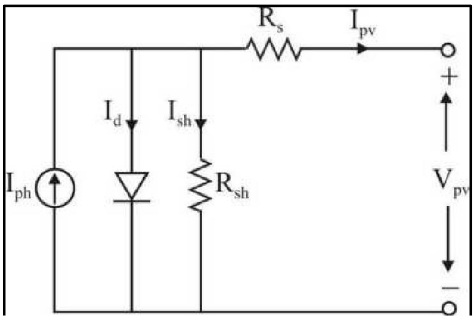

Fig. 3.1: Equivalent Circuit of Single Solar Cell

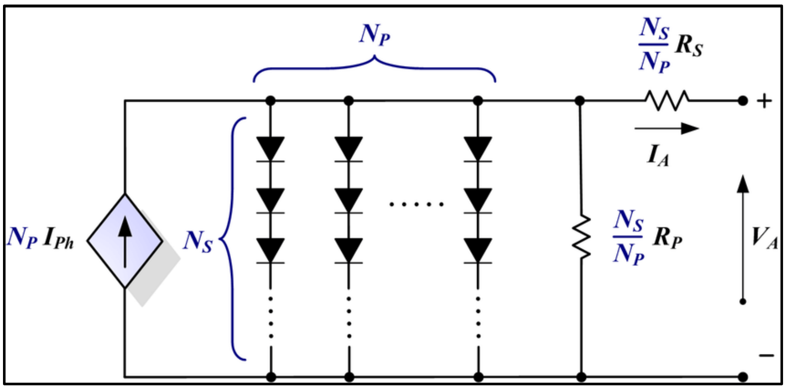

Fig. 3.2 Equivalent Circuit of Solar Panel.

Summary of mathematical equations of the PV panel are given below: Module photo-current, Iph is given by,

$$I_{ph} = [I_{SC} + K_T\,(T - T_r)]\,\frac{G}{G_{ref}} \qquad (3.1)$$

Where,

ISC - Short circuit current60

KT - Temperature coefficient of the cell (KT = - 3.7 * 10 - 3 / °C for mono and poly crystalline Si)

G - Solar radiation in W/m²

Gref - Solar radiation at reference conditions (Gref =1000 W/ m²)

T - Operating temperature

Tr - Reference Temperature

Module reverse saturation current, Irs is given by,

$$I_{rs} = I_{SC}/[e^{\frac{qV_{OC}}{N_s\,k\,n\,T}} - 1] \qquad (3.2)$$

Where,

q - Charge of an electron

VOC - Open-Circuit Voltage

Ns - Number of cells in series

k - Boltzmann's Constant

n - Identity Factor of Diode

$$I_o = I_{rs}\left(\frac{T}{T_r}\right)^3 e^{\frac{q\,E_{go}}{n\,k}\left(\frac{1}{T}-\frac{1}{T_r}\right)} \qquad (3.3)$$

Where,

Ego - Band gap energy of semiconductor

Rs - Series resistance of the cell
Rsh - Shunt resistance of the cell

Simulation Model of PV Panel

The project implementation is done using MATLAB Simulink software. The major blocks is designed in MATLAB as:

1) Simulation of wind energy system using application library in sim power system toolbox.
2) Simulation of solar PV system and MPPT (maximum power point tracking) algorithm using sim power system and commonly used Simulink blocks.
3) Simulation of inverter circuit using power electronics library.
4) Simulation of power system and grid using sim power system toolbox.

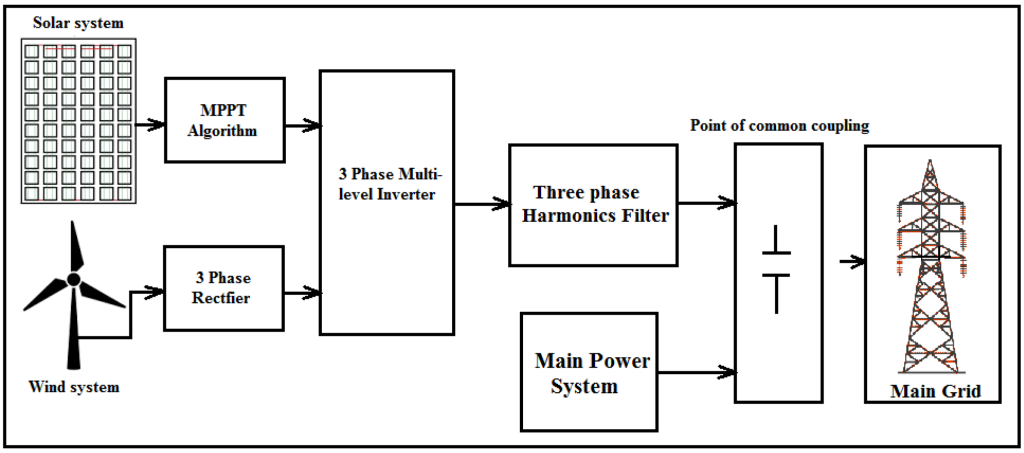

Fig. 3. Block diagram of proposed hybrid power system

It proposed methodology shown in figure 3 implemented using MATLAB Simulink software in which Sim power system toolbox utilized for hybrid power system design, wind energy system design, solar pv system, battery energy system and dc to dc converter subsystem design. Figure 4 shows the complete MATLAB simulation model of proposed approach.

The complete MATLAB simulation model of hybrid power system in which solar PV system and wind energy system generates DC power. This DC power get fed to MPPT maximum power point tracking system for reaching the maximum available DC power from solar and wind energy system. This maximum available power then fed to inverter which convert this dc power to ac power which fed to AC grid by proper synchronization. In parallel with this process one battery charging unit was connected for charging battery. That battery charging is utilized for dc applications.

Table 1 shows the complete MATLAB model specifications and power system rating.

Sr No	MATLAB simulation block	Parameters Specification
1	Solar PV system	Power output = 1KW
2	Wind energy system	Output dc current =50 Amp; Output ac power = 1000 W
3	Battery energy system	Voltage = 200V; Ampere hour rating = 6.5 Ah.
4	Universal bridge (Inverter)	Snubber resistance = 5000Ohm; Ron = 1 mOhm.
5	Three phase transformer	Nominal power = 73 KVA; Frequency = 50 Hz; Primary voltage = 75 Kv; Secondary voltage = 2.4 Kv.
6	Three phase source (Alternator)	Phase to phase Rms voltage =2.4 KV; Frequency = 50Hz;Short circuit level = 25 KVA;X/R ratio = 7.
7	Local three phase load	Nominal phase to phasevoltage Vn= 420V; Nominalfrequency = 50 Hz; Activepower = 10 KW; Inductivereactive power = 100 VAr.

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IV. RESULT ANALYSIS

IMPLEMENTATION OF METHODOLOGY BY USING SIMULATION

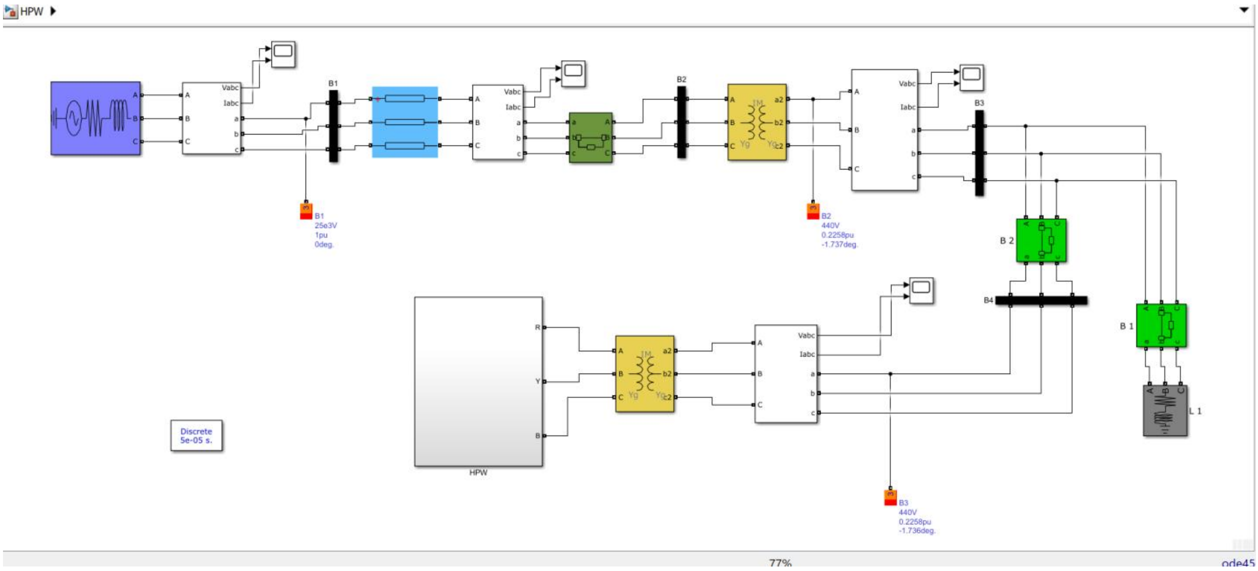
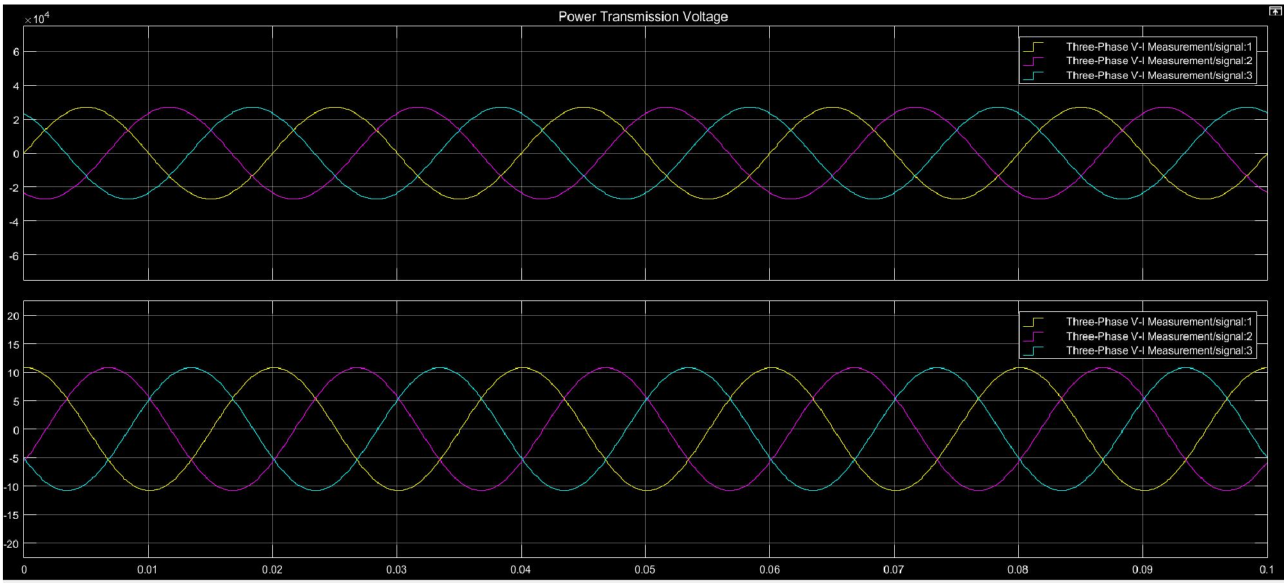


Fig. 4.1 Basic Model For Grid Connected Hybrid Power System Integrated With Solar Pv/Wind And Controlled By Voltage Regulator



The grid voltage and current waveforms play a crucial role in the reliable and efficient operation of electrical power systems. Specifically, when considering a voltage of 33 kV, it represents a typical high-voltage level commonly used for transmission and distribution of electrical power.

In a typical grid voltage waveform at 33 kV, the waveform exhibits sinusoidal characteristics, representing the alternating current (AC) nature of the power system. The waveform follows a periodic pattern, oscillating between positive and negative peaks with a frequency of 50 Hz (in regions with a frequency of 50 Hz) or 60 Hz (in regions with a frequency of 60 Hz). These peaks represent the maximum instantaneous voltage values, while the zero-crossing points indicate the points where the voltage crosses the zero level.

The voltage waveform at 33 kV is typically well-regulated and controlled to maintain a stable power supply within acceptable limits. The waveform is subject to various factors, including power generation, transmission line characteristics, and load demands. Voltage control mechanisms, such as transformers, voltage regulators, and reactive

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power compensation devices, are employed to maintain the grid voltage within specified limits and minimize voltage fluctuations.

The grid current waveform at 33 kV is directly related to the voltage waveform and follows a similar sinusoidal pattern. The current waveform also oscillates between positive and negative peaks with the same frequency as the voltage waveform. The magnitude of the current is determined by the load demand and the impedance of the connected devices. Monitoring and analyzing the grid voltage and current waveforms are crucial for maintaining the stability and reliability of the power system. Deviations from the expected waveform characteristics may indicate faults, imbalances, or other issues within the system. By analyzing the waveforms, power system operators can detect and diagnose problems, enabling timely interventions and corrective actions to ensure continuous and uninterrupted power supply.

Overall, the grid voltage and current waveforms at 33 kV exhibit sinusoidal characteristics, reflecting the alternating nature of the power system. Monitoring and controlling these waveforms are essential for maintaining a stable and reliable electrical grid.

V. SIMULATION RESULTS AND DISCUSSION

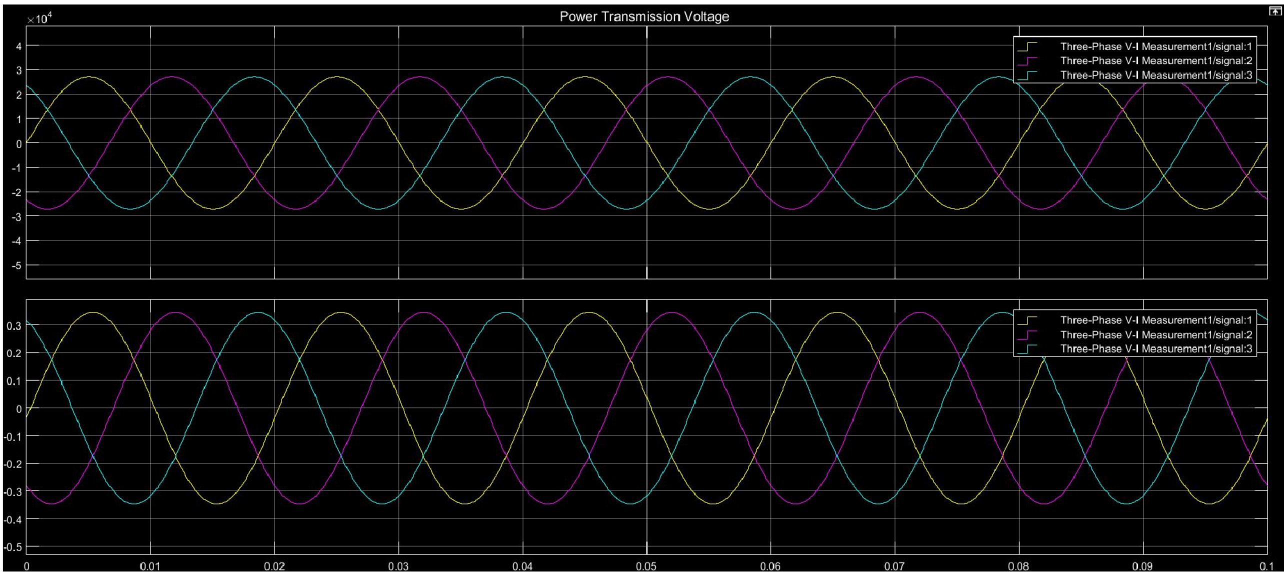

Fig.4.2 Output across the Transmission Line

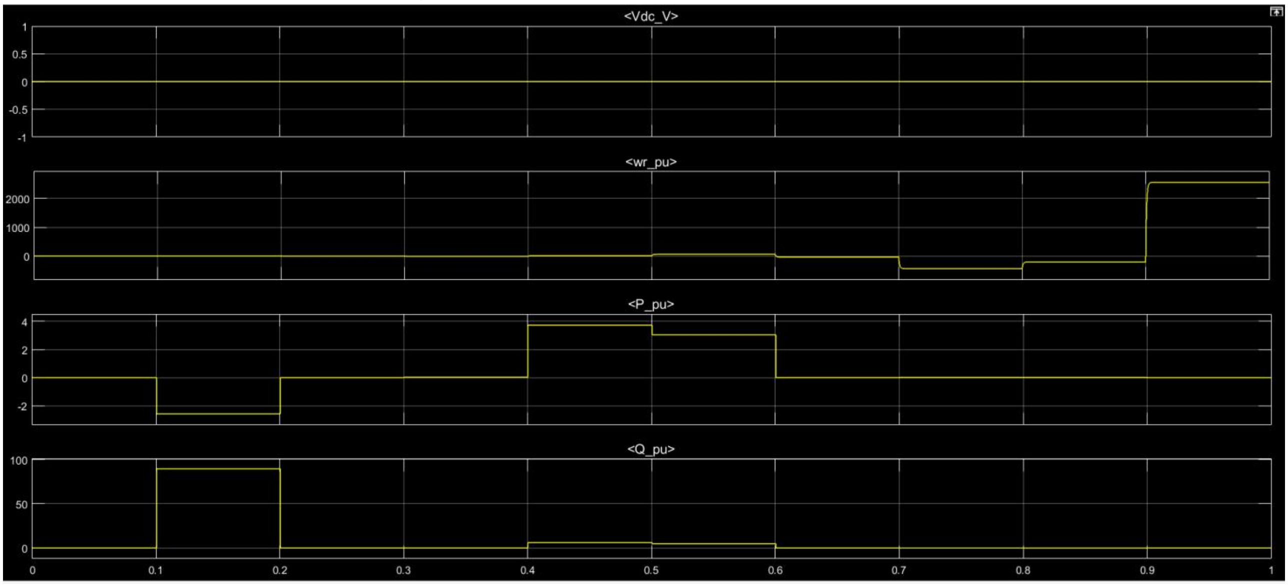

Fig.4.3Output waveforms across PV Panel

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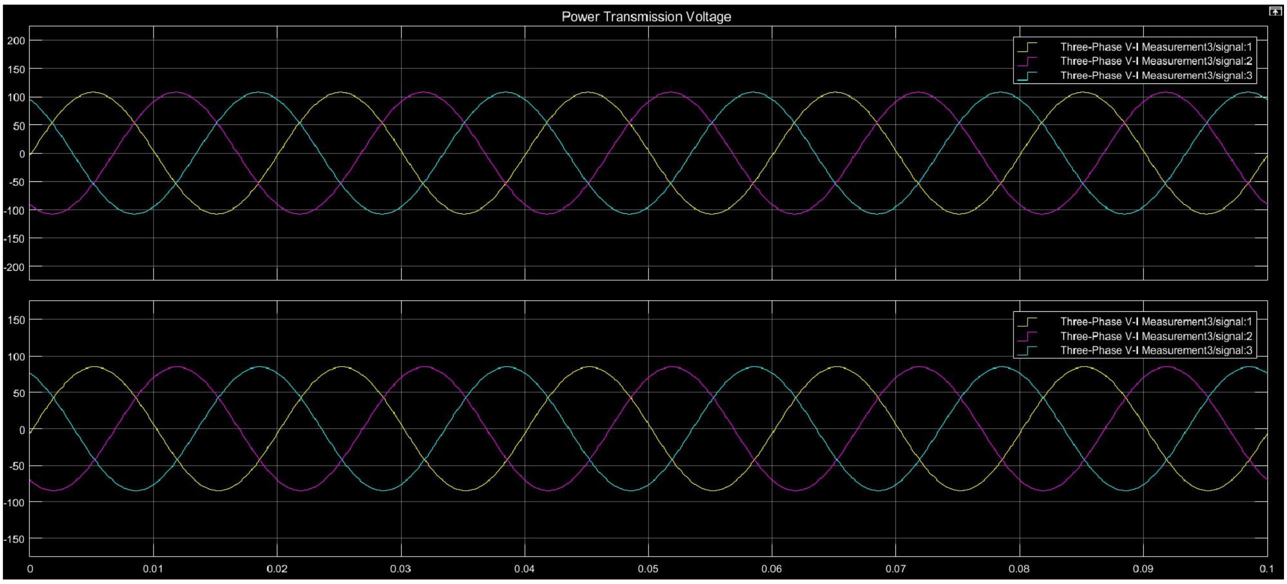

Fig.4.4 Combined voltage and Current feed to the load

In order to validate the model performance, the following simulations were performed with different combinations of solar irradiation and demand profiles with both controllers: P&O controller with fixed step sizing change of duty cycle and fuzzy logic controllers with adaptive step sizing change of duty cycle.is shown in fig.4.6

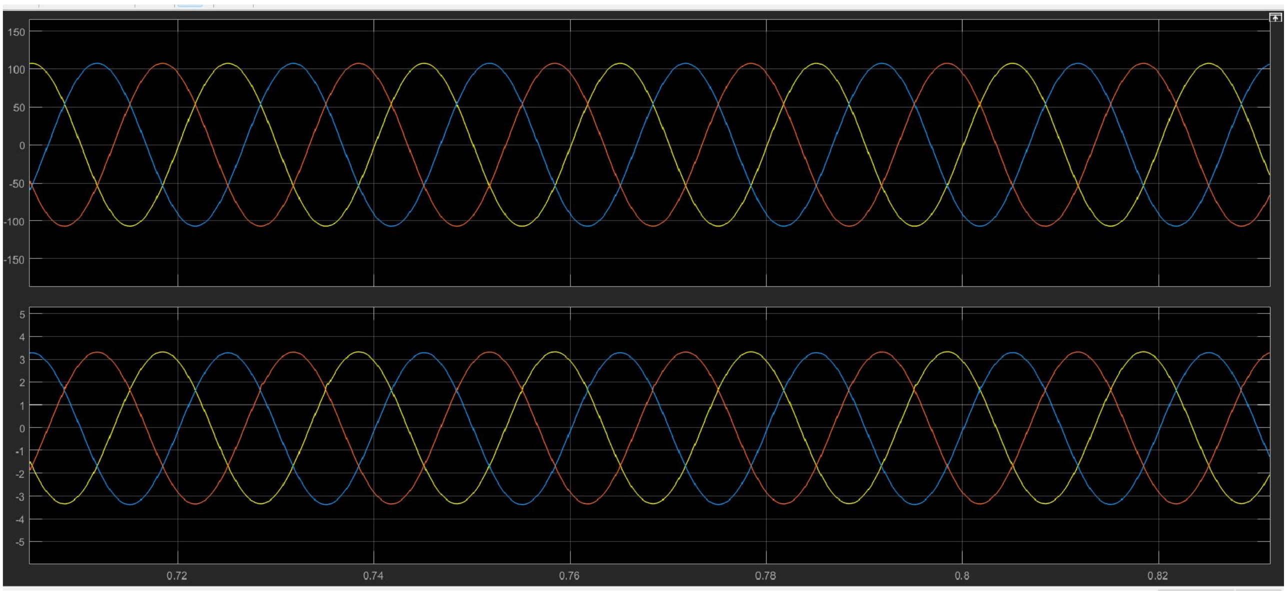

Fig 4.5 Combined voltage and Current feed to the load

VI. CONCLUSION

In conclusion, the modeling and simulation of a grid-connected hybrid power system integrated with solar PV/wind and controlled by a voltage regulator offer a promising solution for meeting the increasing energy demands while utilizing renewable energy sources. This study highlights the importance of non-conventional energy sources in addressing the challenges posed by the depletion of non-renewable resources and environmental concerns.

The hybrid power system combines the complementary characteristics of solar and wind energy, providing a more reliable and efficient power generation solution. The integration of a voltage regulator ensures proper control and optimization of the hybrid system, enhancing its performance and stability.

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Through the modeling and simulation process, key parameters and components of the hybrid power system can be analyzed and improved. This allows for the exploration of optimal system configurations, sizing, and control strategies to achieve maximum efficiency and cost-effectiveness.

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