DESIGN & SIMULATION OF A SOLAR WIND HYBRID POWERSYSTEM USING MATLAB/SIMULINK

UNDER THE GUIDANCE OF

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Abstract:

This project describes the Simulation and analysis of hybrid energy system consisting of wind and solar PV system. The wind and solar PV system are connected to the common load through DC/DC Boost converter and three phase inverter The basic key objective of this project is to generate electrical energy by using renewable and clean energy with minimum pollution. We use a hybrid system to overcome the drawbacks of renewable free-standing generation system. In the stand-alone mode the converter needs to maintain constant voltage and frequency regardless of load imbalance or the quality of the current, which can be highly distorted, if the load is nonlinear. The modelling and simulation of hybrid system along with the PI controllers are done using MATLAB/SIMULINK. Simulation results show that the proposed hybrid system has the potential to meet the electricity demand of an isolated system.

Introduction:

In recent decades, the spotlight has been on renewable energy sources due to their ability to reduce environmental harm, conserve precious resources, and enhance safety. The driving goals behind these systems are to cut down on environmental pollution, reduce dependence on finite energy sources, and ensure a more secure energy future. Renewable energy systems can either be connected to the utility grid or used independently in remote areas where the grid is inaccessible.

Among the wide range of renewable technologies, Photovoltaic (PV) systems and Wind energy systems stand out as particularly promising. A standard PV system includes a PV array that converts sunlight into electricity, a DC-DC converter to adjust voltage levels, a DC-AC inverter to transform the DC power into AC, and a load that consumes the generated power. To maximize the system’s efficiency, it's crucial to control the power converter effectively.

A key strategy to boost the performance of PV systems is Maximum Power Point Tracking (MPPT). Since the power output of a PV array is influenced by its nonlinear voltage-current (V-I) characteristics and fluctuating factors like temperature and solar radiation, MPPT ensures the system is always operating at its maximum efficiency.

By adjusting the DC-DC converter’s duty cycle through a Proportional-Integral (PI) controller, MPPT matches the system to the Maximum Power Point (MPP). This allows the system to continuously extract the highest possible power from the PV array. Despite challenges posed by changing sunlight and temperature, MPPT algorithms play a crucial role in optimizing energy production, ensuring that the system consistently operates at peak efficiency.

Optimizing the control strategies of DC-DC converters is crucial for enhancing both steady-state and dynamic performance, ensuring rapid and smooth convergence to equilibrium. Efficient regulation of these converters is essential for maximizing the performance of photovoltaic (PV) systems. In such systems, inverters act as a vital interface, seamlessly converting DC power into AC at the required voltage and frequency to meet load or grid demands.

Wind energy has become one of the most cost-effective and sustainable alternatives to fossil fuel-based power generation, particularly in regions with abundant wind resources. Over the past decade, wind power has experienced unprecedented growth, driven by advancements in turbine technology and power electronics. Unlike solar PV, which produces fluctuating DC voltage based on irradiation and temperature, wind turbines generate AC power with varying voltage and frequency, especially under variable-speed operation. As a result, sophisticated power electronic interfaces are required for seamless energy conversion and grid integration.

Hybrid renewable energy systems that combine multiple energy sources with storage solutions are gaining momentum as a reliable and efficient approach to sustainable power generation. Among these, standalone solar-wind hybrid systems are particularly effective, as they leverage complementary generation patterns. During monsoon months, when solar output declines, increased wind energy production compensates for the deficit. Conversely, in post-winter months, when wind speeds are lower, solar PV takes over, ensuring a stable and consistent power supply throughout the year.

This research presents a hybrid renewable energy system integrating solar PV and wind power .The regulated DC output is then fed into a state-of-the-art three-phase inverter, ensuring high-quality AC power delivery to the load. The system's performance is rigorously evaluated through MATLAB/SIMULINK simulations, analyzing its efficiency, stability, and dynamic response under diverse environmental conditions. This approach not only enhances power reliability but also paves the way for smarter and more adaptive renewable energy solutions.

PROPOSED HYBRID SYSTEM:

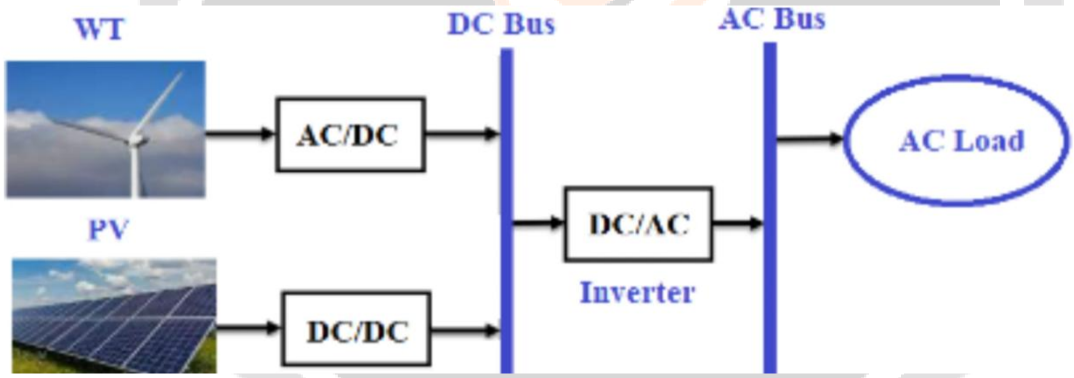

Fig 1 : Schematic diagram of Proposed Hybrid Energy System

The hybrid energy system integrates a photovoltaic (PV) array and an induction generator-based wind energy system to supply a shared load. The PV system employs Maximum Power Point Tracking (MPPT) for optimal solar energy utilization and incorporates DC/AC converter modules. A three-phase inverter ensures seamless connection of these energy sources to the load , which enabling the system efficient power delivery.

MODELLING OF VARIOUS RENEWABLE ENERGY SYSTEMS:

This section delineates the mathematical framework underpinning the energy sources integrated into the proposed hybrid energy system, namely Solar PV, Wind, and power electronic converters.

A. Modeling of photovoltaic system :

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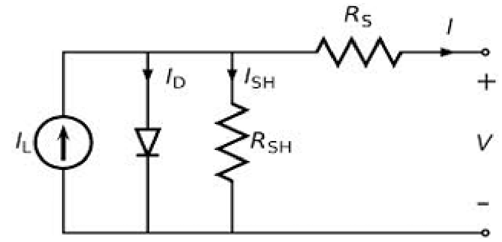

Fig 2:Modeling of Photovoltaic System

The PV subsystem comprises an array of photovoltaic cells paired with DC/AC converter modules. Photons from incident sunlight, exceeding the bandgap energy threshold of the semiconductor material, are absorbed to generate electron-hole pairs proportional to the radiation intensity. The generated photocurrent is governed by the following expression:

$$I = I_{PV} - I_D \qquad (1)$$

Where

$$I_D = I_0[exp\frac{V}{AV_T} - 1] \quad (2)$$

Then equation (1) becomes

$$I = I_{PV} - I_0[exp\frac{V}{AV_T} - 1] \qquad (3)$$

The I-V characteristics of a solar cell is given by

$$I = [\exp\left(\frac{V + I * R_S}{I_{PV - I_0 * V_T}}\right) - 1] \qquad (4)$$

$$P = V\ \{I_{sc} - I_0[\exp\left(\frac{V}{AV_T}\right) - 1]\} \quad (5)$$

The photo-generated current ((I(PV)) is directly proportional to the solar irradiance incident on the photovoltaic (PV) cell, whereas I0 represents the reverse saturation current of the diode. The thermal voltage V(t) of the PV module is influenced by the series-connected cell count Ns, the operating temperature (T), and fundamental constants such as electron charge ((q) and Boltzmann constant (k).

The series resistance (Rs) plays a significant role in shaping the inherently non-linear Current-Voltage (I-V) characteristics of the PV cell. The short-circuit current I(sc), defined as the maximum current produced at zero voltage, serves as a critical parameter for performance evaluation. The diode's ideality factor (A) determines the exponential relationship dictating the diode's operational behavior.

Variations in solar irradiance and cell temperature directly impact the I-V and Power-Voltage (P-V) characteristics of the PV system. These dependencies emphasize the environmental sensitivity of the PV array's energy conversion efficiency, as demonstrated through its characteristic curves.

B. Modeling of Wind System

The rotor of a wind turbine typically consists of two or three blades that are mechanically coupled to an electrical generator, forming the primary mechanism for converting kinetic wind energy into electrical power. The aerodynamic power P(wind) captured by the turbine is mathematically expressed as:

$$P_{\omega=}\frac{1}{2}C_p\rho.A.V_{\omega}{}^{3}$$

Where p is the air density, which is equal to 1.225 kg, Cp is the power coefficient, is the wind speed in (m/s) and A is the area swept by the rotor in. The amount of aerodynamic torque in (N-m) is given by the ratio between the power extracted from the wind and turbine rotor speed in (rad /s) as follows

$$T_w = P_{\omega w_{\omega}}$$

C. DC-DC Boost Converter:

The DC-DC boost converter is a highly efficient power electronic topology, designed to step up the voltage from the output of a full-wave bridge rectifier. Positioned downstream of the rectifier, the boost converter elevates the diode-rectified voltage to the required levels for subsequent system components.

To stabilize the rectified AC voltage and minimize output voltage ripples, a capacitor (C1) is incorporated across the rectifier's output. This ensures a smooth DC input voltage to the boost converter, improving its performance and operational stability. The topology is cost-effective while delivering high conversion efficiency, making it ideal for renewable energy applications.

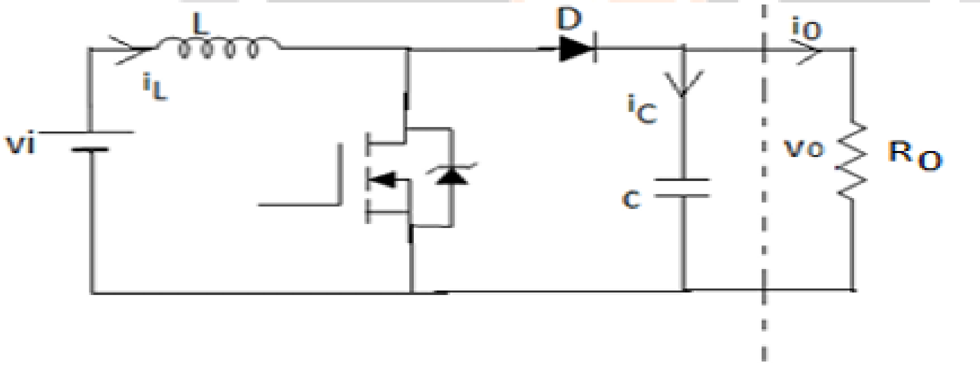

Figure : 3 . DC-DC Boost converter circuit

The development of a boost converter model is crucial for simulating and analyzing its operational behavior. Under ideal conditions, the relationship between the input and output voltage of the boost converter can be mathematically expressed as follows.

$$V_{i=}\ V_0 * (1 - D)$$

The boost converter model is essential for simulating and analyzing its performance. Under ideal conditions, the relationship between the input and output voltages can be determined using the following equations.

$$L_{min} = \frac{(1-D)D\ R_0}{2f}$$

$$C_{min} = \frac{DV_0}{V_r R_0 f}$$

The ripple voltage V(ripple), output resistance (R), and switching frequency (f) are critical factors in the design of DC-DC converters. Synchronous switching is employed to improve efficiency by replacing the traditional flywheel diode with a power IGBT, which has a low "on" resistance. This reduces switching losses significantly.

Pulse Width Modulation (PWM) is utilized to regulate and control the output voltage of the converter. In the off-state, the semiconductor device experiences zero current flow, resulting in no power dissipation. In the on-state, the voltage drop across the device is minimal, ensuring low power loss. This design approach enhances the efficiency and performance of DC-DC converters.

D. 3-phase Inverter :

A three-phase inverter is a crucial device in power electronics, designed to convert DC (direct current) into AC (alternating current) for use in three-phase systems. It is widely applied in industrial motor drives, renewable energy systems like solar inverters, and uninterruptible power supplies (UPS). By controlling both output voltage and frequency, it ensures efficient energy conversion for modern electrical systems.

The inverter uses switches like IGBTs or MOSFETs to regulate current flow, creating a balanced three-phase AC waveform with phases separated by 120 degrees. Techniques like Sinusoidal Pulse Width Modulation (SPWM) are employed to refine the waveform, reduce harmonics, and achieve smooth voltage control. In SPWM, sinusoidal reference signals offset by 120 degrees are compared with a triangular carrier wave to generate precise gating signals for the switches.

Through effective control, three-phase inverters play a pivotal role in providing stable, variable-frequency power for industrial applications and renewable energy integration. Their efficiency and adaptability make them indispensable in various power conversion scenarios.

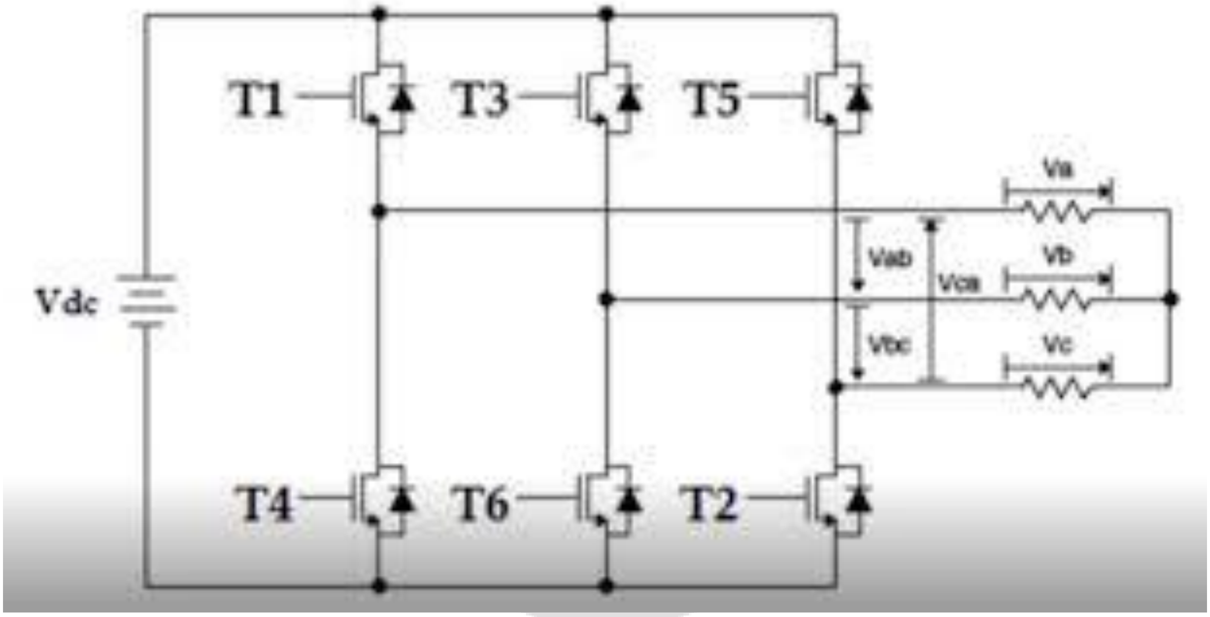

Fig 4: Three-phase inverter

SIMULATION RESULTS AND ANALYSIS:

A hybrid renewable energy system has been simulated using MATLAB/Simulink to integrate a 1.5 MW wind turbine and a 150 Wp solar PV system. The wind and solar PV systems are connected to a common three phase R-load of 500 ohm through three-phase inverter. The inverter operates using Pulse Width Modulation (PWM) with a carrier frequency of 1600 Hz for effective control. Initially, the performance of the wind turbine and solar PV system was assessed independently under varying conditions such as wind speed and solar irradiance. Subsequently, the two systems were combined into a hybrid setup and evaluated under different load conditions. The MATLAB/Simulink model, illustrated in Figure 12, And also includes subsystems for the wind turbine and solar PV system, shown in Figures 5 and 9 respectively.The parameters of wind turbine and Photovoltaic module are described in a Table 1 and 2 respectively.

Case I : Wind Alone:

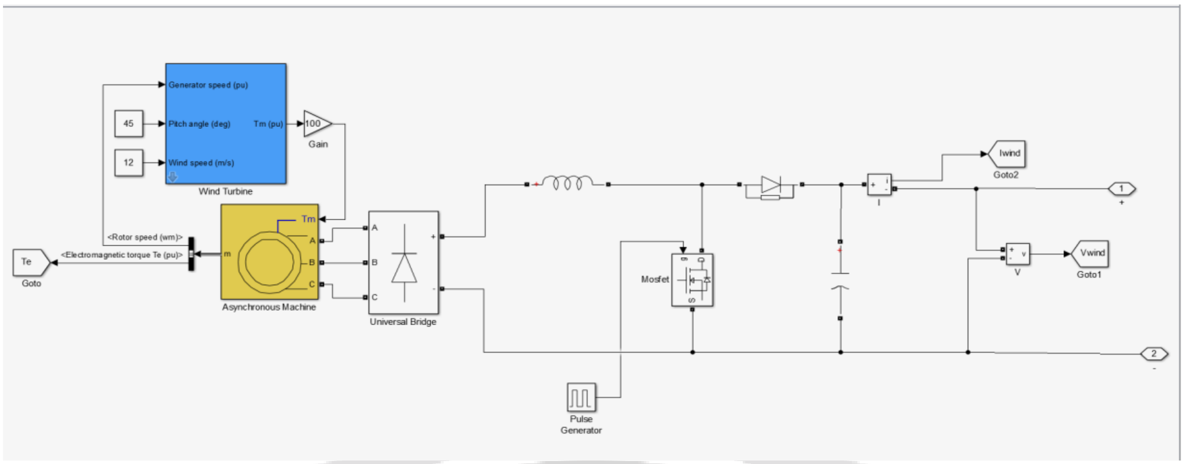

Fig 5: Simulink diagram of Wind Turbine Subsystem

It incorporates a Wind Turbine module, universal bridge rectifier and a DC-DC converter. This simulation results detail the performance of a wind energy system with various operational parameters presented through waveforms .The results obtained are output voltage is 130 volts,output current is 9 amps and output power is 1200 watts at steady state. Figure 6 shows Turbine power characteristics for a variable-speed wind turbine. The system's electromagnetic torque are displayed in Figure 7 as waveforms against time, providing insights into the mechanical dynamics of the turbine. Additionally, Figure 9 illustrates the output voltage ,current and power waveforms of the wind energy system over time, highlighting the electrical performance at a specific wind speed.

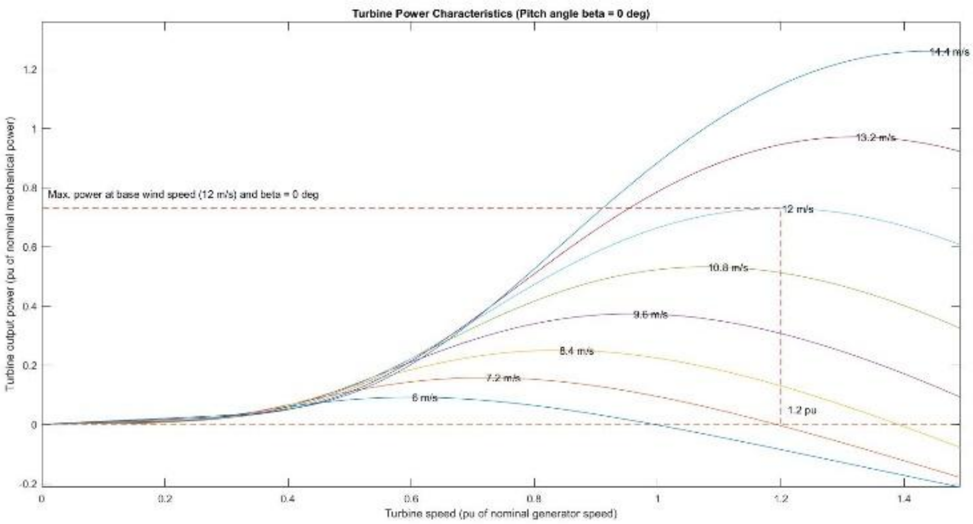

Fig 6: Turbine power characteristics

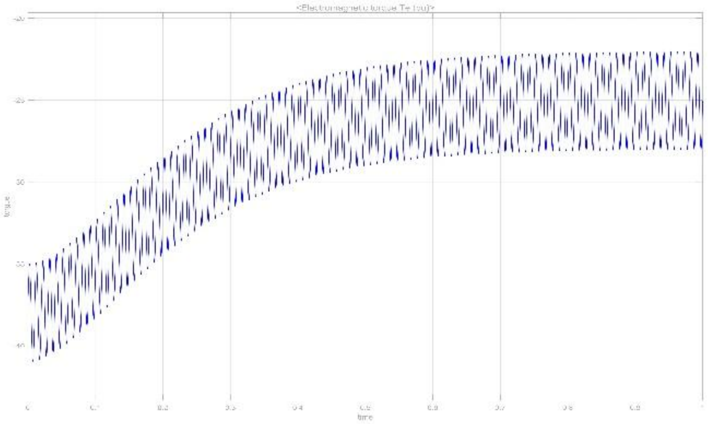

Fig 7: Time vs Torque(N-M) characteristics

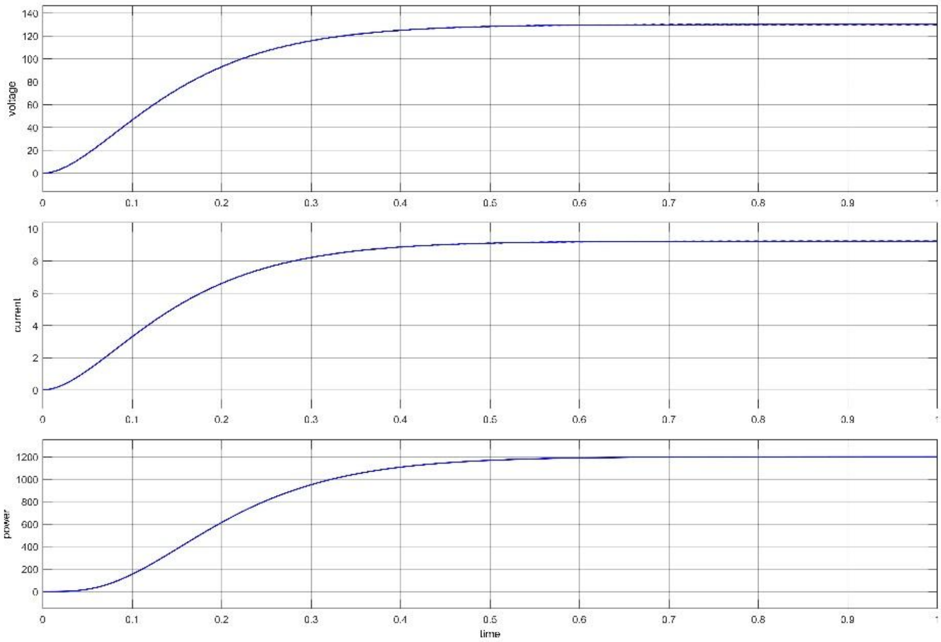

Fig 8: Output waveforms of Wind Energy System

Table I

Parameters of Wind turbine

Rating	1.5MW
Blade Radius	38m
No. Of Blades	3
Air density	0.55kg/[illegible]
Rated Wind speed	12m/sec
Rated speed	2.808 rad/sec
Cut-in speed	4m/sec
Cut-out speed	25m/sec
Blade Pitch angle	0°

Case II : Solar PV alone:

It incorporates a solar photovoltaic module and a DC-DC converter. This simulation results detail the performance of a pv system with various operational parameters presented through waveforms . The solar photovoltaic module generates DC voltage under varying conditions of solar temperature and irradiation. Changes in temperature and solar irradiation have a significant impact on the output voltage and current of the photovoltaic (PV) system. These variations demonstrate how environmental conditions directly influence the performance and efficiency of the system.

However, the energy output of the module is not constant and fluctuates with changes in the intensity of solar rays and temperature in order to minimize the variations we use Mppt technique.

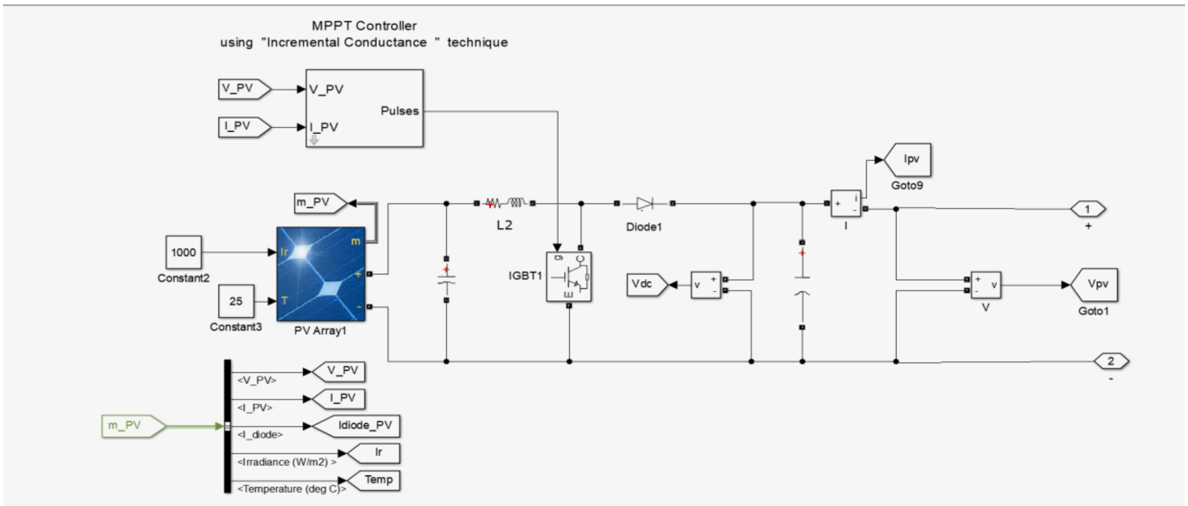

Fig 9: Simulink diagram of Photovoltaic Subsystem.

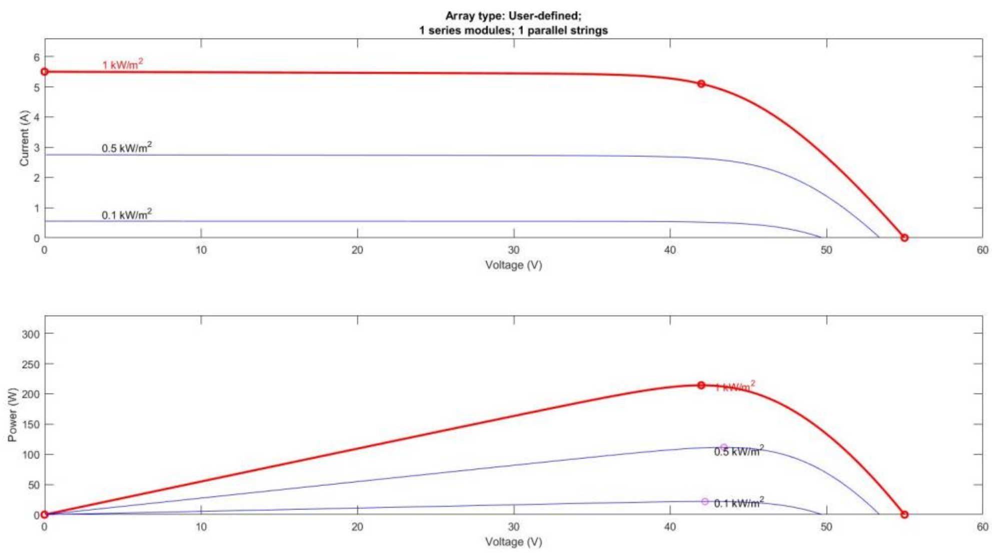

Fig 10: I vs V & P vs V characteristics.

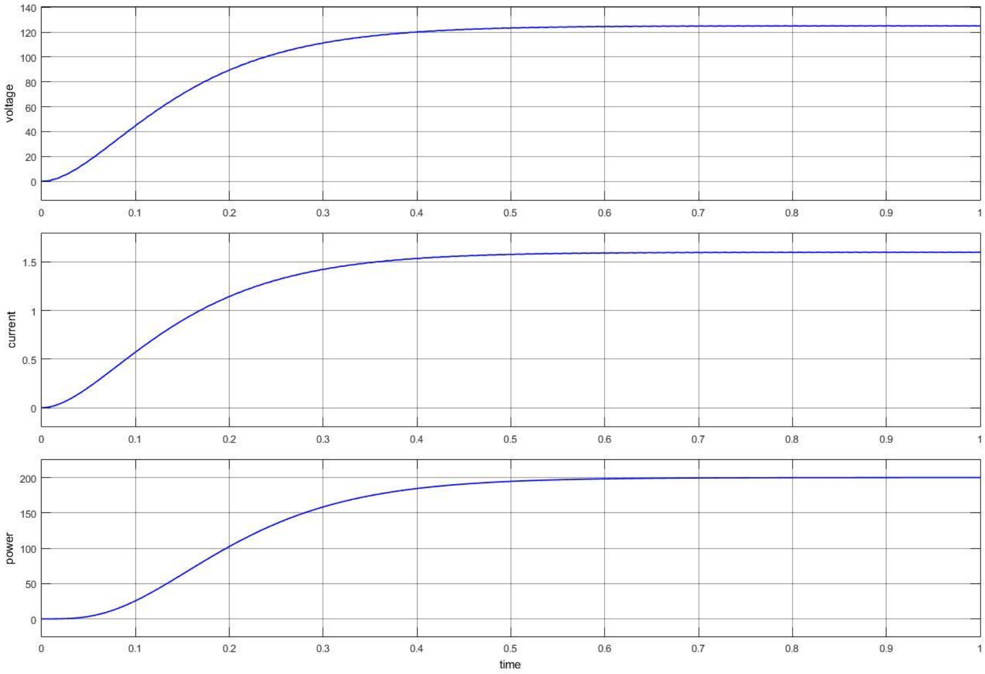

Fig 11: Output waveforms of photovoltaic system.

Figure 10 presents the simulation waveforms displaying the voltage-current ,voltage-power characteristics where as figure 11 represents Output characteristics of a photovoltaic array. The results obtained are output voltage is 124 volts, output current is 1.65 amps and output power is 200 watts.

Table II
Parameters of Photo voltaic Module

Maximum Power	150W
Maximum Voltage	35 V
Temperature Coefficient	25°C

Case III : Hybrid System:

A hybrid system combines both wind and solar photovoltaic systems alongside a 3 phase inverter to achieve an output voltage. Fig 13,12 represents The simulation results and the integration of various components, including the wind turbine model, synchronous generator model, power converter, photovoltaic system, and control blocks respectively. The results obtained are The output voltage is 215volts, the output current is 14 amps, the output power is 4300 watts at steady state.

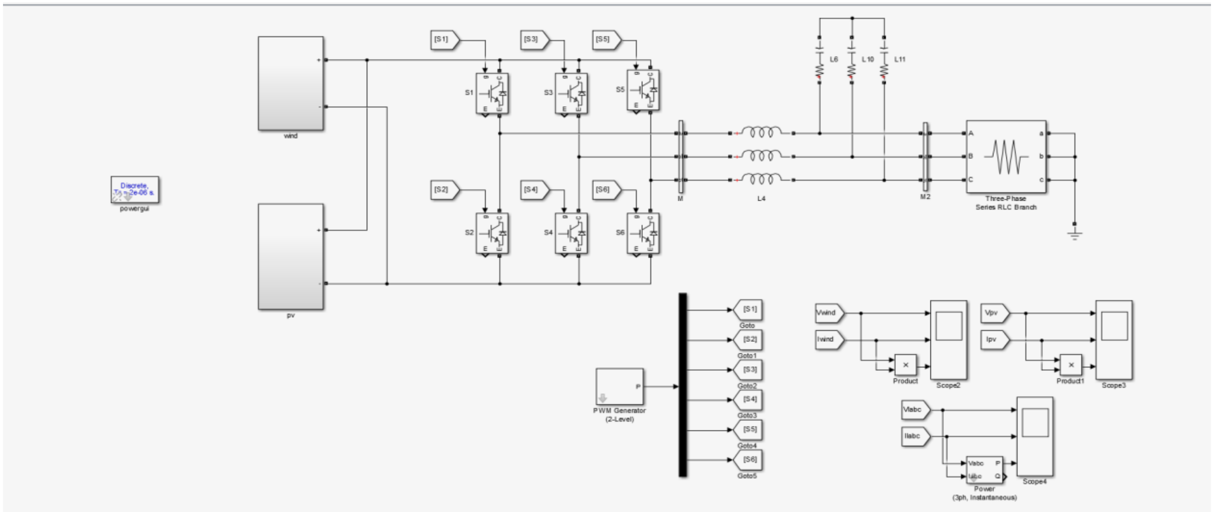

Fig : 12 MATLAB/SIMULINK model of Hybrid system.

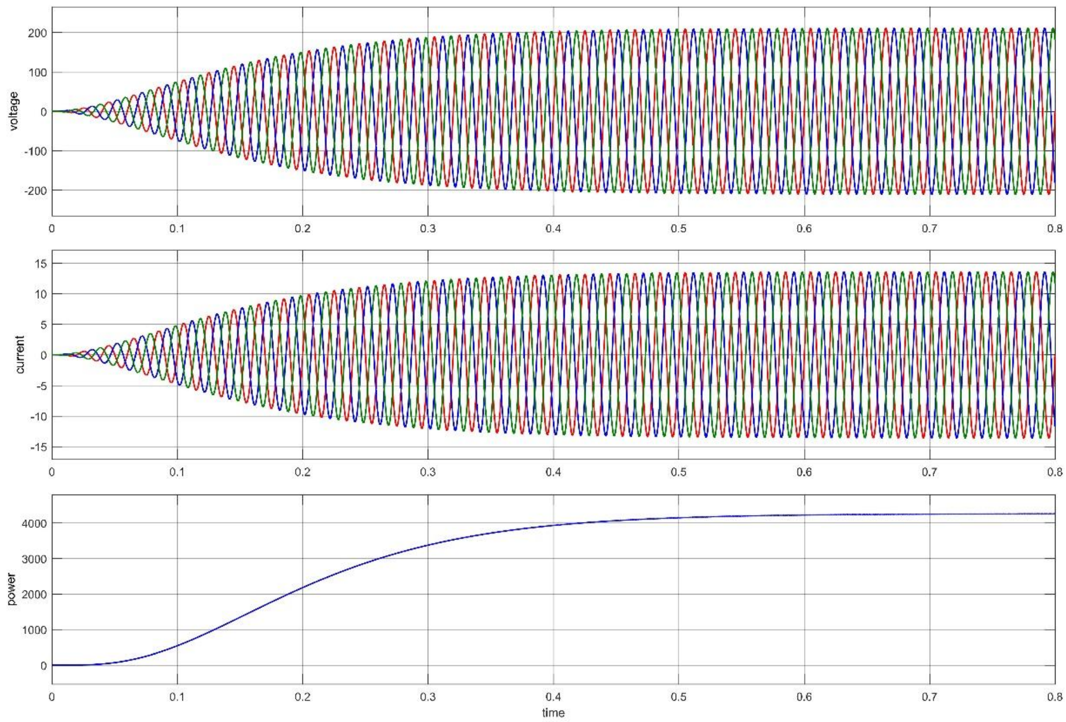

Fig 13: Output waveforms of Hybrid system.

CONCLUSION:

This paper has described a hybrid energy system with variable speed wind generation, photovoltaic system along with power electronic interface under stand-alone mode. Computer simulation was conducted using MATLAB/SIMULINK. In the stand-alone mode the performance of the system is evaluated for various wind speeds and various irradiation levels. Due to variations in wind speed and solar irradiation AC voltage varies. In hybrid system, 12 m/s in wind system and 1000w/m2 in solar PV system performance has been analyzed. This system is expected to meet up electricity demand in a remote area. The performance of the developed system is evaluated in MATLAB/SIMULINK platform and the results are presented.