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# Design And Simulation Of Grid-Connected Solar Wind Hybrid Power System With MPPT Techniques

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The quality of electric power generated and distributed has become an important issue for electric utilities and consumers. Power quality is a notion of many discrete power system disturbances. The concerns that are covered under the power quality notion are not essentially fresh but the factor of cracking to resolve the power quality issue is trending now-a-days. The common thread running through all these reasons for increased concern about the quality of electric power is the continued push for increasing productivity for all utility customers. Poor power quality, characterized by Characterized voltage fluctuations, hormonics, frequency variation and reactive strengthening imbalance, wind stability, efficiency and equipment can adversely affect performance.
This article focuses on the simulation of wind-connected solar wind hybrid power systems using maximum power point tracking (MPPT) techniques. Perturb and observe (P & O) MPPT algorithm are used on both photovoltaic system (PV) and wind power conversion system to maximize power outlets under environmental conditions. The system has modelled and simulated using Matlab/Simulink to analyse performance in terms of power quality and and efficiency. The proposed hybrid system increases energy -reliance by stopping nature by stopping individual renewable sources. The effectiveness of P&O MPPT technique is evaluated by comparing the response time, tracking accuracy and efficiency in dynamic conditions. The results improve better energy consumption, stable voltage profiles and spontaneous integration with grid. This article contributes to the development of effective hybrid renewable systems, which ensure durable and stable power generation.

**Keywords-** Power Quality, Solar-Wind Hybrid System, Wind Integration, Harmonic Distortion, Power Electronics, Energy Storage, Renewable Energy.

## 1. Introduction

Increasing global demand and increasing the anxiety of environmental pollution has made a significant change to renewable energy sources. Solar and wind energy, which is rich, clean and durable, has proven to be the most promising alternative to traditional fossil fuels. However, the underlying periodic intermittent stops and the variation of these energy sources create challenges in maintaining a stable and reliable power supply [1-2]. A hybrid power system that integrates the photovoltaic system (PV) and wind energy can effectively reduce these boundaries by complementing variations of each other. Such hybrid systems can increase energy dependence, improve efficiency and ensure continuous power generation, so that they are a viable solution for wind and standalone applications [2-3]

The design and simulation of a grid-connected solar-wind hybrid power system that use Maximum Power Point Tracking (MPPT) techniques is an important field of research for improving energy efficiency and dependability. Such systems combine solar photovoltaic (PV) panels and wind turbines, with various MPPT algorithms used to maximize energy harvest. The following sections describe the essential components and approaches used in this hybrid system [4-5]. Solar systems frequently employ the Perturb and Observe (P&O) method to efficiently track the maximum power point [4].

Integration of Solar and Wind using boost converters to connect PV panels and wind turbines to a common DC bus, the hybrid system ensures effective energy transfer to the grid [6-7]. When used on wind and solar components, incremental conductance improves the system's capacity to adjust to shifting environmental circumstances [6]. Energy Storage: In order to stabilize output and provide backup power during variations in solar and wind availability, batteries are integrated to store excess energy [8].

To enhance performance in changeable conditions, smooth out disruptions, and guarantee dependable operation, a fuzzy-based MPPT controller has been proposed [8]. MATLAB/Simulink Simulations are used to study the hybrid system's dynamic behavior and show that it can feed power to the grid while maintaining a consistent voltage and frequency [4,7]. While integrating solar and wind energy systems has various benefits, there are still substantial hurdles including as intermittency and the need for enhanced control mechanisms. Addressing these difficulties is critical to the widespread deployment of hybrid renewable energy systems [7].

Gb et al [9] described the construction and control of a distributed generation system powered by an autonomous hybrid solar-wind system (AHSWS) that supplies electricity to a 3ϕ-4 wire system. It was reached maximum effectiveness in a range of circumstances and generated the rated voltage and frequency in both cases. The design and implementation of a solar-grid hybrid system that supplies dc loads with a cost-effective and sustainable power source is presented by Islam et al [10]. The charge controller was constructed with a maximum power point tracking methodology utilizing the perturb and observe method. The P-V and I-V graphs of the solar panel was observed under test and savings were estimated when utilizing a hybrid solar system.

Obaid et al [11] proposed a grid-connected hybrid solar/thermoelectric renewable power source architecture that includes thermo-electric modules in addition to solar photovoltaic panels.

The maximum solar system power was 70 kW and 145 kW was the maximum power that thermoelectric modules were produced.

Rajan et al [12] implemented and analysed the system combining PV and PMSG topologies are examined in-depth in a study on a Solar Wind Hybrid Power Generation System with a modified Luo converter. The system's overall efficiency was improved and a steady grid connection was made possible by the upgraded Luo converter. Simulations that compare various configurations demonstrate how well the hybrid system can produce clean energy. It was improved energy production and use with a hybrid solar-wind system. A robust grid connection for dependable power distribution was made possible by a modified Luo converter.

Tiwari and Singh [13] demonstrated the system's viability and presented the wind solar hybrid system, along with a proposal for a hybrid energy system that combines solar panel and wind turbine parameters to generate electrical power that was fed to a power grid station. The findings of the simulation confirm that the solar and wind systems have complementing features. Household load demand was efficiently met by optimized arrangements. Gharahbagh et al [14] studied a solar farm in a 150,000 m2 solar farm under shade, that study suggested an adaptive MPPT controller for hybrid solar-wind-battery systems that was used shadow motion prediction to increase speed and efficiency while lowering computational burden by 70%.

MPPT technology adjusts the operating points of solar and wind turbines dynamically to ensure maximum power generation. Between different MPPT algorithms, disturbances and inspections (P&O) method are widely used due to its simplicity, easy implementation and efficiency in tracking maximum power points. This technique repeatedly affects the operating voltage or operating cycle and looks at this power generation, and then adjusts it to achieve optimal energy harvesting [15-16].

This article focuses on the design and simulation of a grid-connected solar-Hybrid power system which includes P & O-based MPPT techniques for both solar and wind energy conversion. The system has modelled in Matlab/Simulink to evaluate performance in terms of strength efficiency, stability and grid compatibility. The study analyses the effect of MPPT algorithms on power quality, energy use and system reaction under different loads and environmental conditions. In addition, paper hybrid control strategies discuss with renewable energy systems, current electronics components and wind -crank integration challenges.

## 2. Disruptions in Electrical Quality in Hybrid System

Integration of solar and wind energy into hybrid power systems presents important challenges in maintaining power quality due to the underlying stop and variation for these renewable sources. Electrical quality disorder in such systems is mainly due to ups and downs in voltage, frequency variation, harmonic malformations, reactive power imbalances and power growth, all of which can reduce operating institutions and low efficiency in the power system. Voltage fluctuations are caused by a rapid change in solar radiation or wind speed, resulting in a sudden variation in power generation that can affect the grid's stability. These ups and downs can cause flickering in light systems, affect sensitive electronic devices and degrade the general performance of the power system. Similarly, frequency variations occur due to discrepancies between power generation and load requirements. Unlike traditional power plants, which maintain frequency stability through mechanical inertia, hybrid -renewable systems depend on power electronics, making them more prone to frequency deviations. If these deviations are higher than the acceptable limits, they can lead to malfunctions of the equipment, the reliability of the low system and even wind defects [17].

Another major anxiety in the hybrid system is harmonious deformation, resulting in the use of power-electronic converters as converters, retipers and DC-DC converters. These devices introduce non-sinusoidal waves in the electrical system, causing excessive harmonic streams and voltage that can cause overheating in transformers, engines and transmission lines. Harmonics also reduce the power factor, increase the damage to the system and adversely affect the general efficiency. The spread of non -linear load further enhances harmonic problems, making it necessary to distribute filtration techniques as active and passive filters to reduce the effect. In addition to harmonics, reactive strength in hybrid is an important challenge in renewable systems. Since the wind and solar energy system mainly generate active power, they often fail to provide the necessary reactive power aid required for voltage regulation and power factor correction [18]. This leads to poor power factor status, increase in transmission loss and potential instability in the grid. To address this, reactive power compensation equipment such as static was often used was -competitions (SVC) and static

synchronous competitors (STATCOM) to increase voltage stability and improve system performance [19-20].
In addition, there is sudden power growth and normal disruption in the dropout hybrid system due to the unexpected nature of solar and wind resources. The intensity or rapid change of the sunlight in wind speed can lead to a sudden increase in power generation or reductions, causing tension saws or transient over voltage. These events can damage electrical equipment, reduce the life of the components of the electrical system and introduce operating disabilities. Energy storage systems (ESS), such as batteries and super cappers, play an important role in reducing this disorder by absorbing extra energy during the high generation period and the supply of energy stored when the generation is reduced. By smoothing the electric upside down and down, energy storage solutions contribute to the more stable and reliable hybrid power system. In addition, the variation in the load complicates the demand for power quality control in the hybrid system. A sudden change in the consumer's power consumption can lead to imbalance between supply and demand, affecting stress stability and general network performance. In order to remove these challenges, advanced control strategies such as demand side, load forecasts and adaptive energy security techniques are used to adapt to electricity currents and increase the reliability of the system [21-22].
Another important factor affecting the quality of power in the hybrid system is the interaction between renewable energy sources and existing power grids. The position of a weak grid, characteristic of high impedance and low short-circuit capacity, can increase the voltage and frequency fluctuations, making it difficult to maintain stable operations. Pawan defects, disturbances in the transmission line and traditional power generation contribute to problems with power quality in hybrid systems. To ensure seamless grid integration, synchronization techniques such as phase blocks (PLL) and grid are used to adjust the frequency and phase of the hybrid system with the grid [23]. Flexible AC Transmission System (Facts), including Unified Power Flow Controller (UPFC) and serial machines, are also used to increase voltage control, reduce transmission and improve general power quality [24-26]. In addition, smart network technologies and artificial intelligence (AI) time are used to dynamically adjusting system parameters, improving the reaction time and reducing the effect of disruption of power quality. These intelligent systems benefit from machine learning algorithms and large data analysis, which predict electrically up and down, adapt energy distribution and ensure effective network operations.

## 3. Solar-Wind Hybrid Power System

A solar wind hybrid power system is a permanent energy solution that integrates two renewable energy sources photovoltaic (PV) and wind energy to increase the availability of efficiency, reliability and current. Since solar energy production depends on sunlight and the energy of the air varies at a speed of the wind, a hybrid system provides a more consistent energy supply by supplementing the weaknesses of each source. During the hours of daylight, solar -PV panels generate electricity effectively, while at night or in cloud conditions, the wind turbine can continue production when the wind speed is sufficient. This hybridization reduces electric fluctuations and ensures a stable power supply, making it an ideal solution for both wind cameras and off-slide applications. Important components of the Solar-Hawk Hybrid system include Solar PV panels, wind turbines, maximum power point tracking (MPPT) control, battery storage system, and converter and grid connection options. Solar PV panels convert sunlight to direct current (DC), while wind turbines produce mechanical energy that converts to electric power through a generator. The MPPT controller plays an important role in optimizing power generation by adjusting the operating conditions for solar and wind sources at their maximum power points, which increases efficiency. The battery storage system stores additional energy produced during top generation periods and supply power when reducing energy production. Transmitters convert DC power from solar panels and batteries to alternative power (AC), which is important for domestic and industrial applications.

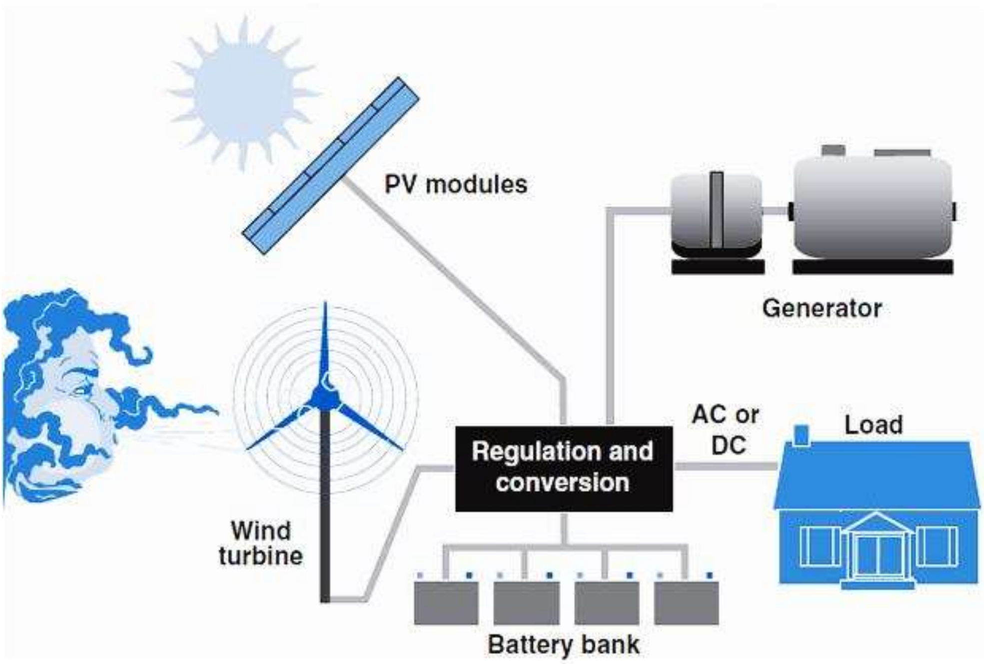


Fig. 1 A Schematic Diagram of Solar Wind Hybrid Power System

In a wind -connected hybrid system, further power can be exported to use networks, while further energy can be deducted from the grid when necessary, when the renewable generation ensures continuous operation even when it is inadequate. The acting theory of Solar-Wind Hybrid Power System is about efficient use of renewable energy sources to maintain electrical stability. During sunny days with minimal air, the system depends mainly on the solar panels, while the wind turbine during the cloud position with night time or strong wind takes as the main source of energy. With sufficient sunlight and air, the system maximizes power generation by using both sources at the same time. MPPT controls adjust the operating voltage and current to solar panels and wind turbines to remove the highest possible power generation. When further energy is generated, it is stored either in the battery or fed into the grid in the grid-lubrication system for later use. During a low -generation period, the system prefers power from the stored battery rids and reduces the dependence on traditional energy sources. The use of smart network integration and AI-based future control mechanisms will increase the efficiency by predicting electric demand and adjusting the energy mixture as dynamic. The advantages of a sun wind system for sun wind include better energy-reflective, low dependence on fossil fuels, increased power quality, low carbon emissions and long-term cost savings. However, these systems face challenges such as variability in the generation of renewable energy, high early costs, room requirements for solar panels and wind turbines, questions of power quality due to ups and downs in voltage and efficient currenting strategies require.

**Table 1: Comparison of Solar, Wind, and Hybrid Power Systems [27-33]**

| Feature | Solar Power System | Wind Power System | Solar-Wind Hybrid System |
|---|---|---|---|
| Energy Reliability | Moderate (only in sunlight) | Moderate (only in windy conditions) | High (complementary energy sources) |
| Power Fluctuations | High (affected by weather) | High (affected by wind speed) | Low (balanced by hybridization) |
| Energy Storage Requirement | High | High | Medium |
| Grid Independence | Limited | Limited | High |
| Cost Effectiveness | Medium | Medium | High (due to optimized utilization) |
| Environmental Impact | Low | Low | Very Low |
| Maintenance Complexity | Low | High (moving parts in wind turbine) | Medium |
| Best Application | Sunny regions | Windy regions | Areas with mixed solar and wind potential |

Table energy highlights the superiority of the hybrid power system in terms of credibility, low fluctuations, cost -effectiveness and stability. The ability to utilize energy from both sources reduces the storage requirements and reduces the dependence on backup. In addition, artificial intelligence (AI) -co -working management systems, real -time seasons and smart network integration improves further efficiency of technological progress and hybrid renewable energy systems.

The real applications of the Solar-Hwa hybrid system are different and grow rapidly. These systems are used to provide power to remote areas for electrification of the countryside where network connection is limited. They are also used extensively in the telecommunications towers which ensure an uninterrupted power supply to the communication network. Industrial and commercial companies use hybrid power solutions to reduce operating costs and reduce carbon footprint.

## 4. Simulation and Results

A Simulink model of a solar and wind inverter grid system without a STATCOM typically includes a solar PV array block that converts sunlight into DC electricity and a wind turbine block that generates power based on wind speed, both feeding into their respective DC-AC inverters. These inverters convert the DC power from the solar and wind sources into AC power synchronized with the grid.

The model also includes a grid connection block that integrates the inverter outputs with the electrical grid, along with measurement blocks for monitoring voltage, current, and power flow. The absence of a STATCOM means that voltage stability and reactive power management rely solely on the inverters and other grid components, which may limit the system's ability to handle voltage fluctuations and power quality issues during dynamic conditions.

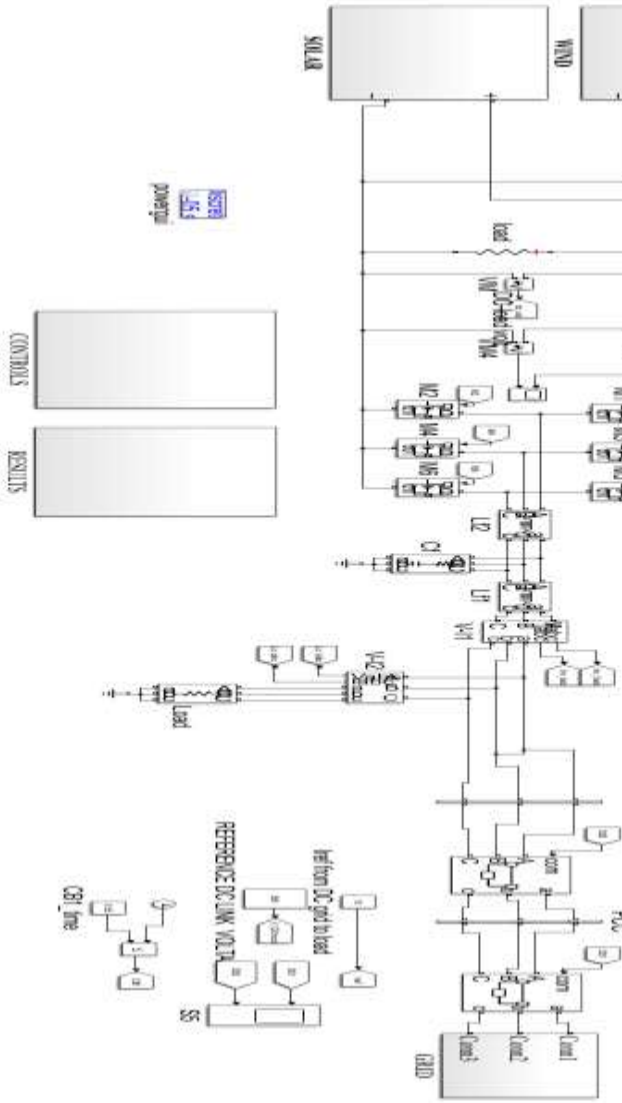


Fig. 2 Simulink model Without STATCOM

Simulation results without a STATCOM (Static Synchronous Compensator) in a power system, modelled using MATLAB/Simulink, typically show enhanced voltage stability, improved power quality,

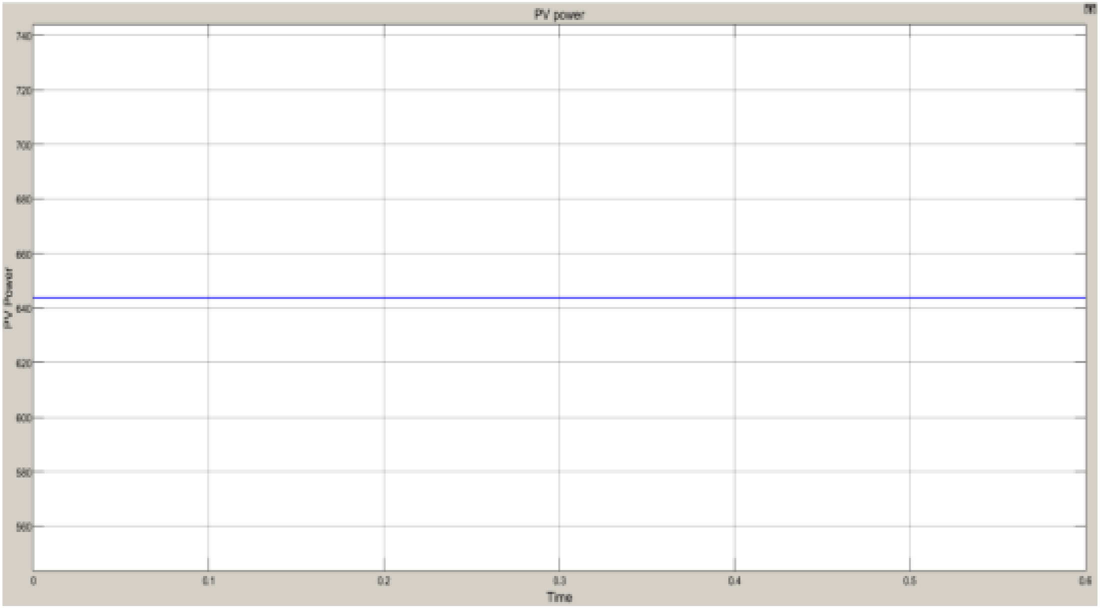


Fig. 3 PV Power

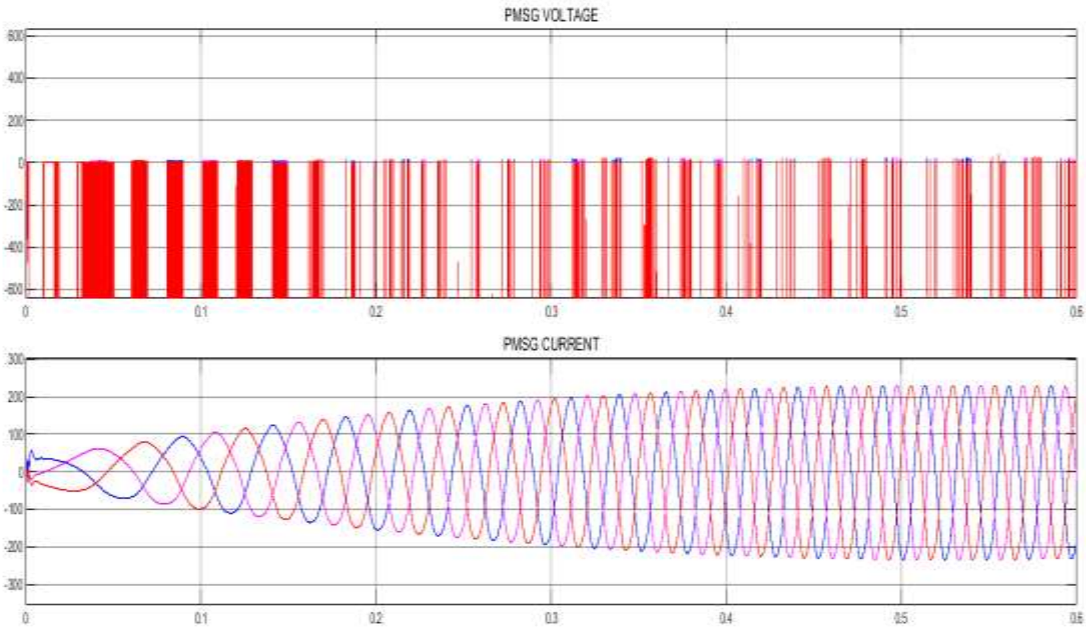


Fig. 4 PMSG Current and Voltage

A Permanent Magnet Synchronous Generator (PMSG) generates AC voltage and current with characteristics dependent on the rotational speed of the generator and the load conditions.

- **Voltage**: The output voltage of a PMSG is sinusoidal and its magnitude is directly proportional to the speed of the rotor and the strength of the permanent magnets. As the rotor speed increases, the induced voltage increases, and it typically remains stable under steady-state conditions.

- **Current**: The output current is also sinusoidal and its magnitude depends on the load connected to the generator and the generator's power output. Under normal operating conditions, the current waveform is smooth, but it can be affected by load variations, leading to changes in amplitude. If the load increases, the current drawn from the PMSG increases, and vice versa

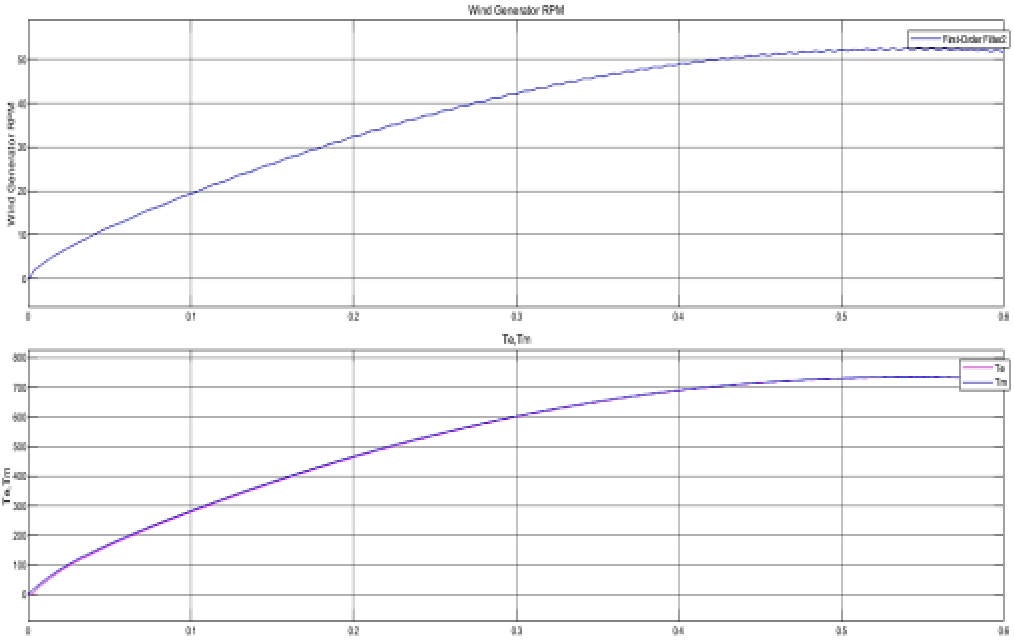


Fig. 5 Wind Generation rpm and Mechanical and Electromechanically Torque

In a wind generation system, the rotational speed (RPM) of the wind turbine is directly influenced by wind speed and turbine design, determining how fast the turbine blades and the connected generator's rotor spin. The mechanical torque is the twisting force exerted by the wind on the turbine blades, which is transferred to the generator's rotor, causing it to rotate. This mechanical torque is a function of both wind speed and rotor blade characteristics. As the generator converts this mechanical energy into electrical energy, the electromechanical torque is the counteracting force generated within the generator due to electromagnetic interactions. This electromechanical torque balances with the mechanical torque to ensure efficient energy conversion, with variations reflecting changes in load or wind speed.

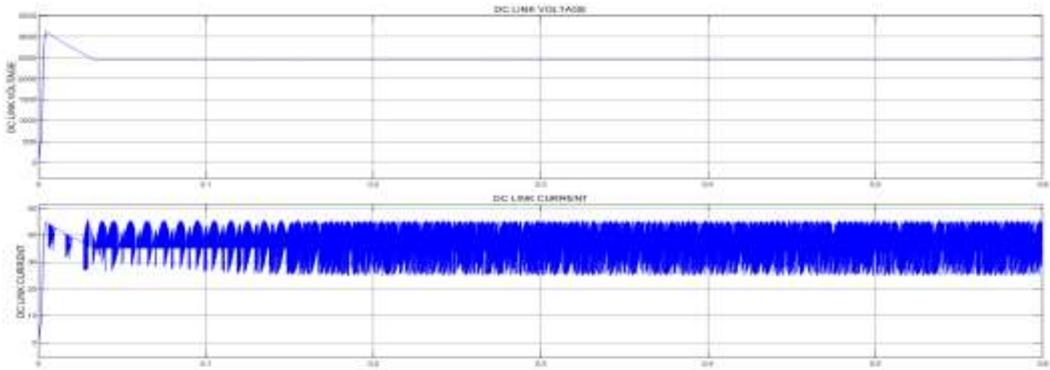


Fig. 6 DC Link Voltage and DC Link Current
his is the voltage level maintained across the DC link capacitor, which connects the DC side of the system to the AC side. The DC link voltage is crucial for the efficient operation of inverters or converters, which convert the DC voltage into AC voltage for grid integration or load supply.

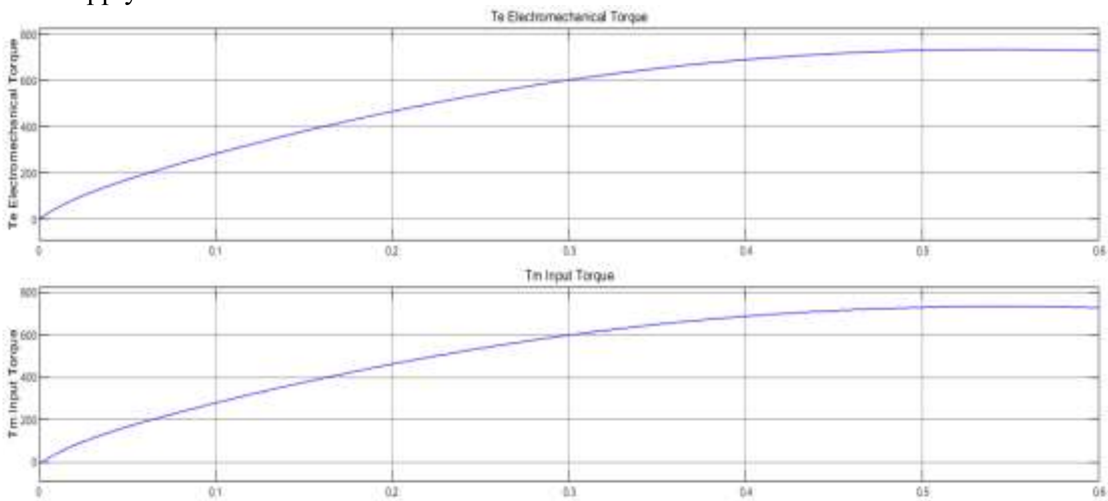


Fig.7 $T_e$ Electromechanical Torque and Tm Input Torque

This is the torque generated by the interaction between the magnetic fields in the generator and the rotor, which results from the conversion of mechanical energy into electrical energy. In a wind turbine system, the electromechanical torque is produced by the generator and is essential for converting the mechanical energy from the wind into electrical energy. It is determined by the generator's electrical characteristics and the load connected to it

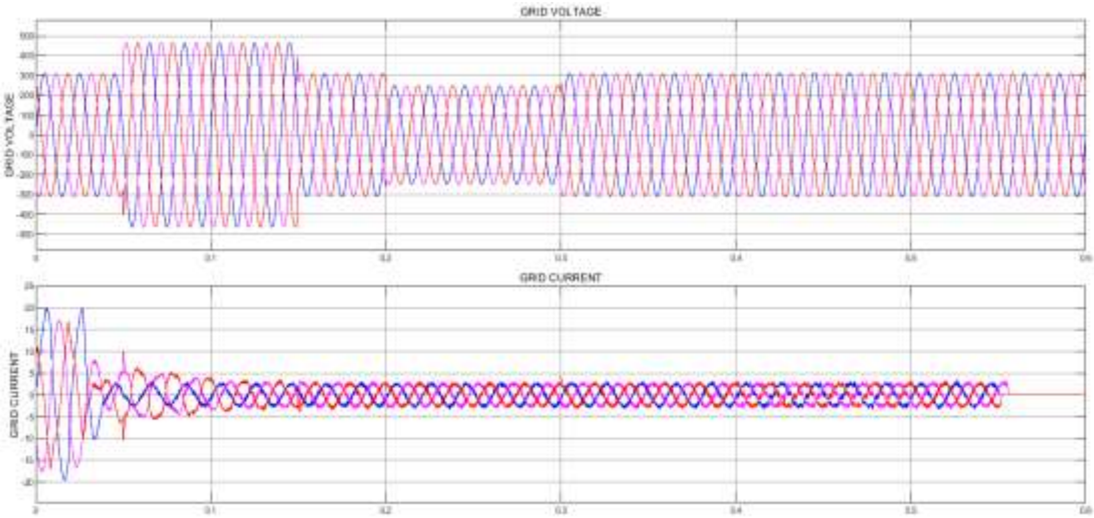


Fig. 8 Grid Voltage and Grid Current

**Grid current** refers to the flow of electrical current through the grid, which varies with the load demand and the power being supplied.

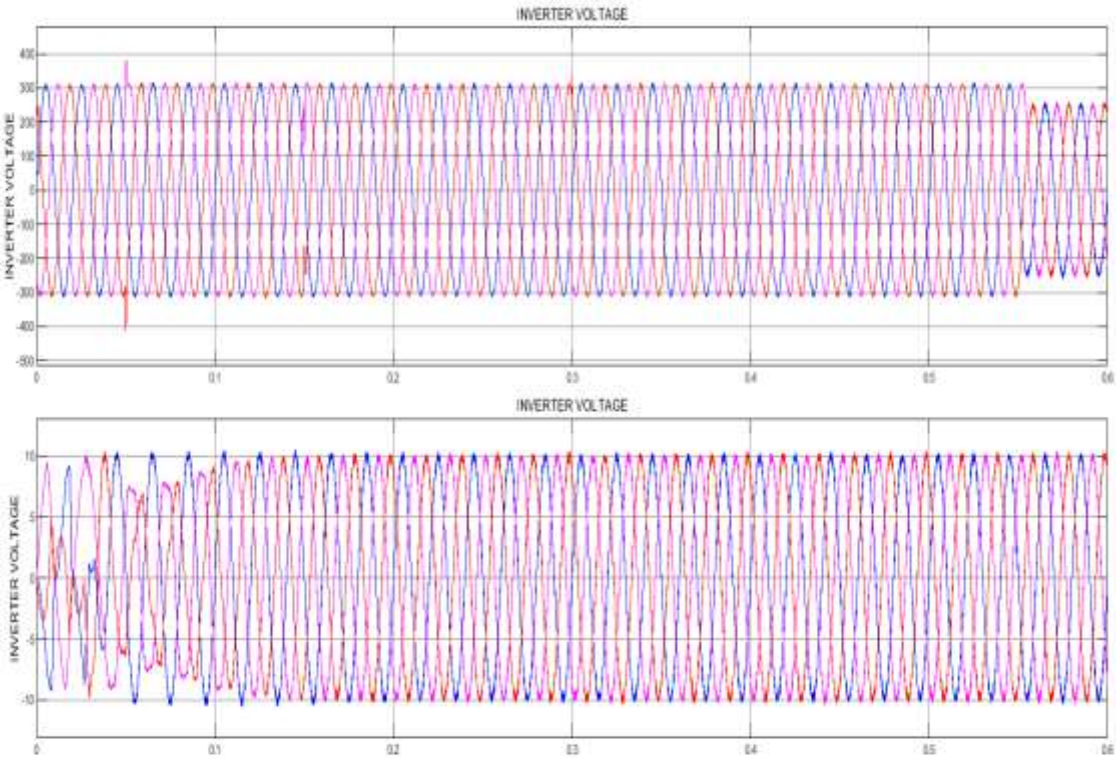


Fig. 9 Inverter Voltage and Inverter Current

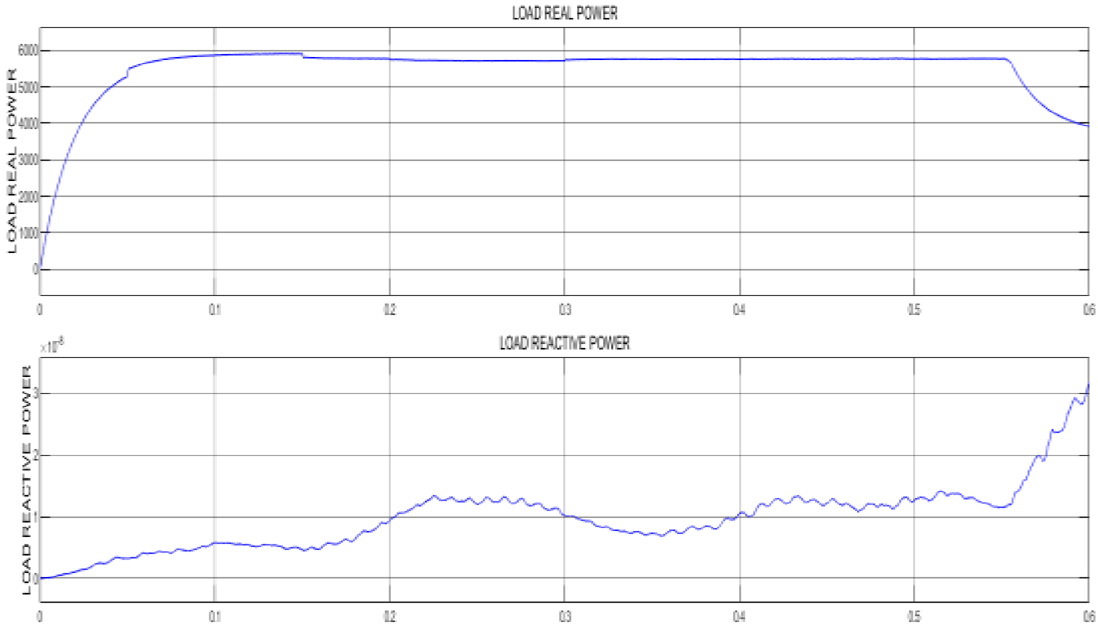


Fig. 10 Load Real Power and Load Reactive Power

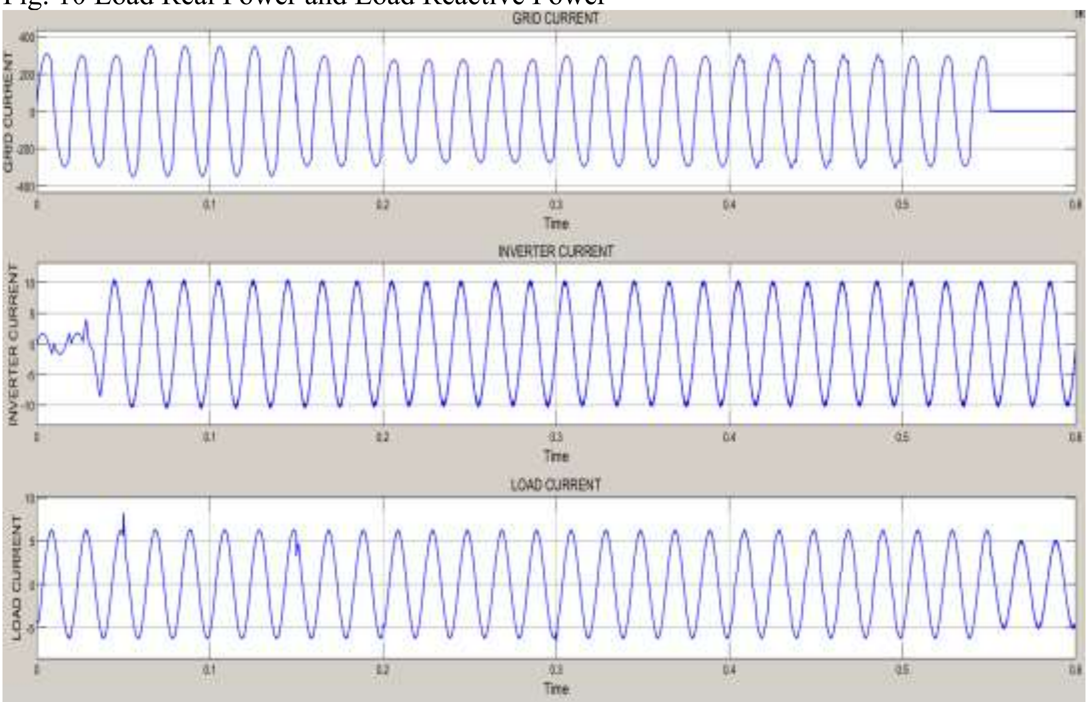


Fig. 11 Grid Current, Inverter Current, Load Current

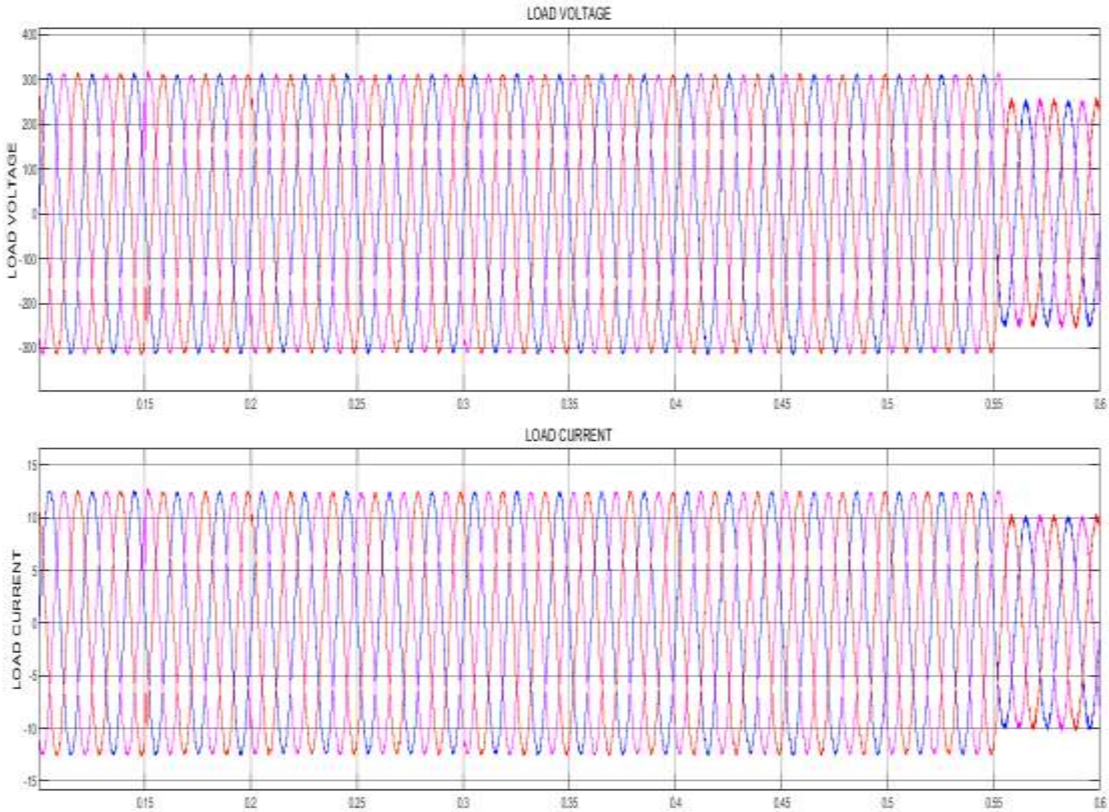


Fig. 12 Load Current and Load Current

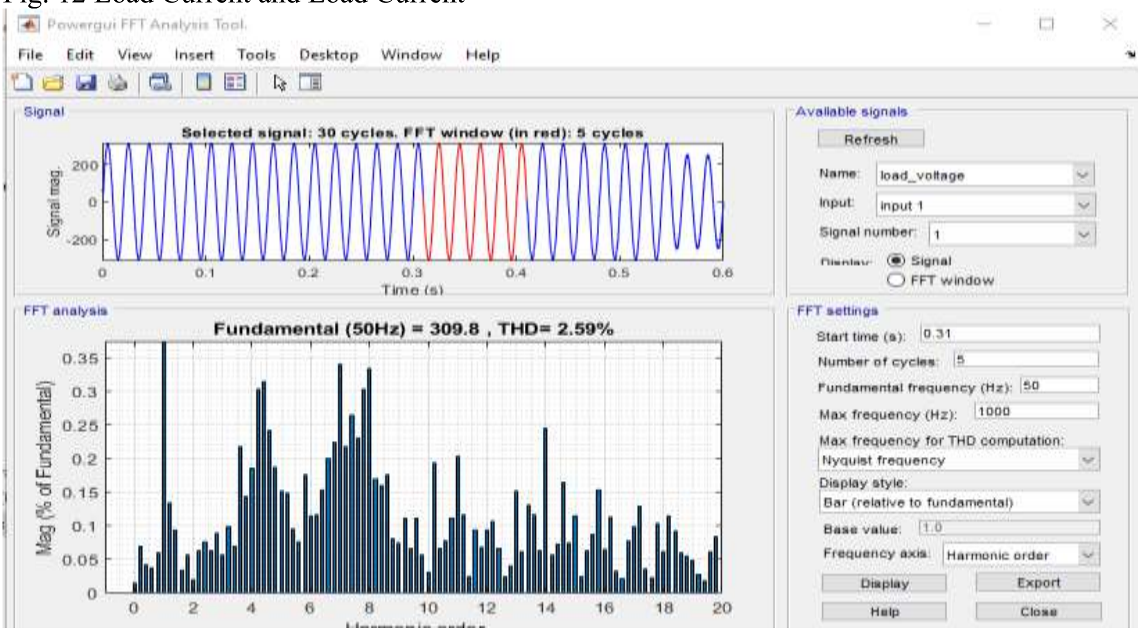


Fig. 13 THD

## 5. Conclusion and Future Scope

The design and simulation of the net's solar wind hybrid power system using MPPT techniques shows significant improvement in power quality and efficiency. By implementing disorders and inspections (P&O) MPPT algorithm for both photovoltaic (PV) and wind power conversion system, the hybrid system effectively maximizes power generation in separate environmental conditions under environmental conditions. The results of simulation using Matlab/Simulink highlight the stability and efficiency of the proposed system.

The analysis of different performance parameters, including network voltage and current, wind production properties, DC connection voltage and power distribution, confirm the reliability of hybrid systems. The absence of a condition in the model suggests that voltage stability and reactive power control completely depend on converters and other grid components. Although it may introduce some limitations, the proposed MPPT control strategy ensures optimal power tracking and efficient energy use. Total harmonic deformation (THD) analysis supports the system's ability to maintain the power quality within acceptable boundaries.

The hybrid system integrates successfully renewable energy sources and reduces the dependence on an energy source and ensures a stable power supply. Simulation results improve energy consumption, better voltage profiles and spontaneous grid integration. By taking advantage of the strength of both solar and wind energy, this hybrid approach increases the stability and energy reliable. Future work can focus on incorporating advanced power conditioning equipment, such as statues, to increase voltage stability and reactive power control under dynamic conditions.

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