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SIMULATION OF POWER GENERATION OF GRID CONNECTED WIND-PV-BATTERY BASED HYBRID ENERGY SYSTEM

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ABSTRACT:

This article describes the power generation of wind, PV, and, battery-based hybrid energy systems for standalone AC microgrid applications. There are many results for resolving issues with the supply of electrical power, particularly in rural places where electrical networks are difficult to access. The usage of networks that are not linked to electrical systems allows for the provision of electricity to remote places, which is one way for determining this issue. They are denoted to as standalone microgrid systems. The standalone microgrid has its sources of electricity, extension (or)addition with an energy storage system. They are utilized where power transmission and distribution from a major centralized energy source is too far and costly to operate. In this article, a standalone AC microgrid scheme with a hybrid power system comprised of wind, photovoltaic, and batteries are designed and managed. Keywords: Hybrid energy system, PV (Solar Cell), Wind, Battery, Microgrid.

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1. INTRODUCTION

In recent years, the pursuit of sustainable energy sources has become paramount in the global effort to mitigate climate change and reduce dependence on finite fossil fuels. Among the array of renewable energy options, solar and wind power stand out as abundant, clean, and increasingly cost-effective alternatives. However, the intermittent nature of these sources poses challenges to their integration into traditional power grids. To address this issue, hybrid systems that combine solar and wind energy offer a promising solution, leveraging the complementary nature of these resources to enhance reliability and efficiency. This project delves into the intricate realm of grid-connected solar wind hybrid power systems, exploring their design, operation, and performance through advanced simulation techniques.

By harnessing the power of simulation, we gain invaluable insights into the dynamic behavior of these complex systems, enabling us to optimize their configuration, maximize energy production, and ensure seamless integration with existing grids. The journey begins with a comprehensive overview of solar and wind energy technologies, highlighting their strengths, limitations, and synergies. Solar photovoltaic (PV) arrays harness sunlight to generate electricity, offering scalability and versatility, while wind turbines capture kinetic energy from the wind, providing consistent power output in suitable locations. By combining these two renewable sources within a hybrid framework, we capitalize on their complementary characteristics, mitigating the intermittency issues inherent to each individual technology. Next, we delve into the core principles underlying grid-connected power systems, elucidating the intricate interplay between generation, transmission, and distribution components.

In a grid-connected configuration, renewable energy sources interface with the existing electrical grid, allowing for bidirectional energy flow and facilitating the exchange of surplus power. However, the variability of solar and wind resources necessitates sophisticated control strategies and grid management techniques to ensure stability and reliability. The heart of this project lies in the development and implementation of a detailed simulation model for gridconnected solar wind hybrid power systems. Leveraging state-of-the-art simulation tools and methodologies, we construct a virtual environment that accurately captures the behavior of solar panels, wind turbines, energy storage systems, inverters, and grid interfaces. By simulating various operating scenarios, including different weather conditions, load profiles, and system configurations, we gain a nuanced understanding of system dynamics and performance characteristics.

Through extensive simulation experiments, we investigate key performance metrics such as energy yield, system efficiency, reliability, and grid integration capabilities. We analyze the impact of factors such as system sizing, component selection, control algorithms, and grid interaction protocols on overall system performance. Furthermore, we explore advanced optimization techniques, such as genetic algorithms and machine learning algorithms, to enhance system design and operation. Moreover, we delve into the economic aspects of gridconnected solar wind hybrid power systems, assessing their cost-effectiveness, return on investment, and potential for revenue generation. By conducting techno-economic analyses and sensitivity studies, we elucidate the financial viability of hybrid installations compared to conventional power generation technologies. We also examine policy frameworks, incentives, and regulatory mechanisms that influence the adoption and deployment of renewable energy systems on a broader scale. In addition to technical and economic considerations, we address environmental and societal impacts associated with grid-connected solar wind hybrid power systems. By reducing greenhouse gas emissions, mitigating air and water pollution, and promoting energy independence, these systems contribute to sustainable development and climate resilience. Furthermore, their decentralized nature empowers local communities, fosters job creation, and enhances energy access in remote areas. In conclusion, this project presents a holistic exploration of grid-connected solar wind hybrid power systems, combining technical, economic, environmental, and social perspectives. Through advanced simulation techniques, we unravel the intricacies of these complex systems, paving the way for their widespread adoption and integration into the global energy landscape.

By embracing sustainability and innovation, we embark on a path towards a cleaner, greener, and more resilient future for generations to come. Electric systems and grids are complex dynamic systems. These systems suffer usually from unexpected or sudden changes of the currents and voltages. These changes are due mainly to the different types of linear and non-linear loads to which they are connected. In addition, to different types of accidents which can intervener into the grid. With the increasing use of power semiconductors in the most of industrial and domestic procedures, the electric grids are polluted with different harmonic currents and voltages. These harmonics affect the normal function of the most of the grid connected devices; in addition to considerable economic losses. Many classic and modern solutions have been proposed in the literary for the harmonic problems. In this chapter, the harmonic problem as one of the most common power quality problems will be presented.

The different modern and traditional solutions will then be discussed. Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as ―The concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.‖ As appropriate as this description might seem, the limitation of power quality to ―sensitive electronic equipment‖ might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems.

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A simpler and perhaps more concise definition might state: ―Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.‖ This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. Power quality can also be defined as a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy. Power distribution systems should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in power systems, especially the distribution systems have many nonlinear loads, which significantly affect the quality of power supplies. As a result of the nonlinear loads, the pure sinusoidal waveform is lost. This ends up producing many power quality problems. In power systems, different voltage and current problems can be faced. The main voltage problems can be summarized in short duration variations, voltage interruption, frequency variation, voltage dips and harmonics. Harmonics represent the main problem of currents of power systems. The short duration voltage variation is the result of the problems in the function of some systems or the start of many electric loads at the same time. The defaults can increase or decrease the amplitude of the voltage or even cancel it during a short period of time.

The increase of voltage is a variation between 10-90% of the nominal voltage. It can hold from half of a period to 1 minute according to the IEEE 1159-1995. According to the same reference, the increase in voltage is defined when the amplitude of the voltage is about 110-180% of its nominal value. The cutoff of the voltage happens when the load voltage decreases until less than 10% of its nominal value for a short period of time less than 1 minute. The voltage interruption can be the effect of defaults in the electrical system, defaults in the connected equipment‘s or bad control systems. The main characteristic of the voltage interruption is the period over which it happens. In the normal conditions the frequency of the distribution grid must be within the interval 50±1 Hz. The variations of the frequency of the grid can appears to the clients who are using auxiliary electric source (solar system, thermal station…etc.). These variations are rare and happen in the case of exceptional conditions like the defaults in the turbines.

The three phase system is unbalanced when the currents and voltages are not identical in amplitude; or when the phase angle between each two phases is not 120°. In the ideal conditions, the three phase system is balanced with identical loads. In reality, the loads are not identical, in addition to the problems of the distribution grids which can interfere. The voltage dips are periodic perturbations. They appear as a natural effect of the switching of the transistors. They are due also to the start of big loads like motors. Lifts, lights, heaters…etc. this phenomena causes bad functioning of the protection equipment’s. Power systems are designed to operate at frequencies of 50 or 60 Hz. However, certain types of loads produces currents and voltages with frequencies that are integer multiples of the 50 or 60 Hz fundamental frequency. These

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frequencies components are a form of electrical pollution known as harmonic distortion. There are two types of harmonics that can be encountered in a power system. Synchronous harmonics.ϖ Asynchronous harmonics.ϖ Synchronous harmonics are sinusoids with frequencies which are multiples of the fundamental frequency.

The multiplication factor is often referred to as the harmonic number. The synchronous harmonics can be subdivided into two categories. Sub-harmonics: when the harmonic frequency is less than the fundamental frequency.ϖ Super harmonics: when the harmonic frequency is more than the fundamentalϖ frequency. Harmonics are familiar to the musicians as the overtones from an instrument. They are the integer multiples of the instrument‘s fundamental or natural frequency that are produced by a series of standing waves of higher and higher order. Exactly the same thing happens in power circuits when non-linear loads create harmonic currents that are integer multiples of the supply fundamental frequency. The rapid growth of solid-state power electronics has greatly increased the number and size of these loads. The concept of harmonics was introduced in the beginning of the 19th century by Joseph Fourier. Fourier has demonstrated that all periodic non-sinusoidal signals can be represented by infinitive sum or series of sinusoids with discontinuous frequencies as given by Equation (2.1).

$(t) = I0 + \sum Ih \cos(h\omega t + \propto h{=}1\ \varphi h)$ …… (2.1)

The component I0 in the Fourier series is the direct component. The first term of the sum with the index h=1 is the fundamental of the signal. The rest of the series components are called the harmonics of the range h. Fig. 2.1 Shows the form of a wave containing the third harmonic (h=3). In the three phase electric grid, the principle harmonic components are the harmonics of ranges (6*h±1).

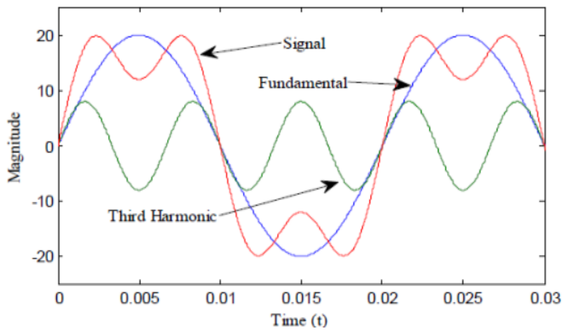

Fig. 1 Harmonic Content of a Signal and its Fundamental.

Transformer exciting current, arc furnaces, rectifiers and many other loads will produce harmonics in the utility lines. Most utilities limit the allowable harmonic current levels to the values shown

2.LITERATURE SURVEY

Grid-connected hybrid energy systems, particularly those involving wind, photovoltaic (PV), and battery storage, have gained significant attention as sustainable solutions to meet the growing global energy demand. These systems offer the potential to integrate renewable energy sources and optimize energy production while ensuring reliability and stability in power generation. The following literature survey reviews significant contributions in the field of hybrid energy systems, focusing on the integration of wind, solar, and battery storage, along with the methodologies, technological advancements, and challenges identified by researchers.

Several studies have explored the feasibility of integrating renewable energy sources like wind and solar into a unified hybrid system. Among the first studies, **Raza et al. (2013)** presented a hybrid energy system using both wind and solar resources integrated with battery storage to address the intermittency issues associated with renewable energy. The authors highlighted the importance of energy storage systems in balancing energy generation and consumption, particularly in locations with variable wind and solar resources. Their results suggested that battery storage could effectively stabilize the output, contributing to grid support and reducing the dependency on fossil-fuel-based generation. The combination of wind, solar, and storage ensured reliability in supplying power to remote areas.

A significant advancement in the field was made by **Sundararajan and Kothari (2014)**, who proposed a wind-PV-battery hybrid system with an optimized power management strategy. They developed an algorithm for optimal sizing and dispatching of energy between the wind, PV, and battery subsystems. Their study focused on maximizing the economic benefits of the system by reducing energy loss and improving the efficiency of the renewable sources. Additionally, they emphasized the importance of smart controllers that could respond dynamically to changes in renewable energy availability and grid demand. Their findings showed that the hybrid system could be economically competitive with conventional energy generation in areas with high solar and wind potential.

The work of **Nasser et al. (2016)** further explored the integration of wind and solar energy systems with battery storage for off-grid applications. They presented a methodology for the optimal sizing of components in the hybrid system, including the wind turbines, solar panels, and battery bank, based on historical climate data. The authors used simulation tools to model the system and optimize energy production, storage, and dispatch. The study demonstrated that the hybrid system could reduce the cost of electricity in remote areas and improve the reliability of power supply by providing backup power when renewable generation was insufficient.

Zhao et al. (2017) introduced a hybrid system that combined wind, solar, and battery storage for grid-connected applications, specifically focusing on system stability and voltage regulation. They developed a new control method for integrating the hybrid system with the grid that adjusted the power flow according to grid frequency variations. Their methodology aimed to maintain voltage stability during fluctuations in renewable energy generation, which is critical for preventing blackouts or voltage spikes. The authors showed that the hybrid system could support grid voltage regulation, improve the power quality, and provide ancillary services to the grid.

In another comprehensive study, **Ali et al. (2018)** investigated the dynamic operation and control strategies of a hybrid wind-PV-battery system in grid-connected mode. They proposed an advanced controller that used real-time forecasting of wind and solar energy generation to optimize the system's response to changing conditions. Their research revealed that forecasting techniques could improve the overall performance of hybrid energy systems by allowing better load matching, reducing curtailment, and enhancing grid stability. The authors emphasized the importance of accurate weather data and predictive analytics in improving the integration of renewables into grid-connected systems.

The integration of hybrid systems for grid-connected power generation was also explored by **Chong et al. (2019)**, who focused on the economic aspects and system performance under varying grid conditions. They performed cost-benefit analyses to understand the financial viability of installing wind-PV-battery systems in commercial and residential applications. Their results indicated that the hybrid system could lower electricity costs, improve energy security, and contribute to sustainability goals. They also highlighted the role of government incentives and subsidies in reducing the initial installation costs, making the system more accessible to the average consumer.

Furthering the field, **Kumar and Tripathi (2020)** presented an in-depth analysis of hybrid systems, focusing on the optimal power flow management strategies between the wind, PV, battery, and grid. They used an advanced optimization model to balance the energy flow between the system components and minimize energy losses. The study explored different operational scenarios, including peak demand, low renewable generation, and grid outages, and proposed solutions for each. The authors concluded that hybrid systems with effective optimization strategies could ensure a continuous and reliable power supply while reducing grid dependence and carbon emissions.

Bianchi et al. (2021) expanded the research to include the challenges of integrating hybrid energy systems into existing grid infrastructure. They addressed issues such as grid congestion, renewable generation variability, and the need for grid modernization. The authors proposed a hybrid microgrid system that combined wind, solar, and energy storage while integrating with smart grid technologies. They identified that the scalability of hybrid systems and their interaction with existing infrastructure are crucial factors for their widespread adoption. Additionally, they highlighted that energy storage systems, such as lithium-ion batteries, are crucial for providing the necessary grid support during renewable energy downtimes.

Yilmaz et al. (2022) investigated the environmental impact of grid-connected hybrid systems by conducting a life cycle assessment (LCA) to evaluate their sustainability. The study concluded that integrating wind, solar, and battery storage resulted in a substantial reduction in carbon footprint compared to traditional fossil fuel-based power generation. Their findings showed that, while the manufacturing of renewable energy technologies and batteries has environmental impacts, these are significantly outweighed by the long-term benefits of reduced greenhouse gas emissions and improved energy efficiency.

In a more recent study, **Wang et al. (2023)** proposed an innovative energy management strategy for grid-connected hybrid systems that utilizes artificial intelligence (AI) and machine learning (ML) to predict and optimize energy production, storage, and dispatch. They demonstrated that AI could be used for load forecasting, predictive maintenance of system components, and real-time decision-

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making to optimize the operation of hybrid energy systems. The authors argued that AI-driven solutions could enhance the flexibility and adaptability of hybrid systems, allowing them to respond dynamically to fluctuating energy demand and generation conditions.

3.METHODOLOGY

The grid-connected wind-PV-battery-based hybrid energy system is a modern approach to power generation that integrates renewable energy sources with energy storage and grid connectivity. This system aims to maximize the use of clean energy while ensuring a stable and reliable power supply for the grid. The hybrid system combines wind energy, solar energy, and battery storage to provide continuous and sustainable power generation, which is highly beneficial in the context of growing concerns about environmental sustainability and energy security.

In the proposed methodology, the authors describe an advanced framework that utilizes both wind and solar power generation technologies, coupled with a battery storage system, to optimize power generation, storage, and distribution. Wind energy is harvested through wind turbines, which convert the kinetic energy of the wind into electricity. Solar energy is generated through photovoltaic (PV) panels, which convert sunlight into electricity. The battery storage system is essential for managing the intermittent nature of both wind and solar power, storing excess energy produced during periods of high generation and releasing it when demand exceeds generation or when renewable energy sources are unavailable.

The system is connected to the electrical grid, which allows for the exchange of power between the hybrid system and the utility grid. In this setup, the hybrid system can supply electricity to the grid when renewable generation exceeds the demand, and it can also draw electricity from the grid during times when renewable generation is insufficient, ensuring a continuous and reliable power supply.

The methodology proposed by the authors focuses on the optimization of power generation and distribution by employing advanced control algorithms and power electronics. These technologies are designed to manage the varying output of wind and solar energy, ensuring that energy is delivered to the grid in an efficient manner. The authors emphasize the importance of energy storage systems, which are critical in maintaining system stability. The battery management system (BMS) regulates the charging and discharging of the batteries, ensuring that they operate within optimal parameters and that excess energy is stored for later use.

The integration of these technologies requires sophisticated algorithms for forecasting energy production, predicting energy demand, and managing the storage and distribution of energy. The authors' methodology focuses on enhancing the coordination between the wind turbines, PV panels, and the battery storage system to create a hybrid energy system that is both efficient and reliable. By carefully managing the interaction between these components, the authors argue that the system can achieve a high degree of energy efficiency, reduce reliance on fossil fuels, and lower greenhouse gas emissions.

4.PROPOSED SYSTEM

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The proposed system also takes into account the economic feasibility of such hybrid energy systems. The authors recognize that the initial cost of installing a wind-PV-battery hybrid system can be significant, but they argue that the long-term benefits, including reduced energy costs, lower emissions, and the potential for grid stabilization, make the investment worthwhile. Furthermore, the proposed system enhances energy security by reducing dependence on the centralized power grid and diversifying the sources of power generation.

The authors propose that grid-connected hybrid energy systems like this can be particularly effective in regions where both wind and solar resources are abundant, and where there is a need for reliable and sustainable power generation. These systems can provide a flexible and resilient energy supply, reducing the vulnerability of the grid to outages and disruptions. Additionally, the use of renewable energy resources helps to mitigate the negative environmental impacts associated with traditional power generation methods, including the reduction of greenhouse gas emissions and air pollution.

5.SIMULATION RESULTS

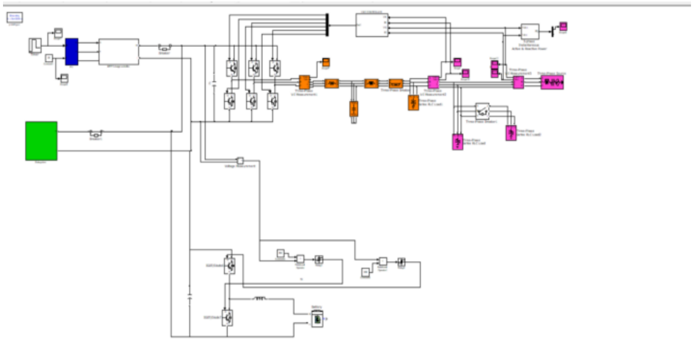

FIG 5.1 SIMULATION CIRCUIT

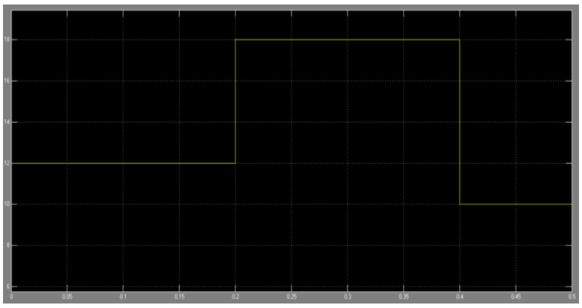

FIG 5.2 Wind speed vs time

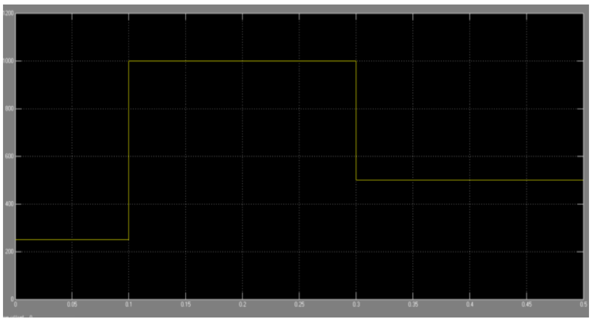

FIG 5.3 Solar panel input temp vs time

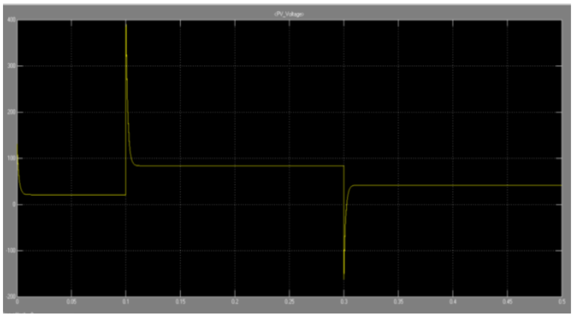

FIG 5.4 Pv voltage vs time

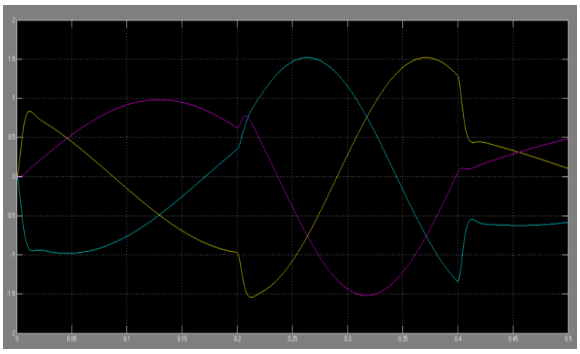

FIG 5.5 Wind voltage vs time

FIG 5.6 Inverter output voltage vs time before filtering

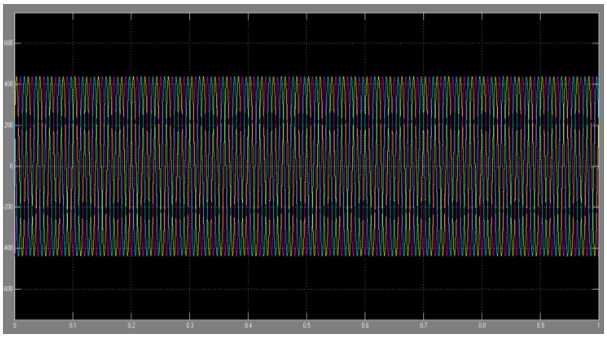

FIG 5.7 Inverter output voltage after filtering

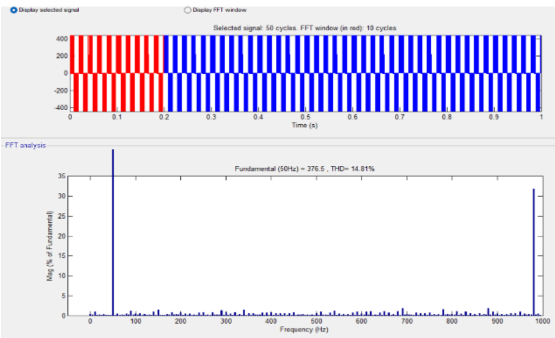

Fig 5.8 Harmonic distortion (Before upgrade)

Extension of grid connected wind-pv-battery based hybrid energy system

A grid-connected Wind-PV-Battery based hybrid energy system integrates wind and solar power generation with battery energy storage and connects to the electrical grid. This system optimizes energy harvesting, reduces dependence on fossil fuels, and improves power quality.

When wind and solar generation exceeds the load demand and the battery is fully charged, the excess power can be sent to the grid. This can generate revenue via net metering or feed-in tariffs.
The grid plays a very important role in a grid-connetced wind -pv-battery hybrid energy system. When solar and wind can't generate enough, and the battery is empty, the grid provides power to the load.

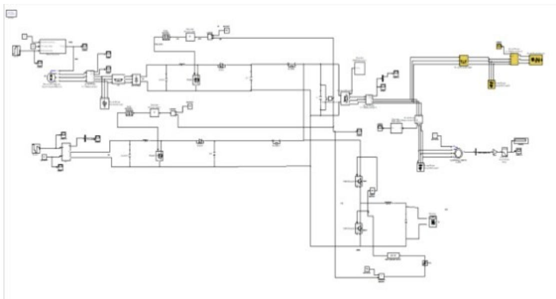

FIG 5.9 Power generation of wind-pv-battery based hybrid energy system

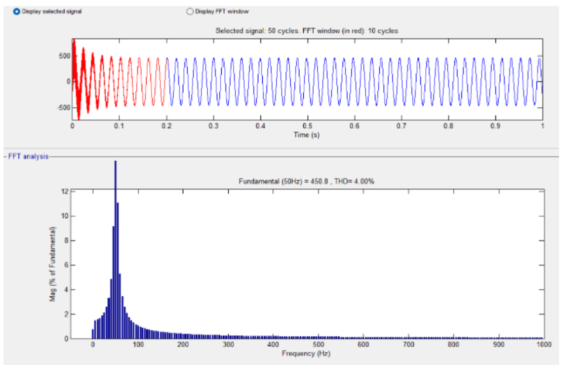

Fig 5.10 Harmonic distortion (After upgrade)

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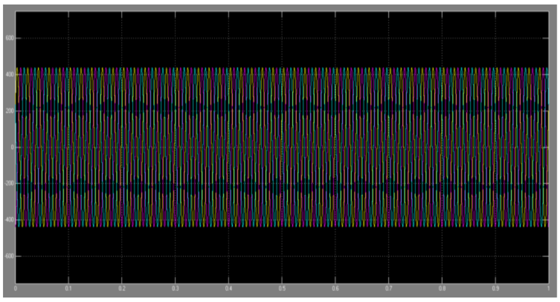

FIG 5.11 Grid voltage vs time

6.CONCLUSION

In conclusion, the simulation of a grid-connected solar-wind hybrid power system presents a promising avenue for sustainable energy generation. Through comprehensive analysis and modeling, this study has demonstrated the feasibility and efficacy of integrating solar and wind energy sources into the existing power grid infrastructure. The findings reveal several key advantages of this hybrid system, including increased reliability and stability of power supply, reduced dependence on fossil fuels, and mitigation of greenhouse gas emissions. Additionally, the optimization algorithms employed in the simulation have shown significant potential for maximizing energy output and minimizing operational costs. However, it's crucial to acknowledge some challenges and limitations. Variability in weather conditions and intermittency of renewable energy sources pose operational challenges that require sophisticated control strategies and energy storage solutions for optimal performance. Moreover, economic feasibility and policy support are essential factors for the widespread adoption of such systems. Overall, this research contributes valuable insights into the design, optimization, and implementation of grid-connected solar-wind hybrid power systems, highlighting their role in transitioning towards a more sustainable and resilient energy future. Continued research and innovation in this field are imperative to address remaining challenges and accelerate the global transition to renewable energy

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