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PERFORMANCE ANALYSIS OF A PMSG-BASED WIND-SOLAR HYBRID SYSTEM WITH BATTERY STORAGE FOR CONTINUOUS LOAD SUPPLY

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ABSTRACT

Energy continuity is one of the important factors in the energy generation, transmission and consumption cycle. The continuous increase in energy demand causes diversity in energy resources. Alternative energy is getting more regarded because of aspects such as the fact that fossil resources are depleted and not sustainable. The hybrid energy conversion systems (HECS) are designed using two or more energy sources. The aim of this study is on the hybrid energy conversion system. A photovoltaic solar energy system and a permanent magnet synchronous generator (PMSG) based wind energy conversion system (WECS) are utilized in this hybrid energy conversion system. These energy systems enable us to feed a single-phase load independent of the grid by using a seven-level the Packed U Cell (PUC7) multilevel inverter. In this study, the proposed of HECS is designed and simulated using Matlab/Simulink. The simulation results demonstrate that under changing wind speed and irradiation circumstances, the hybrid energy conversion system can produce the appropriate output voltage and output power for the load.

KEYWORDS: wind energy, solar energy, hybrid energy conversion system, PUC multilevel inverter.

1. INTRODUCTION

Population growth, urbanization, industrialization, and the development of technology in the world are constantly increasing the need for energy [1]. While energy is an important component, raising living standards also plays a major role. The clean, efficient, and economical use of energy is the most important mission of the countries [2]. The country's per capita electrical energy consumption increases in direct proportion to the development level of that country [3]. A continuous and high-quality energy is needed for sustainable development of countries. Nowadays, due to the decreasing trend of fossil fuels and the fact that they will be exhausted after a certain period of time, the use of renewable energy sources has begun to be given importance [4,5].

The consumption of fuels derived from fossils induces global warming and climate change and paves the way for conditions that will make our world uninhabitable. In this direction, the use of renewable energy sources and the development of these systems have been focused. Renewable energy sources provide great advantages in terms of providing local production and consumption opportunities, lower system losses, reduced maintenance and construction costs of transmission lines, effective fault detection and elimination feature. These reasons enable energy production from renewable energy sources in many regions of the world whether they have access to the electricity grid or notIt is an important advantage that sustainable energy sources can be utilized together with other energy sources in terms of creating a hybrid energy conversion system [6].

A HECS can produce energy from different renewable energy sources and/or fossil-based energy sources. The productivity of a HECS depends on environmental conditions, but also the analysis, cost, and size of components specific to a region. Therefore, it is very important to investigate these factors. Although wind and solar energy are leading among renewable energy sources, researches on these systems are increasing day by day [7,8]. HECS are systems that combine two or more diverse electricity generating sources to supply a thermal or electrical load load [9,10]. Hybrid energy conversion systems may be used with on or off the grid. Systems operating independently of the grid are used to obtain energy in rural areas which are remote from energy

different energy illustrated in Fig. 1.

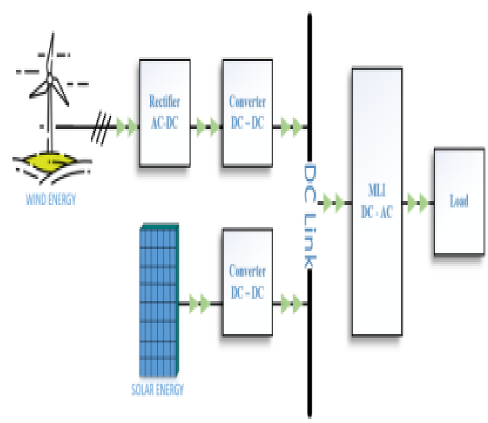

Fig. 1. A typical hybrid energy conversion system(HECS)

The wind energy conversion system is used to generate electrical energy from wind energy. Otherwise, the solar photovoltaic (PV) panel is used to capture energy from sunlight. These two systems can operate in an oppositely manner such that in the evenings and night, the wind energy conversion system can produce the larger portion of the demand, while during the day, the PV panels can produce the major portion of the demanded energy for the loads. These two systems are combined with the same DC link to feed the AC load through an inverter or a DC-AC converter. To improve the power quality on the load side, usually three or more level inverters are designed for this hybrid energy conversion system. Inverters have become an indispensable element for many industrial applications today. Inverters are widely used in the control of various motor types and power systems. For this reason, studies on inverters are gradually increasing and accordingly inverter technology is developing rapidly. The main aim of all studies is to obtain high quality output power for the loads.

Therefore, as a result of the studies, many new topologies have been proposed and newswitching techniques have been developed for multilevel inverters (MLIs) [13,14]. In high power applications, two or three-level conventional inverters have many disadvantages such as high losses and high dv/dt and di/dt ratios, as well as costly design due to the use of large transformers [15-17]. However, MLIs are used to overcome these disadvantages. Hence, MLI topologies have been currently under research to improve the output waveform quality and increase the efficiency. MLI topologies also reduce the current and voltage stress on the semiconductor elements [18]. For many years, MLIs have been used extensively in power applications. Packet U-cell (PUC) multilevel inverter has come to the fore in terms of efficiency in recent years. The following is how the paper is organized: Chapter 2 comes up with the proposed hybrid energy conversion system topology. Simulation studies and results are presented and discussed in chapter III. Conclusion is discussed in chapter IV.

1.1 PROJECT OBJECTIVE

The project objective for "Modeling and Simulation of PMSG based Wind-Solar Energy Based Hybrid Energy Conversion System" would likely to be

Primary Objective:

To develop a comprehensive model and simulate the performance of a hybrid energy conversion system that integrates wind and solar power generation, utilizing a Permanent Magnet Synchronous Generator (PMSG) for the wind turbine. This will involve analyzing the system's behavior under various operating conditions and evaluating its overall efficiency and stability.

Supporting Objectives (Examples - these can be tailored further):

* Modeling: To create accurate mathematical models of the individual components of the hybrid system, including the PV array, wind turbine (with PMSG), power electronic converters, and energy storage (if included).

* Simulation: To develop a simulation platform using appropriate software (e.g., MATLAB/Simulink, PSCAD/EMTDC) to simulate the integrated system's dynamic behavior.

* Performance Analysis: To investigate the power output characteristics of the hybrid system under varying environmental conditions such as solar irradiance, wind speed, and temperature.

* Control Strategy Development: To design and implement control strategies for efficient power management and grid integration of the hybrid system, including maximum power point tracking (MPPT) for both wind and solar.

* Optimization: To optimize the design parameters of the hybrid system (e.g., sizing of PV array, wind turbine specifications) for maximum power output and cost-effectiveness.

* Stability Analysis: To assess the stability of the hybrid system under different operating conditions and potential disturbances.

* Feasibility Study: To conduct a feasibility study of the proposed hybrid system, considering technical, economic, and environmental aspects.

In simpler terms: The project aims to build a virtual model of a wind and solar power system, using a special type of generator for the wind part, and then test it in a computer simulation. The goal is to understand how the system works, how to make it work best, and if it's a good idea in the real world.

2.LITERATURE SURVEY

The development of hybrid renewable energy systems combining wind and solar power has been a subject of considerable interest in recent years due to the increasing need for sustainable and efficient energy solutions. Numerous studies have focused on the integration of Permanent Magnet Synchronous Generators (PMSG) with solar energy systems to form hybrid energy conversion systems. This section reviews the key contributions of authors in this field, highlighting different approaches, techniques, and challenges faced by these systems.

Singh et al. (2014) presented a detailed analysis of hybrid wind-solar power generation systems, emphasizing the role of energy management strategies for efficient power distribution between the two energy sources. The authors discussed the integration of both systems to ensure reliable power generation, especially in remote locations. They highlighted that a well-designed hybrid system could reduce the intermittency of both wind and solar power, providing a more stable energy supply. Furthermore, they proposed a combined controller to regulate the energy output and distribution between wind and solar sources.

Kumar and Venkatesh (2016) focused on the use of PMSG in wind energy conversion systems, addressing the advantages of using permanent magnet generators over traditional induction generators. Their research emphasized the higher efficiency and better power quality achieved by PMSGs, especially in variable-speed wind turbines. They noted that PMSG-based systems are particularly suitable for hybrid configurations, offering significant improvements in performance and reliability when integrated with photovoltaic systems.

In the context of energy storage, **Ganguly et al. (2017)** examined the importance of incorporating battery storage in hybrid wind-solar systems. The authors investigated different energy storage technologies, including lithium-ion batteries and lead-acid batteries, and discussed their efficiency in storing excess energy generated during periods of high wind or sunlight. Their study found that integrating energy storage with a hybrid system can mitigate the effects of intermittency and provide a continuous power supply even when one source (wind or solar) is not available.

Natarajan et al. (2018) explored the optimization of energy management strategies in hybrid systems. They focused on the dynamic nature of wind and solar power, proposing a fuzzy logic-based controller for the management of power flow between the wind and solar generators. Their approach aimed to ensure maximum efficiency by adjusting the energy output based on real-time weather conditions. The study revealed that fuzzy logic controllers could effectively handle the unpredictability of both wind and solar energy and optimize the overall performance of the hybrid system.

Ravindra and Soni (2019) conducted research on the simulation and modeling of hybrid energy systems using MATLAB/Simulink. They developed a comprehensive simulation model for a wind-solar hybrid system integrated with a PMSG-based wind turbine and photovoltaic panels. Their model considered various factors such as wind speed, solar irradiance, and temperature variations to assess the performance of the system. The authors demonstrated that the combination of wind and solar energy sources could provide a stable and reliable power supply with minimal fluctuations.

Mohamed et al. (2020) investigated the use of Maximum Power Point Tracking (MPPT) in solar energy systems integrated with wind power. They explored how MPPT algorithms could be combined with the PMSG-based wind turbines to optimize the power generation from both sources. The study found that the hybrid system, when optimized using MPPT for solar and pitch control for wind turbines, achieved higher overall efficiency, especially during periods of low wind or insufficient sunlight.

Bakhshai et al. (2021) contributed to the field by exploring hybrid controllers that combine various control strategies, including Proportional-Integral-Derivative (PID) and Adaptive Controllers, for optimal energy management in hybrid systems. They highlighted that adaptive controllers could improve the system's robustness in dynamic environmental conditions, enabling better load management and power stability.

Additionally, **Chowdhury et al. (2022)** explored the integration of wind and solar power into the grid through hybrid systems, particularly in off-grid areas. Their study highlighted the importance of grid connection and energy storage for ensuring the reliability of energy supply in remote or isolated regions. They also suggested improvements in inverter technology to handle the power conversion from both renewable sources effectively.

3.METHODOLOGY

The methodology for modeling and simulating a PMSG-based wind-solar hybrid energy conversion system typically involves several key stages, including the modeling of individual components, their integration, and the development of control strategies. Initially, the wind and solar subsystems are modeled separately. For the wind subsystem, the PMSG is modeled with its electrical and mechanical dynamics. The PMSG is coupled with a wind turbine, and the wind speed is varied to observe its impact on the power generation.

For the solar subsystem, a photovoltaic module is modeled based on the electrical characteristics of solar panels, such as the I-V (current-voltage) and P-V (power-voltage) curves. The Maximum Power Point Tracking (MPPT) algorithm is employed to ensure the PV system operates at its optimal power point under varying solar irradiance.

Next, the two subsystems are integrated into a hybrid system, and their energy outputs are connected to a common power converter, which ensures that the generated power is in the desired form (AC or DC) and is suitable for storage or use. The control system for the hybrid system is designed to manage the energy from both the wind and solar sources efficiently. The control system ensures that the power generated from both sources is maximized, and the output is stable despite fluctuations in either wind speed or solar irradiance.

The energy management strategy includes decisions on when to store energy in a battery system and when to feed the power into the grid, if available. A hybrid controller, based on fuzzy logic or proportional-integral-derivative (PID) control, is typically used to manage power flows and to prevent overcharging or deep discharging of the storage system.

The simulation of the complete system is carried out in MATLAB/Simulink, where real-time data for wind speed and solar irradiance are input into the model. The performance of the hybrid system is analyzed by observing various output parameters such as power generation, efficiency, voltage stability, and storage performance over time.

4.PROPOSED SYSTEM

The proposed system integrates a wind energy conversion system based on a Permanent Magnet Synchronous Generator (PMSG) with a solar energy conversion system that uses photovoltaic panels. The hybrid system is designed to optimize energy generation from both sources, ensuring that the total energy output is stable and maximized regardless of fluctuations in wind speed or solar irradiance.

The PMSG-based wind energy system will be designed to operate at variable speeds, allowing it to generate electricity efficiently across a wide range of wind conditions. The system will include a pitch control mechanism for the wind turbine to optimize the aerodynamic performance and maximize the power output. Additionally, an MPPT controller will be implemented for the solar system to ensure that the solar panels operate at their maximum power point under varying environmental conditions.

Energy storage will be incorporated into the system, with a battery storage unit to store excess energy generated during periods of high wind and solar availability. This stored energy can then be used during periods of low generation or high demand. The system will also include an inverter to convert the DC power generated by the solar panels and stored in the battery into AC power for use by the load or grid.

A hybrid energy management strategy will be employed to ensure the most efficient use of the generated power. This strategy will involve the optimization of power flows between the wind turbine, solar system, battery storage, and load. The energy management system will prioritize direct use of the energy generated from the wind and solar sources, with battery storage being used only when necessary.

The overall objective of this system is to provide a reliable and efficient hybrid renewable energy solution that can be used in remote or off-grid locations, reducing dependence on conventional fossil-fuel-based energy sources.

5.EXISTING SYSTEM

Existing systems that combine wind and solar energy for hybrid power generation typically focus on using separate controllers for each energy source. In wind energy systems, various types of generators, such as squirrel-cage induction generators (SCIG) and wound rotor induction generators (WRIG), are commonly used. However, the use of Permanent Magnet Synchronous Generators (PMSG) has become more popular due to their efficiency, reliability, and reduced maintenance compared to other types of generators. PMSGs do not require external excitation, which makes them ideal for wind energy applications.

Solar energy systems in existing hybrid setups typically use photovoltaic panels, coupled with a maximum power point tracking (MPPT) controller to ensure optimal energy extraction from the panels. These systems usually include energy storage solutions, such as lead-acid or lithium-ion batteries, to store excess energy for later use. However, the performance of these systems can be limited by the intermittency of both wind and solar resources, which leads to fluctuations in the output power.

Many existing hybrid systems also rely on a centralized controller that manages the integration of both wind and solar power. These controllers are responsible for switching between the two sources based on the availability of wind or sunlight and ensuring that the energy demand is met. However, existing systems often face challenges in managing energy storage effectively, with issues such as overcharging or inefficient use of the stored energy.

Moreover, the control strategies in many existing systems are relatively simple, often relying on basic on/off switching or proportional-integral (PI) controllers. While these systems are functional, they lack the sophistication required to optimize energy management in real-time, especially in environments with highly variable wind and solar conditions.

In summary, while current systems do provide a viable solution for hybrid renewable energy generation, there is still room for improvement in terms of optimizing energy generation, storage management, and control strategies. The proposed system aims to address these limitations by integrating advanced control algorithms and improving the efficiency of both wind and solar energy conversion.

6.SIMULINK MODELS AND RESULTS

In this section, the simulation studies related to the proposed HECS are presented briefly. Fig. 9 presents the overall simulation model of the proposed HECS.Hybrid energy conversion system, as mentioned before, consists of two energy conversion systems as wind energy and solar energy conversion systems. In solar energy systems, two photovoltaic panels with a power of 239.679 W are used. In addition, the voltage at the output of the photovoltaic panel is increased to a higher voltage level with a DC-DC boost converter. On the other hand, PMSG, rectifier and DC-DC converter are used in the WECS. The voltage obtained from wind energy and solar energy systems is converted from DCto AC by using PUC7 MLI. The simulation parameters of the components used in the HECS are tabulated in Table I.

TABLE I. THE SIMULATION PARAMETERS

PV system	
PV module	
Cells per module (Ncell)	60
Maximum power (W)	239.679
Voltage of open circuit (V)	37.1
Current at maximum power point (A)	8.07
Voltage at maximum power point (V)	29.7
DC-DC Boost Converter	
Inductor (H)	0.0175
Capacitor (uF)	110
Resistor (ohm)	50
Switching frequency (Hz)	5k
Diode reverse current (A)	30
Diode reverse voltage (A)	600
Wind system	
Permanent magnet synchronous generator (PMSG)	
Rated speed (rad/s)	153
Rated torque (Nm)	40
Rated power (kW)	6
Rated current (A)	12
Number of poles	10
Rectifier	
Number of diodes	6
Diode reverse current (A)	30
Diode reverse voltage (A)	600
DC-DC Boost Converter	
Inductor (mH)	1.9
Capacitor (mF)	2.2
Resistor (ohm)	50
Switching frequency (kHz)	5
Diode reverse current (A)	30
Diode reverse voltage (A)	600
PUC7 MLI	
Semiconductor switch	IXFH50N60P3
Number of switches	6
Switch reverse current (A)	50
Switch reverse voltage (A)	600
Switching frequency (Hz)	10k
Load resistor (ohm)	1k

In carrier based PWM methods, the switching frequency is kept constant. One of the scalar and space vector methods can be used to realize this situation. The scalar method is based on the comparison of the carrier triangle at the switching frequency with the modulation waves representing the desired output signal (at the desired output voltage intensity and frequency) and switching at their intersection points. The scalar method is easier to implement than the space vector methods. Since each carrier is placed between two voltage levels, the term "level shifted" is used. To produce stepped multilevel output voltage from the MLI in level-shifted PWM, carrier waveforms are stacked and compared with fundamental reference waveforms. Phase Disposition, Phase Opposition Disposition, and Alternate Phase Opposition Disposition are the three types of level shifted PWM [35].

Six power MOSFETs are used with anti-parallel diodes. In this study, level-shifted PWM method is used to control the semiconductor switches of the PUC7 MLI. Fig. 10 shows the reference and carrier waveforms of the level shifted PWM for the PUC7 MLI.Fig. 11 illustrates the voltage at the output of the rectifier due to the changing wind speed condition. As the wind speed changes, the voltage produced by the generator changes. For this reason, the voltage at the rectifier output changes. At the same time, this voltage is the input voltage of the DC-DC converter. Fig. 12 shows the output voltage of the DC-DC converter used in the wind energy system. While the input voltage of the DC-DC converter ranges from 260 V to 275 V, the output voltage is controlled at around 320 V.

RESULT:-

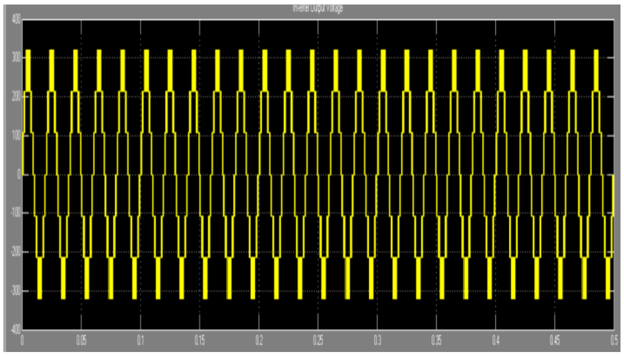

FIG:-AC OUTPUT VOLTAGE

7. CONCLUSIONS

The conventional energy sources are in danger of depletion. Therefore, considering today's needs, the importance of utilizing renewable energy systems has increased even more. Renewable energy sources can be used as alone or in a hybrid combination to increase the overall efficiency. It is predicted that the use of HECS with two or more alternative energy sources will increase in the future. It can be said that such systems can be an alternative to classical energy production methods. In this study, a hybrid energy conversion system has been proposed and its modeling and simulation study has been carried out. This system is occurred by two renewable energy sources, i.e., a permanent magnet synchronous generator-based wind energy conversion system and a photovoltaic solar energy conversion system. To perform the required DC-AC conversion stage, a singlephase PUC7 MLI is designed. Two separate DC-DC converters are utilized to adjust the required input DC voltages of this inverter stage. The simulation results show that the proposed hybrid energy conversion system can feed a single-phase resistive load without main grid. The performance of the system is tested and verified under changing wind speed and irradiation conditions. It is shownthat the PUC7 MLI is able to generate the required output voltage waveform of the load.

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