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HYBRID INVERTER FOR RURAL ELECTRIFICATION

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ABSTRACT

Generating electrical energy in remote areas is challenging due to the scarcity of energy sources. This paper presents a standalone hybrid solar and wind energy system designed for rural electrification. The system maximizes solar power extraction using the Perturb and Observe (P&O) method for Maximum Power Point Tracking (MPPT) and employs a Permanent Magnet Synchronous Generator (PMSG) to convert wind kinetic energy into electrical energy. A five-level Cascaded H-Bridge Inverter is used to convert DC power to AC. To minimize Total Harmonic Distortion (THD), an LC filter is implemented, with results verified through Fast Fourier Transform (FFT) analysis. The hybrid energy system model is simulated using MATLAB/Simulink.

Keywords: Hybrid system, solar and wind generation, Multi-Level Inverter (MLI), Cascaded H-Bridge, Total Harmonic Distortion.

I. INTRODUCTION

Conventional energy sources present significant environmental challenges and are depleting rapidly, making it essential to transition to renewable energy systems to meet rising energy demands. Renewable energy sources are clean, eco-friendly, and well-suited for installation in rural areas. In remote regions, producing electrical energy is difficult due to inefficient diesel power plants, high production costs, and the absence of nearby power infrastructure. Urbanization and industrialization further increase energy demand, making renewable energy a viable alternative to traditional sources. Solar and wind

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energy are abundant in nature and can be reliable sources of electricity generation. Hybrid solar and wind energy systems offer a practical solution for rural electrification.

Solar power generation fluctuates with environmental conditions, and the Perturb and Observe algorithm is commonly used for optimizing PV panels to achieve maximum power point tracking (MPPT) for improved photovoltaic application efficiency. Energy can also be stored for consistent power supply despite the irregular nature of wind and solar resources. The proposed system combines standalone solar and wind systems into a hybrid setup, where the generated power is converted to alternating current using a multilevel inverter. The five-level H-Bridge inverter enhances AC power quality by performing the conversion in smaller voltage steps. Compared to conventional inverters, the multilevel inverter (MLI) offers lower THD, reduced voltage stress across switches, and higher power ratings.

This paper introduces a standalone solar-wind hybrid energy system integrated with a multilevel inverter. The P&O algorithm-based MPPT is utilized to track maximum power for PV applications, and simulations are conducted in MATLAB/Simulink. Section I and II outline the system and proposed methodology, while Section III describes the essential components of the hybrid system. Simulation results and conclusions are presented in Sections IV and V.

II. PROPOSED METHODOLOGY

The proposed hybrid energy system combines solar and wind power sources. The system block diagram shows the solar PV array connected to an inverter via a boost converter to step up the DC voltage. The Maximum Power Point Tracking (MPPT) system is implemented to maximize solar energy extraction. The wind turbine is connected to the inverter through a Permanent Magnet Synchronous Generator (PMSG), which converts the wind's mechanical energy into AC electrical energy. This AC is then rectified to DC power. The DC bus charges the battery, and the voltage is converted to AC by a five-level H-Bridge inverter. The output from the inverter is AC, which is supplied to the load.

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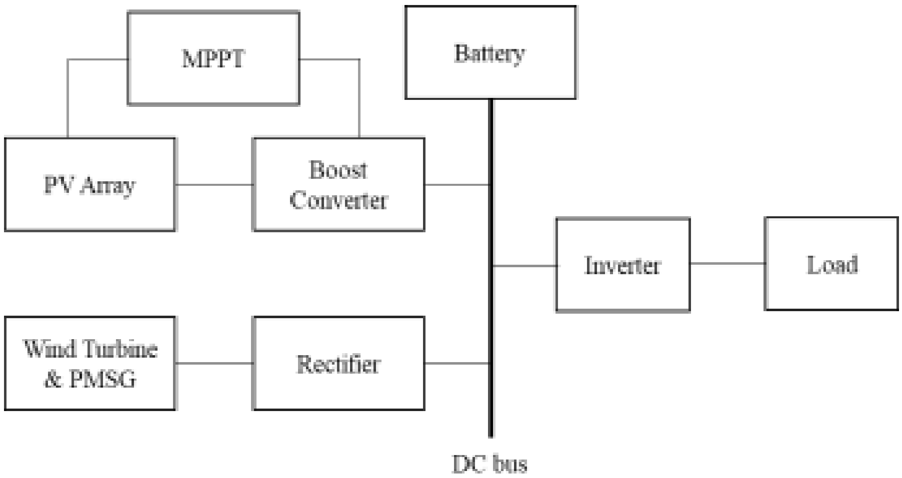

Fig 1: Block diagram of Hybrid renewable energy system

III. HYBRID RENEWABLE ENERGY SYSTEM

The standalone hybrid renewable energy system integrates wind and solar modules to supply power to rural areas using essential power electronic circuits.

1. Solar Energy System:

The solar system consists of PV panels, a boost converter, and an MPPT technique.

PV Panel:Photovoltaic (PV) cells are the primary components of the solar system, converting sunlight into electricity. PV cells are connected to form a PV module, which is further interconnected to create the required PV arrays. Adequate numbers of PV cells are connected in series for sufficient output voltage and in parallel for higher output current.

MPPT:The Maximum Power Point Tracking (MPPT) method optimizes the photovoltaic module's performance. The power output of a PV panel fluctuates with light intensity and temperature. The MPPT technique is employed to track the maximum available power in varying environmental conditions. In the proposed system, the Perturb and Observe (P&O) MPPT algorithm continuously adjusts the operating voltage and current of the PV panel to achieve maximum power.

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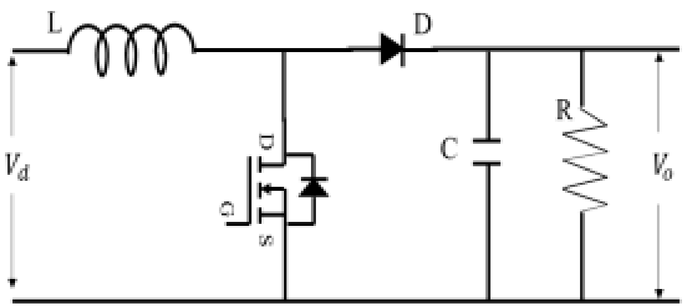

Fig 2: Boost Converter

Boost Converter:A boost converter, a type of DC-DC converter, steps up the voltage level. The output voltage V_o is related to the input voltage V_d by the expression $V_o = \frac{V_d}{1-D}$, where D is the duty cycle obtained from the MPPT block. The controlled output voltage from the boost converter is supplied as input to the inverter via the DC bus.

2. Wind Energy System:

The wind power system includes a wind turbine, generator, and rectifier. The wind turbine converts the linear motion of air into kinetic energy using blades attached to the turbine. This rotational energy drives the Permanent Magnet Synchronous Generator (PMSG), which generates three-phase AC electric power. PMSG is preferred for its low cost, minimal maintenance, high efficiency, and the absence of a need for DC field excitation.

Three-Phase Rectifier:To integrate the wind system with the solar system, a three-phase rectifier circuit is used to convert the AC voltage from the PMSG to DC, ensuring compatibility with the DC output from the solar system.

3. Inverter:

A multilevel inverter converts DC to AC, primarily used in high and medium power applications. It reduces Total Harmonic Distortion (THD) by increasing the steps in the output waveform, approaching a near-sinusoidal waveform.

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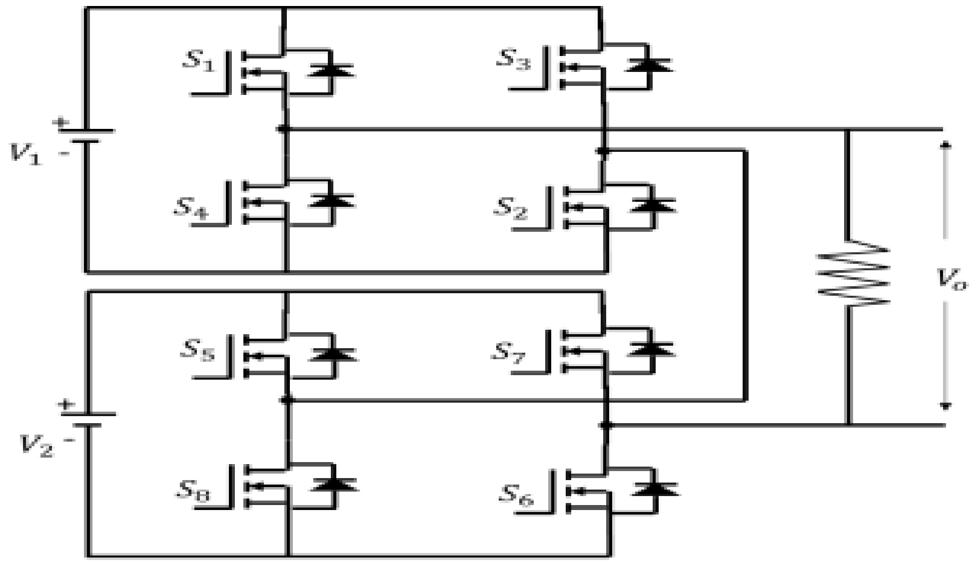

Fig 3: Cascaded H bridge converter

The five-level Cascaded H-Bridge multilevel inverter consists of two full-bridge inverters connected in series. The output voltage levels are \(2V\), \(V\), \(0\), \(-V\), and \(-2V\). If \(m\) represents the output voltage level, then \(2*(m-1)\) switches are required. This converter generates a smooth sinusoidal waveform from the input voltage produced by the hybrid system. The inverter's switching states are controlled by a pulse width modulation technique to reduce harmonic distortion. The switching sequence for a five-level Cascaded H-Bridge inverter is detailed in the following table.

Mode	+2V	+V	0	-V	+2V
S_1	1	1	1	0	0
S_2	1	1	0	0	0
S_3	0	0	1	1	1
S_4	0	0	0	1	1
S_5	1	0	1	0	0
S_6	1	1	0	1	0
S_7	0	0	1	0	1
S_8	0	1	0	1	1

IV. SIMULATION MODEL AND RESULTS:

The proposed methodology is implemented using MATLAB/Simulink. The simulation model of the boost converter is integrated with the PV array. The MPPT block output is fed to the MOSFET switch. The boost converter increases the PV array's output power. The inductor in the boost converter is set to 20mH, the capacitance \(C = 500\mu F\), and \(C_1 = 3000\mu F\), producing an output power of 2094W.The wind power generation model is designed using PMSG. The wind turbine's nominal mechanical output power is set to 2000W at a base wind speed of 12 m/s. The five-level Cascaded H-Bridge inverter is integrated with the phase shift pulse width modulation (PS PWM) technique, with the modulated carrier signal displayed. The phase disposition pulse width modulation (PD PWM) technique is used with the inverter and the carrier signal of the PWM. The solar power and rectified wind power are integrated with the five-level Cascaded H-Bridge multilevel inverter. An LC filter is designed to further reduce the Total Harmonic Distortion (THD) of the output. The final simulation is shown, and the inverter's output voltage with harmonics is displayed. The Total Harmonic Distortion of the output is reduced to 3.21% using the LC filter, as verified by FFT analysis.

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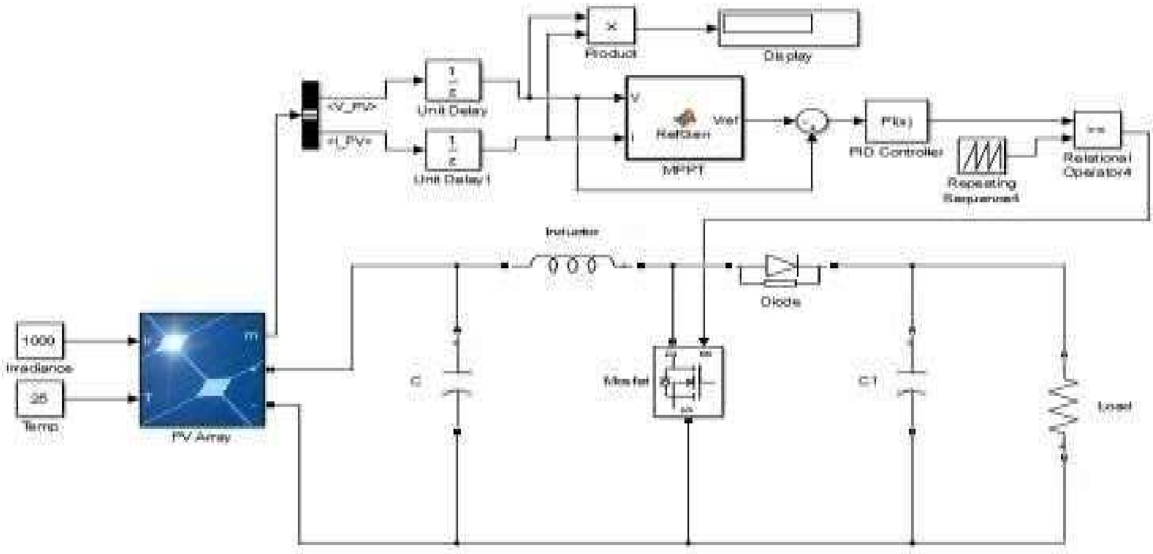

V. CONCLUSION

Hybrid PV-Wind model is proposed to meet the load demands in rural areas and it is better alternative to conventional energy to provide uninterrupted power. The modeling of hybrid system with five level cascaded multilevel inverter is built using MATLAB Simulink. Total harmonic distortion has been reduced and can be observed in FET analysis. The proposed hybrid model of wind and solar renewable energy system can be connected to the grid in future and multilevel inverter can be analyzed for different output levels by changing the modulation index and switching frequency.

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