Design and Analysis of Intelligent MPPT for Multisource Renewable Systems Using Fuzzy-Controlled DC-DC Converters

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Abstract: Intelligent max power point tracking (MPPT) of hybrid renewable sources is the design and analysis which is presented in this paper. The system integrates solar energy, wind energy and battery backup to provide a stable and consistent power supply. The MPPT process is controlled by a fuzzy logic-based controller, which is faster and more efficient than the traditional approach. The DC-DC converter links each source to permit adaptive control to changing weather and load conditions. The model is designed and simulated in MATLAB/ Simulink and the simulation results indicate that the fuzzy MPPT model enhances the energy conversion efficiency, minimizes power losses and offers stability to hybrid renewable system. This renders the proposed approach appropriate to off-grid and distributed energy systems where reliability is paramount.

***Keywords: Fuzzy logic controller, MPPT, hybrid renewable system, solar energy, wind energy,* DC-DC converter, battery storage, MATLAB/Simulink.**

I. INTRODUCTION

Increasing worldwide energy demands based on clean and trusted energy has led to the quickening of research on renewable power technologies, especially that of solar and wind systems. As people grow more environmentally concerned and fossil fuels are quickly becoming depleted, renewable energy sources are becoming critical to sustainable development and carbon reduction. Nonetheless, there are issues, like changing power generation, storage capacities and efficient power transmission, which have not been completely addressed yet, which makes optimization of renewable systems a valuable research field.

A lot of research has been conducted to look into different ways of enhancing renewable energy systems. The fact that the rate of the growth of renewable installations in India is high is reported and implemented by governments, which is followed by the necessity to possess reliable policies and advanced technologies to support the growth of such installations [1]. The issue of wireless charging of electric vehicles has also been discussed recently with more publications dedicated to the efficient design of coils that might improve their energy transfer efficiency and flexibility, and the renewables that might be more effectively combined with transport networks [2], [3].

Solar researchers have considered maximum power point tracking (MPPT) algorithms on the solar side to increase the energy collection efficiency of photovoltaic (PV) systems. According to the conventional and intelligent algorithms comparison, it can be said that the advanced algorithms such as the fuzzy logic and adaptive control have better performance in terms of variable and partially shaded conditions [4], [12], [13], [14]. Moreover, renewable-based energy models incorporating storage facilities and any backup power that could be smart cars are safe and effective in delivering energy to homes and smart grids [5].

The last advances are also a hybrid of energy harvesting based on solar cells and triboelectric and electromagnetic nano generators that generate stronger and more diversified power [7]. Similarly, advancement in power converters has improved the energy conversion performance that stabilizes PV systems and can be integrated into the distribution networks [11], [15]. These articles remind us of the continuous evolution of the actions devoted to the questions of efficiency, stability, and flexibility of renewable systems.

In our paper, we will show a renewable energy system, which is energy efficient and integrates smart algorithms of the MPPT and multifunctional DC-DC converters of the solar equipment. In our design, we focus on maximizing efficiency and reducing energy losses and guarantee the permanence of output under the influence of changing environmental conditions. The results of the simulation prove that the proposed system is much more effective and reliable than traditional procedures, and, therefore, it is an efficient solution to be adopted in renewable energy in the future.

II. LITERATURE SURVEY

Due to good policies and government schemes, renewable energy in India has been on a boom. According to the Ministry of New and Renewable Energy (MNRE) report, the solar and wind projects within the country, the incentive programs, and future directions emerge. This gives a good background on the studies that have argued that it is imperative to exist good energy systems and better MPPT strategies to feed the growing demand [1].

Two recipient coils are used in a system of wirelessly charging electric vehicles described by Mohamed et al. The design improved the alignment and power transfer toleration that reduced one of the main challenges of EV charging. The present innovation has explicit links to renewable energy as efficient charging is the most important factor to integrate EVs with the distributed solar generation [2].

In a separate study, the same authors provided further experimental study of the performance of wireless charging. They studied the geometry of the coils, coupling factors, and load variations which show theoretical real measured results that demonstrated efficiency gains. Researchers interested in implementing renewable-based EV charging into practice can find these empirical lessons useful [3].

Sharma, Gupta and Kumar compared several Maximum Power Points Tracking (MPPT) algorithms of PV systems. The experiment they conducted compared traditional and smart techniques with different colouring and weather conditions and identified the most constant and responsive techniques. The outcomes are required to increase the trustworthiness of PV output and guide the choice of MPPT to be applied in hybrid renewable systems [4].

Ouramdane et al. developed a home energy management system which operates on renewable resources storage and electric cars. Their model showed that it is possible to reduce costs and maximize grid stability, through smart scheduling, especially when EVs are deployed as a backup. This highlights the growing relevance of the coordinated energy management in achieving efficiency and reliability of distributed renewable systems [5].

PV manufacturer datasheets contain e.g. Changzhou EGing Photovoltaic Technology datasheets containing the correct module description and performance curve. These real-life values are crucial to simulation and design to the extent that the modeled systems behave half-life of real installations. Data sheet information is also used to increase validity of the results of experiment-based testing of MPPT and converters [6].

Chen et al. tried to work out hybrid energy harvesting systems by integrating solar cells with triboelectric-electromagnetic nanogenerators. Their construction was better suited to capture energy in various sources and thus the system became more adaptable in a dynamic environment. This idea embraces the idea of hybrid renewable in which mixing up of technologies creates a stable source of energy that is efficient and consistent [7]

III. PROPOSED METHOD

The proposed system is designed to improve the efficiency of a hybrid renewable energy setup by using an intelligent Maximum Power Point Tracking (MPPT) method with fuzzy-controlled DC–DC converters. The steps are explained below:

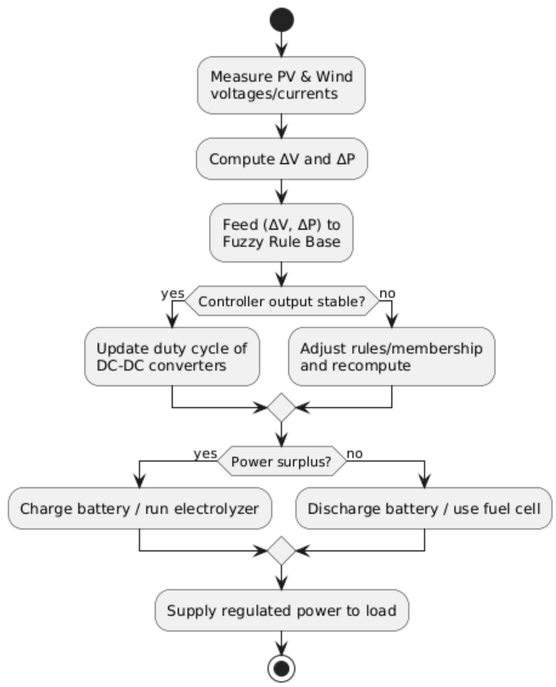

Figure 3.1: Block Diagram of Hybrid Solar-Wind Energy System with Fuzzy MPPT Controller

3.1 System Design: The system comprises of solar panels and wind turbine which are linked together by converting DC to DC. The maximum output of both sources is extracted by a fuzzy logic-based MPPT controller. It contains a battery bank to store the surplus power and provide it when the generation is low.

3.2 Fuzzy Logic MPPT Control: The fuzzy logic controller constantly measures the changes in voltage and power to follow the peak of power. It modulates the DC-DC converters to enhance efficiency, stability and response to changing weather and loading conditions.

3.3 Power management and storage: Helping to balance supply and demand fluctuations is the battery storage system. The control method gives more priority to the renewable power, buffers the excess energy in the battery and keeps the output to the load constant, minimizing interruptions.

3.4 Simulation and Validation: The entire system has been modeled in MATLAB/ Simulink. These are simulated with varying degrees of solar irradiance, wind velocity and load changes. The efficacy and stability of the fuzzy MPPT is contrasted with the standard progress to confirm the enhancement of the performance.

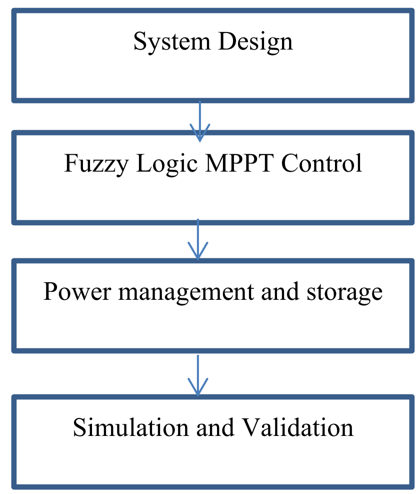

Fig.3.2 Block diagram for proposed method

IV. RESULTS

4.1 Existing System Simulation

The existing system simulation model is to combine the sources of solar PV and wind to provide power to a load. It contains an MPPT control module to draw the maximum power out of the renewable sources and a battery storage to provide power when required. The control method is based on a fixed MPPT method and this is not very good when the weather is changing rapidly. This leads to loss of efficiency and delayed reaction to solar irradiance and wind speed changes. These constraints demonstrate the existence of an enhanced MPPT strategy in hybrid systems that can increase the overall performance.

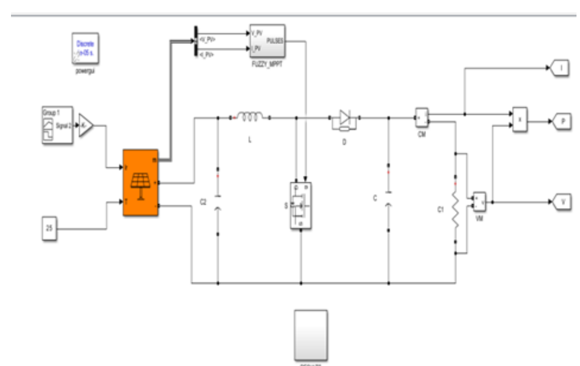

Figure 4.1: Existing System – Simulation Diagram

Block diagram of existing system is shown in above figure.

4.1.1 Fuzzy MPPT Sub System

The MPPT subsystem is a fuzzy logic system that allows solar irradiance and temperature to be inputted to get the best values of the duty cycle in the DC-DC converter. It analyses those inputs with a combination of fuzzy rules and delivers quicker and greater power of maximum point tracking. The process minimizes variations in the output power and is sensitive to fluctuations in the environmental conditions. This is more stable and adaptable than conventional MPPT techniques and is highly suitable in hybrid renewable systems.

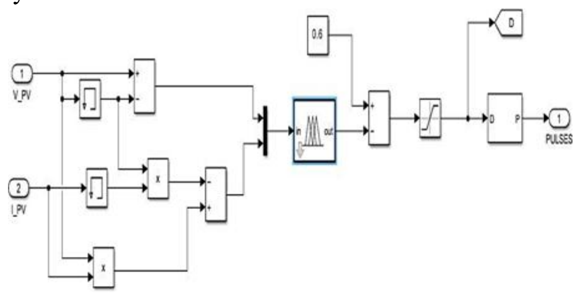

Figure 4.2: Fuzzy MPPT Subsystem

4.1.2 Existing System – Output Waveforms

The waves of voltage, current and power output of the current system show the fluctuations due to the low tracking speed of the fixed MPPT technique. The intermittency of power is more evident when abrupt variations in the irradiance and wind speed occur. Such fluctuations result in poor energy transfer efficiency and irregular operation. These findings justify the use of a more dynamic control method in order to increase power stability and tracking accuracy

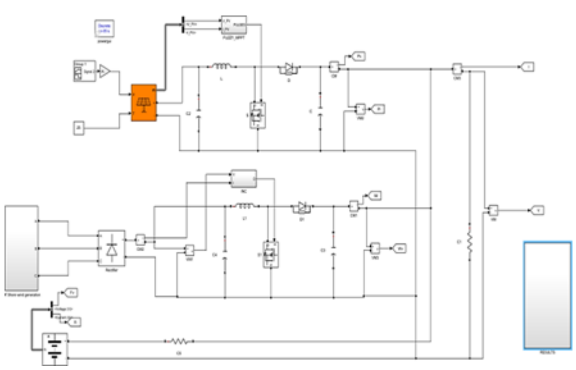

Figure 4.3: Existing System – Output Waveforms

4.2 Proposed System Simulation

The hybrid renewable energy system is proposed to combine Incremental Conductance (INC) MPPT algorithm to solar PV and fuzzy logic control to the wind subsystem. A hybrid energy management controller mediates the exchange of power between sources, the load, and the battery. Such a design guarantees quicker MPPT tracking, greater efficiency, and the stability of performance in different environmental conditions. It solves the shortcomings of the current system to provide more stable and better power production.

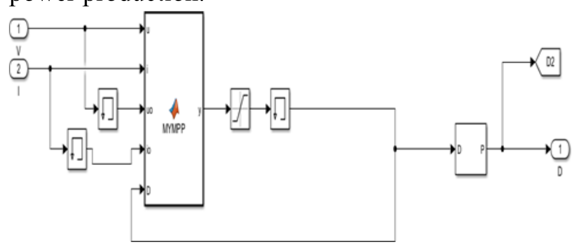

Figure 4.4: Proposed System – Simulation Diagram

4.2.1 Incremental Conductance (INC) MPPT Algorithm

The Incremental Conductance MPPT algorithm uses instantaneous conductance (I/V) in comparison to incremental conductance (DI/DV) to estimate the location of the operating point with reference to the maximum power point. Depending on the outcome, it modifies the duty cycle of the DC-DC converter to ensure that it is operating optimally. This is a way to get accurate tracking that has small steady-state oscillations, particularly when weather condition changes very fast, and thus is a favorite to be used in solar energy systems.

Figure 4.5: Incremental Conductance (INC) Algorithm

4.2.2 Wind Energy Subsytem

The wind energy subsystem is built on a wind turbine attached to a Permanent Magnet Synchronous Generator (PMSG) and then a rectifier and DC-DC converter. The MPPT control using fuzzy logic provides maximum power extraction even when the wind speed changes. Other power conditioning circuits rectify the output prior to its incorporation into the hybrid system. This subsystem is very effective in wind energy use and reliability of the system.

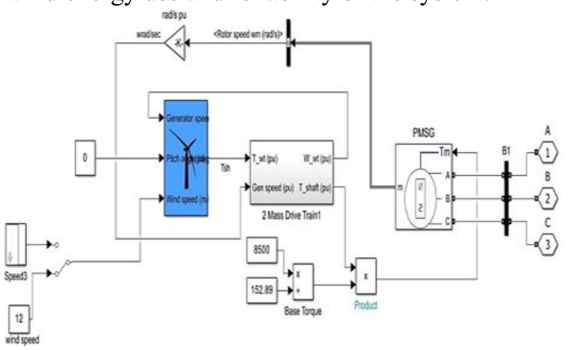

Figure 4.6: Wind Energy Subsystem

4.2.3 Solar Energy Output Waveforms

The voltage, current, and power waveforms for the solar PV system using the INC MPPT algorithm indicate stable and efficient operation. Voltage remains near the optimal point, and current is steady even during irradiance changes. Power output is smooth and close to the theoretical maximum, demonstrating superior tracking performance compared to the existing fixed MPPT approach

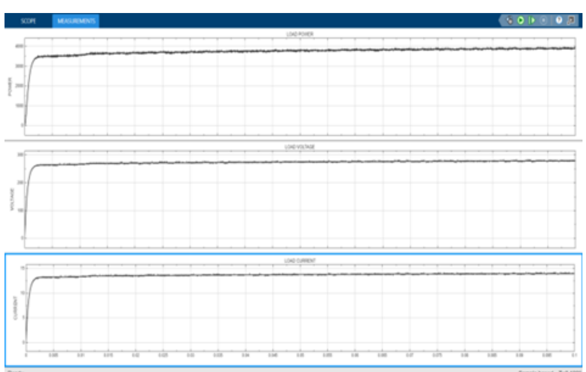

Figure 4.7: Solar Energy Output Waveforms

4.2.4 Wind System Output Waveforms

The wind subsystem's voltage, current, and power waveforms show minimal fluctuations despite changes in wind speed. Fuzzy logic MPPT maintains optimal operating conditions with negligible overshoot. This stable output enhances the overall performance and reliability of the hybrid renewable energy system, ensuring consistent power supply.

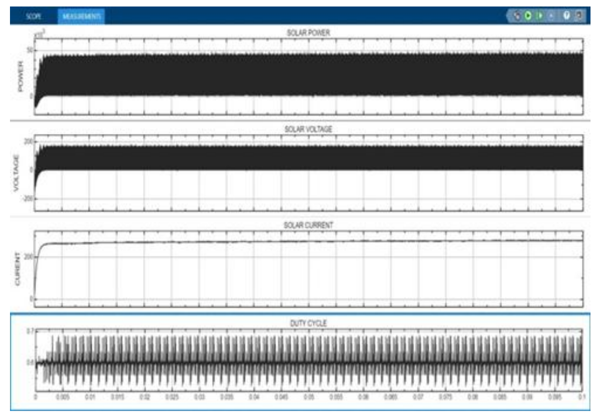

Figure 4.8: Wind System Output Waveforms

4.2.5 Battery Output Waveforms

The charging and discharging characteristics of the battery reveal steady charging during periods of surplus generation and smooth discharging during high load demand. Voltage and current profiles confirm that the hybrid controller effectively manages battery operation, maintaining system stability and prolonging battery lifespan

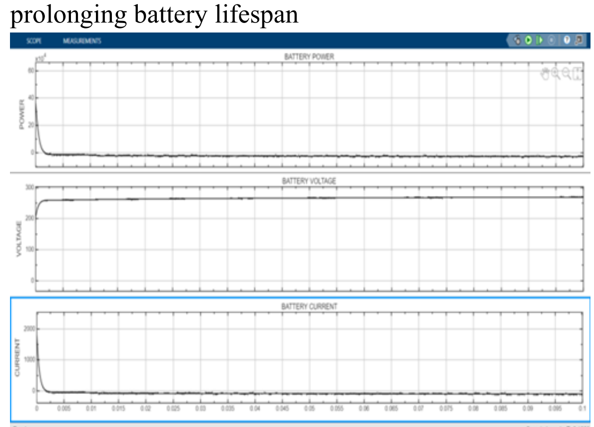

Figure 4.9: Battery Output Waveforms

4.2.6 Load Output Waveforms

The load voltage and current remain stable, meeting demand requirements even during generation fluctuations. The hybrid control strategy ensures coordinated operation of solar, wind, and battery systems, resulting in minimal voltage dips or surges.

This reliable power delivery improves load performance and ensures consistent operation.

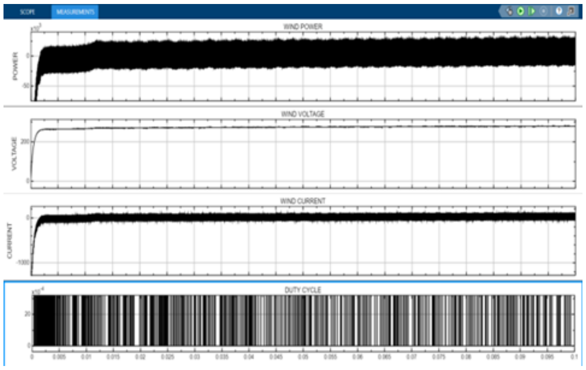

Figure 4.10: Load Output Waveforms

V. CONCLUSION

The research paper establishes that the combination of fuzzy logic with MPPT can really improve the performance of a hybrid renewable system. The system responds more quickly, is more efficient and tolerant to changes in weather conditions due to the dynamic management of solar and wind sources with DC-DC converters. The simulation outcomes confirm that the method provides stable power supply with minimized instability and energy wastage. Generally, the proposed smart MPPT system is a viable and greener solution to enhancing the stability of the renewable energy system, particularly in off-grid and distributed power systems.

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