Particle Swarm Optimization Approach for MPPT-Based Charge Controller in Hybrid Renewable Systems

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Abstract: As global energy demand continues to rise, renewable energy sources have become essential in narrowing the gap between supply and demand. However, the growing use of power electronic devices and non-linear loads in the grid introduces several power quality challenges. These issues—both in terms of energy scarcity and power quality—can be effectively addressed through the integration of inverters within renewable energy grid systems. This research focuses on the development and implementation of a hybrid renewable energy system that ensures a cost-effective and sustainable power supply to connected loads. Although integrating solar power with the conventional grid can be both complex and costly, the proposed system offers a practical, economical, and reliable solution. A charge controller is incorporated, utilizing a Maximum Power Point Tracking (MPPT) algorithm based on Particle Swarm Optimization (PSO) to enhance system efficiency.

Keywords- Renewable Energy system, PV Array, Wind System

I. INTRODUCTION

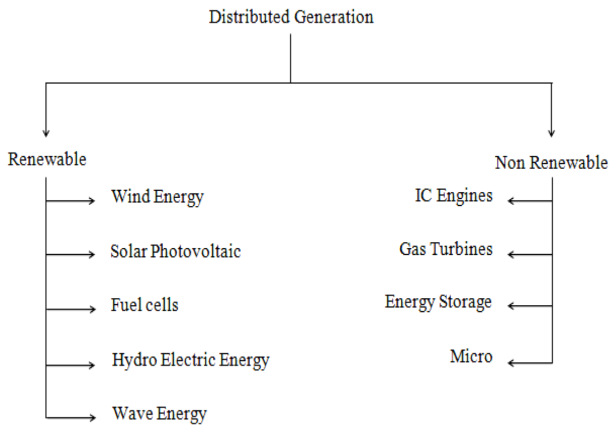
A standalone wind energy system is unable to consistently meet load demands throughout the year due to significant variations in wind speed. To maintain stable performance, incorporating an energy storage system becomes essential. However, such storage solutions are often costly, and their capacity needs to be minimized to ensure the economic viability of the renewable energy setup. The use of hybrid power systems offers an effective way to decrease the dependency on large-scale energy storage.

1.1 DISTRIBUTED GENERATION

Initially, power systems were based on distributed generation (DG) models designed to serve local energy demands. With advancements in technology and the rising need for electricity, large-scale centralized power grids were developed to connect regions and even entire countries. When operated at full capacity, DG systems offer significant advantages in terms of efficiency, power output, and reduced transmission losses. Distributed generation is especially well-suited for specific locations and targeted applications due to its shorter construction time and lower investment requirements. These systems are typically categorized based on their capacity, ranging from a few kilowatts to several megawatts (commonly between 10–50 MW). Depending on the energy source, DG systems can be powered by either renewable or non-renewable fuels.

Distributed Generation (DG), which refers to power generation located at or near the point of consumption, is considered a safe, reliable, and environmentally friendly energy solution. It has minimal adverse social impacts and contributes positively to environmental sustainability. In recent times, due to economic, environmental, and political factors, there has been a growing shift from traditional power systems—characterized by centralized large-scale energy production and long-distance transmission—toward DG systems. For remote and sparsely populated rural regions, decentralized generation proves more practical, as it supplies electricity directly to end-users while eliminating the costs associated with transmission and distribution infrastructure. The DG model is increasingly viewed as an effective approach for delivering decentralized energy, particularly in rural and underdeveloped areas.

According to sources used for production in distribution centers or in the vicinity, they are classified as renewable and non-renewable.



1.2 MODELLING OF PV ARRAY

Grid-connected photovoltaic (PV) systems offer a reliable solution to meet the growing energy demand. One of the key benefits of connecting PV systems to the grid is the improved efficiency in utilizing the generated power. These systems are linked to the grid through inverters, which convert the direct current (DC) produced by PV panels into alternating current (AC). Inverter technology plays a crucial role in maintaining a stable and safe connection between the PV system and the electrical grid. Typically, inverters using controlled voltage sources are employed to integrate renewable energy sources (RES) into the network. However, the increased use of power electronic converters introduces challenges related to power quality, such as the generation of harmonics. These harmonics can disrupt the functioning of protection relays and other control equipment. To ensure smooth operation, it is essential to minimize harmonic distortion. Among various solutions, active shunt power filters are considered the most effective method for harmonic mitigation.

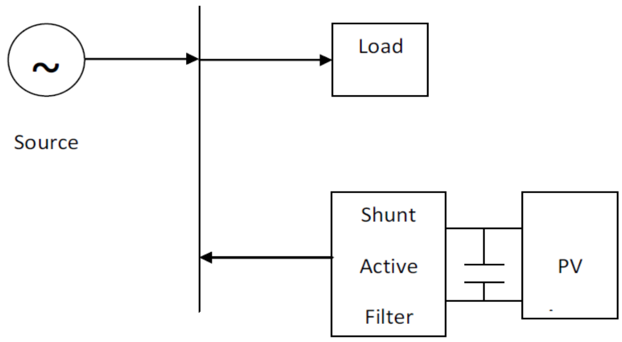


Fig-1 Photovoltaic Interactive Shunt Active Power Filter System

II. SOLAR-WIND RENEWABLE ENERGY GRID SYSTEM

In this work, a grid-connected hybrid renewable energy system combining solar and wind sources has been simulated and examined. The overall system layout is illustrated in Fig. 2. A standard inverter is used to connect the renewable energy sources with the power grid. This inverter not only enables the transfer of real power to the grid but also helps enhance the quality of power in the system. The performance of the inverter greatly depends on the control techniques applied.

Both the photovoltaic and wind systems produce a DC output. To connect these sources to the grid, various power electronic converters are required. This study uses a DC-linked hybrid PV/wind system for grid integration. In the system, the DC outputs from both sources are fed into DC-DC boost converters, which regulate the DC link voltage. The AC output from the wind turbine is first converted to DC using an uncontrolled rectifier, and then passed through a DC-DC boost converter to control and stabilize the DC link voltage.

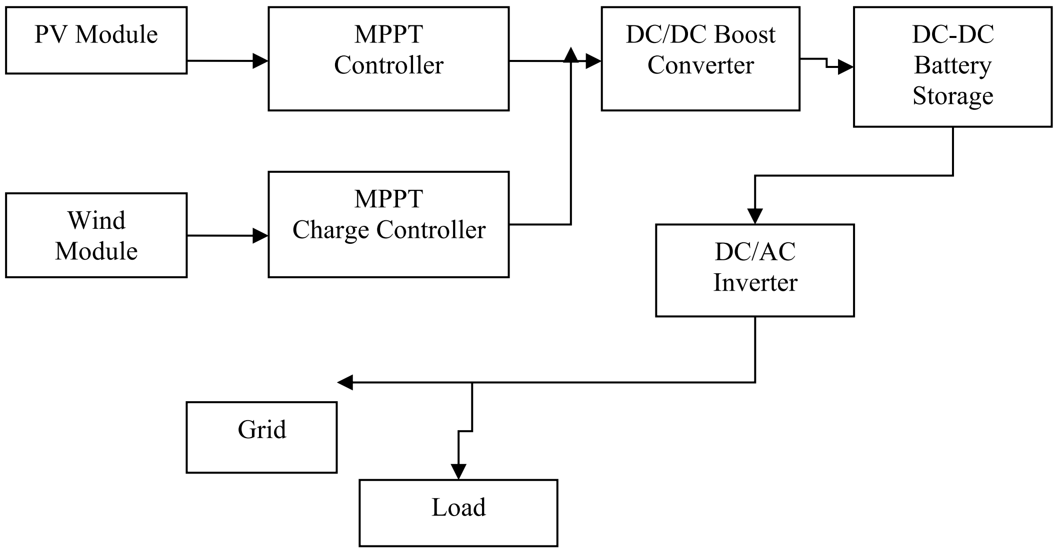


Fig-2 Solar-Wind RE System

III. HYBRID RENEWABLE ENERGY GRID SYSTEM WITH PSO-MPPT AND PI INVERTER CONTROLLER

This research focuses on the simulation and analysis of a grid-connected hybrid renewable energy system. The overall system configuration is illustrated in Fig. 3 and comprises solar photovoltaic panels, a wind energy system, and a fuel cell setup. The system also integrates a particle swarm optimization (PSO)-based maximum power point tracking (MPPT) charge controller, battery storage units, an AC/DC converter with adjustable output voltage, and a proportional-integral (PI) controller to enhance power quality.

In this configuration, the load is supplied through direct current (DC) rather than alternating current (AC). For efficient power transfer, especially during grid synchronization, accurate information about the grid voltage phase angle is necessary.

The photovoltaic system used in this study employs a single-stage conversion process, wherein the PV array is directly connected to a grid-tied inverter. The MPPT algorithm implemented is based on the Particle Swarm Optimization technique. This PSO-based MPPT approach is specifically designed to track the Global Maximum Power Point (GMPP) of the PV array under varying environmental conditions, thereby optimizing the energy output and improving the overall efficiency of the system.

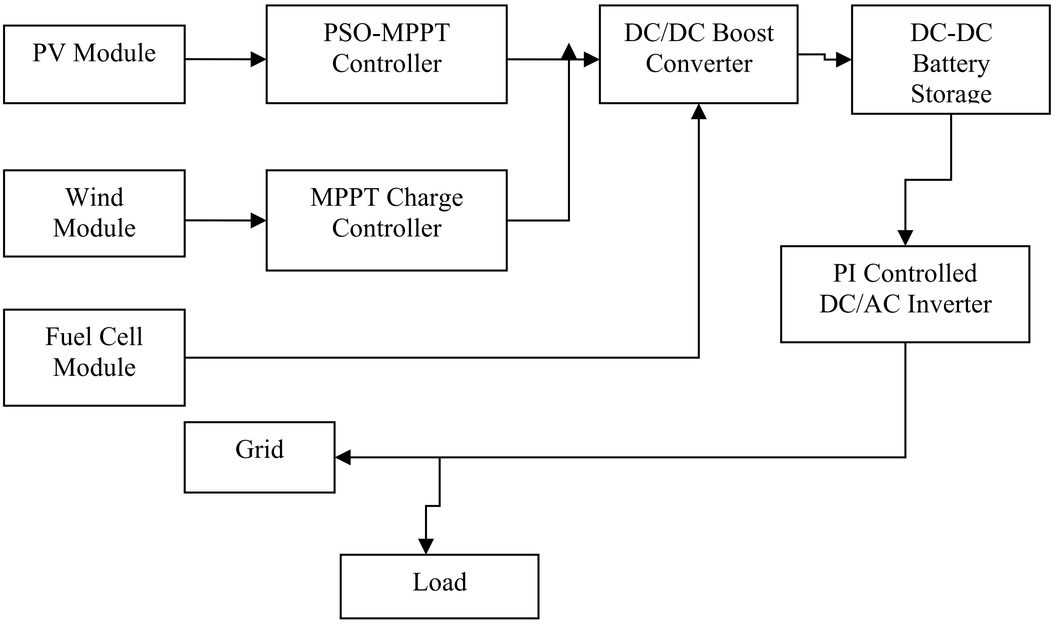


Fig-3 Hybrid RE System with PI Controlled Inverter

IV. RESULTS

The proposed hybrid system introduces power control strategies for a grid-connected generation setup capable of flexible power transfer. This configuration ensures optimal use of renewable resources such as wind and solar energy. To achieve this, a Maximum Power Point Tracking (MPPT) algorithm is employed to extract the highest possible power output from the available sources. The system design enables the two energy sources to operate either independently or in coordination, based on their availability at any given time.

In the wind energy subsystem, the mechanical power output is primarily influenced by the rotor speed of the turbine. For the solar component, the output power is determined by the operating voltage of the photovoltaic cells. The wind energy conversion system incorporates a Permanent Magnet Synchronous Generator (PMSG), which is mechanically linked to the wind turbine to facilitate efficient energy conversion.

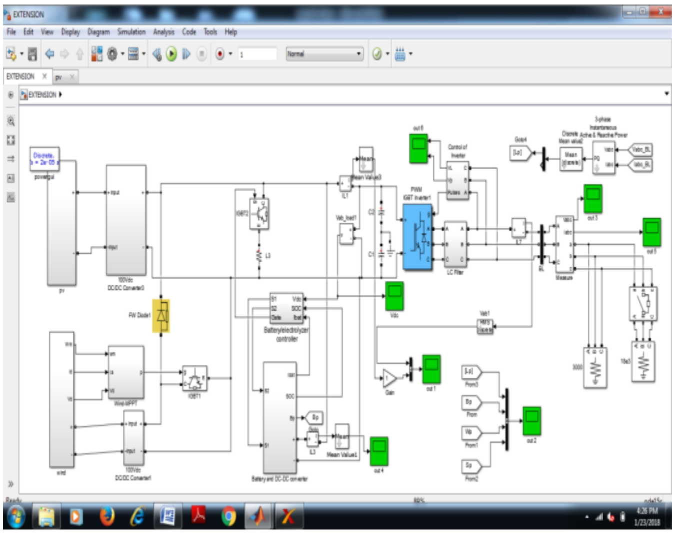


Fig-4.1: MATLAB Simulink Model of Solar-Wind RE System with PI Controlled Inverter

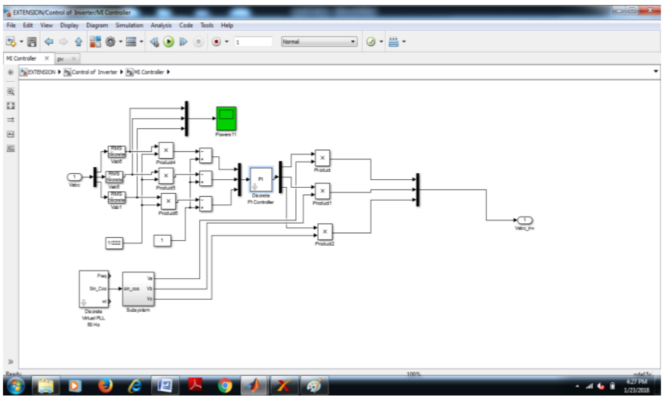


Figure 4.2: MATLAB Simulink Model of Controlled Inverter for Solar-Wind RE System

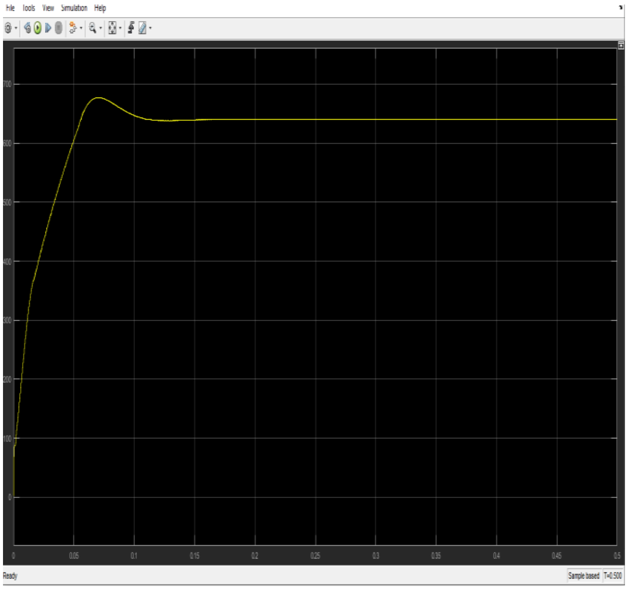


Figure 4.3: DC Voltage obtained in Solar-Wind RE System

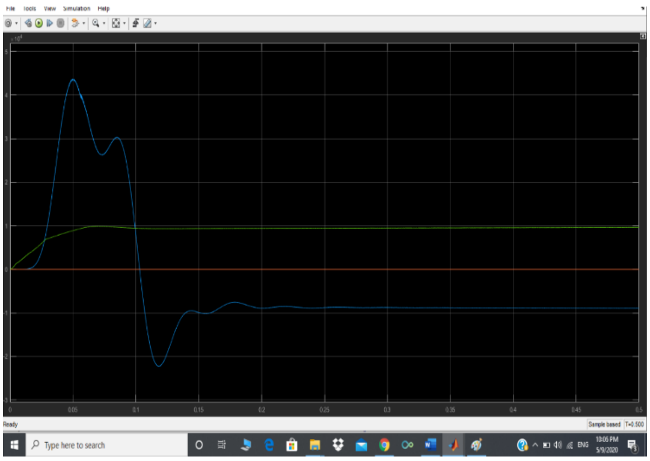


Figure 4.4: Power Obtained in Solar-Wind System RE System

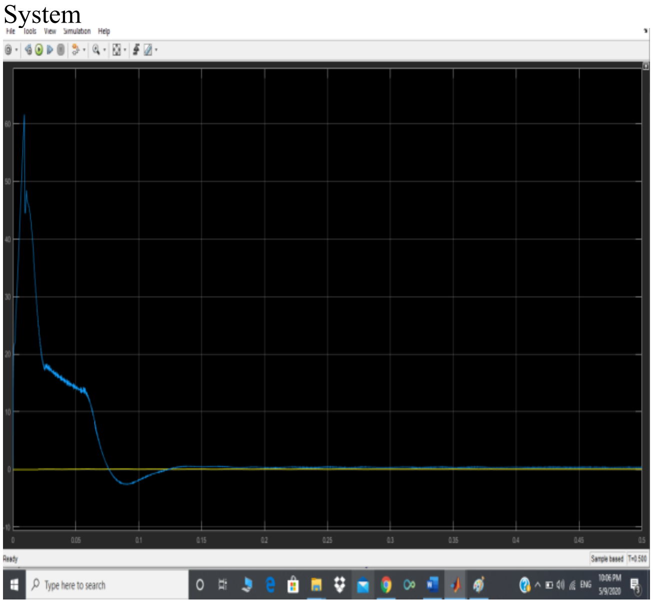


Figure 4.5: Current Obtained in Solar-Wind System RE System

Conflict of Interest: The corresponding author, on behalf of second author, confirms that there are no conflicts of interest to disclose.

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