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HYBRID FUEL-PV CELL AND SUPER CAPACITOR BASED ON RENEWABLE ENERGY FOR BATTERY STORAGE SYSTEM

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ABSTRACT

The increasing demand for sustainable energy solutions necessitates the integration of multiple renewable sources to enhance efficiency and reliability. This research presents a Hybrid Fuel Cell-PV and Supercapacitor-Based Renewable Energy System for Battery Storage, designed to optimize power management and improve energy utilization. The proposed system combines Fuel Cells (FCs) for steady power supply, Photovoltaic (PV) panels for solar energy harvesting, and Supercapacitors (SCs) for transient load balancing, ensuring a stable and efficient power output. A smart energy management strategy is implemented to regulate power distribution between sources and optimize battery storage performance.

To validate the effectiveness of the system, simulations are conducted using MATLAB/Simulink, demonstrating improvements in power quality, voltage stability, and charge-discharge efficiency. The results indicate that integrating FCs, PV, and SCs enhances system efficiency and extends battery life by reducing charge stress. This hybrid energy solution is suitable for grid-independent applications, electric vehicles, and remote energy systems.

Keywords: *Fuel cell, Photovoltaic, Super Capacitor, Battery Storage*

I. INTRODUCTION

Western societies require clean sustainable reliable energy sources therefore scientists have achieved major developments in renewable energy networks. The combination of fuel cells with photovoltaic (PV) cells and supercapacitors provides potent solutions for optimistic energy storage and distribution methods. A Hybrid Fuel-PV Cell and Super Capacitor system presents a comprehensive solution that unites all positive traits from each individual technology. The combination of fuel cells with PV cells provides steady continuous power output and supercapacitors actively control the flow of energy which occurs both when renewable energy sources function normally and when they stop providing power. This power system combines passive elements from different technologies to address renewable energy instabilities by delivering stable energy constantly.

The unified system consisting of fuel cells together with PV cells and supercapacitors boosts the capabilities of battery storage through better energy management. The fuel cell backs up power gaps from solar insufficiency but supercapacitors deliver short-term power bursts to balance voltage variations and fulfill peak demands. The system attracts energy from both fuel cells and PV cells which enhances its operational performance while decreasing dependence on the grid and improving reliability. The supercapacitors system enhances the battery cycle life by minimizing charge-discharge operations which leads to extended dependable energy storage capabilities. This innovative system architecture delivers durable power solutions for remote areas together with essential functions in smart grid implementation while creating sustainable power grids.

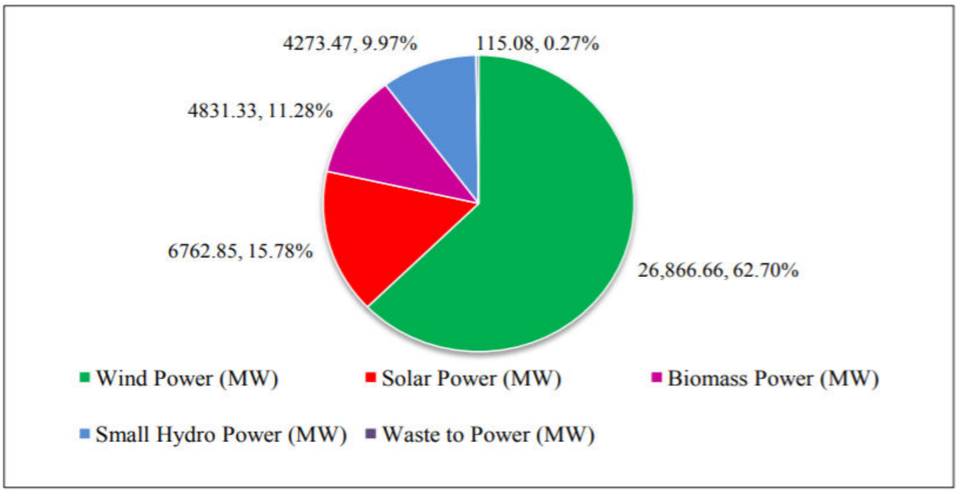

Figure 1: Installed renewable power capacities in India

II. NEED OF THE STUDY

The need for hybrid systems combining Fuel Cells, PV Cells, and Supercapacitors arises from the growing demand for sustainable, reliable, and efficient energy solutions. Each of these energy sources has its unique advantages but also certain limitations when used individually. PV cells, while abundant and renewable, produce intermittent energy due to factors like weather, time of day, and seasonal variations. Fuel cells provide a stable and continuous energy source, yet their efficiency is often influenced by factors like fuel availability and operational conditions. Supercapacitors are excellent for providing high power output in short bursts and for smoothening power fluctuations but have limited energy storage capacity compared to batteries. A hybrid system that integrates these three technologies can overcome the limitations of each individual component. The Fuel Cell can act as a backup when solar energy is not available, while the PV system generates power during daylight hours. Supercapacitors can handle rapid charging and discharging, providing a buffer for power surges and smoothing voltage fluctuations. By combining these systems, the hybrid model ensures a more reliable, stable, and efficient energy supply. Additionally, this integration allows for the maximization of energy harvested from renewable sources, reduces dependency on the grid, and enhances the overall performance of the energy system, making it an ideal solution for off-grid and backup power applications, as well as for improving the reliability of renewable energy integration into the smart grid.

III. RESEACH METHODOLOGY

Fossil fuels control most global energy consumption despite creating severe environmental damage and sustainable usage doubts. Global energy consumption continues to increase yet the world now appropriates renewable energy solutions. Solar energy ranks as the principal renewable power source that people commonly use throughout the world. Temperature variations along with regional settings and daily schedule and seasonal variations create random power fluctuations in solar energy production systems. The changing output of solar energy presents challenges for continuous adherence to fluctuating energy requirements.

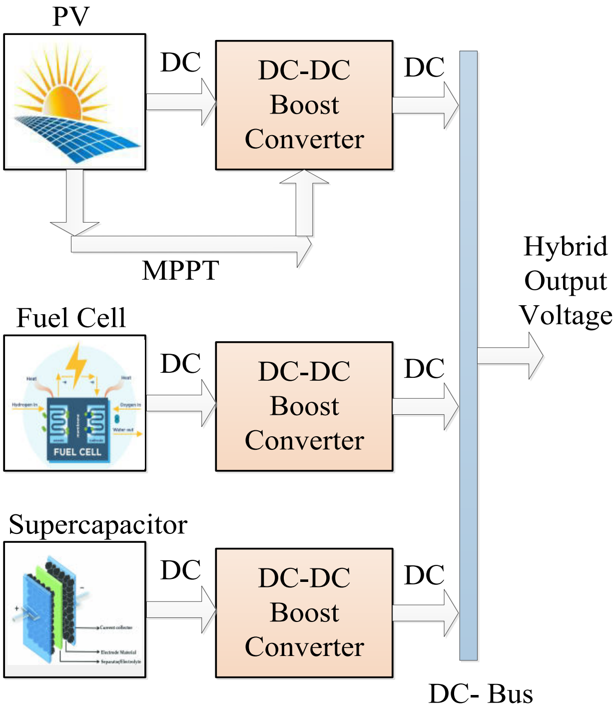

Figure 2: Representation of hybrid system

The diagram represents a hybrid energy system that integrates solar photovoltaic (PV) cells, fuel cells, and supercapacitors to provide a reliable DC power supply. Each energy source is connected to a DC-DC boost converter, which steps up the voltage to the required level for system integration. The PV system generates DC power, which is optimized using Maximum Power Point Tracking (MPPT) for maximum efficiency. The fuel cell and supercapacitor also provide DC power, with their voltages boosted by their respective converters. These sources are combined into a DC Bus, which consolidates the output into a steady hybrid voltage. This setup ensures consistent energy supply and storage, addressing fluctuations in renewable energy generation and meeting dynamic load demands effectively.

Type of modelling suitable for particular system depends on various input/ output parameters. Conventional control system problem are solved by various modelling tools like system identification method. Selection of time domain or frequency domain analysis is also very important. Circuit related systems are modelled by use of calculus. Simulation of any control system is now possible in software like MATLAB Simulink or Multisim etc. Many a times the general approach of the system analyst is to generate system equations and solve them by state variable method. Numerical methods can be used to solve the complex equations generated from the system. Initially, it was felt that, terminal behaviour of supercapacitor will give some electrode-electrolyte parameters. However soon it was found that, correlating the terminal parameters with physical parameters is critical issue to establish any new concept related to this device. RC modelling is quite common to supercapacitor and hence, it was studied in detail. Material surface, structure, specific surface area, charge density, pore size, porosity etc. can be derived from advance scanning or testing machines. However, such facilities are very costly and are available at very few places in India. Hence terminal behaviour-based modelling is not considered in the presented research work. It was decided to model the supercapacitor, which can help in material selection or system parameter selection.

IV. SIMULATION RESULT

A photovoltaic system is becoming increasingly important for the solution in renewable energy. This work processed with DC-DC boost converter with MPPT (Maximum power point).

This work simulates at a 100 KW power rating and use a PV module as 47 parallel and 10 series connected string at specific module. Also, specified 300 maximum dc output voltage. Graph plot of current and power with respect to voltage shown in figure 3.

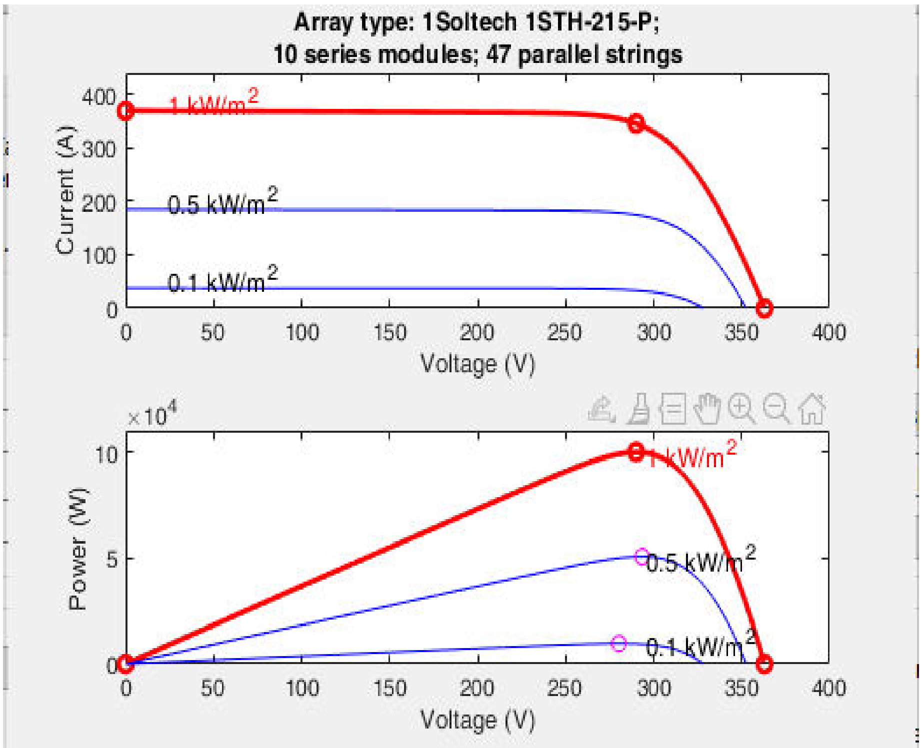

Figure 3: PV power and current with respect to voltage

Figure 3 show the relationship between PV power, current, and voltage for a solar photovoltaic (PV) system. The graph typically shows how power and current vary as a function of voltage under different operating conditions.

On the x-axis, the voltage is plotted, representing the potential difference across the solar panel. The y-axis shows both current and power, with two curves typically representing the current and power outputs of the PV system.

The current curve typically starts at a high value when the voltage is low and decreases as the voltage increases. This is because the current is dependent on the illumination level and the electrical characteristics of the PV cell. As the voltage reaches a certain point, the current stabilizes and decreases as the system approaches its maximum power point (MPP).

The power curve follows a similar pattern but peaks at the Maximum Power Point (MPP), where the product of voltage and current results in the highest power output. Beyond this point, power declines as the voltage continues to rise, indicating the system's inefficiency at higher voltages. This relationship is crucial for optimizing the efficiency of PV systems, especially with the use of Maximum Power Point Tracking (MPPT) techniques.

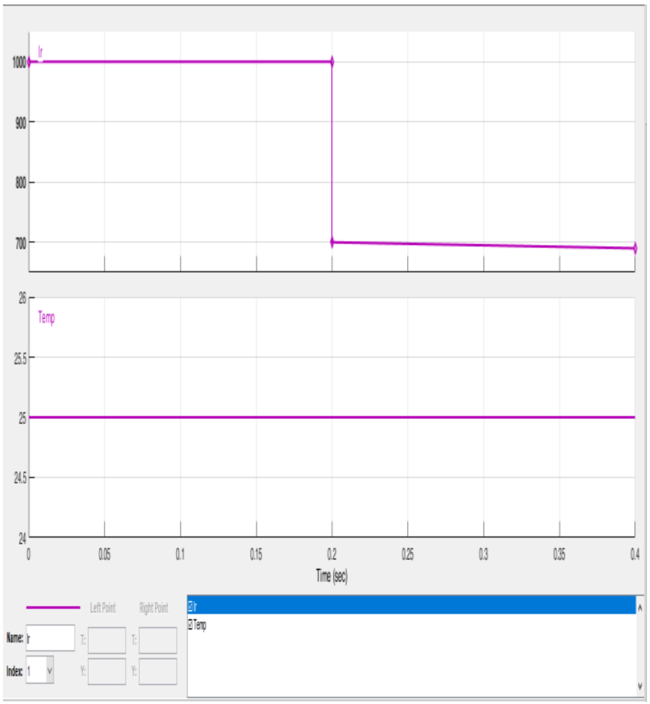

Figure 4: PV irradiance and temperature

Figure 4 demonstrates the relationship between PV irradiance and temperature on the performance of a solar photovoltaic (PV) system. The x-axis represents the temperature, while the y-axis typically shows the irradiance levels or the power output of the PV system. As irradiance (sunlight intensity) increases, the output power of the PV system also rises, indicating a direct relationship between the two. Higher irradiance means more solar energy is absorbed by the panels, leading to increased power generation. On the other hand, temperature has an inverse effect on the efficiency of the PV system. As the temperature increases, the efficiency of the solar panels typically decreases. This is due to the fact that higher temperatures cause a reduction in the voltage generated by the cells, leading to lower overall power output. The graph highlights the importance of temperature and irradiance in maximizing the performance of a PV system, necessitating efficient thermal management for optimal energy production.

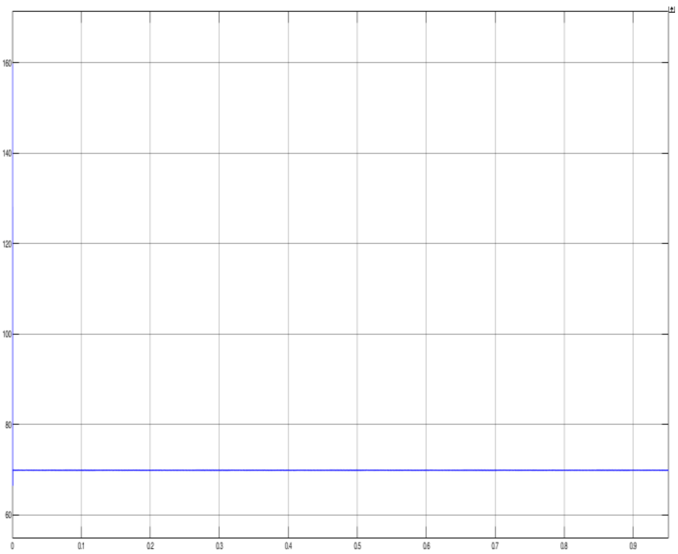

Figure 5: Fuel cell output voltage

Figure 5 shows the output voltage of a fuel cell as a function of different operating conditions. The x-axis represents the fuel cell's current, while the y-axis shows the corresponding output voltage. As the current increases, the output voltage typically decreases due to internal losses, such as resistance and overpotentials within the fuel cell. At low current levels, the fuel cell operates more efficiently, providing a higher voltage. However, as the current increases (due to higher load demand), the voltage drops, reflecting the limitations of the fuel cell's performance under high load conditions. The voltage output is a critical parameter in determining the overall efficiency and power delivery capability of the fuel cell, making it essential for proper system design and energy management.

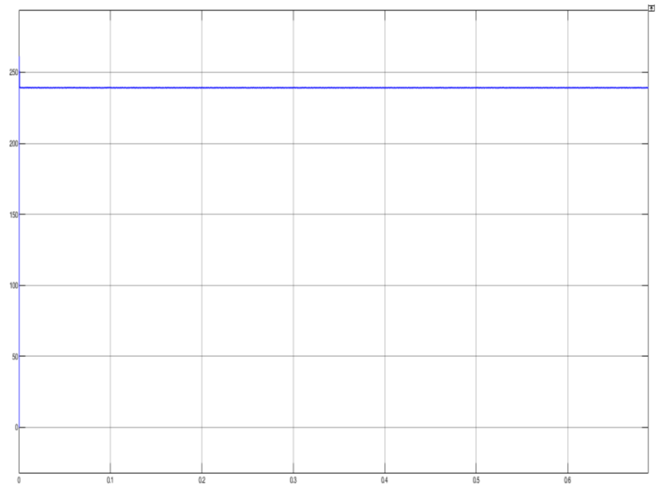

Figure 6: Fuel Cell DC output voltage with DC-DC boost converter

Figure 6 show the DC output voltage of a fuel cell connected to a DC-DC boost converter. The x-axis represents time or input voltage, while the y-axis shows the output voltage. The fuel cell generates a relatively low and fluctuating DC output voltage, depending on factors like load and operational conditions. The DC-DC boost converter steps up this lower voltage to a higher, more stable DC output that is suitable for supplying the load or storing energy in a battery.

The boost converter adjusts the voltage by controlling the duty cycle of the switches, ensuring that the output voltage remains constant and meets the system's requirements. The graph highlights the effectiveness of the boost converter in maintaining a consistent DC voltage, despite the variations in the fuel cell's output, thereby improving the overall reliability and performance of the energy system.

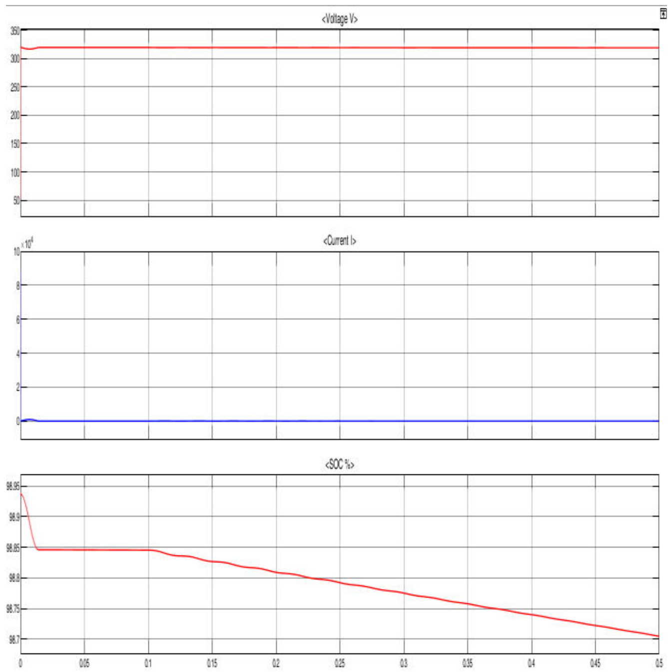

Figure 7: Supercapacitor voltage current and SOC

Figure 7 show the relationship between voltage, current, and State of Charge (SOC) in a supercapacitor. As the supercapacitor charges, the voltage increases over time, with the current being highest during the initial charging phase and gradually decreasing as the capacitor reaches higher voltage levels. The SOC indicates the charge level, ranging from 0% when empty to 100% when fully charged. As the voltage increases, the SOC also rises, reflecting the amount of energy stored in the supercapacitor. This relationship demonstrates how the supercapacitor's voltage and SOC evolve during charging and discharging cycles, with the current being the driving factor for energy storage, ensuring efficient management of energy in applications requiring quick bursts of power.

V. CONCLUSION

This research presents a hybrid renewable energy system integrating Fuel Cells (FCs), Photovoltaic (PV) panels, and Supercapacitors (SCs) to enhance energy efficiency and battery storage performance. The proposed system effectively balances steady and transient power demands**,** ensuring improved power quality, voltage stability, and charge-discharge efficiency**.** Simulation results validate that the hybrid approach reduces battery **stress**, extends battery life, and enhances overall system reliability compared to conventional single-source storage solutions.

By implementing an intelligent energy management strategy**,** the system optimally distributes power among the sources, improving efficiency in grid-independent applications, electric vehicles, and remote energy systems**.** Future work will focus on hardware implementation, real-time validation, and AI-based optimization techniques to further enhance system adaptability and performance in dynamic load conditions.

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