Power Management Scheme for Grid-Connected PV Integrated with Energy Storage System

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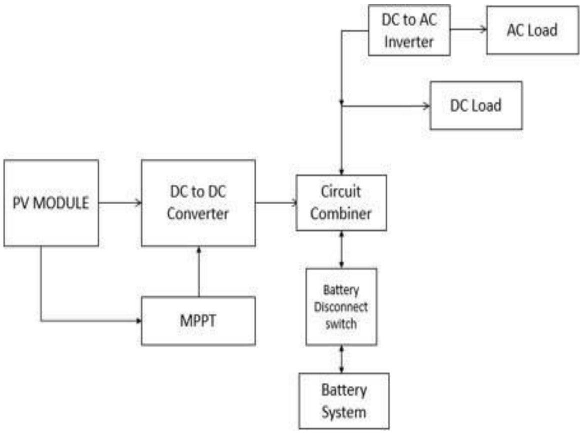
***Abstract*— The report presents a power management scheme for a grid-connected photovoltaic (PV) system with hybrid energy storage, focusing on maximizing solar energy utilization and ensuring grid stability. The scheme incorporates dynamic energy management and power flow control strategies to adjust battery charge/discharge rates based on solar generation and grid demand. A simulation model developed in MATLAB/Simulink evaluates various parameters and performance metrics. Results show optimized solar energy and battery usage, reduced grid dependency, and enhanced grid stability, promising cost savings and improved resiliency. Overall, the scheme offers efficient integration of renewable energy sources, ensuring reliable power supply while minimizing environmental impact and operational costs.**

***Index Terms*— Photovoltaic (PV) system, Hybrid energy storage, Grid-connected system, Energy management Power flow control, Battery charge/discharge rates, Solar energy utilization ,Grid stability, Simulation modeling**

I. INTRODUCTION

The integration of solar photovoltaic (PV) systems into the grid offers sustainable energy solutions but poses challenges due to solar power's intermittent nature. Hybrid energy storage systems, especially battery-based ones, address this issue. A power management scheme optimizes PV system utilization by controlling power flow between the PV array, batteries, and the grid. It stabilizes grid voltage and frequency, provides backup power, and enhances system efficiency. Components include power converters, energy management algorithms, and communication systems. The scheme aims to enhance efficiency, extend battery life, and ensure grid stability. It enables peak shaving, time shifting, and demand response capabilities, leading to improved grid management and reduced energy costs. Advanced control strategies adapt to changing conditions, optimizing system performance. Overall, the scheme maximizes renewable energy utilization, enhances grid stability, and reduces carbon emissions for a sustainable energy future.

II. BLOCK DIAGRAM



The PV system components include the PV array, MPPT controller, DC-DC converter, BESS, grid connection, power management controller, load demand monitoring, power flow control, energy management algorithms, and communication interfaces. The PV array captures solar energy, while the MPPT controller optimizes its output. The DC-DC converter adjusts voltage for battery storage. The BESS stores excess energy. The grid connection involves an inverter. The power management controller monitors and controls system operation, considering load demand and system conditions. Energy management algorithms optimize power flow. Communication interfaces enable remote control and monitoring. This scheme ensures efficient solar energy utilization, effective battery storage, and reliable grid interaction.

III DESCRIPTION

Introduction to Photovoltaic Systems

Photovoltaic (PV) systems are essential for converting solar energy into electricity, serving various applications in sectors such as transportation, residential, and commercial. However, challenges persist in achieving optimal solar cell efficiency due to factors like reflected light and conversion losses.

PV Modeling

PV modeling involves constructing ideal solar cell circuits, integrating current sources and diodes to mimic solar irradiance and the p-n junction. Simulation aims to maximize power output using equations derived from the ideal solar cell circuit.

PV Simulation

Simulation of PV modules involves considering factors such as the number of parallel and series cells, with adjustments made to tailor voltage and current outputs to specific requirements. The simulation typically includes subsystems like shunt, diode, and phase currents.

Incremental Conductance MPPT

Incremental Conductance Maximum Power Point Tracking (MPPT) is a widely used technique for optimizing PV system efficiency. It continuously tracks the system's optimal operating point using algorithms that rely on voltage and current measurements.

Algorithm Basics

The incremental conductance method, one of the most common algorithms for MPPT, calculates the derivative of power with respect to voltage and compares it with the incremental conductance to determine the operating point.

Operating Modes

The incremental conductance algorithm operates in perturb and observe (P&O) or incremental conductance (IncCond) modes, adjusting the system's operating voltage to track changes in solar irradiance and temperature.

Algorithm Behavior

The algorithm adjusts the PV system's operating voltage based on comparisons between the calculated incremental conductance and the power derivative, ensuring that the system continuously operates at the maximum power point (MPP).

Advantages and Considerations

The incremental conductance MPPT algorithm offers advantages such as fast response time and high tracking efficiency. However, it may face stability issues under rapidly changing conditions, necessitating careful consideration during implementation.

Real-World Applications

Incremental conductance MPPT finds widespread application across residential, commercial, and utility-scale PV installations, enhancing energy harvest, reducing losses, and improving overall efficiency.

IV. SIMULATION MODEL

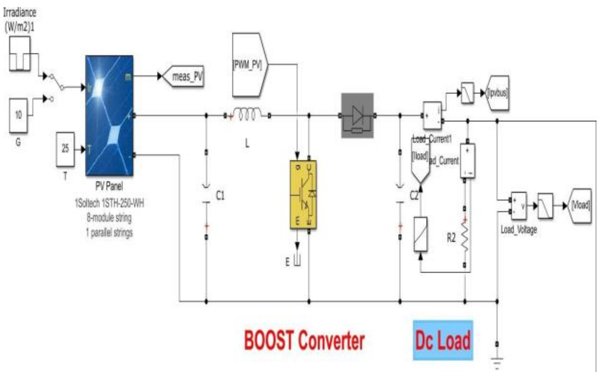


Fig 2. Pv modelling

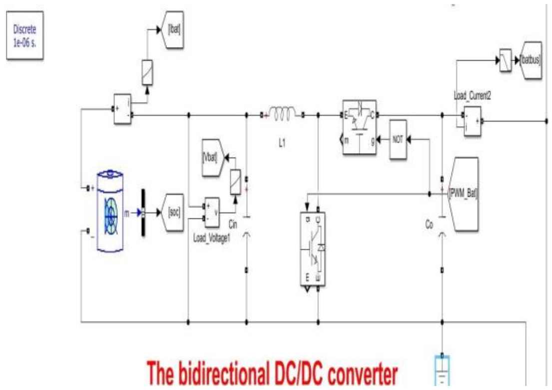


Fig 3. Battery simulation Model

Battery Simulation Essentials:

SoC Estimation

Accurately gauge battery energy levels using voltage, current, and temperature data.

Battery Modeling

Employ models reflecting real battery behavior, considering parameters like internal resistance and capacity.

Energy Management:

Develop and assess strategies such as peak shaving and load leveling to optimize battery usage and solar energy consumption.

PV Simulation

Calculates maximum power point, utilizes 36 cells in series (0.6V each), Simulink model incorporates shunt, diode, and phase current subsystems, offering flexibility for sizing adjustments and optimization for varied conditions.

Grid Simulation Model

Illustrates architecture of grid-connected PV with HESS, comprising components like inductors, capacitors, diodes, switches, and converters to regulate power flow. Utilizes quadratic boost converter for DC-link voltage, incorporates supercapacitors and batteries for energy storage, and employs VSC for grid connection, enabling operation as inverter or rectifier.

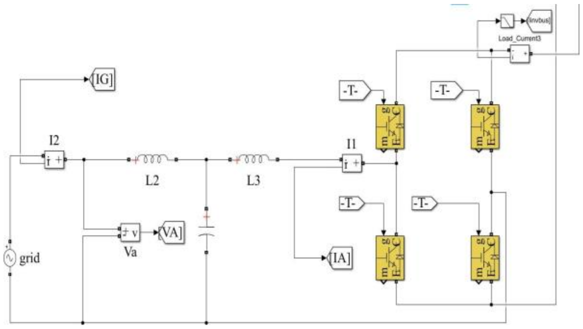


Fig 4. Grid Connection Model

V. IMPLEMENTATION

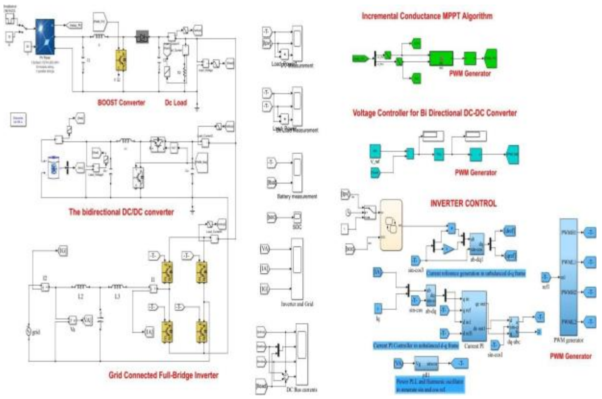


Fig 5. Simulink Model

PV Power Generation Control

Regulates PV array output based on irradiance and temperature for maximum energy extraction.

Battery Charging and Discharging Control

Manages battery charge during excess PV generation and discharge during insufficient PV generation.

Load Demand Monitoring

Continuously monitors load demand to optimize energy utilization from PV and battery sources.

Grid Interaction

Incorporates mechanisms for grid synchronization, voltage regulation, and power factor control.

Priority Setting

Determines order of energy source utilization based on demand, prioritizing PV or battery as needed.

Energy Arbitrage

Identifies favorable charging and discharging intervals to optimize energy costs.

SOC Management

Monitors battery SOC to prevent overcharging or over-discharging, ensuring battery health and lifespan.

System Monitoring and Fault Detection

Continuously assesses system performance and detects faults for timely intervention.

Emergency Backup Power

Automatically switches to battery power during grid outages for critical load supply.

Data Logging and Analysis

Records system parameters for analysis to optimize performance and plan future expansions or upgrades.

VI. SIMULATION RESULTS

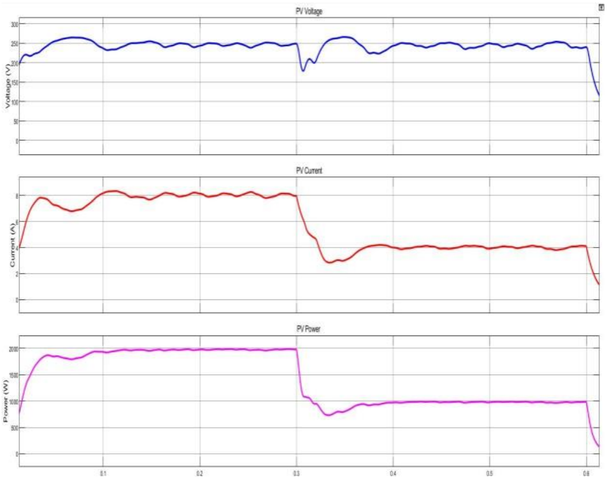


Fig 6 . PV Output Waveforms

Fig 6. PV System Simulink Model simulates PV array output considering factors like shading and temperature coefficients. The power management scheme optimizes grid-connected PV system efficiency by monitoring solar generation, battery status, and grid demand. It regulates battery charging/discharging, forecasts solar generation/grid demand, maintains grid stability, and enables island mode during outages.

Fig 7. Battery Output Waveforms

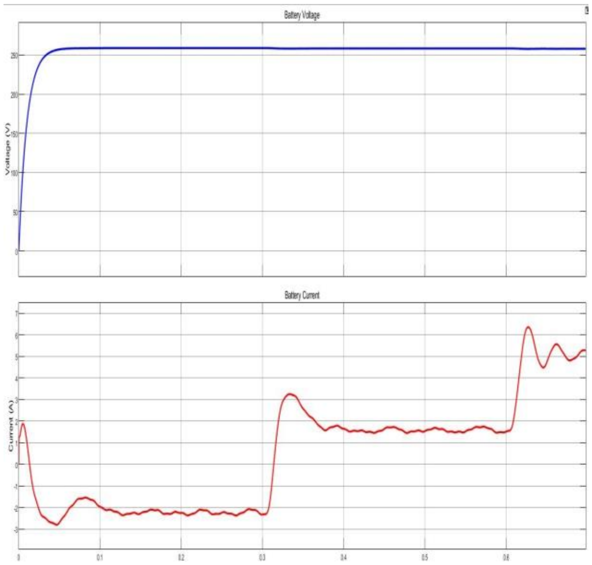
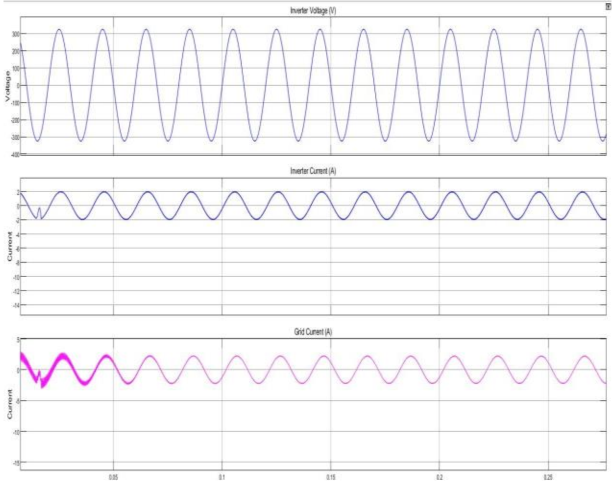


Fig 8. Grid output waveforms



Grid-connected PV systems with hybrid energy storage optimize energy generation, storage, and usage, reducing grid dependency and promoting renewables. PV panels convert solar energy into electricity, while batteries store excess power for use during low irradiation. Effective energy management ensures system reliability and performance optimization.

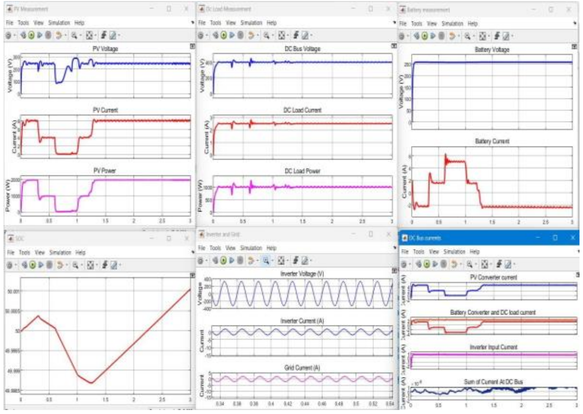


Fig 9. Simulink Model Output Waveforms

The power management scheme for a grid-connected PV system with hybrid energy storage is crucial for efficient energy utilization, grid integration, and system reliability. It should incorporate control strategies, load monitoring, grid interaction features, priority settings, energy arbitrage, SOC management, system monitoring, emergency backup power, and data analysis capabilities to optimize overall performance. After running the simulation, analyzed output waveforms to evaluate PV power output, battery SoC, grid interaction, self-consumption, and other metrics. Validated the scheme's effectiveness in optimizing energy utilization and reducing grid dependence.

VII. CONCLUSION

In conclusion, the power management scheme for a grid-connected photovoltaic (PV) system with a hybrid energy storage system (ESS) consisting of batteries offers numerous benefits. It enables efficient utilization of renewable energy generated by the PV system while ensuring a stable and reliable power supply to the grid. By integrating batteries into the system, excess energy can be stored during periods of high generation and discharged during high demand or low solar availability, enhancing overall system flexibility and reliability.

The scheme, typically comprising a PV array, inverter, battery bank, and control system, plays a crucial role in monitoring and optimizing system operation. It ensures optimal charging and discharging of batteries based on factors such as energy demand, solar irradiation, battery state of charge, and grid conditions.

VIII. REFERENCES

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