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Power Management of Hybrid Microgrid with Coordinated Control

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ABSTRACT: The growing incorporation of renewable energy sources into power networks has resulted in the creation of hybrid microgrids, which amalgamate various energy producing technologies to improve dependability and sustainability. Efficient power management is essential for maintaining steady operations, reducing energy expenses, and optimising resource allocation. This research examines power management solutions for hybrid microgrids that include an Energy Storage System (ESS). The Energy Storage System (ESS) is essential for harmonising supply and demand, alleviating variability from renewable sources, and enhancing power quality. Diverse control methodologies, including real-time energy management, demand response, and predictive algorithms, are examined to improve system stability and efficiency. Simulation results indicate that an optimised power management strategy significantly improves the performance of hybrid microgrids. The research finds that the integration of sophisticated control methods with energy storage technology may enhance the resilience and sustainability of the energy system.

KEYWORDS: PV, Wind, DFIG, Li-on Battery, MPPT, Hybrid Energy System, Hybrid microgrid

I. INTRODUCTION

Electrical electricity is essential for our daily lives. Traditionally, electrical power is supplied to consumers via massive grid-connected conventional power plants. The rising demand for energy in both rural and urban areas for various uses necessitates the expansion of the current power system infrastructure. The progress in power electronics switches and their management, together heightened awareness of environmental concerns and government policies, enables the generation of electrical power from renewable sources at various scales, ranging from tiny to big. Renewable sources such as solar, wind, tidal, geothermal, and small hydro are essential for meeting local electrical power demands without emitting harmful gases. The microgrid idea has significantly contributed to powering isolated rural areas without connecting to the main grid. Microgrids using renewable sources have alleviated the strain on the current grid and significantly contributed to the decrease of pollution levels. A microgrid is a compact assembly of generators, loads, and storage devices, complete with their respective power converters and controllers. A storage device is mandatory in standalone mode and optional in grid-connected mode. The aims of the microgrid are to provide power to isolated areas, alleviate the strain on the current grid, and use local renewable resources. Microgrids are categorised as DC type, AC type, or hybrid type based on the bus type interfacing with generators, loads, and storage devices. A bidirectional AC/DC converter is essential for interconnecting AC and DC microgrids in a hybrid microgrid. The DC microgrid powered by photovoltaic and wind energy has gained popularity owing to its DC generation and the efficiency of DC home loads.

The power management of a hybrid microgrid including an energy storage system (ESS) is crucial for maintaining a steady, efficient, and dependable power supply. Hybrid microgrids amalgamate diverse energy sources, including solar, wind, and traditional generators, which may exhibit variable and intermittent outputs. Efficient power management maximises the allocation of produced energy, equilibrates supply and demand, and improves system stability. The energy storage system (ESS) is essential for storing surplus energy during peak generating times and providing electricity when renewable sources are inadequate. Moreover, power management facilitates frequency and voltage control, load balancing, and the reduction of energy losses. It facilitates uninterrupted operation in both grid-connected and islanded modes, guaranteeing a constant power supply during grid outages. Furthermore, intelligent control techniques improve economic efficiency in power management by decreasing reliance on fossil fuels and optimising the use of renewable energy. In conclusion, effective power management in a hybrid microgrid with energy storage systems is essential for attaining a sustainable, resilient, and economically viable energy infrastructure.

II. LITERATURE SURVEY

Numerous research studies have concentrated on the power management of hybrid microgrids using energy storage systems (ESS) to improve reliability, efficiency, and sustainability. Diverse power management solutions, including as rule-based control, model predictive control (MPC), and artificial intelligence-driven optimisation algorithms, have been investigated to govern energy allocation among renewable sources, energy storage systems (ESS), and loads. Researchers have highlighted the significance of Energy Storage Systems (ESS) in alleviating power fluctuations resulting from the variable characteristics of renewable energy sources like solar and wind. Research has investigated the influence of bi-directional converters and intelligent inverters on facilitating seamless power transfer between DC and AC grids while preserving voltage and frequency stability. Furthermore, innovations in machine learning and IoT-based energy management systems have been suggested for real-time power optimisation and predictive maintenance. Recent research indicates that hybrid microgrids with energy storage systems enhance energy efficiency, lower operating costs, and bolster grid resilience. Nonetheless, issues such as battery deterioration, ideal dimensions of storage systems, and the intricacies of real-time control persist as critical domains of active investigation. The research underscores the need of combining sophisticated power management technologies with energy storage to improve the performance of contemporary hybrid microgrids.

Balancing power production, demand, and losses within a power system is essential for ensuring dependable, stable, and high-quality electricity for users. The actual power balance is achieved by regulating the steam input to the steam turbine in thermal power plants and the water input to the hydraulic turbine in hydroelectric power plants [7]. The reactive power equilibrium is achieved by the regulation of field current in synchronous generators and the management of reactive power compensators positioned at various sites within the power system [8]. Power produced from renewable sources, such as photovoltaic panels and wind turbines, is sent to the grid using power electronics converters inside the distribution network. These renewable sources use a maximum power point tracking (MPPT) algorithm to optimise power extraction via converters under certain weather conditions. The power equilibrium in a grid-connected microgrid is straightforward, since all renewable sources function in Maximum Power Point Tracking (MPPT) mode, with surplus or insufficient power being exported to or imported from the main grid [9]. Microgrids are classified into three categories according on the type of bus supply: alternating current (AC), direct current (DC), and a hybrid kind that combines both AC and DC. The performance of DC microgrids is 10-20% superior than that of AC microgrids due to the absence of issues related to reactive power regulation, skin effect, synchronisation, and harmonics in DC microgrids [10]. Power generation from photovoltaic arrays and fuel cells, energy storage in batteries and supercapacitors, and significant domestic and commercial loads such as light-emitting diode (LED) lamps, brushless direct current (BLDC) motor-operated fans, inverter-operated air conditioners, heaters, televisions, laptops, and mobile phones are of direct current (DC) type. Industrial loads with variable electric drives need a shared DC bus. Among them, the DC microgrid is characterised by simplicity, cost-effectiveness, operational ease, enhanced reliability, and efficiency [11]. In addition to the benefits, there are significant disadvantages, such as the lack of protection in the absence of a natural zero in DC waveforms, the absence of standardisation in voltage levels, and the inconsistency of operational codes [12].

III. METHODOLOGY

The block diagram illustrates a hybrid microgrid system that incorporates several energy sources, such as a battery storage system, solar farm, and wind farm. The system comprises a DC grid and an AC grid, interconnected by many power conversion stages. The battery storage system connects to the DC grid by a bi-directional DC/DC converter, facilitating energy storage and discharge as required. The solar farm produces direct current (DC) electricity, which is amplified via a boost converter prior to integration into the DC grid. The wind farm generates alternating current (AC) electricity, which is then rectified to direct current (DC) and controlled via a buck converter to provide power to DC loads. A bi-directional DC/AC converter facilitates energy transfer between DC and AC networks, maintaining a reliable power supply. An LC filter mitigates voltage and current variations to ensure power quality prior to supplying power to AC loads. This hybrid microgrid system effectively regulates renewable energy sources, improves grid stability, and maximises energy efficiency for sustainable power distribution.

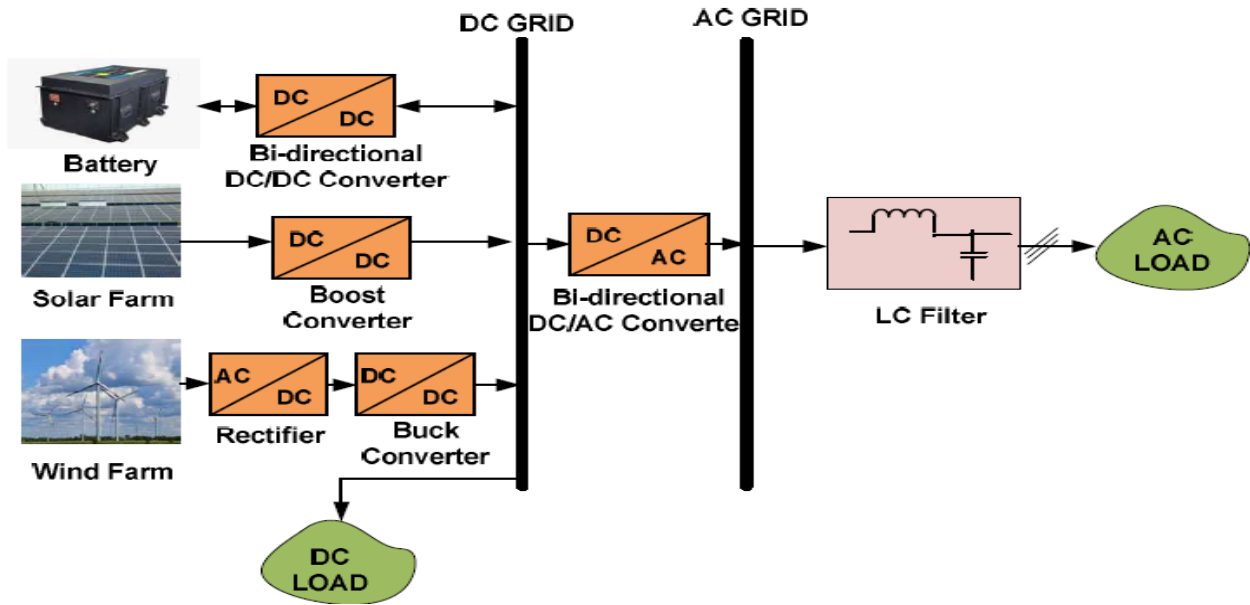


Fig 1: A Hybrid Microgrid System

The coordinated control of dq-abc transformation and a Proportional-Integral (PI) controller is extensively used in power electronics and microgrid systems for effective voltage and current management. The dq transformation (Park’s transformation) turns three-phase abc signals into a rotating dq reference frame, hence facilitating control by transforming AC variables into DC-like ones. In this framework, the d-axis generally regulates active power (P), and the q-axis governs reactive power (Q). A PI controller is then used to govern these dq components, guaranteeing zero steady-state error and enhanced dynamic performance. Following processing in the dq domain, the inverse dq-abc transformation reverts the controlled signals to their original three-phase configuration for inverter functionality. This coordinated control technique improves power quality, stability, and reaction time in both grid-connected and islanded hybrid microgrids. This technology is especially beneficial in applications like inverter-based distributed generation, motor drives, and renewable energy integration, where accurate control of power flow and voltage is essential.

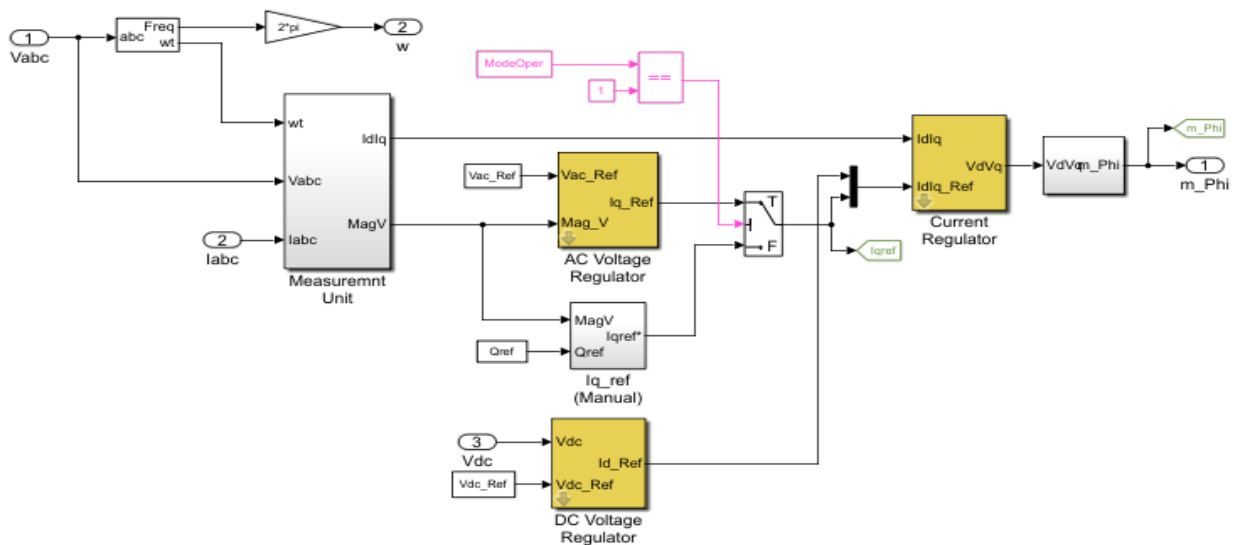


Fig 2: Controlling Technique

The abc to dq transformation is an essential method used in hybrid microgrid controllers to streamline the management of three-phase systems. This transformation turns time-varying abc (three-phase) voltages or currents into dq (direct-quadrature) components, functioning inside a rotating reference frame. The dq transformation facilitates the decoupling of active and reactive power regulation, hence enhancing system stability and performance. A dq-based controller is often used in power converters, grid-following inverters, and energy storage systems (ESS) inside a hybrid microgrid to manage voltage, current, and frequency. The controller efficiently regulates power distribution among renewable sources (including wind and solar), batteries, and loads by the use of proportional-integral (PI) or sophisticated control methodologies. This improves power quality, reduces harmonic distortions, and guarantees steady operation under varying load situations.

IV. EXPERIMENT & RESULTS

The experiment on power management in hybrid microgrids aimed to assess the efficacy of energy distribution among renewable sources, energy storage systems (ESS), and loads under diverse operational situations. A hybrid microgrid testbed was established, including solar photovoltaic systems, a wind turbine, battery storage, and adjustable loads, governed by a bi-directional converter and an inverter-based control system for power flow management. The system underwent testing in both grid-connected and islanded configurations to evaluate its stability, efficiency, and reaction to variations. Experimental findings indicated that the suggested power management technique effectively equilibrated energy supply and demand, guaranteeing steady voltage and frequency control. The Energy Storage System (ESS) adeptly mitigated power variations from intermittent renewable sources, reducing grid reliance and improving system dependability. Additionally, real-time monitoring and PI-based control algorithms enhanced energy efficiency, reducing power losses. The findings validated that an effective power management system in hybrid microgrids augments energy efficiency, elevates power quality, and guarantees sustainable energy distribution, making it a feasible alternative for contemporary decentralised power networks.

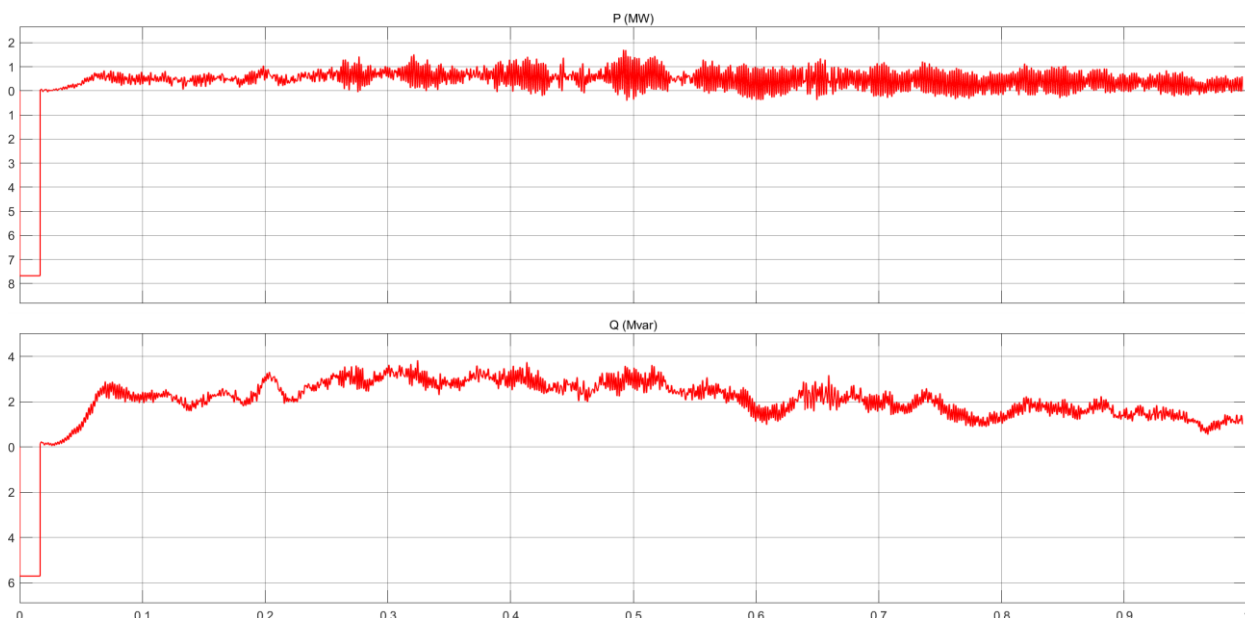


Fig 3: P and Q generated by the wind turbine

Active power (P) denotes the actual power produced by the wind turbine, which is immediately transformed from wind energy into electrical energy for load supply. Reactive power (Q) is essential for voltage regulation and power quality maintenance, particularly in systems experiencing variable wind speeds. Effective control of P and Q in wind systems enhances energy efficiency and maintains a balanced power flow within the microgrid.

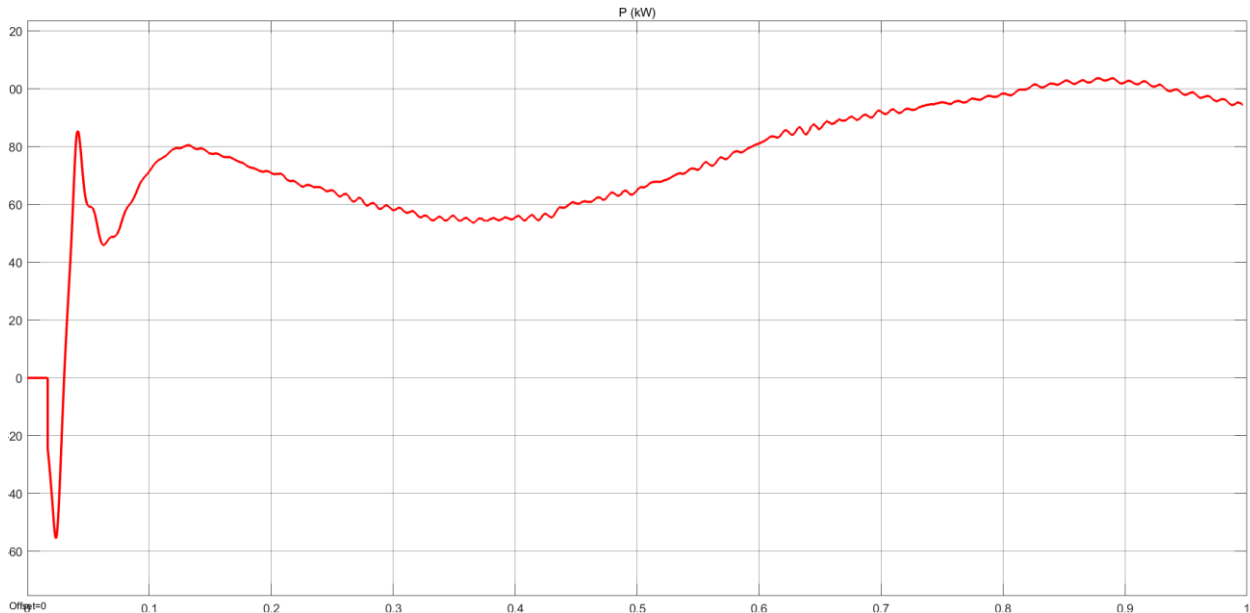


Fig 4 : A hybrid microgrid Power across load

The image illustrates that the proposed system amalgamates various energy sources, including renewable sources such as solar and wind, in conjunction with conventional generators and energy storage technologies. It functions in both grid-connected (0.5 Duration to 1 Duration) and islanded modes (0.1 Duration to 0.5 Duration), guaranteeing reliability and efficiency in power delivery. Efficient power management in a hybrid microgrid optimises energy distribution, stabilises voltage and frequency, and improves sustainability with nonlinear loads.

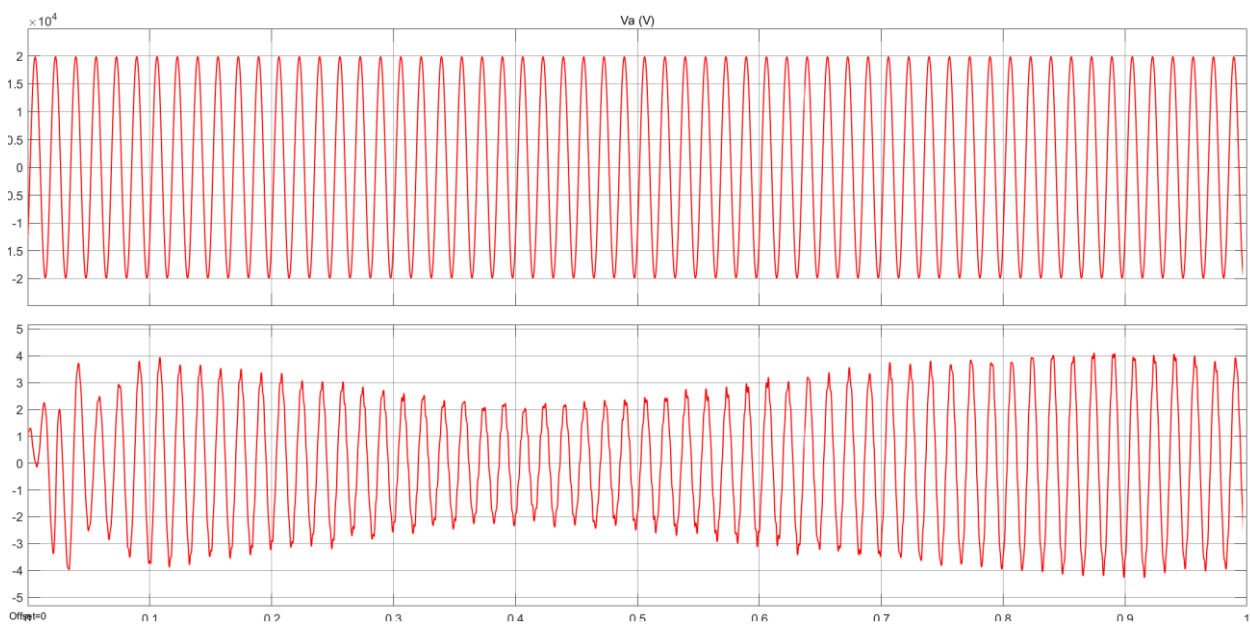


Fig 5 : Load Voltage and Current across (Va & Ia)

In a hybrid microgrid, it is essential to maintain constant load voltage and current, particularly in the presence of nonlinear loads such as power electronics and motor drives. Nonlinear loads generate harmonic distortions that may

impair power quality, induce voltage swings, and elevate system losses. The aforementioned figure clearly illustrates that the recommended effective power management solutions control voltage and current to maintain stable operation. The use of energy storage devices significantly improves power quality by alleviating fluctuations and enhancing the overall performance of the microgrid from a period of 0.6 to 1.

V. CONCLUSION

Efficient power management in hybrid microgrids using energy storage systems (ESS) is essential for maintaining a steady, effective, and resilient electricity supply. Hybrid microgrids reduce dependence on fossil fuels and enhance sustainability by incorporating renewable energy sources such as solar and wind. This paper proposes coordinate control techniques for continuous power management among the source, storage, and battery to provide dependable system operation under fluctuating conditions. The Matlab/Simulink application is used to simulate the whole system. The simulation findings indicate that the proposed system ensures dependable operation under the effects of pulse load and fluctuating weather conditions in an islanding mode. The power flow is managed with remarkable efficiency and efficacy via the use of battery storage.

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