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Power Quality Improvement for Hybrid Microgrid Integrated with Renewable Energy Sources

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Abstract:

Given the present energy crisis and depletion of fossil fuel reserves, there is a pressing need to enhance the integration of Renewable Energy Sources (RES) into the power system. This research focuses on designing and managing a Hybrid Microgrid (HMG) in fluctuating RES. The Direct Current (DC) sub-grid comprises a Wind Turbine (WT), a solar Photovoltaic (PV) array equipped with a Perturb-and-Observation (P&O) Maximum Power Point Tracking (MPPT) method, a boost conversion, and a Battery Energy Storage System (B-ESS) connected to DC demands. The Alternative Current (AC) sub-grid comprises a Permanent Magnet Synchronous Generator (PMSG) WT and a Fuel Cell (FC) integrated with an inverter circuit synced with the grid to fulfill its load requirements. A reversible Interlinking Conversion (IC) connects the AC and DC sub-grid, enabling efficient power interchange across the two grids. The IC's control technique allows it to function as an active energy filter and exchange operator. The IC's active energy filtering function ensures that the power supply of the microgrid complies with the criteria set by IEEE 519. It does this by offering reactive power assistance and decreasing the harmonic levels to below 5%. The suggested method enables the HMG to function in grid-connected and islanded states. During grid-connected operation, power is transferred across the DC and AC sub-grids, ensuring that all load requirements are fulfilled. In the islanded method, a diesel generator provides power to the AC sub-grid to fulfill the needs of essential loads, while the B-ESS sustains the DC microgrid. The suggested model is constructed and simulated with MATLAB, and its outcomes are examined.

Keywords: Power Quality Improvement, Microgrid, Renewable Energy Sources, Converter.

1. Introduction

The energy crisis is a persistent societal problem arising from the anticipated depletion of the oil, gas, and coal reserves, leading to a substantial rise in greenhouse gas emissions [1]. Several experts have expressed concerns over warming temperatures in recent decades, attributing its primary cause to oil and coal consumption for energy production [2]. Moreover, a growing trend of escalating worldwide energy use result in a shortage of fossil fuels in the forthcoming decades. The abundance of resources is a significant cause for worry, increasing the need for alternate energy production. Microgrid technologies are becoming more popular [3]. A microgrid is a compact component of an electrical system that can function in two distinct modes: islanding state and grid-connected state. The microgrid was interconnected with battery storage, load, and generating systems. The microgrid will be regarded as a controlled load during the grid-connected scenario. Microgrid configurations employ Renewable Energy Sources (RES) in their generation circuits to fulfill the need for electricity, therefore addressing the power shortage problem [4]. Implementing microgrid networks offers several advantages for consumers and electricity utility providers. Incorporating the microgrid into the grid improves the system's performance, decreases emissions, and lowersuser prices [5].Potential threats to the safety of the new energy distribution network are discussed in this study [6].

The extensive consumption of fossil fuels has resulted in climate change and several environmental concerns. Research is conducted to optimize the use of RESto produce sustainable and eco-friendly energy [19].Air quality monitoring and information system development is detailed in this document. The system provides data on the amount of target gaseous pollutants in a specific region where sensors are set [7].Several outlying areas have sporadic power delivery from the electrical system. Several regions possess ample supplies of RES, such as wind, solar, biomass, and hydropower. Therefore, it is more advantageous to include RESsuch as Dispersed Generators (DG) at specific locations to decrease reliance on the grid by circumventing the transmission lines [21]. Recent progress in power electronics has led to the integration of different kinds and sizes of Direct Current (DC) and Alternating Current (AC) loads into the power network. These situations have stimulated the investigation of HMG for its integration with the primary power grid and ability to fulfill local energy needs [8]. Given the intermittent nature of the grid, a microgrid must transition smoothly between an islanded and a grid-connected state. Appropriate controllers facilitate the effective operation of DG systems in both islanded and grid-connected scenarios. To ensure the reliability of the entire structure, all DG units must run synchronously when integrated into the network.

This study presents a system consisting of a RES with a Maximum Power Point Tracking (MPPT) [9], a Permanent Magnet Synchronous Generator (PMSG) wind turbine (WT), and a Battery Energy Storage System (B-ESS) that forms the DC sub-network [10]. The AC sub-network is also established by integrating a PMSG WT, an FC, and a DG. A decentralized control approach is suggested to incorporate and effectively coordinate many DG units inside the system. A converter that links the DC and AC microgrids facilitates the transfer of electricity between the subgrids. The suggested control technique enables the IC to function as a virtual Active Power Filter (APF), effectively addressing power-quality problems and providing reactive power assistance to AC loads. The control approach also ensures continuous monitoring of the smooth transition between grid-connected and islanded scenarios while maintaining a constant power source in a standalone approach.In this research, we provide a novel approach for resource selection, with the goal of reducing server power usage and load balancer overhead [20].

The following sections are organized in the specified sequence: Section 2 provides an in-depth analysis of the existing literature on enhancing power quality in hybrid microgrids. Section 3 suggests enhancing the power quality of a hybrid microgrid by using renewable energy sources. Section 4 examines the findings about enhancing electricity quality in a hybrid distributed grid. Section 5 provides an analysis and summary of the study findings.

2. Literature Overview

This section discusses the power quality improvement in RES. This study provides a comprehensive examination of the incorporation of wind and solar microgrids into the primary power grid to effectively regulate the flow of electricity, enhance power quality, and alleviate the load, reinforcing the central grid [11]. A simulation was conducted to test asmart grid system with many microgrids connected to a RES. The system included tariff control and efficient power flow administration, aiming to enable power-sharing and improve the quality of electricity.

The suggested research on grid-connected photovoltaic (PV) systems effectively operates continuously, regardless of constant or fluctuating solar irradiation, while being linked to a relatively consistent load [2]. This solution demonstrates the intelligence to function in several modes, including the detection of solar PV power and the capacity to facilitate reversible or multidirectional electric power without human interventions.

This study proposes creating a cluster of microgrids powered by RES. The microgrids would be formed by connecting different buildings within an urban neighborhood [3]. This improves the dependability of the electrical supply by effectively controlling the energy inside the cluster, independent of the utility grid. A fuzzy spatial vector pulse width modulator is suggested to regulate the inverter, enhancing power supply reliability.

An Improved Water Wave Optimisation method has been suggested to improve energy handling and boost power quality [4]. This algorithm incorporates adaptive population count and adaptable wavelength factor for better effectiveness. The approach efficiently and flexibly adjusts the settings of the Proportional Integrated controller to provide optimal performance.

This study examines a power control strategy for inverter-based DG in an isolated microgrid, focusing on efficiency [5]. The control approach comprises an inside current control loop and a third power controlling loop, using a synchronized reference framework and a typical PI controller.

A novel control strategy is suggested to increase the power quality of RES, including PV, WT, FC, and batteries [6]. The Moth Flame Optimization Algorithm is used to improve the query behavior of a method by minimizing the function of errors. The primary objective of the suggested technique is to improve the energy quality by considering the variation in both active and reactive energy.

This work focuses on developing a microgrid with a static transmission compensation to enhance power quality. The control strategy used in this system is droop regulation [7]. Therefore, a novel approach is introduced to improve the hang-regulated microgrid's electrical quality and enhance the DC-link electricity's fluctuating reaction under load variations. This approach uses an online developed polynomial petra fuzzy neural networking controller as the DC-link electricity administrator, replacing the conventional proportional-integral (PI) control system.

This system regulates the inverters for every microgrid inside the cluster and the voltage-generating converter-based distributed static compensation at the point where the group and the power grid connect [8]. This control technique utilizes the benefits of fuzzy logic and artificial neural networks, thus efficiently managing the network.But the current approach uses computationally intensive functions, which means it uses more power and has greater computational overhead. We provide a hybrid secure approach that is both energy efficient and secure for communication between cluster heads and base stations[22].

Although these strategies provide favorable outcomes, they need to be improvedregarding complexity and associated system concerns. The objective of the proposed study is to provide a method for enhancing the power quality of a hybrid microgrid by using RES.

3. Power Quality Improvement for HMG

This study presents two potential methodologies. One method uses a fast-charging idea to incorporate vehicle-to-grid and grid-to-vehicle technologies into a microgrid. To comprehend the concept of the microgrid and its constituent elements, it is essential to examine the relevant studies conducted by other scholars. The importance is the energy-storing system of the microgrid. The energy storage component of the system is the aggregation of Electric Vehicles (EVs) that will link to the charging facility's DC bus via an external charger. The layout of the microgrid should include meteorological data conducive to the optimal functioning of the RES used as generators in the system. The charging station arrangement, which relies on the fast-charging idea, is simulated using MATLAB. Utilizing a blend of calculation, representation, and programming makes it more convenient. Analyze and evaluate the Simulink model to enhance system efficiency and power quality while lowering Total Harmonic Distortion (THD). If the Simulink design succeeds, many EVs will be integrated into a single B-ESS and linked to the suggested charging facility setup, designed for fast charging, as seen in Figure 1.

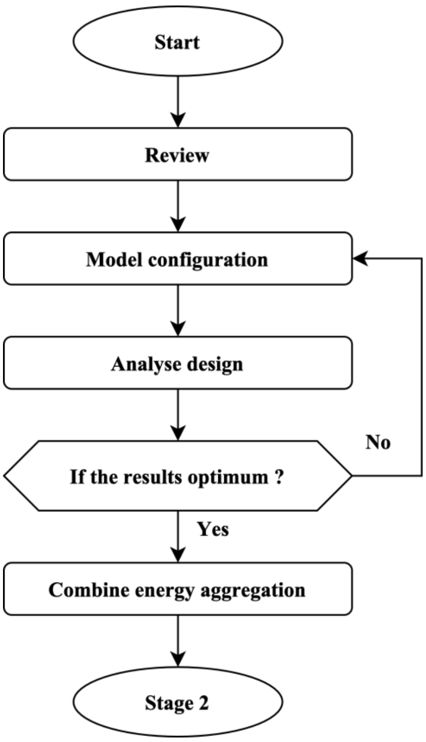

Figure 1. Workflow of the system design

The next step involves consolidating EVs into a single battery storage facility. The charging and discharging of EV cells need to be regulated, including a converter. The control systems in EV batteries and converters are crucial because they allow reversible power transmission between EVs and the microgrid via the power electronics interface's controller. Before commencing, examining and analyzing the existing techniques used to create control methods for battery adapters and converters is essential. This evaluation will enable to ascertain the effectiveness and efficacy of the equipment in question. In control schemes, multiple controllers are sequentially used for assessment, which is suitable for two methods. The initial control method employs an ongoing electricity control technique to regulate the discharging and recharging of EV cells. The subsequent technique is a cascade controller designed for the converter system, specifically in the synchronized reference framework. If the system demonstrates satisfactory performance, the suggested charging station setup, which relies on the fast-charging idea, will undergo testing. This testing will enable high-power reversible recharging for EVs using off-board adapters and enhance the electrical quality by reducing the structure's THD, as seen in Figure 2.

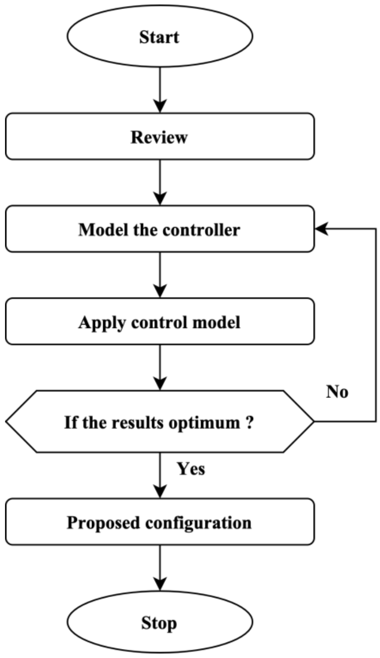

Figure 2. Proposed system configuration design flow

The suggested microgrid utilizes several control techniques. All DG units use decentralized control devices, which will be explained in the following sections.

3.1. Solar PV Control

To get the highest power output from the photovoltaic system, it is recommended to use the Perturb-and-Observation (P&O)-based MPPT method, as seen in Figure 3.

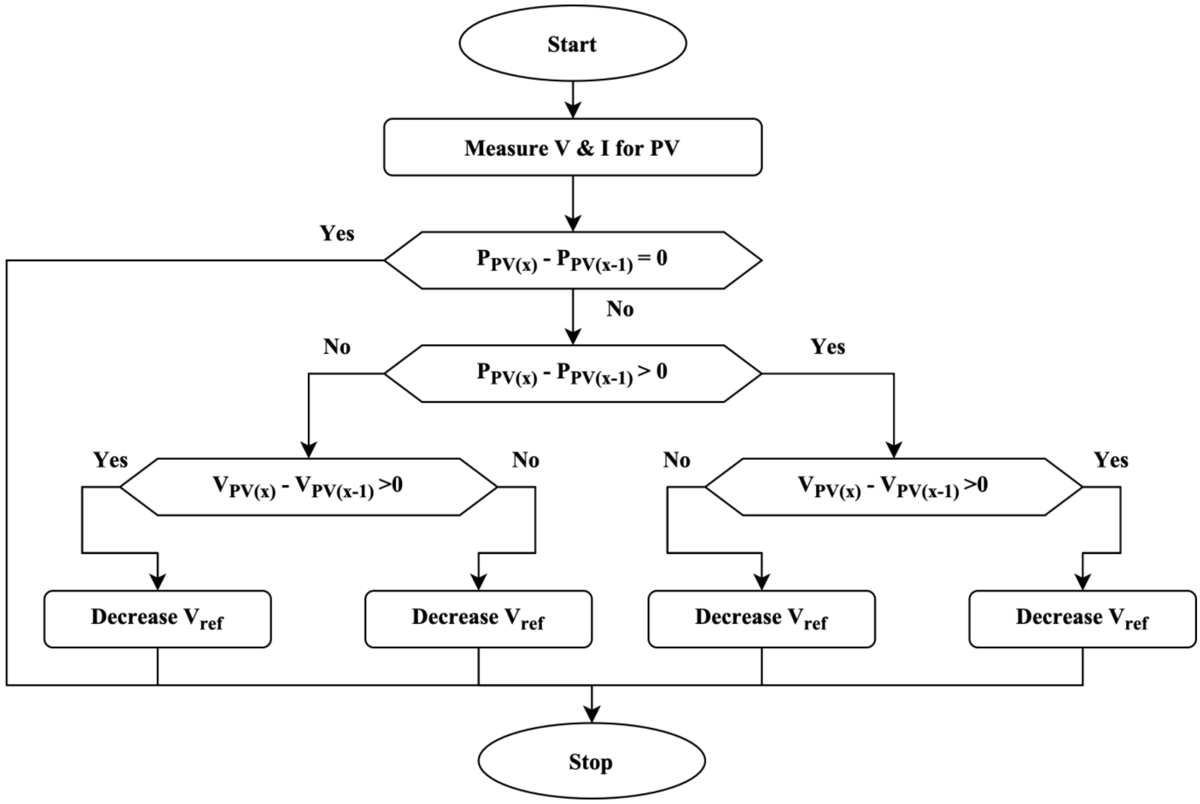

Figure 3. PV system controlling method

Its simplicity and high efficiency characterize the MPPT approach. The MPPT processor continually adjusts the duty cycle of the boost conversion to obtain the most incredible power. Following the flowchart shown in Figure 4, a perturbation in the duty cycle results in an observable change in P_{PV}, and V_{PV}.

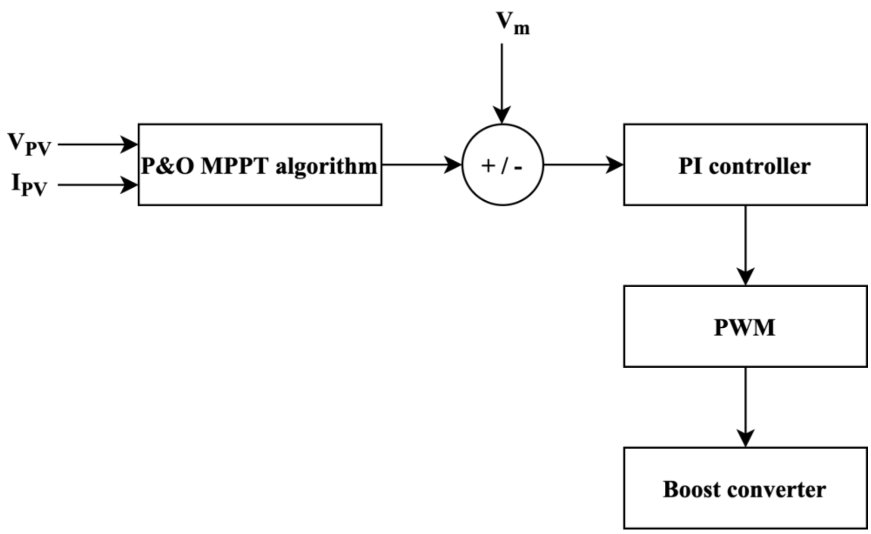

Figure 4. Controller design for power quality improvement

The controlling mechanism of the P&O MPPT-based boost conversion is shown in Figure 4. The duty period is adjusted depending on the detected alterations. The duty period is sent to a Pulse

Width Modulation (PWM) generator, which produces the switching impulses for the boosting conversion. This procedure is iterated to get optimal power production.

3.2. Inverter Control

Integrating the WT generator and FC into the AC sub-grid involves the employment of two distinct converters. As the primary goal of these two DG units is to inject actual power, the converter terminals are synced with the standard voltage and maintained in a mode where the electrical current is regulated. During the grid-connected scenarios, the frequencies and voltages of the grid serve as the benchmark indicators. To get consistent output, it is necessary to stabilize the DC connection of the converter. The DC-link signal of the converter is contrasted to the standard electricity, and the resulting error signal is then sent to a PI regulator. The result of the PI regulator is directly related to the energy dissipation in the DC-link capacitor, which is necessary to ensure the consistency of its power. The discrepancy between the produced energy and energy loss via the DC connection determines the power required to be introduced into the circuit. The standard signal is derived from the grid power and grid frequencies in the grid-connected state. In the islanded scenario, the legal information is obtained from the power and frequencies of the diesel generator. The three-phase standard signal is inputted into a Phase-Locked Loop (PLL) block to calculate the angle θ.

Next, Park converts the electrical signal from the abc plane to the dp plane. Equation (1) is used to derive the corresponding d-axis electrical signaling.

$$i_d = \frac{1}{3}\frac{P_g*V_d+Q_g*V_q}{(V_d)^2+\left(V_q\right)^2} \quad (1)$$

The corresponding q-axis electrical signal is set to 0 as the active power is supplied. The reversed Park's conversion moves the current electrical current information from the dq planes to the abc planes with an angle θ. The standard power signal created and the actual converter outgoing power signal are sent to a hysteresis power regulator to get the gate impulses for the converter. The hysteresis regulator limits the fluctuations in current and ensures a sinusoidal current flowing from the converter.

3.5. Control in HMG Approach

There is a growing need to incorporate numerous microgrids to boost stability and optimize energy handling. The suggested distributed management is implemented in the multi-microgrid technique, as seen in Figure 5. An interconnecting converter is required to be installed among the microgrids. Decentralized management has the capability of integrating several independent systems.

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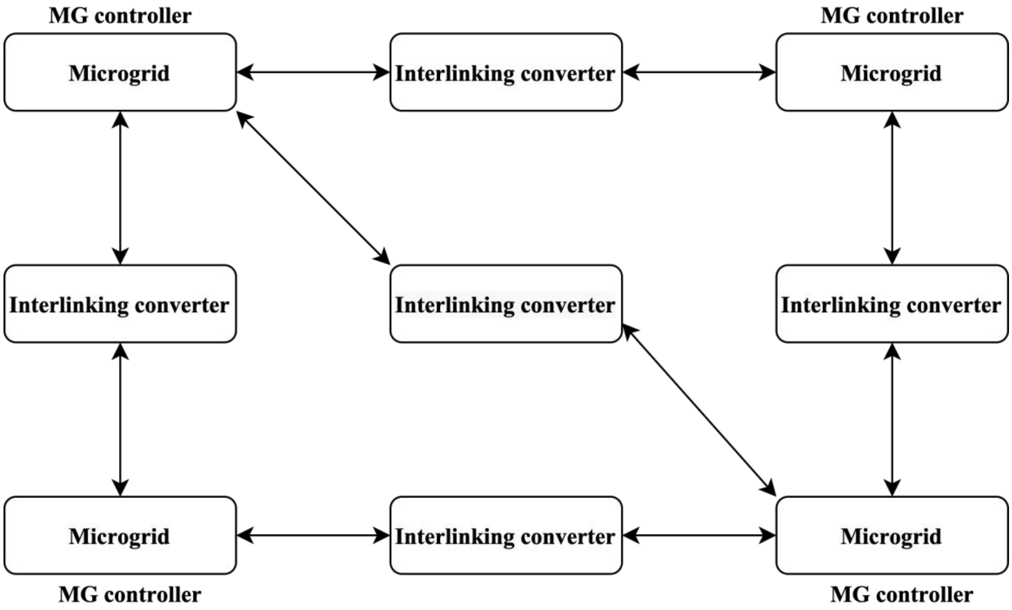

Figure 5. HMG controlling model

4. Experimental Findings

This section presents the simulation outcomes of the suggested system. The system is constructed and simulated using the MATLAB surroundings, and the simulation outcomes of several situations are analyzed. To demonstrate the efficacy of the suggested control method, the structure is subjected to various conditions, including electrically linked and islanded choices, power exchange among the DC sub-grid and AC sub-grid via the IC, battery charging and discharge, and proactive filtration of the IC.

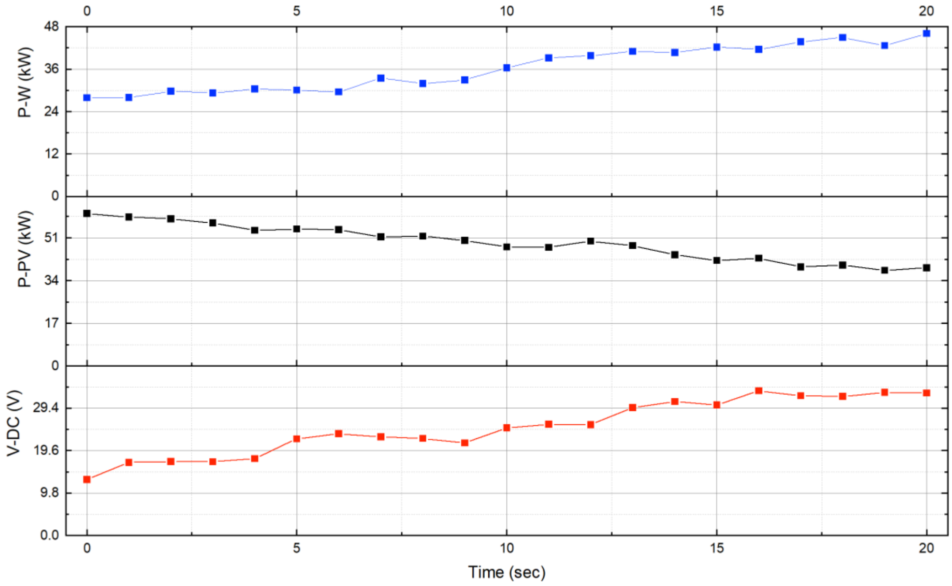

Figure 6. Behaviour of HMG

Figure 6 displays the dynamic behavior of the hybrid microgrid elements throughout the selected periods. The direct current voltage (V-DC) has a steady pattern, suggesting reliable functioning within the range of 12.9V to 33.03V. The power output of the photovoltaic system (P-PV) first varies, peaking at 60.75kW and then gradually stabilizing at roughly 39.09kW during 20 seconds. The power generated by the microgrid (P-W) steadily increases, reaching a value of 46.08kW after 20 seconds. The mean values demonstrate a consistent DC voltage of 23.74V, effective solar power production at 49.21kW, and a total power output of 34.09kW. These results highlight the effective design and management of the hybrid microgrid, guaranteeing consistent and environmentally friendly electricity production despite fluctuations in time.

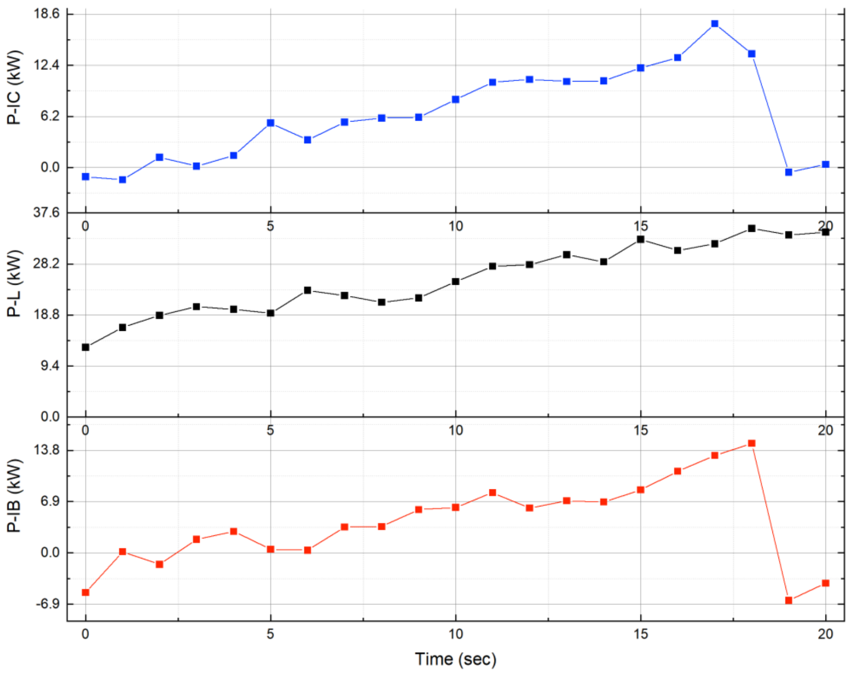

Figure 7. Time-varying performance of parameters

Figure 7 illustrates the time-varying performance of crucial parameters in the hybrid microgrid. The bidirectional power (P-IB) exhibits fluctuation, ranging from -5.32kW to a high of 14.75kW, with an average of 2.9kW for 20 seconds. The power usage gradually rises, reaching 34.72kW in the 18th second, with an average of 24.2kW. The connecting converter power (P-IC) exhibits variations, reaching a maximum of 17.44kW during the 17th second and having an average value of 9.16kW. The findings emphasize the fluidity of power transfer in the microgrid, where P-IB represents energy flow in both directions, P-L indicates the power demand, and P-IC reflects power transfer across subgrids. The mean values underline the comprehensive equilibrium and effectiveness of the hybrid microgrid system, demonstrating its capacity to manage electricity sustainably and responsively over an extended period.

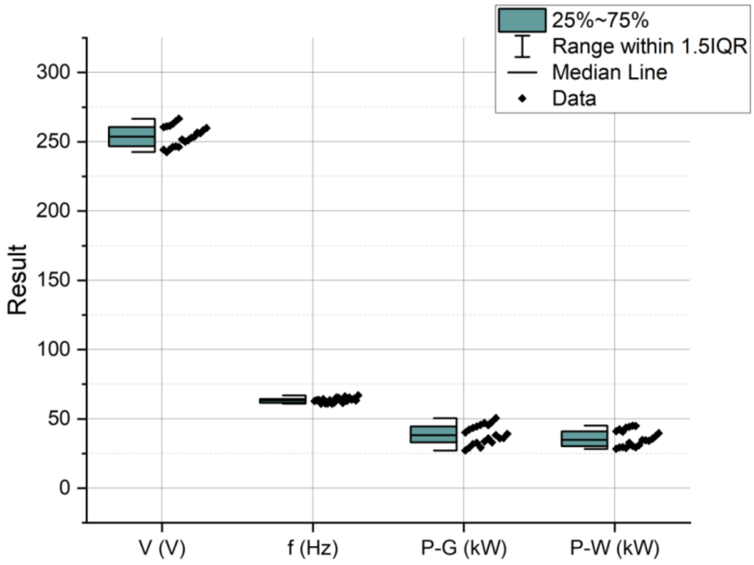

Figure 8. Dynamic properties of HMG

Figure 8 depicts the dynamic properties of essential parameters in the hybrid microgrid throughout time. The voltage (V) demonstrates slight fluctuation around a mean value of 255.42V, guaranteeing a consistent electrical setting. The frequency (f) exhibits little variations, with an average of 63.31Hz, suggesting a stable functioning of the power system. The power production undergoes dynamic fluctuations, reaching a high of 50.53kW and maintaining an average of 37.45kW. The power consumption (P-W) shows fluctuations, peaking at 45.14kW at the 19th second and having an average of 33.79kW. The findings demonstrate the robustness and effectiveness of the hybrid microgrid in maintaining a consistent power supply and efficiently managing frequency and power exchange across the sub-grids within the designated time frame.

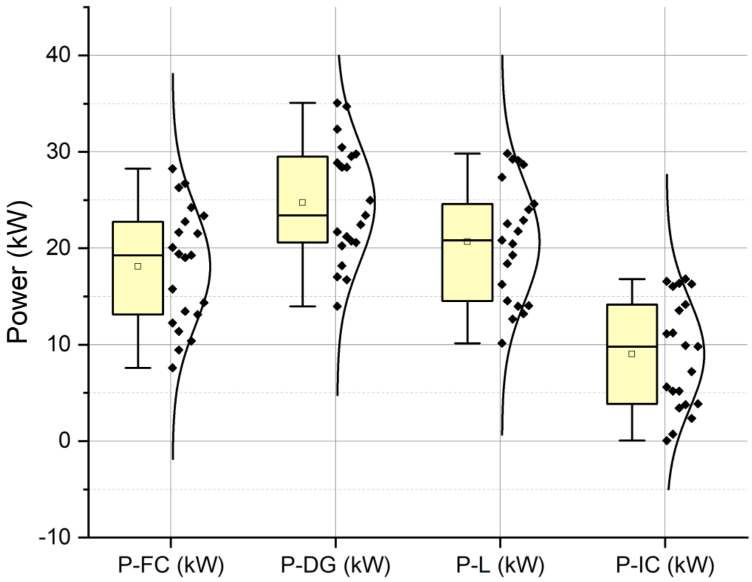

Figure 9. Performance analysis of HMG

Figure 9 presents a thorough summary of the performance parameters of the hybrid microgrid across a specific period. The power output of the fuel cell (P-FC) begins at 7.6 kilowatts and reaches a maximum of 28.26 kilowatts, with an average of 20.49 kilowatts. The power output of the distributed generator (P-DG) varies between 13.98kW and 35.07kW, with an average of 24.06kW. The power usage (P-L) fluctuates, peaking at 29.82kW during the 17th second and averaging 21.45kW. The interlinking converter power (P-IC) exhibits fluctuations, reaching a high of 16.81kW and an average of 10.39kW. The findings highlight the effective control of power production, use, and transfer between different parts of the hybrid microgrid, guaranteeing a dependable and environmentally friendly energy provision during the designated timeframe.

5. Conclusion

The HMG system is subjected to modeling and simulation. The simulation findings confirm that different forms of RESare effectively included in the AC and DC microgrid structure, allowing for the most significant energy extraction. The system efficiently harnesses electricity from RES during high demand or stores excess power during isolated operations. In addition to facilitating power transfer among AC and DC microgrids, the enhanced control technique allows the inverter converter to function as a virtual active power filter to improve power quality when there are imbalances and non-linear loads. The THD of the grid current is consistently kept below 5% by the specifications outlined by the IEEE519 guidelines. Distributed management enables smooth transitions between grid-connected and islanded phases. The system maintains stability across all modes of functioning, successfully satisfying all load requirements at specified energies and frequency levels. The suggested control system for the HMG effectively manages power sharing, ensures smooth change, improves power quality, maintains voltage and current management, and regulates the frequency range of the AC grid, even when there are changes in load.

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