

Research Article

Inertia Theory Frequency Dynamic Analysis and Control of Power System with High Proportion of Renewable Source

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Power plant emissions are a major cause of pollution in the environment. This necessitates the progressive replacement of conventional power plants with renewable energy sources. Changes in the quotas for conventional generating and renewable energy sources present new issues for modern power networks for example photovoltaic and wind turbines are replacing conventional power plants, which do not add to system inertia and due to the earth's diurnal cycle and weather conditions. Solar radiations are not consistent all through the day, and photovoltaic (PV) generation is sometimes insufficient to meet the power requirement of the shifting local load. The amount of inertia in the power system, as well as the action of adjustable frequency reserves and the amount of power imbalance, all have an impact on frequency stability. As a result, estimating power system inertia and assessing frequency response are required so that necessary actions can be taken to assure frequency stability. In this way, the system frequency, power, and voltage stability are the major issues when high proportion of renewables are added. In this paper, we explained estimating power system inertia-related frequency problems. The approach account for the frequency and voltage fluctuations that occur after a disturbance and estimate the system's total inertia constant as well as its overall power imbalance. The anticipated technique based on computational intelligence is used to analyze frequency responses from simulations of a test system under various circumstances on SIMULINK and focuses on the standalone PV system is critical for controlling it. As a result, the modelling of a PV system, battery, and generator using analogous circuits is discussed. As a matter of fact, maximum power should be harvested from a PV array to increase its efficiency that is depicted from the result outcomes of this research.

1. Introduction

This section of the article provides background information on the microgrid in the context of renewable energy penetration including inertia and frequency. The introduction and significance of microgrids and renewable energy sources are discussed and the awareness of the renewable connected to microgrid problems is also focused. A brief overview of the research background of inertia and frequency stability of grid with penetration on renewable sources and explanation of the research motivation and project's problem statements are highlighted. The previous researches done to cope these issues are explained along with the objectives.

Malaysia has abundant solar energy resources and is one of the world's sunniest countries. At the moment, Malaysia's

wind, light, and other renewable energy generation accounts for a relatively small proportion of total energy generation. To promote energy transformation, the government has issued a series of reform plans, with the goal of achieving more than 30 percent renewable energy generation by 2030 [1]. Renewable energy sources have emerged as a viable option for meeting rising energy demand, mitigating climate change and contributing to sustainable growth [2, 3]. The introduction of such systems is primarily accomplished through the use of well-organized microgrid systems; this provides a collection of technical explanations that allow the sharing of knowledge between customers and distributed generation centers, implying that they must be handled optimally [4].

Exponential energy demand has contributed to the reduction of fossil fuels such as oil, coal, and biomass. This in

turn raises the emissions from the greenhouse effect. Power systems have integrated small and large-scale renewable energy sources, such as wind, solar, tidal energy, and biomass to alleviate the above difficulties on a worldwide platform. The rise in energy demand and the reconsidering of energy systems have led to the generation of power near the depletion sites. This power comes from renewable sources, which are becoming extremely important fall in costs, particularly in the situation of solar photovoltaics and wind power.

The inertia problem can be divided into three parts: inertia theory, inertia identification, and virtual inertia control. The power electronic equipment are constantly replacing the synchronous generators because of the physical structure of power electronic equipment that differs from the traditional synchronous generator. This results in gradual change in power system inertia [2]. The research in this domain has emphasized that high-energetic power penetration system is increasing energy efficiency. A large number of wind turbines and photovoltaic systems have taken the place of many synchronous generators. But the rotating inertia of the synchronous machines itself was lacking, which resulted in a reduction in constant, poor inertia equivalent system steadiness.

The high proportion of renewable energy power systems in operation faces a slew of dynamic security issues. According to [3], renewable energy generation is highly volatile and random. When the system's inertia is insufficient, and renewable energy output fluctuates widely, the system may produce new regional power grid security and stability problems due to a lack of effective resistance to this energy fluctuation, which not only severely limits access and utilization of renewable energy but also causes systematic security risks. As a result, further investigation into the inertia principle of renewable energy power systems is required.

There are, however, few studies on the inertia principle of high proportion new energy power systems at the moment. More research is being done on virtual inertia (VI) control and the effect of decreasing system rotation inertia on system frequency stability after increasing renewable energy permeability. Reference [4] examines the relationship between the frequency change rate, the lowest point of frequency, and the inertia of system to reveal the effect of system inertia reduction on frequency stability. Instead of synchronous generators, system reserve capacity and battery energy storage are used to provide inertia energy for smoothing renewable energy generation fluctuations [5]. A wind turbine is used to add virtual inertial control to the system's inertial support capacity, allowing wind power inertial capacity to match traditional grid inertial capacity [6].

Electric power frequency is a metric for power system balance. Frequency stability is defined as the capacity to refurbish system generation and load demand balance with minimal load loss as shown in Figure 1.

The influential aspects of frequency control are frequency response phase, control object, control number, and control algorithm. According to the different frequency response phases, the control participants can be divided into

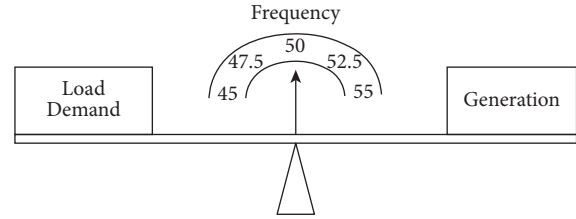


FIGURE 1: Relationship between frequency and variations in load demand and generation.

inertial controls, primary frequency regulation, and secondary frequency regulation. Depending on the number of controllers, to control the various frequency reaction stages of a given object and coordinate several objects during the same frequency reaction stage. According to the various control algorithms, the frequency response stages of the same object can be divided into coordination control, and multiple object coordinating control in the same frequency reply stage is devised. Examples include linear quadratic control [7], adaptive control [8], sliding mode control [9], and fluid control [10]. For a particular stage of frequency response, the control strategy used with a specific control object must be proposed.

In the last decade, solar PV energy has gotten a lot of attention. It was one of the fastest increasing sources in 2018, with 181 GW installed globally [11]. This is due to the fact that the cost of PV modules has steadily decreased over the last decade. It is also widely accepted by many industries due to its ease of installation, scalability, and low maintenance requirements and owing to the lack of moving parts in its operation. PV charge controllers are extensively used in unconnected systems such as street lighting, rural electrification, and other applications [12]. Maximum power point tracking (MPPT) tracker and a battery charge controller are both included in a Solar PV MPPT charge controller. The MPPT observers and distributes as much power as possible from the solar panel to the charge controller. The charge controller creates a hybrid charging strategy to ensure that the battery is charged efficiently while avoiding overcharging and excessive heat, which can cause battery damage. Many research papers mentioned the modelling of solar PV charge controllers [13], but there was little modelling detail and no efficiency analysis, as well as no model validation reference point with commercial charge controllers. To summarize, the models presented in the preceding literatures were incomplete, lacking MPPT and whole charge controller efficiency performance examination, as well as validation of the model with commercial charge controllers [14]. Combined power plants use synchronous generators with inertial response to abrupt frequency variation. Furthermore, if there are sufficient rotating reservoirs, their droop characteristics contribute to load-frequency regulation. Renewable energy system-based plants, unlike conventional power plants (CPP), are grid connected via power electronic converters [15]. In wind power plants, such power electronic interfaces decouple grid frequency from CPP. Static dc generators are also used in PV plant. As a result, RES-based plants cannot provide inertial response or load-frequency regulation on

their own and their large-scale integration. This problem may cause the loss of inertia and primary frequency reserve.

However, because an increment in power output is characterized by a decrease in the speed of rotor, resulting in a shift in the operating point, the increase in output power is only temporary. The duration of this assistance is usually around 10 seconds. Furthermore, while the rotor speed recovers, a second frequency dip may occur. Grid stability could be jeopardized as a result of such an occurrence [16]. The authors of [17] looked into how HVDC technology by differing the DC voltage, inertial response can be provided. In addition, the demand-side management (DSM) method is appropriate for delivering primary frequency response through the use of temperature controlled loads [18]. DSM, on the other hand, would necessitate the deployment of new infrastructure, such as smart devices and communication networks. Electric vehicles (EVs) will be used as a source of frequency support in future concepts, such as vehicle connected to the grid and grid connected to the vehicle [19]. However, the infrastructure is not yet in place, and the current fleet of electric vehicles is not enough to keep the grid running. Furthermore, energy storage system (ESS), which provide a variety of storage devices, are available [20], which offer both IR and primary frequency response (PFR) as viable options [20, 21]. As an outcome of environmental regulations and hard work to improve energy conservation, the number of renewable energy sources for electricity production has increased [22]. The increase in electricity generation from PE converter RES has no inertia without a proper control technique. A high inertia and rate of change of frequency (ROCOF), which can cause protective relays to trip, is the first challenge identified by Irish grid operators [23]. Load shedding and cascading failure can be caused by large frequency deviations [24, 25].

In [26], various imitated inertia control methods for PE converters were anticipated to mimic the synchronous generator inertia characteristics. These methods are primarily concerned with control design, with only a few addressing practical application. Emulated inertia control (EIC) is discussed as a developing concept to implement regulating the frequency in this paper. The EIC approach is a good fit for a system with low inertia. In [27, 28], a small-signal investigation of EIC implemented at an ideal grid-connected inverter was evaluated. However, previous EIC research has primarily focused on controller design, with only a few researchers discussing EIC functional implementation [29]. The concept of deloading control method for PV systems in addition to the EIC for controlling frequency and providing an inertial response is also proposed [30]. On the other hand, PV modules are forced to operate at a lower power level.

Rising energy costs, power system losses, and the dangers of nuclear power generation are all encouraging people to find new ways to generate electricity. Everyone in the globe wants to rely increasingly on renewable energy resources (RERs) for electricity generation [31, 32]. RERs provide economic benefits while increasing greenhouse gas emissions. By integration of more renewable resources, the stability issues take places in the system so we motivated to

study the stability issues and to provide the solution for unstable states as follows:

- (i) Inertial constraints: because solar technologies are static generation technologies, they have no inertia. When combined with conventional energy resources, it causes an inertia problem.
- (ii) Fluctuations in frequency: PV systems have low inertia and pose a hazard to the mechanical inertia balance of the power system. It poses a significant challenge to the power system's frequency stability.
- (iii) Voltage fluctuation: the intermittent nature of the PV system causes voltage fluctuation in the power system's generation profile. Falls, tripping, and blinding of protection devices can occur as a result of islanding events.
- (iv) Issues of stability: PV systems can put a strain on traditional system operations if their penetration increases the grid's hosting capacity.

Solar and wind are the two widely used and capable renewable sources for producing electrical energy among the various RERs. They are linked by converters that disconnect them from the electric grid, despite their intermittent nature. As a result, when traditional generators are replaced with RER, the electrical grid's effective inertia is reduced [33]. Frequency reliability and dynamic response are harmed when a huge amount of renewable sources are integrated into the grid [34]. In fact, over a short time period, a system having less inertia is linked to a faster ROCOF and larger frequency deviations [35]. Total system inertia is expected to decrease as renewable energy generation increases and conventional steam generation decreases [36]. This could be especially important in a scenario where the grid has a high renewable penetration but little demand. In these circumstances, the frequency drop may be severe enough to require additional safeguards like load shedding [37]. When the frequency goes below to 49 Hz, 10–20% load shedding is required [36]. At 48.7 and 48.4 Hz, additional shedding of 10–15 percent of the load is required. The generators must be disengaged from the grid to avoid blackout if the above procedures does not stop the frequency descent at 47.5 Hz. Fast frequency response's main aim is to decrease frequency dip and the degree at which they occur in the system to safe from blackouts. The use of conventional generators is one traditional solution. Consider synthetic inertia, such as the SVC PLUS Frequency stabilizer, or batteries. Full power availability is one of their advantages.

This paper's goal is to give a broad overview of system inertia and how it affects the grid stability. The research looks at a variety of frequency response solutions. Both conventional and alternative solutions, as well as their experimental specifications, are explained. In conventional generators, the amount of energy and highest available power for the initial inertia response have been indicated to be restricted. These solutions explain that the active power is exchanged when the value of frequency deviates with the power grid. For instance, the energy needed before a less frequency event can be kept during a successive event. In this section, the

lithium-ion battery storages and the SVC frequency stabilizer have been thoroughly examined. Battery storage systems are becoming more popular in developed countries as a result of the growing trend of highly volatile renewable energy in the grid. A variety of battery storage systems in various capacities are available. High load management, power quality, power storage, voltage regulation, auxiliary grid services, and renewable stabilizing are just a few of the applications that have been discussed with such solutions. On the other hand, the high permeation of renewable energies into the power grid creates difficult reliability and security issues. Frequency instability caused by synchronous generator replacement is a significant challenge [38].

The moment of inertia of a synchronous generator can be haul out to backing frequency deviancy because the speed of rotor is tightly fixed with the grid frequency. Renewable energy sources, on the other hand, lack inertia in most cases. A doubly fed induction generator, for example, has a restricted inertial reaction [39]. A permanent magnet synchronous generator's rotor speed is completely detached from grid-related frequency, and it has no inertial response, unlike solar PV. PV usually run in MPPT mode, which explains that the active power interaction with the grid fluctuates, resulting in an absence of inertia energy when it is needed. A second major trial is the complication of power system dynamics [40]. In the past years, some power instability events have been noted in delayed fed induction generator (DFIG) wind plants [41]. As a result, power grids with high renewable energy penetration will require improved damping capability. To increase stability, a control scheme called virtual inertia or virtual synchronous generator is proposed to make renewable energies act like synchronous generators [42]. To achieve sufficient power interaction with the grid in the case of PV, an ancillary energy storage unit is used. Auxiliary damping controllers for wind turbines are also designed to improve damping [43]. However, performing well in practice is never easy for them.

A converter's surplus load and transitory voltage support abilities are inferior to those of a synchronous generator because it cannot support high amount of short circuit current when sudden and huge disturbance occur. To achieve sufficient power interaction with the grid in the case of PV, an ancillary energy storage unit is used. Auxiliary damping controllers for wind turbines are also designed to improve damping [43]. However, performing well in practice is never easy for them. A converter's surplus load and transitory voltage support abilities are inferior to those of a synchronous generator because it cannot support high amount of short circuit current when sudden and huge disturbance occur. There is a substantial body of research papers that supports the use of the additional services market to bridge the gap between grid and DG resources. The concept of "unbundled or ancillary services" is discussed in reference [44]. Voltage regulation, frequency control, load following, spinning reserve, additional reserve, standby supply, and maximum shaving are all examples of ancillary services that active, nonactive power regulation support can provide.

The value derived from ancillary services is determined by technical and economic factors, as well as dependability. These services can also be classified according to the maximum advantage they would deliver to the grid, the DG owner, or both. The availability of high-energy density storage devices and advancements in semiconductor technology have given these services a new edge [44, 45]. They emphasize the importance of developing new standards of grid and developed new mathematical models for forecasting system behavior in the existence of high insertion intermittent energy resources.

Renewable energy source's stochastic nature has also been investigated. For forecasting ancillary services, Bevrani et al. used an ANN-based approach. This method aids in the prediction of spinning and nonspinning reserves, as well as up and downregulation requirements [45]. Raugei and Frankl [46] also pointed out that by using the twofold increase in PV generation would reduce cost by 1/5th. Liu and Bebic have connected the increase in PV inverter insertion to the level to which voltage regulation equipment on a line can be replaced. So even though a 5% increase does not have any effect during high load demands, an increase of 30% to 50% can completely displace the voltage-regulating capacitors. Tapanlis and Wollny proposed using AC coupling to control the frequency and voltages of microgrids powered by solar, wind system, and batteries. Borlea et al. [47] projected an ideal solution for ancillary service facility at the substations. In this study, they considered using FC (fuel cells) as a standby reserve for system support.

To further investigate the problem of inertia, frequency, and voltage fluctuation in high proportion renewable energy power systems, we attempted to redefine system inertia from the standpoint of system energy and angular momentum, and we investigate a new method of carrying out this research. To begin, the power system's inertia principle and the mechanism of new energy injecting energy and angular momentum into power grid nodes to affect the inertial behavior of the power system are investigated. Second, the inertia transfer and frequency dynamic process are investigated. We investigated the voltage fluctuation and the improved method in the standalone conditions. Finally, the agent group control of source load coordination improves system frequency stability based on the inertia theory as major objective.

To regulate active and reactive power from solar and an ESS, Babu et al. [48] projected a power management structure with consecutive multilevel inverters combined into the grid. For reactive power control between PV panels and batteries, a two-stage DFT and PLL strategy founded on active and reactive power management was utilized. Sun et al. used DC to DC converters for solar arrays, DC to AC converters for the grid linking, and a DC to DC converter for the battery to join the PV generation system and battery to the grid. Switching between constant voltage and MPPT operations is prompted by the DC bus signals.

Wu et al. have explained an end-user power controlling strategy that includes a PV system and battery storage. They were able to achieve multimode operation of the system by using inverters to connect the individual sources on the AC side. It becomes more expensive to perform frequency

control using only conventional generation. The combination of demand-side manageable devices to adjust frequency is a novel technique for meeting the growing demand in nonrenewable power generators [49]. DERs are getting increasingly more appealing for supplying loads together with traditional generators. EV, BESS, and water heaters are a challenge. As a result, DER allocation is critical for improving power system frequency and enhancing the integration of these power sources [50]. A review of bottleneck management approaches for the distribution network with excessive DER perception was also presented in [51].

The procedures for power regulation [52] presented load regulator with the addition of electric vehicles and DG. As per technicality and market situations, the load-shifting optimization problem was solved. This method can be used for a variety of DERs, including smart charging for electric vehicles. The market and direct control methods were discussed. Furthermore, under the smart grid scenario, an analysis of PE-based DER and their stability issues was proposed. Power electronics-based DERs were cited as examples of renewable energy resources and modern loads. In today's power systems, IEDs are the typical protection and control apparatus. These smart devices are used for a variety of purposes, including system regulator and protection, and as a result, power system modelling and analysis can get off to a good start [53]. In [54], demand-side frequency control and battery energy storage system were considered in the power system of the United Kingdom. They are DER's most significant components in today's power system. In previous work, BESSs were considered for the use of frequency regulation in the power system. It had a quick dynamic reaction and recompensed for load fluctuations on the electric grid. As a result, the combined BESSs can influence the frequency of both low- and high-frequency reserve services.

In an electric power system, frequency is a constantly varying variable that represents the equilibrium between generation and demand. The National Grid is operator in the United Kingdom, and it is responsible for keeping the power system's frequency response within acceptable limits. The working limit, which is equivalent to 0.2 Hz, and the statutory limit, which is equivalent to 0.5 Hz, are the two key levels that describe these limits. An interruption by frequency protection relays is provided to regulate frequency of both the generation side and demand side when the major frequency drops happen. The facilities cover both supply and utilize side. FFR, MFR, and EFR are examples of frequency response services [55]. The National Grid recently negotiated 201 MW of EFR facilities from ESS from a variety of providers. By the end of 2021, the majority of these providers should be able to offer their services [56, 57]. Timescale of the frequency response in accordance with load response in the system can be seen in Figure 2.

Large-sized synchronous generators, such as those used in the United Kingdom's power system, account for roughly 70% of the system's inertia. Small-sized synchronous generators deliver regulated power in the moderate power grids [56]. Challenges of inertia reduction due to their power electronics, some RES, such as wind and solar, do not have through connection between the machine and the system,

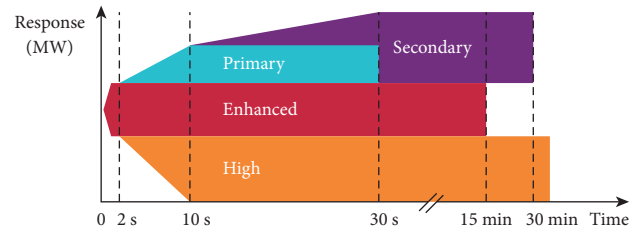


FIGURE 2: Timescale of frequency response.

preventing their spinning mass from backing to system inertia [57, 58]. As a result, RES decreases total system inertia, resulting in decrement in system steadiness and increasing the difficulty of power system process and regulator. Due to variations in wind speed and solar irradiance, RESs experience power fluctuations, which have an important impact on the frequency deviancy's stability.

2. Materials and Methods

This paper focuses on a microgrid test that uses a renewable energy-based power generation system that includes a PV array, batteries as ESS, diesel generator, power converters, filters, controllers, loads, and electric grid. A comprehensive simulation has been conducted of a grid-connected PV, battery and diesel generation system. A converter is used to optimize PV output and an inverter to convert the solar panel DC voltages into an AC system connected to the PV array and a utility grid. Meanwhile, a charge controller connects the battery to the common DC bus to deliver regulated PV voltage. The projected model of all components and the control method of system is replicated using the MATLAB/SIMPOWERSYSTEM program. The results validated the strength of the models and the efficiency of control mechanism.

A prototype of the model is also designed and developed to show the stability of the system. We integrated the PV, battery, and diesel generator in isolated system. We developed the inverter successfully and converted the DC supply to AC supply. We used DC bus bar, and all the sources are connected to it. We controlled the battery PV with the microcontroller to make coordination between them and controlled the load through IoT to turn it on and off.

2.1. Modelling of Energy Resources and Storage System. The important hurdles of using most renewable energy resources as distributed generators, such as wind farms and PV systems, are that their output powers are changeable and uncontrollable. Indeed, these key characteristics increase extra worries about the use of DG in a power system. An ESS is one of the most suitable approaches in this field. Due to which the Engineers can now achieve the power system more excellently. Furthermore, the fluctuation of RES and the corresponding decrease in system inertia requires innovative, flexible controllers and energy storage for optimal integration. Exact models for the diesel generator, PV array, and battery stacks must be developed in order to test our control techniques.

2.2. Diesel Generator Model. Due to the DG's complexity and high nonlinearity, investigations of diesel generators are now limited to the existing mechanical or electrical dynamics of the process. This study reviews many models that can be used to represent the complete dynamic process of a diesel generator. A model is then used to study the interplay between mechanical and electric aspects of a DG. The conventional model of the diesel generator and governor for speed management is depicted in the form of block diagram in Figure 3. This model is broadly employed because the active behavior of small generator sets is precisely reflected. The power delivered and inertia provided by the DG can only be controlled if the impact and proportion of the renewable sources are determined with a careful parametric analysis. This is the main reason behind the simulation analysis and design of DG model.

2.3. Photovoltaic Array Model. The PV cell is one of the most fundamental generating component in an electrical system. To replicate silicon photovoltaic cells, a single-diode mathematical model with a PV current source I_{ph} , nonlinear diode, and inner resistances R_s & R_{sh} can be used as depicted in Figure 4.

In the diode equivalent circuit, the mathematical relationship between current and voltage is as follows:

$$I + I_{ph} - I_s \left(e^{q(V - IR_s)/kT} - 1 \right) - \frac{V + IR_s}{R_{sh}}, \quad (1)$$

where I_{ph} is the photoelectric current, I is the current of diode saturation current, and q is the constant coulomb equals to 1.602×10^{-19} Coulombs, k is known as the Boltzmann constant equals to 1.38×10^{-23} Joule/Kelvin, t is the PV cell temperature in Kelvin, A is the ideal of the P-N connection, and R_s and R_{sh} are parallel to the inherent series. A solar radiation and cells temperature function of photocurrent is explained. The simulation design of solar inverter is depicted in Figure 5.

$$I_{ph} = \left(\frac{S}{S_{ref}} \right) [I_{ph} - ref + C_t (T - T_{ref})], \quad (2)$$

where S is the true PV solar rays (W/m^2); the solar radiation, the absolute cell temperature and $I_{ph} - ref$ are S_{ref} , T_{ref} and $I_{ph} - ref$ respectively; in conventional test conditions CT is the temperature coefficient (A/K). The saturation current of a diode changes with cell temperature. The simulation design and analysis of the inverter system as shown in Figure 5 is required because all the renewable sources' output depends on the attributes and parameters of this device.

2.4. Energy Storage Model. The energy storage itself and the operator of devices such as electronic, electrical, and mechanical that allow the storage and rescue methods to take place are both included in a simulation of the storage subsystem. The driver subsystem is a generic wrapper for a complex system that uses a number of different technologies. For active simulation, the batteries corresponding circuit model are most suitable. Based on the battery model, a general battery model for simulation is proposed, supposing that the battery model is assembled with a controllable

voltage source and resistances as shown in Figure 6. The simulation design of all the abovementioned components of the system is given in Figure 7.

2.5. Prototype Design. The design of hardware prototype is on the integration of PV system with battery to stabilize the system and to increase its working time. The reason to integrate RES is that traditional power is highly expensive; we use RES since it is less expensive, and the energy produced by RES does not pollute the environment.

For the project, we used 18 volt dc and 150 watt solar panel, and we used AC generator and connected all the sources with the common DC bus bar. The DC supply is converted into AC supply using an inverter. A battery with PV panel in parallel position is used. We controlled the PV and battery coordination with Arduino microcontroller. After the conversion in the AC supply, we supplied the AC to loads to run them. Finally, we used IoT technology for the load management system and display all the parameters of the system on mobiles. The block diagram of the hardware design is shown in Figure 8.

2.6. Power Sources. We used three power sources as also mentioned in the block diagram and their pictorial view is shown in Figure 9. These power sources include PV panel, battery, and AC generator.

2.7. Inverter and Rectifier. An inverter is a device that is used to alter direct current (DC) power into alternating (AC). H-bridge Inverter circuit is designed to alter DC supply from the PV panels to AC for loads. Arduino-based microcontroller is used to provide voltage signals of 5 V to input terminal. It has the total capacity of 1 kW. We connected all sources from DC bus bar to inverter, as shown in Figure 10. A rectifier is a modest dc current convertor with a voltage output vary from 0 V to 12 V. We used a complete wave rectifier with a voltage regulator to yield a consistent output. To connect all sources on the DC bus bar, we used a rectifier to convert 220 AC voltages from the generator 12 V DC.

2.8. IoT Control of Prototype. Distributes power usage to appliances under its supervision by connecting with load controllers. Using Bluetooth (BLE), connect to a smartphone provides all of the information required to be displayed on display screen. It performs multiple useful functions including, data collection from sensors, data collection from appliances, and scheduling of switching of electrical loads. Flowchart of the prototype design and IoT system is shown in Figure 11, highlighting the explanation of the flow process of the whole IoT system. This flowchart gives each step from the configuration of the mobile with the Bluetooth device including the operation of the relay and ends at showing the status of the loads on the LCD display.

Figure 12 gives a pictorial view of all the components that are assembled and connected. This also depicts all the loads connected.

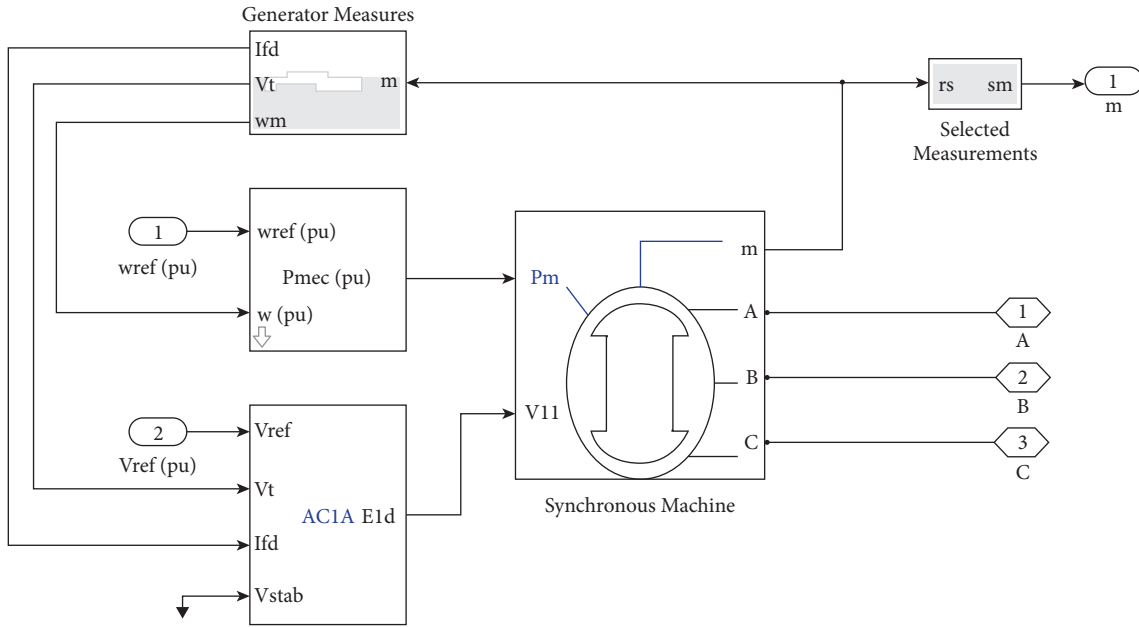


FIGURE 3: Diesel generator Simulink model.

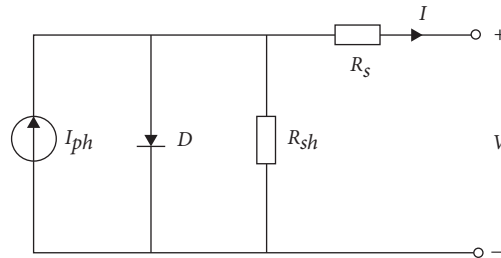


FIGURE 4: Simple model of single PV cell.

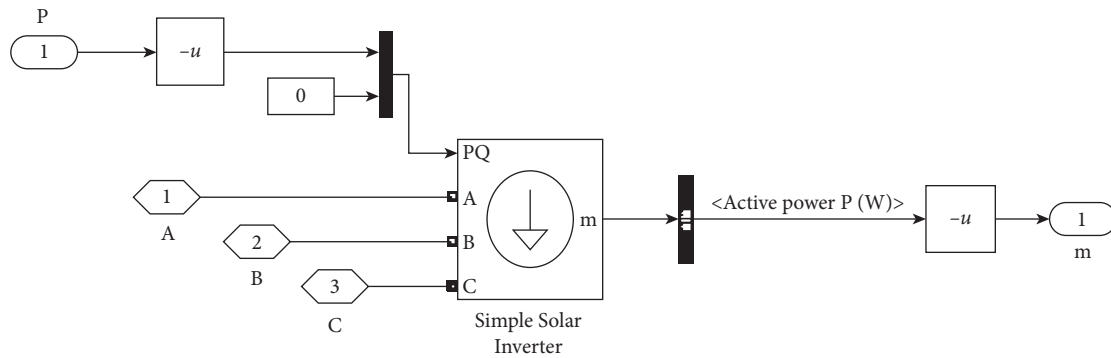


FIGURE 5: Simple solar inverter system in Simulink.

3. Results and Discussion

Taking into account the frequency instability and inertia in the renewable fed microgrid systems, multiple experiments are conducted. The results of these experiments along with the problem factors, as well as the technical methods and techniques for addressing them for the system, are described in this section. Figure 13 depicts the frequency of grid starting at the 50 Hz then at the moment of 15 sec the

microgrid is islanded from the utility that is the reason why the frequency is dropping and the other event happens when load increases from 200 kW to 500 kW at that point the frequency deviation take place.

Figure 14 depicts that the power of the distributed power resources that is shown in yellow with solar power curve. The line in red is diesel generator starting with relatively low power, but when the microgrid is disconnected, it increases power immediately and will deliver

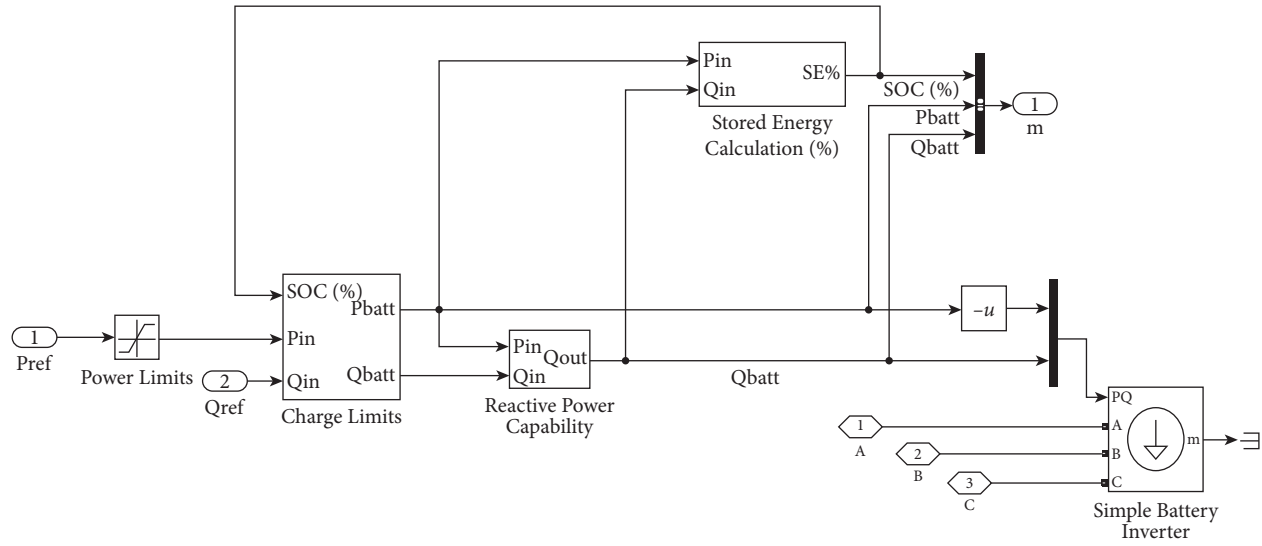


FIGURE 6: Battery block connection Simulink model.

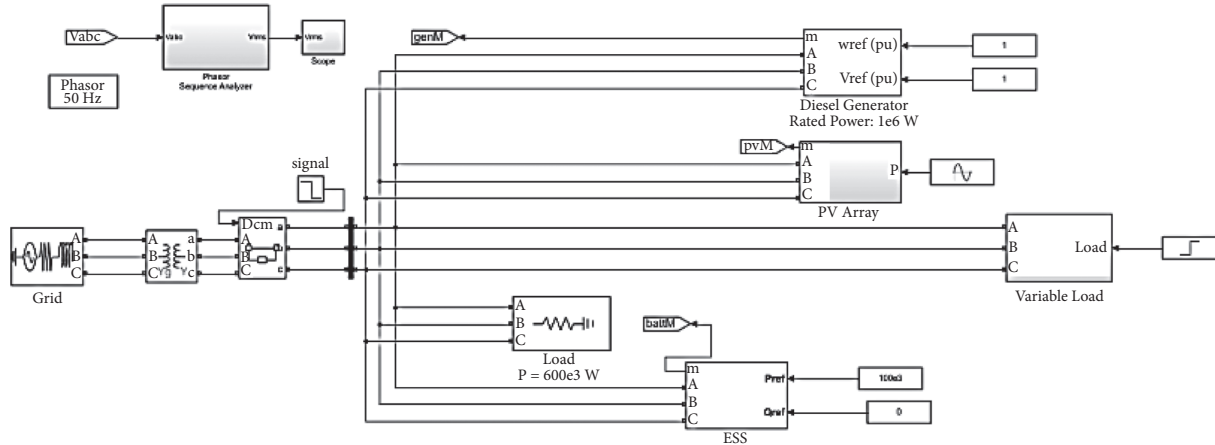


FIGURE 7: Complete grid-connected system simulation.

power that sums up with the solar power to the required power level from the loads similarly we gets another step when load is increased.

Figure 15 shows the battery is operated in which it is just giving power to the grid so that is the main reason that SOC is decreasing. We used battery as an ESS so that when our primary backup system generator also gets off, then ESS can supply power to stable the whole system.

Figure 16 shows microgrid voltages level, and it depicts the voltage disturbances happening at the point when frequency deviates at the time of islanding and addition of the loads and shows the recovery of voltages as well.

3.1. Prototype Results. The voltage, as we know, is load dependent, and the voltages in PV panel are determined by the amount of energy received from the sun and the amount of current drawn. Many solar panels are watt-rated. Because the generated power is affected by lighting conditions, either the current or voltage is variable.

The type of PV material used, the amount of irradiation received, the PV cell temperature, resistances, clouding and other shading effects, inverter efficiency, dust, module alignment, weather conditions, topographical location, cable width, and so on are some of these factors that affect the efficiency of panel. All the critical parameters of the system including PV voltage, battery voltage, generator voltage, time, frequency, power, and motor RPM are summarized in Table 1.

As can be seen from Table 1, the variation in the PV voltage has a direct impact on RPM and hence the frequency. However, the system power and battery voltage can be maintained due to their negligible impact on the system load. The last column shows the relevance of the frequency and RPM. It has been noticed that the PV voltages varies with the time as irradiances changes. We recorded the change in voltages and recorded in the table. It is important to check the voltage of PV continuously because it has the direct effect on power of the systems. If desired PV voltages are not obtained, it can damage the load connected and whole system can get off, as shown in Figure 17.

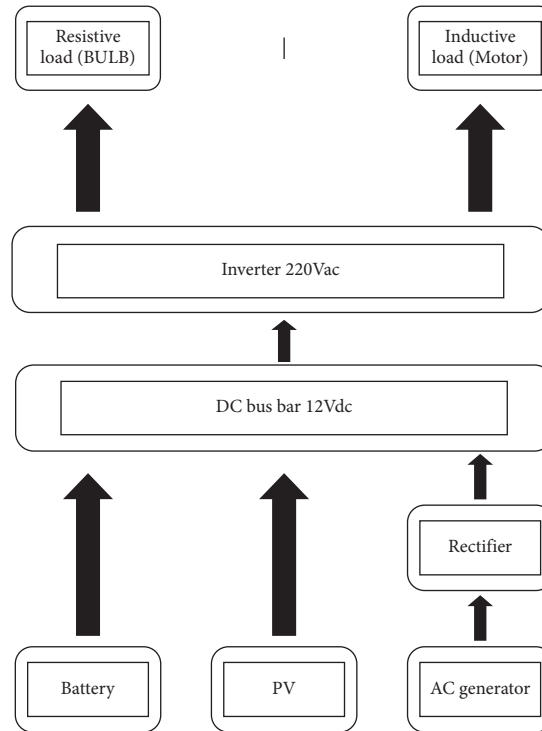


FIGURE 8: Block diagram of hardware prototype.



FIGURE 9: Integrated power sources solar panel, battery, and AC generator.

An inverter is a device that consists of different components to alter a direct current (DC) supply to an alternating current (AC) supply. It is important that the inverter should provide constant voltages and the frequency designed for the load. As the frequency fluctuates more than the allowed limit, it can cause the damage to the whole system, if the frequency increases the limit, the loads can be damaged, and if it decreases the limit, then the system can get trip.

So during our testing of the hardware, we operated our system with different loads and different sources to check our inverter output frequency, we notes down all the readings in table and depicted the variation in the form of graph shown in Figure 18. We noticed that our frequency remained constant at 50 Hz, but it fluctuates once and frequency drops.

A motor of 450 W is used in the project as an inductor load. We operated the motor at different RPM. We decreased RPM to check the effect on the system stability and

effect on resources. Initially, the motor is operated at its maximum RPM and later on the RPM are decreased gradually with the help of regulator. The impact of decreasing of RPM is represented in graph shown in Figure 19.

The change of the rpm of the motor is to check the effect on generator voltages. Initially, we operated the motor at maximum RPM of 2200 and recorded the voltages of generator at that time which was 220 V utilizing the maximum voltages gradually the RPM are reduced with the help of regulator to 2070 and voltages at that time was recorded as 200 V. This show that when we reduces RPM of motor the voltages also decreases. We recorded all the RPM and voltages in Table 1 and depicted the voltage decreasing trend in the graph shown in Figure 20.

Figure 21 shows the power stability of the system. As PV source voltages change with time, it effects on the power of the system. The purpose of integrating different resources

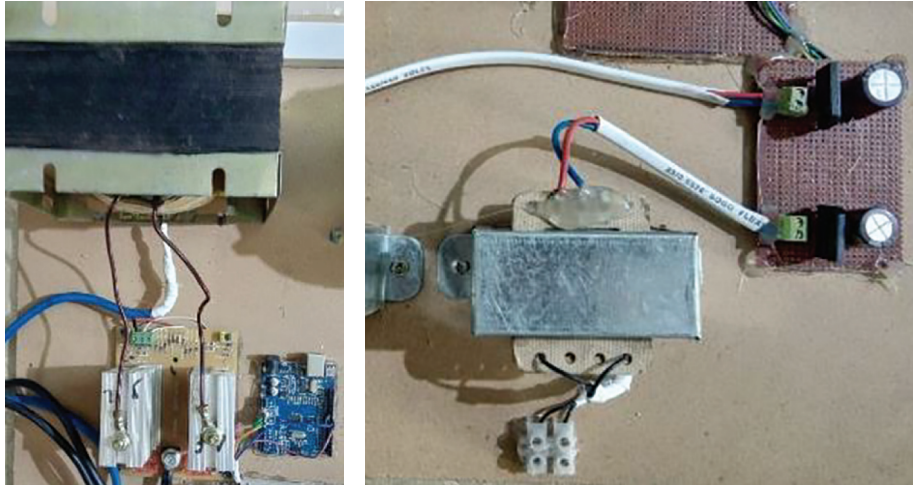


FIGURE 10: Hardware design of inverter and rectified.

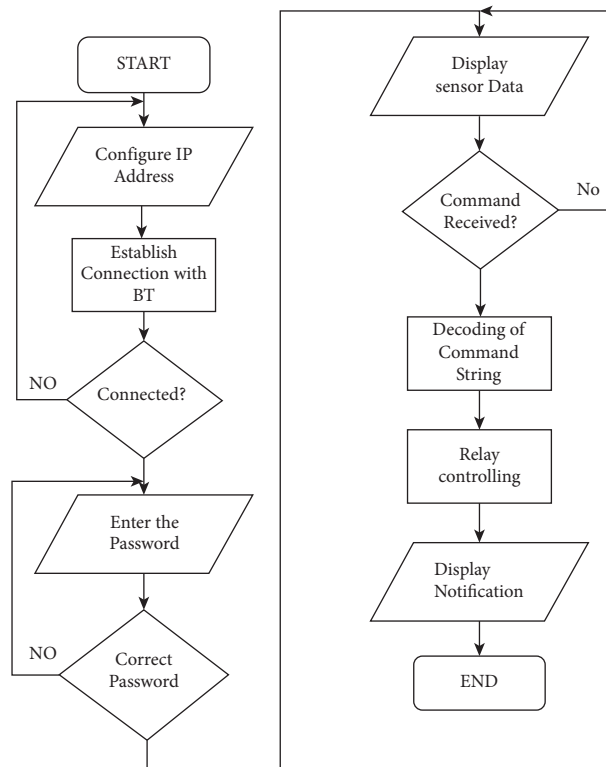


FIGURE 11: Flowchart for IoT control of prototype.

plays its role to keep the whole system balanced, which includes the battery and AC generator to fill the differences and to make the whole desired power constant. In this way, the system provides the accurate amount of the power to keep proper functioning of the loads.

In Figure 22, relationship between the motor RPM and generator voltages is shown. It makes clear that whenever the RPM decrease the voltages at the generator side also decrease as shown in the graph. In contrary, when RPM decrease from 2200 to 2070, the voltage

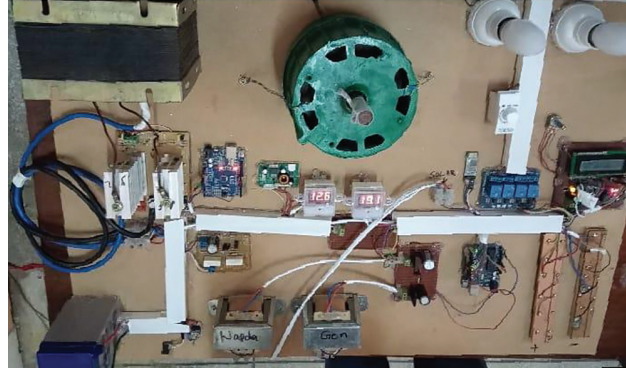


FIGURE 12: Pictorial view of complete hardware prototype.

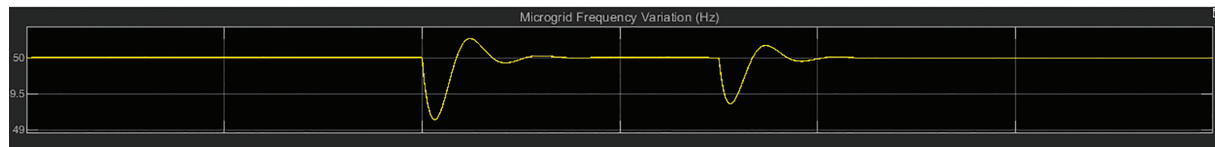


FIGURE 13: Grid frequency regulation.



FIGURE 14: Distributed resources response.

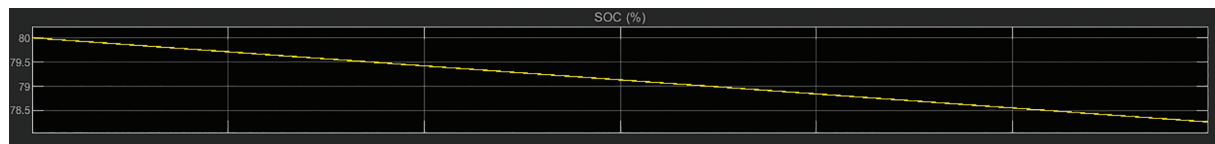


FIGURE 15: Battery SOC.

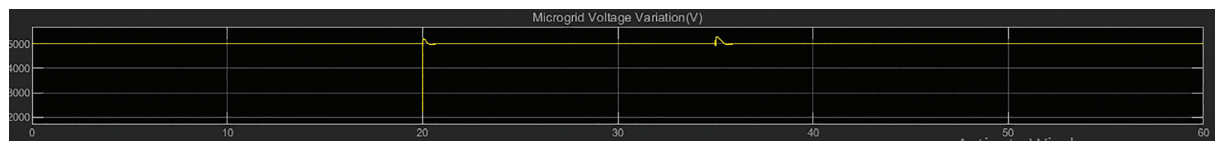


FIGURE 16: Grid voltage regulation.

TABLE 1: Hardware prototype readings (1 RPM = 0.01667 Hz).

PV (V)	Battery (V)	Time	Inverter frequency (Hz)	Power (W)	Motor RPM	Generator (V)	RPM to Hz
18.1	12.6	1	50	480	2200	220	$2200 * 0.01667 = 36.667$
15.3							
19.1	12	7	50	480	2070	200	34.50
14	12	18	49.5	480	1937	180	32.28
20	12	23	50	480	1795	150	29.92
17	12	30	50	480	1645	140	27.417

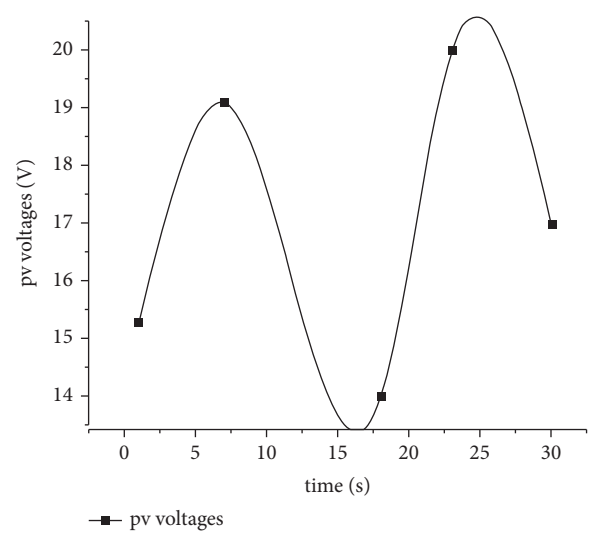


FIGURE 17: PV voltage variation graph.

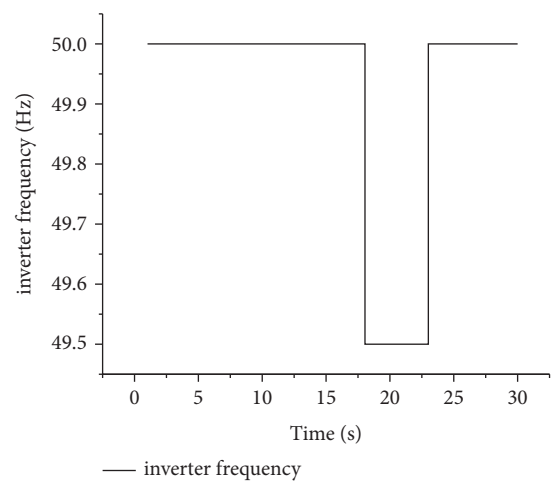


FIGURE 18: Inverter frequency variation graph.

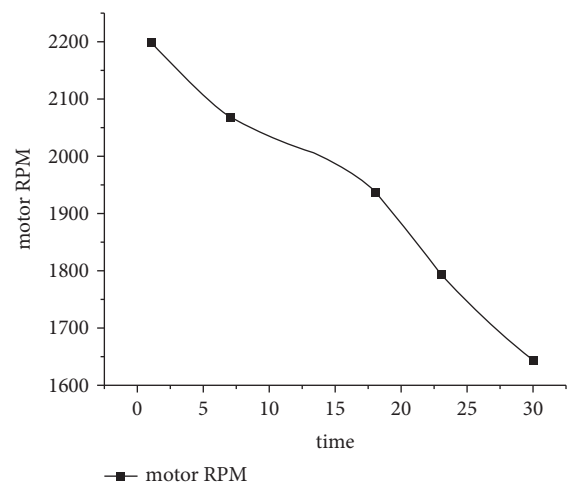


FIGURE 19: Motor RPM variation graph.

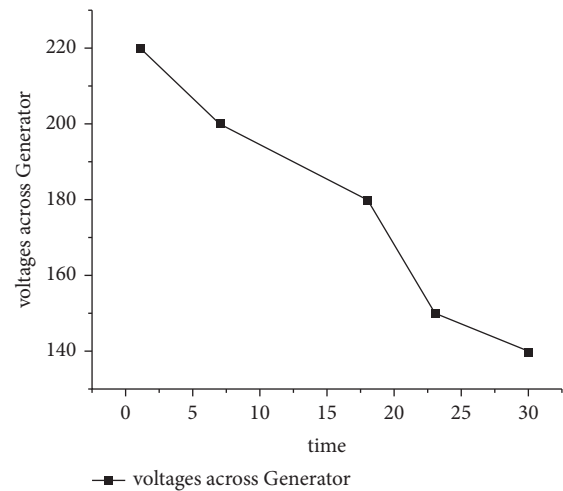


FIGURE 20: Generator voltage variation graph.

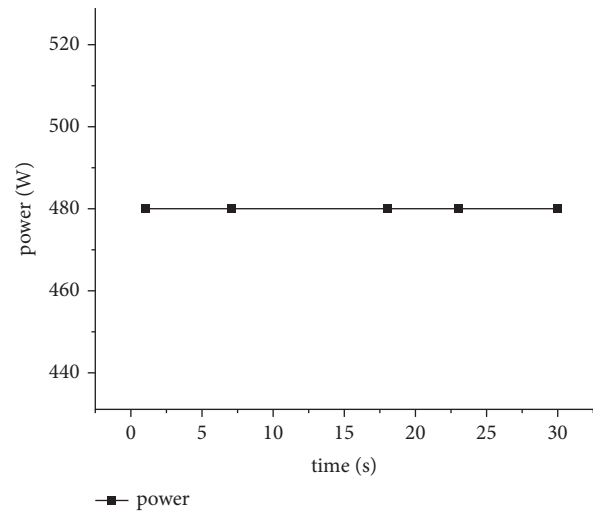


FIGURE 21: Power graph of the system.

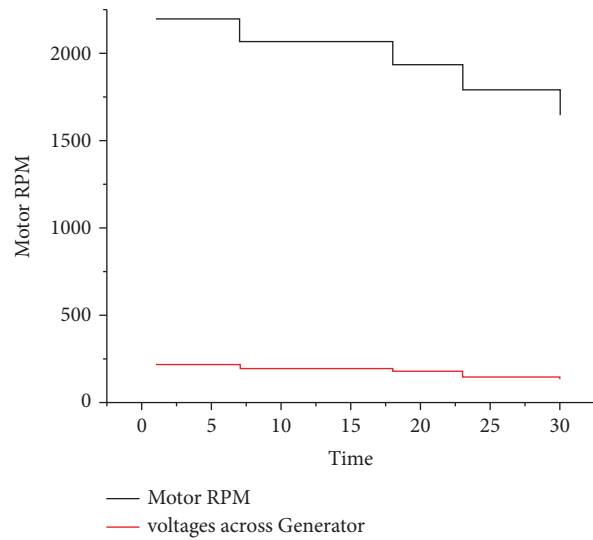


FIGURE 22: Graph between motor RPM and generator voltages.

across the generator drops from 220 V to 200 V. Since the load changing effects the voltages of the generator.

4. Conclusions

Due to the depletion of natural resources, the world is currently experiencing an energy crisis. Pollution of the environment is caused by natural resources such as fossil fuels. They emit CO₂ that contributes to the greenhouse effect and global warming. Price fluctuations affect countries whose economies are reliant on fossil fuels because the majority of sectors rely on gas and oil. As a result, renewable energy production is becoming increasingly significant. In this research, the focus is on power system inertia-related frequency problems. The approach account for the frequency and voltage fluctuations that occur after a disturbance and estimate the system's total inertia constant as well as its overall power imbalance. This was achieved by including a function that approximates the frequencies and voltages that show reliance of loads. The proposed method used was the PV, battery, and diesel generator integration in grid-connected system to analyses frequency responses from simulations of a test system under disturbance. Furthermore, it also focuses on the standalone PV system when they are integrated with the microgrid systems for controlling the critical parameters. As a result, the modelling of a PV system and a battery using analogous circuits are discussed. As the maximum power should be harvested from a PV array to increase its efficiency. A buck converter has a capability of shifting power in both directions with acceptable voltage level, which is used for the purpose of charging and discharging the accumulators in the system. The inverter alters the direct current dc bus voltage to a single-phase alternating current voltage with the suitable amplitude and frequency to power any load or appliance. A control loop is used for optimal power extraction from the PV module, as well as a battery control loop is implemented for bidirectional power flow between batteries. Computational intelligence based IoT technique is used to control the loads with the ease. This system's prototype is designed and tested to validate the simulation results in real time systems.

Data Availability

No data were used in the study.

Disclosure

The statements made and views expressed are solely the responsibility of the authors.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

All authors contributed equally to this article.

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