

Minimizing the Frequency Deviations in the Interconnected Microgrids considering Renewable Energy Sources

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Abstract

Nowadays, the use of Microgrids is increasing due to their ample applications and advantages. Microgrids have much smaller financial commitments, and they use renewable resources; hence are more environmentally friendly with lower carbon footprints. Also, microgrids require fewer technical skills to operate, rely more on automation, and are isolated from grid disturbance or outage. Traditionally, microgrids have been employed in remote locations that cannot be connected to the central power grid and serve critical infrastructure. Due to the recent advancements in technology, microgrids have become more accessible and economically feasible. Microgrids can be employed in organizations that intend to lower their energy cost. The paper explains a detailed literature review and the contributions of the authors in Interconnected Microgrids. Also, the data taken from the survey was used in the transfer function blocks in simulation. The simulation of the interconnected microgrids comprising Thermal, solar, and wind turbine systems is formulated on MATLAB. The frequency error and ACE are reduced to zero in a quick time by using a fuzzy PID controller. Also, the paper aims at achieving one of the most important United Nations Sustainability Development Goals (UNSDGs), Affordable and Clean Energy (UNSDG- 7).

Keywords: Area Control Error (ACE), Interconnected Microgrids (IMs), Proportional, Integral and Derivative (PID) Controller, Frequency Deviation (FD), Demand Response (DR).

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1. Introduction

Microgrids (MGs) are a mass of electricity sources and loads that serve institutions, industries, communities, and other customers. Microgrids have distributed energy sources and battery banks for storing power, which can be used to serve local community energy groups or communities [1].

Interconnected Microgrids are a system in which one microgrid is connected with another microgrid in order to deliver electrical power effectively in case of power shortage or blackout. Recent developments in interconnected microgrids have provided customers with different service qualities and value. Also, renewable energy

sources like wind, solar, and hydro have helped mankind as these are environment friendly and produce less pollution.

Interconnected Microgrids have helped the living community bring the supply of power from remotely located power plants to local generation systems from where it can be distributed to the nearby load centers [2]. They provide systematic, economical, clean energy and upgrade the working and stability of the geographical electric grid. The advantage of Interconnected Microgrids is that they provide an explanatory framework that surges dependability and flexibility, reducing grid “congestion” and extreme loads. Overall, interconnected microgrids maintain system stability by continuously managing the power transfer. If one microgrid fails to operate, the other can help supply

electrical power in case of emergency or high load demand. DC droop control gains can be selected in order to guarantee a prescribed current sharing in DC grids without using secondary control.

The detailed literature review focuses on the techniques, methodologies and algorithms applied to interconnected microgrids. Also, a detailed survey was taken across the companies and firms working in microgrids in India, where the valuable suggestions by company people and experts are consolidated and used in selecting values for simulating the MATLAB system model. The Simulink model of interconnected microgrids was simulated in MATLAB, considering the distributed energy sources. The necessary graphs were obtained showing the minimization of the frequency deviations quickly.

A frequency deviation is proportional to the corresponding value of the active power mismatch (the difference between total generation and total consumption). Therefore, adjusting the frequency requires controlling the active power balance, a global problem.

The paper is categorized into 5 sections. Section 2 explains the Literature Review conducted in the field of Interconnected Microgrids. Section 3 explains the survey result obtained from the survey taken by the companies working in interconnected microgrids. This is followed by the simulation of interconnected microgrids, including results and necessary system equations and graphs in Section 4. Section 5 concludes the paper.

2. Literature Review on Interconnected Microgrids

Literature Review is very important as every researcher has to complete it because it enables the researcher to find the research problem. The researcher finds the work already done in the field and work under process, which helps the researcher conclude the problems are persisting in the field. Then the different methodologies or algorithms are applied to achieve the desired results, giving a better solution that other authors failed to achieve. In this way, the researcher's research will be highly beneficial to society.

Literature Review done earlier in the field of interconnected microgrids and was categorized into the following important topics:

- Load Frequency Control in the areas connected within the Power Systems,
- Control procedures in interconnected power systems,
- Role of Artificial Intelligence in interconnected Microgrids
- Optimization Algorithms used and
- Challenges & issues in Microgrids.

In continuation to this work, more emphasis was given to finding the problems and challenges encountered by the

authors while researching in the area of interconnected microgrids.

Deepak Kumar Lal et al. minimized the frequency deviations using Grasshopper Optimization Algorithm Optimized Fuzzy PID Controller [3]. The simulation results prove that the controller gives good dynamic responses than the PID controller when used to simulate the same Simulink model. The area control error reduction time is 3 seconds.

Figure 1 shows the frequency deviations with ESS (Energy Storage System) and without ESS in Area 1. Error Settling time is more when fuzzy PID Controller is used without ESS.

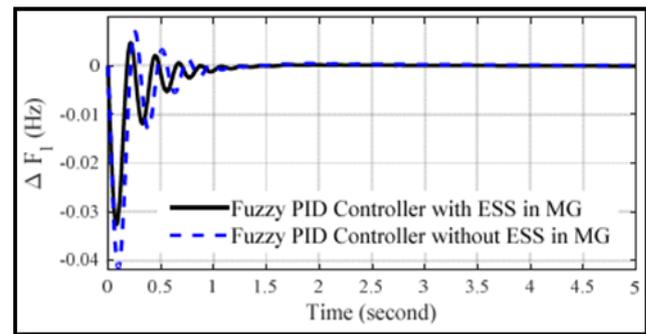


Figure 1. Frequency deviation in area-1 (ΔF_1) with and without ESS in both areas

Figure 2 shows the frequency deviation with ESS (Energy Storage System) and without ESS in Area 2. The research Problem in this author's work was non-linearity and the complexity of the system is increased along with power fluctuations and variations in load demands. Tie line Power flow is interrupted.

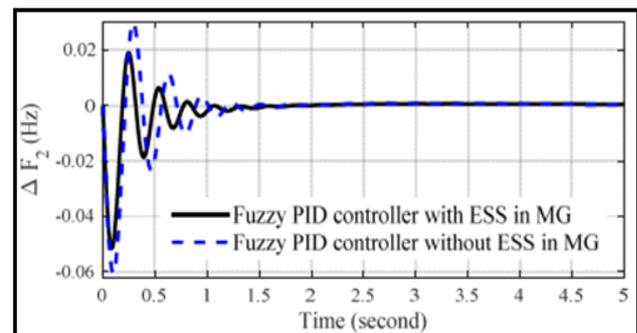


Figure 2. Frequency deviation in area-2 (ΔF_2) with and without ESS in both areas

Figure 3 shows the frequency deviation with BES (Battery Energy Storage) in Area 1, and it shows the settling time is 300 seconds.

In extension to work done in frequency control, Muwanga W. Siti et al. studied the variations in system frequency in microgrid interconnected systems. They found that the Battery Energy Storage (BES) system has a lot of advantages [4]. The frequency reduction time is 50 seconds which is very high.

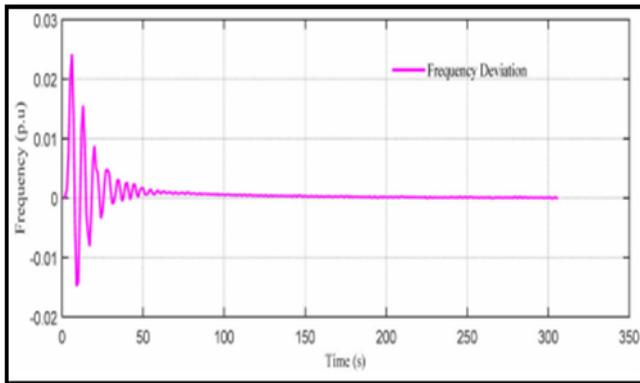


Figure 3. Responses of the frequency deviation with BES in area 1

Figure 4 shows the frequency deviation without BES (Battery Energy Storage) in Area 1, and it shows the settling time is 500 seconds. The research Problem in this author's work is Area control error arising due to generation and demand imbalance in the system. Changes in frequencies affect the overall performance and tie-line power.

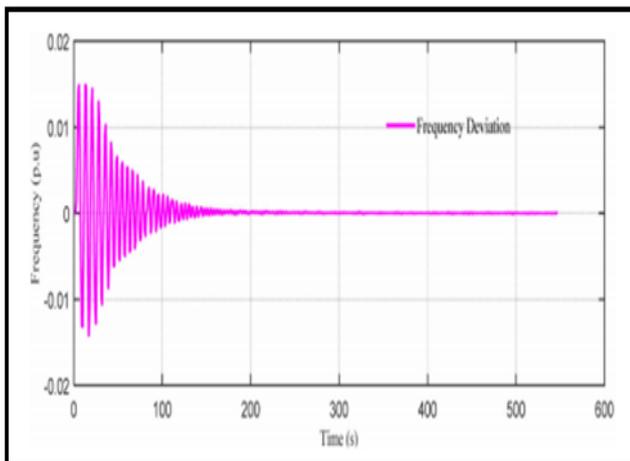


Figure 4. Responses of the frequency deviation without BES in area 1

Lei Xi et al. proposed a strategy for AGC of Interconnected Microgrids [5]. The research Problem in this author's work was that, Without the proposed strategy, power generation cost and the convergence time of the area control error was very high. Without VGE Strategy, the frequency stability of interconnected microgrid is not maintained.

Furthermore, Pietro Ferraro et al. proposed a strategy along with an Additive Increase Multiplicative Decrease (AIMD) algorithm to control and regulate the flow of power in interconnected microgrids (MGs) [6]. He found the algorithm showed better results and controlled the frequency fluctuations, which was difficult with a centralized strategy. The research Problem in this author's work was the Improper flow of power in interconnected Microgrids leading to instability of the system. Parameter gains are not within the range.

In extension to work done in Interconnected Microgrids, Saroja Kanti Sahoo et al. controlled the frequency fluctuations by using fuzzy logic and SOC-based control of battery in many microgrids connected [7].

Table 1 shows the frequency in the MMG (Multi Microgrid) during transient states. The research Problem in this author's work was the state of charge in batteries altered with the load variations. DC bus voltage, battery current, power mismatch, and netload power changes in interconnected microgrids must be kept under nominal value to maintain system stability. Abdul Latif et al. proposed evaluating WCA optimized non-integer controller to two-area interconnected microgrid system [8]. Frequency deviation was observed and reduced in 10 seconds. The system efficiency and dynamic responses are affected. Gains of the system parameters are not tuned, making the system unstable. Frequencies unstable under step and random disturbances. The authors presented a controller to control the frequency deviations in the interconnected microgrids. He and his team presented that if the gains of the controllers are not tuned, it makes the system unstable, meaning the frequency deviations rise, which affects the flow of electrical power from one microgrid to another within the system.

Table 1. Frequency in the MMG system during transients

The author proposed a technique to stabilize the frequency variations when connected to the wind turbine.

	Time instant, s	Frequency, Hz (PI-based f-controller)	Frequency, Hz (proposed f-controller)
MG-1	3	50.28	49.91
	13.3	49.85	49.95
	25.2	50.17	50.04
MG-2	4	49.6	49.98
	10	50.2	50.02
MG-3	13.3	49.6	49.98
	25.2	50.2	50.03

The Research Problem was found that the Tie line power flow is disturbed. The frequency variation curve is also not within the range, thus affecting the system's overall performance in the effective transfer of power from one microgrid to another.

Further, Dariush Fooladivanda et al. focus on the optimal utilization of the microgrids connected to the grids. The research Problem observed was increased operating cost resulting in the system's instability.

In extension, Amar Kumar Barik et al. proposed regulating the load-frequency oscillations with demand response (DR) [9]. The research problem was that the frequency oscillations increased as demand response DR supported both isolated and interconnected modes. Disturbances in source and load demand increased without any energy storage units.

Figure 5 shows the tie-line power shared among 2 areas in interconnected microgrids.

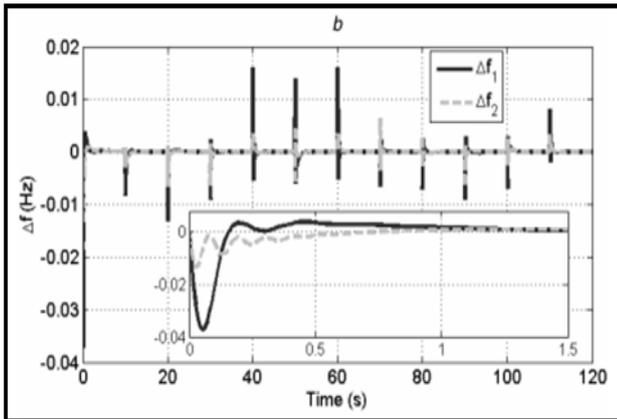


Figure 5. Tie-line power loading (ΔP_{t12})

In extension to the above work, Sarmad Majeed Malik et al. proposed a Converters placed in Interconnected Hybrid Microgrids technique. Research Problem found that the Power flow was underloaded [10]. Also, the problem of inherent frequency and dc voltage deviations exists.

Avisha Tah et al. proposed a technique and applied it to dc microgrid with droop control which is very useful in eliminating the limitations of droop control [11].

Jianguo Zhou et al. investigated the issues arising due to active power flow in the microgrids [12]. A control mechanism was developed that adjusted the active power load for each microgrid.

H. Wang et al. proposed the energy trading problem in interconnected microgrids, and C. Zhang et al. proved that stability could be achieved even under huge variations of renewable sources [13-14]. M. Naderi et al. explored the modelling of power-electronics-based interconnected AC microgrids, and the model was examined with a Prony method [15]. FL et al. proposed the OPF problem of various interconnected microgrids [16]. C. N. Papadimitriou et al. presented a strategy where a microgrid can shift from islanded to interconnected mode resulting in quick operation [17]. L. K. Gan et al. presented the basic mismatch between the actual and approximated system states of an Energy Management System EMS [18]. M. J. Hossain et al. proposed a structured method for designing strong controller and droop controllers to improve the stability of remote microgrids [19]. M. Fathi et al. managed the load demand to decrease the operational cost dispersed smart grids [20]. M. Zolfaghari et al. presented a unique controller to balance the power flow in AC-DC Microgrids [21]. H. Zou et al. studied state of the art in energy management research for Interconnected Multi microgrids IMMGS [22]. F. Nejabatkhah et al. presented the structured methods of controlling the power in the hybrid AC/DC microgrids [23].

Abdulsamed Tabak et al. presented a grasshopper optimization algorithm for fractional-order frequency PID control of microgrid considering renewable energy sources [24]. C. A. Hans et al. presented a strategy to control the

interconnected MGs to increase the overall infeed of renewable energy sources [25]. M. Naderi et al. presented two models for self-governed AC microgrid, and the necessary graphs were compared with the other existing algorithms like PSO and Genetic Algorithm (GA) [26].

Gourav K Suman et al. presented the H_2/H_∞ Control Approach strategy to control the frequency deviations in the interconnected microgrid systems using renewable energy sources. The results obtained were compared with other existing controllers [27]. Veerapandiyan veerasamy et al. Presented automatic load frequency control (ALFC) of the two-area multisource hybrid power system (HPS) Using PSO-GSA Optimized Cascade PI-PD Controller. Further, the system's stability was analyzed in the frequency domain for different operating cases [28]. H. Shayeghi et al. presented a fuzzy cascade controller for frequency control of fully-renewable interconnected microgrid considering the demand response [29]. Chao Liu et al. presented the Mayfly optimization technique for Frequency Regulation for Power Grid With Wind Energy Penetration [30]. Hassan Haes Alhelou et al. presented dynamic power systems models for assessing the frequency response due to different types of disturbances and uncertainties from renewable energy sources [31]. Baseem Khan et al. presented the chapter showing the detailed issues associated with microgrid integration and highlighted the problems related to interconnecting and balancing the frequency between the connected systems. He also focussed on the methods and algorithms used for bringing the control errors to zero. [32].

The conclusion of the Literature Review explains the problems and challenges faced by the authors in carrying out their research work in interconnected Microgrids [33-37].

Non-linearity and complexity of the system are increased along with power fluctuations and variations in load demands [38]. Tie line Power flow is interrupted. Area control error arising due to generation and demand imbalance in the system [39]. Changes in frequencies affect the overall performance and tie-line power. Improper flow of power in interconnected Microgrids leads to instability of the system [40]. Parameter gains are not within the range. DC bus voltage, battery current, power mismatch, and netload power changes in interconnected microgrids must be kept under nominal value to maintain system stability. Gains of the system parameters are not tuned, making the system unstable [41-43]. Frequencies unstable under step and random disturbances [44-49]. Tie line power flow is disturbed, and the frequency variation curve is not within the range, thus affecting the system's overall performance ineffective transfer of power from one microgrid to another [50].

Many authors worked in Interconnected Microgrids and used many techniques and algorithms to achieve the desired results [51-53]. The work that other authors could not achieve will be our proposed work in controlling frequency deviation and other factors in interconnected microgrids using an algorithm that will reduce error minimizing time to less than 1 second [54].

3. Survey Report on Interconnected Microgrids

As all of us know, the most common challenge faced during the interconnection of Microgrids is maintaining the equilibrium between generation and load, which is the most common factor for frequency variations [55-59]. If this balance is not maintained, it can lead to system instability, resulting in reduced or interrupted power flow to the consumers [60].

The survey was conducted through The Institution of Green Engineers (IGEN) - GREEN9 to develop recommendations to resolve the problems faced during interconnecting the Microgrids to ensure a reliable flow of electrical power to the consumers [61-65].

Figure 6 shows the data collected from different companies working in the field of Microgrids like Greenpeace India, Omnigrids, Gram Power India Pvt Ltd, Desi Power, Timdaa, MS Power projects Pvt Ltd, Voltas, Minda NextGen Tech, Mera Gao Power, four Solar Energy Systems The information obtained from the survey will help in finding better results during simulation of the proposed model [66].

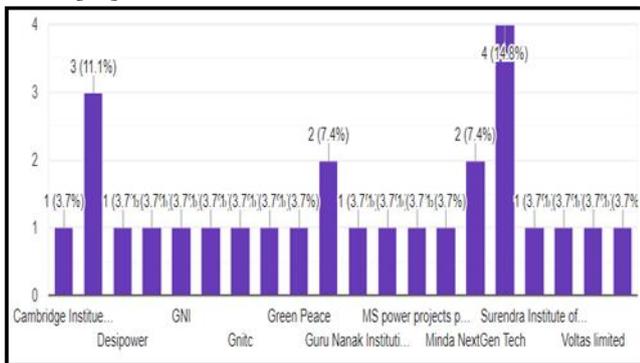


Figure 6. List of Companies working in the field of Microgrids

Figure 7 shows the responses stating the type of renewable energy sources used in the companies, and the results show that the maximum comes from the distributed energy sources.

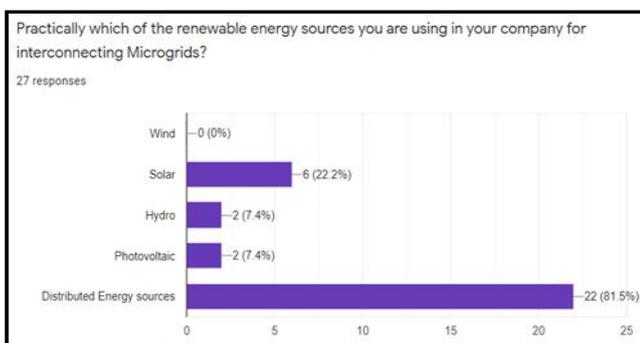


Figure 7. Responses stating the type of renewable energy sources used in different companies

Figure 8 shows the responses showing how technology used is working in interconnected microgrids. i.e., is it creating any faults or creating minor or major faults.

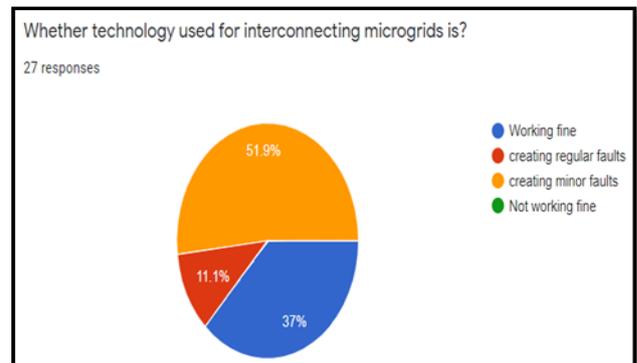


Figure 8. Responses about how technology works in interconnected Microgrids.

The survey was taken to find the existing problems associated with installing different sources and panels in interconnected microgrids. The site engineers working in microgrids have entered their valuable suggestions in understanding the operation of interconnected microgrids. They have also given the solution to overcome the problems and explained the type of methodology to be followed while simulating the microgrid structure and framework. Figure 9 shows that the maximum demand performance percentage is performed at both the utility and consumer sides.

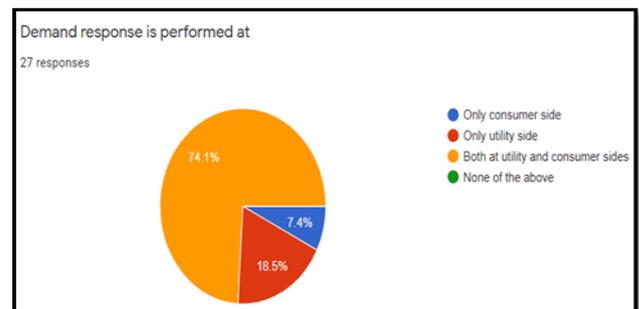


Figure 9. Response showing demand performance in consumer or utility side or both

Following are the important points achieved from the survey taken on interconnected microgrids:

- (i) The renewable energy sources you are using in your company for interconnecting Microgrids Distributed energy sources.
- (ii) Interconnection methodology used to interconnect two Microgrids are metered power and Overload Management Technique.
- (iii) The challenges faced during interconnection are short-circuiting, voltage dip, energy losses, voltage fluctuations, Data connection inconsistency due to remote sites. Lack of technical experts in this area and a lot of programming between energy sources.

- (iv) The parameters you control during interconnection are transient influx, power factor correction, Load shedding, energy source priority, storage, export of surplus power, diesel-solar control.
- (v) The challenges faced after interconnection are over, and Undervoltage, any small change in one grid or energy source requires programming, change of technology requires an additional component making it expensive, out of business (Vendor or technology) cost is high, migration from one technology to another is high and cumbersome, data connectivity issues will make it hard to manage more energy sources or grids.
- Also, there were many other problems faced during the interconnection of Microgrids, which are short-circuiting, voltage dip, energy losses, voltage fluctuations, Data connection inconsistency due to remote site, lack of technical experts in this area, a lot of programming between energy sources, Sag and instability, Time delay, load distribution, assembling the sources and Tie lines.
- (vi) The software used for monitoring and control in Interconnected Microgrids is SCADA with PLC, LabView, MATLAB, RSCAD, PSCAD, HOMER, dynamic predictive control method, Third-party software customized.

The type of Transmission Loss is considered in interconnected Microgrids Losses among the Microgrids, Losses between Microgrid and the main grid. The stability in interconnected Microgrids is measured by sudden blackouts and the number of power failures.

Conclusion: A practical survey is conducted in Interconnected Microgrids to find the challenges faced during interconnection and the methodology used to overcome these problems. Also, the practical values have been considered in the proposed Simulink diagram of interconnected Microgrids to obtain the best results and solutions. The practical values are obtained from the survey circulated among the companies working in interconnected microgrids and applied in the transfer function blocks used in the microgrids while doing simulation in MATLAB.

4. Simulation of Interconnected Microgrids and Results

This section considers the Simulink model of 2 interconnected microgrids with each microgrid comprising thermal power plant, solar, wind turbine systems, battery energy storage systems, and system equations. The whole model was developed by selecting the transfer function blocks in each case, i.e., thermal, solar, and Wind Turbines, by choosing appropriate values. Also, the values were finalized by trial-and-error method and running the Simulink model till the desired result or output was obtained. Area

control error (ACE) is also calculated in each microgrid. ACE is the instantaneous difference between a balancing authority's net actual and scheduled interchange with all adjacent interconnected balancing authority areas. The purpose of AGC is to ensure that the actual MW output of an area is equal to the scheduled MW output of the area. The AGC system accomplishes this by first calculating the Area Control Error (ACE), which is defined as

$$ACE = \text{Pactual} - \text{Pscheduled}.$$

4.1. System Equations

The system equations involved in 2 interconnected Microgrids are shown below:

Equation 1 gives the change in the frequency that arises due to the mismatch between the generated power and demand in the microgrid system.

$$\Delta f(s) = G_P(s) [\Delta P_T(s) - \Delta P_D(s)] \quad (1)$$

Equation 2 shows the change in frequency in microgrid 1, where the generated powers of thermal, PV, Wind and Battery energy storage systems are considered along with the power demand in microgrid 1.

$$\Delta f_1 \propto \Delta P_{T1} - P_{D1} - \Delta P_{12} + P_{T(PV1)} + P_{T(WT1)} + BESS_1 \quad (2)$$

Equation 3 shows the change in frequency in microgrid 2, where the generated powers of thermal, PV, Wind and Battery energy storage systems are considered along with the power demand in microgrid 2.

$$\Delta f_2 \propto \Delta P_{T2} - \Delta P_{D2} - \Delta P_{21} + P_{T(PV2)} + P_{T(WT2)} + BESS_2 \quad (3)$$

If there is a change in Microgrid 1 load, there should be supplementary control only in Microgrid 1 and not in Microgrid 2. For this purpose, the area control error (ACE) is used.

The Area Control Errors (ACEs) for 2 interconnected microgrids are given below

Equation 4 gives the area control error in microgrid 1 in terms of change in the power from microgrid 1 to 2.

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1 \quad (4)$$

Equation 5 gives the area control error in microgrid 2 in terms of change in the power from microgrid 2 to 1.

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2 \quad (5)$$

The Area Control Errors (ACEs) for 2 interconnected areas are given below:

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie1} - \Delta P_{tie3} - \Delta P_{tie4} \quad (6)$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{tie2} - \Delta P_{tie1} \quad (7)$$

The incremental change in tie-line power is given below:

$$\Delta P_{tie1} = \frac{2IT_{12}}{s} [\Delta f_1(s) - \Delta f_2(s)] \quad (8)$$

Figure 10 shows the MATLAB model of Interconnected Microgrids comprising Hydraulic power Plant, PV, and Wind Turbine. The main controller used to reduce the area control error is a fuzzy-tuned Proportional, Integral, Derivative (PID) Controller. The power demand in both the microgrids is kept equal. The fuzzy-PID controller helps bring the frequency variations quickly, analyzes the error, calculates it, and applies the fuzzification and defuzzification process to execute the error.

Renewable Energy Sources (RESs) can Win the bid in a

Microgrid or Electricity Market. A dc-dc boost converter in closed-loop operation is used to control the voltage of the dc bus. Also, we can use the Battery converter itself to control the Dc bus.

5. Results

In this section, the results and graphs obtained by the simulation of Interconnected Microgrids are discussed. By applying a fuzzy PID controller, the frequency and area control errors are minimised, thus achieving system stability.

Graph 1 shows the Area control error in Microgrid 1 after the error is tuned using fuzzy PID. The error reduction time in Microgrid 1 is 2 seconds. The X-axis indicates the ACE_1 , and Y-axis indicates the time in seconds.

Graph 2 shows the Area control error in Microgrid 2 after the error is tuned using fuzzy PID. The error reduction time in Microgrid 2 is 2 seconds. The error reduction time in Microgrid 1 is 2 seconds. The X-axis indicates the ACE_2 , and Y-axis indicates the time in seconds.

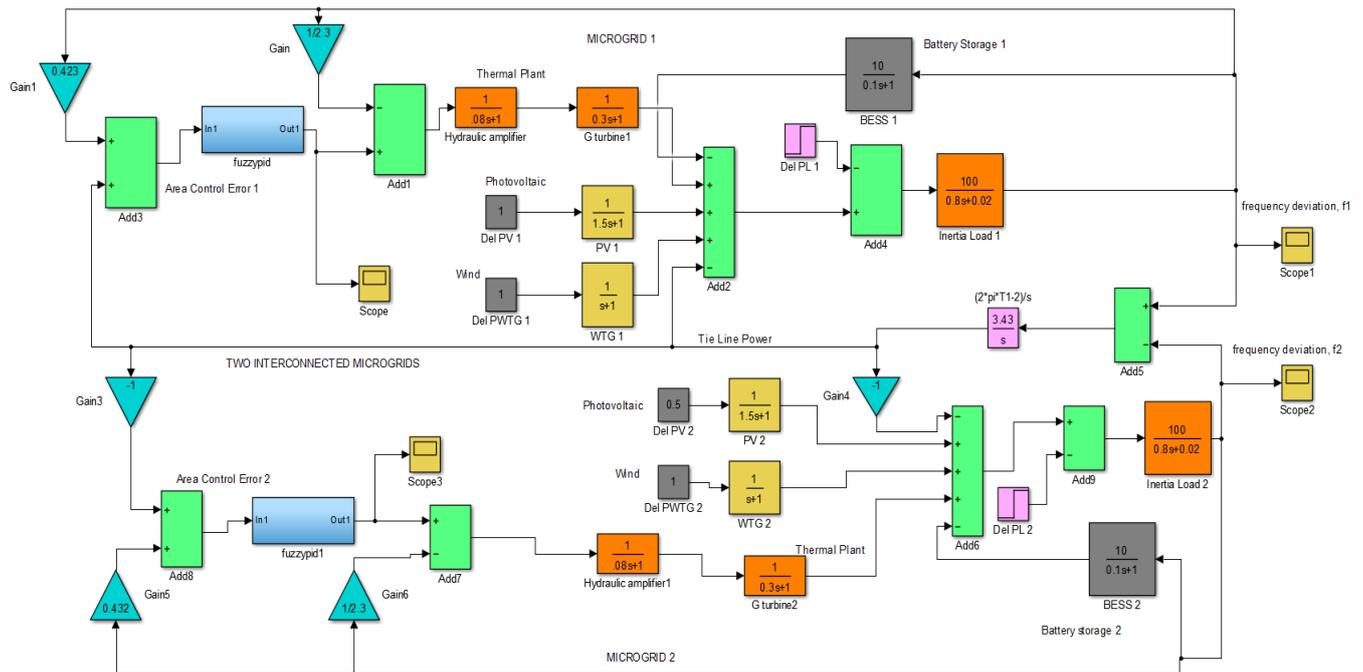
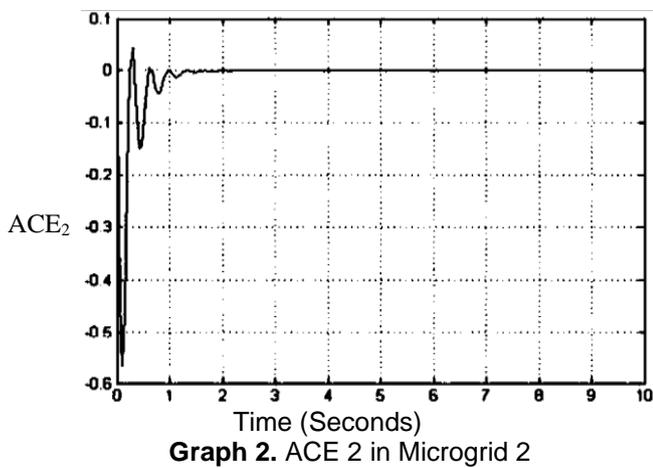
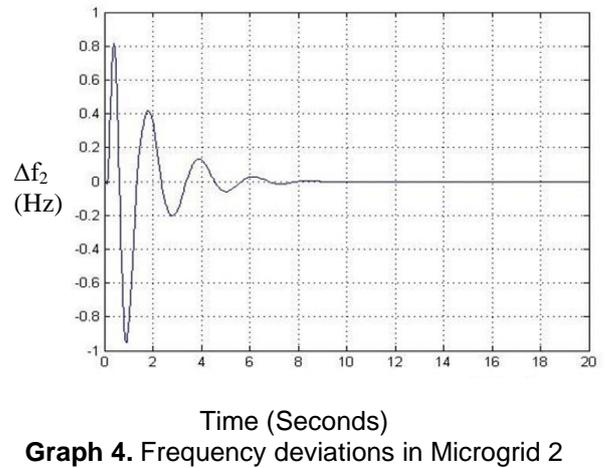
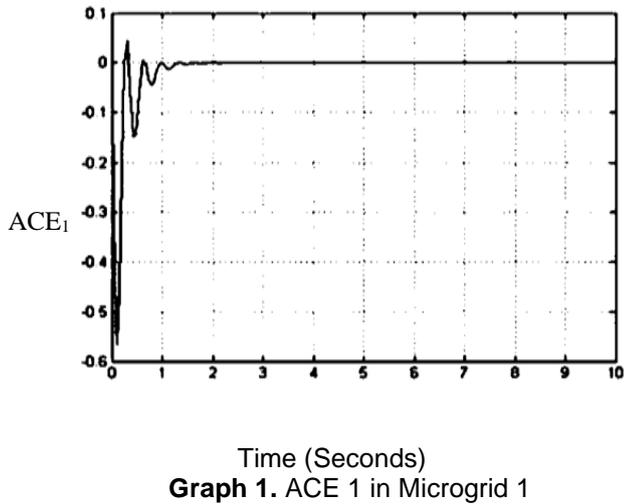
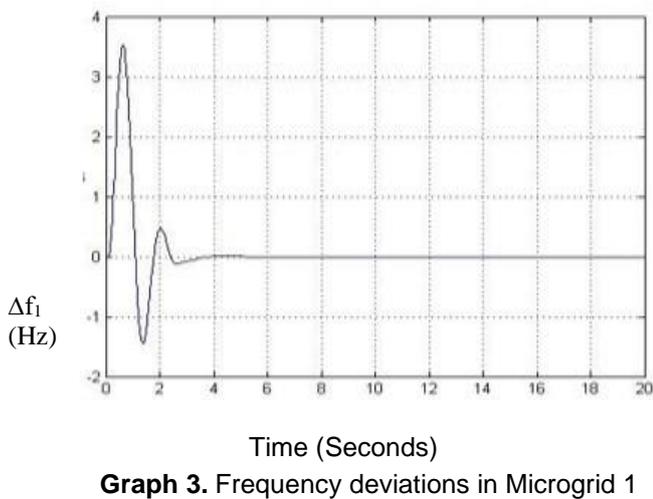


Figure 10. MATLAB Model of Interconnected Microgrid



Graph 3 shows the frequency deviations in Microgrid 1 after the system is tuned using fuzzy PID. The deviations are reduced to zero in reduction time in 3 seconds.



Graph 4 shows the frequency deviations in Microgrid 2 after the system is tuned using fuzzy PID. The error reduction time in Microgrid 1 is 9 seconds.

Figure 11 shows the controls after an imbalance in the microgrid system is observed.

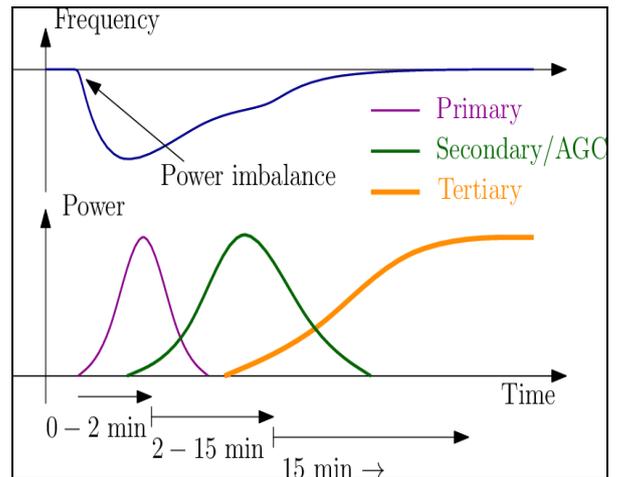


Figure 11. Activation of the primary, secondary (AGC) and tertiary control after the imbalance on the power

Primary control is continuous, automatic, and the fastest control among the other controls because of its less response period placed locally at the generators. It is often based on proportional control, and it instantaneously covers the power imbalance between produced and consumed power. However, it does not ensure that the frequency is restored to its set point. For this, secondary control is needed. Secondary control is a slower, centralized, automatic controller that releases primary control. It is often referred to as automatic generator control (AGC), and this term will be applied in the following.

Tertiary control is a slower centralized controller, which again releases the AGC. This is manually operated by the transmission system operator (TSO).

Figure 12 shows the first two levels of control after a frequency event in the microgrid system. The green line and the red-dashed line show two different responses according to the inertia level of the system (power systems with low generation produced by rotating machines will have low inertia levels).

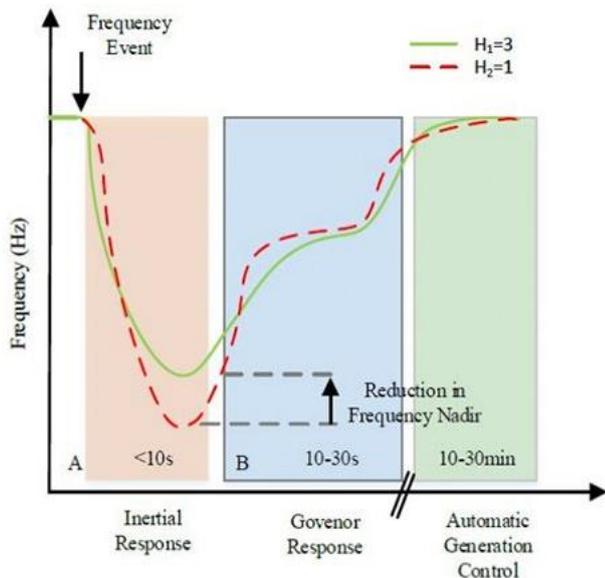


Figure 12. Frequency response obtained after the occurrence of frequency event

After doing the simulation of 2 Interconnected Microgrids, the area control error in both the microgrids was observed and reduced in 2 seconds which is considered good because if this error continues for a longer time, it will affect the stability of the entire system and also reduce the overall power flow from one microgrid to another.

The fuzzy PID Controller helps to bring the error caused due to mismatch between generation and demand to a minimum value to ensure effective power flow from one microgrid to another. Also, the frequency deviations are minimized in both the microgrids within 10 seconds. Also, several control techniques like sliding mode control, model predictive control, etc. PI controller is just a linear control technique that is easy to implement, reasonably robust, and widely popular. Hybrid energy storage systems are necessary for future grids to improve the power quality and maintain grid stability under the high penetration of renewable sources.

Table 2 shows the challenges in the microgrids and the methods used to control and minimize the problems/challenges. Also, the examples are given below for each

method and technology used in solving the challenges faced in interconnected microgrids.

The objective function used in this paper is the Integral of time multiplied absolute error (ITAE), which helps find the ideal value for the controller parameters. The objective function M is shown below, which helps in finding the desired error, and it is this error that needs to be minimized for the stability of the system and effective flow of power:

In equation (9), ΔF represents system frequency variations (which arise because of the mismatch between generation and demand in the interconnected areas in the microgrid) and t_{sim} represents the lower and upper limits of the simulation time.

$$M = ITAE = \int_0^{t_{sim}} |\Delta F| \cdot t \cdot dt \quad (9)$$

Equation 10 represents the function that is formulated in this paper. Each microgrid observes changes in frequencies, and tie-line power is formulated in graphs.

$$J = \int_0^t (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie 12}^2) dt \quad (10)$$

Table 2. shows the values of the constants used in the transfer functions used in the Simulink Model of Interconnected Microgrids.

Table 2. Values of parameters used in the Simulink Model

SI No.	Parameters	Values
1.	Time constant of Hydraulic Amplifier (T_a)	0.08
2.	Time constant of Turbine (T_t)	0.3
3.	Time constant of PV (T_{pv})	1.5
4.	The time constant of Wind Turbine (T_{wt})	1
5.	Regulation	2.3
6.	Gain	0.423
7.	Time constant of BESS (T_{BESS})	0.1

Table 3 shows the challenges in the microgrids and the methods used to control and minimize the problems/challenges. Also, the examples are given below for each method and technology used in solving the challenges faced in interconnected microgrids.

Table 3. Challenges faced in interconnected microgrids and methods to overcome with examples

Microgrid challenges	Methods/technologies	Comments/examples
Power quality	Energy storage	Electrical batteries, mechanical flywheel storage, thermal storage
	Filtering	Active power conditioners (APC)
	Proper control methods	f-P, V-Q droop control, optimal power control
	Energy storage + Filtering	Flywheel storage and active power filter
Control strategies	Primary (local) control	Frequency/voltage droop control
	Secondary centralized control	Non-model-based fuzzy and neural network controllers and model-based predictive controllers
	Secondary decentralized control	Multiagent-based control approaches
	Tertiary (optimization) control	Part of the main utility grid and not microgrid itself
Energy management	Combined energy storage	Combined batteries and supercapacitors, hybrid fuel cell/battery
	Power generation prediction and load forecasting	Managing power flow among the different energy sources and the storage system within the microgrid
	Voltage-droop characteristic	Voltage regulation and load reactive power compensation
Energy optimization	Multi-objective optimization using intelligent methods	Genetic algorithm, fuzzy neural networks, particle swarm optimization (PSO), and ant colony optimization (ACO)
Stability	Proper control strategies	Supplementary control loop around the primary droop control loop
Modelling	Software-based model	PSCAD/EMTDC and MATLAB/Simulink
	Comprehensive small-signal model	Accurate, but very complex
	Reduced small-signal model	Model order reduction and linearization around an operating point
Protection	Adaptive protection system	
	Digital relays	
	Current-limiting algorithms	
	Voltage-based fault detection	
	State observer	

The major findings of the paper are as follows:

- (i) The Simulink diagram is modelled using distributed energy sources like solar and wind in MATLAB 2014b.
- (ii) The frequency deviations are minimized in quick time in interconnected Microgrids, i.e., within 2 seconds.
- (iii) The system's stability is maintained, and proper flow of electrical power is observed as frequency deviations are minimized quickly.
- (iv) The simulation results show that the frequency is kept in specified limits, which solves the problem of future system failures and outages.
- (v) This paper will meet the requirement of electrical power in the future and contribute to the United Nations Sustainable Development Goal (UNSDG) 7 Affordable and Clean Energy as the sources used are Renewable.

Table 4 shows the time in seconds when frequency and Area control errors in both the microgrids are minimized. Also, applying the fuzzy PID controller made it clear from the graphs obtained that the frequency errors in Microgrids 1 & 2 reduced in 3 and 9 seconds, respectively. Area Control errors in both the Microgrids were reduced in 2 seconds, keeping the load demand equal.

Table 4. Error reduction time of frequency error and Area Control Error in both the Microgrids

Sl. No.	Parameters	Error reducing time (seconds)
1.	Frequency error in Microgrid 1 (Δf_1)	3
2.	Frequency error in Microgrid 2 (Δf_2)	9
3.	Area Control Error in Microgrid 1 (ACE_1)	2
4.	Area Control Error in Microgrid 2 (ACE_2)	2

Major challenges of active distribution systems and microgrids include Voltage stability, Optimal load flow, harmonics, protection and equipment design adequacy of fault currents, demand management, and storage issues in the future. Previously a lot of research was done in interconnected microgrids by various researchers. Many researchers have integrated solar, PV, wind, gas power plants into 2 microgrids. New algorithms like the MayFly algorithm, PSO-GSA Optimized Cascade PI-PD Controller, Ant colony optimization were formulated to tune the gains of the controllers and bring the system frequency error to zero. Also, the results obtained were compared with existing controllers, which gave a clear picture of the controllers' effectiveness. Researchers applied different algorithms to bring the frequency error to null position in 4, 6 seconds, and more.

This paper presents the Simulink model comprising thermal, PV and wind turbine systems to minimize the frequency deviations. After simulation of the model in the MATLAB 2014b, the frequency error was minimized in a quick time which is 2 seconds.

The cost of a solar PV-based DC microgrid system can be reduced by knowing the solar radiation profile in the site of design, size of your panel and battery to cover the energy demand, and maximising the PV panel's extracted power by using some kind of MPPT control. Many researchers have recently done a lot of work in interconnected microgrids. Recently the authors presented the Mayfly optimization technique for Frequency Regulation for Power Grid With Wind Energy Penetration. The H2/H ∞ Control Approach strategy was formulated to control the frequency deviations in the interconnected microgrid systems using renewable energy sources. The results obtained were compared with other existing controllers. The fuzzy cascade controller was recently introduced to control the frequency deviations in the microgrid system. With the command xlsread, we can easily import excel data into Matlab and assign each column to a vector. In order to assign data to the vector, u can do this:

```
vector = xlsread('myFile.xls')
```

It is possible to run the AC load flow method in DC MICROGRID Systems. Still, the microgrid system has to be properly modelled to understand the power flow, then

numerical methods like Newton Raphson (NR) can be applied. To summarise the procedures of the proposed direct NR method, a flowchart for the main program and a flow chart of the subprogramme of the NR method with step size optimisation (NRSSO) are presented in figure 13.

Renewable Energy Sources (RESs) can Win the bid in a Microgrid or Electricity Market. A dc-dc boost converter in closed-loop operation is used to control the voltage of the dc bus. Also, we can use the Battery converter itself to control the Dc bus.

The levelized cost of energy (LCOE), or levelized cost of electricity, measures the average net present cost of electricity generation for a generating plant over its lifetime. In several market designs, the Levelized Cost of Energy (LCoE) of generation resources are covered in a capacity market.

RESs bid at zero or negative bids does NOT mean they receive the prices. In nodal markets in the US, RESs receive the nodal price at their nodes based on system-wide supply and demand and transmission constraints. RESs make a lot of money in those markets. **Figure 14.** This shows that the cost of renewables has declined with the increase in the implementation of renewable energy sources.

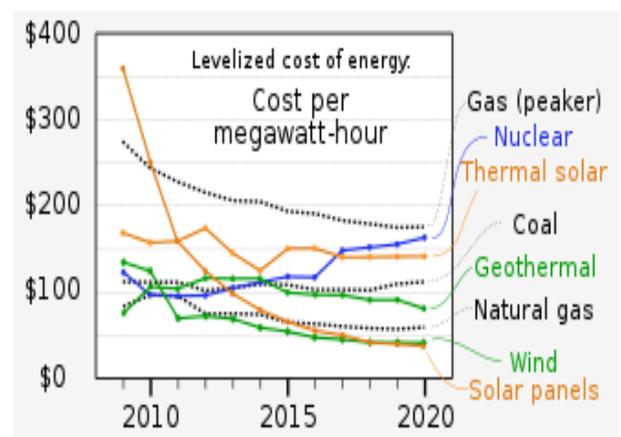


Figure 14. Cost: With increasingly widespread implementation of renewable energy sources, costs for renewables have declined, most notably for energy generated by solar panels

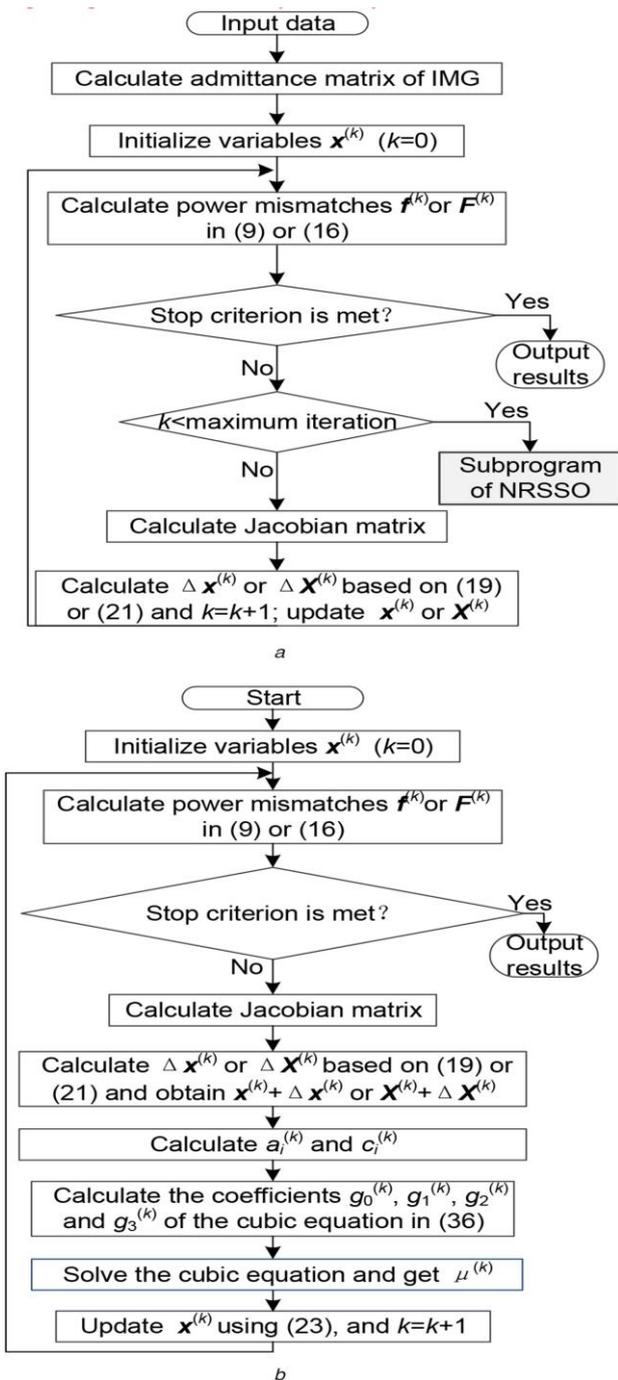


Figure 13. Flowchart of the proposed flow calculation method

- (a) Flowchart of the main program
- (b) Flow chart for the subprogram of NRSSO

More future work can be carried out in this field if an effective algorithm can be used, bringing down the system frequency deviations to a null position.

6. Conclusion

A lot of research work is done in interconnected Microgrids to reduce error, minimise time, achieve an effective power flow, and control active and reactive power. This is achieved by using an effective PID Controller equipped with fuzzy, which brings the frequency error to zero. The literature review is done for finding the research work done by different authors in the field of interconnected Microgrids. Also, the research problems were formulated and taken into consideration in the present work and as well as in the proposed work. The proposed work focuses on eliminating maximum research problems obtained while doing a Literature review. The practical values obtained from the survey are considered very important in getting the desired results while doing simulation. It also gives a brief idea of the works being carried out and methodologies being used in interconnected Microgrids.

Conflict of Interest.

The authors declared that there is no conflict-of-interest statement.

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Abbreviations

- CHP- Combined Heat and Power
- BES- Battery Energy Storage
- (AIMD)-Additive Increase Multiplicative Decrease
- MMG- Multi Micro Grid
- DR- Demand Response
- SOC- State of Charge
- DER- Distributed Energy Resource
- IMGs- Interconnected Microgrids
- ESS- Energy Storage System
- AGC- Automatic Generation Control
- IDR- Integrated Demand Response
- ITAE- Integral Time Absolute Error
- PV- Photovoltaic
- ESs- Electric Springs
- ACE- Area Control Error

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