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Controlling the Frequency Response in AC/DC Microgrid using an Energy Storage Device

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Abstract

This paper deals with the issue of frequency regulation in a small insulated low inertia grid with a large participation of renewable energy sources (RESs). A strong decentralized control strategy is used, allowing various RESs such as batteries, supercapacitors, and fuel cells to provide additional frequency recovery service.

A small grid with a synchronous machine, photovoltaic cells, and fuel cells was developed as generation units to test the effectiveness of the suggested technique. Furthermore, the battery and supercapacitors were added to the system to give additional service to suppliers. Simulating the system response to numerous uncertainty is used to evaluate the controller's performance. the controller's efficiency is displayed in Graphical form.

This paper will show how a decentralized method that allows all units to provide active power supports not only adjusts frequency nadir points but also minimizes the amount of active power required in the process. As a result, the electrical pressure on each element that supports the network against the heavy usage of RESs is reduced.

Keywords:- Rate of Change of Frequency, Deloading method, Virtual Inertia Control, Energy Storage Device.

I. INTRODUCTION

Great efforts are being made towards directing the world to inject renewable energies into electric power plants as a result of the negative impact of fossil fuel stations represented by future fuel permeability and environmental pollution. Therefore, researchers are doing their best to reduce greenhouse gas emissions.

Integrating renewable energy sources with their intermittent nature and traditional energy sources requires great effort to ensure the stability and reliability of the generation networks. Since the productivity of clean energy sources is variable, the instability of the network and the difficulty of covering the energy needs of the loads become more complex [1]. The higher the rate of participation of renewable energies in electric power generation, the greater the need to add additional units to provide services that help stabilize the network.

Renewable energy sources are connected to the electric grid using electronic devices, so they are unable to provide an inertial moment. As a result, the system's moment of inertia will be reduced, causing large changes in frequency at a high rate [2, 3]. This makes the system less stable and more volatile and may lead to the impossibility of providing consumers with energy [4]. Also, the integration of renewable energy sources with low or no rotational energy into the electrical network leads to a vibration in the stability of the system. One of the most prominent problems that we face when reducing the use of traditional energy sources is the decrease in the reserve of kinetic energy stored in the rotating part of these sources. Consequently, the system becomes less reliable [5]. Therefore, there is a need to use appropriate control methods to operate these small networks based on renewable energy sources. [6, 7]. With the increasing need to use clean energy sources, this topic has become of interest to many researchers. Wind turbines consist of rotating parts with stored kinetic energy, so they can provide little inertia. This stored energy is extracted to simulate inertia through the use of appropriate control techniques and certain strategies.

In [8, 9], the droop control technique is discussed to improve the frequency response. With this control technique, wind turbines can participate in an inertial simulation in the network, but this may cause electrical and mechanical stress on the wind turbines to increase. In addition to wind energy, solar cells have a significant contribution to generating electrical energy. In [10], the energy reserve is maintained by setting the active power set point under the maximum power. Thus, adopting this method makes the solar panels work at full power. As a result, not every geographic condition is economically acceptable. After summarizing all of the above literature, the author concludes that microgrids require a different set of sources or discharging units to supply helpful services. As a result, researchers believe that Virtual Synchronous Machines (VSM) are required [11, 12]. Virtual Synchronous machines mimic the characteristics of traditional synchronous machines. VSM is made up of 3 main components: inverters, regulators, and energy storage systems (static DC sources). These components can support weak networks in maintaining frequency and voltage. To offer frequency and inertia support, a variety of regulatory techniques can be used [13, 14]. Table 1 gives a quick overview of these strategies.

As previously stated, separate dump units may be more appropriate for providing auxiliary services. Dump loads such as supercapacitors, ultracapacitors, battery systems, E.V batteries, flywheels, and fuel cells could be employed to provide various extra services.

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Electric vehicles are considered simple storage units, so they can be organized to provide additional services that help with the stability of the system. One of these services is dealing with the problems of electrical power systems, including power outages, reactive power regulation, voltage, and emergency situations. Hence, improving the efficiency and reliability of the electrical network.

Table 1. Methods frequency support

Method	Descriptions
Emulations of Inertia [13]	Power is proportional to the rate of change in frequency.
Fast Power Reserve [14]	Set electricity is supplied for a set amount of time at the moment of the disruption.
Droop Control [13]	Power is provided in proportion to a frequency deviation.
DE loading method [14]	Assures the availability of a fixe or variables reserve to sustain frequency and another service.

In [15,16], EV batteries are utilized with droop control methods to provide frequency responsiveness for grids with a high penetration of wind power. Separate battery banks, in addition to EV batteries, can be employed for providing frequency response, as mentioned in [17]. Engineers are interested in testing supercapacitors in electrical grids due to the rapidly emerging technologies for supercapacitors and fasting dynamics. They are well suited to providing helpful services in poor networks due to their quick dynamics and huge storage capacity plus lifetime. [18, 19] looked at using supercapacitors to simulate system inertia. Fuel cells are a particularly appealing choice for expanding the power grid's generation portfolio. They can give electricity as long as they have a source of fuel because they are non-intermittent sources [20]. Voltage control solutions for integrating fuel cells with the grid were described in [21]. By reading the literature, the researchers concluded that employing a single type of fixed source to provide many additional services was inappropriate. Using one of these options, such as batteries or supercapacitors, to provide these primary frequency responses and inertia control can put a strain on machines. Supercapacitors and battery systems have distinct reaction times, which means they charge and discharge at varying rates. So, running either of them to provide both services is not an acceptable solution. Furthermore, the role of fuel cells in supplying auxiliary services, particularly in support of the frequency, has received little attention. The amount of inertia required to keep frequency inside limits determines how inertia is simulated via DC supplies through controllers, which can also be planned alongside auxiliary services.

In this research, PFR was calculated using the battery's properties. Because of their rapid dynamic reaction, supercapacitors are used to determine VIC. The fuel cell properties are also examined in the subsequent section to offer a primary frequency response to support frequency. For this research, a clean network was created (all sources are powered by renewable energy). The generating part consists of biofuel generators (conventional synchronous machines operating as swing generators), solar photovoltaics, fuel cells with battery systems, and supercapacitors acting as dumping devices. The batteries and supercapacitors only become effective when a problem happens, resulting in a frequency error signal. There are two kinds of services planned to create a disturbance. Firstly, a significant portion of the load suddenly changes. Second, the amount of solar energy available varies depending on the situation. The method of research will look across both controllers for each disturbance, namely PFR via batteries and VIC using supercapacitors, the following figure shows the steps of this work. The consequences of these occurrences are computed in two scenarios: the first assumes limited RES penetration, while the second analyzes high RES penetration. The controllers' and supporting components' capacity to simulate inertia is graphically depicted. In addition, a grid with controllers was investigated using the MATLAB simulation environment.

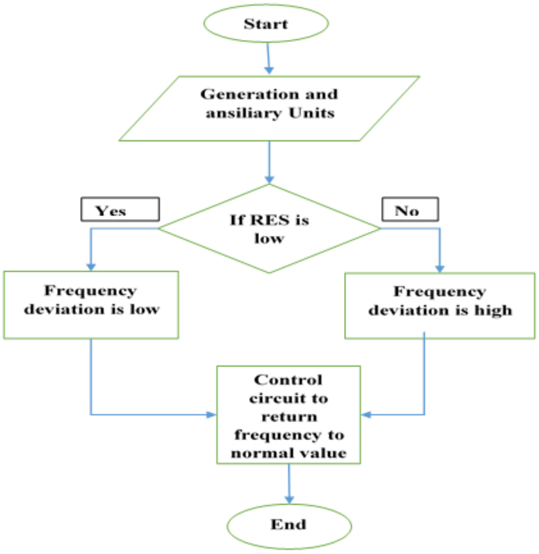


Figure1.flowchart of this work.

II. THE TECHNIQUE TO BEING USED

The main idea of the research methodology proposed in this article is to design a small grid based on renewable energy sources. This network consists of a solar cell, a fuel cell, and a diesel generator. These sources act as generating units. In addition, some batteries and supercapacitors have been modeled to provide additional services. The modeling and simulation of this network were done by simulation in the Matlab program. To test batteries and supercapacitors in support of frequency and inertia, the following points were followed:

The small grid consists of two types of generation. The first generation is the A.C. generation, represented by a diesel generator. The other is a DC generation, represented by a fuel cell and a solar cell. These sources work as renewable energy sources. In addition, there are energy storage devices represented by batteries and capacitors that are used to provide additional services to the network.

This system is simulated with the creation of certain disturbances. One of these disturbances is a sudden change in the load or a change in a generation. In addition to the use of batteries and supercapacitors as discharging units, Repeating the previous scenario but with the use of batteries and supercapacitors to provide support for frequency and inertia(P.F.R and VIC), The controller is tested when renewable energy sources are involved in a high percentage of generation. Finally, all the results are analyzed and discussed.

A. *Construction Of Frequency And Virtual Inertia Response Controllers*

This portion includes the strategy for enhancing the frequency range in a minimal inertia microgrid system via primary frequency control and inertia emulation [7].To employ the controlling strategy, frequency deviation will be observed at a lower local first, then real and reactive power reference set points of D.C sources should be given for rectifiers using the droop method of control. equation (1) can be used to model the principle of Primary Frequency Control as shown in equation (2) It depicts the variation in reference active power as a function of the controller's droop characteristics. The controller will be active when the P.F.C controller detects a frequency deviation. the PP.F.C,ref will be set for the R.E.S. depending on the droop parameter KP.

$$P_{freq,ref} = K_{P.F.C}\Delta f + K_{IN}\frac{\Delta f}{\Delta t} \tag{1}$$

$$P_{P.F.C,ref} = Kp\Delta f \tag{2}$$

$P_{P.F.C,ref}$ will be the real reference active power for the converter that can provide P.F.C control, Kp droop control constant, Δf is the variation in the frequency error signal following a disturbance

Likewise, equation (3) could be used to define virtual inertia simulations. Unlike P.F.R, the frequency change rat has been detected here and multiplied by the inertia constant K_{IN} to get the real power reference point for trying to limit the variation of frequency. The influence may be more noticeable when there are big fluctuations and the frequency changes at a greater rate.

$$P_{IN,ref} = K_{IN}\frac{\Delta f}{\Delta t} \tag{3}$$

$\frac{\Delta f}{\Delta t}$ Is the rate of change frequency error i.e. ROCOF signal after disturbance, $P_{\mathrm{IN,}ref}$ is the new active power set point for inverters to provide inertial power, and K_{IN} is the droop control constant for inertia control.

The main benefit of using equation (3) to regulate inertia is that it speeds up total control. That means that, unlike P.F.C, the controller responds rapidly to disturbances since it observes the rate of frequency change with regard to time.

In the case of a major disturbance, the need for an inertial controller will become much more apparent since it will cause a rapid drifting between generation and load. As a result, the frequency will increase or decrease at a greater rate throughout that time. As a result, the inertial emulation control activates quickly in the disturbance, leading to regulating the frequency more quickly.

Before modeling the dynamics of the controller of batteries and supercapacitors, there are a few things to consider. The following are some of the points to consider:

1. Dead Band: The dead band must be included within the control system. This preserves those controls against responding to the smallest power differences. These will guarantee the effectiveness of batteries and supercapacitors.
2. Maximum and minimum power limits: Maximum and minimum power limits should be established. Fig.2 depicts the graphical representation of the controller design, which will then be employed in the study.

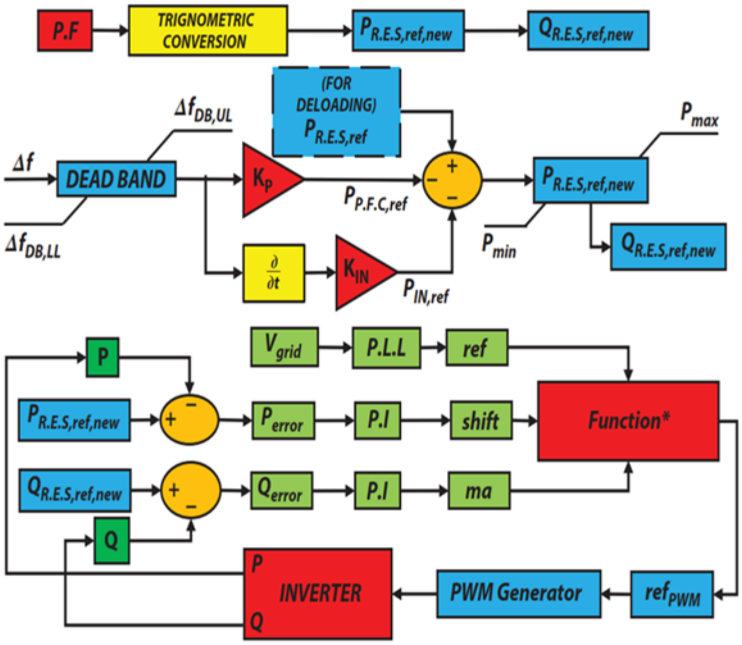


Figure 2. Control block diagram of a controller

III. TEST SYSTEM

The research framework and control design are validated by designing and simulating a separate small grid with solar PV, biofuel generators, fuel cells, storage batteries, and supercapacitors in the MATLAB Matlab/Simulink software. The designed controller (Fig. 2) operates on various distributed energy resources (batteries, super-capacitors, and fuel cells) that are linked to a diesel generator. P and Q are the DG's active and reactive power outputs when compared to the expected signals PR.E.S, ref, new and QR.E.S, ref, new. The comparison results are injected into controllers (Figure.2) and used to generate reference signals for the inverter.

Various types of synchronous generators with ratings of 85 and 60 kVA are designed for analyzing various scenarios with high and low RES permeation. To connect R.E.S with an AC system, 50 kilowatt AC/DC rectifiers with active and reactive power controls are simulated. And in the cases of photovoltaic and fuel cells, the inverter would then distribute energy based on the preset values. Furthermore, in the case of batteries and supercapacitors, a rectifier would then interact based on the frequencies of error signals plus its rating of changes. Below are all the cases that will be tested to see how well frequency works with inertia simulation.

First, there is a rapid change in loads combined with a generating (photovoltaic) condition at a lower RES penetration.

Second, at higher RES penetration, rapid load variation is combined with generating (photovoltaic) conditions.

Third, an extensive scenario is being developed to investigate the properties of fuel cells in order to maintain frequency.

The cases discussed above would be analyzed first with no control. Second, just with Primary Frequency Response (PFR) control. In scenarios three and four, respectively, Virtual Inertia Control (VIC) and PFR control are used. As a result of each case, a graphic representation of the frequency response will be presented.

A. Case 1: Simulations and Analysis

Through case 1, various options would be presented to understand the mechanism of PFC and VIC (smaller RES penetration). In the first scenario, 20% of the total normal load (90 kilowatts) would be changed at different times to create a fluctuation. In the second scenario, the PV system may only change. Each case is described in depth in the sub-sections that follow.

1. Case1: Scenario A

Case A is evaluated using a small grid equipped with an 85 kVA synchronous generator, 17 kilowatts of photovoltaic generation, and 17 kilowatts of fuel cell generation. There are 3 sub-scenarios in this case. During the one sub-scenario, no controls are provided, which means the batteries and supercapacitors are perfect. Second, the battery provides droop control for the primary frequency controller. Finally, besides the battery together with PFC, supercapacitors are used in the third sub-scenario to simulate inertia via virtual inertia control.

During t = 2 seconds, 20% of the total load, or 18 kilowatts, will be removed from 90 kilowatts to simulate a disturbance. Fig. 3 shows the frequency variation as a result of this change in load. Similarly, at t = 4 sec, 18 kilowatts are introduced. In this instance, the frequency goes down and then is optimized with PFC and VIC. Fig. 4 depicts the absorption of additional power and supply of power requirements during disturbances, mostly from batteries and supercapacitors. When there is an unexpected increase in the demand for energy, the batteries and supercapacitors will drain their energy to meet the consumer's need for energy, thus helping to keep the stability of the frequency.

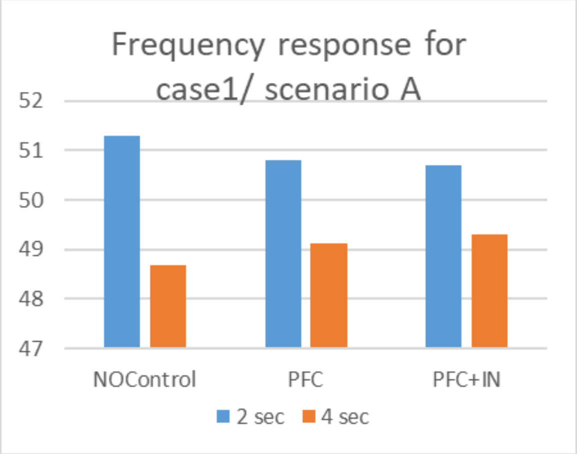
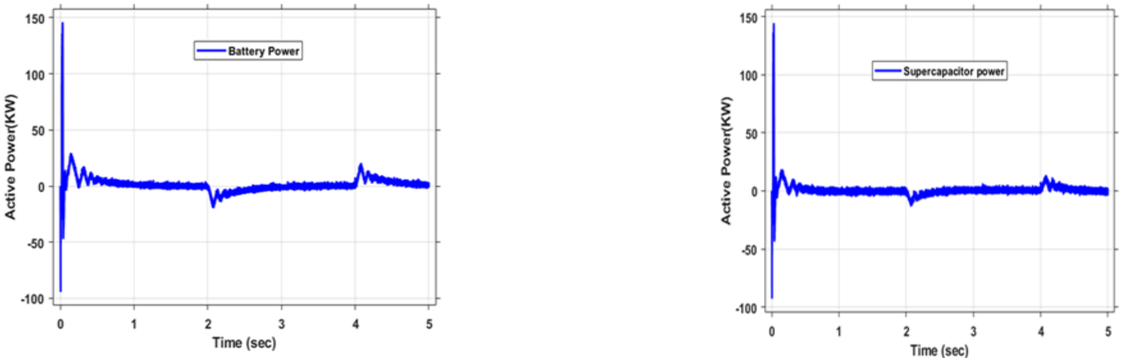


Figure 3**.** Frequency response during unexpected load changes with lower renewable energy usage.

The frequency of the system will be affected by solar PV's intermittent nature. PV power would be varied at various time intervals. The power of the solar cell changes from 17 to 7 kW at time t = 1.5 s, and from 7 kilowatts to 23 kilowatts at time t = 3 s, then changes from 23 to 17 kilowatts at t = 4 s. Fig.5 illustrates these changes.

This leads to an energy imbalance, which will cause frequency fluctuations to occur. As shown in Fig. 6, controllers are used to stabilizing the frequency. Here, the results are shown when there's no controller applied to the system, and then the results are improved using an inertia controller and PFC.



(a) (b)

Figure 4**.** Active power of a storage device.(a) Battery power (b) Supercapacitor power

2. *case1: scenario B*

The frequency of the system will be affected by solar PV's intermittent nature. PV power would be varied at various time intervals. The power of the solar cell changes from 17 to 7 kW at time t = 1.5 s, and from 7 kilowatts to 23 kilowatts at time t = 3 s, then changes from 23 to 17 kilowatts at t = 4 s. Fig.5 illustrates these changes.

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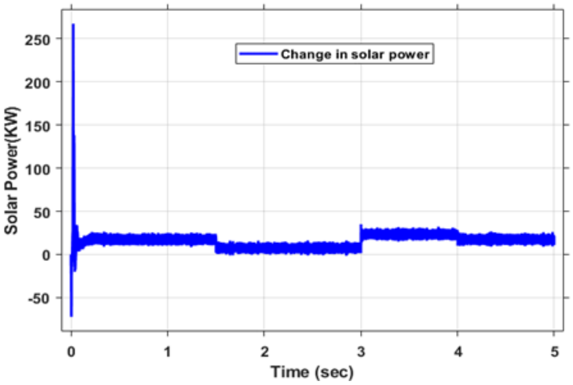


Figure 5. Change in solar power

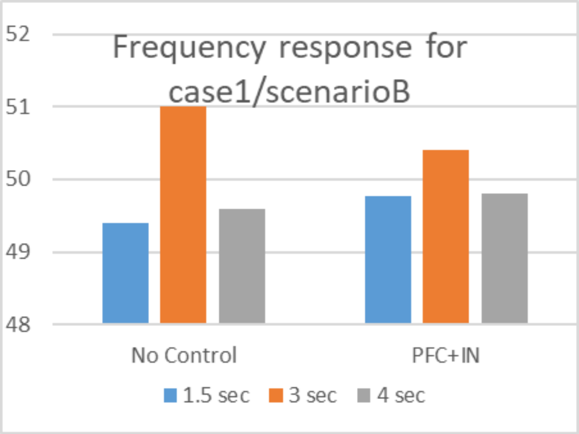


Figure6. Frequency response for p.v. change.

3. *Discussions Of Case 1*

A supercapacitor with inertia control provides immediate active power support in the first seconds following disturbances. Therefore, it may be said that battery packs and super-capacitors plus PFC and inertia regulators quickly react to frequency changes and effectively regulate the frequency inside the prescribed limits, hence increasing the microgrid's stability and security.

B. *Case 2 Simulations And Analysis*

The purpose of this case is to investigate the impact of increased R.E.S. penetration on system frequencies. Solar PV generation is boosted to 32 kilowatts to emulate such a scenario. The fuel cell generation capacity has also been boosted to 24 kilowatts. As a result, the demand for a traditional generator is minimized, and its size is lowered to 60 kVA. In this case, two stages will be studied in order to investigate the behavior of PFC and VIC. In scenario A, 20 percent of the overall load will be adjusted in order to cause a disturbance. Solar PV generation will also be adjusted in scenario B. In the subsections that follow, the scenarios are studied.

1. *case2: Scenario A*

During time = 2 seconds, 20% of the load capacity, or 18 kilowatts out of 90 kilowatts, is lost. Fig. 7 Explains the role of control circuits in frequency optimization. Likewise, at t = 4 s, 20 percent of the system's load capacity is introduced to the system. In this case, the frequency begins to decrease and then is enhanced by PFC and VIC. Fig. 8 depicts the active power of the battery bank plus supercapacitors.

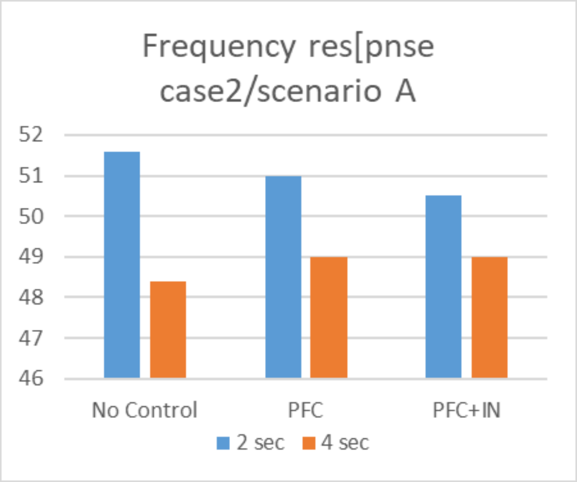
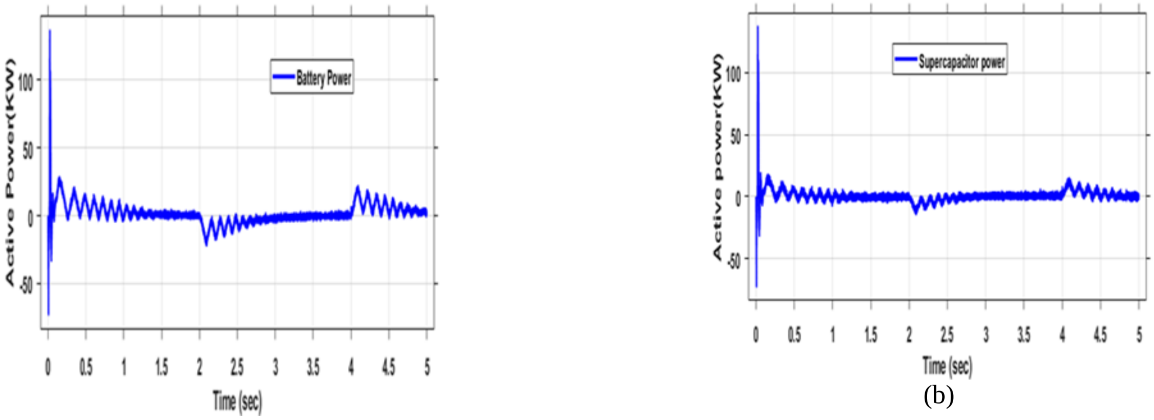


Figure 7**.** Frequency response for unexpected load changes with great R.E.S penetrates



(a)

(b)

Figure 8**.** Active power of a storage device during an unexpected load variation with a high RES sharing. (a) Battery power(b) Supercapacitor power.

2. case2: Scenario B

This scenario was designed to investigate the consequences of photovoltaic fluctuations in a microgrid with such a large RES share. The power of solar will change from 34 kilowatts to 20 kilowatts at time t = 1.5 s and then from 20 to 28 kilowatts at time t = 2.5 s. Furthermore, solar output ranged from 28 to 38 kilowatts at t = 3.5 s Fig.9. As a result, frequency variations will occur. The effect of controllers on recovering frequency Within acceptable limits is depicted in Fig.10.

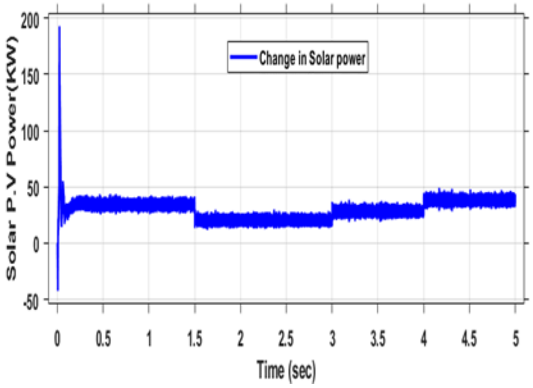


Figure 9. Solar power variation

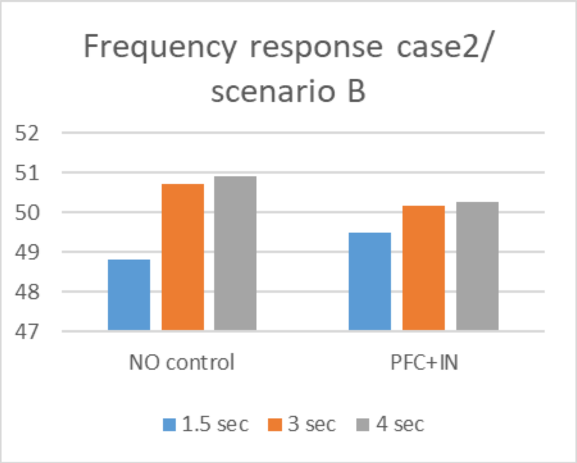


Figure 10**.** Frequency response for PV.

3. Discussion Of Case 2

The issues of small inertia in the network are addressed in Case 2. The physical inertia of the system is reduced because of the decreasing size of traditional generators at large penetrations of R.E.S.
The controller's response time was another thing that was noted. The inertia regulator is turned on by that rate of frequency change. These characteristics allow the components to respond more quickly.

C. Case 3 Simulations And Studies

Fuel cells can be utilized to provide helpful support to the network because they are non-intermittent forms of energy. The fuel cell is designed and linked to the power system, as stated in [20, 22]. This case will be tested to investigate the properties of fuel cells in terms of frequency support, resulting in a much more decentralized system. In this case, a fuel cell is used to provide two functions. It serves as a fixed generator for the microgrid, delivering 18 kW of power. In the second function, by using inverters, the fuel cell's active power is managed, which provides primary frequency support via the de-loading method. Inertia controls are used with energy storage systems in addition to fuel cell controls. In this case, a small inertia microgrid is simulated using a 60 kVA synchronous generator with 32-kilowatt photovoltaics. Adding and withdrawing 20% of the load, or 18 kilowatts from a total of 90 kilowatts, causes the disturbance (same as in previous cases).

1. Discussions In Case 3

Additionally, when fuel cells offer auxiliary services, regulating them helps ease the electric strain on other auxiliary devices (batteries and supercapacitors). The variation in power output of a fuel cell is depicted in Fig. 11. The chemical dynamics of fuel cells are slow, but the electrical response is quite fast. The graphic shows that the fuel cell can absorb the new reference set point rapidly in less than 0.1 seconds. According to this result, fuel cells are able to offer primary frequency support. This paper employed a reconfigurable decentralized control method, whereby all fixed energy sources could transfer power in the event of unexpected disturbances. That guarantees stability, reliability, and flexibility and also reduces electrical pressure on different components.

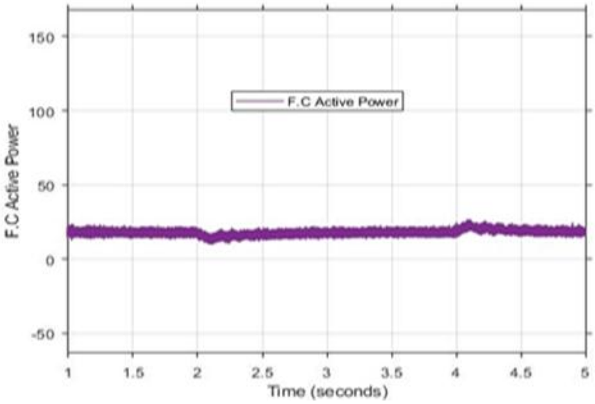


Figure11. Change in fuel cell-active power for deloading procedure.

IV.CONCLUSION

In this paper, the frequency stability was studied in a small network isolated from the main network, where a decentralized control method was used, the purpose of which was to obtain the active power from the distributed generation units when there was a shortage of electric power generation and energy storage devices were relied on to provide auxiliary services to the network. The research was carried out on different levels of renewable energy sources. In the first case, the highest percentage of electricity generated was for the synchronous generator. Therefore, when the frequency results were observed in the absence of contact circuits, the frequency deviation was not at a high rate due to the ability of the synchronous generator to address the problem of deviation in frequency. In the second case, it was increasing the proportion of renewable sources in a generation, and in return, the capacity of the synchronous generator was reduced, so there was a large deviation in frequency, which was solved through the control circuits for batteries and supercapacitors that work when any deviation in the frequency value occurs when there is a shortage in generation and an increase in demand for energy There is a drop in frequency, so the storage devices work to discharge their energy and start charging when there is an excess of the energy generated in the third case. The fuel cell, batteries, and supercapacitors played an important role in the network's frequency stability.

IV. APPENDIX

P.F.R	Primary Frequency Response
C.P.P	Conventionals Power Plant
ROCOF	Rates of Changes of Frequency
E.V	Electricals vehicles
D.S.O	Distribute systems operators
V2G	Vehicles to grids
P.V	PhotoVoltaic
FC	FuelCell
SC	Supercapacitors
A.C	Alternating Current
D.C	Direct Current
S.O.C	State of Charge
V.I.C	Virtual Inertia Control
V.S.M	Virtual Synchronous Machine
R.E.S	Renewable Energy Sources

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