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RESEARCH ARTICLE

Active Power Sharing Method for Microgrids With Multiple Dispatchable Generation Units Using Modified FFC and IFC Mode Controller

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ABSTRACT This paper suggests a method for active power sharing between several dispatchable and dispersed generation units in a microgrid with one or more connections to the main grid. The dispatchable power sources within the microgrid must promptly and adequately make up for natural demand changes and the intermittent nature of renewable energy resources for optimal operation. In microgrids with one or more grid connectivity, the paper presents a novel active power-sharing strategy that achieves the above-mentioned goal effectively. The suggested method's robustness is verified under various microgrid operating circumstances. Results confirmed the proposed method's adaptability to different operating conditions in the real world. Active power-sharing approaches are examined for a microgrid with several dispatchable distributed generation units (DDGU) operating in grid-interconnected and independent/isolated modes. Multiple grid connections at different points of the microgrid are investigated and recommended approaches are appraised. On a microgrid with one or more links to the conventional grid, this paper provides a novel and trustworthy approach for active power sharing across several DDGU. The proposed active power-sharing method is an effort to establish a feasible power-sharing technique that can be categorised for all, or most, types of interconnected microgrids. The outcomes demonstrate how the suggested technique can be adjusted to fit a range Results demonstrate how the proposed technique can be adjusted to fit a wide range of real life operational circumstances of microgrids.

INDEX TERMS Active power sharing, dispatchable generation, FFC, IFC, microgrid.

I. INTRODUCTION

Microgrids with high renewable penetration, once an idea, have now very much turned into a real-world reality [1]. With the vast proliferation of distributed power generation sources, the concept of microgrid has evolved as one of the most practical and flexible option for disintegrating large power systems into smaller and more manageable operational units. Traditionally, electric power has been generated in bulk at centralized power plants, typically located at far distances from the consumers [2]. Here are some examples of centralized power plants: Coal-fired power plants: Coal-fired power plants generate electricity by burning coal to produce steam, which drives steam turbines to generate electricity. These power plants are often located near coal mines, which are usually located far away from urban areas.

Nuclear power plants: Nuclear power plants generate electricity by using nuclear reactors to heat water to produce steam to drive turbines. These plants are typically located

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away from urban areas due to safety concerns associated with the radioactive materials used in the reactors.

Hydroelectric power plants: Hydroelectric power plants generate electricity by using the energy of falling or flowing water to turn turbines. These plants are built near large bodies of water, which may be located far away from urban areas.

Natural gas power plants: Natural gas power plants generate electricity by burning natural gas. These plants are often located near natural gas pipelines or storage facilities, which may be located far away from urban areas.

In all of these examples, the power plants are typically located far away from the consumers, which requires the electricity to be transmitted over long distances through transmission lines to reach the consumers. This is known as the traditional centralized model of electricity generation and distribution. The generated energy is delivered to the consumers over transmission and distribution networks. Large AC interconnected power systems were developed all over the world, connecting distant power generation units to the consumers.

A. BACKGROUND

Conventionally, islanded operation of a segment of a network, even with sufficient distributed power generation sources was not initially considered to be among the best practices or recommended mode of operation for various utilities [3]. However, nowadays, to take the full benefit of the increased penetration levels, proliferation of high efficiency and low cost distributed power sources and also to reduce the cost of having a reliable and redundant grid infrastructure, microgrids are considered to be smart, viable and sustainable option for the grid operators [4]. This specific area of research has attracted a lot of interest and attention of the researchers.

Many technical and financial difficulties in operating a microgrid have been recognized and published, and multiple solutions have been put out in the published works [5], [6], [7]. One of the major technological problems relevant to the natural operation of a microgrid is the effective active power sharing mechanisms of the dispatchable distributed generating units (DDGUs) within the microgrid. If a microgrid only consists of a few small scale non-dispatchable distributed generation units (NDDGUs) and a single large dispatchable generating unit. Any differences in demand or generation from NDDGUs will need to be made up for by the single DDGU. Nevertheless, if the microgrid comprises more than one DDGU, they must all respond to changes in demand, generation intermittency of renewable sources, and network configurations in a coordinated manner. A microgrid with strong connection(s) to a larger and stiff grid might not experience any change in the frequency as a result of any internal load or generation variation. The large grid can dictate the frequency by maintaining it to a constant value and consequently challenge the effectiveness of the frequency based active power sharing mechanism [8].

The ideal role for networked, interconnected microgrids is to act as a stable load or source for the primary grid [9]. This standard operating situation is attainable if the local (to microgrid) DDGUs are able to account for variations in the load or generation inside the microgrid only. The DDGUs must respond favourably to any load or generation fluctuation either caused by the intermittency of the renewable DDGUs or due to the loss of any power producing facility.

B. LITERATURE SURVEY

Frequency-based droop controllers have traditionally been very effective, straightforward, and dependable mechanisms to control a DDGU's reaction to changing load or generation in a microgrid system. To make sure that the units can respond quickly to the system's changing demand, some studies employed (P-f) droop control [10]. Unfortunately, the droop control method has a number of flaws that restrict its applicability for modern power systems. These flaws include poor transient performance, ignorance of load dynamics, lacking the ability to perform black startup, performing poorly in distribution networks, being unable to provide accurate power sharing with output impedance uncertainties, being unable to impose a fixed system frequency, and being unable to impose repaired synchronism [11].

Instead of relying on links for reliable activity, droop management solutions depend on precise estimations of the system state variables that lead to appropriate and total excess DG. It offers several enticing qualities, including flexibility, particularity, and expandability. In stochastic meteorological circumstances, the droop strategy-based controller is subject to a number of restrictions regarding voltage and frequency management. The droop controller for the local DDGUs in [12] continually modifies the droop settings in accordance with the DDGUs current reserve rather than their capacity. A novel approach that emphasizes the efficient dispatch of the units by breaking up the microgrid into smaller pieces is suggested in [13]. A method for centralized power sharing control with a lower bandwidth web-based communication network is presented in [14]. The divergence from the usual frequency/voltage magnitude during a substantial load fluctuation is one of the challenges of the primary droop frequency control approach, which may result in power quality concerns [15]. However, power quality difficulties, bidirectional power flow, voltage and frequency changes, coordinated operation of many distributed generators, stability, power management, and economic operation are all related with microgrid operation and control [16].

One study presented in [17] provided two intelligent and adaptive control techniques for controlling the microgrid frequency, voltage in grid-isolated mode and allowing seamless switching between grid-isolated and grid-tied modes. The proposed controllers were developed on basis of H-infinity and model predictive control (MPC) approaches to improve the performance of the droop control method. The H-based control strategy is used to regulate the microgrid in its islanded mode and to provide a smooth transition between the microgrid's two operational modes [18]. The main drawbacks of adaptive control and intelligent control lies in the difficulty of adjusting to unknown processes or random disruptions.

Renewable energy adoption in off-grid systems is limited by the significant unpredictability associated with renewable power output. Advanced control techniques enable more effective use of non-dispatchable sources [19]. Planning the despatch of distribution systems entails a number of decision-making issues involving service workers and various equipment operations. These problems include routing, scheduling, assigning trucks, performing service maintenance and repairs, and assigning cars to service requests. Together with conventional offline dispatch, new technological developments have reignited interest in the challenges of online dispatch. The likelihood of a more efficient dispatch is increased, but the complexity of the issue also rises. Electric power distribution systems are being drastically transformed into smart power distribution systems on the power grid, fusing traditional and emerging energy sources [20].

In any case, looking into these control strategies has become essential to improve the design and operation of future distributed geothermal and solar thermal-based microgrids. Future trends in charge methods for microgrids that are connected to energy insurance and administrations include the interest reaction, stockpile management, display support, and ideal power stream [21]. These developments might be fascinating when connecting microgrids to the main grid or when transporting different microgrids. Hierarchical control and multi-agent frameworks could coordinate the flow of energy across microgrids or, alternatively, microgrid groups in this manner. As a result, research on microgrid innovations is increasingly focusing on multi-agent control and hierarchical controllers, while communication frameworks are becoming more crucial to the development of these applications.

Accurate power sharing in islanded microgrids is a difficult undertaking for a variety of reasons, most notably a mismatch in feeder impedance. An analysis published in [22] proposes a distributed event-triggered power sharing control mechanism to address this issue. The proposed approach adaptively manages virtual impedances at both fundamental positive/negative sequence and harmonic frequencies, allowing distributed generating units to appropriately exchange reactive, unbalanced, and harmonic powers. The recommended method reduces communication overhead while maintaining system performance by requiring no prior knowledge of feeder impedance and simply transferring information between units during event-triggered times [23].

A dispatchable droop control technique is offered for many dispersed generators that can be applied in isolated alternating current microgrids by this analysis [24]. First-order inertia components are used in the proposed system to generate pseudohierarchical control, enabling the generators to autonomously divide the load on a smaller time scale while complying with the dispatch order on a larger time scale. The recommended method combines frequency restoration control and active power regulation. It has either a voltage control or a reactive power regulation control for various conditions. The suggested strategy is still useful even if the stated power control references are impossible. A MATLAB/Simulink simulation is used to show how effective the suggested technique is. For microgrid applications, methods based on constant droop were shown to be more suitable and resilient. Nevertheless, if the value of the droop constant continues to depend on the network design (series/radial or parallel) and/or the number of machines in the system at any particular moment, the technique can be categorized as either adjustable or constant droop. In such systems, if the central controller is missing for an extended period of time, operators must manually compute new droop constants for each unit [25].

C. CHALLENGES OF EXISTING MICROGRIDS

Innovations in flexible AC transmission system (FACTS) and power electronics-based or inverter-based renewable generation (IBRG) technology allowed for the partial dispatchability of NDDGUs by integrating battery energy storage systems (BESS). The development of grid-forming inverters with advanced grid-supporting capabilities, such as quick frequency response, virtual synchronous machine (VSM) control, and dynamic voltage management, is another result of developments in power electronics-based generation [26]. These innovations have shown that a microgrid can meet all of its demand using just renewable energy sources [27]. The main challenges of existing microgrids can be summarised in the below bullet points:

- operating a networked microgrid in its ideal configuration, i.e., acting as either a constant demand or a constant source for the conventional grid.
- putting forth a coordinated effort in response to changes in internal load or generation.
- ensuring a stable operation during and after the grid isolation.
- when a microgrid contains several grid interconnections, certain amounts of active power flows must be maintained at the interconnections.

One or more DDGUs must be operated in feeder flow control (FFC) mode since the underlying goal of all power sharing strategies is to make the microgrid a reliable power consuming or supplying entity. The flow from the grid must be kept as high as is practicable in order to have adequate reserve in the DDGUs (in FFC mode) to accommodate for any load/generation change inside the microgrid. On the contrary, more frequency variation will happen during isolation (and transition mode) if the flow from (or to) the grid is strong [28]. For the microgrid to withstand an unanticipated isolation event, a vital balance must be kept. Options for power sharing are recommended for microgrids with a single active grid connection. However, the creation of suitable power sharing techniques for microgrids with numerous active grid linkages received little consideration in the literature. With one or more active grid linkages, the microgrids studied in this paper are assumed to adopt a novel generic power sharing approach. The main objective of this research is to design a real power-sharing mechanism for the DDGUs in a connected microgrid with one or more grid interconnections to ensure optimal performance under variable load and intermittent renewable generation.

Technical difficulties in power systems could range from system stability, control, and operation issues to power quality, fault detection, and protection problems. Active power sharing methods for microgrids with multiple dispatchable generation units involve coordination and control of different distributed energy resources to achieve optimal power sharing and ensure stability and reliability of the microgrid.

Depending on the specific approach proposed, technical difficulties could include designing effective control algorithms to regulate the power flow, mitigating voltage fluctuations and frequency deviations, optimizing the dispatch of generation units to achieve efficient use of resources while maintaining system stability, and ensuring seamless switching between different operational modes.

D. CONTRIBUTION

From the above discussion, the main contribution of this paper is to design an active power sharing mechanism that comprises the below features:

- ability to ensure operation as a constant load or generation for the entire microrid.
- applied to microgrids with a single or several grid linkages.
- allowing stable independent operation of microgrid.
- capability to control the active power flow on all or some identified interconnection lines from the main grid.
- ability to adapt to changes in network configurations.

The remaining sections of the paper are organized as: section II discusses the research methodological approach, section III presents the results and discussion while key conclusions are drawn in section IV.

II. RESEARCH METHODOLOGY

In comparison to a microgrid with just one active grid interconnection, a microgrid with many active grid interconnections that can import and export power will be more reliable. Numerous grid connections increase operational flexibility and dependability while also adding additional complication to the automatic active power sharing systems used by DDGUs. Microgrids can be connected to numerous grid systems or to a single grid system through multiple links. Grid hookups may occur at various points of connection or even at various voltage ranges.

Power flow must be maintained constant across all interconnections in order to operate the microgrid as either a continuous source or load. In this paper, interconnection flow control (IFC), a method of active power sharing, is presented as a governor controller that maintains the total actual power flows across the interconnection lines constant until all DDGUs reach their headroom capacity. It is recommended that all DDGUs in a microgrid operate in IFC mode.

A. OPERATING POWER CONTROL MODES

The isolated microgrids or microgrids with a single active grid link are the main application scenarios for the active power sharing control systems. Little to no attention has been paid to creating sufficient power-sharing plans for microgrids with several active grid links [29], [30], [31]. Multiscale consensus has lately been researched as a novel idea in the field of multi-agent systems. The proposed approach can accommodate numerous complex coordination control tasks when values are assessed on multiple scales due to physical environment constraints [32]. The proposed techniques in the literature have several limitations and are found to be effective under one or only a handful operating conditions. Moreover, some of the proposed techniques require central and complex dispatch controller, which creates challenges related to reliability and availability of the overall system to ensure stable and microgrid's ideal operation.

The mode of microgrid control techniques, named FFC and proposed IFC are explained in the section below.

B. FFC-FEEDER FLOW CONTROL MODE

The FFC control mode maintains the power flow at a selected place inside the microgrid at a predetermined value, known as FL_{REF} while the microgrid is linked to the main grid. For all units running in FFC in an internal feeder, FL_{REF} is set to the value FL_{FEEDER} ($FL_{REF1} = FL_{FEEDER1}$ and $FL_{REF2} = FL_{FEEDER2}$). If the load demand rises (or generation falls) on the microgrid, the generating units in FFC mode increase their real power output to maintain the power flow at FL_{REF} value, which is the flow at a specific location in the microgrid.

Instead of using produced power versus frequency (P - f) droop when the microgrid is isolated, a feeder flow versus frequency (FL - f) droop controller is used to keep the flow at the specified point. Mathematically, FFC mode is expressed as:

$$f'' = f^n - K^z(FL' - FL^0) \tag{1}$$

where, FL', f'' and FL^0, f^n, are the final and initial values of power flow and frequency respectively, K^z refers to the FFC droop constant. Equation 1 refers the FFC mode of operation while in islanded mode. This droop operates according to the change in the feeder flow instead of change in the DDGU active power output. This is to ensure that the feeder flow should remain constant. If feeder flow increases, due to increase in the load, the frequency decreases to increase the active power output from the unit. The FFC mode of operation is illustrated in Figure 1. The power system model that is used to test and demonstrate the performance of the IFC mode is shown in the Figure 1. This is the most simplified and most representative network of a micro grid mimicking a micro grid which is serving a large residential/commercial area or a small industrial system. The two interconnection lines are

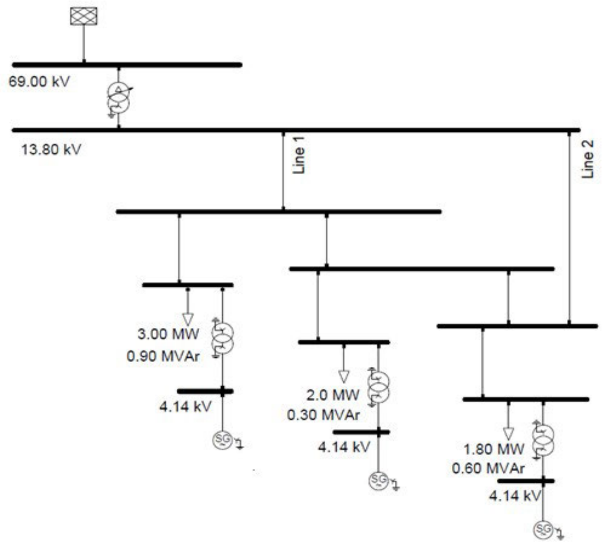

FIGURE 1. **Illustration of operating mode: FFC model for active power sharing.**

connected at two different nodes within the micro grid. Having interconnection lines connecting at two different nodes within the micro grid allows different values of active power to flow on the lines according to the physical laws of the load flow. In contrast, having two interconnection lines at the same node or connection point within a micro grid can only provide increased reliability, but the active power flow will always be symmetrical (equal) on each line. This modelling method is applied to simulate a challenging operating scenario for testing the performance of the designed IFC controller. This will also help in demonstrating that the designed controller is sensitive to the overall flow of active power and allows flexible active power flow on individual interconnections. The individual interconnection lines can have active power flow which is best suited for the most optimal power flow solution without having any undue operational restriction.

C. INTERCONNECTION FLOW CONTROL (IFC) MODE

In comparison to a microgrid with just a single activated grid interconnection, a microgrid with many active grid interconnections that can import and export power will be more reliable. Numerous grid connections increase operational flexibility and dependability while also adding additional complication to the automatic active power sharing systems used by DDGUs.

Power flow must be maintained constant across all interconnections in order to operate a microgrid as either a constant load or source. It is more likely that the total active power flows across interconnections will remain constant, independent of the specific flows on each interconnection. IFC, a method of real power sharing, is described in this paper as a governor controller and calls for maintaining a constant total active power flow across the interconnection lines until all DDGUs reach their headroom capacity. On a microgrid, IFC mode should be used by all DDGUs.

When a microgrid is linked to the conventional grid, IFC evaluates the active power flow from every interconnection, adds those flows to its controller, and compares them to a reference value. Each DDGU will respond in accordance with its K_I (gain of the PI controller) value if the total active power flow deviates from the reference value. To help the overall active power flow stay within a given range, the model might also contain a dead band. The local DDGUs will also make up for any load changes inside the microgrid. To maintain a steady total actual power flow via interconnections, the DDGUs will react in a coordinated manner if one of them trips. Compared to the FFC mode, where each DDGU simply reacts to changes in its own feeder flow, this is a significant benefit. Equations 2 and 3 can be used to explain IFC mode and Figure 2 depicts the IFC mode controller design. An IFC (immediate frequency response-based control) mode controller is a type of controller used in microgrid systems that responds to changes in frequency in the microgrid by adjusting the power output of the generation units. The IFC mode controller operates in a decentralized manner, meaning that each generation unit has its own IFC controller that communicates with other units in the microgrid. The design of an IFC mode controller typically involves measuring the frequency deviation of the microgrid and using this information to adjust the power output of the generation units. The controller can be designed using various methods, such as classical control theory or modern control techniques. The specific design of the IFC mode controller in Figure 2 of the paper may involve additional features or modifications to suit the particular requirements of the microgrid under consideration. The details of the design, including the control parameters, feedback signals, and communication protocols used, are likely explained in the paper. For equation 2, in FFC mode the individual feeder flow is used as the machine flow reference to change it's active power output (equation 1). However, for IFC mode all DDGUs have the same flow reference that is equal to the sum of active power flow on the monitored interconnection lines.

$$FL_{REF} = FL_{REF1} = FL_{REF2} = FL_{REF3} = FL_{LINE1} + FL_{LINE2} \quad (2)$$

$$\frac{f' - f^0}{K^I} + (FL_{REF} - FL_0) = toPIcontroller \quad (3)$$

In this equation, f^i represents the frequency measurement of the i^{th} unit, f^0 represents the nominal frequency of the microgrid, k^i is the frequency controller gain for the i^{th} unit, FL_{REF} is the reference frequency loading, FL_0 is the nominal frequency loading, and *toPIcontroller* is the output of the PI controller.

The equation is a representation of the IFC mode controller design, which uses the frequency deviation ($f^i - f^0$) of each generation unit to adjust their power output. The term

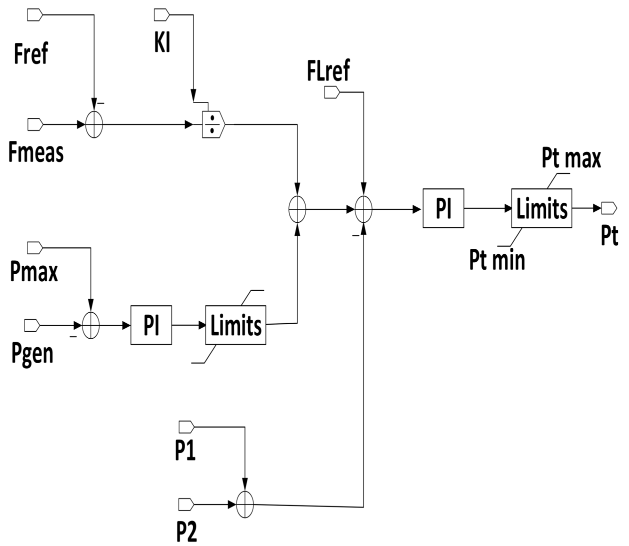

FIGURE 2. IFC mode controller for active power sharing.

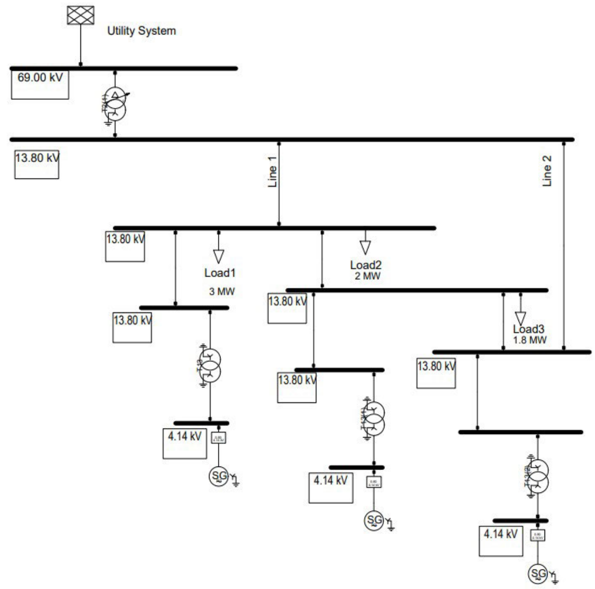

FIGURE 3. Network model of the studied microgrid.

TABLE 1. Comparison between operating modes.

Feature	FFC	IFC
Compensate internal generation and demand variations while connected to grid	Limited to connected feeder level	Yes
Ensure ideal operation of the microgrid in grid connected mode	Needs as many DDGUs as the number of internal feeders	Yes
Compensate the attached microgrid for the loss of DDGU	No	Yes
Respond to change in the system frequency	Yes	Yes
Dependence on network configuration	Yes	No

$(f^i - f^0)/k^i$ represents the control action of the frequency controller for the i^{th} unit. The term $(FL_{REF} - FL_0)$ represents the difference between the reference frequency loading and the nominal frequency loading, which is added to the control action of the frequency controller. The resulting value is the output of the PI controller, *toPIcontroller*, which is used to adjust the power output of the i^{th} unit.

Table 1 provides a summary comparison table between FFC and IFC modes of operation.

III. RESULTS AND DISCUSSION

The power system model that is used to test and demonstrate the performance of the proposed IFC mode is illustrated in the Figure 3. The studied system comprised two lines, "Line1" and "Line2" that connect the microgrid to the main utility system. The system's three DDGUs are modeled as synchronous generators (SGs) with respective outputs of 3.75 MVA, 2.5 MVA and 3.125 MVA to meet the 6.8 MW demand. The same value of KI is used to operate all three DDGUs in IFC mode. The following case studies are considered to assess the effectiveness of the recommended governor controller or manner of DDGU operation:

- Case Study - 1 – IFC mode performance is tested if the network configuration is changed within a microgrid. The loads are moved to different buses within the microgrid and then varied which mimics electrical vehicles in future grids. IFC and FFC modes are compared for the same load variations.
- Case Study - 2 – A third interconnection with another grid system is added to the microgrid. The third interconnection line "Line3" is connected to another bus within the microgrid. This case is to test the IFC mode capability to maintain the summation of real power from the two previous interconnection lines constant under varying operating conditions.

A. CASE STUDY-1: CHANGE IN NETWORK CONFIGURATION

The events listed below are simulated in this case:

1. At $t = 1.2$ second, load1 (near G1) was scaled down by 20% in 0.2 seconds.

2. At $t = 6$ second, load3 was scaled up by 33% in 0.2 seconds.

The network configuration as depicted in Figure 3, has been used to test the flexibility and functionality of the IFC-mode under varying network conditions. Load1, Load2 and Load3 were moved within the microgrid and placed on different busses, as highlighted in Figure 4. This modified network configuration is referred as "Configuration 2" in the discussion.

The shift in load distribution within the microgrid has an impact on the total active power flow within the system. No change in the summation of real power flow from the

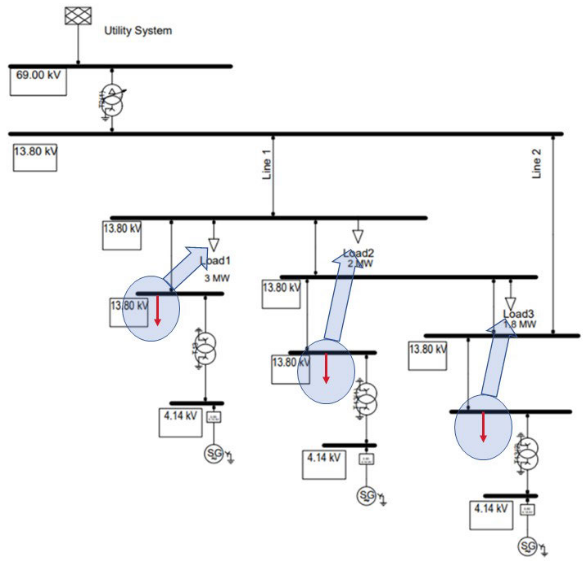

FIGURE 4. Configuration 2 with load transfer highlighted. Red arrows show the previous location of the loads.

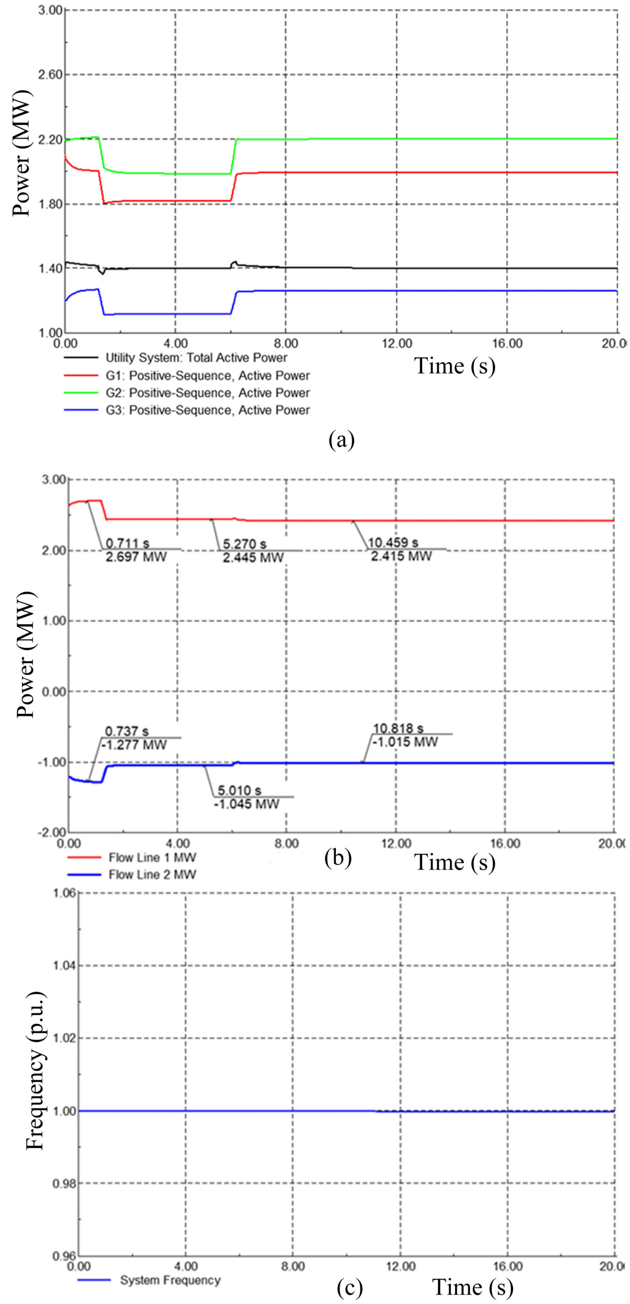

FIGURE 5. IFC mode: (a) G1, G2, G3 and utility system real power response; (b) Line1, Line2 real power flow; (c) microgrid frequency.

Utility system is noticed since the value of loads and generation from DDGUs are kept practically constant (1.4 MW in both cases).

The local DDGUs compensate for all load variations, as seen in the Figure 5. DDGUs in the microgrid maintained a consistent total active power flow from the conventional grid. The amount of electricity flowing through the two interconnection lines changed, while the total amount coming from the main grid did not. This phenomenon is an important aspect of IFC mode of active power sharing as it allows to have varying value of active power import or export on individual interconnection lines (Line1 or Line2), as required by the load while maintain the summation of the overall real power import or export at a constant level. Positive or negative individual flows are possible on the interconnecting lines. The main grid (Utility System) maintained a constant frequency.

The results in Figure 5 demonstrate that each DDGU reduced its real power output according to its capacity for a decrease of 0.6 MW (Load1) at $t = 1.2$ second. Similar to this, when the exact amount of demand(0.6 MW) was imposed at another location inside the microgrid (Load3), all DDGUs returned to their initial levels of real power generation at $t = 6$ second. Throughout this modification of active power dispatch, the total amount of actual power flowing via the interconnection lines was maintained constant.

As soon as the DDGUs returned to their initial starting values of actual power generation, the final values of the real power flow across the two interconnection lines deviate from their initial values. The changing load distribution of the microgrid is the cause of this shift in flow. The microgrid's overall load or demand resumed its previous value after two load variation events, but because these variations were simulated at separate sites, the actual power flow via the interconnected lines ended up with a different value. When operating in IFC mode, DDGUs in a microgrid are not affected by where variations occur because they all help to balance out changes in load or generation everywhere on the microgrid.

In case DDGUs were run in FFC, rather than the suggested IFC mode, for the modified network configuration and for the same load variations, the contributions from the DDGUs are shown in Figure 6.

It is evident from the results that none of the DDGUs contributed during the load variations. All the required change in

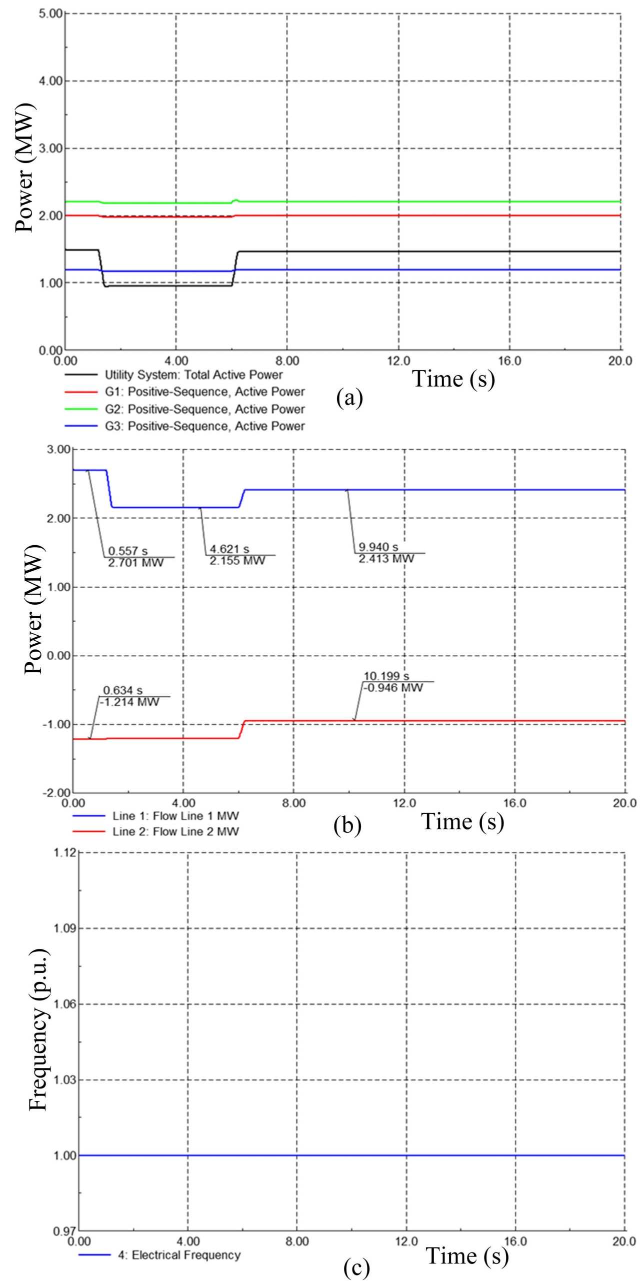

FIGURE 6. FFC mode: (a) G1, G2, G3 and utility system real power response; (b) Line1, Line2 real power flow; (c) microgrid frequency.

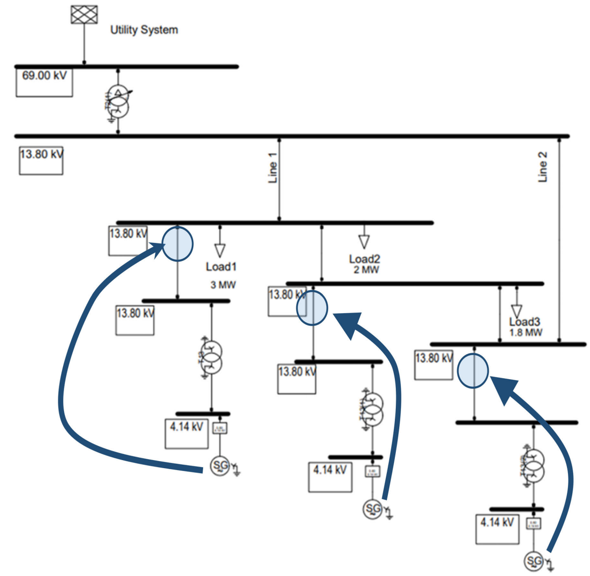

FIGURE 7. Active power measuring points for DDGUs in FFC mode.

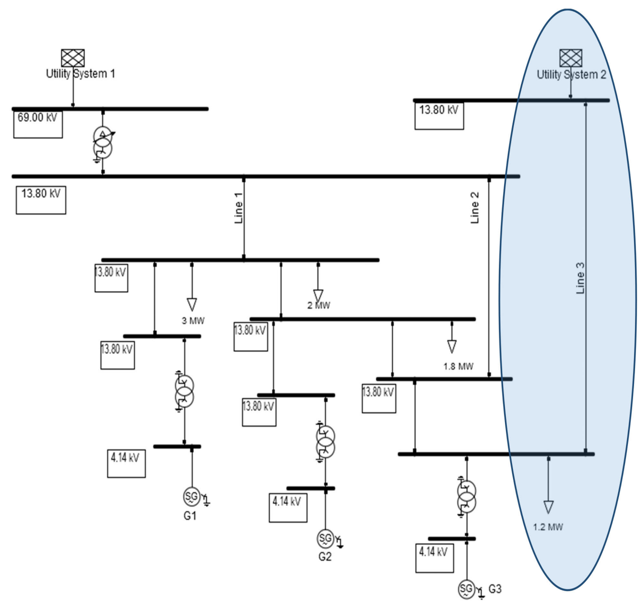

FIGURE 8. Network configuration with 3 interconnection lines (Network Configuration 3).

active power to compensate for the load variations were provided by the utility system (or main grid). This is because in the modified network configuration, all the loads are moved to buses which are not monitored by the DDGUs in FFC mode. In FFC mode, DDGUs only monitor flows on their feeder. The monitored points for each of the DDGU in FFC is highlighted in Figure 7.

B. CASE STUDY-2: CONNECTION WITH TWO UTILITY SYSTEMS

In this case study section, the below events are simulated:

1. Load1 (near to G1) was scaled down 20% in 0.2 second, a $t = 6$ second.
2. At $t = 12$ s, G3 was tripped.
3. At $t = 15$ s, Load3 (near to G3) was scaled up by 33% in 0.2 second.

The network configuration has been further modified from Configuration 2, by adding another interconnection line (Line3) with another utility system (utility system2), as shown in Figure 8. This network configuration is designed to model a microgrid of multiple interconnections with multiple grid systems. IFC mode of operation is used in a manner that it works to maintain the summation of the real power flow

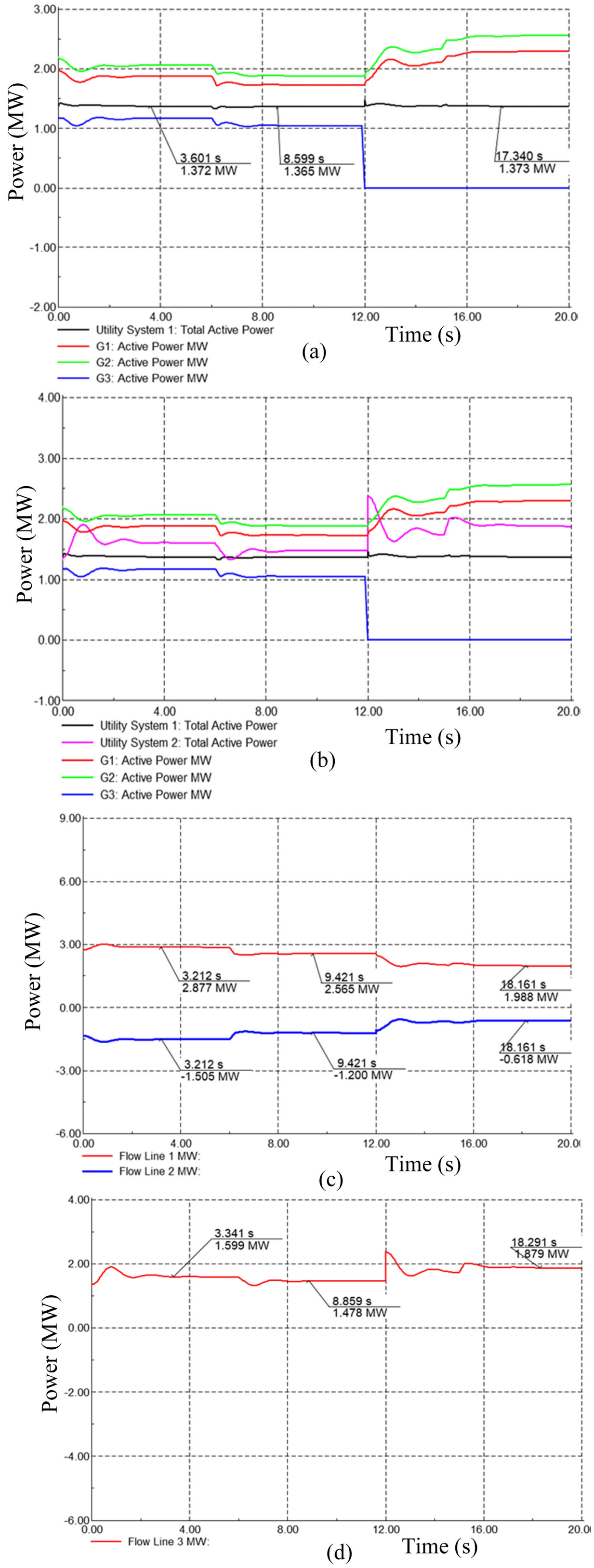

FIGURE 9. Network configuration 3: (a) G1, G2, G3 and utility System1 real power response; (b) G1, G2, G3, Utility System1 and Utility System2 real power response; (c) Active power flow on Line1 and Line2; (d) Active power flow on Line3).

from Utility System1 over two interconnection lines (Line1 and Line2), while allowing a natural flow of active power on the other interconnection line (Line3 from Utility System2). Another load of 1.2 MW is added at the bus connected to the Utility System2. Modifications to test network configuration are highlighted in Figure 8. This network configuration is referred as "Configuration 3" in the discussion.

Configuration 3 is also designed to test the flexibility and performance of the IFC mode under varying network conditions. Figure 9 provides the results of the simulated events for this case study.

For the first load variation all DDGUs and Utility System2 contributed to the load change, while the sum of flow from the two interconnection lines from Utility System1 remained constant at 1.4 MW as designed. This network configuration is designed to model a microgrid with multiple interconnections with several grid systems. IFC mode of operation is used in a manner that it works to maintain the sum of the active power flow from Utility System1 over two interconnection lines (Line1 and Line2), while allowing a natural flow of active power on the other interconnection line (Line3 from Utility System2). Another load of 1.2 MW is added at the bus connected to the Utility System2. When G3 was tripped at 12 s, remaining DDGUs (G1 and G2) and Utility System2 compensated for the loss of generation of G3. Sum of imports from Utility System1 still remained constant. Finally, when Load3 was increased at 15 s, the increased demand was also provided by G1, G2 and Utility System2. The results demonstrated in the Figure show that the IFC mode is successfully able to maintain the summation of real power flow from one utility system even when the microgrid is interconnected with another equally strong grid system.

While simultaneous load power and voltage regulation has been considered for DC microgrids [33], not much attention was given to tackle this issue in AC microgrids with multiple dispatchable generation. This can be a good subject for further research to improve the presented method in this paper. Also, Fluctuations in renewable energy sources such as solar and wind power that may pose challenges to the operation and stability of microgrids, especially when multiple dispatchable generation units are involved has not been considered in this paper. These fluctuations can be mitigated using proper energy storage or backup generation to ensure stable and reliable operation of the microgrid.

IV. CONCLUSION

The recommended strategy for active power sharing of dispatchable distributed generating units (DDGUs) should be chosen by utilities or operators of microgrid depending on the design, configuration, and load distribution of their particular microgrid. The active power sharing methodologies described in the available published literature are meant to operate a microgrid using the FFC control methodology of operation, with a focus on microgrids that have a single link to the conventional main grid. In this study, an improved and more flexible active power sharing method known as IFC is proposed. The IFC not only overcomes the FFC's drawbacks, but it also performs effectively for microgrids that have numerous connections to one or more conventional main grids. Using DDGUs in the suggested IFC mode of operation allows them to respond for any demand/generation changes anywhere inside the microgrid in a unified way, that is, as one sizable virtual generating unit, as opposed to restricting their reaction to a specific place inside the microgrid. The IFC mode can employ the real power producing capacity inside the microgrid more effectively than the FFC can. It has been demonstrated through testing in various simulated situations that the proposed technique is successful in preserving the overall actual power flow from or to the main grid. The recommended approach permits a range of active power flow values at different interconnections while maintaining the total active power flow to or from the microgrid at a preset level. This suggested method provides a new direction to the research work, as the microgrids with multiple grid connection has not yet been discussed in detail in the literature. This work has initiated a discussion which will need further elaborations on following related operational aspects of microgrids with multiple grid connections:

- Reactive power flow control from main grid(s),
- Economic Dispatch, and
- Transient and voltage stability limits at different interconnectors etc.

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