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Analysis of Reactive Power Sharing in Islanded Micro Grid Using an Improved Droop Control Strategy

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Abstract: In this paper, a reactive power sharing strategy that employs communication and the virtual impedance concept is proposed to enhance the accuracy of reactive power sharing in an islanded microgrid. Communication is utilized to facilitate the tuning of adaptive virtual impedances in order to compensate for the mismatch in voltage drops across feeders. Once the virtual impedances are tuned for a given load operating point, the strategy will result in accurate reactive power sharing even if communication is disrupted. If the load changes while communication is unavailable, the sharing accuracy is reduced, but the proposed strategy will still outperform the conventional droop control method. In addition, the reactive power sharing accuracy based on the proposed strategy is immune to the time delay in the communication channel. The sensitivity of the tuned controller parameters to changes in the system operating point is also explored. The control strategy is straight forward to implement and does not require knowledge of the feeder impedances. The feasibility and effectiveness of the proposed strategy are validated using simulation results for a 2-kva micro-grid.

Keywords- ***Microgrid, Droop control, Distributed Generation, reactive power.***

1. Introduction

Fossil fuel reserves are going to vanish in the near future, so human beings will need to find alternative energy sources to avoid this disaster. Increased concerns about rising price of conventional energy (e.g. Fossil fuel) and environmental impacts are fast shifting the focus to the use of renewable and sustainable energy sources. The use of renewable energy sources is becoming popular along with fossil fuels depletion [1-3]. The unpredictable and intermittent nature of renewable energy sources has kept them from integrating with the utility grid.

The popularity of distributed generation systems is growing faster from last few years because of their higher operating efficiency and low emission levels. Distributed generators make use of several micro sources for their operation like photovoltaic cells, batteries, micro turbines and fuel cells. During peak load hours dgs provide peak generation when the energy cost is high and stand by generation during system outages. A microgrid is built up by combining a cluster of loads and parallel distributed generation systems in a certain local area. Microgrids have large power capacity and more control flexibility which accomplishes the reliability of the system as well as the requirement of power quality.

In an islanded mode, the load power in the microgrid should be properly shared by multiple DG units. Usually, the droop control method which mimics the behavior of a synchronous generator in the traditional power system is adopted, which does not need the use of critical communications. The active power sharing is always achieved by the droop control method easily. However, due to effects of mismatched feeder impedance between the dgs and loads, the reactive power will not be shared accurately [4,5]. In extreme situations, it can even result in severe circulating reactive power and stability problems in this project, a new reactive power sharing method is proposed.

The microgrid concept acts as a solution to the conundrum of integrating large amounts of micro generation without disrupting the operation of the utility network. With the intelligent coordination of loads and micro-generation, the distribution network subsystem (or 'microgrid') would be less troublesome to the utility network, than a conventional micro generation. The net microgrid could even provide ancillary services such as local voltage control. In case of disturbances on the main network, micro grid Could potentially disconnect and continue to operate separately [6]. This operation improves power quality to the customer.

The proposed method improves the reactive power sharing by changing the voltage bias on the basis of the conventional droop control, which is activated by a sequence of synchronization events through the low-bandwidth communication network. The associated operations for a reduction in reactive power sharing error will result in a decrease in PCC voltage. To cope with the problem, the voltage recovery operation will be performed. That is to say, if the output voltage of one DG unit is less than its allowed low limit, then the DG unit will trigger the voltage recovery operation until its output voltage is restored to rating value.

2. Distributed Generation

A distributed generator is defined as an electric power source connected to the distribution network or directly to the customer application. Due to the increasing load requirements on the electrical system and the high capital investment that large centralized power plants require, a study by the Electric Power Research Institute (EPRI) indicates that by 2010, 25% of the new generation will be distributed. The high penetration of distributed generation units in the electrical system can significantly impact the flow of power and voltage conditions at the end customers [7].

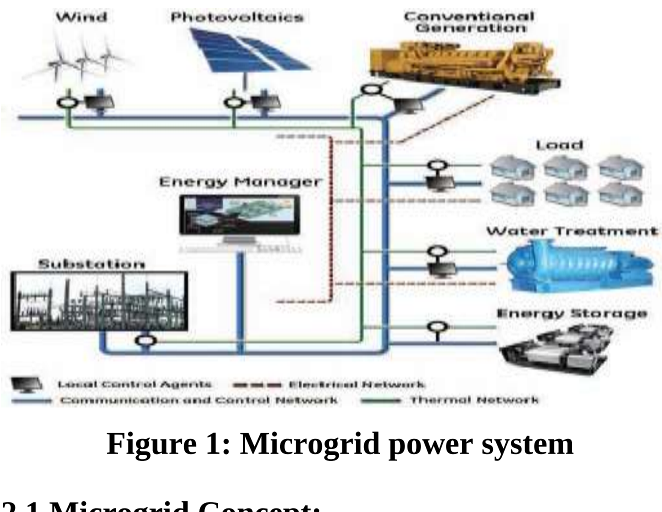

Figure 1: Microgrid power system

2.1 Microgrid Concept:

It has been proposed that one solution to the reliability and stability issues is to take advantage of microgrid technologies. The term "microgrid" is quickly becoming a popular topic within the power community but it still remains vaguely defined [8].

Application of combined heat and power technology

- Opportunities to tailor the quality of power delivered to suit the requirements of end users
- Create a more favorable environment for energy efficiency and small-scale renewable generation investments

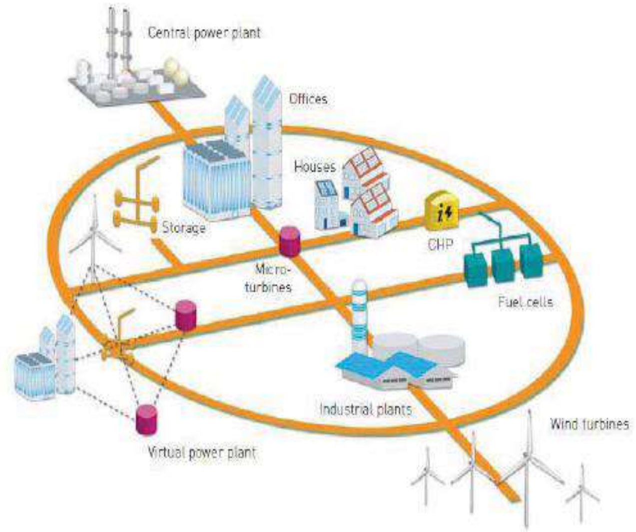

Figure 2: Connection diagram of microgrid

The use of waste heat through co-generation or combined heat and power processes (CHP) implies an integrated energy system, delivering both electricity and useful heat from an energy source.

2.2 types of Microgrid

Usually, there are four types of micro grids

- Campus Environment/Institutional Micro grid
- Remote "Off-grid" Micro grids
- Military Base Micro grids
- Commercial and Industrial (C&I) Micro grids

A. Campus Environment/Institutional Micro grid

The focus of campus micro grids is aggregating existing on-site generation with multiple loads that located in tight geography in which owner easily manage them.

B. Remote "Off-grid" Microgrids

These micro grids never connect to the Macro grid and instead operate in an island mode at all times because of economical issue or geography position.

C. Military Base Micro grids

These micro grids are being actively deployed with a focus on both physical and cyber security for military facilities in order to assure reliable power without relying on the Macro grid.

D. Commercial and Industrial (C&I) Micro grids

These types of micro grids are maturing quickly in North America and Asia Pacific; however, the lack of well –known standards for these types of micro grids limits them globally. Main reasons for the installation of an industrial micro grid are power supply security and its reliability.

2.3 ARCHITECTURE OF MICROGRID

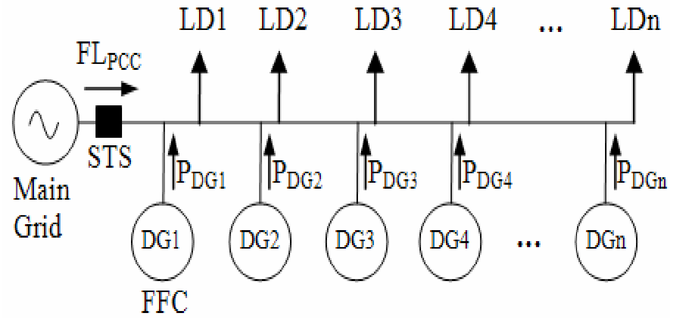

Figure 3: Architecture of Microgrid

The Fig.3 shows the simplified diagram of grid connected microgrid which comprises of multiple dgs.

2.4 modes of operation of a microgrid

A microgrid is connected to the utility grid through a bidirectional power converter that continuously monitors both sides and manages power flow between them [9-11]. If there is a fault in the utility grid, the power converter will disconnect the microgrid from the grid, creating an islanded energy system. Concluding, there are two operation modes for a microgrid:

A. Grid Connected Mode

In the grid-connected operation mode, the grid-tied power converter has control over the DC link voltage level. If the output sum of the power of the distributed generation systems is sufficient to charge the storage devices, any excessive power is supplied to the utility grid.

B. Islanded Mode

When a DC microgrid must be separated from the utility grid and switch to the islanded mode, the grid-tied power converter releases control of the DC link voltage level, and one of the converters in the microgrid must take over that control.

A smooth transfer between grid-connected and islanded mode is essential for the reliability of a microgrid. When grid faults occur, in order to protect the power electronic devices and some sensitive loads, the STS disconnect the microgrid from the grid.

2.5 Islanding Detection Techniques

The main philosophy of detecting an islanding situation is to monitor the DG output parameters and system parameters and decide whether or not an islanding situation has occurred from a change in these parameters [12].

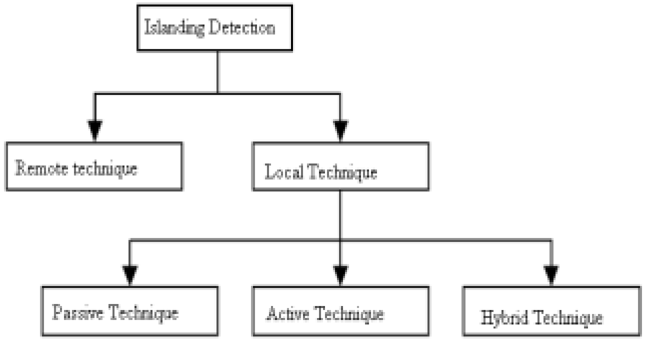

Figure 4: Islanding Detection Techniques

A. Remote islanding detection techniques:

Remote islanding detection techniques are based on communication between utilities and dgs. Although these techniques may have better reliability than local techniques, they are expensive to implement and hence uneconomical. Some of the remote islanding detection techniques are as follows:

(I) power line signaling scheme:

These methods use the power line as a carrier of signals to transmit islanded or non-islanded information on the power lines. The apparatus includes a signal generator at the substation (25+ kv) that is coupled to the network where it continually broadcasts a signal as shown in the Fig. 5.

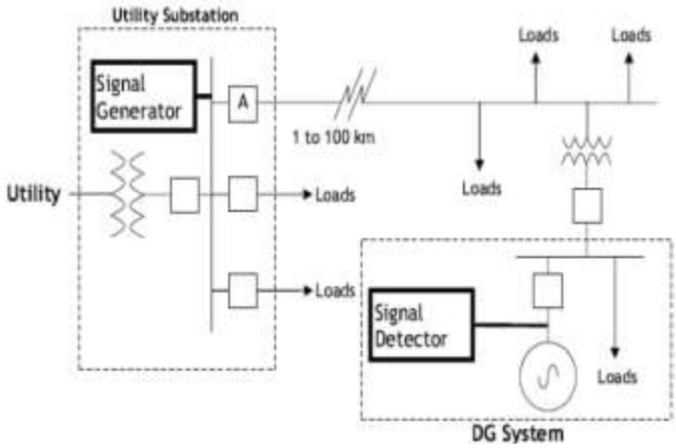

Figure 5: Power line signaling scheme

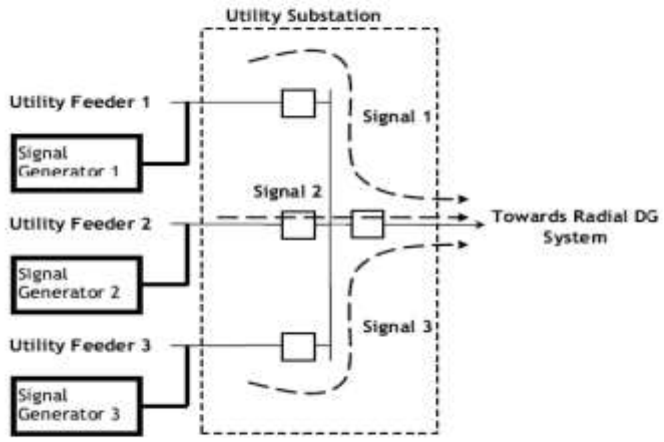

Figure 6: Radial network for island signaling

This method has the advantages of its simplicity of control and its reliability. In a radial system, there is only one transmitting generator needed that can continuously relay a message to many dgs in the network. The only times the message is not received is if the interconnecting breaker has been opened.

(II)Transfer Trip Scheme:

The Basic Idea Of Transfer trip scheme is to monitor the status of all the circuit breakers and reclosers that could island a distribution system. Supervisory Control and Data Acquisition (SCADA) systems can be used for that.

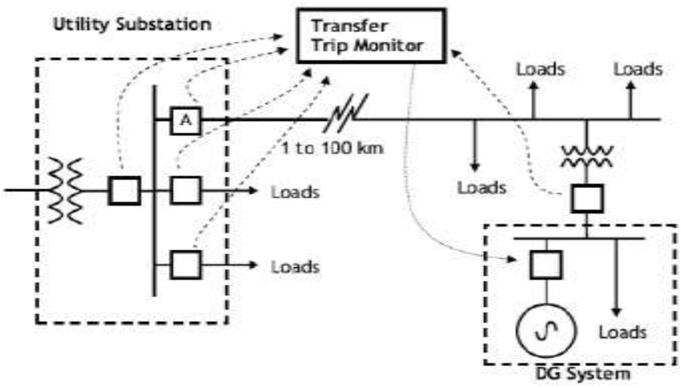

Figure 7: Transfer trip scheme

The weaknesses of the transfer trip system are better related to larger system complexity cost and control. As a system grows in complexity, the transfer trip scheme may also become obsolete, and need relocation or updating

B. Local Detection Techniques

It is based on the measurement of system parameters at the DG site, like voltage, frequency, etc. It is further classified as: Passive and Active Detection techniques.

(I) Passive Detection Techniques

Passive methods work on measuring system parameters such as variations in voltage, frequency, harmonic distortion, etc. These parameters vary greatly when the system is islanded. Differentiation between an islanding and grid connected condition is based on the thresholds set for these parameters. Special care should be taken while setting the threshold value so as to differentiate islanding from other disturbances in the system.

A. Rate 0f Change of Output Power:

The rate of change of output power, dp/dt, at the DG side, once it is islanded, will be much greater than that of the rate of change of output power before the DG is islanded for the same rate of load change.

B. Rate of Change of Frequency:

The rate of change of frequency, df/dt, will be very high when the DG is islanded. The rate of change of frequency (ROCOF)

$$ROCOF, \frac{df}{dt} = \frac{\Delta p}{2HG} \times f \quad (1)$$

Where, ΔP is power mismatch at the DG side
H is the moment of inertia for DG/system
G is the rated generation capacity of the DG/system

Large systems have large H and G where as small systems have small H and G giving larger value for *df/dt* ROCOF relay monitors the voltage waveform and will operate if ROCOF is higher than setting for certain duration of time. The setting has to be chosen in such a way that the relay will trigger for island condition but not for load changes.

C. Rate of Change of Frequency Over Power:

Df/dt in a small generation system is larger than that of the power system with larger capacity. Rate of change of frequency over power utilize this concept to determine islanding condition. Furthermore, test results have shown that for a small power mismatch between the DG and local loads, rate of change of frequency over power is much more sensitive than rate of frequency over time.

D. Voltage Unbalance:

Once the islanding occurs, DG has to take change of the loads in the island. If the change in loading is large, then islanding conditions are easily detected by monitoring several parameters: voltage magnitude, phase displacement, and frequency change. However, these methods may not be effective if the changes are small.

E. Harmonic Distortion:

Change in the amount and configuration of load might result in different harmonic currents in the network, especially when the system has inverter based dgs.

(II) Active Detection Techniques

With active methods, islanding can be detected even under the perfect match of generation and load, which is not possible in case of the passive detection schemes. Active methods directly interact with the power system operation by introducing perturbations

A. REACTIVE POWER EXPORT ERROR DETECTION:

In this scheme, DG generates a level of reactive power flow at the point of common coupling (PCC) between the DG site and grid or at the point where the Reed relay is connected. This power flow can only be maintained when the grid is connected. Islanding can be detected if the level of reactive power flow is not maintained at the set value.

B. Phase (Or Frequency) Shift Methods:

Measurement of the relative phase shift can give a good idea of when the inverter based DG is islanded. A small perturbation is introduced in form of phase shift. When the DG is grid connected, the frequency will be stabilized. When the system is islanded, the perturbation will result in significant change in frequency. A SMS curve is given by the equation:

$$\theta = \theta_m \sin\left(\frac{\pi}{2}\frac{f^{(k-1)} - f_n}{f_m - f_n}\right) \quad (2)$$

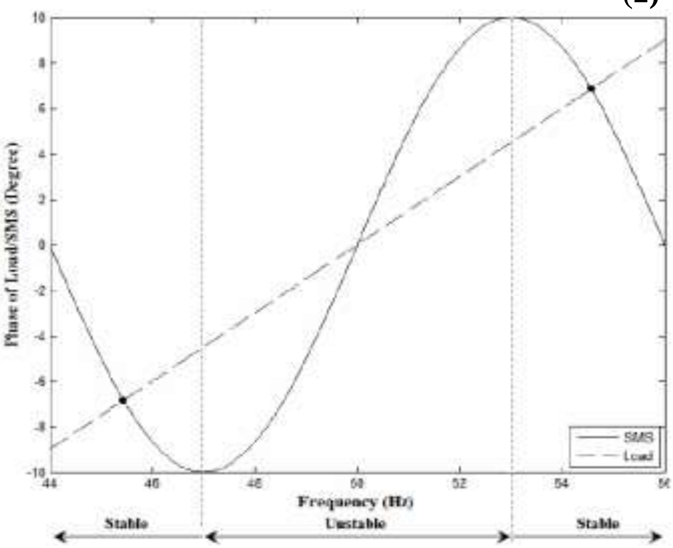

Figure 8: Phase response of DG and local load

Where θ_m is the maximum phase shift that occurs at frequency fm. Fn is the nominal frequency and $f^{(k-1)}$ is the frequency at previous cycle. A SMS curve is designed in such a way that its slope is greater than that of the phase of the load in the unstable region. A SMS curve, with θ_m =10° and f_m = 53 Hz, is shown in Fig. 8.

This detection scheme can be used in a system with more than one inverter based DG. The drawback of this method is that the islanding can go undetected if the slope of the phase of the load is higher than that of the SMS line, as there can be stable operating points within the unstable zone.

3. Control Methods for Distributed Generation With In A Microgrid

Micro grids have been designed with the objective to add more reliability and robustness to the conventional grid system. Advanced controller design and control strategy has facilitated the integration of a large number of renewable energy sources to the utility grid, which has encouraged distributed supply demand. Moreover, the capability of the distributed generators (DG) to meet a considerable amount of load demand has greatly reduced the stress on the centralized grid system [13,14]. Therefore, micro grids consisting of these dgs are now able to maintain an uninterrupted power supply for its loads, even during a grid outage.

3.1 Previous Works Involving The Control Of Microgrids:

One of the methods proposes inverters in close proximity operate in a master-slave relationship and load sharing between distant groups using frequency droop. The master inverter uses repetitive voltage control at the common node to suppress harmonic distortion and slave inverters use the repetitive control in current mode. It proposes to modify the droop characteristic such that generation is increased at nodes with a large local load so that power exchanges through the distribution system are reduced from those that would occur in conventional droop schemes. Simulation results show that this hybrid control configuration can improve waveform quality by reducing the total harmonic distortion.

3.2 Droop Control

For power systems based on rotating generators, frequency and active power are closely interconnected. A load increase implies that the load torque increases without a corresponding increase in the prime mover torque, which means that the rotational speed, and directly the frequency, decreases.

3.3 Power Sharing In Microgrid

Besides frequency and voltage stability, power sharing is an important performance criterion in the operation of microgrids. Here, power sharing is understood as the ability of the local controls of the individual generation sources to achieve a desired steady-state distribution of the power outputs of all

generation sources relative to each other, while satisfying the load demand in the network. The relevance of this control objective lies within the fact that it allows to pre-specify the utilization of the generation units in operation.
E.g.: to prevent overloading.

3.4 Technical Challenges In Microgrid

The protection system is one of the major challenges for microgrid which must react to both main grid and microgrid faults. The protection system should cut off the microgrid from the main grid as rapidly as necessary to protect the microgrid loads for the first case and for the second case the protection system should isolate the smallest part of the microgrid when clears the fault. A segmentation of microgrid, i.e. A design of multiple islands or sub-microgrids must be supported by micro source and load controllers [15]. In these conditions problems related to selectivity (false, unnecessary tripping) and sensitivity (undetected faults or delayed tripping) of protection system may arise.

3.5 Proposed Method For Control Of Micro Grid

In this project, a new reactive power sharing method is proposed. The method improves the reactive power sharing by changing the voltage bias on the basis of the conventional droop control, which is activated by a sequence of synchronization events through the low-bandwidth communication network. It is a cost-effective and practical approach since only a low bandwidth communication network is required. Simulation and results are provided to verify the effectiveness and feasibility of the proposed reactive power sharing method.

4. Configuration Of The Proposed Microgrid

4.1 Conventional Droop Control Method

Fig. 9 shows the equivalent model of a DG unit, which is interfaced to the common bus of the AC microgrid through a power inverter with an output LCL filter.

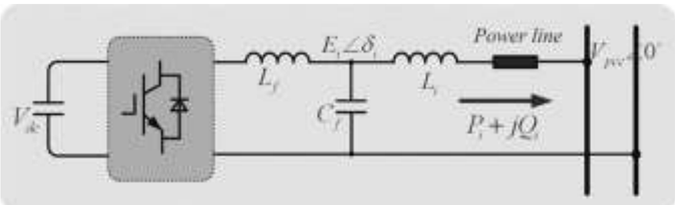

Figure 9: Model of a DG unit

As shown in Fig. 9, $E_i \angle \delta_i$ the voltage across the filter capacitor, and $V_{pcc} \angle 0°$ is the common ac bus voltage. Compared with the inductance of the LCL filter, the line resistance can be ignored. Then, the impedance between inverter and the common bus can be described as Xi (Xi = ωli).
According to the equivalent circuit in the above Fig. 9, the inverter output apparent power is S_i, and it can be given by

$$S_i = P_i + jQ_i = \frac{E_i V_{PCC}}{X_i} \sin\delta_i + j\left[\frac{E_i V_{pcc} \cos\delta_i - V_{pcc}^2}{X_i}\right] \quad (3)$$

From (1), the output active and reactive power of the DG units are shown as

$$P_i = \frac{E_i V_{PCC}}{X_i} \sin\delta_i$$

$$Q_i = \left[\frac{E_i V_{pcc} \cos\delta_i - V_{pcc}^2}{X_i}\right] \quad (4)$$

Usually, the phase-shift angle δ_i is small. Therefore, the real power P_i and reactive power Q_i of each DG can be regulated by δ_i and the output voltage amplitude respectively. Then, the conventional droop control is given by

$$\left.\begin{aligned} \omega_i &= \omega^* - m_i . \overline{P_i} \\ E_i &= E^* - n_i . \overline{Q_i} \end{aligned}\right\} \quad (5)$$

Where ω^* and E^* are the nominal values of DG angular frequency and DG output voltage amplitude, mi and ni are the active and reactive droop slopes, respectively. Pi and Qi are the measured averaged real and reactive power values through a low-pass filter, respectively

4.2 Reactive Power Sharing Error Analysis

For simplicity, a simplified microgrid with two DG units is considered in this section. According to Eq. (4) and (5), the reactive power of the I_{th} DG unit is obtained

$$Q_i = \frac{V_{PCC}(E^* \cos\delta_i - V_{pcc})}{X_i + V_{pcc} n_i \cos\delta_i} \quad (6)$$

Assume the I_{th} and j_{th} DG unit are working in parallel with the same nominal capacity and droop slope. Note that shift angle δ_i is usually very small ($\sin \delta_i \approx \delta_i$, $\cos \delta_i \approx 1$), then the reactive power sharing relative error with respect to Q_i can be expressed as follows:

$$\Delta Q_{err} = \frac{Q_i - Q_j}{Q_i} \approx \frac{X_j - X_i}{X_j + V_{PCC} n_j} \quad (7)$$

It shows that the reactive power sharing relative error is related to some factors, which include the impedance X_j, the impedance difference ($X_j - X_i$), the voltage amplitude V_{pcc} of the PCC, and the droop slope n_j. According to Eq. (7), there are two main approaches to improve the reactive power sharing accuracy: increasing impedance X_j and the droop gain n_j. Usually, increasing impedance is achieved by the virtual impedance which requires a high-bandwidth control for inverters. Increasing the droop gain n_j is a simpler way to reduce the sharing error. However, it may degrade the quality of the microgrid bus voltage, and even affects the stability of the microgrid system.

5. Proposed Reactive Power Sharing Error Compensation Method

The proposed droop control method is given as follows

$$\omega_i = \omega^* - m_i . P_i \quad (8)$$

$$E_i(t) = E^* - n_i Q_i(t) - \sum_{n=1}^{k-1} K_i Q_i^n + \sum_{n=1}^{k} G^n \Delta E \quad (9)$$

According to Eq. (9), the control is a hybrid system with continuous and discrete traits. In the digital implementation of the proposed method, the continuous variables $E_i(t)$ and $Q_i(t)$ are discredited with sampling period Ts, and Ts is greatly less than the time interval between two consecutive synchronization events.

$$E_i^k = E^* - n_i Q_i^k - \sum_{n=1}^{k-1} K_i Q_i^n + \sum_{n=1}^{k} G^n \Delta E \quad (10)$$

$$E_i^k = E_i^{k-1} - n_i\left(Q_i^k - Q_i^{k-1}\right) - K_i Q_i^{k-1} + G^k \Delta E \quad (11)$$

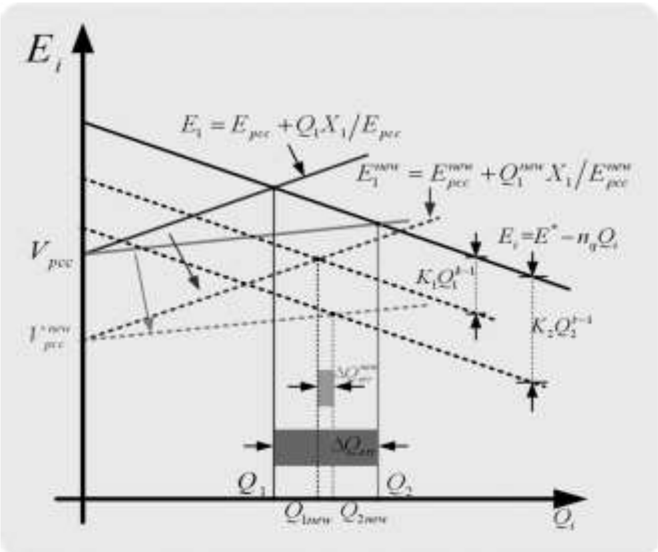

Figure 10: Schematic diagram of sharing error reduction operation

If the aforementioned operation is repeated with time, the reactive power sharing error will converge. However, the associated operations will result in a decrease in PCC voltage.

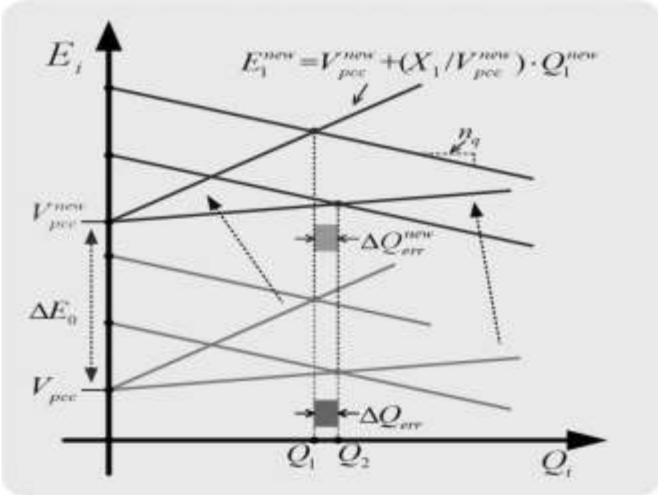

Figure 11: Schematic diagram of voltage recovery mechanism

5.1 Communication Setup

A DG unit can communicate with other DG units by RS232 serial communication. Each DG unit has the opportunity to trigger a synchronization event on the condition that the time interval between two consecutive synchronization events is greater than a permissible minimum value and the output voltage of each DG unit is in the reasonable range

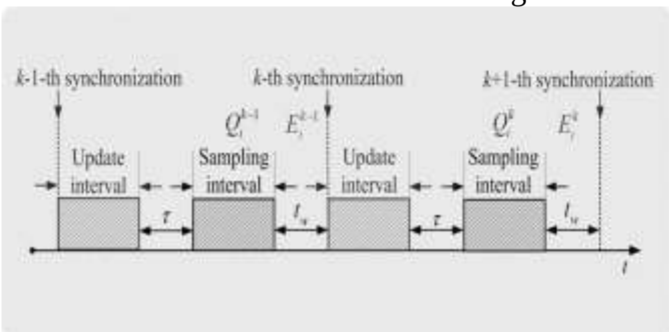

Figure 12: Control timing diagram of one DG with two consecutive synchronization events

5.2 Convergence Analysis

In this section, the convergence of the proposed method will be proved. Without loss of generality, the sharing reactive power error between DG-*i* and DG-*j* with the same capacity will be analyzed. According to Eq. (11), the reactive droop equation for DG-*j* can be expressed as

$$E_j^k = E^* - n_j Q_j^k - \sum_{n=1}^{k-1} K_j Q_j^n + \sum_{n=1}^{k} G^n \Delta E \quad (12)$$

By Subtracting

$$\Delta E_{ij}^k = -n \Delta Q_{ij}^k - \sum_{n=1}^{k-1} K \Delta Q_{ij}^n \quad (13)$$

Where $n=n_j=n_i$, $K=K_j=K_i$ and ΔE_{ij}^k is the voltage magnitude derivation of DG i and j in the kth control period ΔQ_{ij}^k is the reactive power sharing error

Similarly, we can get Eq. (13) in the (k+1)th interval

$$\Delta E_{ij}^{k+1} = -n\Delta Q_{ij}^{k+1} - \sum_{n=1}^{k} K\Delta Q_{ij}^{n} \quad (14)$$

Combining Eq. (13) and (14) it yields

$$\Delta E_{ij}^{k+1} - \Delta E_{ij}^{k} = -n\Delta Q_{ij}^{k+1} + n\Delta Q_{ij}^{k} - K\Delta Q_{ij}^{k} \quad (15)$$

According to the feeder characteristic, the following expressions can be obtained:

$$\Delta E_{ij}^{k+1} = \frac{1}{V_{PCC}^{k+1}}\left(Q_i^{k+1}X_i - Q_j^{k+1}X_j\right) \quad (16)$$

$$\Delta E_{ij}^{k} = \frac{1}{V_{PCC}^{k+1}}\left(Q_i^{k}X_i - Q_j^{k}X_j\right) \quad (17)$$

Assume the PCC voltage value satisfies the following:

$$V_{PCC}^{k+1} \approx V_{PCC}^{k} \approx V \gg 1 \quad (18)$$

Subtracting Eq. (15)from (16) it yields

$$\Delta E_{ij}^{k+1} - \Delta E_{ij}^{k} = \frac{X_j}{V}\left(\Delta Q_{ij}^{k+1} - \Delta Q_{ij}^{k}\right) + \frac{\Delta X}{V}\left(Q_i^{k+1} - Q_i^{k}\right) \quad (19)$$

Where $\Delta X = X_i - X_j$

Combining the expression Eq. (15) and (19) then

$$\Delta Q_{ij}^{k+1} = r\Delta Q_{ij}^{k} - \frac{\Delta X}{V\left(n+\frac{X_j}{V}\right)}\left(Q_i^{k+1} - Q_i^{k}\right) \quad (20)$$

Where $r = \frac{n+\frac{X_j}{V-K}}{n+\frac{X_j}{V}} < 1$ According to the contraction mapping theorem, if $|r| < 1$ and $\Delta X = 0$, then reactive power sharing error will converge to zero. Generally, $\Delta X \neq 0$, we should also consider the effect of the second term of Eq. (20).

According to the feeder characteristic, we have

$$Q_i^{k+1} - Q_i^{k} = \frac{\left(E_i^{k+1} - E_i^{k}\right)V}{X_i} \quad (21)$$

Because of the voltage recovery mechanism, we can ensure $E_{min} \leq E_i^k \leq E_{max}$ for all k

$$\left|Q_i^{k+1} - Q_i^{k}\right| \leq \left(E_{max} - E_{min}\right)\frac{V}{X_i} \quad (22)$$

Therefore the second term of Eq. (20) is bounded. According to aforesaid analysis,it could be concluded that the reactive power sharing error is also bounded.

6. SIMULATION RESULTS

A microgrid with three DG units is simulated in the PSCAD/EMTDC environment to validate the proposed control strategy, and to demonstrate the feasibility of the proposed controller for microgrids with more than two units. The microgrid system parameters are shown in Table I.

$$Q_{er,i}\% = \frac{Q_i - Q_i^*}{Q_i^*} \times 100 \quad (23)$$

1)The performance of Conventional Controller:

The performance of the system using only conventional droop control is illustrated in Fig. 12 for two different loads. The total reactive power load is changed between 1030 and 388 var while the real power load is changed between 1215 and 910 W.

2) The performance of the Proposed Controller:

The performance of the proposed controller is demonstrated in Fig. 13. The controller is enabled at t = 1 s which reduces the reactive power sharing error to zero in 2 s as can be seen in Fig. 13(b).

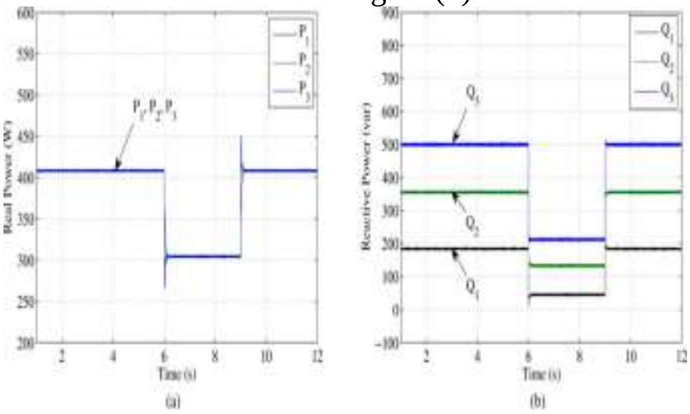

Figure 13: Simulated performance of conventional droop control. (a) Real power. (b) Reactive power.

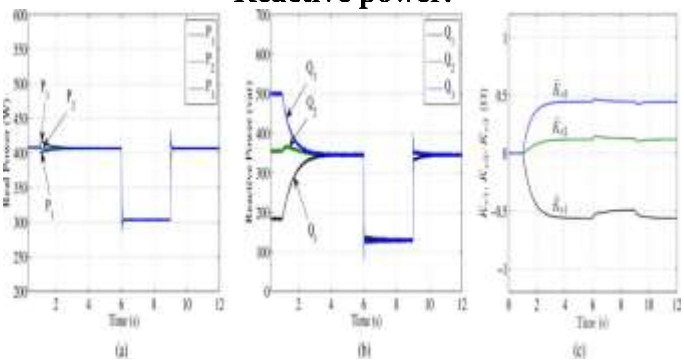

Figure 14: Simulated performance of the proposed controller (activated at t = 1 s). (a) Real Power. (b) Reactive Power. (c) Real-time tuning of the virtual impedance variables.

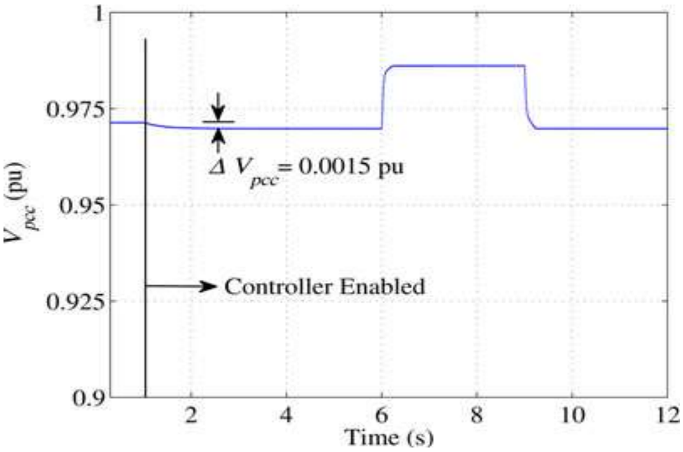

Figure 15: Behavior of the microgrid bus voltage (*V*pcc) when the controller is enabled at *t* = 1 s.

3) Effect of The Communication And Information Update Delays:

To show the main concept of the controller, two factors were neglected in the simulation of Fig. 16. The first is the time delay mismatch among the communication channels, and the second is the information update delay. In Fig. 16, the load is intentionally changed at the same moment Q∗ is updated so there is no information update delay

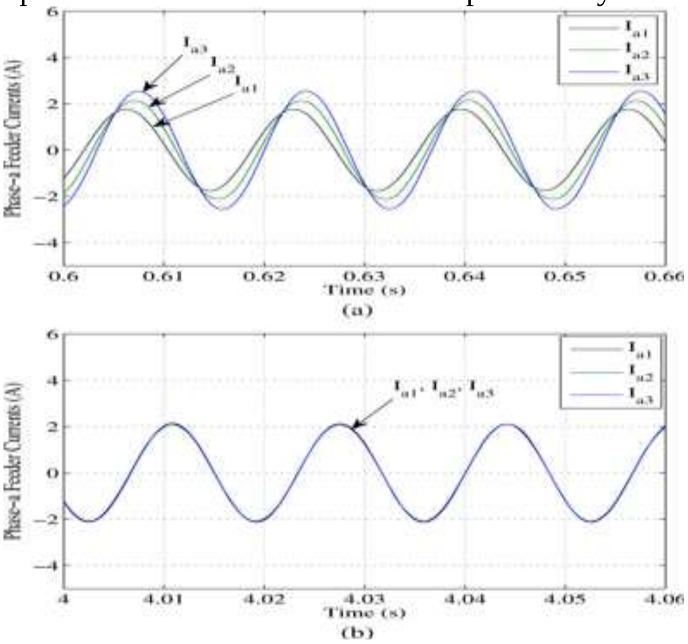

Figure 16: Simulated feeder currents. (a) Under conventional control (before enabling the controller). (b) Under the proposed control strategy.

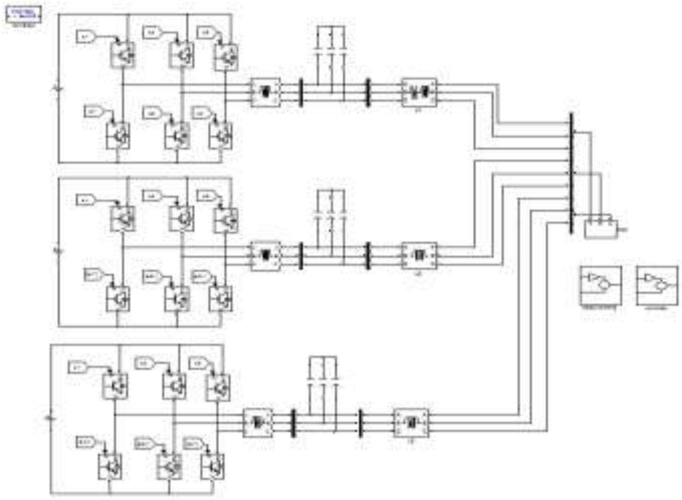

Figure 17: Simulation circuit diagram

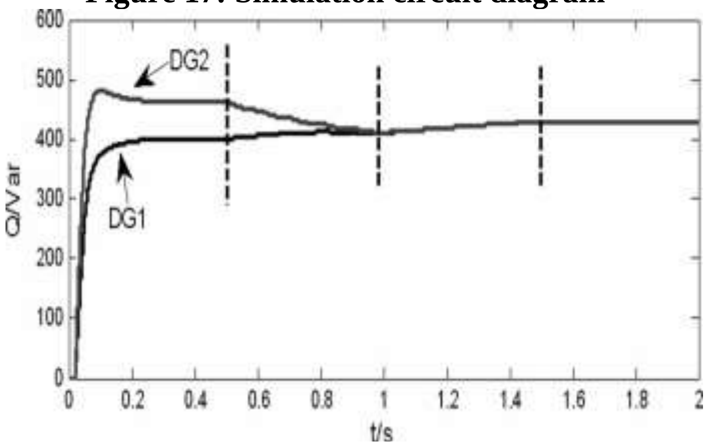

Figure 18: Output reactive powers of two inverters with the improved droop control.

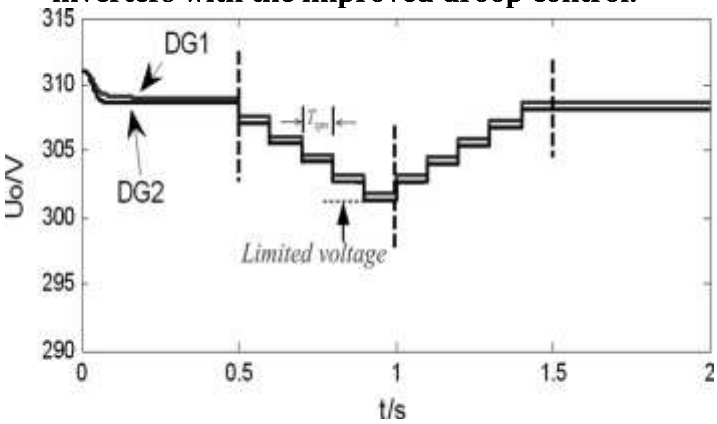

Figure 19: Output voltage amplitude of two inverters with the improved droop Control.

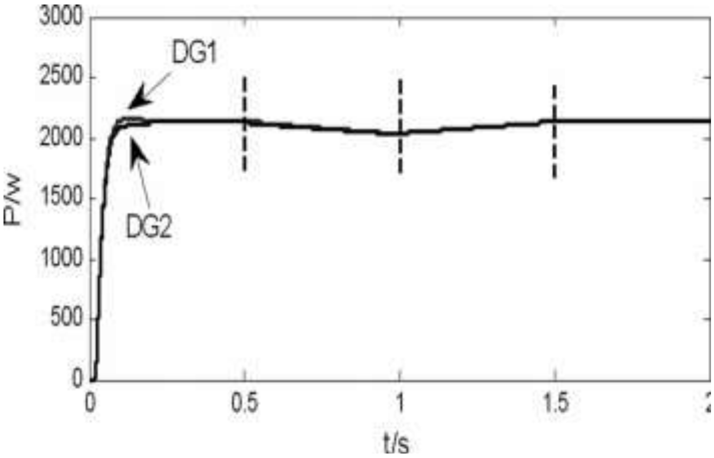

Figure 20 : Output active powers of two inverters with the improved droop control.

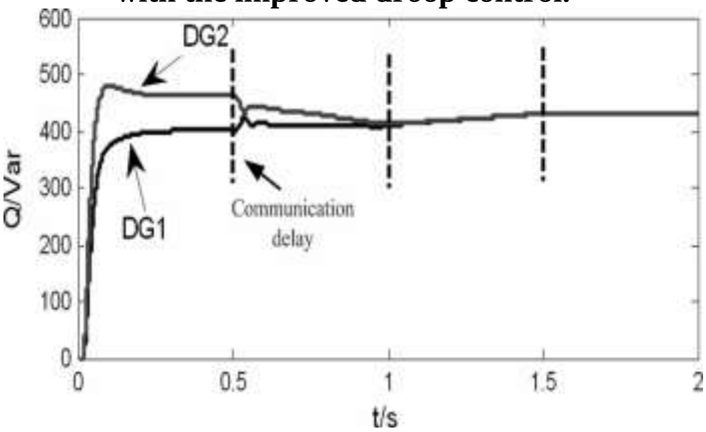

Figure 21: Output reactive powers of the two inverters when 0.02-s time delay occurs in synchronization signal of DG1 unit.

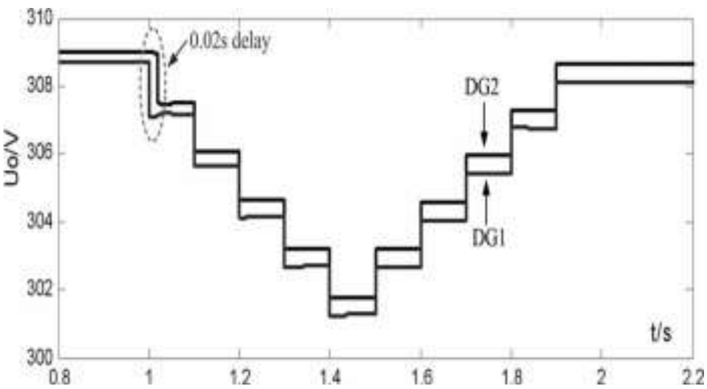

Figure 22: DG output voltage of the inverters when 0.02-s time delay occurs in synchronization signal of DG1 unit.

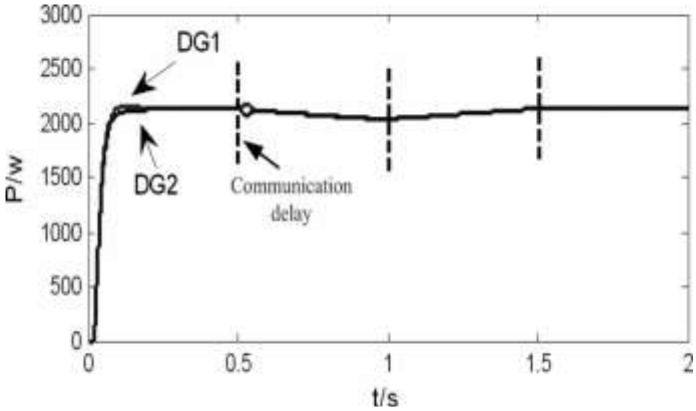

Figure 23: Output active powers of the two inverters when 0.02-s time delay occurs in synchronization signal of DG1 unit.

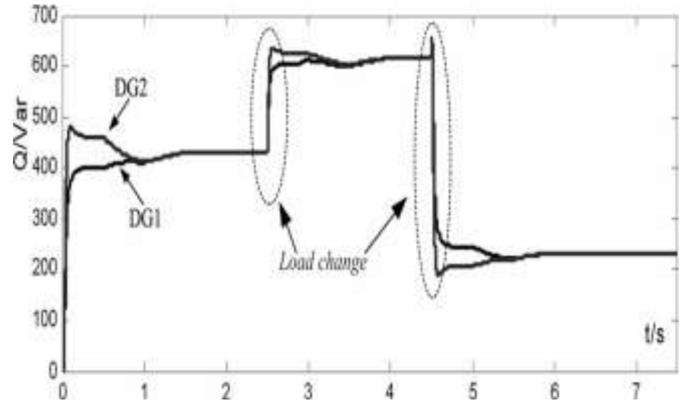

Figure 24: Reactive power sharing performance of the improved droop control (with load changing).

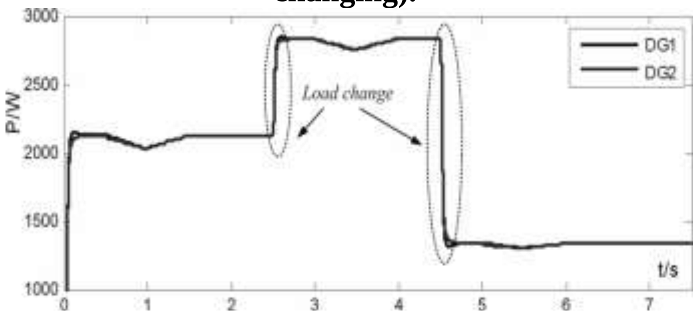

Figure 25: Active power sharing performance of the improved droop control (with load changing).

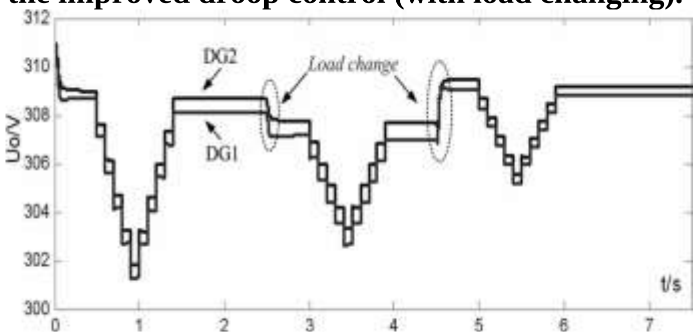

Figure 26: DG output voltage of the improved droop control (with load changing).

7. Conclusions

A control strategy to improve reactive power sharing in an islanded microgrid has been proposed and validated in this project. The strategy employs communication to exchange the information needed to tune adaptive virtual impedances in order to compensate for the mismatch in feeder impedances. The control strategy does not require knowledge of the feeder impedances and is straightforward to implement in practice. It is also insensitive to time delays in the communication channels. It has been shown that the proposed technique is tolerant of disruptions in the communication links while still outperforming the conventional droop control method. The sensitivity of the tune controller parameters to changes in the system operating point has also been investigated. It has been shown that the system operating point is mainly determined by the power factor, and the higher the load power factor, the less sensitive the parameter are to the operating point. The control strategy has been simulated in a 2-kva system and has been verified to be effective under operating point changes and realistic communication failures.

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