Load demand Sharing using multiple distributed generation units for the operation of microgrids to realize satisfied power sharing

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Abstract: The important task for the operation of autonomous micro grids, is to share the load demand using multiple distributed generation units. In this paper to realize satisfied power sharing without the communication between DG units, the voltage droop control and its different variations have been proposed. Generally, in a low-voltage micro grids, due to the effects of feeder impedance, the droop control is subject to the real and reactive power coupling and steady-state reactive power sharing errors. The complex micro grid configurations often make the reactive power sharing more challenging. To improve the reactive power sharing accuracy an enhanced control strategy that estimates the reactive power control error through injecting small real power disturbances, which is activated by the low-bandwidth synchronization signals from the central controller The proposed compensation method achieves accurate reactive power sharing at the steady state. Simulation and experimental results validate the feasibility of the proposed method.

Key words: Distributed generation, droop control, , micro grid, reactive power compensation, real and reactive power sharing.

I.   INTODUCTION

The application of distributed power generation has been increasing rapidly in the past decades. Compared to the Conventional centralized power generation, distributed generation units(DG), deliver clean and renewable power close to the Customer's end. As Most of the DG units are interfaced to the grid using power electronics Converters, they have the opportunity to realize enhanced Power generation through a flexible digital control of the power Converters. On the other hand, high penetration of power electronics based DG units also introduces a few issues, such as system Resonance, protection interference, etc. In order to overcome these problems, the micro grid concept has been proposed, which is realized through the control of multiple DG units. Compared to a single DG unit, the micro grid can achieve superior power management within its distribution networks. In an islanded micro grid, the loads must be properly shared by multiple DG units. Conventionally, the frequency and voltage magnitude droop control is adopted, which aims to achieve micro grid power sharing in a decentralized manner. However, the droop control governed micro grid is prone to have some power control stability problems when the DG feeders are mainly resistive. It can also be seen that the real power sharing at the steady state is always accurate while the reactive power sharing is sensitive to the impacts of mismatched feeder impedance. Moreover, the existence of local loads and the networked micro grid configurations often further aggravate reactive power sharing problems.

To solve the power control issues, a few improved methods have been proposed. In, the virtual frequency–voltage frame and virtual real and reactive power concept were developed, which improve the stability of the micro grid system. However, these methods cannot suppress the reactive power sharing errors at the same time. Additionally, when small synchronous generators are incorporated into the micro grid, proper power sharing between inverter-based DG units and electric machine based DG units will be more challenging in these methods. In, both the reactive power and the harmonic power sharing errors were reduced with the non-characteristic harmonic current injection. Although the power sharing problem was addressed, the corresponding steady-state voltage distortions degrade the micro grid power quality. In, the reactive power sharing error reduction is realized using additional PCC voltage measurement. In, the predominant virtual output inductor is placed at the DG output terminal, which is mainly focused on preventing the power control instability. In addition, within the virtual impedance control frame, the reactive power sharing errors can be further reduced through an

interesting model-based droop slope modification scheme. As the virtual impedance aided control method has the ability to address the power control instability and power sharing errors at the same time, it is considered to be a promising way to provide superior micro grid performance.. Then the accurate reactive power sharing is realized by manipulating the injected transient real-reactive power coupling using an intermittent integral control. With the proposed scheme, reactive power sharing errors are significantly reduced.

II. DISTRIBUTED GENERATION

Distributed generation, also called on-site generation, dispersed generation, embedded generation, decentralized generation, generates electricity from many small energy sources. Currently, industrial countries generate most of their electricity in large centralized facilities, such as fossil fuel nuclear or hydropower plants. These plants have excellent economies of scale, but usually transmit electricity long distances and negatively affect the environment. Most plants are built this way due to a number of economic, health & safety, logistical, environmental, geographical and geological factors. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature limited to operating at sites with sufficient water flow. Most power plants are often considered to be too far away for their waste heat to be used for heating buildings. Recently interest in Distributed Energy Systems (DES) is increasing, particularly onsite generation. This interest is because larger power plants are economically unfeasible in many regions due to increasing system and fuel costs, and more strict environmental regulations. In addition, recent technological advances in small generators, Power Electronics, and energy storage devices have provided a new opportunity for distributed energy resources at the distribution level, and especially, the incentive laws to utilize renewable energies has also encouraged a more decentralized approach to power delivery.

The research works in the recent papers about DES focus on being utilized directly to a standalone AC system or fed back to the utility mains. That is, when in normal operation or main failures, DES directly supply loads with power (standalone mode or standby mode), while, when DES have surplus power or need more power, this system operates in parallel mode to the mains. Therefore, in order to permit to connect more generators on the network in good conditions, a good technique about interconnection with the grid and voltage regulations should overcome the problems due to parallel operation of Power Converter for applications to DES.
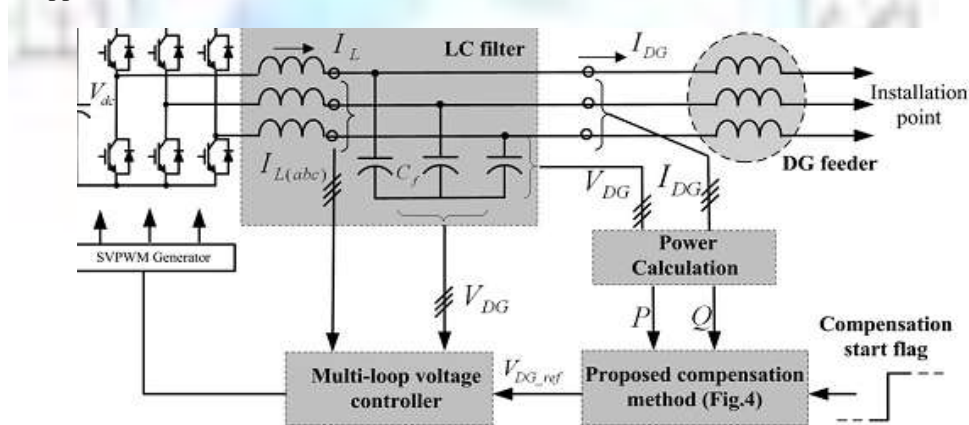

Fig. 1: Configuration of the DG unit.

III. PROBLEM DESCRIPTION

These new distributed generations interconnected to the low grid voltage or low load voltage cause new problems which require innovative approaches to managing and operating the distributed resources. In the fields of Power Electronics, the recent papers have focused on applications of a standby generation, a standalone AC system, a combined heat and power (cogeneration) system, and interconnection with the grid of distribution generations on the distribution network, and have suggested technical solutions which would permit to connect more generators on the network in good conditions and to perform a good voltage regulation. Depending on the load, generation level, and local connection conditions, each generator can cause the problems described in the previous chapter. The main goals which should be achieved will thus be: to increase the network connection capacity by allowing more consumers and producer customers connection without creating new reinforcement costs, to enhance the reliability of the systems by the protections, to improve the overall quality

of supply with a best voltage control. Power Converters supplying power in a standalone mode or feeding it back to the utility mains Fig. shows a block diagram of multiple power converters for a standalone AC system or feeding generated powers back to the utility mains.

In case of parallel operation of UPS systems, a recent critical research issue is to share linear and nonlinear load properly by each unit. In general, the load sharing is mainly influenced by non uniformity of the units, component tolerance, and line impedance mismatches Distributed Generation (DG) is commonly defined as electric power generation facilities that are not directly connected to a bulk power transmission system. They cover a multitude of energy sources, fuels, and conversion methods to produce electricity through photovoltaic (PV) arrays, wind turbines, fuel cells, micro turbines, liquid and gas-fueled reciprocating engines, etc. Given the wide variety of sources, it is natural that specific impacts associated with DG would vary with type and application.

IV.   MICROGRIDS

Distributed generation located close to demand delivers electricity with minimal losses. This power may therefore have a higher value than power coming from large, central conventional generators through the traditional utility transmission and distribution infrastructure. With the use of renewable distributed generation, the dependency on fossil fuels and on their price can be minimized. This step will also lead to a significant reduction of carbon dioxide emissions, which is required in several government programs. If, in addition, distributed generation and consumption in a certain area are integrated into one system, reliability of the power supply may be increased significantly, as shown in figure 2. The importance and quantification of these benefits has been recognized, although these are yet to be incorporated within the technical, commercial, and regulatory framework [11].

However, under today's grid codes, all distributed generation, whether renewable or fossil-fueled, must shut down during times of utility grid power outages This is precisely when these on-site sources could offer the greatest value to both generation owners and society.

A micro grid is a regionally limited energy system of distributed energy resources, consumers and optionally storage. It optimizes one or many of the following: Power quality and reliability, sustainability and economic benefits and it may continuously run in off-grid- or on-grid mode, as well as in dual mode by changing the grid connection status.
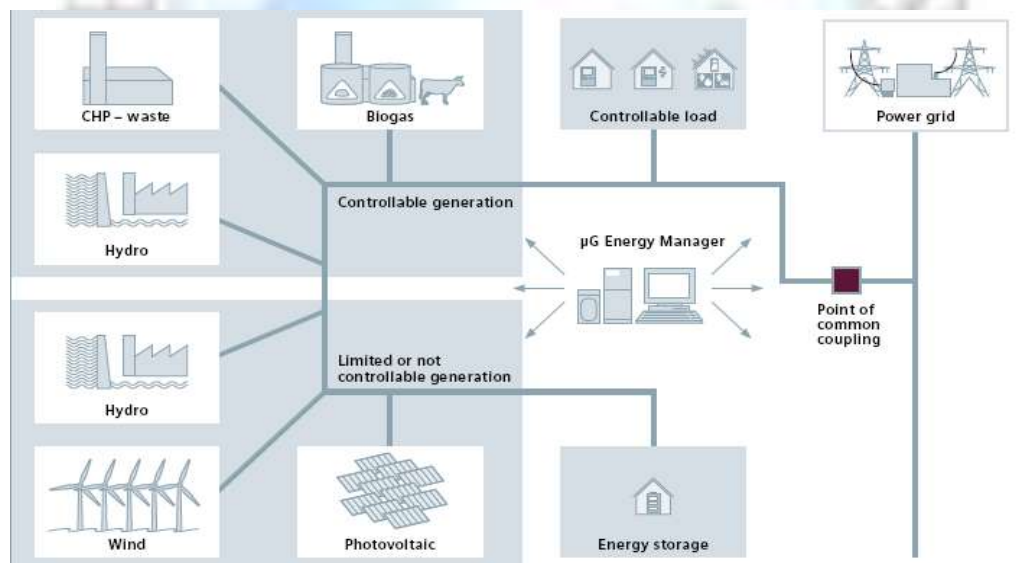

Figure 2: Microgrid with one common point of coupling to the utility grid

According to this definition, a micro grid maximizes the benefits of distributed generators and solves the above-mentioned disadvantage, also utilizing distributed generation during utility power system outages. In grid-connected mode, the micro grid operator can take economic decisions – such as to sell or buy energy depending on on-site generation capability, its cost, and the current prices on the energy market. In case of a utility power system outage, the point-of-common-coupling breaker will automatically open, and own generators will continue to supply power to loads within the micro grid.

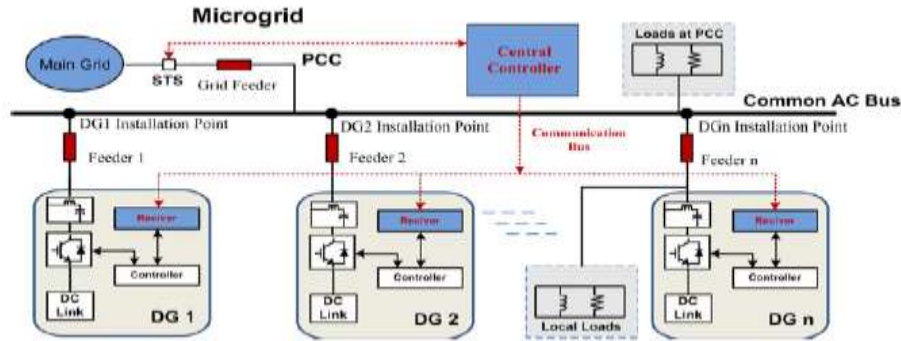### V.   ANALYSIS OF THE CONVENTIONAL DROOP CONTROL METHOD

Fig.3: Illustration of the micro grid configuration.

Fig. 3 illustrates the configuration of a micro grid. As shown, the micro grid is composed of a number of DG units and loads. Each DG unit is interfaced to the micro grid with an inverter, and the inverters are connected to the common ac bus through their respective feeders. Considering that the focus of this paper is the fundamental real and reactive power control, nonlinear loads are not considered in the micro grid. The micro grid and main grid status are monitored by the secondary central controller. According to the operation requirements, the micro grid can be connected (grid-connected mode) or disconnected (islanding mode) from the main grid by controlling the static transfer switch (STS) at the point of common coupling (PCC). During the grid-connected operation, real and reactive power references are normally assigned by the central controller and the conventional droop control method can be used for power tracking. However, to eliminate the steady-state reactive power tracking errors, the PI regulation for the voltage magnitude control was developed. Therefore, power sharing is not a real concern during the grid-connected operation. When the micro grid is switched to islanding operation, the total load demand of the micro grid must be properly shared by these DG units. During the islanding operation, DG units as illustrated in Fig. 2 can operate using the conventional real power–frequency droop control and reactive power–voltage magnitude droop control as

$$\omega = \omega_0 - D_P \cdot P \quad (1)$$
$$E = E_0 - D_Q \cdot Q \quad (2)$$

Where ω_0 and E_0 are the nominal values of DG angular frequency and DG voltage magnitude, P and Q are the measured real and reactive powers after the first-order low-pass filtering (LPF), D_P and D_Q are the real and reactive power droop slopes. With the derived angular frequency and voltage magnitude in (1) and (2), the instantaneous voltage reference can be obtained accordingly. It is not straightforward to evaluate the reactive power sharing accuracy in a complex networked micro grid. For the sake of simplicity, this section first considers a simplified micro grid with two DG units at the same power rating. The configuration is shown in Fig. 2, where each DG unit has a local load. $R1$ and $X1$, and $R2$ and $X2$ are the feeder impedances of DG1 and DG2, respectively.
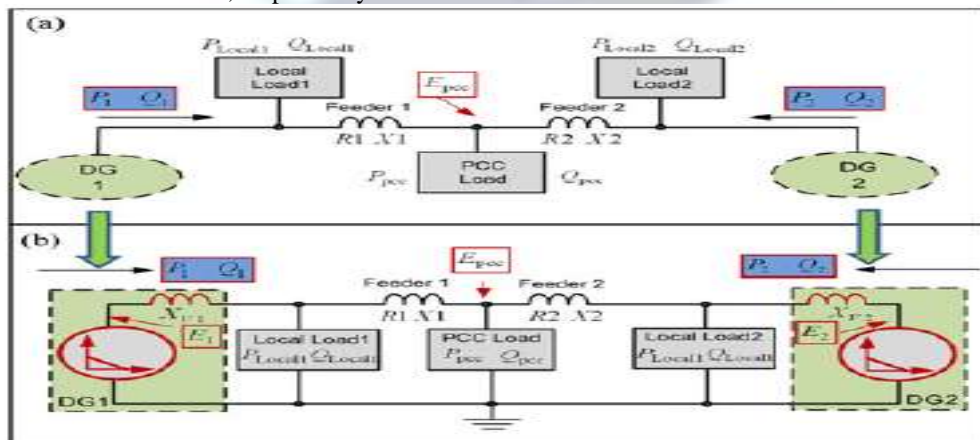

Fig.4. Power flow in a simple micro grid

$$E_1 = E_0 - D_Q \cdot Q_1 \tag{3}$$

$$E_2 = E_0 - D_Q \cdot Q_2 \tag{4}$$

Where E1 and E2 are the DG voltage magnitudes regulated by the droop control, and Q1 and Q2 are the output reactive powers of DG1 and DG2, respectively. For the power flowing through either physical or virtual impedance, its associated voltage drop on the impedance yields the following approximation as

$$\Delta V \approx \frac{X \cdot Q + R \cdot P}{E_0} \tag{5}$$

Where P and Q are the real and reactive powers at the power sending end of the impedance, R and X are the corresponding resistive and inductive components of the impedance, E_0 is the nominal voltage magnitude, and ΔV is the voltage magnitude drop on the impedance.

Applying the voltage drop approximation in (5) to the presented system in Fig. 2, the relationships between DG voltages (E_1 and E_2) and the PCC voltage (E_{PCC}) can be established in (6) and (7) as

$$E_1 = E_{PCC} + \frac{X_1 \cdot (Q_1 - Q_{Local1}) + R_1 \cdot (P_1 - P_{Local1})}{E_0} + \frac{X_{V1} \cdot Q_1}{E_0} \tag{6}$$

$$E_2 = E_{PCC} + \frac{X_2 \cdot (Q_2 - Q_{Local2}) + R_2 \cdot (P_2 - P_{Local2})}{E_0} + \frac{X_{V2} \cdot Q_2}{E_0} \tag{7}$$

It is important to note that with system frequency as the communication link, the real power sharing using the conventional droop control is always accurate. Therefore, for the illustrated system at the steady state, the output real powers of DG1 and DG2 are obtained as

$$P_1 = P_2 = 0.5 \cdot P_{Total} = 0.5 \cdot (P_{pcc} + P_{Local1} + P_{Local2} + P_{Feeder1} + P_{Feeder2}) \tag{8}$$

Where P_{Total} means the real power demand within the islanded micro grid, and PFeeder1 and $P_{Feeder2}$ are the real power loss on the feeders. Similarly, the reactive power demand (Q_{Total}) is defined as

$$Q_{Total} = Q_{pcc} + Q_{Local1} + Q_{Local2} + Q_{Feeder1} + Q_{Feeder2}$$

Where $Q_{Feeder1}$ and $Q_{Feeder2}$ are the reactive power loss on the feeders.

By solving the obtained formulas from (3) to (7), the reactive power sharing error ($Q_1 - Q_2$) can be derived.

VI.   PROPOSED REACTIVE POWER SHARING ERROR COMPENSATION METHOD

Since the reactive power sharing errors are caused by a number of factors and micro grids often have complex configurations, developing the circuit model-based reactive power sharing error compensation strategy is difficult. Therefore, the objective of this section is to develop an enhanced compensation method that can eliminate the reactive power sharing errors without knowing the detailed micro grid configuration. To initialize the compensation, the proposed method adopts a low-bandwidth communication link to connect the secondary central controller with DG local controllers. The commutation link sends out the synchronized compensation flag signals from the central controller to each DG unit, so that all the DG units can start the compensation at the same time.

This communication link is also responsible for sending the power reference for dispatch able DG units during the micro grid grid-tied operation. Therefore, the proposed compensation scheme does not need any additional hardware cost. The communication mechanism can be realized using power line signaling or smart metering technologies, or other commercial

infrastructures, such as digital subscriber lines, or wireless communications. These techniques have already been suggested to construct the future smart grid systems. As the focus of this paper is the enhanced power sharing scheme realized at the DG unit local controller, further discussion on the communication system is out of the scope of this paper. Note that in the proposed compensation method, only one-way communication from the central controller to DG local controllers is needed for starting the DG compensation with a synchronized manner. The intercommunication among DG units is not necessary, so that the plug-and-play feature of a DG unit will not be affected. It is important to point out that although the averaged real power (P_{AVE}) is measured at this stage, the real and reactive powers used in droop controller is shown in Fig. 5.
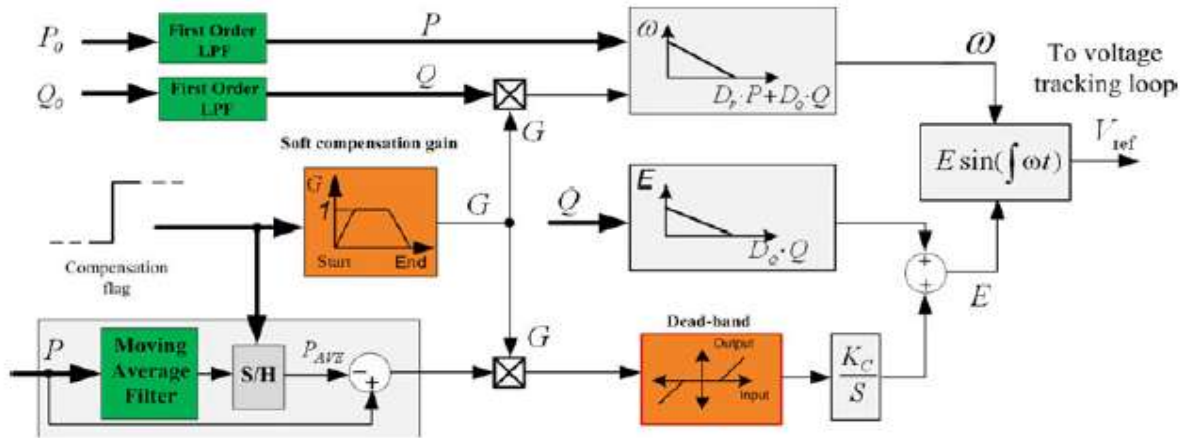

Fig. 5. Synchronized reactive power compensation scheme

Power Sharing Improvement Through Synchronized Compensation: In Stage 2, the reactive power sharing error is compensated by introducing a real-reactive power coupling transient and using an integral voltage magnitude control term. As this compensation is based on the transient coupling power control, it shall be carried out in all DG units in a synchronized manner. Once a compensation starting signais received by the DG unit local controller, the averaged real power calculation stops updating, and the last calculated PAVE is saved and used as an input of the compensation scheme.

During the compensation process, the combination of both real and reactive powers is used in the frequency droop control as shown in (9), while the reactive power error is suppressed by using an additional integration term as illustrated in (10)

$$\omega = \omega_0 - (D_P \cdot P + D_Q \cdot Q) \tag{9}$$

$$E = E_0 - D_Q \cdot Q + \left(\frac{K_C}{s}\right) \cdot (P - P_{AVE}) \tag{10}$$

Where, K_C is the integral gain, which is selected to be the same for all the DG units.

It can be observed that with the control strategy in (9), the real and reactive power is coupled together for the frequency droop control. Compared to the conventional droop control, the reactive power droop term ($D_Q \cdot Q$) in (9) can be considered as an offset for the conventional real power droop control for frequency regulation. If there are any reactive power errors, the unequal offsets ($D_Q \cdot Q$) from different DG units will affect the DG output frequencies, which subsequently introduce the real power disturbances. This real power disturbance will then cause the integral control term in (10) to regulate the DG output voltage.

With this integral control, the real power from a DG will eventually be equal to PAVE, meaning that accurate real power sharing is still maintained in Stage 2 (assume that there is no micro grid real power demand variations in the compensation period of Stage 2). Further consider that the modified frequency droop control in (9) essentially enables equal sharing of the combined power ($D_P \cdot P + D_Q \cdot Q$) in Stage 2; the accurate sharing of both the combined power and real power means that the reactive power sharing will also be accurate.

Compared to the conventional droop control, it can be seen that the renovated droop control method in (9) and (10) involves additional power couplings. In order to investigate the stability and transient performances of DG units during the compensation process, small-signal analysis methods can be applied. First, the power flow of the DG unit is obtained as

$$P = (EVY \cos(\theta) - V^2Y) \cdot \cos(\phi) - EVY \sin(\phi)\sin(\theta) \tag{11}$$

$$Q = (V^2Y - EVY \cos(\theta)) \cdot \sin(\phi) - EVY \cos(\phi)\cos(\theta) \tag{12}$$

Where P_0 and Q_0 are the instantaneous output powers of the DG unit; Y and Φ are the magnitude and angle of DG feeder admittance; E and V are the voltage magnitude at the DG unit output and the installation point, respectively. θ is the power angle. Accordingly, real and reactive power variations according to DG voltage disturbances can be obtained in (13) and (14) as

$$\Delta P_0 = \left(\frac{\partial P_0}{\partial \theta}\right) \cdot \Delta\theta + \left(\frac{\partial P_0}{\partial E}\right) \cdot \Delta E$$
$$= k_{P\theta} \cdot \Delta\theta + k_{PE} \cdot \Delta E \tag{13}$$

$$\Delta Q_0 = \left(\frac{\partial Q_0}{\partial \theta}\right) \cdot \Delta\theta + \left(\frac{\partial Q_0}{\partial E}\right) \cdot \Delta E$$
$$= k_{Q\theta} \cdot \Delta\theta + k_{QE} \cdot \Delta E \tag{14}$$

Where the operator Δ means small-signal disturbance around the DG system equilibrium point; $k_{p\theta}$, k_{pE} , $k_{Q\theta}$, and k_{QE} represent the power flow sensitivity to voltage angle and magnitude regulation.

When there are some power fluctuations during the compensation, by expanding the proposed compensation method in (9) and (10), the small-signal response of the DG voltage is expressed from (15) to (18) as

From the detailed small-signal analysis, it can be concluded that the stability and damping performance of the micro grid is affected during the compensation process. This phenomenon is very similar to the situation of reactive power tracking error elimination in the grid-connected mode, where the replacement of conventional reactive power droop controller with the PI controller makes the system performance more sensitive to the control parameter variations. However, as will be demonstrated in the next section, the well-designed control parameter can maintain satisfied stability and damping performance during both steady-state operation and compensation transients.

VII.   MATLAB DESIGN PRACTICAL RESULTS

The mat lab simulated main block diagram of the system operational scheme is shown in Fig: 5 and the mat lab Simulation results are shown in Fig 7 to 14.
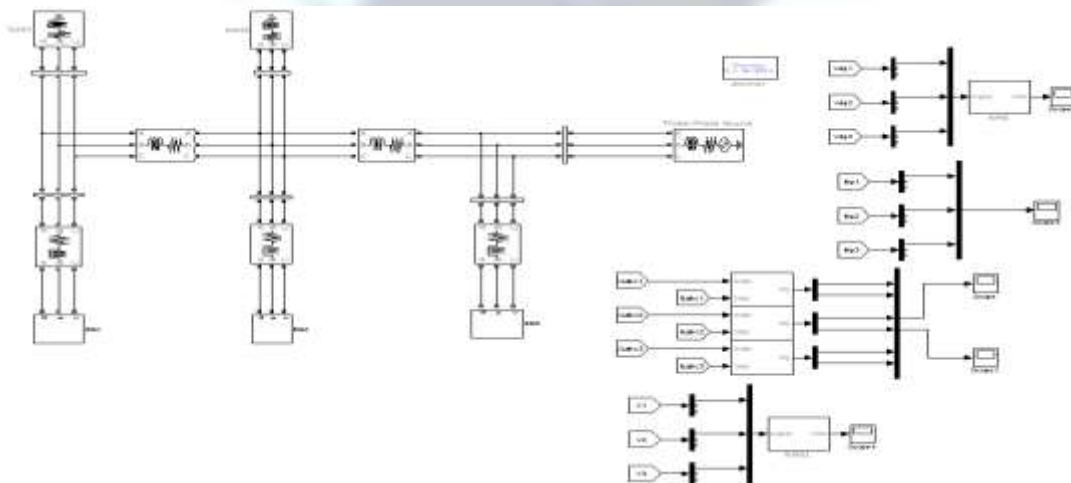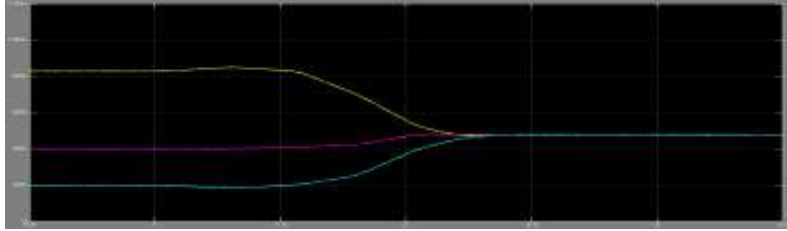

Fig 6:   system operational scheme

Fig. 7. Simulated reactive power sharing performance in a networkmicrogrid (reactive power verses time)
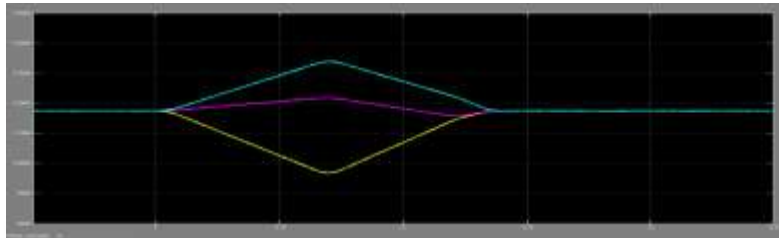

Fig. 8. Simulated real power sharing performance in a network microgrid (Real power varses time)
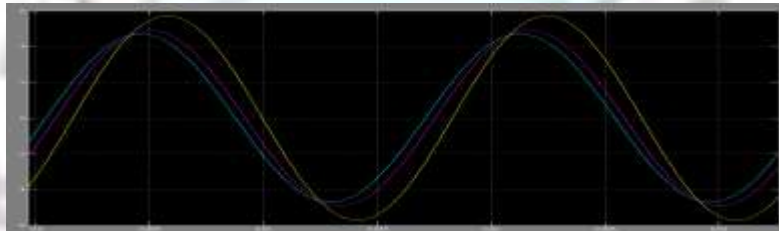

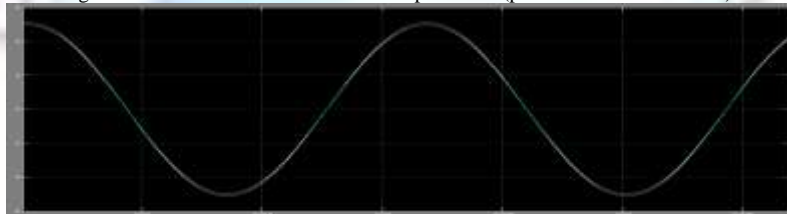Fig. 9 Simulated DG currents before compensation.(phase current verses time)

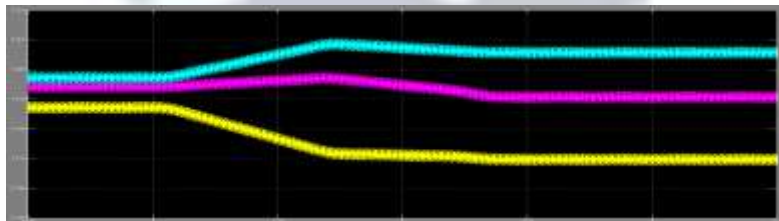Fig. 10. Simulated DG currents after compensation. .(phase current verses time)

Fig. 11. Simulated DG voltage magnitudes.(RMS voltage verses time)
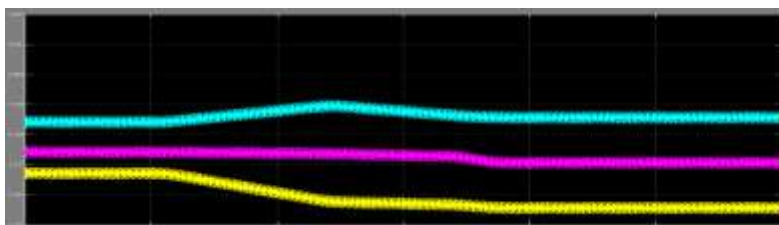

Fig. 12. Simulated installation points voltage magnitudes. .(RMS voltage verses time)
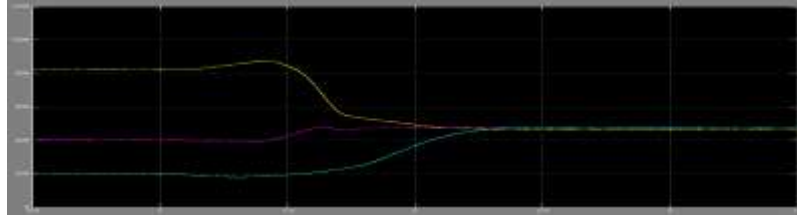
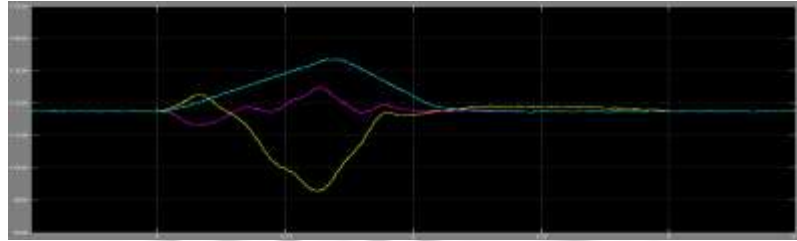Fig. 13 Simulated reactive power sharing performance in a networkmicrogrid reactive power verses time)

Fig. 14. Simulated real power sharing performance in a network microgrid (Real power varses time)

CONCLUSION

In this paper, an improved micro grid reactive power sharing strategy was proposed. The method injects a real-reactive power transient coupling term to identify the errors of reactive power sharing and then compensates the errors using a slow integral term for the DG voltage magnitude control. The compensation strategy also uses a low-bandwidth flag signal from the micro grid central controller to activate the compensation of all DG units in a synchronized manner. Therefore, accurate power sharing can be achieved while without any physical communications among DG units. In addition, the proposed method is not sensitive to micro grid configurations, which is especially suitable for a complex mesh or networked micro grid.

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