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Active power Sharing and Self Frequency Recovery in an Islanded Microgrid

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Abstract: ***Due to increase in demand of electricity as use of devices that consume electricity increases. The major problem is to meet this demand of electricity. However the electricity supply has become saturated due some factors such as social, environmental and geographical. To fulfill these problems and to meet the electricity demand there are two ways such as via micro grids and distributed generation (DGs). Microgrid works with two operating modes of operation such as grid integrated mode and islanded mode of operation. In case of grid connected operation micro grid is connected to main grid having large system inertia which helps to maintain micro grid frequency almost to nominal value. But in case of islanded mode operation micro grid must supply its own demand and maintain its frequency which is mainly done by DG units. There are various methods or control techniques for distributed generation to control active power sharing as well as frequency in islanded micro grids. Generally most commonly used method of control is droop control. In that active power – frequency is used for DG controller and frequency deviation is recovered by DG itself by self-frequency recovery control without using any secondary frequency control. But the electrical distance i.e. impendence between each DG and loads are different which may cause frequency deviation among the DG units. This difference are fed into the integrators of self –frequency recovery control which may cause the error in operation of active power sharing .So to solve this problem new technique or control method is developed which share active power more accurately , this method is compensation control method . In that active power sharing is done by considering droop coefficients of each of DG units.***

Keywords: Active power sharing, distributed generation (DG), islanded micro grid, self-frequency recovery.

I. INTRODUCTION

The Microgrid is defined as one independent grid providing continuous power to load on grid and compromising two or more micro sources with enough capacity so as to operate independently storage assets and load. The Microgrid consists of a low- or medium-voltage distribution network containing loads and distributed energy resources. A micro grid includes central controller (CC), local controllers (LCs), a static switch, loads, and various types of energy sources. A micro grid has operated in two different modes: grid-connected mode and islanded mode, depending on the connection state with the main grid. In grid-connected mode, a microgrid is connected to the main grid, which usually has large system inertia; this is reason of the microgrid frequency is almost identical to the nominal value. So, DG units in a microgrid typically inject the desired output power, and the electrical power mismatch between supply and demand is balanced by the main grid. However, in islanded mode, using DG units the microgrid must supply its own demand and maintain its frequency solely.

In active power–frequency (P–f) droop control was developed for active power sharing by emulating conventional power systems composed of synchronous generators. In oppose to conventional droop control, a tunable droop controller with two degrees of freedom was proposed, considering an adaptive transient droop function. Islanded microgrids were introduces for Single-master and multiple-master operating modes considering secondary load–frequency control for frequency recovery. A virtual impedance control scheme was used for decoupling the active and reactive power to enhance the control stability and power sharing ability. A method for determining the droop coefficient based on the generation cost of each DG unit was proposed. Control method was used rather than frequency droop in a constant frequency and the state of charge of a battery energy storage system was used to monitor changes in the system load.

Most reports have considered frequency deviation in sharing active power however, the frequency must be restored to its nominal value according to the requirements of the grid code, and secondary control is required to achieve. Problems may arise if the frequency deviation is too great. Under these circumstances, this will impose too much burden on the frequency control units. It has been suggested that constant frequency control could be used making frequency restoration unnecessary; however, active power sharing was not considered.

A DG control method that simultaneously implements accurate active power sharing and self-frequency recovery. Using this control method, DG units share the changes in load with a predetermined ratio and are able to restore their output frequency to the nominal value autonomously (hence the term "self-frequency recovery") immediately following a change in load. However, the self-frequency recovery action may lead to (small) errors in power sharing due to variations in the impedance among DG units.

II. MICROGRID CONCEPT

The main components of Microgrid are mini-hydro, solar cell, wind energy, fuel cell and energy storage system. These are integrated for electricity generation, energy storage, and a load that normally operates connected to a main grid (micro grid). Generation and loads in a Microgrid are usually interconnected at low voltage. But one issue related to Microgrid is that operator should be very alert because numbers of power system are connected to Microgrid. In the past, there was single entity to control. In Microgrid generation resources can include such as fuel cells, wind, solar, or other energy sources. These multiple different electric power supply generation resources have ability to isolate the Microgrid from a large network and will provide highly reliable electric power. Produced heat from generation sources such as microturbines could be used for local process heating or space heating, allowing flexible tradeoff between the needs for heat and electric power.

The followings are parameters of Microgrid:

- Small Microgrid covers 30 - 50 km radius;
- The small Microgrid can produce power of 5 - 10 MW to serve the customers;
- It is free from huge transmission losses and also free from dependencies on long-distance transmission lines.

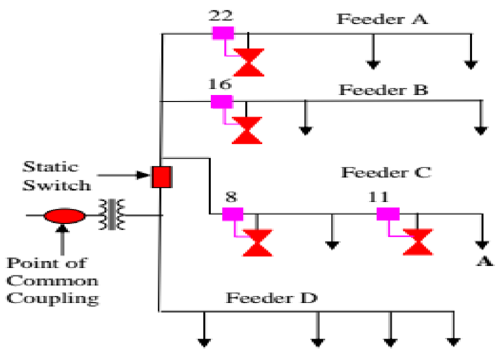

Fig. 1 Basic microgrid architecture

Basic microgrid architecture is shown in Figure 1. This consists of a group of radial feeders, which could be part of a distribution system or a building's electrical system. There is a single point of connection to the utility called point of common coupling (PCC). Some feeders, (Feeders A-C) have sensitive loads, which require local generation. The non-critical load feeders do not have any local generation. Feeders A-C can island from the grid using the static switch that can separate in less than a cycle. In this example there are four micro sources at nodes 8, 11, 16 and 22, which control the operation using only local voltages and currents measurements.

When there is a problem with the utility supply the static switch will open, isolating the sensitive loads from the power grid. Non-sensitive loads (feeder D) rides through the event. It is assumed that there is sufficient generation on feeders A, B, and C to meet the loads' on theses feeders. When the microgrid is grid-connected power from the local generation can be directed to the non-sensitive loads.

III. DISTRIBUTED GENERATION (DG)

Distributed generations are small electric power generators. DG can be installed close to the customers because of its size and clean energy technology. Installation & operation of electric power generation units connected to the local network or off-grid generation.

Depending on the type and depth of penetration of distributed energy resource (DER) units, load characteristics and power quality constraints, and market participation strategies, the required control and operational strategies of a microgrid can be significantly, and even conceptually, different than those of the conventional power systems. DER units include both distributed generation (DG) and distributed storage (DS) units with different capacities and characteristics. The electrical connection point of the microgrid to the utility system, at the low-voltage bus of the substation transformer, constitutes the microgrid point of common coupling (PCC).

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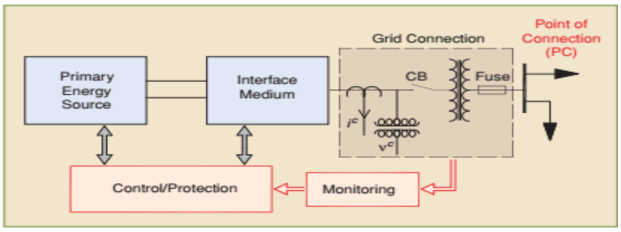

Fig. 2 Basic Distributed Generation unit

Fig.3. Shows the Configuration of the microgrid test system model. This system model consists of step down transformer, Static switch, local controller (LC), central controller (CC), loads & various types of energy sources. The microgrid system model, which is connected to a 13.8 KV, 60 Hz main grid system by a static switch. The component models used for the simulation are as follows:

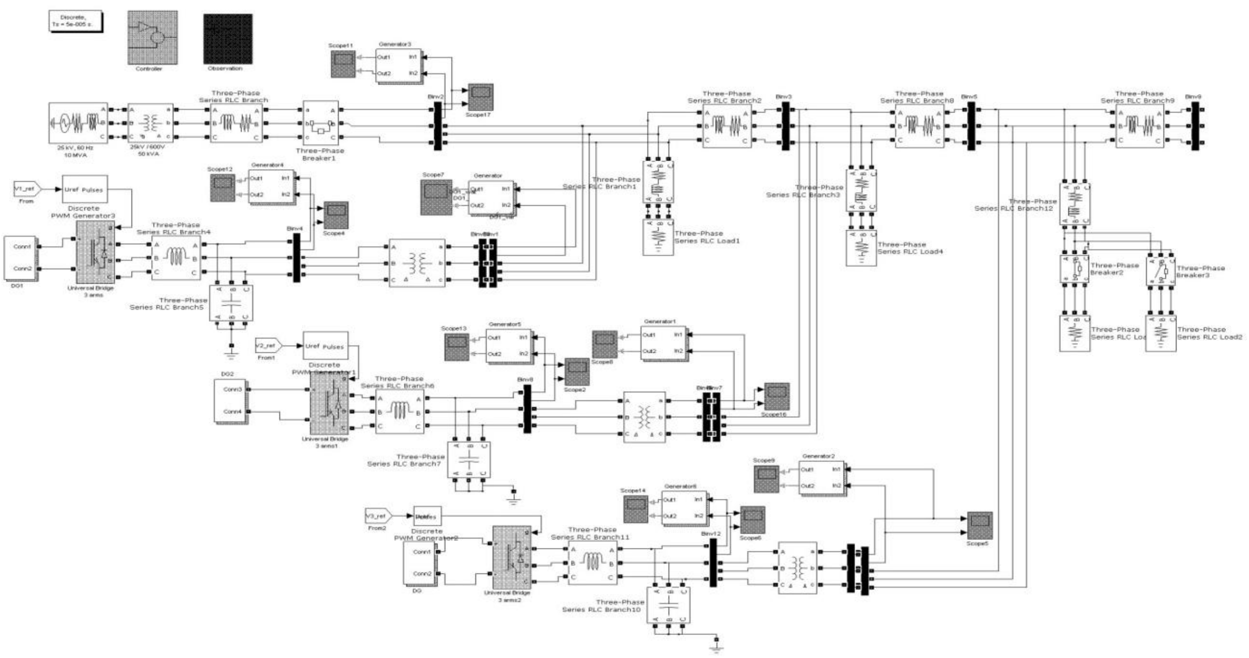

Fig. 3 Configuration of the microgrid test system model.

The main grid is represented by a 69 KV three phase voltage source with the short circuit capacity of 1000 MVA & X/R ratio of 22.2. The three phase triple- pole circuit breakers at both ends of the 69 KV line are modeled as ideal switches which can open at line current zero crossing instants. The substation 69/13.8 KV step down transformer and the load transformers are represented as linear. The rating of transformer is 158 MVA, 60 Hz. The line impendence is 0.15+j0.296. (Resistance is 0.15Ω and inductance is 0.296 H). The static switch is connected between microgrid system. The static switch (three phase breaker) is initially closed and switching of phase-A, phase-B, phase-C.

IV. MICROGRID CONFIGURATION

A. Analysis of power sharing during load variation

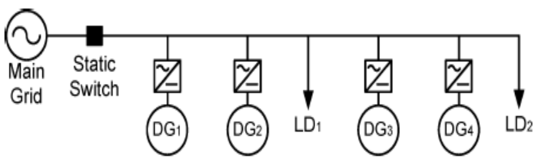

Fig. 4 Sample system for the Analysis of power sharing during load variation

In this section, power sharing among multiple DGs is investigated with respect to the load variation. When a microgrid consists of multiple DGs, power sharing among the DGs is mainly dependent on their output control mode.

Fig.4.4 shows a sample system for investigating the power-sharing principle with various combinations of control modes. We will investigate three combinations as follows.

- All of the DGs operate in the UPC mode.
- Only operates in the FFC mode, while the others operate in the UPC mode.
- And operate in the FFC mode, while the others operate in the UPC mode.

Power sharing among the DGs during the transition from grid-connected to islanded operation will be analyzed in detail in the following section.

1) *All DGs Operate in the UPC Mode*

When all DGs operate in the UPC mode, the power-sharing principle is the same as the conventional droop control of synchronous machines. During islanded operation, all DGs share the load variation, regardless of the location of the load. The power picked up by each DG is proportional to the inverse of its droop constant. The system frequency also changes according to the load variation.

2) *Only One DG Operates in the FFC Mode*

The DG1 (FFC mode) tries to compensate for the variation of all loads in the microgrid. As discussed in the previous section, the frequency will not change during either islanded operation or grid-connected operation. During grid-connected operation, DG1 changes its power output to match the load variation while the other DGs maintain constant output. If the load variation exceeds the reserve DG1 power of , the remainder of the variation will be compensated by the main grid. This means that there is an inevitable change in the feeder flow. During islanded operation, if DG1 has sufficient reserve, it can adjust its output to compensate for the load variation while the output of the other DGs remains constant. The frequency also will not change. However, if DG1 does not have sufficient reserve, it can supply up to its power limit, and the remainder of the load variation will be shared by the other DGs with an appropriate change in frequency.

3) *Two or More DGs Operating in the FFC Mode*

If there are two or more FFC-mode DGs, the power-sharing principle depends on the location of the varying loads, which is not an important factor in the previous combinations. For example, variation in LD1 can be picked up by DG1 , while variation in LD2 can be compensated by the other FFC mode unit DG3. During grid-connected operation, the variation in LD1 can be picked up by DG1. Therefore, the other DGs can maintain their outputs, and the frequency will not be changed. If has insufficient reserve, the main grid will compensate for the remainder, as in the previous scenario. If changes and has sufficient reserve to accommodate the variation, the other units can preserve their outputs unchanged. Otherwise, DG3 will supply power up to its limit and DG1 will attempt to compensate for the remaining variation. If the output of DG1also reaches its limit, the main grid will participate in the power balancing. In any case, the outputs of DG2 and DG4 the system frequency will remain unchanged. During islanded operation, the power-sharing principle for the LD1 variation is similar to that of grid-connected operation. However, when the load variation is larger than the reserve of DG1, the other three DGs will share the remainder of the load variation, since the main grid is unavailable. In this case, the system frequency will be changed. When LD2 varies, the principle is similar to that of grid-connected operation only if the sum of the reserves of DG3 and DG1 is larger than the load variation. In this case, DG3and DG1 (if needed) compensate for the LD2 variation with unchanged frequency. If the reserves are insufficient, DG2 and DG4 will participate in the power-sharing control, and the frequency will then change according to the P–*f* droop characteristics ofDG2 and DG4.

1. Central Controller (CC)

The Central Controller executes overall control of the microgrid, including protection, power sharing, mode transition, and economic scheduling via a communications system. The main objectives of the Central Controller are typically to maintain the system frequency and voltage at the specified level, as well as to operate the microgrid economically; here, however, the Central Controller was used only for compensation control, assuming that the dispatched output power for each DG unit has already been determined by the Central Controller.

The proposed compensation control method is used for a short duration to reduce the dependence of the DG control system on the communications infrastructure; this is important due to the potential for failure of the communications network, which decreases system reliability.

2. Local Controller (LC)

The main function of the LC is to control the power and/or frequency, as well as the voltage of DGs (or controllable loads) in response to a disturbance or change in load. In this study, because there are no controllable loads, the role of the LC is to control the DG units.

V. PROPOSED DG CONTROL METHOD

A. *Droop control*

Droop control is a control strategy commonly applied to generators for primary frequency control (and occasionally voltage control) to allow parallel generator operation (e.g. load sharing). For basic control of active power sharing, the conventional P–f droop control was applied.

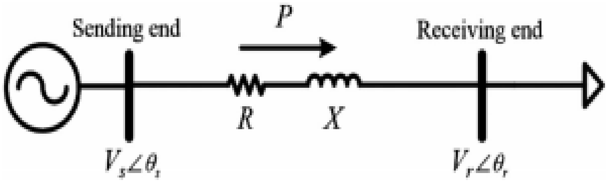

Fig. 5 Single-line diagram of a simplified islanded microgrid.

The active and reactive power transmitted across a loss less line are:

$$P = \frac{V_1 V_2}{X} \sin\delta \qquad \text{.. (1)}$$

$$Q = \frac{V_2}{X}(V_2 - V_1 \cos\delta) \qquad \text{………………………............ (2)}$$

Since the power angle is typically small, we can simplify this further by using the approximations $\sin\delta \approx \delta$ and $\cos\delta \approx 1$:

$$\delta \approx \frac{PX}{V_1 V_2}$$

$$(V_2 - V_1) \approx \frac{QX}{V_2}$$

From the above, we can see that active power has a large influence on the power angle and reactive power has a large influence on the voltage difference. Restated, by controlling active and reactive power, we can also control the power angle and voltage. We also know from the swing equation that frequency is related to the power angle, so by controlling active power, we can therefore control frequency.

This forms the basis of frequency and voltage droop control where active and reactive power are adjusted according to linear characteristics, based on the following control equations:

$$f = f_0 - k_p(P - P_0) \qquad \text{..}$$

(3)

$$V = V_0 - k_q(Q - Q_0) \qquad \text{..}$$

(4)

Where

f is the system frequency

f_0 is the base frequency

k_p is the frequency droop control setting

k_q is the voltage droop control setting

P is the active power of the unit

P_0 is the base active power of the unit

V_0 is the base voltage

Q is the reactive power of the unit

Q_0 is the base reactive power of the unit

These two equations are plotted in the characteristics below:

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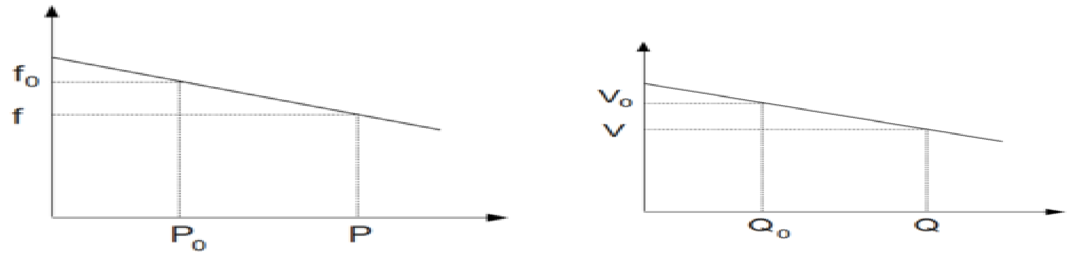


Fig. 6 Frequency and Voltage droop characteristic

B. Self-Frequency Recovery Control

The principal objective of self-frequency recovery control is to distribute the measures required to achieve frequency recovery among the DG units that participate in active power sharing using P–f droop control according to a predetermined ratio. The frequency restoration of the ith DG unit due to self-frequency recovery control can be expressed as

$$\Delta f_{i,res} = k_f \int (f_{nom} - f_i)\, dt \qquad \text{...} (5)$$

Where kf is all the same value for every DG unit, which means that the burden of frequency restoration is shared equally among the DGs.

In the transient state (and in contrast to the steady state), the instantaneous output frequencies may differ among DG units due to differences in the impedance of each DG unit, as well as the location of the change in the load. The difference in transient output frequency between DG units due to differences in impedance can be explained using a simple power system network model, as shown in Fig.5.

This figure shows P is the active power from the sending end to the receiving end; R and X are the resistance and reactance of the network impedance, respectively; Vs and Vr are the voltage magnitudes of the sending end and the receiving end, respectively; and θs and θr are the voltage angle of the sending end and the receiving end, respectively. The active power can be expressed as follows:

$$P = \frac{RVrVs \cos(\theta s - \theta r) + VrVs \sin(\theta s - \theta r) - RV\,2r}{R2 + X2} \qquad \text{...} (6)$$

In medium- or high-voltage networks, the resistance is assumed to be much smaller than the reactance (i.e., R<< X), and the voltage angle difference is assumed to be small (i.e., $\theta s - \theta r = \delta \approx 0$, such that $\sin \delta \approx \delta$ and $\cos \delta \approx 1$. The active power flow across the impedance can therefore be simplified to

$$P \approx VrVs\,(\theta s - \theta r)X \qquad \text{……………………………………...........}(7)$$

Because the voltage magnitudes at the DG units differ slightly in medium-voltage networks, from (5.3), it follows that the voltage angle difference across an impedance is proportional to the impedance for active power flow. Hence, for a change in load, the voltage angle deviations will differ among DG units if the impedances across the load and the DG units vary.

The output frequency of the ith DG unit can be expressed as a function of the output voltage angle θi as follows:

$$\int 2\pi f_i dt = \theta i. \qquad \text{……………………………………………….}(8)$$

Consequently, from (5) and (8), the difference in voltage angle deviations among DG units leads to different frequency restorations Δfres. These differences lead to unequal sharing of the output active power among the DG units, and as a result, the ratio of active power sharing among DG units no longer varies in proportion to the P–f droop coefficients of the DG units.

C. Compensation Control

To offset the errors in active power sharing caused by self-frequency recovery control, a compensation control scheme was developed, as shown in Fig. 2. The main purpose of the compensation control is not to reduce transient frequency difference but to reduce the active power sharing error. Even if the transient frequency difference is small, the active power difference may be large since it depends on time of integration of the frequency difference and magnitude of line impedance. The output active power deviation of the ith DG is given by

$$\Delta P_{i,dis} = P_i - P_{i,dis}. \qquad \text{………………………………………} (9)$$

The aggregate of all DG units can be found by summing the contributions from each unit; i.e.,

$$\Delta P_{dis,tot} = \sum_{i=1}^{N} \Delta P_{i,dis} \qquad \text{………………………..……………} (10)$$

where N is the number of DG units participating in active power sharing. Because the objective of compensation control is to share the active power according to the ratio of the droop coefficients (i.e., m1 ,...,mN), ΔPdis,tot should be distributed among the DG units considering the droop coefficients. Hence, the parameter ci (see Fig. 2) was determined as follows:

$$c_i = \frac{1/m_i}{\sum_{j=1}^{N}\left(\frac{1}{m_j}\right)} \qquad \text{………………………………………………………} (11)$$

By multiplying ci by ΔPdis,tot, we obtain the contribution of the ith DG unit to frequency recovery. Consequently, the compensation recovery control can be expressed as

$$\Delta f_{i,com} = k_c \int (c_i \Delta P_{dis,tot} - \Delta P_{i,dis})dt \quad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

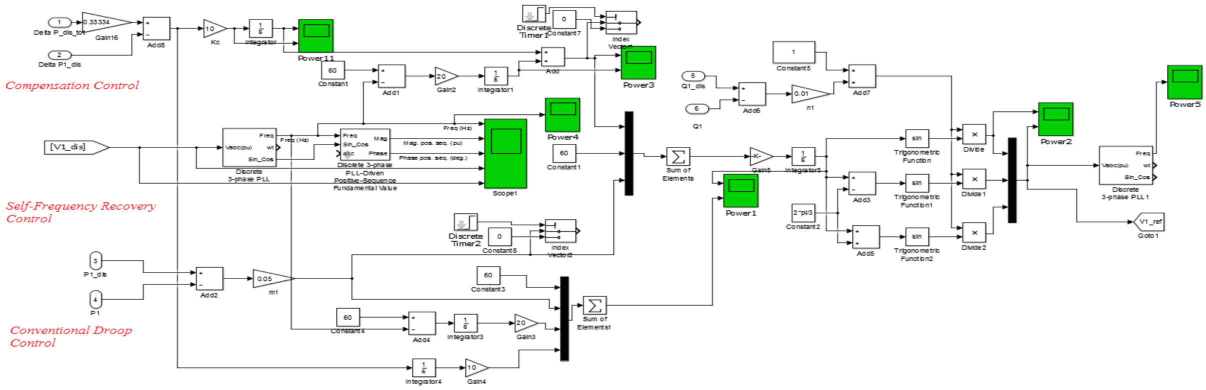


Fig. 7 Proposed control scheme for distributed generation DG units.

VI. CASE STUDY

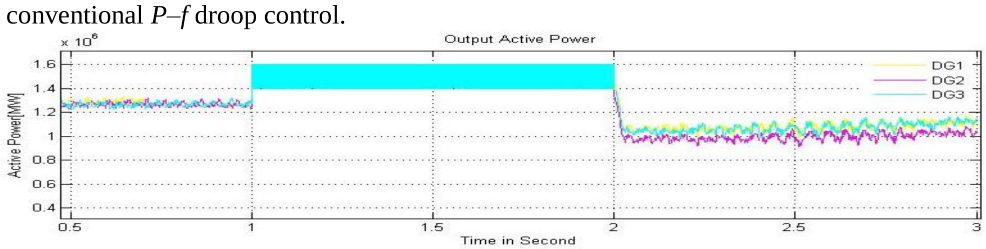
To verify the effectiveness of the proposed control method for DG units, case studies were implemented.

TABLE I

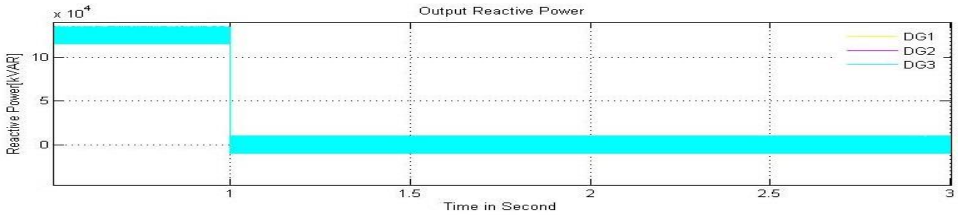
Lists the simulation parameters for all scenarios.

Microgrid components Static switch	Setting		
	Closed → Opened at 1 s	Static switch	Closed → Opened at 1 s
DG units	*P*1, dis *P*2, dis *P*3, dis *Q*1, dis *Q*2, dis *Q*3, dis	DG units	*P*1, dis *P*2, dis *P*3, dis *Q*1, dis *Q*2, dis *Q*3, dis
Loads	L1 L2 L3	Loads	L1 L2 L3
Integral gains	*kf* *kc*	Integral gains	*kf* *kc*
Microgrid components	Setting	Microgrid components	Setting
Static switch	Closed → Opened at 1 s	Static switch	Closed → Opened at 1 s

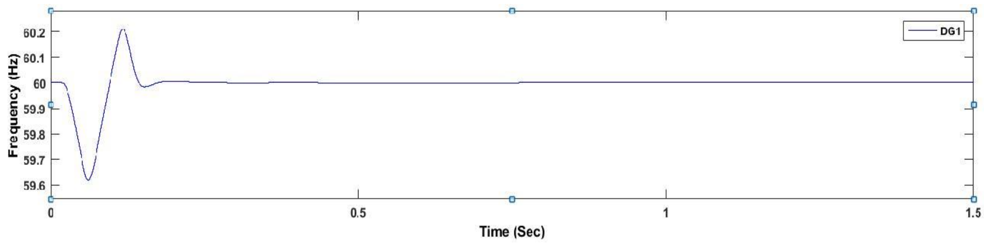
To verify the effectiveness of the proposed control method for DG units, case studies were implemented. Table I lists the simulation parameters for all scenarios. The control performance of the microgrid was investigated for mode transition (i.e., when the static switch was opened at 1 s) and for the load change (i.e. when L3 was decreased at 2 s). Two scenarios were investigated for different ratios of active power sharing, and for each the proposed control method was compared with conventional *P*–*f* droop control.



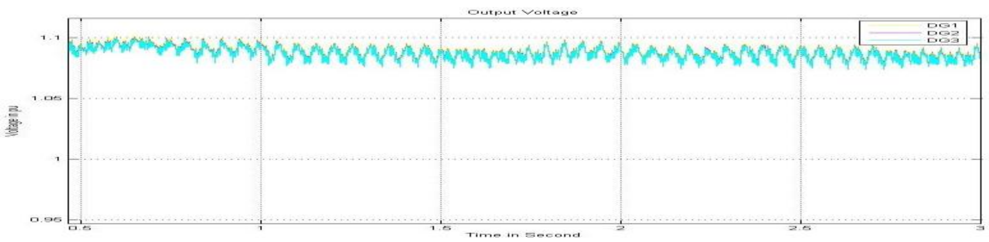
(a)



(b)



(c)



(d)

Fig. 8 Simulation results for Case I by adopting the conventional P–f droop control method.(a)Output active power (P) .(b)Output reactive power (Q). (c) Output frequency (f). (d)Output voltage (V).

CONCULSION

Simulation model of islanded microgrid has been developed to implement accurate active power sharing and self-frequency recovery. Active power – frequency (P-f) droop control has been developed for active power sharing by considering power system including synchronous generators. Using this control methods, DG units share the changes in load with a predetermined ratio and are able to restore their output frequency to the nominal value autonomously and immediately follows a change in load. This change in load, which may cause them to reach their output more quickly and hence generation cost increases.Simulation results shows that the frequency was restored almost immediately following frequency deviation using self-frequency control and also using compensation and droop control active power was shared accurately and effectiveness of the proposed method was verified.

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