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Optimal Power Sharing for Microgrid with Multiple Distributed Generators

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Abstract

This paper describes the active power sharing of multiple distributed generators (DGs) in a microgrid. The operating modes of a microgrid are 1) a grid-connected mode and 2) an autonomous mode. During islanded operation, one DG unit should share its output power with other DG units in exact accordance with the load. Unit output power control (UPC) is introduced to control the active power of DGs. The viability of the proposed power control mode is simulated by MATLAB/SIMULINK.

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1. Introduction

Nowadays interest in distributed generation systems (DGs) is rapidly increasing, particularly onsite generation.

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This concern is due to unfeasibility of many larger power plants economically in many regions because of increasing plant and fuel costs, and stricter environmental conventions. In addition, modern technological improvement in small size generators, power electronics, and energy storage devices has provided a new chance for distributed energy resources and decentralized approach to power delivery at the distribution side due to the utilization of green energies [1]-[7]. Accordingly distributed generators (DGs) have been installed in power systems and tested for better configurations and control schemes.

Microgrids can realize a coordinated approach to facilitate the penetration of DG into the utility network [8]. The CERTS defines the microgrid as a small-scale, low-voltage system consisting of a combination of generators, loads, and energy storage elements [9]–[11]. A microgrid is essentially an active distribution network that can be exploited in two operating conditions. In a grid-connected mode, the microgrid is connected to the distribution grid at a single point connection, the point of common coupling (PCC). In islanded mode, the microgrid is disconnected from the main grid. A key advantage is that the microgrid appears as a single controllable unit to the power network enabling it to deliver the cost benefits of large units. Furthermore, microgrids can enhance local reliability, reduce feeder losses, provide reactive power and local voltage support, remove transmission and distribution bottlenecks, increase efficiency through the use of waste heat and provide uninterruptible power supply functions [2], [12]. The increased amount of small-scale power sources are not directly online requires the development of converter-based microgrids [13]. Hence, the microgrid control focuses on the control of these converters.

There are many technical issues related to microgrid operation, including interconnection schemes between microgrids and the main grid [14], voltage-control schemes within a microgrid [15], [16], [17], and frequency control during islanded operation [14]. Among these, this paper highlights the active power and frequency-control strategies for sound operation of a microgrid with multiple DGs.

This paper focuses on proper active power sharing of each DG. Many innovative control techniques have been used for stability of the system as well as for proper load sharing. The most commonly used method is the application of droop characteristics for wireless load sharing. Local signals are used as feedback signals to control the parallel converters, since in a real system the distance between the converters may make an inter-communication impractical. Unit output power control (UPC) is proposed [18] to control and share the active power among multiple DGs. During UPC, the output power of the DG is constantly controlled according to the power reference.

The organization of this paper is divided into five sections. Section 1 forms an introduction. Section 2 describes a complete description of the power-control methods. Section 3 presents a simulation model. Section 4 shows a simulation results. Section 5 contains concluding remarks.

### Nomenclature

| Symbol | Description                      |
|--------|----------------------------------|
| V      | voltage (volt)                   |
| F      | system frequency (Hertz)         |
| I      | distributed generator (DG) output current (Amp) |
| P      | distributed generator (DG) active power output (MW) |
| FL     | power flow in the feeder (MW)    |

### 2. Description of Power – Control Modes

#### 2.1. Unit Output Power Control (UPC) Mode

The objective of this mode is to control the power injected by a DG unit at a desired value \( P_{ref} \) [18]. The voltage \( V \) at the interconnection point and the DG output current \( I \) are measured to accomplish this mode as shown in Fig 1. The power injection \( P_{DG} \) is calculated from the measured voltage and current and fed back to the generator controller (GC).

When the microgrid is connected to the main grid, the DG is able to maintain a constant output power...
regardless of the load variation because the power mismatch can be compensated by the grid. However, during islanded operation, DGs must follow the load demand exactly. In numerous studies, a power versus frequency ($P-f$) droop control has been adopted for DG power-sharing methods [15], [19]–[23]. This control uses the frequency of the microgrid as a common signal among the DGs to balance the active power generation of the system [15]. $P-f$ droop-based power controllers have proven to be robust and adaptive to variation in the power system operational conditions, such as frequency- and/or voltage-dependent loads and system losses [15], [23]. The relationship between the frequency ($f$) and the power output of a DG ($P$) can be expressed as

$$f' = f^0 - K^U \left( P' - P^0 \right)$$

where $K^U$ is the UPC droop constant, $f'$ and $P'$ are the frequency and DG output power at a new operating point, and $f^0$ and $P^0$ are the nominal values. When the load increases during islanded operation, the DG output power also increases, and the frequency decreases according to the droop characteristic, as given by Eq. (1).

Fig. 1. Unit Output Power Control (UPC)

2.2. DG Active Power Controller

Fig 2 shows the real power-control block of a DG, where the inputs are local measurements of frequency ($f$) and power output ($P$), or feeder flow ($FL$), and the set points are provided by the central controller.

The output is the axis current reference signal for the current controller or the angle of the desired voltage. The control block contains two additional functions: 1) frequency droop control and 2) output limit control.

During grid-connected operation, $P$ and $FL$ can be maintained constant, since the microgrid frequency is nearly the same as the nominal value. If the microgrid is islanded, the droop control function dynamically balances the power mismatch, and the system will reach a steady state with new values of $P$ and $f$ according to Eq. (1). In [15] and [24], the methods of restoring the frequency to the nominal value are proposed, but the secondary load-frequency control function is not considered in this study.

The output limit control function restricts the steady-state output power of the DGs within the limits. Since the energy sources of DGs have a finite capacity for storing or generating energy, the output limit should be enforced [18], [22], [24]. The function will be activated only when the power output violates the limits and effectively enforces the output limits [18].

3. Simulation Model

3.1. Test System and Simulation Scenario

Fig 3 shows a single-line diagram of the microgrid test system model, which is connected to a 13.8-kV, 50-Hz main grid system by a static switch. The system parameters are similar to [15] and [25], with slight modifications in the line connections and parameters. The test model contains three DGs with voltage ratings of 4.14 kV, and maximum power generation limits (arbitrarily chosen to be 2.5, 3.0, and 2.0 MW respectively) are included in the simulations. We set the UPC droop constants of the DGs to be equal to 1.2, 1.0, and 1.5 Hz/MW respectively,
Fig. 2. Block diagram of a DG active power control

which means that 0.05-p.u. frequency deviation causes a 1.0-p.u. change in the power output of each DG [26]. Three lumped balanced loads represent the sensitive loads, whose demands are arbitrarily chosen. The test system with DG controllers is modelled by MATLAB/SIMULINK.

The simulation sequence is as follows: Load$_1$ is decreased from 3.0 MW and 0.9 MVAr to 2.4 MW and 0.6 MVAr at 1.2 s to inspect the power sharing in terms of load variation during grid-connected operation. At 2.0 s, the static switch is opened so that the microgrid is islanded from the grid. During islanded operation Load$_3$ is increased from 1.8 MW and 0.6 MVAr to 2.4 MW and 1.2 MVAr at 3.0 s to demonstrate the effect of load variation.

4. Simulation Results

Fig 4 shows the active power outputs, feeder flows and system frequency of all DGs. Since all DGs are operated in the UPC mode, the output of each DG is maintained constantly at its initial power references as 2.0, 2.9, and 1.5 MW respectively until 2.0s. Approximately 2.5-MW power is imported from the main grid to match the loads and losses in the microgrid. Fig. 6 shows the DGs power outputs, feeder flows and the system frequency.

Fig. 3. Single-line diagram of the microgrid system
At 1.2 s, the main grid compensated for the variation of Load1, so that the power flow from the main grid (FL1) is reduced to 2.49 MW.

After islanding at 2 s, all DGs increased their output to match the load demands. In the new steady state, the outputs of the DGs are approximately 2.28, 2.95 and 1.80 MW respectively, and the system frequency is dropped to 48.7 Hz.

At 3.0 s, the outputs of the DGs are increased to the new steady-state values of 2.30, 2.99, and 2.00 MW to compensate for the variation of Load3. Since the output of DG2 reached its maximum limit, the output changes of DG1 and DG3 are greater than they would have been if no DG output limit has been violated. The system frequency is decreased to 48.6 Hz.

![Active Power Output of DGs](image1)
![Power Flow in the Feeders (MW)](image2)
![System Frequency](image3)

Fig. 4. Simulation results of UPC mode (a) active power output of each DG; (b) power flow in the feeders; and (c) system frequency.

5. Conclusion

This paper has presented the active power-sharing principles of multiple DGs by considering its control modes. During islanded mode of operation, the load demand has been matched by DGs alone. In the application of UPC mode, the islanded mode operation is more advantageous than the grid connected mode. The simulation results have indicated that all DGs share the proper amount of power especially in islanded mode.
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