Optimal power sharing of multiple distributed generators engineering essay

Engineering

Chitra. N1 Logeshwari. V2 Senthil kumar. A3 Prof. Josiah Munda41, 2 Assistant Professors, Department of Electrical & Electronics Engineering, 3 Postdoctoral researcher, 4Associate Dean, 1, 2S. K. P Engineering College, 3, 4Faculty of Engineering and the Built Environment, Tshwane University of Technology, 1, 2Thiruvannamalai, Tamil Nadu, India, 3, 4Pretoria, South Africa, sivakumar. poruran@gmail. comAbstract. This paper describes the optimal power sharing in multiple distributed generators (DGs) in a microgrid, operating in 1) a grid-connected mode and 2) an islanded mode. For controlling the active power of DGs unit output power control (UPC) and feeder flow control (FFC) are introduced. When the microgrid is in autonomous mode, the FFC control mode is limited by the existing droop controller. Hence, we propose an algorithm to modify the droop constant of the FFC-mode DGs to ensure optimal power sharing among DGs. The feasibility of the proposed power control mode is simulated by using MATLAB/Simulink. Keywords: Active power control, distributed generator, droop characteristics, microgrid. 1 IntroductionRecent interest in distributed generation systems (DGS) is rapidly increasing, particularly onsite generation. This interest is due to the facts that larger power plants became economically unworkable in many regions due to increasing fuel costs and environmental regulations. In addition, a new opportunity have provided by the recent technological improvements in small generators, power electronics, and energy storage devices to distributed energy resources at the distribution level, and especially, the incentive laws to utilize renewable energies have also encouraged a more decentralized approach to the delivery of power[1]-[3]. 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 [4]. The CERTS defines the microgrid as a small-scale, low-voltage system consisting of a combination of generators, loads, and energy storage elements [5]–[7]. Essentially, a microgrid is an active distribution network that can be exploited in two operating conditions. In grid-connected mode, the microgrid is connected to the distribution grid at a single point of 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 to the power network as a single controllable unit, 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 [8], [9]. The increased amount of small-scale power sources that are not directly online requires the development of converter-based microgrids [10]. 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 [11]; voltage-control schemes within a microgrid [12], [13], [14]; and frequency control during islanded operation [12]. Among these, this paper focuses on 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 common methodology is the use of droop characteristics for wireless load sharing. Local signals are used as feedback to control the parallel converters, since in a real system, the distance between the converters may make an inter-communication impractical. To control the active power among multiple DGs, unit output power control (UPC) and feeder flow control (FFC) are proposed [15]. During UPC, the output power of the DG is constantly controlled according to the power reference, whereas during FFC, the power flow in the feeder is manipulated according to the flow reference. The remainder of this paper is divided into five sections. Section 2, presents a detailed description of the power-control modes. In Section 3, presents a simulation model. In Section 4, presents a simulation results. In Section 5, contains concluding remarks. 2 Description of the Power – Control Modes2. 1 Unit Output Power Control (UPC) ModeThe objective of this mode is to control the power injected by a DG unit at a desired value (Pref) [15]. To accomplish this, the voltage (V) at the interconnection point and the DG output current (I) are measured as shown in Fig. 1. The power injection (PDG) is calculated from the measured voltage and current and fed back to the generator controller (GC). Fig. . Unit output power control (UPC). 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 [12], [16]–[20]. This control uses the frequency of the microgrid as a common signal among the DGs to balance the active power generation of the system [12]. 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 [12], [20]. The relationship between the frequency (f) and the power output of a DG (P) can be expressed as

$$()$$

where is the UPC droop constant, and are the frequency and DG output power at a new operating point, and and 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 (1). 2. 2 Feeder Flow Control (FFC) ModeIn this mode, the DG output power is controlled in order that the active power flow remains constant (FLref) in the feeder where the unit is installed. When the load increases during grid connected operation, the DGs increase their output to maintain a constant feeder flow. The power supplied by the grid will then remain unchanged regardless of the load variation within the microgrid. Hence, the microgrid looks like a controllable load from the utility point of view [15]. The voltage (V) at the interconnection point and the line current (IFeeder) must be measured to calculate the feeder power flow (FLLine), as shown in Fig. 2. Fig. 2. Feeder Flow control (FFC). During islanded operation, the flow (FL) versus frequency (f) droop characteristic can be used instead of the P– f droop control [2]. The relationship between flow and frequency can be written as

(2)

where is the FFC droop constant. Since the sum of the FLLine and the DG output is equal to the load (represented by (3)), the value of is chosen to have the same magnitude and opposite sign of (i. e., =) in the existing droop controller [15], [16]

$+ =$

(3)

2. 3 DG Active Power ControllersFig. 3 and Fig. 4 show the active power-control block of a DG to enforce limits with unit power control and feeder flow control respectively, 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. Fig. 3. Control-Diagram to Enforce Limits with Unit output power control (UPC). Fig. 4. Control-Diagram to Enforce Limits with Feeder Flow control (FFC). 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 (1) and (2). In [12] and [21], the methods of restoring the frequency to the nominal value are proposed, but the secondary load-frequency control function is not considered in this stud The output limit control function restricts the steady-state output power of the DGs to within the limits. Since the energy sources

of DGs have a finite capacity for storing or generating energy, the output limit should be enforced [15], [19], [21]. The function will be activated only when the power output violates the limits, and effectively enforces the output limits [15]. 3 Simulation Model3. 1 Test System and Simulation ScenarioFig. 5 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 [12] and [22], 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. 0MW, 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, which means that 0. 05-p. u. frequency deviation causes a 1. 0-p. u. change in the power output of each DG [23]. Three lumped balanced loads represent the sensitive loads, whose demands are arbitrarily chosen. The test system modeled with DG controllers is modeled by using the MATLAB/Simulink. The simulation sequence is as follows. Load1 is decreased from 3. 0 MW and 0. 9 MVAr to 2. 4 MW and 0. 6 MVAr at 1. 2 s to investigate 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. To demonstrate the effect of load variation during islanded operation is increased from 1. 8 MW and 0. 6 MVAr to 2. 4 MW and 1. 2 MVAr at 3. 0 s. In order to demonstrate power sharing of DGs according to the control mode of the DGs, and to verify the performance of the proposed method for determining droop constants, we simulated three cases as follows. Case 1)

All DGs operate in the UPC mode. Case 2) The control modes of DG1 through DG3 are FFC, UPC, and FFC, respectively, and the values for DG1and DG3 are set equal to -1. 2and -1. 5 Hz/MW, respectively. Case 3) The control modes of DGs are the same as Case 2, but the values aredetermined by the proposed method. 4 Simulation Results4. 1 Results for Case 1)In this simulation, the initial power references of the DGs are set at 2. 0, 2. 9, and 1. 5 MW, respectively, and 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. Since all DGs are operated in the UPC mode, the output of each DG is maintained constant at its initial reference value until 2. 0 s. 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. This demonstrates the drawback of the UPC-only configuration under load variation during grid-connected operation. 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. 4. 2 Results for Case 2)Fig. 7 shows the simulation results for Case 2. The values of FLref for DG1and DG3 and Pref for DG2 are set at 1. 4, 0. 9, and 2. 3 MW, respectively. Therefore, the DGs initially generated approximately 2.

0, 2. 3, and 1. 5 MW, respectively, and the imported power from the grid is 1. 4 MW. In this simulation, the feeder flows remained constant before islanding, despite the variation of Load1. Instead, the output of DG1 (the FFC-mode DG installed just upstream of Load1) is decreased to 1. 9 MW after 1. 2 s. After islanding, PDG2 and PDG3 reached their maximum limit, whereas PDG1 is decreased slightly to 1. 8 MW. This means that more power sharing is imposed on the downstream DGs. The system frequency is dropped to 49. 5 Hz. At 3. 0 s, since the output of DG3 has already reached its limit, the variation of Load3 is compensated by the other FFC-mode unit DG1. 4. 3 Results for Case 3)In this case, the initial power and flow references of the DGs are the same as in Case 2). However, the values of DG1 and DG3 are calculated by the proposed method. is still -1. 5 Hz/MW, since the DG3 is installed at the end of the feeder, but is changed to -0. 4 Hz/MW by using (24) in [24]. As Fig. 8 indicates, the power outputs of the DGs and the feeder flows are the same as Case 2) while the microgrid is connected to the main grid. DG2 and DG3 are increased their outputs after 2. 0 s to the amount of power need to compensate for the loss of the mains. The outputs of the DGs are changed to approximately 1. 6, 2. 2, and 1. 8 MW, respectively. The new steady-state system frequency is 49. 60 Hz. Fig. 4. Single-line diagram of the microgrid test system.(a)(b)(c)Fig. 5. Simulation results for Case 1 – all DGs operate in UPC mode. (a) Active power output of each DG. (b) Power flow in the feeders and (c) system frequency.(a)(b)(c)Fig. 6. Simulation results for Case 2: FFC-UPC-FFC configuration with = -. (a) Active power output of each DG. (b) Power flow in the feeders. (c) System frequency.(a)(b)These results prove that DGs can share power properly via the proposed method, even when there are multiple series-configured FFC-mode DGs. At 3. 0 s, attempted to compensate for the variation of Load3 in order to hold FL3 constant. However, because the amount of variation exceeded the reserve of DG3, its output has reached the maximum limit. To compensate for the remainder of the variation, the other FFC-mode unit DG1 is increased its output to 1. 8MW, while the output of the UPC- mode unit DG2 is changed slightly and the system frequency is at 49. 20 Hz which is less than the case 2).(c)Fig. 7. Simulation results for Case 3: FFC-UPC-FFC configuration with values calculated by the proposed method. (a) Active power output of each DG. (b) Power flow in the feeders. (c) System frequency. 5 ConclusionThe power-sharing principles of multiple DGs are examined according to their control modes and configurations. The principle of the FFC mode is not as straightforward as that of the UPC mode, but it is advantageous for the main grid and the microgrids. FFC-mode DGs could automatically match the variation of downstream loads within their capacity limits during islanded and grid-connected operation. However, FFC-mode DGs connected in series could not share power properly with the existing droop controller during transition from grid-connected to islanded operation. To overcome the limitations of the existing FFC droop controller, we proposed an innovative method for determining the FFC droop constants. Using this method, we can now effectively design droop controllers for series-connected FFC units or FFC-and-UPC-mixed microgrids, which provide appropriate and stable power-sharing schemes. The simulation results indicated that all DGs shared the proper amount of power via the proposed method, and the system frequency is also maintained within acceptable limits.