The Controller Parameters Optimization for Droop Controlled Distributed Generators in Microgrid

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Keywords: Distributed generators, Droop control, Particle swarm optimization, Voltage-sourced inverter, Microgrid.

Abstract. Microgrids are attracting a great deal of attention as integrated renewable energy resource can benefit both the utility and the customers. The droop-control method is popular for the microgrid stable operation as it avoids circulating currents among the converters without using any critical communication between them. The distributed generators should have high speed to follow the reference given by the droop controller, otherwise the system will fluctuate and even black out. Renewable energy powered Distributed Generators (DGs) are mostly inverter-interfaced and controlled by PI controllers. The Particle Swarm Optimization (PSO) was used to optimize the PI parameters with the objective of high tracking speed of the Inverter-interfaced DGs. Simulation studies in Matlab demonstrate the effectiveness of the optimized control parameters.

Introduction

In order to supply the increasing demand for electricity, the DGs encompassing a wide range of prime mover technologies (such as micro-turbines, photovoltaic, fuel cells, wind-turbines and storage devices) is emerging [1]. By using DGs, the distance between generation and loads is reduced, which can reduce losses, postpone investments in new transmission and large scale generation systems [2]. To the utility, the microgrids can operate as a single dispatchable unit to provide power or ancillary services; to the customers, they can improve power quality by supporting local voltage and frequency [3, 4].

The droop control methods are presented as wireless control techniques that avoid circulating currents among the converters without using any critical communication between them. A lot of publications suggest that droop control methods are the best option for controlling DGs in microgrids [3]. Furthermore, the droop-control method is often applied in many experimental microgrids because of the advantages it offers, such as flexibility, absence of critical communications [1, 5].

In microgrids, renewable energy powered Distributed Generators (DGs) are mostly inverter-interfaced and controlled by PI controllers. In order to follow the reference given by the droop controller, the distributed generators should have high speed, otherwise the system will fluctuate and even black out. Nowadays, many researchers have focused on improving the inverter controller and many improved methods have been proposed. The small signal model based parameters optimization was discussed in [6-8], but the model parameters are determined by the running status of the system, which is time-varying and difficult to acquire accurately. The transformer function model of the system and controller was proposed in papers [9-11]. They optimize the controller based on root-locus or bode-diagram. It also requires accurate system parameters, which is impractical.

For the nonlinear microgrid, the linearization of the complete system for controller optimization may result in fluctuation and even black out. In this paper, a power-electronic-switch-level simulation model using Matlab/Simulink is builded and the controller parameters are optimized by PSO algorithm. The integrated time-weighted squared error (ITAE) for the voltage controller is taken as the PSO’s objective function. Simulation studies in Matlab demonstrate the effectiveness of the optimized control parameters.
The rest of this paper is organized as follows. In section 2, the droop controlled distributed generators in microgrid is presented. Section 3 proposes optimization controller parameters based on particle swarm optimization. Section 4 presents the simulation and results. Finally, Section 5 concludes this paper.

**Droop Controlled Distributed Generators in Microgrid**

The droop control methods are presented as wireless control techniques that avoid circulating currents among the converters without using any critical communication between them. Fig. 1 shows the control block diagram of inverter-interfaced DGs in the $d$-$q$ rotating reference frame. Details of the $abc$/$dq$ transformation and its sign convention is shown as

$$C_{abc/dq} = \frac{2}{3} \begin{bmatrix} \cos(wt) & \cos(wt - 2\pi/3) & \cos(wt + 2\pi/3) \\ -\sin(wt) & -\sin(wt - 2\pi/3) & -\sin(wt + 2\pi/3) \end{bmatrix}. \quad (1)$$

The transformation $dq/abc$ is shown as

$$C_{dq/abc} = \begin{bmatrix} \cos(wt) & -\sin(wt) \\ \cos(wt - 2\pi/3) & -\sin(wt - 2\pi/3) \\ \cos(wt + 2\pi/3) & -\sin(wt + 2\pi/3) \end{bmatrix}. \quad (2)$$

As shown in Fig. 1, the DG controllers involve three type controllers: the droop controllers, the voltage controllers and the current controllers. The droop controller calculates the output voltage reference, whereas the voltage controllers and current controllers control the inverters’ voltage and current, respectively. Voltage controllers and current controllers are all PI controllers.

From Fig. 1, we can derive the $P$ vs. $f$ droop curve as shown

$$w = w_o + mp(P_{loadref} - P_{inv}). \quad (3)$$

The $Q$ vs $U$ droop curve is shown as

$$u = u_o + mq(Q_{loadref} - Q_{inv}). \quad (4)$$

In Equation (3) and Equation (4), $mp$ and $mq$ are active power and reactive power droop parameters, respectively. $u_o$, $w_o$, $P_{inv}$, and $Q_{inv}$ are the bus Root-Mean-Square (RMS) voltage reference, the system frequency reference, and the locally measured active and reactive powers, respectively, and the subscript $o$ represents the preset values of normal operating points.
Optimization Controller Parameters Based on Particle Swarm Optimization

Particle Swarm Optimization. The PSO [12] is one kind of Swarm Intelligence methods and was used for NP-Hard problems commonly, for it is very effective in solving this kind of optimization tasks. As one kind of swarm optimization algorithm, the PSO has fast convergence speed [13], and its parameters are easy to adjust [14]. So the PSO algorithm is chosen to optimize the controller parameters.

In the PSO algorithm, a particle represents a candidate solution to the problem. Each particle adjusts its flight over the search space based on its own and its best neighbor’s flight experiences. The particle’s velocity is updated as [15].

\[ v_{i,j}^{k+1} = \omega v_{i,j}^k + c_1 r_1 (p_{best_{i,j}}^k - x_{i,j}^k) + c_2 r_2 (g_{best_{j}}^k - x_{i,j}^k) , \quad i = 1,2, ..., m; \quad j = 1,2, ..., N. \]  

The particle’s position is updated as

\[ x_{i,j}^{k+1} = x_{i,j}^k + v_{i,j}^{k+1} , \quad i = 1,2, ..., m; \quad j = 1,2, ..., N. \]  

Where \( x_{i,j}^k \) represents the \( j \)th dimension for the \( i \)th particle at the \( k \)th iteration; \( v_{i,j}^{k+1} \) represents the velocity rate; \( m \) is the population size; \( N \) is the dimension of the search space; \( k \) indicates the iteration number; \( c_1 \) and \( c_2 \) are the acceleration coefficients; \( r_1 \) and \( r_2 \) are random numbers uniformly distributed in \([0,1]\); \( p_{best_{i,j}}^k \) is the \( j \)th dimension of the best position that the \( i \)th particle has achieved at the \( k \)th iteration; \( g_{best_{j}}^k \) is the \( j \)th dimension of the best position for all the particles at the \( k \)th iteration; \( \omega \) is the inertia weight.

Controller Parameters Optimization. Let \( X_i = [x_{i,1}, x_{i,2}, x_{i,3}, x_{i,4}] = [K_{pu}, K_{iO}, K_{pt}, K_{iI}] \) be a trial vector designating the \( i \)th individual of the population to be evolved, where \( X_i \) is the voltage and current PI controllers’ parameters.

The integrated time-weighted squared error (ITAE) for the voltage controller is taken as the PSO’s objective function. Then, the cost function can be designed as

\[ J = \sum_{t=t_0}^{t_1} [(t - t_0) \cdot W \cdot |E(t)|]. \]  

Where \( t \) is the sampled simulation time; \( t_0 \) and \( t_1 \) are the starting and ending times for the simulation; \( W \) is a weighting matrix; \( E(t) \) is the absolute error matrix defined as

\[ E(t) = [u_{ad}(t) - u_{ad}(t), u_{aq}(t) - u_{aq}(t)]. \]  

The PSO algorithm in this paper can be described as follows:

1) Start and Initialize parameters (particle position, particle velocity, particle quantity, maximum iterations, position limits, inertia weight, acceleration factor and so on).
2) Calculate the value of fitness function of each particle through Equation (7).
3) Update the individual best position and the global best position.
4) Generate new generation by update each particle’s velocity and position according to Equation (5) and (6).
5) If satisfy the termination criteria go to 6, or go to 2.
6) End PSO and export the optimized PI parameters.

Simulation and results

The microgrid model for case study is shown in Fig. 2, and it has been implemented using Matlab/Simulink. The microgrid parameters are shown in Table 1.
The simulation sequence is as follows.

1) 0-0.4 s. The microgrid is black-started in island mode. Load1 and Load2 are set to 20kW and 10 kVar each, so that the total load is 40kW and 20 kVar. The $P_{loadref}$ and $Q_{loadref}$ are set to zero.

2) 0.4-1.2 s. The microgrid is connected to the grid after the synchronization process, so that the microgrid switches to the grid-connected mode.

3) At 0.9 s. The $P_{loadref}$ and $Q_{loadref}$ are set to 15kW and 10kVar for each DG.

4) At 1.2 s. The breaker disconnects the microgrid from the grid so that the microgrid switches to the island mode.

5) At 1.5 s. The Load2 is suddenly disconnects from the microgrid, so that the total load change to 20kW and 10kVar.
maintained around the nominal values by the grid. When the microgrid is start up, the frequency and voltage can be well maintained in the island mode and grid-connected mode.

Fig. 4 shows the simulation results of active and reactive powers. As the droop parameters of DG1 and DG2 are the same, each DG generate half of the total load demand in island mode. That is, during 0-0.4 s and 1.2-1.5 s each DG output 20kW active power and 10 kVar reactive power; during 1.5-2 s decrease to the half of the original output, as Load2 is turned down. During 0.4-1.2 s, the microgrid is in grid-connected mode, the active and reactive powers Generated by each DG can be changed by the value of $P_{\text{load}ref}$ and $Q_{\text{load}ref}$ as shown in Fig. 4.

Fig. 5 shows the control performance of the inverter voltage controller. The $d$-$q$ voltage reference signals are from the droop controllers. From this figure, we can find out that the voltage reference can be tracked quickly.

Fig. 6 shows the voltage and current waveforms when the microgrid change from grid-connected mode to the island mode. From Fig. 6, we can see that the voltage is almost unchanged when the microgrid disconnected from the grid, and the current are increase quickly to compensate active and reactive powers supplied by the grid.
Conclusions

In this paper, a power-electronic-switch-level simulation model using Matlab/Simulink is built and the controller parameters are optimized by PSO algorithm. The integrated time-weighted squared error (ITAE) for the controller is taken as the PSO’s objective function, taken all the cases of grid-connected mode running, island-mode running, modes switching and load variation into consider. Simulation studies of the microgrid during different running modes and cases demonstrate the effectiveness of the optimized control parameters.

Acknowledgements

This work was supported by the Natural Science Foundation of China under contract (61100159, 61233007), the National High Technology Research and Development Program of China (863 Program: 2011AA040103), Foundation of Chinese Academy of Sciences under contact (KGCX2-EW-104), financial support of the Strategic Priority Research Program of the Chinese Academy of Sciences under contact XDA06021100.

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