Parameter Design and Analysis of Grid-connected Characteristics of Virtual Synchronous Generator

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Abstract

The grid-connected stability of new energy power generation systems has become a hot spot in microgrid technology research.Virtual Synchronous Generator (VSG) control technology simulates the operating characteristics of synchronous generators (SGs) through grid-connected inverters, making them have inertia and damping characteristics. The design of VSG controller parameters is difficult, and the grid connection effect obtained using traditional calculation methods is not ideal. Comparing the simulation results of the power grid under frequency and voltage disturbances, it is verified that the improved differential evolution algorithm is more suitable for VSG grid connection stability than the traditional algorithm.

Keywords

Microgrid；Virtual synchronous generator；Improved differential evolution algorithm；Grid stability.

1. Introduction

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The inverters of the microgrid and the grid energy exchange interface are static components with low inertia. A large amount of integration into the grid will result in insufficient inertia of the power system and affect the stable operation of the system [1]. Relevant scholars at home and abroad have proposed the concept of virtual synchronous generator (VSG), which improves the inverter control strategy by simulating the rotor motion of synchronous motors, so that the microgrid has a virtual rotational inertia [2].

The microgrid system based on VSG control technology has the advantages of fast response, strong inertial performance, adjustable parameters and so on, which has attracted the attention of scholars. However, the VSG grid connection effect obtained by the traditional calculation method is not ideal, and an intelligent optimization algorithm is introduced for this. Differential evolution algorithm has the advantages of simple principle, good robustness, and strong global convergence ability. It is widely used in complex parameter optimization problems. However, in the early stage of optimization, DE's population difference is easy to fall into convergence stagnation, and the algorithm is easy to fall into local optimal solution [3]. In this paper, the defects of the differential evolution algorithm are improved, and the optimal controller parameter combination is optimized by setting the desired performance index. In addition, a traditional VSG and improved DE optimized VSG simulation model were built on the Matlab / Simulink simulation platform. Comparing the output power characteristics of the power grid under frequency and voltage disturbances, it is verified that the improved DE has better grid connection stability than traditional algorithms.

2. The basic principle and control strategy of VSG

2.1 VSG topology

The micro-grid based on VSG technology is mainly composed of micro-sources, energy storage devices, power electronic inverter devices, etc. The principle block diagram is shown in Figure 1 [4].

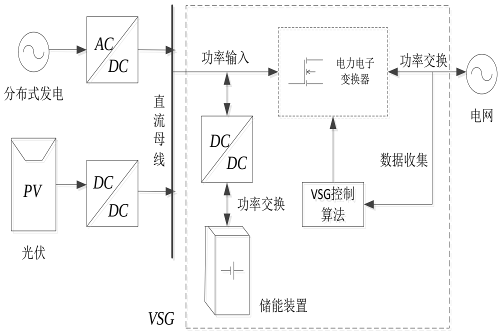

Fig.1 VSG functional block diagram

2.2 Rotor motion equation

Combining the friction loss of the generator and the inertia of the rotor motion, the swing equation of the rotor motion of the synchronous generator is given [5]:

$$\begin{cases} J\dfrac{d\Delta w}{dt}=\dfrac{P_m}{w_0}-\dfrac{P_e}{w_0}-D_p\theta' \\ \theta'=\Delta w=w-w_0 \end{cases} \tag{1}$$

Where Pe is the electromagnetic power, θ is the rotor angle, ω0 is the rated angular frequency of the rotormotion, Dp is the damping coefficient, and J is the rotational inertia.

he governor detects the deviation of the rotor speed, and feedback adjusts the size of the output active power to maintain the frequency stability. When the generator terminal voltage deviation occurs, the feedback signal is input to the excitation adjustment system to control the excitation current, thereby adjusting the reactive power to maintain the voltage stability. The above process can be expressed by a formula[3]:

$$f=f_0-K_m\left(P-P_0\right) \tag{2}$$

$$U=U_0-K_n\left(Q-Q_0\right) \tag{3}$$

Where Km and Kn are P-f and Q-U droop control coefficients, using the first-order synchronous motor model, ignoring the influence of damping characteristics, combined with the rotor motion equation and frequency modulation formula:

$$Jw_n\theta''=P_{ref}-P-K_m\left(w-w_n\right) \tag{4}$$

Where Pref is the reference active power, P is the VSG output power, and θ is the virtual rotor angle[4].

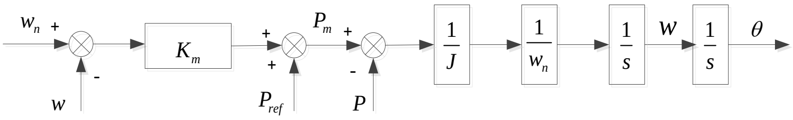

Fig.2 VSG power frequency control block diagram

The relationship between the excitation current of the synchronous motor and the terminal voltage is:

$$i_f = M_f(s)\left(U_{ref} - U\right) \tag{5}$$

Where Mf (s) is the excitation regulator; Uref is the reference value of the terminal voltage U. According to the concept of synchronous generator excitation current adjustment, the control of the current is changed to the control of the amplitude of the control adjustment signal, which is expressed as[5]:

$$E = \frac{1}{K_s s}\left(U_{ref} - U\right) \tag{6}$$

Figure 4 shows the overall structure of the microgrid system controlled by VSG. Among them, the voltage loop parameters kup = 0.15, kui = 21.5, the current loop parameters kip = 27.0, kii = 2346.2. The main parameters of the system are shown in Table 1.

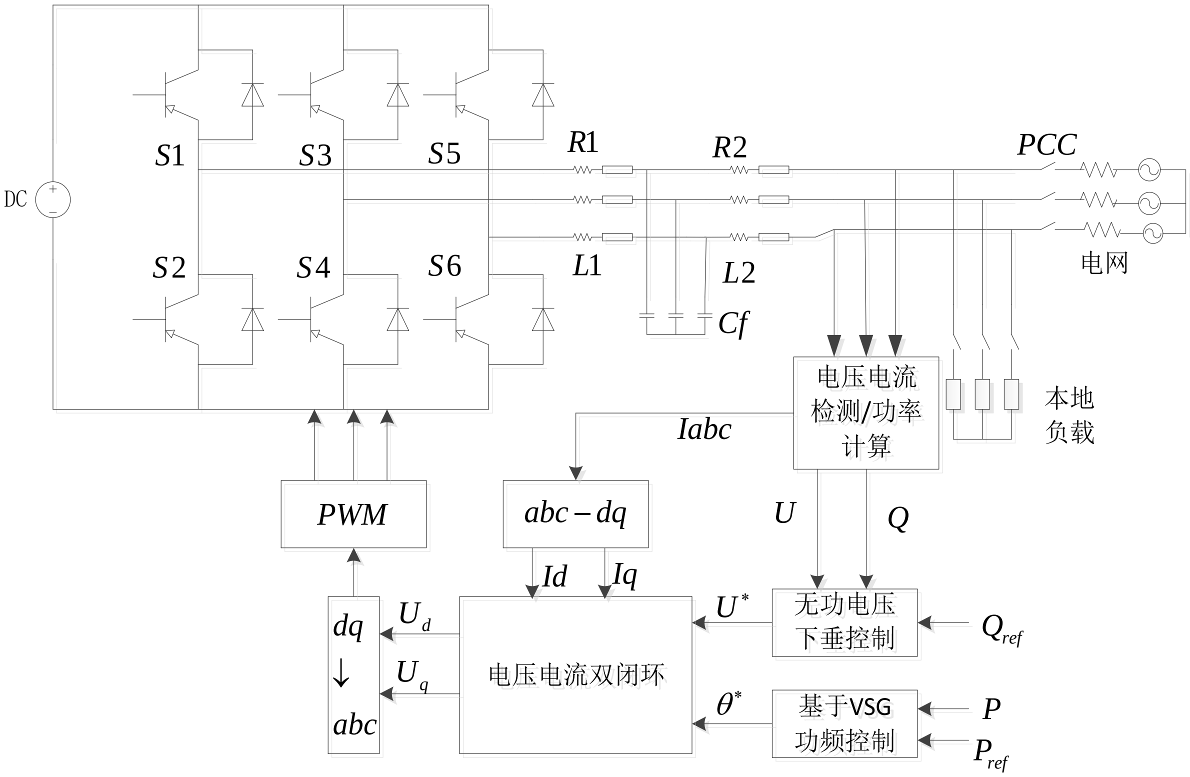

Fig.3 VSG Overall control system

Tab.1 main parameters of the system

Iteam	number	Iteam	number
power	20KV	R	0.134Ω
frequence	50HZ	L	1.2mH
voltage	700V	C	1.2F

3. Improved differential evolution algorithm

3.1 Introduction

In the later stage of the standard differential evolution algorithm, the population difference is getting smaller and smaller, and the parameters are fixed and adaptive, and it is easy to fall into the local optimal solution. Corresponding improvements are made to this, and the optimal parameters are sought in conjunction with the VSG control model[6].

3.2 Improved differential evolution algorithm

The DE parameter is fixed and has poor adaptability, and it is easy to fall into the local optimal solution. To improve this, give full play to the parameters F and CR to optimize the performance of the algorithm. As shown in equations (8) and (9):

$$F=\begin{cases} F_1\dfrac{\arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)}{\pi/2} & \arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)\ge\pi/6 \\ F_1(1-\dfrac{\arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)}{\pi/2}) & \arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)<\pi/6 \end{cases} \tag{8}$$

$$CR=\begin{cases} CR_1(1-\dfrac{\arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)}{\pi/2}) & \arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)\ge\pi/6 \\ CR_1\dfrac{\arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)}{\pi/2} & \arcsin\left(\dfrac{f_{ave}}{f_{\max}}\right)<\pi/6 \end{cases} \tag{9}$$

Using arcsin (fave / fmax) as the critical condition can realize the parameter adaptive effect. When the average fitness value of the population is close to the maximum value, the individual value of the diversity difference of the population is relatively concentrated. At this time, the CR value should be reduced, and the F value should be increased at the same time, so that the algorithm is out of the limit to search the whole world.

3.3 Determination of system fitness function

Considering the smooth and stable expectation of the output power waveform of the VSG grid-connected, the total harmonic distortion rate (THD) is used as the evaluation index; the system requires reducing the influence of steady-state error, so the absolute value integration of error (ITAE) is used as the evaluation function; the expression of the objective function for:

$$F_{object}=a\left(\int_0^T t\left|e_d\left(t\right)\right|dt+\int_0^T t\left|e_q\left(t\right)\right|dt\right)+b\frac{\sqrt{\sum_{n=2}^{\infty}U_{lo}}}{U_o}\times 100\%$$

In the formula, ed = id2-id2 *, eq = iq2-iq2 *, ed and eq represent the dq axis coordinate system inductance current error, U0 represents the output voltage fundamental wave, and Ul0 represents the voltage harmonic amplitude. a, b represent the proportion of ITAE and THD in the objective function respectively.

4. Simulation analysis

Based on the Matlab / Simulink simulation platform, this paper builds a simulation model under the two parameters of traditional VSG and improved DE optimized VSG. In order to compare the power response effect in the grid-connected state, the topology shown in Figure 4 and the circuit parameters shown in Table 1 are adopted. Set the value of J to [0.1 4], the value of Kn [6000 8000], and the value of Km [10000 12000]. The population number NP = 25, the maximum iteration number G = 100, and the parameter combination after improved DE optimization is J = 0.1012, Kn = 6327.6, Km = 6000.

Two independent experiments were conducted under the same environment. (1) The microgrid is operated with a load of 12kW, and it is incorporated into the power grid in 0.4s. The grid frequency drops to 49.2Hz when it runs stably until 1s. (2) Set the initial reactive power command of the microgrid to 6 kVar, merge into the grid in 0.4s, and the amplitude of the grid voltage suddenly drops from 311V to 298V when it runs to 1s. The simulation results are shown in Figure 4:

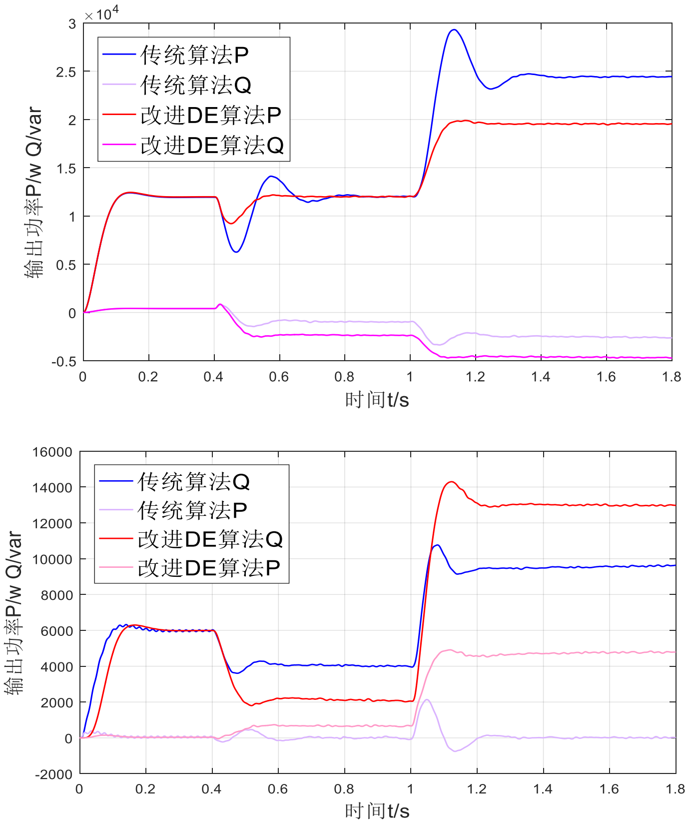

Fig.4 Simulation results

5. Conclusion

In this paper, starting from the VSG control technology of the microgrid, the active frequency control and the reactive voltage control of the VSG are designed. The small signal model is used to analyze the traditional algorithm to set the controller parameters. For the problem of VSG output power oscillation under grid-connected voltage and frequency disturbances, an improved differential evolution algorithm is applied and its parameters are optimized. The simulation compares the VSG output power waveform and verifies that the improved DE algorithm is more suitable for VSG grid-connected stabilization than the traditional algorithm.

References

[1] Zhong Qingchang, Thomas. Holnik. Key technologies of inverter control for new energy access to smart grid [M]. Beijing: Machinery Industry Press 2016.

[2] Du Qian. Research on control strategy of virtual synchronous generator based on MMC [D]. Beijing Jiaotong University, 2019.

[3] Li Fei, Liu Jianchang, Shi Huaitao, Fu Ziying. Multi-objective particle swarm optimization algorithm based on decomposition and differential evolution [J]. Control and Decision, 2017, 32 (03): 403-410.

[4] Zheng Tianwen, Chen Laijun, Chen Tianyi, et al. Virtual Synchronous Generator Technology and Prospect [J]. Power System Automation, 2015, 39 (21): 165-175.

[5] ZHENG TW, CHEN LJ, CHEN TY, et al. Review and prospect of virtual synchronous generator technologies [J]. Automation of Electric Systems, 2015, 39 (21): 165-175.

[6] Alipoor J, Miura Y, Ise T. Stability Assessment and Optimization Methods for Microgrid With Multiple VSG Units [J]. IEEE Transactions on Smart Grid, 2018, 9 (2): 1462-1471.

[7] Yang Congrui, Qian Qian, Wang Feng, Sun Minghui. Application of improved adaptive genetic algorithm in function optimization [J]. Computer Application Research, 2018, 35 (04): 1042-1045.