Research of droop control strategy based on virtual impedance

Yunze Wang
China Huadian HongKong Company Limited (CHDHK), Beijing,100031, China
E-mail:YUNZE-WANG@CHDHK.COM

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Abstract. In a parallelly operated system composed of multi distributed generations (DGs), traditional droop control is usually utilized for load distribution. This article introduces the basic principle which is based on the characteristics of the parallel inverters power droop, and analyzes the circulation phenomenon of parallel inverters in Micro-grids. Due to the influences of feeder impedances and local load, a larger power distribution error may be caused by traditional droop control; a new kind of droop control strategy which was based on virtual impedance was put forward to improve the unequal distribution of power by adjusting the droop parameters. Results of simulation and experiments show that the proposed control strategy is feasible.

1. Introduction

With the crisis of fossil fuel and environmental pollution, the renewable energy such as wind and solar gets more and more attention. Renewable energy, energy storage devices, inverter and controller can form distributed generations (DG), which can composition micro grids by a number of DG, provide high-quality electricity to the user. The inverter, however, is an important part of the micro-grids, the control of which mainly focuses on the control of micro-sources. The system usually consists of several parallel inverters, which have no need to communicate to each other when the load of grid changes. So the whole droop control system is redundant.

Address the above problem, this paper proposes an improved droop control scheme, which distribution can load accurately and eliminate the line impedance inconsistency; it can work in the case of prorated load. Simulated in Simulink of Matlab, confirming its superiority in terms of system stability when adjusting the frequency and voltage.

2. Analysis of the Characteristic of Power Droop

In practice, however, there is always difference in circuit parameters of the parallel system, so voltages cannot be exactly the same due to the changing load and some other inherent characteristics problems. Voltage difference is the cause of circulating current in the internal system, which will have a negative impact on power devices or even destroy the whole system by interrupting the power supply. Hence, it is urgent to take effective measures to curb the circulating current.

As shown in Fig.1, the system can make the micro-source inverter equivalent to a voltage source with internal resistance.

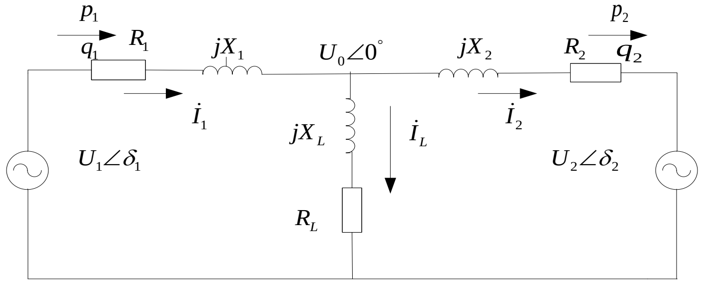


Fig.1 The model of micro source parallel system

Inverter output power:

$$S_i = P_i + Q_i j \tag{1}$$

Inverter output current:

$$\dot{I}_i = \frac{U_i\angle\delta_i - U_0\angle 0^\circ}{R_i + jX_i} \tag{2}$$

Circulation definition of the parallel inverters system:

$$\dot{I}_H = \frac{\dot{I}_1 - \dot{I}_2}{2} = \frac{1}{2}\left(\frac{U_1\angle\delta_1 - U_0\angle 0^\circ}{R_1 + jX_1} - \frac{U_2\angle\delta_2 - U_0\angle 0^\circ}{R_2 + jX_2}\right) \tag{3}$$

Formula (3) shows that the results display that the direct cause of the system circulation is difference. The system circulation can be reduced by adjusting the frequency and amplitude of the inverters output voltage [5].

From figure 1, the active and reactive powers can be calculated:

$$\begin{cases} P_i = (U_i U_0 \cos(\varphi_{Zi} - \delta_i) - U_0^2 \cos\varphi_{Zi}) / Z_i \\ Q_i = (U_i U_0 \sin(\varphi_{Zi} - \delta_i) - U_0^2 \sin\varphi_{Zi}) / Z_i \end{cases} \tag{4}$$

According to the equation (4), the results display that the active and reactive powers of the droop control are related to amplitude and phase angle of the output voltage [2]. After using the control algorithm of voltage negative feedback, the control discipline of the voltage - phase angle droop control can be obtained.

$$\begin{cases} u_i^* = u_{i-ref} - m_i (P_i - P_i^*) \\ \omega_i^* = \omega_{i-ref} - n_i (Q_i - Q_i^*) \end{cases} \tag{5}$$

In equation (5), ω_{i-ref} and u_{i-ref} are the reference values of the inverters output voltage frequency and amplitude; P_i^* and Q_i^* are the power fundamental point values of the droop control curve; ω_i^* and u_i^* are the actual output voltage frequency and amplitude of the inverters respectively, which usually take the system's rated frequency; m_i and n_i are the droop coefficients of micro-grids control system; P_i, Q_i are the actual output active and reactive power of the inverters respectively [6].

As can be seen from the equation (5),when the inverters adopt the P-V droop control, the output active power of the inverters adjust the voltage amplitude and the reactive power regulate the voltage frequency. The P-V control characteristic curve is shown in figure 2.

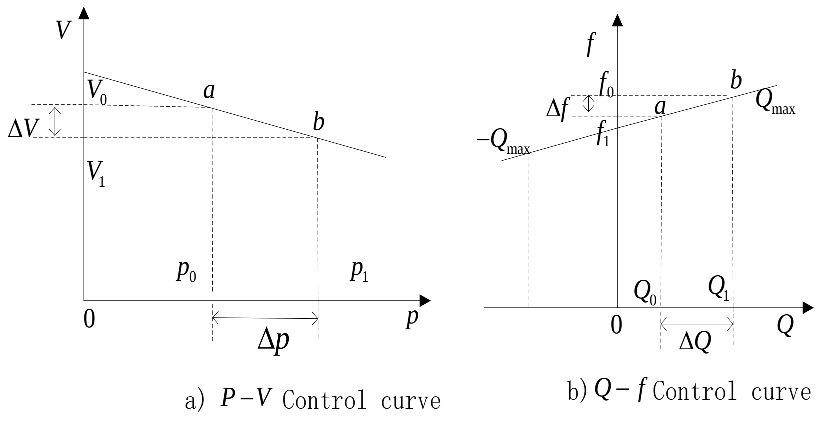


Figure 2 The P-V control characteristic curves

3. The Modified Droop Control Algorithm Based on Virtual Impedance

When the output impedance and line impedance of the parallel inverters present resistive, the traditional low micro-grids droop control was proposed. In fact, there is a problem that the impedance present resistive and inductive simultaneously, in order to solve this problem, the literature [5] proposed a virtual impedance system which is able to decouple the active and reactive power flow [7].If it is assumed to introduce a virtual impedance into this system, micro source active power (P) and reactive power (Q) can be calculated together with droop control method, then the voltage (V) and frequency (f) are obtained. After combining into reference voltage (E_i), the virtual impedance voltage drop of source output current can be calculated, after which reference voltage of source output (V_i^*) is gained as the expression (6) as below:

$$V_i^* = E_i - I_i Z_{viri} \qquad (6)$$

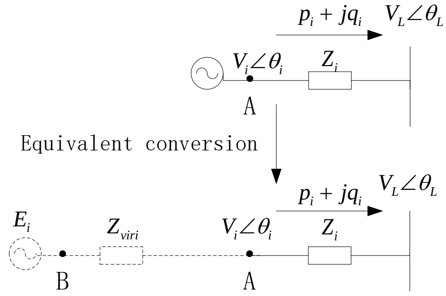


Figure 3.The equivalent process of virtual impedance system

According to the equation (6) the voltage reference (V_i^*) of the inverter output is obtained. Then according to the voltage source control, to control the inverter output voltage.

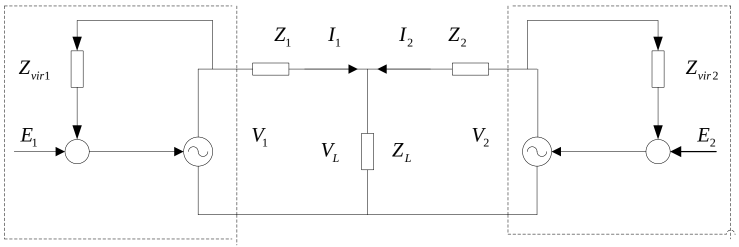


Figure 4.The Control block of Virtual Impedance

Introduce a virtual impedance(Z_{viri}) to connect point A, when the virtual impedance is impedance, using the droop control to the virtual impedance, and adjusting the size of amplitude and phase angle of virtual impedance can realize decoupling control of P and Q.

4. Simulation Results

4.1 Simulation Model

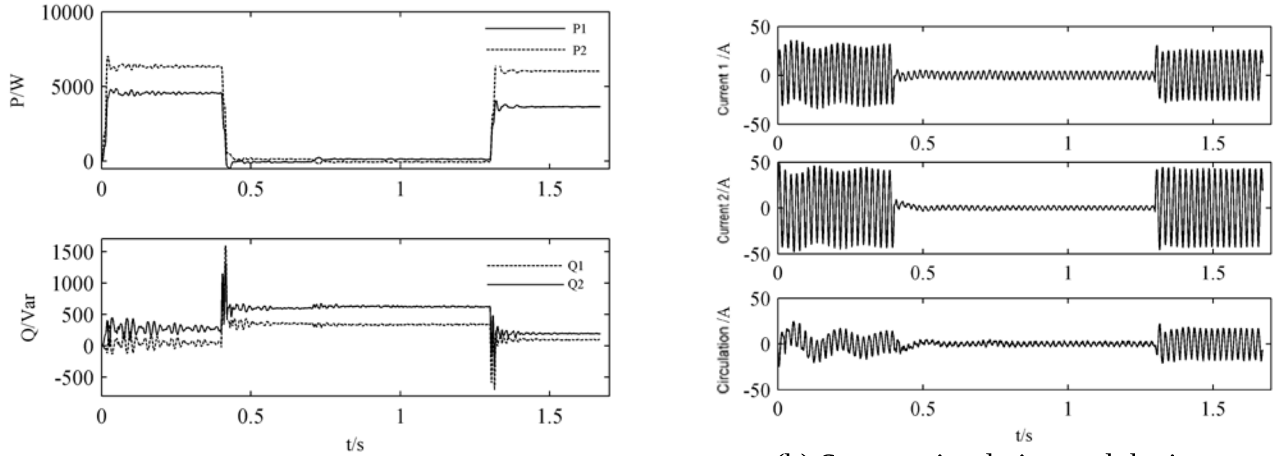
According to the low micro-grids droop control strategy which was proposed by this paper, the micro-grids droop control system model of two parallel inverters, which is based on the Matlab, was built and a experiment for the mutation load and evenly distribution of power was made.

Inverters parameters: The output voltage: AC 220V/50Hz, system voltage 311V, all switching tube: IGBT, The filter circuit: LCL, output filter inductors, respectively: 5.5mH and 1mH, the filter capacitor: 20 μF .Parameters of the control modules: the Controller parameters of the Voltage loop: $K_P = 0.2$ and $K_i = 400$; the Controller parameters of the Current loop: $K_P = 0.1$

4.2 Simulation of traditional droop control

Simulation process of system：In the conventional P-V droop control, the K_P of the DG1 is -0.002V/W, Kq=0.0002Hz/Var; the K_P of the DG2 is -0.001V/W, Kq=0.0001Hz/Var;The line impedance of the DG are 0.18Ω+j0.074mH and 0.18Ω+j0.074mH respectively; when the public load changed from purely resistive to inductive resistive. After 0.4s, the system put into the inductive load, based on a purely resistive load. After 0.65s, the K_P of the DG1 is -0.008V/W, the DG2 is -0.004V/W and the K_q unchanged; from 0.95s to 1.3s, the line impedance of the DG1 increased to 0.30Ω+j0.074mH. The simulation results are shown in figure 5.

From figure 5, when the system public loads changes, the inverter output power has a fluctuations and the system circulation fluctuates more serious. The active power of the system is almost zero. At the same time, due to the larger reactive power flow in system, reactive power cannot be allocated in strict accordance with the proportion of 1:2. In the process, the coupling phenomenon of active and reactive power is found when the coefficients are being adjusted.



(a) The power of each inverter (b) System circulation and the inverter current

Fig.5 the experimental results of parallel inverters in micro grids system

In summary, the traditional droop control is influenced by the output of the system, line impedance and the droop parameters, and can cause some problems, such as the system circulation, frequency error, power coupling and power distribution.

3.3 Simulation of improved droop control

In the control process of micro grids, each inverter droop coefficients must meet the following [6]:

$$\begin{cases} m_1 P_1^* = m_2 P_2^* = const1 \\ n_1 Q_1^* = n_2 Q_2^* = const2 \end{cases} \tag{7}$$

When the system run at the steady state, the inverter operating frequency to the same. Formula can be drawn:

$$\begin{cases} m_1 P_1^{'} = m_2 P_2^{'} \\ n_1 Q_1^{'} = n_2 Q_2^{'} \end{cases} \tag{8}$$

If the inverters can distribute active power evenly, the equation (9) can be obtained:

$$m_1 \frac{U_1 U_0}{R_1} \delta_1 = m_2 \frac{U_2 U_0}{R_2} \delta_2 \tag{9}$$

If $\delta_1 = \delta_2$, $U_1 = U_2$,then, the following can be obtained:

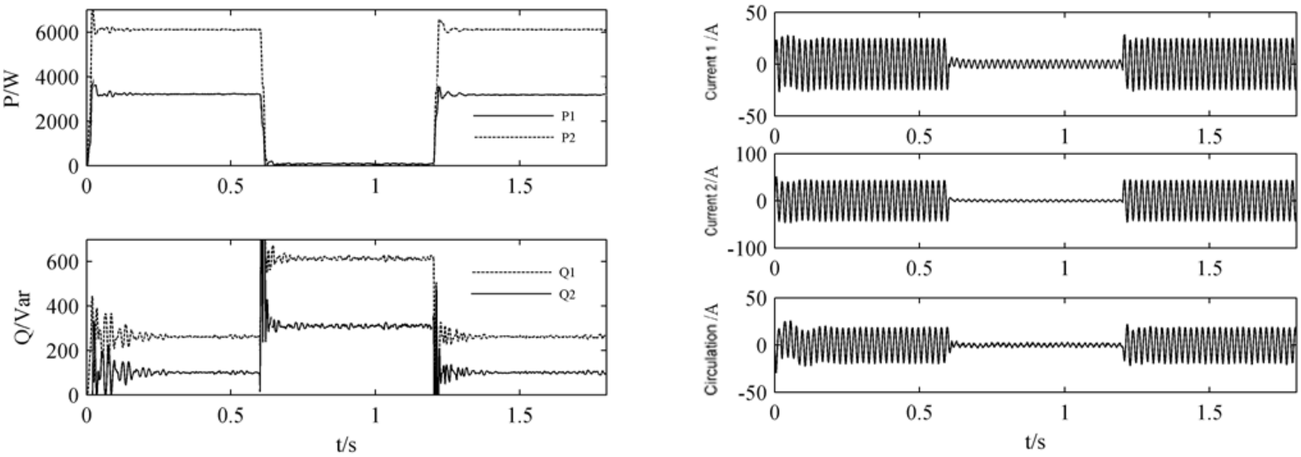
$$\frac{m_1}{R_1} = \frac{m_2}{R_2} \tag{10}$$

Similarly, to ensure that the reactive power split, then, the following can be obtained:

$$\frac{n_1}{R_1} = \frac{n_2}{R_2} \tag{11}$$

In the actual droop micro grids control system, the circuit impedance of the droop control presents inductive and resistive, mostly. According to the traditional droop control, the power which is between the inverters is not easy to distribute evenly. Hence, this paper proposes an improved droop control scheme of add the virtual impedance to distribute power evenly.

The system simulation process of the modified control algorithm：From 0.272s to 1.5s,in the conventional P-V droop control, the KP of the DG1 is -0.008V/W, Kq=0.0002Hz/Var; the KP of the DG2 is -0.004V/W, Kq=0.0001Hz/Var; The line impedance of the DG are 0.12Ω+j0.049mH and 0.18Ω+j0.074mH respectively; When the system is added to a virtual impedance, the DG1 added virtual resistance of 0.24Ω,after 0.5s, the system input load, which the public load from a purely resistive load to inductive. The simulation results are shown in figure 6.



(a) The power of each inverter

(b) System circulation and the inverter current

Fig.6 The experimental results of parallel inverters in micro grids system

From figure6, it is clear that the improved Droop control strategy greatly improved the power quality of the system, and the modified droop control active and reactive powers are always in proportion of 1:2 distributions, which is P1:P2=1:2，Q1:Q2=1:2.

5. Conclusions

In the paper, firstly, introduce the droop control principle, and analyze the equipartition conditions ofthetraditionaldroopcontrolpower.Secondly,applied to the limitations of the traditional droop contr ol system,an improved droop control algorithms have been proposed based on virtual impedance. The results shows that improved droop control power allocation algorithm can achieve a good distribution in proportion to maintain system stability and assurance power quality of th e system.

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