Micro-Grid Converter Droop Control Strategy and Simulation

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Abstract: - Prominent worldwide environmental problems makes the development of new energy distributed generation technology has been developed. Direct access to the low-voltage distributed power distribution network makes the system affected to some degree, in the form of micro-grid integration of distributed power is a good solution, and the presence of a large number of micro-grid inverter, micro-network research inverter controls are important. In the micro-grid, droop control strategy to simulate the droop characteristics of traditional power systems, active by changing the output of reactive power to control the frequency and amplitude of the output voltage, so that the micro-grid system can stabilize voltage in island operation mode point work, and with the voltage grid mode or less smooth transition when switching can guarantee the normal work load undisturbed, is an important variable flow control methods. On PSIM simulation software droop control strategy simulation, circuit simulation designed specifically for the control strategy, and the output waveform is studied. Simulation results show the schematic design of the control strategy is correct.

Key-Words: - distributed power source,microgrid,droop control,PSIM,simulation,Converter

1 Introduction
Today's power system development has already closely integrated with modern control theory. Power grid is developing toward two distinct directions: a large capacity, long-distance, high pressure, even UHV AC and DC transmission level and a large grid interconnection; the other is small capacity and relatively independent micro-grid. For these two directions, there are still some common problems (such as the optimization of operation, coordinated scheduling and control, etc.) to be resolved. Over the past decades, power grid develops rapidly ,and now has become a major power transmission channel. But with the power grid scale up and the whole society deepen the dependence on electricity, the drawbacks of ultra-large-scale systems are also reflected, such as high cost, difficult to run and so on. In addition, worldwide energy supply remains tense, it is imminent to rationally develop and utilize new energy. Distributed generation with the installation location flexibility and high efficiency of energy use, can effectively solute many problems of large centralized power grid. Therefore, distributed generation was put on the agenda. Distributed power has obvious advantages, there are also some problems, such as high-cost to access to distributed power, difficult to control. Moreover, for a large grid, distributed power source is not controllable. The system often take quarantine and restriction approaches to DG, to reduce the impact on the grid. In addition, IEEEP1547 provides DG network standard, that is, if the system fails, the distributed power must be immediately quitted running. This leads to distributed power can not be fully effectived. Scholars in order to coordinate the contradiction between DG and large grid, put forward the concept of micro-grid.

Micro grid (MG) can be combined with the loads, generators, control devices and energy storage devices into a manageable unit, with a lot of non-linear distributed power. It can not only solve the problem of large-scale distributed power access, but also bring the user and the system many benefits. Thus microgrid research is useful supplement of the existing backbone network .It is of great significance whether for the use of new energy from the environmental point of view, or considering increasing the supply of quality and reliability of power supply from the backdrop of China's power grid interconnection . Among them, one of the key problems of the study of micro-grid is coordination and control technology and energy management systems research.
In summary, micro network converter control method study has great significance and application prospects.

2 Micro-Grid Inverter Control

Micro-network (MG) has a variety of different types of distributed power (DG) and extensive power electronic devices to interconnect, resulting in the existence of a fundamental difference between micro-grid and general transmission and distribution systems; In addition, because of micro-grid system can run on-grid and can run off-grid operation mode. It need to switch. It also brings many complex control problems. That must take control methods different from the traditional methods, or make a large adjustment.

For parallel operation of DG, the main control methods are several programs such as non-contact line control based on droop, master-slave control, centralized control and decentralized logic control. Last three options need contact line to communication. In distributed generation systems, each power supply spacing stays away. The transmission signal is complex, reducing system reliability. No tie-line control scheme is that droop control based on local electrical quantities to adjusted DG. it can respond MG dynamic process in a very short period of time, to meet the requirements of real-time control.

3 Droop Control

3.1 Droop Control Method Operating Principle

Droop control is in essence the voltage source inverter voltage-controlled method, by adjusting the voltage amplitude and phase to achieve control of the transmission power. In the inductive transmission line, active power mainly depends on the power angle. Reactive power depends on the voltage difference. So Power angle can be used to control active power and voltage difference can be used to control reactive power.

In the micro-grid, the droop control strategy simulates the droop characteristics of traditional power system, by changing the output of active and reactive power to control the frequency and amplitude of the output voltage, so that micro-grid system can work on stabilize voltage point in island operation mode. And it is less different with the network mode voltage. Transition is smooth when switching, that can guarantee the load undisturbed to normally work. The figure below shows the frequency - the active and voltage - reactive droop curve.

![Droop Control Chart](image)

Figure 1. Drooping curve: (a) f-P droop (b) V-Q droop

Wherein the \( f_0 \) is no-load frequency. The \( f_N \) is the nominal frequency. The \( f_{\text{min}} \) is minimum frequency for the power quality permission. The \( P_N \) is nominal active power output. The \( P_{\text{max}} \) is maximum power output. The \( V_{\text{max}}, V_{\text{min}} \) is the maximum and minimum output reactive power. The \( V_N \) is rated voltage. The \( Q_{\text{min}}, Q_{\text{max}} \) is the minimum and maximum output reactive power.

The control strategy: To get the output current and voltage by current and voltage sensors detecting. Then the micro-power active and reactive power output is calculated at this time to obtain voltage frequency and amplitude reference values in accordance with the droop curve setting. And then to control the inverter output current and voltage. Entire droop control system consists of the power calculate unit, droop control unit, voltage and current double closed loop control unit and modulation unit and other units, as shown below.

![Droop Control System](image)

Figure 2. drooping curve droop control chart
3.1.1 Power Calculation Unit
First transform three-phase AC voltage and current detected by sensors by Parker to two-phase DC voltage and current, with two-phase DC quantities to represent the three-phase AC quantities, can make computing easier, and is good to the inverter output astatic regulation.

3.1.2 Droop Control Unit
Droop control unit is a core unit of distributed power droop control. Enter the active and reactive power issued by inverter. Output reference value of the voltage amplitude and phase angle $\omega_t$. Previously given frequency droop and voltage sag slope $m$ and $n$, by calculating the output power of the inverter determine the voltage amplitude and frequency output of distributed power at this time. Calculate the voltage and frequency reference value in accordance with the graphics this time.

\[ f = f_N + m(P_N - P) \]  
\[ V = n(Q_N - Q) \]

The $f_N$ is the nominal frequency, typically 50Hz. The $P_N$ and $Q_N$ stand for inverter rated active power and reactive power. The $Q_N$ usually sets to 0. The $P$, $Q$ stand for the previous unit input active and reactive power. The $f$, $V$ are the frequency and voltage amplitude reference value. The $m$, $n$ are the frequency and voltage droop coefficient.

After obtained the frequency reference value $f$, by integrating operations, and then multiply $2\pi$ can get the phase angle reference value $\omega_t$.

\[ 2\pi f = \omega = \frac{d\delta}{dt} \]

3.1.3 Voltage and Current Double Closed-Loop Control
Voltage and current double closed-loop control unit is also droop control strategy important aspect, in which the outer ring is the voltage closed-loop. The inner loop is the current loop. The current loop control is mainly to improve the dynamic response of the system. The outer voltage control is mainly to eliminate the system steady-state error, for the output of distributed power better tracking presets. To obtain the voltage amplitude and phase angle reference value then can generated a three-phase modulated wave signal. Before comparing with the triangular carrier, it need to get through a voltage and current double closed-loop control unit, to achieve the output waveform astatic control. First convert three-phase sine wave signal to dq two-phase signal. Respectively calculate the difference with the sensor detects the output voltage $U_d$, $U_q$, and the output current $i_d$, $i_q$. Then get through the proportional regulator. And finally converted back to a three-phase AC quantities to become modulated wave signal.

3.1.4 Modulation Unit
Three-phase AC modulation wave signal is compared with the triangular carrier signal. When the modulation signal is greater than the carrier signal, control IGBT conduction. When the modulation signal is less than the carrier signal, control IGBT turn-off. That can get output voltage SPWM waveform, then filter out high harmonics by the low-pass filter, and ultimately get the three-phase sinusoidal voltage waveform.

When micro-grid uses the droop control strategies, the micro-powers do not require to contact with each other, as long as detecting local output voltage and current size, then according to the principle of droop control to obtain the output voltage frequency and amplitude reference value. It is for peer control between the system micro power. When the rated capacity of micro-power is unequal, each micro power voltage, frequency droop coefficients can be separately calculated based on the rated capacity. To make all micro-power droop coefficients and the rated power’s product is equal, as the following equation. This allows the system micro-power according to their rated capacity to distribute reasonable loads. That will not cause a micro power underutilized or overload damage.

\[ m_1 \times S_1 = m_2 \times S_2 = \ldots = m_n \times S_n \]  
\[ n_1 \times S_1 = n_2 \times S_2 = \ldots n_n \times S_n \]

Wherein the $S_1$, $S_2$ ...... $S_n$ are for each distributed power rated capacity. The $m_1$, $m_2$, ...... are each distributed active power droop curves slope. The $n_1$, $n_2$ ...... are each distributed active power droop curves slope.

3.2 Build Simulation Models
3.2.1 First Convert abc Three Phases AC Quantities to dq Two-Phase DC Quantities
Voltage and current double closed-loop control unit is also droop control strategy important aspect, in which the outer ring is the voltage closed-loop. The inner loop is the current loop.

![Figure 3. abc-dq transformation](image)

3.2.2 Then Calculate the Output Active and Reactive Power

![Figure 4. power calculation unit](image)

3.2.3 Droop Control Unit
Set the rated voltage amplitude 311V and rated frequency 50Hz. Set rated active power and reactive power 4000 and 2000 respectively. Active and reactive droop coefficient are 0.0005 and 0.01 respectively. Generated phase δ is as other aspects of input.

![Figure 5. droop control unit](image)

3.2.4 Generates Three-Phase Modulation Wave Signal with the Voltage Amplitude and Phase Angle Reference Value

![Figure 6. modulation wave signal generating unit](image)

Figure 6. modulation wave signal generating unit A phase angle is α. B is with a phase lag 2.0944 radians. C phase is ahead of A phase 2.0944 radians. Then convert the three-phase alternating current signal back to two-phase DC signal.

3.2.5 Power Calculation Unit voltage and current double closed-loop control
The voltage source control is the outer loop. The proportional controller gain is 0.3. The current source control is inner loop. The proportional regulator gain is 3. After the voltage and current double closed-loop control, then converting dq two-phase signal back to abc three-phase signal, the signal can be obtained as the modulation wave signal, involved in generating a PWM waveform.

![Figure 7. dual-loop control](image)

Figure 7. dual-loop control
3.2.6 Modulation Aspects

Figure 8. modulation unit
Triangular wave generator parameters: peak voltage is 800V. Frequency is 7000Hz. DC offset is -400V. DC voltage source is 800V.

3.2.7 The Entire Droop Control Simulation Circuit

Figure 9. Droop control diagram
The line reactance is much larger than the resistance parameters. The load is DC load after three-phase bridge rectifier circuit. Voltage sensor measured current through the low-pass filter cut-off frequency is 1000Hz. Power calculation unit output active and reactive power also need to go through the filtering effect. The cutoff frequency is set to 1000Hz. Modulation wave signal need enter a restrictor before through a comparator, limiting the amplitude of the waveform. The parameter is set from -400V to +400V.

3.3 Simulation results

Triangular wave generator parameters: peak voltage is 800V. Frequency is 7000Hz. DC offset is -400V. DC voltage source is 800V.

1) Inverter output three-phase current and voltage are shown in figure below, showing the output current stabilized after 0.04 seconds, and control is the rapid.

(a) output current
(b) output voltage
Figure 10. (a) output current (b) output voltage
Output voltage after low-pass filter is as shown.

Figure 11. low-pass filter output voltage
2) Output voltage amplitude:
\[ U_m^2 = U_\alpha^2 + U_\beta^2 \]
It is consistent with figure the output voltage waveform magnitude.
3) output active power and reactive power:

Active power stabilized at about 2kW, and is less different with values calculated by the inverter output voltage and current.

4) voltage magnitude and phase angle reference value:

Level curve is voltage amplitude pattern. Tilt curves is angle graphics. The voltage amplitude reference value is about 270V. The slope of the curve of the phase angle curve is approximately 317.08. That can calculate at this time frequency reference value is 50.46Hz ($\omega = \frac{d\delta}{dt}$).

5) A phase modulated carrier signal: it can be seen that modulated signal is a three-phase sinusoidal wave signal.
4 Conclusion and Outlook

4.1 Conclusion and Summary
This article describes the micro-grid inverter study background and significance. The working principle of micro-grid droop control method is studied and built their model circuit diagram on psm software. After simulation operation, the output waveforms show that the control strategy designed can stabilize the output power, and satisfy the system requirements of voltage amplitude and frequency. That proves the correctness of such a microgrid control strategy.

4.2 Prospects
Due to time constraints, as well as lack of practical experience, this article only do a little preliminary research on micro-grid inverter control this broad field, which will inevitably be some flaws. You also need to do more research in the following areas and learning:

1) The simulation results output waveform contain higher harmonics. Three phase voltage and current waveforms are not completely symmetrical, also need more in-depth study on the design of the filter circuit.

2) Simulation circuit parameters need to be optimized. It uses an approximate method that considering active power only related to d-axis current and reactive power only related to q-axis current. In order to make the output more accurate, it also need to decouple control dq axis.

3) DC side uses a DC voltage source, in less ideal circumstances, the distributed power situation is very complex. There are intermittent and persistent type of distributed power generation division.

4) It also requires in-depth study of the case of multiple parallel micro power generation power distribution, voltage balance and other aspects.

References: