Research on Dual Mode Unified Control Strategy of Grid Connected Inverter Based on Droop Control

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Abstract. There is a big difference between the two modes of grid connected inverter in micro-grid operation. In order to avoid large voltage and current impact, advanced control strategy is needed to realize smooth conversion during operation mode switching. A droop control method based on voltage amplitude change rate is proposed, which is suitable for dual-mode unified control of inverter. While ensuring the stability of the system, the reactive power of the inverter can be accurately shared during islanding operation. This method can realize smooth switching between grid connected inverter and islanding mode. The feasibility of the method is verified by simulation and experiment.

1. Introduction
Recently, distributed generation technology based on renewable energy is developing rapidly[1]. The key technology of reasonable and effective utilization of distributed generation is to connect the distributed generation with large power grid to realize grid-connected generation[2]. At the same time, in order to ensure the power supply reliability of sensitive load, these distributed energy resources must can work in island operation mode when the great grid break down. Therefore, its interface inverter usually has three operating states: islanded operation, grid-connected operation and the switching process. In order to reduce the impact of distributed micro source on power grid and improve power quality of sensitive loads, the switching process must be smoothly[3]. But if the control variables were changed in the mode conversion process, voltage and current impact can extremely be caused, especially in three-phase grid system, the sensitive loads maybe have big impacts[4]. Scholars at home and abroad put forward a variety of solutions to solve the impact problem produce during the mode switching process[5-6]. But if systems use two control strategies it must bring complexity and diversity problem, so dual mode inverter integrated control is proposed.

This paper presents a droop control inverter integration control strategy based on voltage amplitude variation. When the inverter work at islanded operation, it exist reactive power sharing error. And when the inverter work at grid-connected operation the reactive power is not controllable. The proposed strategy can solve these problems, at the same time makes the switching process smoothly.

2. Proposed droop control method
The core strategy of this paper is \( P - \omega, Q - \dot{V} \) droop control strategy, and its expression is

\[
\omega = \omega_b + k_p (P - P_b)
\]

(1)
\[
\begin{aligned}
\dot{V} &= V_0 - k_0 (Q - Q_0) \\
V &= V_0 + \int \dot{V} \, dt
\end{aligned}
\]  
(2)

\( \dot{V} \) is the changing rate of the inverter output voltage amplitude, compared with the conditional droop control, \(Q - \dot{V}\) droop control strategy use the output voltage amplitude changing rate as the control variable instead of the amplitude of output voltage \(V\). This feature will reduce the dependence of inverter’s reactive power control performance on the impedance of transmission line. The strategy can used to inverters with the same capacity.

The two inverters will work at a steady operation when they have the same amplitude change rate, so

\[n_1 (Q_1 - Q_{01}) = n_2 (Q_2 - Q_{02})\]  
(3)

If choosing \(n_1Q_{01} = n_2Q_{02}\) as the droop coefficient, then the output reactive power value of every DG will satisfy (4), namely the output reactive power matching the reactive power capacity.

\[\frac{Q_1}{Q_{01}} = \frac{Q_2}{Q_{02}}\]  
(4)

In steady state, the amplitude changing rate must be recovered to 0 to prevent the amplitude of output voltage continue change, Therefore, the application of \(Q - \dot{V}\) must match the \(V\) recovery control, the control principle shows in figure 1.

Figure 1 shows that at \(t_2\) moment the \(\dot{V}\) recovery operation starts, the difference value between \(\dot{V}_1(t_2)\) and \(\dot{V}_{01}\) (typically 0) makes the reactive power set point \(Q_{01}\) moves to \(Q_1\).Therefore \(Q - \dot{V}\) droop control curve upward, while \(\dot{V}_1\) close to it’s set value0. At \(t_3\) moment, the recovery process reaches the steady state. The time constant of the recovery process should be less than the time constant of \(Q - \dot{V}\) droop control, to make the function of promote the reactive power distribution of the \(Q - \dot{V}\) droop control into full play. But this constant should be not too large, in order to avoid the output voltage amplitude of the inverter is far from the rated value. When the dynamic performance of the two inverters’ amplitude change rate of recovery control are the same, then in the recovery process the two inverters’ voltage amplitude difference is relatively unchanged, so the steady-state reactive power distribution remains unchanged.

\(Q\)

\(V\)

(a) \(Q - \dot{V}\) Principle of voltage recovery control

(b) \(Q - \dot{V}\) Dynamic regulation process of voltage recovery

Fig.1 Principle of \(\dot{V}\) recovery control

Still use DG1 as the example,

\[Q_{01} = \int k_{resq} (\dot{V}_{01} - \dot{V}_1)\]  
(5)
Similar to the $Q-V$ droop control and $V$ recovery control, this text adding frequency recovery control based on the $P-\omega$ droop control. Therefore, when the inverters’ frequency recovery control dynamic performance are the same, the active load can be equally divided, and the load is equal to the set value of the active power, namely the inverter output active power, and the output voltage frequency is the rated value, thus ensure the load voltage quality when working at island operation.

In conclusion the expressions of the $\omega, V$ recovery control are

$$P_0 = \frac{k_{resP}}{s}(\omega_0 - \omega)$$  \hspace{1cm} (6)

$$Q_0 = \frac{k_{resQ}}{s}(V_0 - V)$$  \hspace{1cm} (7)

3. Dual mode control intergation strategy

The dual mode inverter control strategy based on $P-\omega$ and $Q-V$ droop control is shown in Figure 2.

![Fig.2 Structure graph control strategy of dual mode inverter based on improved control](image)

Working at independent operation, through the cooperation of $P-\omega$, $Q-V$ droop control, and $\omega, V$ recovery control and the virtual impedance dependence, the frequency of the load voltage can be maintained at the rated value, and greatly improve the accuracy of reactive power distribution. before switch on the grid, active synchronous controllers obtain the disturbing quantity of the angular frequency $\Delta\omega$ and the disturbing quantity of the amplitude change rate $\Delta V$ according to the PCC voltage and the grid voltage phase difference and amplitude difference. and under the effect of the two disturbance, the synchronization process can be completed quickly, achieving smooth switching. At islanded operation the power set points $P_0$ and $Q_0$ are set by the recovery control depending on the load, when working at grid connected operation, in order to realize the constant power control of the inverter, remove the recovery control link, directly set the power point size $P_{ref}$, $Q_{ref}$, when the grid voltage is fixed, because the common coupling point voltage is clamped by the grid, the active and reactive power value in steady state are the same with the power set point, therefore, the power injected to the grid can be changed indirectly by control the output power of the inverter through change the $P_{ref}$ and $Q_{ref}$. On the other hand, make the angle frequency setting value of the $P-\omega$ droop
control the same to the power grid angular frequency $\omega_g$, it can maintain the active power output from
the inverter when the frequency of the grid fluctuate.

When the $Q-V$ droop control working at the grid connected operation the adjusting process is shown in figure 3.

![Fig.3 Regulating process of droop control during grid-connected operation](image)

Figure 3 shows that before connected to the grid the inverter is at steady state, $\dot{V}$ is 0, and the
system is running at point A. And at the connected moment, the reactive power output of the inverter
is negative because active power make the voltage value on the line impedance decrease, though
system running at point B. At this moment, $\Delta \dot{V}$ makes the output voltage of the inverter rise up, then
the inverter reduce the output reactive power, the working point moves from point B to point A. When
the point return to A, the output voltage does not change any more, while the output reactive power
become to 0, thus, it may be known that when use the $Q-V$ droop control the reactive power adjusting
process is similar to the active power adjusting process when use the traditional $P-\omega$ droop control,
this is because the droop control strategy use frequency and amplitude change rate to control the phase
difference and amplitude difference which are directly related to the power, and there is integral
element in the loop.

The aforementioned $P-\omega$, $Q-V$ droop control solves the problem of the reactive power can’t be
control when use the traditional droop control strategy. However, the problem of the active power
control when the frequency of the grid changed can not be ignored. The control process of the output
active power of the inverter when the grid frequency fluctuation is shown in figure 4. Figure 4 shows
that, in the initial state, the grid voltage has a nominal frequency and amplitude. The inverter output
active power value is the rated value $P = P_0$, droop curve is $L_1$, and the system runs at point A. When
the power grid voltage fluctuation, the frequency becomes $\omega_{grid} = \omega_0 + \Delta \omega$, if not control, the operation
point of the inverter will moved from the point A to the point B, the output active power decreases to
$P_1$, the system will working at another steady state. In this paper, at the connected operation the set
angular frequency $\omega_0$ of the droop control is obtain from the grid voltage phase locking, so when the
frequency of the grid fluctuations, the curve can immediately increased from $L_1$ to $L_2$, and the inverter
operating point moves from point A to point C. Comparing point B and point C, it can be seen that
when the grid frequency becomes to $\omega_{grid} = \omega_0 + \Delta \omega$, the steady-state operating frequency of the grid
connected systems are both $\omega_{grid} = \omega_0 + \Delta \omega$, and the difference is that the output active power of the
inverter at point C is maintained at the rated value.
Combination with the figure 2, the expression of droop control working at grid connected operation is

\[
\omega = \omega_g - k_p (P - P_{ref}) \\
\dot{V} = V_0 - k_p (Q - Q_{ref}) \\
V = V_0 + \int \dot{V} \, dt
\]  

(8)  

(9)

4. Simulation and experiment

4.1 Simulation analysis

Based on MATLAB software, the control strategy of dual mode inverter based on \( P - \omega \) and \( Q - V \) droop control is simulated and verified in this paper. And simulation parameters is set as follow: the DC input voltage value is 160V, and the rated output voltage value is 60V, the circuit filter inductance value is 4mH, and filter capacitor value is 6.8 F, switching frequency is 20kHz, angular frequency value is 314rad/s, and the amplitude variation rate V is set as 0, the output rated active power value is 500W, reactive power is 0Var and the grid voltage grade is 60V.

The operation process of the inverter is set as follow: at the initial time system working independently with resistive load, and begin the active synchronization when the connected signal is received at the 1s moment; at 2s moment the synchronization operation is completed, closing the grid connected switch, then the system working at connected operation, and in steady state, the output power value of the inverter is set at 500W; at 3s moment change the output power set value, set the inverter output power st 400W; at 4s moment open the connect switch then the system restore to independent operation.

Figure 5 shows that the grid voltage and grid current have phase difference, this is because the output reactive power of the inverter is set to 0, the power loss caused by the filter and the circuit impedance and other reasons is compensated by the grid.

Figure 6 shows that, when use the proposed control strategy, the output active power of the inverter has no overshoot at the connected moment and realizes the smooth switching between the operation mode; reactive power is recovered to zero after the transient state, so the controllability of reactive power is guaranteed. When working at connected operation, changing the active power reference value
from 500W to 400W, then the output power of the inverter be changed following the set value and final work at stable operation, due to the local load unchanged, input power of the inverter will be changed, so changing the reference values can also changing the power values injecting to the grid, in the whole operation, the power can be smooth transited, which is the advantage of the droop control strategy proposed in this paper.

In order to verify the power control performance of grid connected inverter when the grid frequency fluctuation, the running process of the inverter is set as follow: at Initial moment the system working independently with resistive load, and begin to run the active synchronous operation at 1s moment when receive the connect single; at 2s moment, the synchronous operation completed, close the connect switch, and the system working at connected operation, the output power value is the set value 500W, and the grid angular frequency is the rated value $100\pi$ (rad/s); at 3S moment the grid angular frequency change to $101\pi$ (rad/s); and at 4S moment the grid angular frequency recovery to the rated value $100\pi$ (rad/s). Figure 7 shows the waveform of frequency in both operations when the grid frequency has fluctuations.

Figure 7 (a) shows that when $\omega_0$ is rated value, at 3S moment the grid frequency fluctuation makes the inverter output active power value fluctuate to another steady value 350W, when the frequency is restored to the rated value at 4S moment, the output power of the inverter is recovered to the rated value 500W, that is, when the frequency of the grid fluctuating, the output active power of the inverter is not controllable. Figure 7 (b) shows that if $\omega_0$ is set as grid angular frequency, when the grid frequency fluctuating the output power of the inverter can maintain at the rated value 500W, this ensures the high performance of the distributed generation system, also ensures the safe and stable of the inverter.

### 4.2. Experimental results

A three phase grid connected inverter experimental platform which use the DSP+FPGA as the main control circuit is built. The experimental parameters and simulation parameters are completely consistent, Figure 10 shows the waveform of PCC transient voltage at connect moment and the current of phase A.
Figure 8 shows that the PCC point voltage has no significant change at the grid connected moment, and the output current of the inverter transit smoothly, which is consistent with the simulation analysis. Figure 9 shows the waveform of the grid voltage of phase A and the current input to the grid of phase A, and there is a difference between the two waveform, this is consistent with the simulation analysis. Figure 12 shows the waveform of the output power of the inverter in both the off and connect grid operations.

Figure 10 shows that before connect to the grid the system working with a active power load independently, the value of the output active power is 270W, and the reactive power is 0. After closing the grid connected switch, the output active power of the inverter has no overshoot at the connect moment, reducing the connected current impact, making the operation mode switching smoothly; The reactive power will return to zero after the transient and can also change the setting value of the reactive power of the inverters to make them join the reactive power compensation operation according to their capacity. When working at grid connected operation, the output active power value is 500W, and the reactive power value is 0, changing the reference value from 500W to 400W, the output power will change follow the set value and finally work at a steady point, because the local load unchanged, the input power of the inverter changed, so if change the reference value the power injected into the grid can be changed. After open the grid connected switch, the system starts working independently, and the output power is automatically matched with the load.

5. Conclusion
The realization of the integrated control of the dual mode inverter is the research direction of the micro grid operation based on the inverter interface. The micro source inverter which using the peer to peer control strategy usually use the droop control method. But the traditional droop control method has large deviation in the output power of the micro grid inverter, which is difficult to be directly applied to the dual mode inverter system. This paper presents and design a dual mode inverter control strategy based on voltage amplitude variation droop control. Working at grid connected operation, this strategy
can make both the active and reactive power in controllable state, and can not be affected by the frequency fluctuation of the power grid, what’s more the power injected to the grid can be changed by changing the reference value of the power; when working at islanded operation the working frequency of the inverter is the rated value at the steady, which reduces the dependence of the reactive power control performance on the line impedance; and the dependence of reactive power control performance on line impedance is reduced; at the same time, the proposed active synchronization control strategy only needs to adjust amplitude and phase, then the smooth switching of operation mode is realized, finally realizing the design of integrated control of the dual mode inverter based on droop control, the feasibility and validity are proved by simulation results and experiment results.

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References
[1] JI Ping, WU Shouyuan, ZHOU Xiaoxin. (2013) Determination of Regional Renewable Energy Planning Scheme for Urban Power Grid Containing Wind Farm and Its Important Impacting Factors. Power System Technolog, 02:334-341.(in Chinese)
[2] Qing-Chang Zhong, Tomas Hornik. (2013) Control of Power Inverters in Renewable Energy and Smart Grid Integration. America: John Wiley & Sons Ltd.
[3] WANG Xiaohuan, ZHANG Chunjiang. (2012) Design and Implementation of Grid-Connected Seamless Transfer Algorithm for Distributed Generation Systems. Power System Technology,07:191-194(in Chinese).
[4] Li Ling, Wang Huanhuan, Xie Lili. (2010) Research of Grip Connection Monitor System of Distributed Power Supply Based on Distributed Control System[J]. Computer Measurement and Control, 18(3):580-585(in Chinese).
[5] Y. A.-R. I. Mohamed and A. A. Radwan. (2011) Hierarchical control system for robust microgrid operation and seamless mode transfer in active distribution systems. IEEE Trans. Smart Grid, 2(2) :352-362
[6] Z L Yao, L Xiao, Y G Yan. (2010) Seamless Transfer of Single-Phase Grid-Interactive Inverters Between Grid-Connected and Stand-Alone Modes[J]. IEEE Trans. On Power Electronics, 25(6): 1597-1602