A Decentralized frequency regulation strategy of PV Power Plant based on droop control

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***Abstract*—In order to make full use of the active function of the photovoltaic (PV) power unit itself, a decentralized frequency regulation strategy for PV plant is proposed based on droop control idea in this paper. The active power regulation value, as an additional active power reference, is obtained according to the frequency regulation coefficient of PV unit; then the active power output of the PV unit is quickly regulated to the reference value, so that the frequency recovery of power system is restored. Since each PV unit in the power plant can achieve frequency regulation directly through the change of terminal frequency value, the response time will be faster than other control modes. Finally, a PV power plant which adopts the decentralized frequency regulation system is modelled on the DIgSILENT PowerFactory platform, and the control effect of the decentralized frequency regulation is verified by simulation results under different disturbances.**

***Index Terms*—PV plants, droop control, decentralized frequency regulation, DIgSILENT PowerFactory**

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I. INTRODUCTION

With the outbreak of the energy crisis and the increasingly serious environmental problems, the development and utilization of renewable energy has become the core issue of the strategic transformation of energy in the world. Renewable energy is gradually becoming an important source of new type power, in the meantime the structure and operation mode of power system will undergo major changes. By the end of 2017, the cumulative installed capacity of China's grid-connected wind power reached 164 million kilowatts, and the cumulative grid-connected capacity of PV power reached 130 million kilowatts. The wind and PV power systems are connected to the grid via power electronical converters. Generally speaking, when they operate in the maximum power point tracking (MPPT) mode, they do not participate in the power grid frequency regulation. However, when capacity of renewable energy integrated in power system exceeds a certain value, there exists a requirement for renewable energy to participate in grid regulation to ensure the safety of power system [1-3].

Renewable energy [4-9] and energy storage system [10] all can provide active power and frequency support for power system. However, the high cost and short service life of the energy storage system are its main shortcomings. National standards of many countries (such as China [11-12]) specify that wind farms and PV power plants need to have the ability to participate in power system frequency regulation. In Northwest China, fast frequency response tests of the PV inverters have been conducted, and it is shown that the fast frequency response contribution of PV inverters is equivalent to hydropower generating units with the same capacity [6]. Research on frequency regulation by wind power generation has been relatively adequate [5], while the research on PV is lacking.

In this paper, a decentralized frequency regulation strategy of PV power plant based on the droop control idea is proposed, which makes full use of the fast adjustment of own active power. After each PV power unit get change of the system frequency, the active power adjustment amount is calculated according to the frequency modulation coefficient, which is added to the PV power unit active power control system, and rapidly changes the active power output of the PV power unit, therefore the frequency of the system is restored.

II. IMPLEMENTATION PRINCIPLE OF DECENTRALIZED FREQUENCY REGULATION CONTROL

A. Principle of PV participation in system frequency regulation

According to the inverter *dq* control equation (1).

$$\begin{bmatrix} U_{sd} \\ U_{sq} \end{bmatrix} = -\begin{bmatrix} R+Ls & wl \\ wl & R+Ls \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} U_{cd} \\ U_{cq} \end{bmatrix} \tag{1}$$

Where s is differential operator.

When the grid voltage vector is used as the standard for d-axis positioning, the voltage of the q-axis $U_{sq}=0$, then the active power P and the reactive power Q are expressed in the dq0 coordinate system as

$$\begin{cases} P = \frac{3}{2}(U_{sq}i_q + U_{sd}i_d) = \frac{3}{2}U_{sd}i_d \\ Q = \frac{3}{2}(U_{sq}i_q - U_{sd}i_q) = -\frac{3}{2}U_{sd}i_q \end{cases} \tag{2}$$

The PWM control then may be governed by changing the modulation ratio M and the phase shift angle δ of the modulated wave. When the value of U_{cd} and U_{cq} are given, the modulation ratio M and the phase shift angle δ can be obtained as follows,

$$\begin{cases} \delta = \arctan(U_{cq}/U_{cd}) \\ M = 2\left[(U_{cq})^2 + (U_{cd})_2\right]^{\frac{1}{2}} / u_{dc} \end{cases} \tag{3}$$

The block diagram of the inverter transient control model can be obtained according to (1) ~ (3). As can be seen from Fig.1, the control of the current values of i_d and i_q on the output loop control of the inverter is realized by changing the output voltages U_{cd} and U_{cq}, the output voltage is controlled by changing the modulation amount M and the phase shift angle δ of the PWM, and the active power P and the reactive power Q can also be controlled by the way shown as Fig.1. However, there is mutual coupling between the d and q axis current in this control, which makes it difficult for independent control. Therefore, in order to reduce the difficulty of control design, decoupling control is needed.

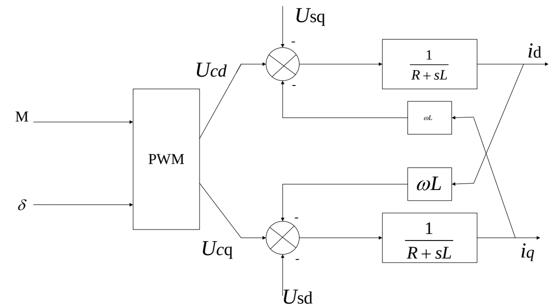


Fig.1. Block diagram of the inverter PWM control model

Normally, each inverter is expected to achieve independent control of active and reactive power when the grid-connected PV power system is running. The output of PWM can be controlled by modulation ratio M and phase shift angle δ, so that the inverter can control these two quantities. The active power of PV system is balanced, that is, the loss of the system active power and the output of AC side are balanced with the active power of PV output, so the constant DC voltage control is a common control method for PV system integrated into power system.

Assuming that the acquisition frequency of the grid-connected side is f, which is transmitted to the droop control. The reference frequency of the PV array is set to f_0, and the difference Δf indicates the deviation of the system frequency, which is caused by the active power fluctuation of the PV array. The frequency regulation control schematic is shown in Fig. 2.

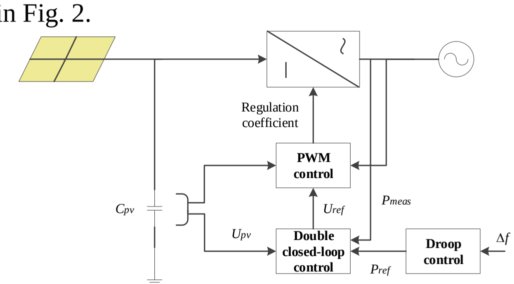


Fig. 2. Schematic diagram of PV array control

B. PV participation system frequency regulation control structure

The active power output of PV system should be reduced when the system frequency increases. The power control command is obtained through the feedback of the frequency deviation Δf, then the inverter controls the inner loop current output by adjusting the reference value of the outer loop voltage to reduce the PV output. When the system frequency is reduced, the PV should increase the active power output. Similarly, the inner loop current output is controlled by adjusting the reference value of the outer loop voltage to increase the output of the PV.

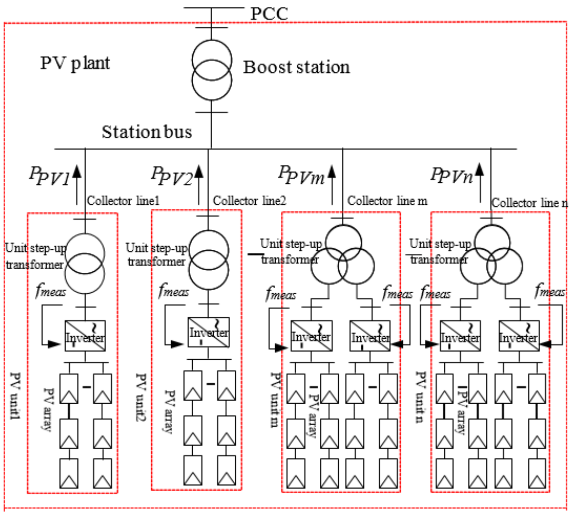


Fig. 3. System structure of decentralized frequency regulation

The structure of the decentralized frequency regulation control system is shown in Fig.3. The specific implementation is as follows: each PV power unit acquires the system frequency from measurement. When the system frequency deviation exceeds the dead zone of frequency regulation, the active power reference value of PV power unit is changed according to the preset frequency-power adjustment coefficient. Therefore, the active power output of the converter is adjusted according to P_{ref}. The process is as shown in Fig.4, and the implementation principle is the same as the active output control of the centralized frequency regulation control mode. The implementation of the active power-frequency regulation control system is shown in Fig.5.

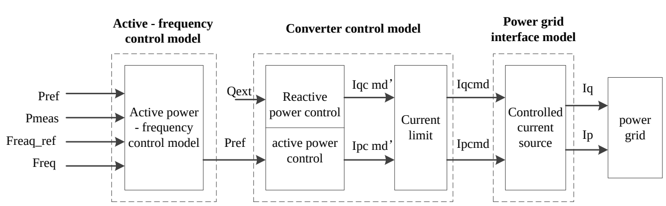


Fig.4. PV power generation unit with frequency control

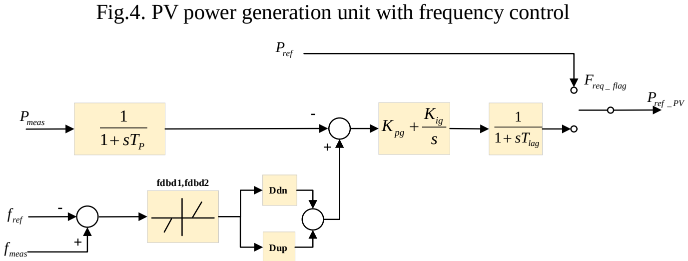
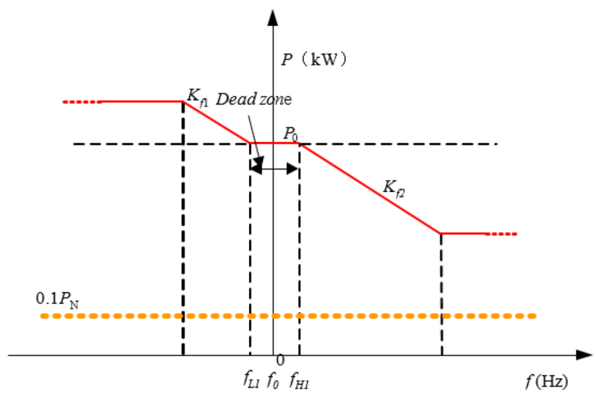


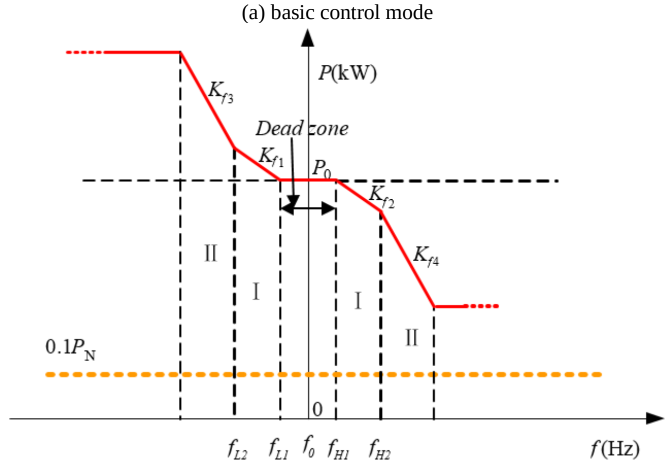
Fig.5. Active-frequency control system model

III. PRINCIPLE OF SEGMENTED FREQUENCY MODULATION CONTROL

For PV power plants with decentralized frequency regulation control, PV inverters can set different frequency regulation dead zones and active power-frequency adjustment coefficients according to grid scheduling requirements. In order to make full use of the rapid active power regulation characteristics of PV inverter to support system frequency recovery, the subsection control mode of the PV inverter is proposed on the basis of the original frequency regulation control mode which based on the internal inverter control form and the location of the PV plant integrated into power system. When the system frequency and the reference frequency deviate greatly, a larger frequency-active adjustment coefficient is needed to obtain large amount of active power support to maintain frequency recovery; conversely, a smaller frequency active power adjustment coefficient is set to reduce the overshoot of frequency. The implementation of the original frequency regulation control mode and the segmentation control mode is shown in Fig.6 and the meaning of the parameters in the figure is shown in Table 1.



(a) basic control mode



(b) subsection control mode

Fig.6. Curve of frequency regulation control mode

Table 1 Parameter definition of the subsection frequency regulation control

Parameter	Definition
P_0	Steady-state initial value of active power
P_N	Active power rated value
f_0	System reference frequency
f_{L1}	Dead zone threshold of frequency action
f_{L2}	Action threshold of frequency adjustment II
f_{H1}	Dead zone threshold of over frequency action
f_{H2}	Action threshold of over frequency adjustment II
K_{f1}	Active frequency regulation factor (under frequency I)
K_{f2}	Active frequency regulation factor (over frequency I)
K_{f3}	Active frequency regulation factor (under frequency II)
K_{f4}	Active frequency regulation factor (over frequency II)

IV. SIMULATION VERIFICATION

A. Model construction

A two-area four-machine system, as shown in Fig.7, is established based on the DIgSILENT PowerFactory platform [13].

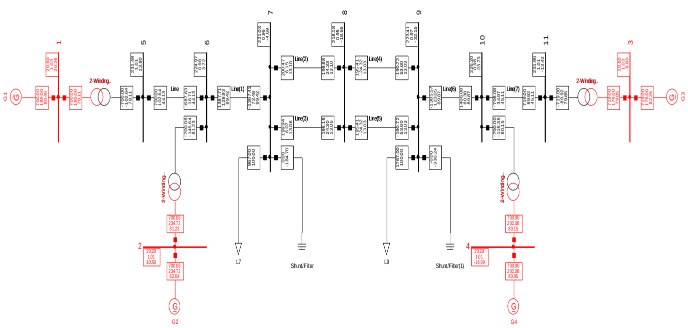
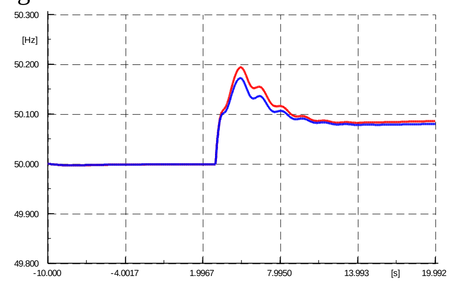


Fig.7. The two-area four-machine power system based on PowerFactory

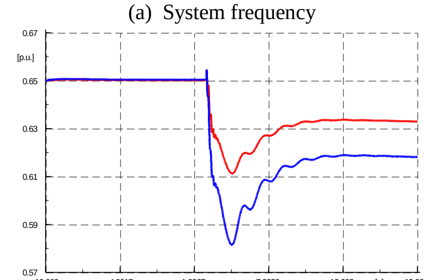
In order to conveniently study the operation performance of the PV power plant participating in the system frequency regulation control, some large-scale PV power plants are connected to bus08 and bus09 of the classic two-area four-machine power system. Specifically, four PV power plants are connected to the bus08, which installed capacity are 200MW (plant I), 100MW (plant II), 200MW (plant III), and 200MW (plant IV) respectively. The installed capacity of PV power plants connected to bus09 are 400 MW (plant I) and 400 MW (plant II) for analyze and compare the performance differences between the centralized and decentralized frequency regulation control mode. The plant I and plant II under the bus08 node were selected to set up in detail. Among them, the plant I has 8 feeders and the plant II has 4 feeders.

B. Simulation verification

When t=3s, the load L7 connected to bus07 drops 200MW, and the system frequency changes. In order to verify the frequency regulation performance of the decentralized frequency regulation control system of the PV power plant, the simulation comparison of the basic and the subsection control mode was carried out. The curves of the system frequency and the active power output in two different control modes are shown in Fig.8.



(a) System frequency



(b) Active power output of PV power plant

Fig.8. Simulation curve (red line: basic control; blue line: subsection control)

The simulation results show that when the system load drops, the system frequency rises, each PV power plant unit execute the frequency control according to the preset active frequency adjustment coefficient immediately after sensing the system frequency deviation. Thereby, the active power output of the power plant is rapidly reduced, and the frequency of power system is restored.

V. CONCLUSION

This paper proposes a decentralized frequency regulation strategy for PV power plant based on the droop control. After the system frequency changes, each PV power unit calculates the active power adjustment amount according to the frequency regulation coefficient, which is added to the PV unit active power control system. Thereby, the active power output of the PV unit can be quickly changed and the system frequency can be recovered. The response time should be faster since the PV units realize the frequency regulation control through the change of the terminal frequency value. Finally, based on the DIgSILENT PowerFactory platform, the PV power plant adopting the decentralized frequency regulation is connected to the two-area four-machine power system, the control effect is verified by setting the load change disturbance.

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