Research on output power quality control technology of three-phase inverter

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Abstract—With the wide application of new energy and distributed generation system, high-performance inverter plays an important role as the key link of power system access. Its performance determines the quality of output power. Therefore, the output power quality control technology of three-phase inverter has become one of the important research directions in this field. This paper introduces the current main inverter power quality control methods, summarizes and compares the advantages and disadvantages of a single control method, and points out that the composite control method is the development trend of inverter output power quality control technology.

1. Introduction
The formulation of the goal of "carbon peaking and carbon neutralization" and the implementation of relevant policies have greatly promoted China's new energy revolution and the diversification of energy structure. With the continuous improvement of the penetration rate of new energy and distributed generation system, high-performance inverter plays an important role as the key link of power system access. Its performance directly or indirectly determines the quality of output power and is the key to the normal operation of new energy generation system[1]. With the continuous popularization of various complex, precise and power quality sensitive electrical equipment, load mutation, load nonlinearity and load imbalance put forward higher requirements for the design of high-performance inverter power supply. Therefore, the output power quality control technology of three-phase inverter has become one of the important research directions in this field.

Generally speaking, power quality refers to high-quality power supply, including voltage quality, current quality, power supply quality and power consumption quality. Power quality problem can be defined as the deviation of voltage, current or frequency that leads to the failure or failure of electrical equipment, including frequency deviation, voltage deviation, voltage fluctuation and flicker, three-phase imbalance, instantaneous or transient overvoltage, waveform distortion, voltage sag, interruption, rise and power supply continuity.

An ideal power system should supply power to users at a specified voltage level with constant frequency and sinusoidal waveform. In three-phase AC power system, because the parameters of each element of the system are not ideal linear or symmetrical, the load properties are different and change randomly, coupled with the imperfection of regulation means, operation, external interference and
various faults, this ideal state does not exist in reality, resulting in power grid operation various problems in electrical equipment and power consumption also produce the concept of power quality.

2. National standard for power quality

Among the national standards for power quality formulated by the National Technical Committee for voltage, current level and frequency Standardization, the following five are mainly related to inverter output, as shown below is the abstract of national standards for power quality[2].

1. GB/T14549-1993 Power quality-Harmonics in public Power Grid: The total harmonic distortion rate limit of harmonic voltage of 0.38kv public power grid is 5%, the odd harmonic voltage content is 4%, and the even harmonic voltage content is 2%.

2. GB/T12325-2008 Power quality-Supply voltage deviation: The three-phase power supply of 10kV and below shall be less than ± 7%. The single-phase power supply of 220V shall be 7% ~ -10%.

3. GB/T15945-2008 Power quality-Power system frequency deviation: The normal allowable deviation is ± 0.2Hz. If the system capacity is small, it can be relaxed to ± 0.5Hz. The frequency change caused by user impact shall generally not exceed 0.2Hz.

4. GB/T12326-2008 Power quality-Voltage fluctuation and flicker: Allowable voltage fluctuations are 2.5% for 10kV and below; 2% for 35~110kV; 1.6% flicker for 220kV and above; Flicker: 0.4% in case of high requirements and 0.6% in general.

5. GB/T15543-2008 Power quality-Three phase voltage unbalance: The negative sequence voltage imbalance shall not exceed 2%, and shall not exceed 4% in a short time. The allowable value of negative sequence voltage imbalance of each user is generally 1.3%.

3. Inverter output power quality control method

Focusing on the control goal of inverter output power quality, a variety of control technologies have been applied to the design of inverter power supply. As shown in Figure 1, the working principle framework of the inverter system is shown. Common inverter output power quality control methods mainly include the following:

3.1. PID control

PID control has the advantages of simple structure, simple algorithm, high reliability, high robustness and convenient debugging process. It has become the most classic and widely used control method in modern control theory. Figure 2 shows the PID control principle block diagram of the inverter. In order to improve the effect of inverter waveform control, the feedforward control of reference sinusoidal signal can be combined with the PID control of output voltage error to improve the dynamic response performance of the inverter and the quality of steady-state output waveform.
According to the principle of internal mode, PID control cannot realize non-static error tracking of sinusoidal signal, so it is usually necessary to add external loop mean feedback to improve the steady-state accuracy of the system [3]. With the appearance of DSP and ARM controller, the instantaneous value feedback digital PID control of inverter becomes possible. Because the inverter system has strong oscillation when no load, the proportion of PID control must be limited, but this will obviously reduce the dynamic performance of the control system; As a result, the controller cannot eliminate errors in real time, and the output performance and waveform quality are affected, especially the THD value of the output voltage is large under nonlinear load conditions.

3.2. PR (proportional resonance) control
PR controller is a controller based on resonance effect. Its control loop has an infinite gain mode at a special frequency. In this way, any nonlinear influence or interference influence will be completely eliminated at this frequency. Therefore, zero error steady-state tracking of sinusoidal signal can be realized at this resonance frequency. For a complex inverter, the output voltage contains multiple harmonics in addition to the fundamental wave. In order to effectively suppress harmonics of different frequencies, PR controllers with different resonant frequencies can be added [4]. As shown in Figure 3, the principle diagram of multiple PR control of the inverter is shown. However, this control method needs to connect the resonant controllers under multiple resonant frequencies in parallel, which will increase the complexity of control, and the design of proportional link in PR control is basically the same as that of PI control, so the dynamic performance of the system is still general.

3.3. Hysteresis control
At present, the most widely used control method in tracking harmonic current is hysteresis comparison control. The principle of hysteresis comparison control is to compare the controlled value with its given value within a given range to determine the switching timing of inverter switching elements. Hysteresis comparison control has the advantages of fast response speed, high control accuracy, easy implementation and no need to understand the load characteristics; The main disadvantage is that the switching frequency is not fixed, there is serious phase to phase interference when used in three-phase three wire system, and the controlled quantity cannot be effectively controlled when the load is changed [5]. Combining with vector control can effectively overcome the above shortcomings.

3.4. State feedback control
In the linear system state space theory of automatic control theory, feedback quantity includes output quantity and state quantity. State feedback can get more feedback information and system change rule from the system through system pole allocation, and the controller will become more accurate and better, and can compensate disturbance better. Pole assignment can improve the damping of the system, and thus improve the dynamic performance of the system, and reduce the transition response time. However, the disadvantage of state feedback control is that it has poor improvement effect on the steady-state performance of the system, and it has poor ability to suppress the output waveform distortion caused by various disturbances. In the actual inverter control, state feedback is often combined with other control methods to improve the dynamic performance of the system, and
compound control to suppress the output waveform distortion caused by interference to improve the steady-state performance of the system[6].

3.5. Double loop control

Figure 4 shows the principle block diagram of inverter double loop control. Because the single loop control of inverter is not ideal for the regulation of AC voltage, an inductor/capacitor current inner loop can be added on the basis of PWM inverter voltage single loop to improve the dynamic and static performance of the system.

![Figure 4. Inverter double loop control principle block diagram](image)

Reference[7] realizes the control of inverter based on the predictive voltage and current regulator with the same structure, which shows good dynamic and static performance. However, the dual loop control requires a comprehensive analysis of the open-loop and closed-loop frequency characteristics of the inverter under different controller parameters. In addition, in order to suppress the disturbance of output voltage and nonlinear load, the current inner loop must have a sufficiently high bandwidth to obtain satisfactory performance, which increases the difficulty of realizing the digital controller.

3.6. Adaptive control

The inverter system is bound to be affected by load disturbance and other environmental factors in the actual operation process. Using a conventional controller to adapt to various changes with a set of constant controller parameters is obviously difficult to achieve satisfactory results. Figure 5 shows the principle block diagram of inverter adaptive control.

![Figure 5. Inverter adaptive control principle block diagram](image)

The adaptive control method can identify the system model on line[8], and then adjust the controller parameters according to the system model and control index to achieve high precision control. The disadvantages mainly exist in the following aspects: the present parameter estimation methods are asymptotically convergent with time approaching infinity under ideal conditions, but the practical engineering application needs the fast convergent parameter estimation methods in finite time; The dynamic performance of some adaptive controllers during startup or transition process can not meet the actual requirements. Low order controller has high frequency unmodeled; Because of the contradiction between the control precision and parameter estimation, the measurement precision directly affects the controller parameters, and then affects the system performance.

3.7. Sliding mode variable structure control

The principle of sliding mode variable structure control is to design the switching phase plane of the system according to the expected dynamic characteristics of the system, and force the state variables of the system to move from outside the phase plane to a pre designed "sliding mode" trajectory in the
switching phase plane through the sliding mode controller, so as to achieve the expected performance. Sliding mode variable structure control has the advantages of fast response, insensitive to parameter changes and disturbances, no system on-line identification, simple implementation and good dynamic performance. The main difficulty of applying sliding mode control in inverter system is that it is difficult to select the ideal sliding mode switching phase plane of the system; If sliding mode control is realized by analog circuit, the hardware circuit is too complex. Therefore, only digital circuit can realize its application value, and higher system sampling frequency is required to achieve better control effect, so as to eliminate the system instability caused by discrete sampling[9].

3.8. Deadbeat control
K. P. Gokhale et al. First proposed the deadbeat control method of inverter in 1987. Its main idea is to calculate the switching control value of the next cycle according to the state equation of the system and the current state information, and finally achieve the purpose of making the output value track the input value. Its principle block diagram is shown in Figure 6.

![Figure 6. Block diagram of inverter beat free control principle](image)

Deadbeat control[10] has the advantages of good dynamic response performance, good output voltage tracking effect, low harmonics and high waveform quality. The disadvantages of the controller are that the accuracy of the system mathematical model is high, the robustness is poor, the transient response overshoot is large, and the real-time calculation is strong, so the hardware requirements are very high. The performance of deadbeat control can be greatly improved by adopting disturbance state observer or optimal predictive control.

3.9. Repetitive control
Repetitive control is mainly used to eliminate the influence of periodic disturbances such as inverter dead time effect and nonlinear load, and improve the waveform quality of output voltage. Its basic idea is to assume that the distortion in the previous fundamental cycle will repeat in the next cycle, and the controller determines the control signal according to the error between the given signal and the feedback signal, This signal is then superimposed on the original control signal of the next cycle to eliminate repetitive distortion. Figure 7 shows principle block diagram of inverter repetitive control.

![Figure 7. Inverter repetitive control principle block diagram](image)

The repetitive control algorithm is simple. Only by sampling the output voltage, the inverter can obtain the steady-state output waveform with low THD under periodic disturbance. However, due to the fundamental cycle delay in the repetitive controller, the repetitive controller does not produce any regulation effect in the first fundamental cycle of load step change, and the dynamic response is poor. If the disturbance is aperiodic, repetitive control will increase the error of inverter output voltage. In order to solve this problem, reference[11] proposes a new frequency adaptive repetitive control (FARC) method applied to grid connected inverters, which uses all-pass filter to replace the delay unit...
in the repetitive controller. When the grid frequency changes, it can effectively suppress voltage harmonics by adjusting the coefficient of all-pass filter online.

3.10. Fuzzy control

The inverter system is a nonlinear time-varying system. The traditional control method usually needs to give a very accurate system model in order to accurately suppress the disturbance signal, which greatly improves the control difficulty. The fuzzy controller has no requirements for model accuracy. It can accurately suppress the disturbance signal and optimize the inverter voltage waveform without being affected by the modeling accuracy of the controlled object. Fuzzy control look-up table occupies a short time of digital chip, so a higher sampling frequency can be used to compensate the control deviation caused by limited fuzzy rules. Literature[12] combines fuzzy control with repetitive control. Fuzzy control has the characteristics of parameter adaptation. When sudden disturbance or distortion occurs, it can quickly adjust parameters according to fuzzy rules to adjust the waveform in time, so as to overcome the cycle delay caused by repetitive control. However, due to its use of fuzzy principle and fuzzy rule base, Therefore, the adjustment of waveform is not very accurate.

Although it has been proved theoretically that fuzzy control can simulate any nonlinear function with arbitrary accuracy, due to the lack of perfect theoretical basis, the formulation of fuzzy controller rules still depends on human experience. Therefore, there are many irrationalities, which seriously affect the performance of the controller. The application of fuzzy control technology mainly lies in further research Improve fuzzy variable segmentation and fuzzy rules.

3.11. Neural network control

Neural network control belongs to the category of intelligent control. Its control idea is to obtain the optimal control law of the system through off-line analysis of inverter experimental and simulation data, and apply it to the inverter system to realize on-line control[13]. The control has low requirements for the calculation accuracy of the mathematical model of the system control object, good robustness and strong ability to adapt to the environment. However, neural network control is difficult to be realized in hardware, so it is rarely used in the control of power electronic equipment such as inverter power supply.

4. Development trend of inverter output power quality control technology

Each power quality control scheme has its advantages, at the same time, various methods also have shortcomings. Therefore, a single control method is difficult to meet the performance requirements of high-performance inverter power supply. In order to make the inverter output waveform have satisfactory dynamic and static characteristics, compound control can be selected to make different control methods interact and learn from each other. Compound control is the inevitable trend of the future development of inverter output power quality control.

Reference[14] proposes a new resonance control method with frequency adaptive ability for three-phase grid connected inverter. In the two-phase static coordinate system, the whole control system can be equivalent to a first-order frequency servo system by introducing frequency tracking link and pre current feedback link. The problem that the traditional proportional resonance controller can’t realize the zero steady-state error tracking control of AC flow when the power grid frequency is offset is solved. Reference[15] proposed an optimal control method combining state feedback accurate linearization and quadratic type. According to the passivity control idea, the analysis and design method of quadratic optimal controller is given, and the values of Q and R are optimized by using the passivity energy function, so as to reduce the output voltage harmonic and improve the harmonic performance of inverter system. Reference[16] proposes an optimal control strategy based on linear quadratic theory, which not only eliminates the inherent resonance phenomenon of LCL filter, but also realizes the compensation of harmonic, reactive and unbalanced current at the parallel node. The feedforward control method suitable for linear optimal control is used, the stability of the system and the power quality at the parallel node are improved.
5. Conclusions
In order to improve the quality control method of the inverter, this paper summarizes and compares
the advantages and disadvantages of multiple single control methods, and points out that the
composite control method is the development trend of the inverter output power quality control
technology, and the selection of the composite control method is the result of the selection of the
performance indicator requirements of specific goals, and the advantages and advantages are
complementary.

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