Research on Harmonic elimination Feedback Control Technology of Sine Wave Inverter Based on Instantaneous Reactive Power Theory

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Abstract. Aiming at more and more occasions where the sine wave output inverter is used for power supply of a non-linear load, the sine wave output waveform distortion of the inverter caused by the non-linear load is serious. The feedback control strategy of sine wave inverter based on instantaneous reactive power is proposed. Through the fundamental wave instantaneous tracking feedback control based on the instantaneous reactive power theory and the detection and feedback control of the output harmonic signal, this paper realizes the ability of the inverter to maintain the output waveform with high sine degree and low distortion under various load conditions, it guarantees the error-free control of the fundamental wave and has a good dynamic response performance. This solution has the advantages of easy controller stability design and good implementability. The simulation circuit is built by Matlab / Smiulink, and the correctness of the theory is verified by the simulation results.

1. Introduction

Sine wave inverters are used in UPS, special AC power supply, photovoltaic power generation and other renewable energy power generation systems[1]. The control methods of the sine wave inverter mainly include proportional integral (PI) control, proportional resonance (PR) control, repetitive control, deadbeat control, hysteresis control, etc. Among them, PI control is easy to implement, but the waveform amplitude control accuracy is poor, and it is affected by load changes[2]; the PR controller working at the fundamental wave frequency can approximate the fundamental wave without difference tracking, but the ability to suppress harmonics is weak, in order to suppress the low-order harmonics, multiple PRs working at harmonic frequencies are required to be used in parallel. The algorithm is complicated and the amount of calculation is large[3]. Although repetitive control can eliminate steady-state errors and improve control accuracy, the coordination between stability design and dynamic response is difficult, and controller parameter design is difficult[4], the switching frequency of deadbeat control is fixed and has good dynamic performance, but the accuracy of its mathematical model seriously affects the control effect, and it is sensitive to parameters and has poor robustness[5]. Although the control of hysteresis is simple and the dynamic response is fast, the switching frequency is not fixed, which makes the filter design difficult [6]. For strategies that combine control methods,
such as PI+repetitive control [7], PR+repetitive control [8], Repeat+deadbeat control[9], etc. these control strategies overcome the shortcomings of a single control method and improve the system performance, but the structure is more complicated.

This paper proposes harmonic elimination feedback control technology of sine wave inverter based on instantaneous reactive power theory, which has the advantages of high sine wave control accuracy, small circuit operation amount, easy to implement structure, and high practicability.

2. Main circuit topology and control model

2.1. Main circuit topology

The topology diagram of the main circuit of the sine wave inverter feedback control based on instantaneous reactive power theory is shown in figure 1.

![Figure 1. Main circuit topology](image)

The inverter is a three-phase full-bridge structure. Each phase of the output of the inverter bridge is connected with a low-pass filter composed of an inductor L and a capacitor C. The voltage signal is sampled on the output line and solved by a signal based on the instantaneous reactive power theory. Form a feedback control signal to control the drive of the inverter switch.

2.2. Control model

Analyzing the working principle of the circuit, we can get:

\[ u_1 - u_0 = L \frac{di}{dt} \]  \hspace{1cm} (1)

\[ i_c - i_o = C \frac{du_o}{dt} \]  \hspace{1cm} (2)

So we get the structure diagram of the controlled object model:

![Figure 2. System flow chart](image)
$G_{spwm}(s)$ is the transfer function of the SPWM modulation inverter bridge, She can be equivalent to the proportional link $K_{spwm}$, $W_h(s)$ is the harmonic component generated during the inverter process, $u_i$ is the output voltage of the inverter bridge, $u_0$ is the sinusoidal output voltage, $i_1$ is the inductor current, and $i_0$ is the load current.

3. System control scheme

Figure 3 is a diagram of the proposed system feedback control scheme, in which the fundamental wave tracking control branch transforms the error between the given reference signal and the output voltage feedback signal based on the theory of instantaneous reactive power to obtain the fundamental wave error signal; Harmonic feedback branch extracts harmonics in the feedback signal. Then, the signals obtained by the two branches are superimposed and compared with the triangular wave to obtain the SPWM switch control signal. The voltage output from the inverter bridge passes the LC filter and the transformer to output a sine wave.

3.1. Fundamental feedback control based on instantaneous reactive power theory

The three-phase AC voltage output by the inverter is sampled by a sampling transformer to form a sampling signal in closed-loop feedback control, and the sampling signal is compared with a given reference sinusoidal signal to obtain a three-phase voltage error signal. The instantaneous value of the voltage error of each phase is $\Delta e_a$, $\Delta e_b$, $\Delta e_c$. In the fundamental wave tracking control branch, the voltage error signal passes through the ip-iq transform and low-pass filter to obtain the fundamental wave instantaneous error control signal expressed in direct current under the rotating coordinate system.

This error signal provides conditions for eliminating control errors using a DC PI regulator, and the DC regulator design method is mature and simple to use. The signal is adjusted by PI compensation and inverse transformation of ip-iq transform, the fundamental wave instantaneous error control signal is restored, which creates conditions for the realization of fundamental wave feedback. As shown in the dotted box of the fundamental wave tracking control branch of figure 3.

3.2. Harmonic feedback control based on ip-iq method

When the load is a linear load, the three-phase output voltage distortion rate is low; when the load is a non-linear load, each harmonic will be generated on the main circuit. The harmonic feedback branch is added, and the ip-iq method is used to obtain each harmonic without the fundamental wave for the output three-phase alternating current error.
3.3. Design of PI parameters for compensation

The system block diagram of the fundamental wave tracking control branch is shown in figure 5.

The open-loop transfer function is as follows:

\[ H(s) = G_{LPF}(s) G_p(s) K_{g} (L C s^2 + G_{m} k_s L C s + 1)^{-1} \]  \[ (3) \]

Among them, LPF is a low-pass filter introduced by the mathematical transformation process of the signal, which has a significant impact on the dynamic performance of the control loop. Therefore, as a link of the control loop, the transfer function of LPF is:

\[ G_{LPF}(s) = (6.33 \times 10^6 \times s^2 + 0.01378s + 1)^{-1} \]  \[ (4) \]

\( G_p(s) \) is the PI regulator transfer function:

\[ G_p(s) = K_p + \frac{1}{s} \]  \[ (5) \]

The input voltage of the inverter is DC500V, the output is the effective value of the phase voltage fundamental wave 220V, and the fundamental wave voltage frequency is 50Hz. Take the output filter inductance \( L = 1 \text{mH} \) of each phase of the inverter, the capacitance \( C = 30 \text{uF} \); the transformer secondary primary transformation ratio \( k_f = 2 \), voltage feedback coefficient \( k_f = 6/220 \), inverter bridge inertia. The time constants, SPWM modulation factor \( K_{SPWM} = 58.93 \), are changed to damping by adding active damping of the inductor current feedback, and the feedback proportional coefficient \( k_z = 0.1 \).

4. Experimental simulation

The simulation circuit is built by Matlab / Simulink for simulation. The simulation parameters are as in section 3.3. Suppose the system switching frequency is 25kHz, the three-phase reference voltage amplitude is 8.48V; the triangle wave amplitude is 8.48V, the frequency is 25kHz, and the compensator PI parameter is \( K_p = 45, K_i = 300 \), the rectifying smoothing capacitance is \( C = 3300 \text{uF} \), and the simulation load resistance is \( R = 10 \) for simulation.

Under non-linear loads, when harmonic feedback is not applied, the quality of the output three-phase AC voltage waveform is observed through simulation, and the harmonic content in the three-phase output voltage is also observed. Poor quality, the voltage harmonic content in the output three-phase alternating current THD = 24.43%.
On the basis that other conditions remain unchanged, add a harmonic feedback branch, observe the quality of the output three-phase AC voltage waveform through simulation, and observe the harmonic content in the three-phase output voltage. By adding the harmonic feedback branch, the waveform quality is better, and the harmonic content is significantly reduced to 0.85%.

Finally, observe the tracking between the feedback value and the given value and the change of the output voltage when the nonlinear load changes suddenly. At t=0.6s, switch R=10 ohm to R=50 ohm.

From Figure 8, the feedback value can quickly track the given reference value and achieve error-free tracking in a short time. When T=0.6s, the resistance changes from heavy to light, and the three-phase output voltage quickly recovers and stabilizes, and the robustness is good.

5. Conclusion
This paper proposes a harmonic elimination feedback control technology. Theoretical analysis and simulation verification show that this method has a good control effect in the instantaneous feedback.
control of sine wave inverters. For nonlinear loads, this method can well eliminate the harmonics generated on the line; From the dynamic response of the output voltage when the load changes suddenly, it can be seen that the system has strong robustness and high steady-state accuracy. Therefore, this method has high practical value in the research of inverter regulated output, and can be widely used in the control of sine wave output inverter.

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