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Current Control with Improved Anti-interference Ability for Grid-connected Inverters

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***Abstract*— In order to improve anti-interference ability of current control in the grid-connected inverter, this paper presents a current control method based on the disturbance observer. According to the disturbance observer control principle, the model of closed-loop current control is used to design current disturbance observing controllers, which makes the change of three-phase grid voltages as external disturbance. This method can reduce the output current harmonics caused by the unbalanced voltages or the voltage distortion, and the simulation results are provided to demonstrate the effectiveness of the proposed method.**

***Index Terms*—current control, disturbance observer, grid voltages, current harmonics.**

I. INTRODUCTION

The grid-connected inverters are widely applied in the utility grid to convert the electric energy of DC sources to the ac power suitable for the grid transmission [1]. The power quality of grid-connected inverter is the important technical index, which is determined by the control effect of the inverter output currents.

The current control will be disturbed by the abnormal conditions of grid voltages, such as the unbalanced voltages, the voltage distortion due to the high harmonic content. The grid voltage disturbance can lead to the increase of current harmonics, and the injection of current harmonics will make the worse grid condition. The feed-forward grid voltage control is generally adopted by inverter control systems in practical application [2], which can compensate the influence of grid voltages to some extent, but cannot cope with the severe voltage disturbance.

The disturbance observer (DOB) based control schemes for linear and nonlinear systems have been put forward and applied successively in many control fields [3]–[6]. The DOB can effectively restrain the external disturbance in the closed-loop system and does not rely on precise disturbance models, which can generally be used for the feed-forward compensation design. This paper presents a current control method based on the DOB principle [7], [8], which makes the change of grid voltages as external disturbance and reduces the current harmonics caused by the abnormal conditions of grid voltages. The simulation results proves the proposed method can improve the output current quality of inverter under the unbalanced grid voltages or grid voltage distortion, and the total harmonic distortion (THD) of inverter currents is obviously lowered due to the ability of rejecting disturbances.

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II. SYSTEM MODELING

The topology of three-phase voltage source inverter (VSI) grid-connected system is shown in Fig.1. The output ac currents i_a, i_b and i_c of inverter is converted from the dc current I_{dc} of DC source through regulating the three-phase voltages v_a, v_b and v_c of VSI. The currents i_a, i_b and i_c can be the stable sinusoid wave under ideal conditions. However, the grid voltages e_a, e_b and e_c, as the external factor of current control, can make the negative impact on the quality of output currents.

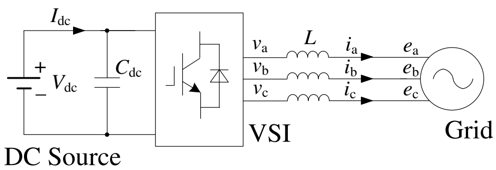


Fig. 1. Topology of three-phase VSI grid-connected system

When the voltage V_{dc} of DC source is constant, the control system of grid-connected VSI can directly achieve the decoupling control of the active and reactive power through the *dq* current components i_d and i_q of the single current loop. The block diagram of current control is shown in Fig.2, where k=*d* or *q*, i_{kr} is the reference of i_d or i_q, $R_i(s)$ is the current regulator, K_p is the equivalent gain of inverter bridge, and e_k is the *dq* component of grid voltages. The stability of current control can be strong when e_k is constant, and the change of e_k is unexpected and confused to the current control loop.

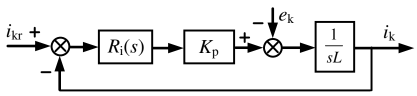


Fig. 2. Block diagram of current control

III. PROPOSED CURRENT CONTROL METHOD

A. Disturbance Observer Model

The structure of the conventional DOB is presented in Fig. 3, where $P(s)$ represents the real plant with the single input and single output, $P_n(s)$ is the nominal model of $P(s)$, d is the external disturbance, $C(s)$ is the external controller, and $Q(s)$ is a low-pass filter with unity gain. The plant output y can be given as

$$y(s) = T_r(s)y_r(s) + T_d(s)d(s) \tag{1}$$

where T_r and T_d are

$$T_r = \frac{P_n PC}{P_n(1+PC)+Q(P-P_n)} \tag{2}$$

$$T_d = \frac{P_n P(1-Q)}{P_n(1+PC)+Q(P-P_n)} \tag{3}$$

When the control signal frequency is lower than the cut-off frequency of $Q(s)$, $T_r \approx P_nC/(1+P_nC)$, $T_d \approx 0$, the equation (1) can be simplified as

$$y(s) = \frac{P_n(s)C(s)}{1+P_n(s)C(s)} y_r(s) \tag{4}$$

In this situation, the external disturbance d is removed from the expression of $y(s)$, and the change of d is not connected with the $y(s)$ in theory. Therefore, the DOB can reject the particular frequency of the external disturbance d in the closed-loop system.

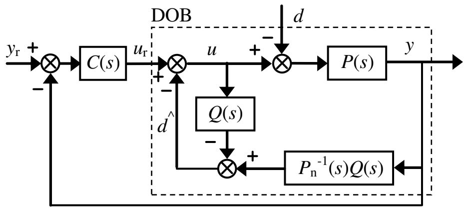


Fig. 3. Structure of the conventional disturbance observer

B. *The Design of the Proposed Method*

According to the characteristic of current control and the disturbance observer, the proposed current control method is designed as shown in Fig.4.

In this method, the external controller is the proportional integral (PI) regulator, $Q(s)$ is the second order low-pass filter, K_c is the constant coefficient which is K_p/L, and e_{ke} is the equivalent value of the grid voltage disturbance. The target of the proposed method is to reduce the current harmonics caused by the abnormal conditions of grid voltages and the upper limit of harmonics is determined by the cut-off frequency of low-pass filter. Because the harmonic types of grid voltages are generally the lower harmonics, the cut-off frequency is set at 2kHz.

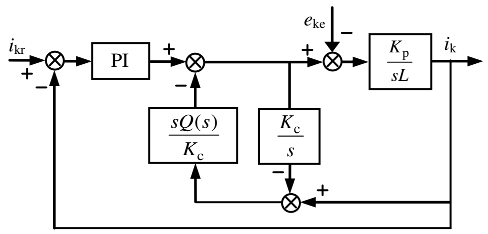


Fig. 4. Proposed current control method

IV. SIMULATION RESULTS

The simulation model of grid-connected inverter system shown in Fig.1 is built by using Matlab/Simulink. The system parameters are set as follows: VSI parameters: C_{dc} is 1100uF, L is 0.25mH, V_{dc} is 600V, the active power is 30kW, and the sampling period of control system is 0.2ms; Three-phase grid parameters: frequency is 50Hz, the rms value of line-to-line voltage is 380V.

When the phase A voltage of three-phase grid drops to 92%, the simulated results are shown in Fig.5. Fig.5(a) is the waveform of three-phase grid voltages, Fig.5(b) and (c) are the waveforms of three-phase currents without proposed method and with proposed method respectively. Fig.5(d) and (e) are the THD of the two groups of current waveforms. Compared with the results, the proposed method can effectively lower the negative impact on the current control under the unbalanced grid voltages. And the THD is reduced to 3.46% from 7.52%.

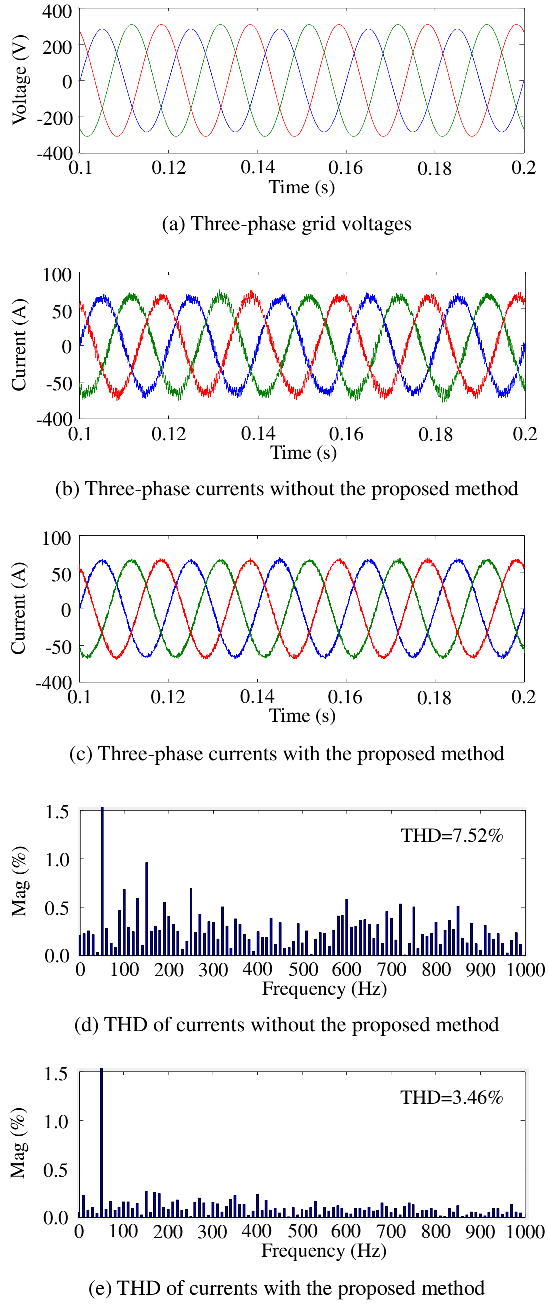
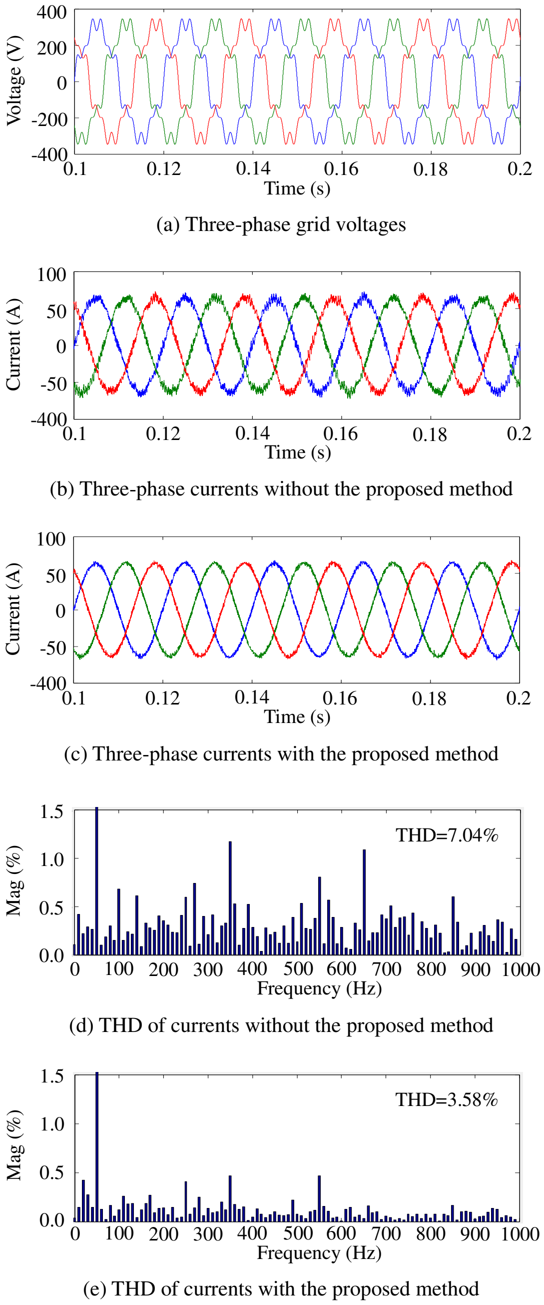


Fig. 5. Simulation results under unbalanced grid voltages

When the grid voltages contains different lower harmonics, for example, 10% fifth harmonic, 10% seventh harmonic and 10% eleventh harmonic, the simulated results are shown in Fig.6. Fig.6(a) is the waveform of three-phase grid voltages. Compared with the current waveforms without and with the proposed method, as shown in Fig.6(b) and (c), the proposed method also can reduce the current disturbance by the grid voltage harmonics, and the current THD is changed from 7.04% to 3.58% as shown in Fig.6(d) and (e).



(a) Three-phase grid voltages

(b) Three-phase currents without the proposed method

(c) Three-phase currents with the proposed method

(d) THD of currents without the proposed method

(e) THD of currents with the proposed method

Fig. 5. Simulation results under grid voltage distortion

V. CONCLUSION

This paper presents an improved current control method of grid-connected inverter based on the single control loop with the disturbance observer. The proposed method can reduce the current harmonics caused by the grid voltages due to the additional current disturbance observer. The simulation results show the effectiveness of the proposed method in two abnormal grid voltage conditions, and the improvement is quantitative by the total harmonic distortion of inverter currents.

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