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The Iterative Control Improvement Scheme of Inverter Based on Pole Configuration

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ABSTRACT: Repetitive control has strong robustness, but the dynamic performance is not high.To be able to improve dynamic performance on the basis of retaining repetitive control stability.In this paper, an improved repetitive controller is introduced in detail, and the method of instantaneous value feedback is used to implement pole configuration of inverter and combine with repetitive controller.Through the pole assignment of inverter to improve the inverter's own damping size, improve the dynamic characteristic of the inverter power supply, using repetitive control, each cycle correction voltage instruction to improve accuracy of amplitude, and compensate for waveform distortion.The simulation result shows that the design to improve the performance of the inverter, effectively reduce the total harmonic distortion rate of inverter, maintained the repetitive control itself already has good steady-state performance, but also because of pole assignment and dynamic performance of the system was improved.
Keywords: inverter; pole placement; repetitive contro*l;*

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I. INTRODUCTION

In digital control technology, repetitive control has good steady-state output performance and can control the inverter's output voltage accuracy under different loads. However, due to its own design features, the control output lags one cycle, so the ability of dynamic control of repetitive control is not sufficient. The state feedback waveform control system freely adjusts the poles of the closed---loop system by changing the gain matrix in the state space. Dynamic characteristics, increase the dynamic performance of the system itself. The composite control method of "pole configuration + repetitive control" not only satisfies the dynamic characteristics of the inverter but also realizes the steady-state accuracy. Finally, the feasibility of this scheme is proved by simulation.

II. THE MATHEMATICAL MODEL ESTABLISHMENT AND ANALYSIS OF INVERTER

In this paper, the object of UPS inverter, in fact, is a nonlinear system, thetheoretical analysis of the process has some difficulties. In order to facilitate the analysis, the inverter bridge is simplified, to build a single-phase voltage SPWM inverter. Therefore, this paper assumes that the constant DC voltage, the inverter output fundamental frequency is low enough, the LC filter resonant frequency and the switching frequency is only relatively small[1], you can get the state model circuit shown in Figure 1-1:

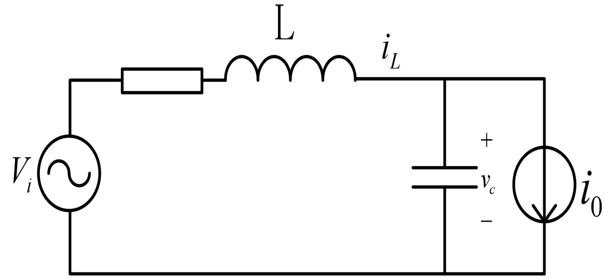

FIG. 1 state model circuit of single-phase voltage SPWM inverter

As shown, the voltage source v_i is actually a series of PWM pulse sequences that represent the output voltage of the inverter bridge. Current source i_o and filter inductance L and filter inductance equivalent series resistance r mutual synthesis, the waveform can be arbitrary. According to Kirchhoff's theorem, the small signal model of the inverter can be obtained by analyzing this model:

$$\begin{aligned} \frac{dv_c}{dt} &= \frac{1}{C} i_L - \frac{1}{C} i_o \\ \frac{di_L}{dt} &= \frac{1}{L} v_i - \frac{1}{L} v_c - \frac{r}{L} i_L \end{aligned} \quad (1)$$

The state variable chooses the capacitor voltage v_c and the inductor current i_l , you can get the inverter's continuous time state side:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx \end{aligned} \quad (2)$$

Where:

$$\begin{aligned} x &= [v_c \quad i_L]^T \\ u &= [v_i \quad i_o]^T \quad (3) \\ y &= v_c \end{aligned}$$

$$A = \begin{bmatrix} 0 & \frac{1}{C} \\ -\frac{1}{L} & -\frac{r}{L} \end{bmatrix} \quad (4)$$

$$B = \begin{bmatrix} 0 & -\frac{1}{C} \\ \frac{1}{L} & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

This mathematical model analysis shows that this is a two-input, single-output second-order linear system. Control input inverter bridge output voltag-e v_i , while the load current i_o can be regarded as disturbance input. In this way, the mathematical model is more representative even when theload brought by the inverter is non-linear and only shows in the nonlinear perturbation [2].

To build a digital controller based on a discrete space model, the control system must be discretized, taking into account the need to introduce the instantaneous value of the sampling period as the actual sampled value for that period into the zero-order retainer. Through the method of "increasing the zero order retainer discretization", the following discrete state space model is deduced further:

$$\begin{aligned} x(k+1) &= Gx(k) + Hu(k); \\ y(k) &= Cx(k); \end{aligned} \quad (5)$$

Where:

$$\begin{aligned} x(k) &= \left[v_c(k) \quad i_L(k)\right]^T; \\ u(k) &= \left[v_i(k) \quad i_0(k)\right]^T; \\ y(k) &= v_c(k); \quad (6) \\ G &= e^{AT}; \\ H &= A^{-1}(e^{AT} - 1)B; \end{aligned}$$

Inputs $u(k)$ As mentioned above, a series of PWM pulse sequences, according to the "impulse equivalent principle", the voltage of a cycle v_i pulse average can be regarded as this sample value.

III. THE PLAN OF REPEAT CONTROL

Repetitive control is based on the internal model proposed inverter control. The advantage is that it has a strong robustness, but the disadvantage is that its control output lags behind one cycle, so the ability of dynamic adjustment is not sufficient.

3.1 repeat the controller

The block diagram is as follows:

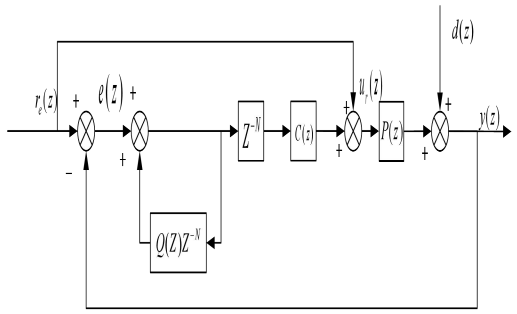

FIG. 2 block diagram of repetitive control

$r_e(z)$ in the above figure is the periodic sine reference signal, and the sampling period is T. $e(z)$ is the error, $y(z)$ is the inverter output voltage, and the fundamental period is an integer multiple of the load disturbance $d(z)$. According to the system structure chart experiment, build simulation platform, as shown below:

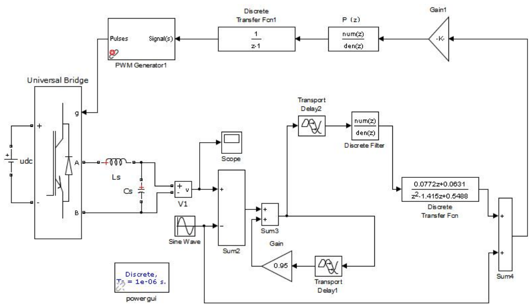

FIG. 3 simulation experiment of repetitive control

For the ideal repetitive controller, there is $Q(e^{j\omega T})=1$. From this analysis, it can be obtained that the repetitive control under any periodic disturbance can realize the tracking input instruction without steady-state error.

3.2 improved repetitive control signal generator

According to the empirical value, the repetitive control signal generator $Q(z)$ is set to 0.95, and the mathematical equation of the improved repetitive signal generator is obtained as:

$$u(k)=e(k)+0.95u(k-N); \quad (7)$$

The equation shows that the repeater loses its conditioning effect when the input error is equal to 5% of input. Therefore, the repetitive controller essentially changes the pure integral of the error to "quasi-integral" and weakens the non-static difference in improving the stability.

3.3 repeated control compensator

When the error information is generated in the previous cycle, the compensator will $C(z)$ provide the appropriate control amount in the next cycle to weaken the effect of the error. By providing phase and amplitude compensation, to improve the stability of the premise, to improve the effect of waveform correction.

The phase frequency characteristics of the best is the inverse of the object $P(z)$, in order to offset the control object $P(z)$ zero pole. $P(z)$ is a second-order linear system with phase lag characteristics. It is envisaged to utilize the delay section z^{-N} such that the control amount is delayed by the appropriate time of the next cycle so as to obtain the "advance" of the controlled object, cancel the phase lag characteristic and improve the dynamic response of the controlled object. The leading edge of Z^k has a modulus constant of 1, which is proportional to the frequency under consideration. Therefore, lead phase Z^k advanced phase characteristics in the low frequency band on the controlled object $P(z)$ and filter $C(z)$ introduced phase lag, so that $Z^k P(z)C(z)$ in the low band is approximately zero phase Moving characteristics.

The general form of compensator $C(z)$ is:

$$C(z) = k_r z^k S(z) \quad (8)$$

Where $S(z)$ filter gives asymptotic stability by attenuating the resonant peak of the inverter; k_r can be selected as the repeat control gain in the range of [0,1]. The design of the filter $S(z)$ must be designed under no-load conditions because the system has the least damping and the highest resonant peak of the inverter when the inverter is in no-load.

3.4 repeat the controller performance analysis
Analysis of the error can be obtained System block diagram is:

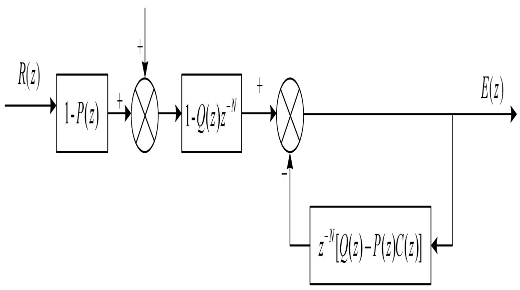

FIG. 4 block diagram of error system

Combined with the principle of small gain, the system is analyzed. It can be seen that when the gain of the open-loop function of the feedback loop is always less than 1, the system must be stable.

IV. INVERTER POLE CONFIGURATION SCHEME

The standard repetitive control generator is equivalent to a cyclical integration, which allows the system to have N poles on the unit circumference, greatly affecting the stability of the system. The most direct way to improve the inverter's own damping and increase the stability is to increase the inverter's damping by increasing the pole of the inverter away from the imaginary axis of the s-domain by introducing state feedback [3] [4].

4.1 inverter pole configuration program

Through multiple considerations, the inverter feedback state should choose the capacitor current. After the above analysis, the state feedback $U = r - KX$ is introduced into the discrete-state space model of a single-phase voltage inverter, where r is the reference instruction of the closed-loop system and K is the feedback gain matrix, then the closed-loop system The equation of state is

$$\begin{aligned} X(k+1) &= (A - BK)X(k) + Br(k) \\ y(k) &= CX(k) \end{aligned} \quad (9)$$

The eigenvalues of $(A - BK)$ determine the poles of the closed-loop system. With the appropriate feedback gain matrix K, the pole of the system can be configured to the desired location.

The mathematical model draws the state feedback link as shown in the figure below. The basic principle is to reconstruct a virtual dynamical system that itself forms a closed-loop system

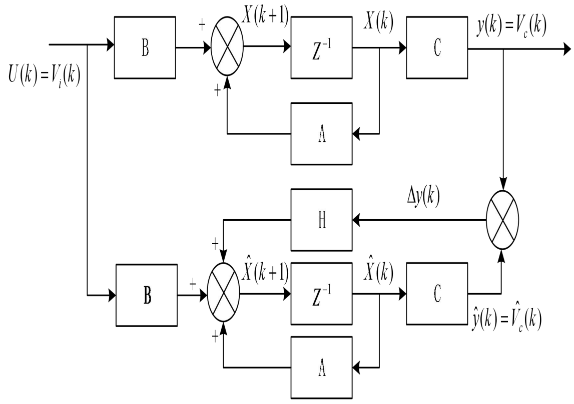

Figure 5 status feedback

The state variable $\hat{X}(k)$ as the observation value of the actual variable; the difference between the observer and the actual system output $\Delta y(k)$ corrects the observed value of the state variable; H is the output of the error state variable observation value Feedback matrix. The error expression is:

$$e_x(k+1) = (A - HC)e_x(k) \quad (10)$$

Among them:

$$e_x(k) = X(k) - \overline{X}(k) \quad (11)$$

To observe the error of the state variables, the above error system's dynamic process is determined by his two poles. As long as the eigenvalues of（$A - HC$）are located in the Z plane, the error expression of the state observer will converge.

4.2 with integral pole configuration

When the system damping ratio is 0.707, the dynamic quality of the system should be the most excellent. However, in practical applications, the inverter damping system with a load increase. Therefore, in the case of no-load, set the system damping to 0.5 to reserve the margin.

The known inverter equation of state is:

$$\begin{aligned} X(k+1) &= AX(k) + BU(k) \\ y(k) &= CX(k) \end{aligned} \quad (12)$$

The state variables are the capacitor voltage and the capacitor current, and the output y value and the state variable x are used as the feedback variables. The new variable is X_I and satisfies:

$$\dot{X}_I = CX = y \quad (13)$$

The original system becomes:

$$\begin{bmatrix} \dot{X}_I \\ \dot{X} \end{bmatrix} = \begin{bmatrix} 0 & C \\ 0 & A \end{bmatrix} \begin{bmatrix} X_I \\ X \end{bmatrix} + \begin{bmatrix} 0 \\ B \end{bmatrix} u \quad (14)$$

The main dynamic characteristics of the system are determined by S of the dominant pole $-2227 \pm 3858i$, and the system feedback gain matrix is $\begin{bmatrix} 0.77827 & 2 & 9.3 \end{bmatrix}$.

V. COMPOUND CONTROL

The design scheme proposed in this paper includes repetitive control and pole-state configuration based on state feedback. By combining the advantages of the two and compensating each other, the new composite control system is formed. The overall structure of the block diagram is as follows:

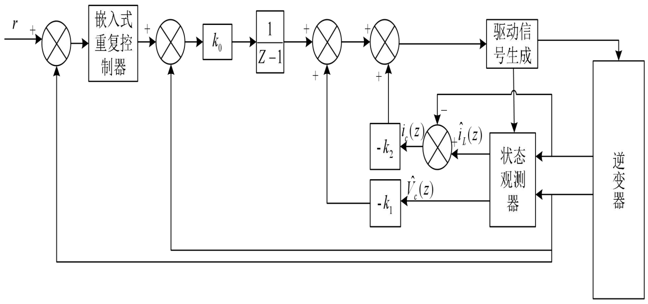

FIG. 6 block diagram of complex control system

According to this block diagram, the simulation model is constructed as shown below:

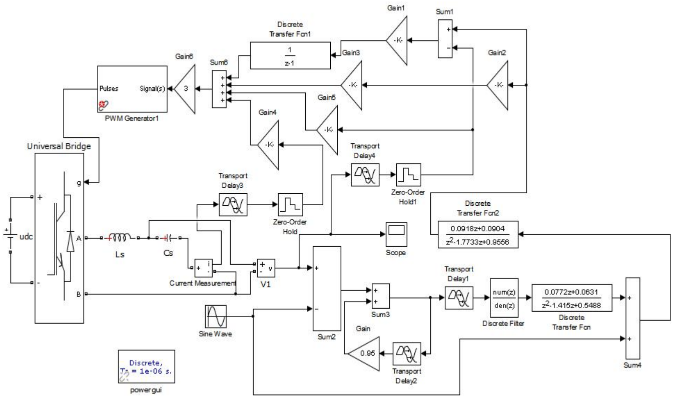

FIG. 7 composite control simulation model

In this system, the pole configuration formed by the state feedback improves the dynamic performance of the system and is in the system. Repeated control reduces the waveform distortion outside the system. In principle, when both controls are individually stable, then the result of compound control should also be stable.

VI. SIMULATION RESULTS

Simulation of the above said design, in the case of no-load can be repeated control and composite control simulation results were as shown below:

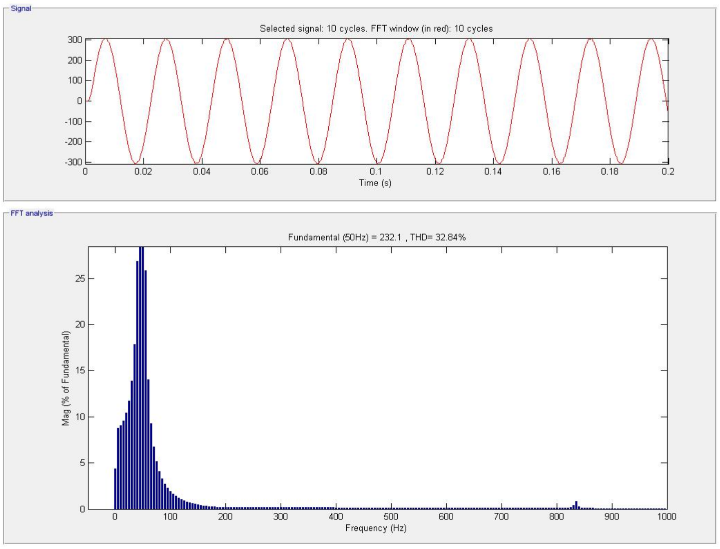

FIG. 8 control simulation result graph

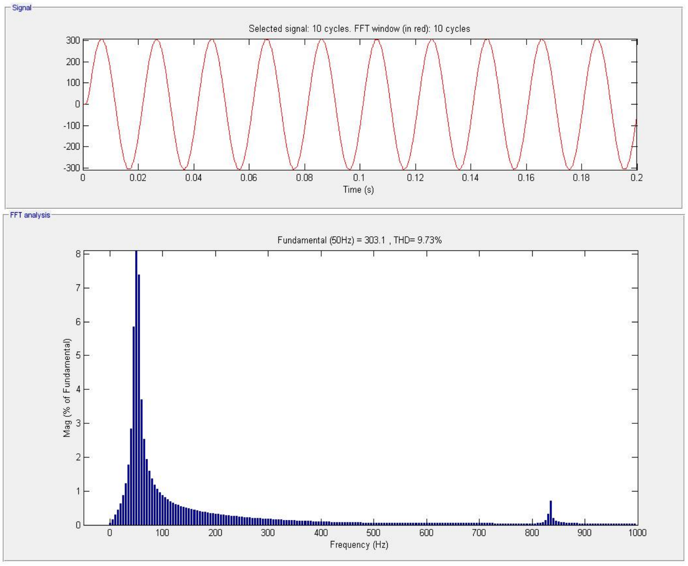

FIG. 9 simulation results of composite control

By comparing the results of two simulation experiments, it can be seen that the output voltage waveform of a single repetitive control can reach a steady state faster, but the THD content is higher. In the experimental results shown in the second figure, the composite output of the inverter with the combination of the pole configuration has an ideal output waveform, and the voltage harmonic distortion rate is obviously decreased, which is better. In order to verify the circuit with the load function, the circuit simulation of sudden load reduction circuit simulation, draw the waveform results as shown below:

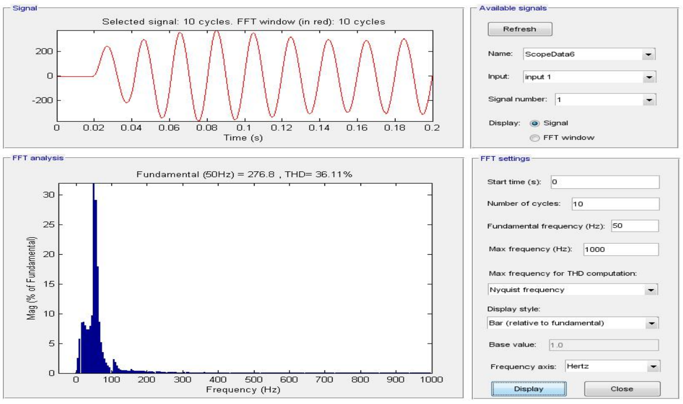

Figure 10. Repetitive control process loading

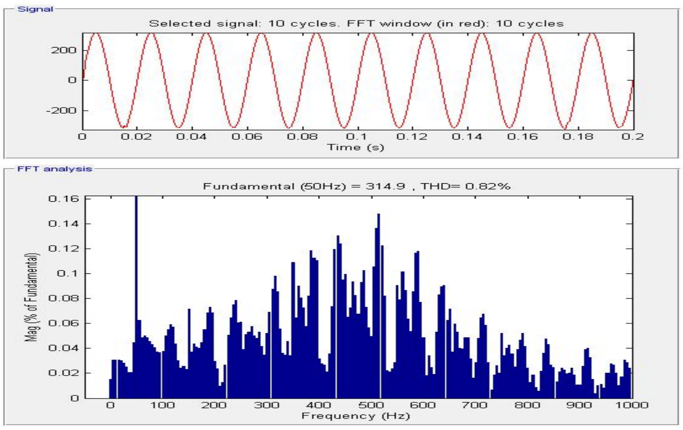

Figure 11. Composite control process loading rendering

It can be seen from the analysis that the waveform distortion is larger in the process of sudden load reduction and sudden load control. With the introduction of state feedback, the output waveform distortion rate is significantly reduced and the waveform quality is also improved.

VII. CONCLUSION

In this paper, the application and principle of repetitive control in inverters are analyzed in detail, and a new type of repetitive control strategy based on pole assignment is proposed through the study of pole placement method. The experimental results show that , The program is effective, has some practical value, can make the system get more ideal stability and dynamic characteristics.

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