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Research on Waveform Control of Repeating Pulsed Flat-Top Magnetic Field Based on Pulsed Generator-rectifier System

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I Introduction

Repeating pulsed flat-top high magnetic field (RPFHMF) can promote the development of the science researches such as neutron diffraction, terahertz source and biomedical. In the applications that only need several repeating waveforms, pulsed magnets can be used for its advantage of being compact, cheap and easy to use. But due to the limited capability of heat dissipation, the magnet resistance gradually becomes bigger and bigger which leads to inconsistencies of the waveforms. Therefore it is necessary to control the magnetic field waveforms to be consistent.

Problem：

Pulsed power system, energy is difficult to manage

The acute change of the magnet resistance

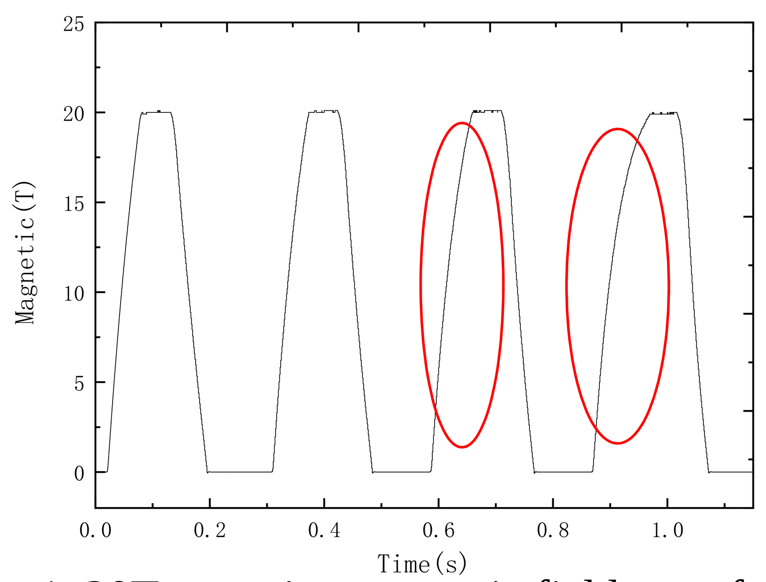


Fig. 1. 20T repeating magnetic field waveform

In this paper, by analyzing the feature of repeating pulsed magnet, a pulsed generator-rectifier system is used as the power supply. Based on the accurate power supply modeling of external characteristics, the control method of GPC is proposed. In this GPC, a 3-levels least square algorithm is designed to get the real-time magnet resistance, in order to restrain the effect by the load changes. Finally, the results verified the feasibility and validity of the waveform control method of RPFHMF.

II Power topology and modeling

Topology Considering of the discharging current and resistance change, a pulsed generator-rectifier system is used to generate the RPFHMF for its' advantage of storage energy and control ability .

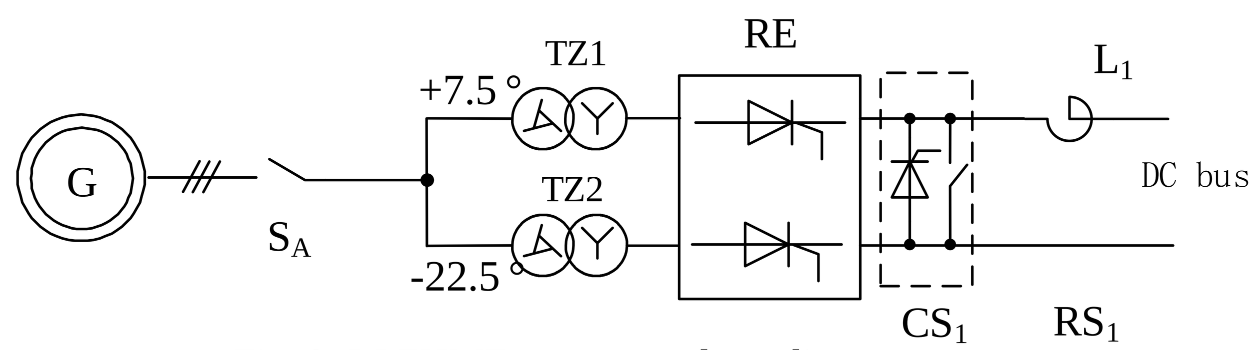


Fig. 2. RPFHMF power topology diagram


Fig.3. The picture of 100 MVA / 100 MJ Generator and a 67.5 MW rectifier

Coupling Controlled Voltage Source

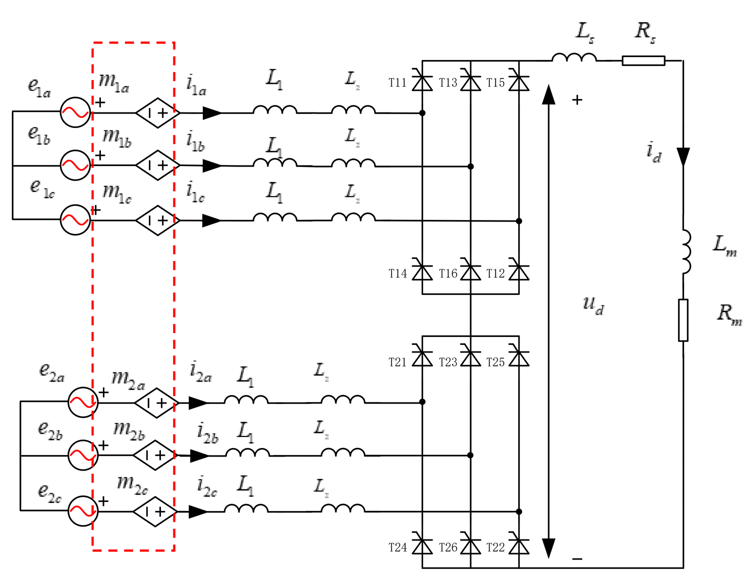


Fig. 4. Equivalent circuit of RPFHMF system

Modeling Due to the discharge current is large, one 6-pulse rectifier working will affect the input voltage of the other. There is strong coupling between these two rectifiers, so it's difficult to get the output voltage external characteristic. In this paper, an equivalent circuit model based on coupling controlled voltage source is proposed, and the related voltage matrix expressions are obtained, which include the information of the phase-shifting transformers. Accordingly, the external characteristic equation of the output voltage considering overlap angle of commutation is obtained.

$$\begin{cases} E_1 = [e_{1a} \quad e_{1b} \quad e_{1c}]^T = A_1 E_0 = A_1 [e_a \quad e_b \quad e_c]^T \\ E_2 = [e_{2a} \quad e_{2b} \quad e_{2c}]^T = A_2 E_0 \\ M_1 = [m_{1a} \quad m_{1b} \quad m_{1c}]^T = A_1 A_2^{-1} \left[-L_1 \frac{di_{2a}}{dt} \quad -L_1 \frac{di_{2b}}{dt} \quad -L_1 \frac{di_{2c}}{dt} \right]^T \\ M_2 = [m_{2a} \quad m_{2b} \quad m_{2c}]^T = A_2 A_1^{-1} \left[-L_1 \frac{di_{1a}}{dt} \quad -L_1 \frac{di_{1b}}{dt} \quad -L_1 \frac{di_{1c}}{dt} \right]^T \\ L_1 = L_1' / k^2 \end{cases}$$

The Matrix expression of the coupling controlled voltage source

$\gamma < 30^\circ$

$$\begin{cases} V = V_{D0} - \Delta V = \frac{6\sqrt{2}V_l}{k\pi}\cos(\alpha) - 12f(L_1 + L_2)i_d \\ \cos(\alpha) - \cos(\alpha + \gamma) = \frac{2k\omega(L_1 + L_2)}{\sqrt{2}V_l} i_d \end{cases}$$

$30^\circ < \gamma < 60^\circ$

$$\begin{cases} I_d = \frac{\sqrt{2}V_l}{k\omega}\left(16167\sin(\alpha + \gamma - 49.1^\circ) + 9247\sin(\alpha - 18.6^\circ)\right) \\ V = \frac{6\sqrt{2}V_l}{k\pi}\left(0.67\sin(\alpha + \gamma - 23.1^\circ) - 1.25\sin(\alpha - 43.0^\circ)\right) \end{cases}$$

External characteristic equation

III Control method

Based on the accurate mathematical model of pulsed generator-rectifier system, a control strategy based on GPC is proposed to solve the problem of inconsistent waveforms of multi-pulse flat-top high magnetic field.

Control Structure The generalized model predictive control is fast, robust and adaptive, so that it can be well applied to time-delay and nonlinear systems. The proposed GPC control system structure is shown in Figure 5. Firstly, the least square method is used to real-time calculate the magnet resistance and the phase-locked loop (PLL) is carried out according to the generator voltage; secondly, the firing angle of the next period is predicted by the input and the external characteristic equation of the model; finally, the PI controller is used to eliminate the model error.

Generalized model prediction

Fast and accurate

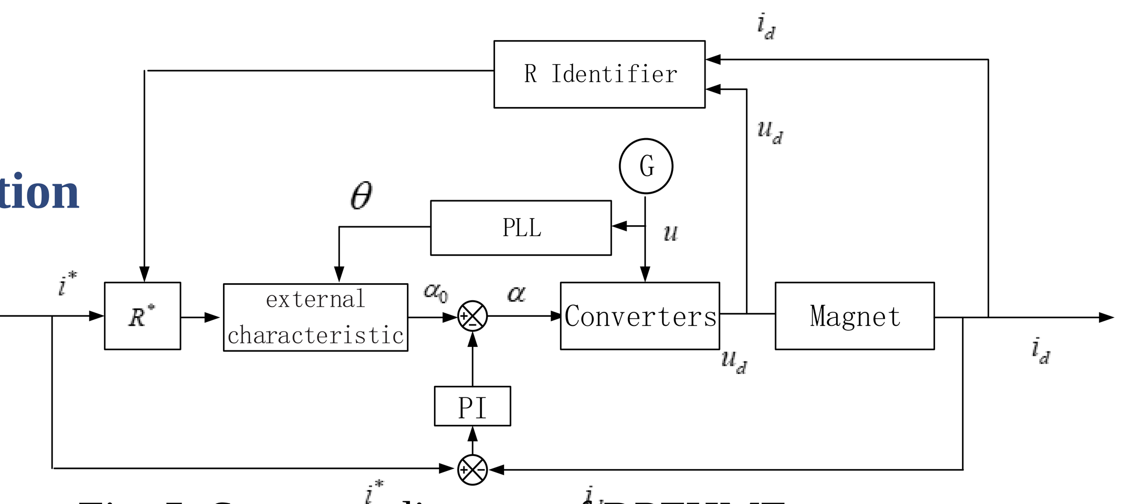


Fig. 5. Structure diagram of RPFHMF system

Initial Parameter

Keep some space for control

$$\alpha_0 = 50^\circ$$

$$E_0 = \frac{\pi k}{6\sqrt{6}}(L_s + L_m)\cos(\alpha_0)\frac{di_0^*}{dt}$$

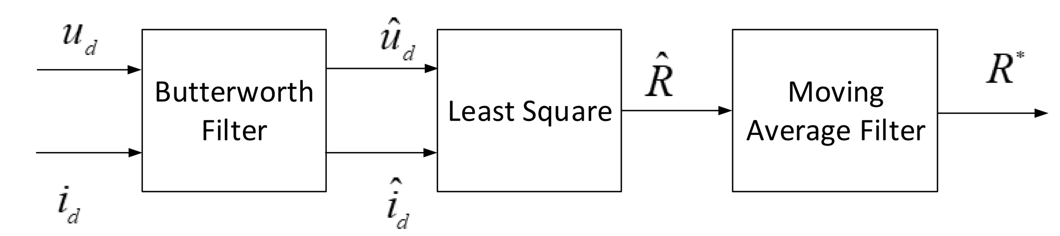
PLL In order to quickly and accurately achieve the phase-locked, a genetic algorithm (GA) PLL based on virtual generator voltage is applied in the system.

Genetic algorithm (GA) PLL Based on Virtual Voltage

$$E_0^* = U + L_1' \frac{di}{dt}$$

Real-time Calculation of Magnet Resistance

In order to identify magnet resistance quickly and accurately, a real-time least square identification algorithm with three-stage structure, as shown in figure 6, is proposed in this paper.



Measure noise filter **R calculator** **Calculation error filter**

Fig. 6. Resistance parameter identification system

IV Results

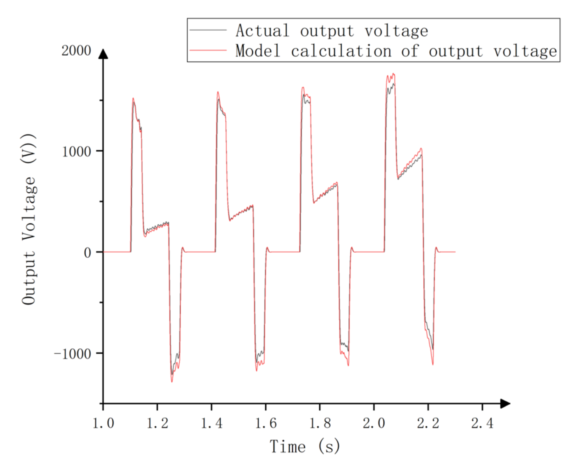


Fig.7. Output voltage of rectifier

The external characteristic model is feasible

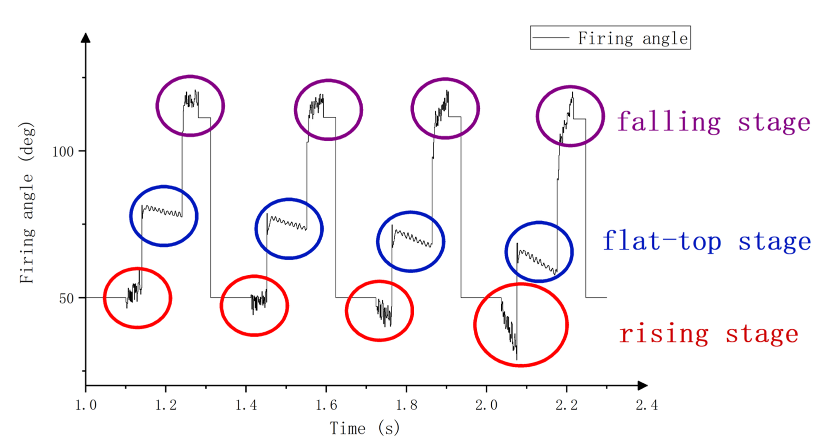


Fig. 8. Firing angle

Firing angles of 3 stages are suitable

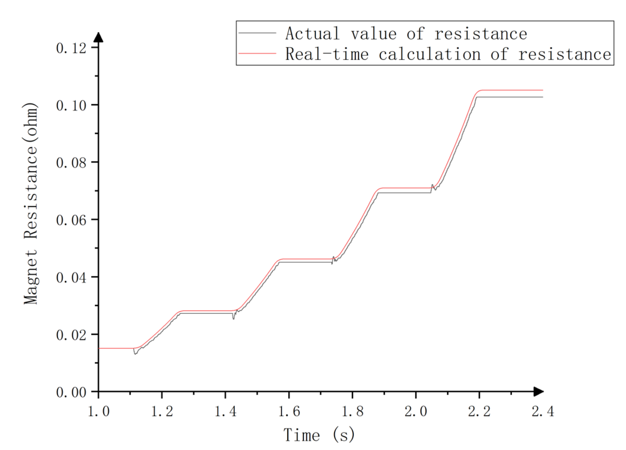


Fig. 9. Real-time calculation of resistance

Calculation Error less than 5%

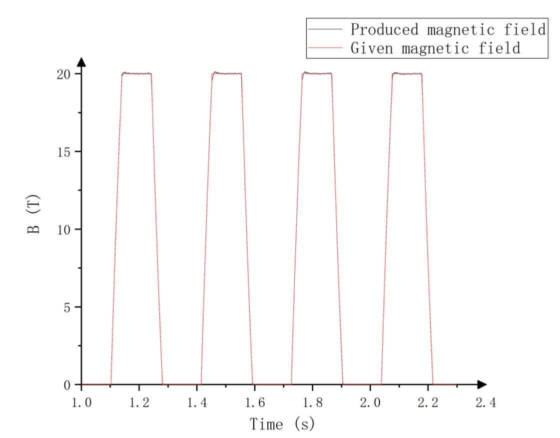


Fig. 10. Repeating magnetic field waveform with GPC

Good waveforms consistence

V Conclusion

- According to the change in the magnet resistance, the pulsed generator-rectifier system is used as power supply to generate multi-pulse flat-top magnetic field and an accurate mathematical model is established.
- The magnet resistance is identified in real time, and a strategy based on GPC is designed to control the magnetic field waveforms.
- The whole process control of multi-pulse flat-top magnetic field is realized, and the pulsed flat-top magnetic field with good repeatability is obtained.