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Design of a Hybrid Power Supply for Quasi-continuous High Magnetic Field with a Dual-coil Magnet

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I. Introduction

With the growing application of physics, biology, NMR and many other scientific fields [1], the pulsed high magnetic field is required for a high magnetic field, a low ripple and a long duration of the flat-top [2]. The quasi-continuous high magnetic field (QCMF) with above-mentioned features has received a lot of attention in recent years [3], [4].

Considering the power supply developed at the WHMFC [7], this paper proposes a hybrid power supply to generate a QCMF with high parameters. The power supply combines the advantages of both GRPS and capacitor power supply (CPS). CPS reduces the rise time of the magnet current by high dis-charge voltage, and the GRPS sustains the flat-top by varying the trigger angle of the rectifiers.

II. QCMF System

A. Power Supply

As shown in Fig. 1. The power supply of QCMF system is composed of GRPS and CPS. GRPS consists of a 100 MW/100 MJ pulse generator and two 12-pulse rectifiers (RE_1, RE_2) [8]. Rectifiers are connected in parallel through smoothing reactors L_3 and L_4. CPS consists of capacitor C_0, crow bar and switch T_1. C_0 is made up of 11 high density 3.2 mF/25 kV/1 MJ capacitor modules [9]. The capacitor modules are charged to an initial voltage of 24kV to energize the coil.

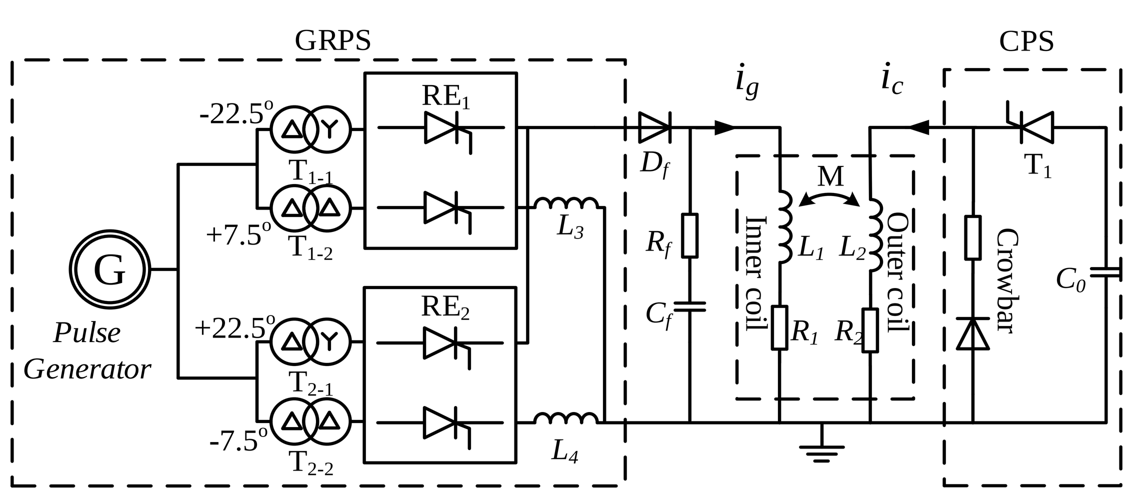

Fig. 1 The fundamental structure of QCMF system.

B. Dual-coil Magnet

For safety reasons, the magnetic force and temperature of the conductor must be kept below a certain value. Therefore, the dual-coil magnet is more suitable to generate a QCMF with high parameters compared to the single-coil magnet [10]. Efficient design software PMDS [11] is adopted to design the 65 T/100 ms dual-coil magnet. The inner coil which is represented by L_1 and R_1 is powered by GRPS. The outer coil which is represented by L_2 and R_2 is powered by CPS.

III. Protection of Hybrid Power Supply

A. System Fault Analysis

The short circuit fault which occurs between the first turns of the two coils is the worst fault. The over-voltage and frequency are so high that the rectifiers will break down immediately.

The simplified QCMF system is shown in Fig. 2. R_f and C_f represent the resistance and capacitance of the R-C branch. D_f represents the diode array (type D6001N, made by EUPEC).

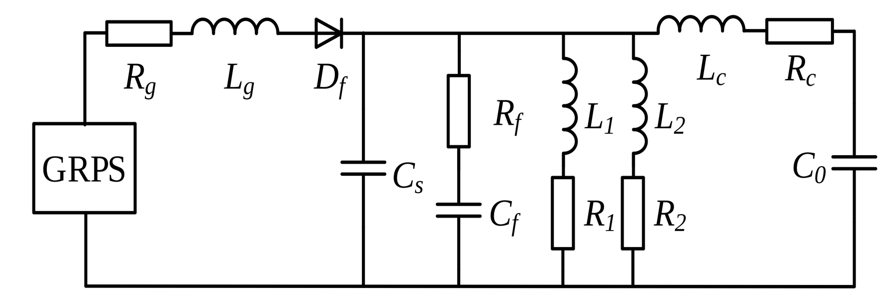

Fig. 2 The simplification of QCMF system.

B. R-C Branch and Diode Array

R_f = 4 Ω and C_f = 7 μF are the most appropriate parameters configuration of the system. The peak value of the fault voltage has been reduced from 46.5 kV to 23.75 kV. The optimal number of series and parallel of diode array are 6 and 2 respectively. As shown in Fig. 3, the maximum voltage of rectifiers RE_1 and RE_2 is reduced to 6000 V. This scheme gets the voltage redundancy more than 20%. Additionally, the R-C branch and diode array can be transformed from the existing equipment in WHMFC.

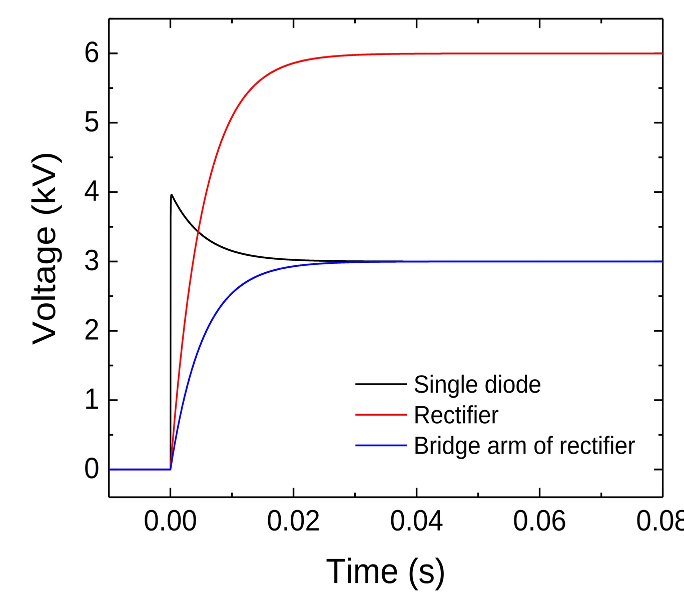

Fig. 3 Fault voltage.

IV. Control Strategy

The control strategy is shown in Fig.4. When the start signal is introduced to the system, CPS begins to energize the outer coil. When the outer coil current i_c reaches the designed value, GRPS begins to power the inner coil with a trigger angle of 10°. When the synthetic magnetic field reaches the given value, the self-adaptive PI feedback controller starts to control the trigger angle of rectifiers.

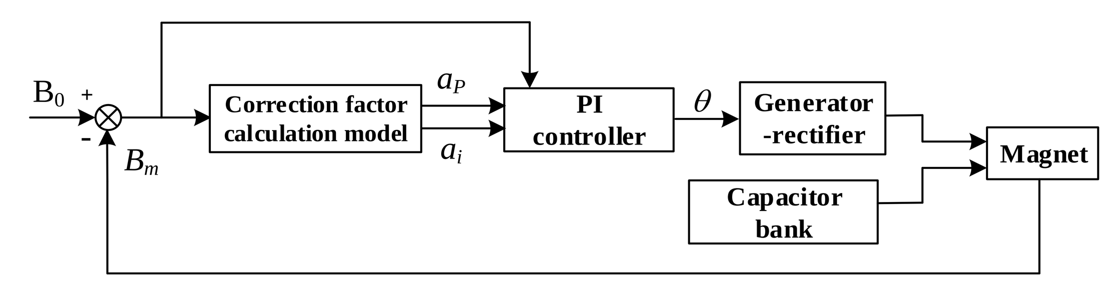

Fig. 4 Control loop of the system.

As shown in Fig. 5, the back propagation learning algorithm is applied in the network and the system could reach the minimum error in the least-squares sense [12]. a_p and a_i are the correction factors to make the coefficients of the PI controller change with the fluctuation of error. According to (1), the weights can be adjusted. K_P and K_I can be adjusted with the fluctuation of the magnetic field and sustain the flat-top at a given value. According to (1), the weights can be adjusted. K_P and K_I can be adjusted with the fluctuation of the magnetic field and sustain the flat-top at a given value.

$$\Delta W_i^1(k) = -n\times(dE(k)/dW_i^1(k)) + a\times\Delta W_i^1(k-1)$$
$$W_i^1(k) = W_i^1(k-1) + \Delta W_i^1(k) \qquad i=1,2,3$$
$$\Delta W_{i,j}^2(k) = -n\times(dE(k)/dW_{i,j}^2(k)) + a\times\Delta W_{i,j}^2(k-1)$$
$$W_{i,j}^2(k) = W_{i,j}^2(k-1) + \Delta W_{i,j}^2(k) \qquad i=1,2 \quad j=1,2,3 \qquad (1)$$

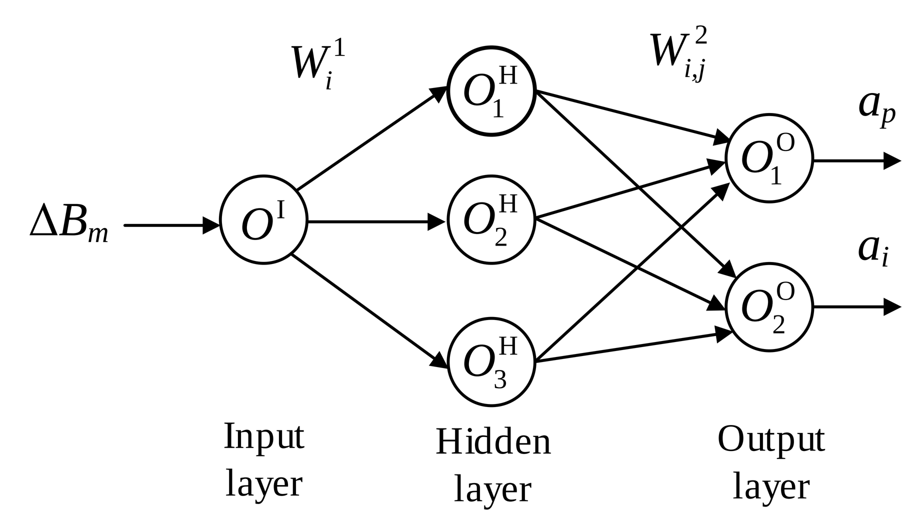

Fig. 5 Diagram of BP neural network. The network is a multilayered network with an input layer, a hidden layer and an output layer

V. Simulation Results

The Matlab/Simulink is used to model and simulate the proposed system and the control strategy. K_P and K_I are shown in Fig. 6 and Fig. 7 respectively. Fig. 8 shows the magnetic flux density curve in the center of magnet. The magnetic field presented by the dotted line in the outer coil has a peak value of 39.1 T and the dashed line shows the maximum of inner coil is 41.8 T. Therefore, the 65 T QCMF with 100 ms flat-top can be obtained by adding two magnetic fields together. The inset graph shows that flat-top lasts from 0.079 s to 0.18 s and has a ripple less than 160 ppm.

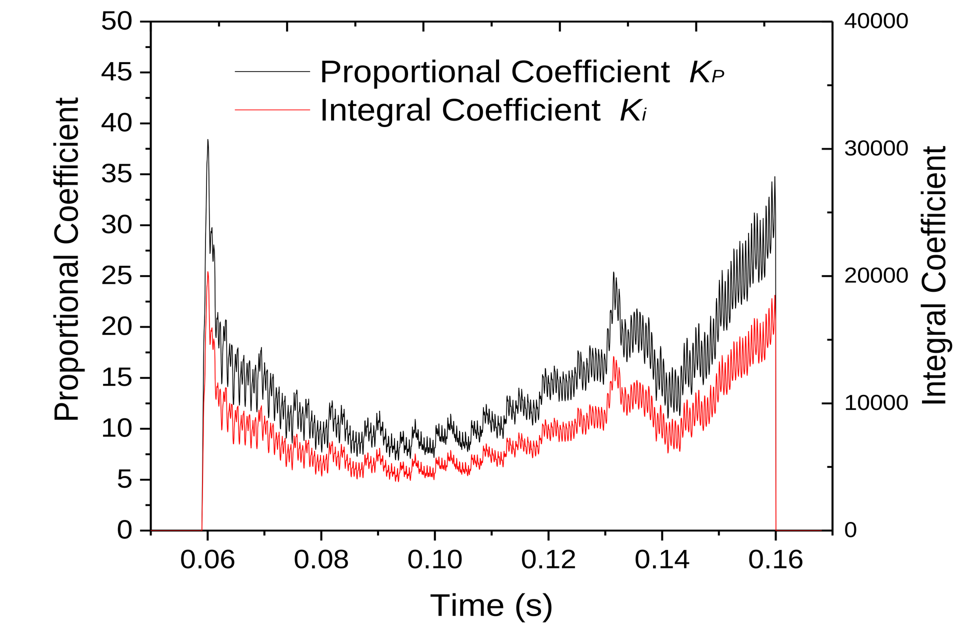

Fig. 6 Proportional coefficient and integral coefficient of PI controller.

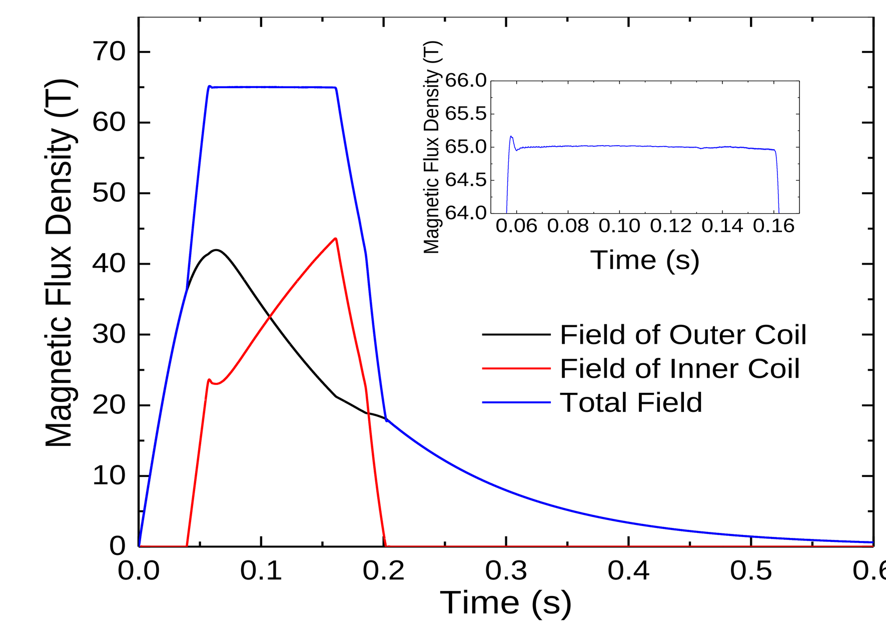

Fig. 7 Magnetic flux density.

VI. CONCLUSION

This paper proposes a 65 T/ 100 ms QCMF system consisting of a 100 MVA pulsed-generator and a 10.14 MJ capacitor bank. The protection circuit consists of an R-C branch and a diode array steps the short-circuit voltage of rectifiers from 45 kV to 6 kV. The self-adaptive PI controller based on the BP neural network re-places traditional PI controller and the ripple of the flat-top is reduced to less than 160 ppm (0.016%). The system is under construction and experimental results will be introduced in the near future.

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