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The Design and Analysis of Power Supply Topology for High-field MRI Superconducting Magnet

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1. Introduction

High-field magnet resonance imaging (MRI) is designed as a large aperture human body imaging system. The magnet will operate in persistent mode, which means there is a superconducting switch (SS) parallel to magnets. The SS is on resistance state during excitation and demagnetization and on superconducting state during constant current operation. The power supply : charge to magnet when exciting, maximum +40 V; invert magnet energy to power grid when demagnetizing, maximum - 40 V; output current: 250 A; output voltage ripple rate: 500 ppm.

The thyristor rectifier can meet the requirements of energy feedback, but it has shortage i.e. low operating frequency, slow response and low power factor. This paper proposes a topology of three-phase PWM rectifier plus H-bridge circuit.

2. Topology introduce

The circuit topology consists of three stages: input stage, middle stage and output stage. The input stage is three-phase PWM rectifier. The middle stage is H-bridge converter. The output stage is inductance-capacitance-resistance (*LCR)* filter circuit. The circuit topology is shown in Fig. 1.

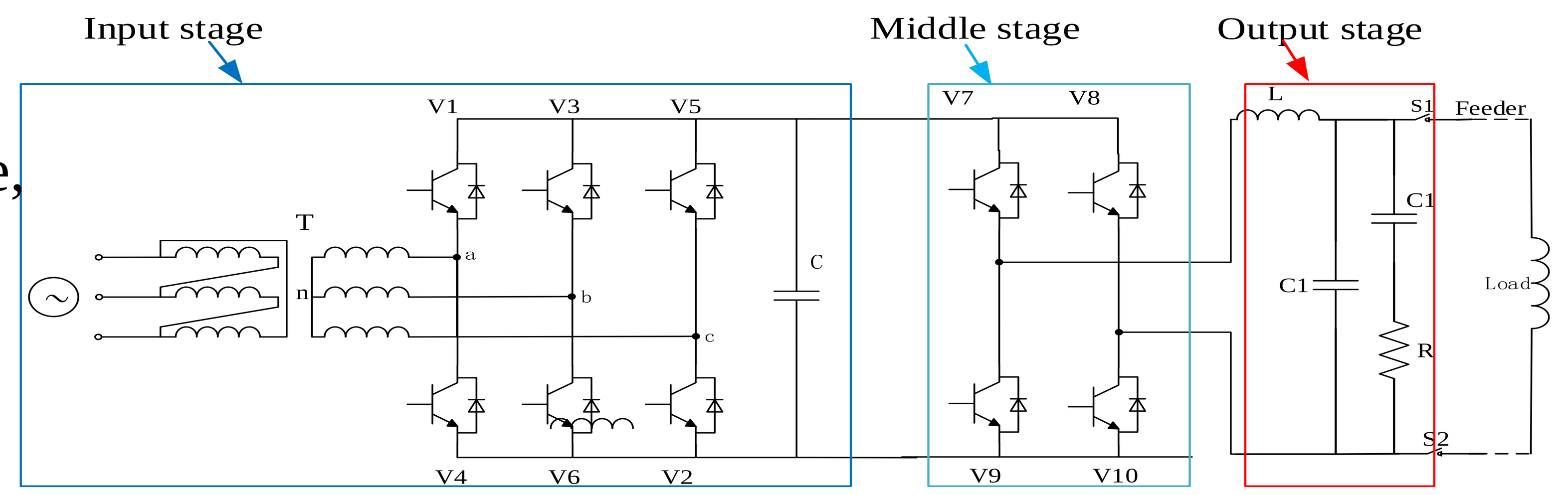


Fig. 1 The topology of power supply

- During excitation, input stage is in rectifier state and the middle stage works as buck chopper with V7&V9 switching, V8 closed state and V10 conduction state.
- During demagnetization, input stage is in inverted stage. V8 & V10 are switching with V7 closed and V9 conducting.

3. Topology analysis

3.1 Input stage The model circuit of PWM rectifier consists of AC circuit, power switch bridge circuit and DC circuit. Among them, AC circuit includes AC electromotive force *e* and inductance *L* on the network side, DC circuit includes load resistance R_L and load electromotive force e_L (see Fig. 2).

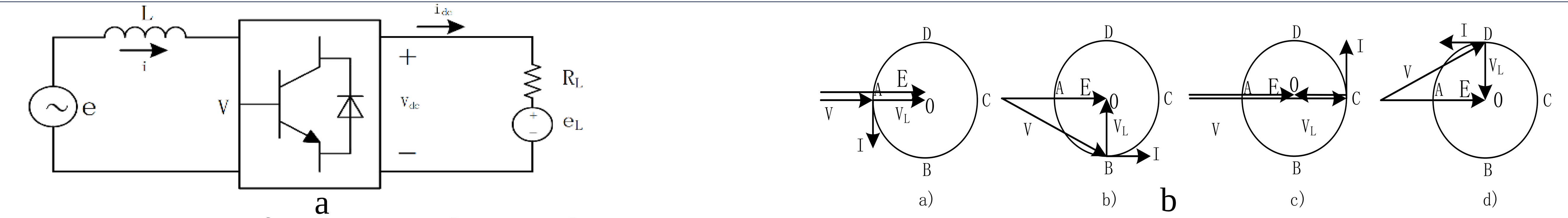


Fig. 2 PWM rectifier circuit and vector diagram

To realize the two-quadrant operation, it is necessary to control the current on power grid side. When exciting, PWM rectifier is on the state of rectifier with **V** being on the , which absorbs active and reactive power from power grid. When demagnetizing, PWM rectifier is in the state of active inversion, which transmits active and inductive reactive power to power grid.

3.2 Middle stage The output voltage of PWM rectifier cannot be lower than a certain value and the power supply should provide negative terminal voltage during demagnetization. So, we choose H-bridge to increase regulation range to meet the operating requirements of superconducting magnets. The control block diagram is seen in Fig. 4. The control system adopts double-loop structure. We use the proportion integration (PI) plus feed forward to improve the dynamic performance.

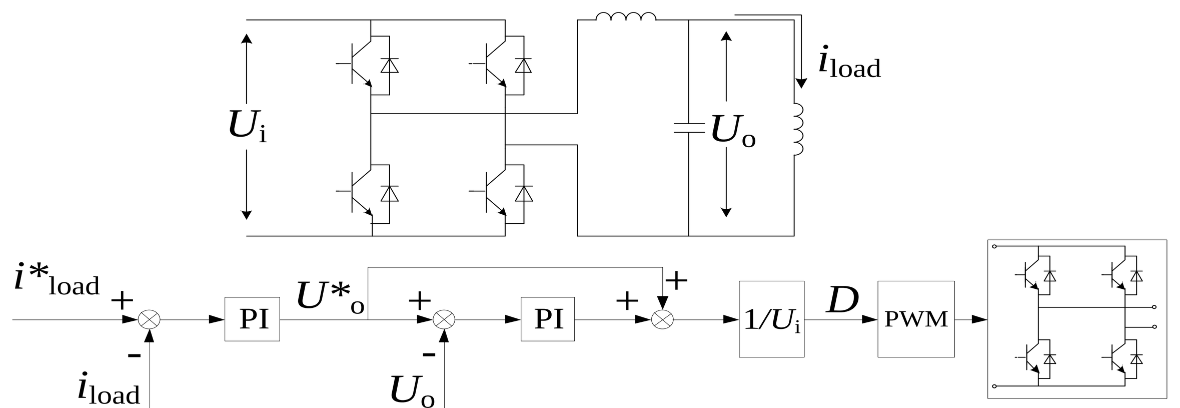


Fig. 4 The control block of H-bridge

3.3 Output stage The output stage is used to filter the high frequency voltage ripple from the front stage, and the inductance-capacitance-resistance (*LCR)* filter is used. The transfer function from input E_i to output E_o:

$$\frac{E_o}{E_i}=\frac{2\frac{w}{w_0}j+1}{2m(\frac{w}{w_0})j^3+(m+1)(\frac{w}{w_0})^2j^2+2(\frac{w}{w_0})j+1} \quad (1)$$

$m = C_1/C_2$

$R_2 = 2\times(L/C_2)^{1/2}$

$W_0 = (L/C_1)^{-1/2}$

a)Attenuation at 50Hz ≥ 14 dB

b)Roll-off of approximately 12 dB/octave

c)Filter must not ring

d)Peak in-rush current for step voltage ≤250 A

Select: m=0.2, then:

$L = 1.49\times10^{-3}$ H

$R_2 = 0.19\ \Omega$

$C_1 = 0.342$ F

$C_2 = 0.171$F

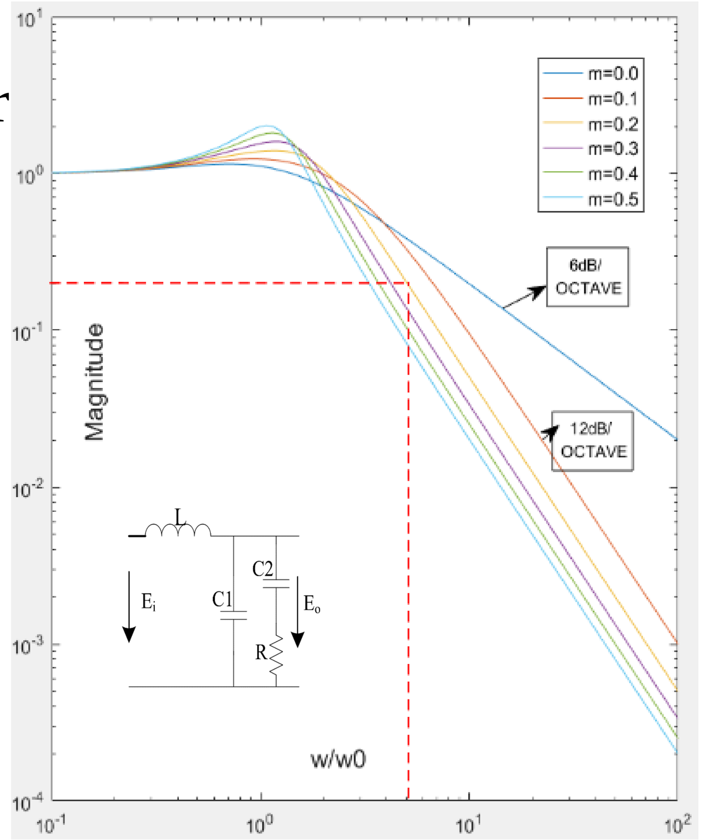
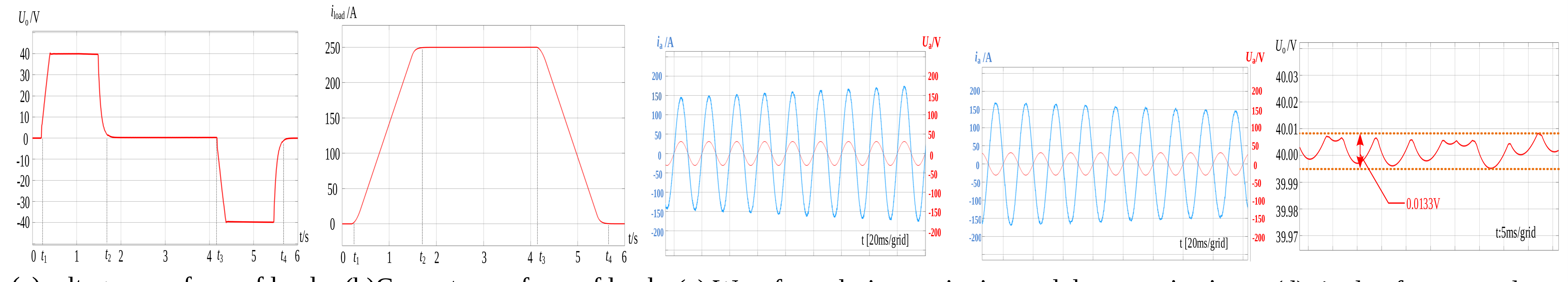


Fig. 5 The circuit of LCR

4. Simulation and conclusion

Transformer ratio380/30, AC side filter inductance 200 µH, resistance 0.1 mΩ, DC side capacitance 0.15 F, using fixed frequency double-loop direct current control method; DC side setting voltage 60 V.



(a)voltage waveform of load (b)Current waveform of load (c) Waveform during excitation and demagnetization (d) ripple of output voltage

Fig. 6 The waveform of simulation

The results show the topology has the characteristic of bidirectional energy flow and stable and adjustable output voltage. Besides the power supply has high power factor and the output voltage ripple meets the requirements with good sinusoidal input current. Moreover the input current waveform in power grid is near-sinusoidal. Therefore, the proposed topology can meet the relevant requirements of superconducting magnets, which provides theoretical support for further research.