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TITLE OPTIMIZATION OF RESONANT POWER SUPPLY CIRCUIT

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OPTIMIZATION OF RESONANT POWER SUPPLY CIRCUIT

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Abstract

A Resonant Power Supply has been proposed to power Rapid Cycling Accelerator magnets. The Resonant Power Supply circuits were studied extensively [1,2], but were not optimized. Most designs assume equal choke and magnet inductance, however, the variation of inductance affects both performance and cost of the system. This paper optimizes the Resonant Power Supply Circuit by selecting the most feasible choke inductance. For this optimization, a computer model and an approximate design method were developed. The effect of choke inductance on the components rating and cost was determined. It was found that the increase of choke inductance reduces the maximum and increases the minimum choke current, which leads to a significant increase of system losses. The maximum voltage is independent of the choke inductance. The designed change of choke current reduces the current of the By-pass Thyristor Switch and the Capacitor Bank Switch, which results in cost reduction. The increase of choke inductance reduces the size of capacitor banks. The loss increase requires larger Make-up Power Supply and AC supply systems. It also increases the operation costs. The system cost function has a minimum, when the choke inductance is about 1.5-2 times larger than the magnet one. The application of the result will lead to a more economical and efficient Resonant Power Supply.

Introduction

The Resonant Power Supply is economical and efficient to supply a Rapid Cycling Accelerator magnet system. The system concept was presented by Frazer [1]. An engineering design and system description was published by Karady et al [2]. The system design is based on the magnet data, which is the result of careful computer studies. The choke inductances in the previous studies were selected equal to the magnet inductance. This determines the currents and voltages of all other components, which defines the components rating. However, recent studies indicated that the selection of choke inductance is critical and its value has a significant effect on the system operation parameters and economics.

The objective of this paper is the optimization of the Resonant Power Supply circuit and the determination of the most feasible choke inductance value.

Equivalent Model for Computer Analysis

The resonant power supply one line diagram is shown in Fig. 1. The resonant current waveform is shown in Figure 2.

The equivalent circuit for computer analysis is shown in Fig. 3. The resonant current waveform is shown in Figure 2. The resonant current waveform is shown in Figure 2.

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Figure 1. Resonant Power Supply One Line Diagram

Figure 2. Equivalent Circuit For Computer Modeling

b Choke inductance is twice the magnet inductance

c Choke inductance is four times the magnet inductance

Figure 3: System Voltage, Magnet and Choke Current.

Approximate Analysis

The sum of the energy stored in the magnet and choke is constant and remains the same during flat top and injection.

The energy balance equation is

$$\frac{1}{2} L_m I_{m_{max}}^2 + \frac{1}{2} L_{ch} I_{ch_{min}}^2 = \frac{1}{2} L_m I_{m_{min}}^2 + \frac{1}{2} L_{ch} I_{ch_{max}}^2 \quad (1)$$

The definition of the currents are shown in Figure 3. From equation 1 the current values are calculated:

$$I_{ch_{min}} = \sqrt{\frac{L_m}{L_{ch}} \left(I_{m_{max}}^2 - I_{m_{min}}^2 \right)} \quad (2)$$

$$I_{ch_{max}} = \sqrt{\frac{L_m}{L_{ch}} \left(I_{m_{max}}^2 + I_{m_{min}}^2 \right)} \quad (3)$$

The capacitor bank is a parallel combination of capacitors connected to the power supply.

The change of the inductance after the setup of capacitor bank is $L_{ch} = L_m + L_{ch}$. The capacitor bank is a parallel combination of capacitors connected to the power supply. The change of the inductance after the setup of capacitor bank is $L_{ch} = L_m + L_{ch}$.

Figure 4: Maximum and Minimum Choke Current

Figure 5 shows that the percentage capacitance variation is significant. If the choke inductance is five times the magnet inductance, the capacitor banks rating can be reduced by 40 %.

Figure 5: Change of Capacitor Bank Rating

The thyristor switch current is the difference of the magnet and choke current. Its value can be expressed as

$$I_{thy} = I_{m_{max}} - I_{m_{min}} - I_{ch_{min}} \quad (4)$$

Figure 6: Thyristor Switch Current

A similar equation can be derived for Capacitor Bank 2 Thyristor Switch. The equation shows that both currents are reduced by the increase of choke inductance.

For the system loss calculation, the choke current as a function of the time is determined. The magnet losses are not affected by the choke inductance. The currents during the injection and flat top periods are constant and their values are shown in Figure 5. The currents during acceleration and reset are described by a sine function. The choke current during acceleration is

$$I_{ch(alt)} = 0.5 [(I_{ch \text{ max}} + I_{ch \text{ min}}) \sin(\omega t) + (I_{ch \text{ max}} - I_{ch \text{ min}}) \sin(\omega t)] \quad (17)$$

The choke current during reset is

$$I_{ch(res)} = 0.5 [(I_{ch \text{ max}} + I_{ch \text{ min}}) \sin(\omega t) + (I_{ch \text{ max}} - I_{ch \text{ min}}) \sin(\omega t)] \quad (18)$$

The total current is

$$I_{ch(t)} = I_{ch(alt)} + I_{ch(res)} \quad (19)$$

Where T_1, T_2, T_3, T_4 marks the end of acceleration, flat top and reset respectively.

The choke loss is

$$\text{Loss}_{ch} = R_{ch} \int_0^T I_{ch}^2 dt \quad (20)$$

Where T is the repetition time.
 $R_{ch} = K_{ch}/k$ is the choke resistance.

It is assumed that the I_{ch} , K_{ch} is constant, therefore the choke resistance is proportional with the k factor.

The losses in the thyristor, capacitor bank and ac system were also calculated. The variation of the total losses as a function of choke inductance is shown in Figure 7. The figure shows that the system loss increases significantly with the increase of choke resistance. This is an important finding because the system loss determines the operation cost and affects the Make-up, Power Supply and AC system rating.

Figure 7. System loss versus Choke Inductance

Figure 8 shows the variation of the hardware cost as a function of choke inductance. The hardware cost increases significantly with the increase of choke resistance. This is an important finding because the hardware cost determines the operation cost and affects the Make-up, Power Supply and AC system rating.

Table 1. Choke inductance effect on the major cost components

Cost Component	Effect of Choke Inductance Component Cost
Magnet	none
Magnet P/S	none
Choke	small cost increase
Make-up P/S	significant cost increase
Capacitor bank	substantial cost increase
Thyristor Switch	substantial cost increase
Capacitor bank	substantial cost increase
Switch	small cost reduction
AC system	significant cost increase
Total hardware cost	moderate cost increase
Operation cost	moderate cost increase

Figure 8. System cost versus Choke Inductance

Discussion

The results indicate that the hardware cost, operation cost and system cost increases with the choke inductance, while the system loss decreases with the choke inductance.

The hardware cost decreases as the beam current increases, but the operation cost increases with the beam current. However, the hardware cost, Make-up, Power Supply and AC system cost increases with the beam current.

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