Computer Simulation Analysis of Magnetically Controlled Reactor Using Matlab/Simulink for Minimizing of Power Grid Loss

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Abstract. This paper introduces the basic structure and working principle of single-phase four-column magnetically controlled reactor. Using Matlab to build the simulation of equivalent circuit model of the reactor, the harmonic and response characteristics are analyzed in the simulation. Through analysis, it is found that reasonable selection of compensation device is very important to improve the quality of power grid, and proper selection can minimize the loss of power grid and meet the safety, reliability and quality requirements of power system, which has good practical engineering research value.

1. Introduction
More and more high demand of power supply quality and reliability, increase in the number of all kinds of power load in the power system, the drastic change of power load and so on, which lead to more demanding requirements for reactive power and dynamic balance in power systems. According to the current running status and development trend of electric power industry. It will become a key technical topic to be paid attention to and solved in the construction and improvement of electric power system in our country that is the development and use of new reactive power compensation devices. Therefore, magnetically controlled reactor (MCR for short) has become one of the current research topics [1].

2. Structure and principle of MCR

2.1. Structure of MCR
The basic structure of single-phase four-column MCR is shown in figure 1 below. The two main core pillars in the middle are marked A and B, which have the same cross-sectional area and the same height. The two core columns next to the main core are called side yokes, the cross-sectional area and height of which are equal. In order to ensure that the magnetic induction intensity in the main core column A and B is in the nonlinear saturated state under normal working condition, The cross-sectional area of the side yokes is designed to be slightly larger than that of the main core A and B when designing MCR.

The main core column A and B are wound with the upper winding $L_{g1}$ and $L_{k1}$, the lower winding $L_{g3}$ and $L_{k3}$, the upper winding $L_{g2}$ and $L_{k2}$, and the lower winding $L_{g4}$ and $L_{g4}$. The winding with subscript g is the working winding and the number of turns is counted as $N_g$. The winding with subscript k is to control the windings, the number of turns to $N_k$. The number of turns of upper and lower windings of main core A and B is the sum of the number of turns of the working winding and the number of turns...
of the control winding, which is denoted as \( N \) (\( N = N_g + N_k \)). The MCR’s self-coupling ratio is \( \delta \), where \( \delta = N_k / N \). Thyristor T1 and T2 play the role of rectification. When the AC power passes zero, both T1 and T2 are in the cut-off state before the thyristor trigger pulse arrives, and then the DC control circuit cannot be connected, which leads to the unstable working state and poor performance of MCR. To solve this problem, a continuation current diode D is needed to be connected, which can maintain the conduction of the DC control circuit when both thyristors are turned off. The upper and lower windings of main core A and B are connected to the power grid in parallel.

![Figure 1. Structure diagram of single-phase four-column MCR.](image)

2.2. Working principle

When T1 and T2 of MCR are in cut-off state, the working state of MCR is equivalent to that of a no-load transformer [2-3]. When the AC power supply is in positive half wave, T2 will be cut off due to bearing the reverse voltage, but T1 will bear the forward voltage at this time. After reaching the set trigger initiation angle, the trigger circuit will send a trigger signal to the power thyristor T1, at which time T1 will be triggered to conduct. If the thyristor is regarded as an ideal device, the tube pressure drops of which is ignored, then points A and B in figure 2 are equipotential points. At this time, the ac current flowing through the windings on the main core A and B provides the control current to the windings after the auto-transformer \( L_{k1} \) and \( L_{k3} \) with variable ratio \( K = N_k / N \). The figure shows that the DC control current \( i_{d1} \) and \( i_{d2} \) generated by rectification are in the same direction as the ac current \( i_1 \) and \( i_3 \) flowing through the upper winding and the lower winding of main core A respectively, which played the role of magnetic enhancement in the main core A. On the contrary, it plays the role of reducing magnetic field in the main core B.
Figure 2. Equivalent circuit diagram of MCR.

In the same way, when the power supply is negative half wave, T1 is turned off and the positive voltage is applied at both ends of T2. The figure shows that the dc control current $i_{d1}$ and $i_{d2}$ generated by rectification are in the same direction as the ac current $i_2$ and $i_4$ flowing through the upper winding and the lower winding of main core A respectively, which played the role of magnetic enhancement in the main core B. On the contrary, it plays the role of reducing magnetic field in the main core A. When T1 and T2 are respectively on, the equivalent circuit diagram of MCR is shown in figure 3 and 4 below.

Figure 3. Equivalent circuit for T1 conduction.  Figure 4. Equivalent circuit for T2 conduction.

In order to change the magnitude of the DC control current in the winding of the main core, it is necessary to change the magnitude of the triggering Conduction Angle of the two thyristors, which can change the magnetic saturation of the main core column in MCR, so as to achieve the purpose of smoothly regulating the electrical capacity of MCR in the power system. Finally, the aim of smooth adjustment of MCR capacitance in power system is realized.

3. Establishment of MCR simulation model

According to the working principle of MCR and mathematical model analysis to establish the simulation circuit [1-4]. The MCR simulation circuit consists of three parts: ac working circuit, intermediate coupling circuit and DC control circuit. The equivalent circuit diagram of MCR is shown in Figure 5. The relevant rated parameters of MCR are rated capacity $S_N$, rated voltage $U_N$, winding resistance $R_A$, and autocoupling ratio $\delta$. According to literature [2-4], the self-coupling ratio $\delta$ of MCR is generally designed as 0.015-0.05. In the design of MCR, the following formula needs to be met:

$$1.5\% \leq \frac{\pi S_N R_A}{2U_N - \pi S_N R_A} \leq 5\%$$

The simulation circuit is established by equivalent circuit, as shown in figure 6. In this simulation experiment, rated capacity $S_N$ is 1500kVar, rated voltage $U_N$ is 10kV. Since the characteristics of single-phase MCR are analyzed in this paper, it is necessary to change the saturated transformer parameters into the corresponding parameters of single-phase MCR by calculation when designing parameters. Therefore, the rated capacity $S_N$ should be $15,000/3 = 500$kVar, and the rated voltage $U_A$ should be $10\sqrt{3}$ kV. In the simulation experiment, the self-coupling ratio of MCR is set at 3%. The winding
resistance $R_A$ of MCR can be obtained through calculation, $R_A = 1.236\Omega$. Therefore, it is shown in the simulation circuit figure 6, $R_1 = R_2 = 1.236\ \Omega$, $R_3 = 0.077\ \Omega$.

Figure 5. Equivalent circuit diagram.

Figure 6. Simulation circuit diagram MCR.

4. Simulation analysis of MCR

4.1. Working current simulation analysis
The core saturation of MCR is denoted as $\beta$. By the literature [2, 4], core saturation $\beta$ and magnetic induction intensity $B$ of MCR satisfies the following equation:

$$\beta = 2\arccos \frac{B_x - B_s}{B_s}$$  \hspace{1cm} (2)
BS is the AC component of magnetic induction intensity and Bd is the AC component of magnetic
induction intensity in the formula. According to references [1,2,4-6], it is also known that the triggering
Conduction Angle and core saturation of MCR satisfies the following equation:
\[
\cos \alpha = \frac{2}{\pi} \left( \sin \frac{\beta}{2} - \frac{\beta}{2} \cos \frac{\beta}{2} \right) - 1
\]  
(3)

The fundamental wave current amplitude I1 and core saturation β of MCR satisfies the following
relation:
\[
I_1 = \frac{1}{2\pi} (\beta - \sin \beta)
\]  
(4)

When the triggering Conduction Angle α is 0°, 60° and 120° respectively, the steady-state current
waveform is shown in the figure below.

Figure 7. α = 0°, working current waveform.
According to the analysis of simulation figure 7-9, When the triggering Conduction Angle of thyristor increases, DC control current will decrease, resulting in low DC magnetic bias and core saturation. Eventually, the ac working current decreases. On the contrary, the ac working current increases. According to the waveform analysis, it can be known that when the triggering conduction Angle increases, the harmonic component [6-8] of ac working current also increases.

4.2. Analysis of response characteristics
As for the response characteristics, the following two cases are mainly analyzed, and the simulation waveforms are as follows.
Figure 10. Variation of working current waveform at Conduction Angle from 120° to 0°.

Figure 11. Variation of working current waveform at Conduction Angle from 0° to 120°.

According to the analysis in figure 10-11, the AC working current which is from 27A to 75A goes through about 10 cycles and AC working current which is from 75A to 27A also passes through about 10 cycles. Thus, it can be seen that the response time is relatively fast. In the power system, if the balance of reactive power is not adjusted in time after the reactive power shortage, it will affect the normal production and life, and even cause large economic losses or accidents. Therefore, it is of great significance for the stability of the power system to realize rapid response switching of MCR.

5. Conclusions
In this paper, single-phase MCR is introduced, and its basic structure and working principle are analyzed. Then the equivalent simulation circuit model of reactor is built by Matlab/Simulink, and its current, harmonic and response characteristics are simulated and analyzed. The output ac working
current of MCR increases and the harmonic component decreases with the reduction of the triggering Conduction Angle. Besides that, it can be seen that the response time is relatively fast. Thus, the analysis of the harmonic current output of MCR and its rapid response characteristics is conducive to the rational selection of compensation devices, the improvement of power quality, the improvement of system stability and the reduction of transmission loss, etc., which is also of great research value for practical engineering applications.

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