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Research of the Exciting Current Detection Method of MCR

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Abstract

Magnetic valve controllable reactor (MCR) is a kind of dynamic reactive power compensation device. The exciting current of MCR is one of the important indexes of operating condition of MCR. This paper firstly analyzed the principle of MCR, and deduced the relationship between the exciting current and the output current, verified by MATLAB/SIMULINK. And then an effective method to detect the exciting current was proposed by this paper. The method has the advantages of optical fiber isolation, high detection precision, strong anti-interference, etc. Finally, a 220v/1200var MCR was experimented in detail. The results demonstrate the accuracy of the theoretical analysis.

***Keywords**: Magnetic valve controllable reactor; running state; the exciting current; detecting method*

1. Introduction

Reactive power compensation devices are effective measures to improve the quality of electric energy [1-4]. Magnetic valve controllable reactor (MCR) is a promising type of reactive power compensation device. It has many advantages, compared with other types, such as low loss, low harmonic, high voltage and high reliability. Thus, MCR has been widely applied in the modern power system dynamic reactive power compensation, overvoltage suppressing [5-8].

The basic principle of MCR is controlling the value of the exciting current to change the saturation of MCR. In this way, the output reactive power capacity of MCR can be continuously adjusted [9-10]. The larger the value of the excitation current is, the larger the saturation of the iron core. Therefore, reactive power capacity of MCR would be larger. So the exciting current of MCR is a control signal to adjust the reactive power capacity.

However, the relationship between the exciting current and the output current of MCR is nonlinear. When the output capacity of MCR exceeds its rated capacity or the windings of MCR suffers from the internal short-circuit faults, the output current increases little, however, the exciting current could increase largely and lead to make the windings' temperatures rise, so as to increase the loss of MCR, even affect the normal operation of MCR. Thus, the exciting current is one of the important indexes of the operation condition of MCR. The operation condition MCR can be on-line monitored through detecting and monitoring the value of the excitation current, ensuring the normal operation of MCR. Hence, the precise detection method of the exciting current is very important. As MCR is applying in high-voltage power system, the detection circuit should be also electrically isolated with the main high-voltage circuit of MCR effectively. Therefore, the research of a precise and effective detection method of the exciting circuit is very significant.

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This paper proposed the basic principle of MCR. The relationship between the exciting current and the output current of MCR was analyzed in detail. Then, a kind of exciting current detecting method was proposed. The method has the advantages of high optical fiber isolation, high precision, strong anti-interference performance, *etc*. Finally, the simulation and experiments results of 220V/1200VAR MCR verified the affectivity of the theory and the exciting current detecting method proposed by this paper.

2. The Basic Principle of MCR

MCR is a device based on the principle of core magnetic saturation. The structure schematic diagram of MCR is shown in Figure 1[11]. The main core of magnetic control reactor is divided into two cores. Each core is wound by two winding symmetrically. The two winding would in each core have two taps (tapping ratio is δ), connecting the thyristors K_1 and K_2, respectively.

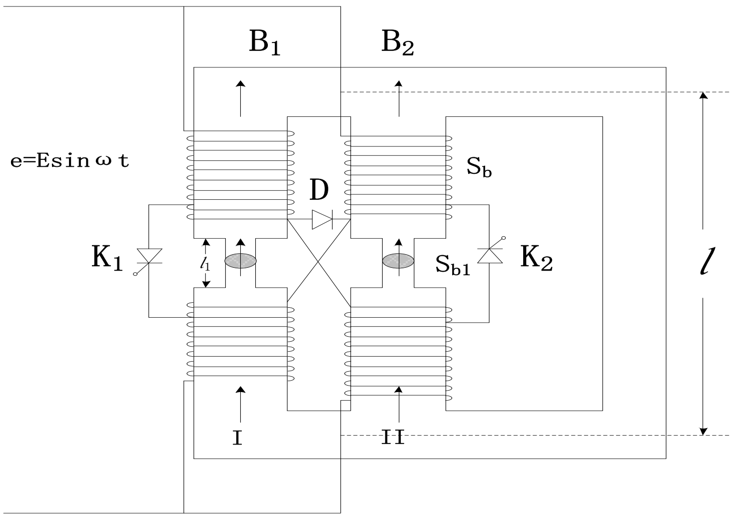


Figure 1. The Structure of MCR

If thyristor K_1 and K_2 are turn-off, due to symmetry of the windings, the MCR is in no-load condition. The output current of MCR is small. In the positive half cycle of the power source, the voltage of thyristor K_1 forward, and the voltage of thyristor K_2 is negative. If thyristor K1 is triggered, the power source provides the control DC voltage and the exciting current ($i_k^{'}$, $i_k^{''}$) through the self-coupling coil with the tapping ratio δ the equivalent circuit when thyristor K_1 is turn-on is shown in Figure 2(a). Similarly, when the thyristor K_2 is triggered in the negative half cycle of the power source, the equivalent circuit when thyristor K_2 is turn-on is shown in Figure 2(b). It can be seen from Figure 2, the direction of the exciting currents when thyristor K_1 and K_2 are turn-on is the same. Hence, the exciting current can be equivalent as a direct current. By changing the value of the operating trigger angle, the value of the exciting current can be changed.

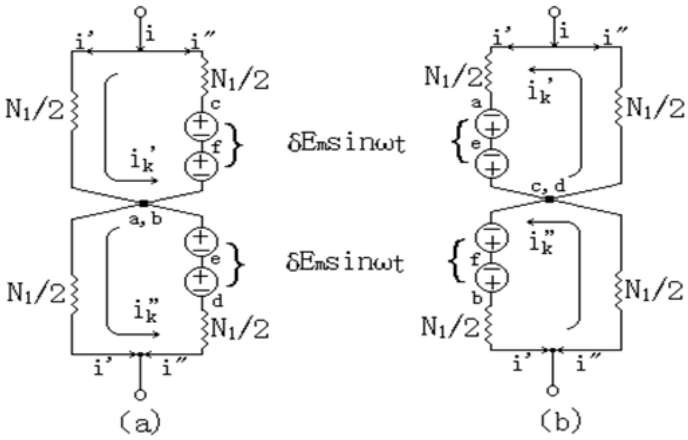


Figure 2. The Equivalent Circuit of MCR

Actually changing the exciting current is to control the dc component of the magnetic flux intensity Bd. The controllable dc component is added on the AC component of the magnetic flux intensity B_I, as shown in Figure 3. The length of the horizontal axis of the shadow section is the saturation time of the core in a period, referred to as the magnetic saturation. If β=180 it is called as half limited saturation (HLF). In this time, the cores of MCR are just fully saturated in the whole period, the harmonic of the output current is smallest. If 180<β<360the excitation current could increase largely so as to make the iron core saturate excessively, producing large loss. Thus, the rated capacity of MCR is usually designed in the capacity of half limited saturation. The condition when 180<β<360is called as the state of the over-excitation.

$$\beta = 2arccos\frac{B_m - B_d}{B_m} \tag{1}$$

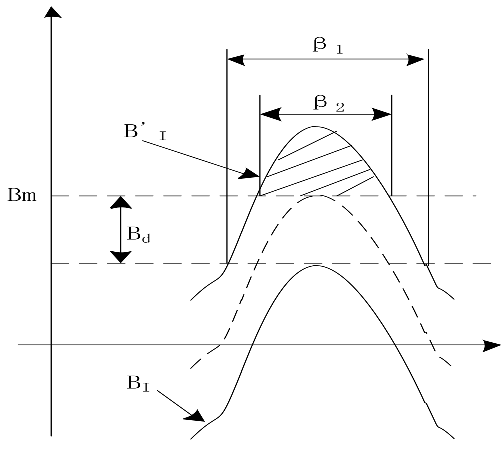


Figure 3. The Analysis of Magnetic Saturation

3. The Theoretical Analysis of the Exciting Current

The equivalent circuit of MCR is shown as Figure 4. N is the turns of AC coils. Nk is the turns of the DC coils, N= N_k. the i is the AC output current, and ik is the exciting current.

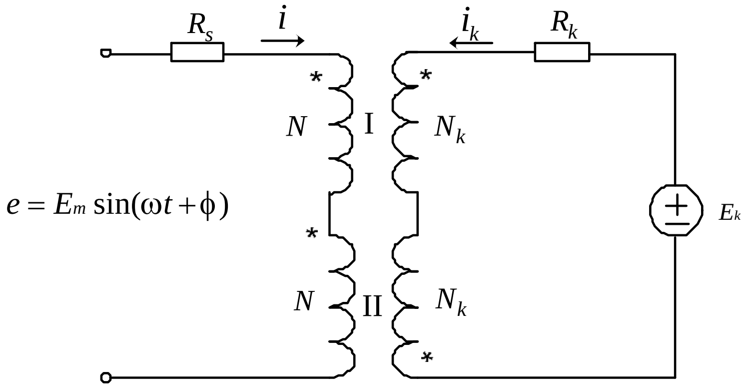


Figure 4. The Equivalent Circuit of MCR

If 0<β<180 the MCR is below the state of HLF. In the positive half cycle of the initial state, both of the core I and II are unsaturated. The condition of MCR can be expressed as follows

$$\begin{cases} i = i_k = 0 \\ e = NA(\frac{dB_1}{dt} + \frac{dB_2}{dt}) \\ E_k = N_k A(\frac{dB_1}{dt} - \frac{dB_2}{dt}) \end{cases} \tag{2}$$

It can be seen from the equation above, if 0<β<180, the rates of magnetic flux field change dB/dt of core I and II are different. Due to the DC voltage E_k, dB/dt of core I is increased, but dB/dt of core II is decreased. Therefore, when the core I is saturated, the core II is unsaturated. At this time, dB/dt of core I is very small, equivalent to be short-circuit. The coils of the core II almost undertake the whole source voltage. Therefore, the MCR could be equivalent to a transformer. As the value of R_k and E_k is very small, they can be neglected. Thus,

$$\begin{cases} i = e / R \\ i_k = \frac{N}{N_k} i \end{cases} \tag{3}$$

Due to N= N_k, when 0<β<180the rms value of the exciting current i_k is equal to that of the output current i after rectification.

$$i_k = i \tag{4}$$

If 180<β<360 the MCR is above the state of HLF, the core I and II may be saturated at the same time. If the value of □□is larger, the time of saturation of two cores simultaneously is larger. Thus,

$$i_k = \frac{\cos(\beta / 2)}{\sin(wt)} i > i, 0 \le wt \le \frac{\beta - \pi}{2} \tag{5}$$

Therefore, if 180<β<360, the relationship of the exciting current and output current would not satisfy the transformer ampere-turns principle and be nonlinear. The rms value of the exciting current i_k would be larger than that of the output current i.

$$i_k > i \tag{6}$$

In this paper, the ratio of the rms values of the exciting current and output current is referred to the over-excitation coefficient λ. If λ=1 the operation condition of MCR is normal. If λ>1, the operation condition of MCR is over-exciting.

4. The Design of Excitation Current Detecting Circuit

The exciting current of MCR is not only a control signal to adjust the reactive power capacity, but also one of the important indexes of the operation condition of MCR. Thus, measuring the exciting current should have high accuracy. Because MCR is used in high-voltage power system, the detection circuit and the main high-voltage circuit of MCR should be electrically isolated effectively. In view of the problems above, this paper proposes a kind of the excitation current detecting method of MCR. The method proposed in this paper has the advantages of high optical fiber isolation, high detection accuracy, strong anti-interference performance, *etc*. The exciting current detection circuit is composed of five parts, the MCR, the voltage sampling circuit, V/F conversion circuit, optical fiber transmission circuit and F/V conversion circuit. Figure 5 shows the schematic diagram of the excitation current detecting circuit. The shunt in series with the exciting circuit of MCR between the points D1and D2, is used to convert the excitation current signal to the voltage signal, as shown in Figure 6.

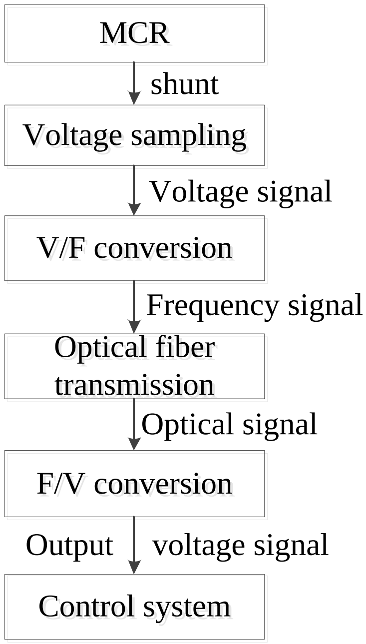


Figure 5. The Schematic Diagram of Measuring the Excitation Currents

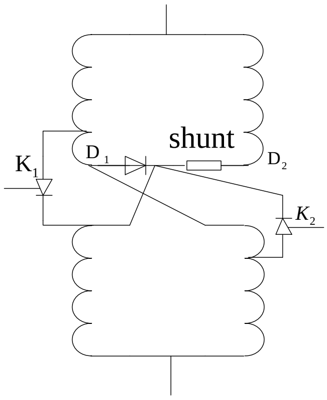


Figure 6. The Structure of Measuring the Excitation Currents

4.1. Voltage Sampling Circuit

The voltage signal obtained through the shunt firstly is divided by two resistors. Then the divided voltage signal is amplified through the instrumentation amplifier. The amplifier gain is about 50. Therefore, the amplified voltage signal, used the following V/F conversion circuit, is the output signal of the voltage sampling circuit, as shown in Figure 7.

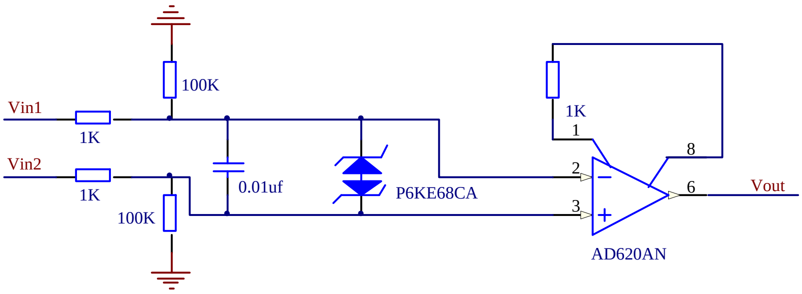


Figure 7. Circuit of Voltage Acquisition

4.2 V/F Conversion Circuit

Before the V/F conversion, the voltage signal should be gone through a voltage follower firstly. It has the advantages of signal buffering and isolation. Through synchronization V/F converter, the useful voltage signal is converted to the frequency signal used to the optical fiber transmission circuit, as shown in Figure 8.

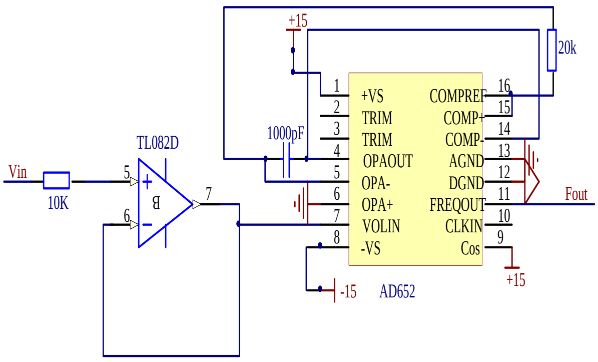


Figure 8. V/F Conversion Circuit

4.3 Optical Fiber Transmission Circuit

The optical fiber transmission circuit is mainly composed to the AND gate drive circuit, the optical transmitter and optical receiver. The transmission of the signal uses the optical fiber cable. The AND gate drive circuit is used to produce the enhanced driving power. The fiber optic transmitter is used to convert the frequency signal into the optical signal. The fiber optic receiver is used to receive the optical signal after fiber optic cable transmission, and convert the optical signal into the frequency signal, prevent the interference. The signal obtained from the optical receiver should have the shaping processing, beneficial for recognition signal recognition of the F/V conversion circuit, as shown in Figure 9.

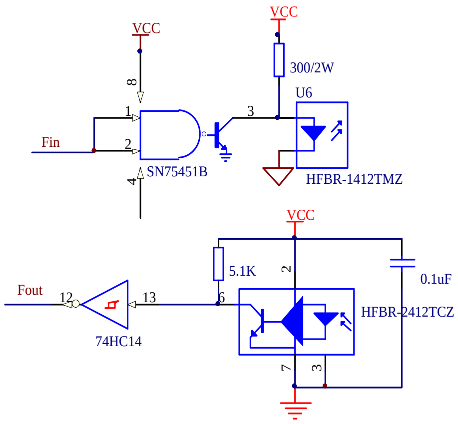


Figure 9. Optical Fiber Transmission Circuit

4.4 F/V Conversion Circuit

The F/V conversion circuit is used to convert the frequency signal into the voltage signal. The output voltage signal is the converted exciting current signal of MCR, as shown in Figure 10. It is the bipolar voltage signal. The output voltage signal can be transferred to the control system of MCR, used to monitor the status and over-excitation protection of MCR.

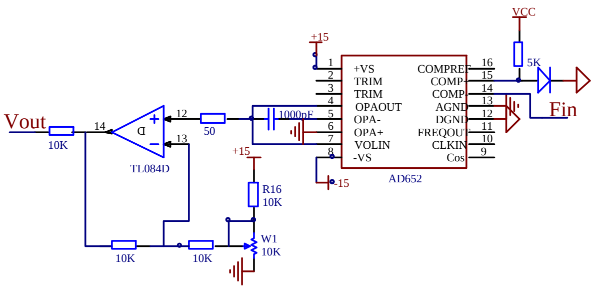


Figure 10. F/V Conversion Circuit

It can be seen from the analysis above, the exciting current detection method proposed by this paper can make the detection circuit isolate with high voltage circuit effectively using optical fiber isolation, enhance the anti-interference performance, meet the requirement of the exciting current detection accuracy.

5. Simulation and Experiments

5.1 Simulation Research of MCR

This paper firstly sets up a single phase simulation model of MCR through MATLAB/SIMULINK for the analysis of the relationship between the exciting current and the output current. The simulation parameters of MCR are: Rated voltage of MCR is 35kV, Rated current of MCR is 250A, and the rated capacity of MCR is 5 MVAR. The simulation model is shown in Figure 11.

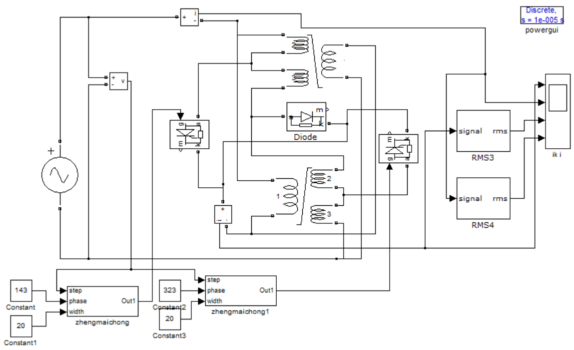
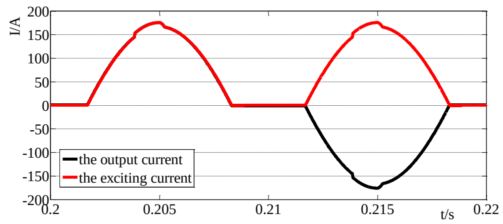
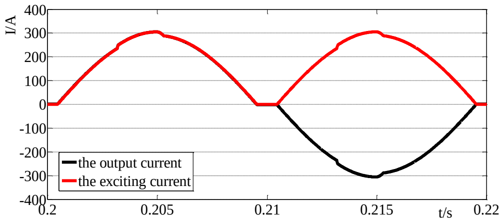


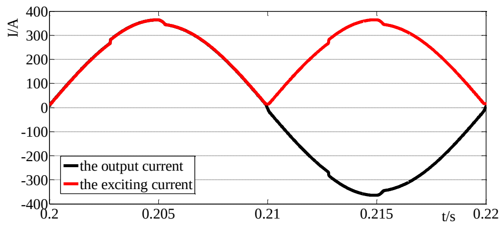
Figure 11. The Simulation Model of MCR

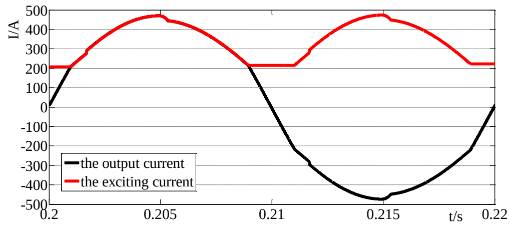
Figure 12 show the simulation results of the exciting current and output current when the output capacity of MCR is 40%, 80%, 100%, 140% and 160% respectively. The output capacities of 140% and 160% are used to simulate the over-exciting state.



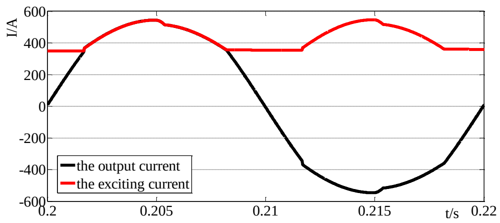


(a) Output Capacity=40%, λ=1 (b) Output Capacity=80%, λ=1





(c) Output Capacity=100%, λ=1 (d) Output Capacity=140%, λ=1.006



(e) Output Capacity=160%, λ=1.065

Figure 12. The Relationship between the Excitation and Output Currents under Different Capacities

It can be seen from Figure 12 that, if $0<\beta<180$(40%, 80%), the output capacity of MCR is below the rated capacity. The rms value of the exciting current i_k is equal to the output current i after rectification, namely $\lambda=1$ the relationship between the exciting current and the output current of MCR is linear. And the frequency of the exciting current i_k is twice as much as that of the output current i. When the MCR is in the rated capacity (100%), the exciting current waveform is just the full-wave rectified sinusoidal waveform. However, if $180<\beta<360$(140%, 160%), the output capacity of MCR would be larger than the rated capacity, the excitation current would be larger than the output current, namely $\lambda>1$ the relationship between the over-excitation coefficient and the output capacity of MCR is shown in Figure 13.

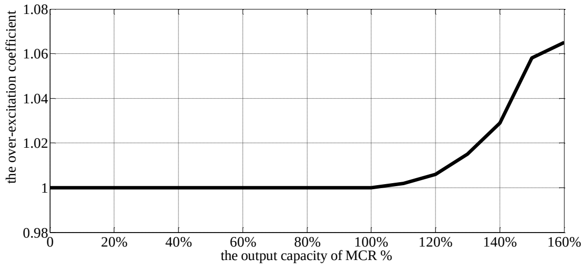
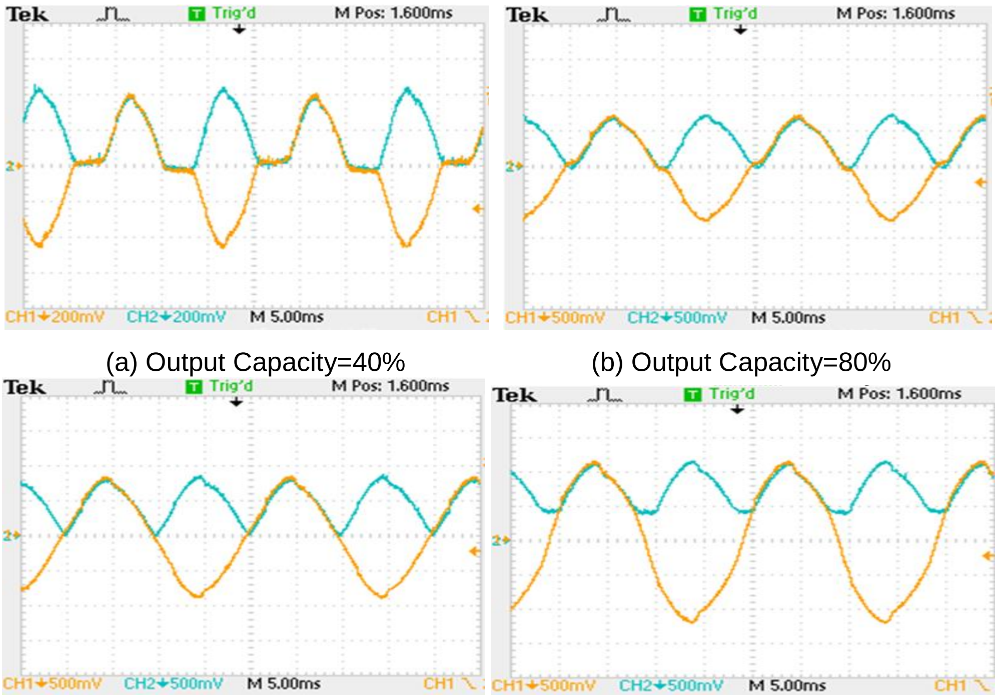


Figure 13. The Relationship between the Excitation Factor and the Output Capacity of MCR

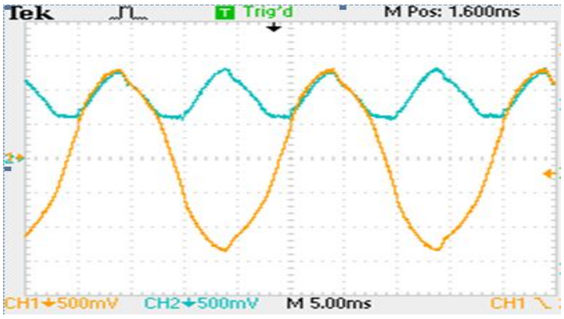
5.2 Results of Experiments

This paper designs a single 220V/1200VAR phase MCR and takes some experiments to validate the theory and simulation about the excitation current of MCR above. Figure 14 the experimental results of the exciting current and the output current when the output capacity of MCR is 40%, 80%, 100%, 140% and 160% respectively. The yellow curve is the output current waveform, and the blue curve is the exciting current waveform.



(a) Output Capacity=40% (b) Output Capacity=80%

(c) Output Capacity=100% (d) Output Capacity=140%



(e) Output Capacity=160%

Figure 14. Experimental Results of the Exciting Current and Output Current under the Different Capacities

It can be seen from the experimental results that, if 0<β<180(40%,80%), the waveform of the exciting current is the output current waveform after rectification. When the output capacity of MCR is in the rated capacity (100%), the exciting current waveform is just full-wave rectified Sinusoidal waveform. If 180<β<360(140%, 160%), the excitation current would be larger than the output current.

Therefore, the experiments and simulation proposed by this paper verify the correctness of the theoretical analysis about the exciting current of MCR.

6. Conclusions

1. The exciting current is one of the important indexes of the operation condition of MCR. Hence, the excitation current could be used to on-line monitor the operation condition of MCR and the over-exciting protection.

2. If the output capacity of MCR is below the rated capacity (0<β<180), the waveform of the exciting current is the output current waveform after rectification. Thus, the rms value of the exciting current is equal to that of the output current.

3. If the output capacity of MCR is larger than the rated capacity (180<β<360), the rms value of the exciting current would be larger than that of the output current, referred as the over-excitation state. When the MCR is in the over-excitation state, the loss of MCR would increase largely, the temperature of the coils would rise. Thus, it could influence the normal operation of MCR.

4. The exciting current detection method proposed by this paper has the advantages of high optical fiber isolation, high precision, strong anti-interference performance, meets the requirement of the exciting current detection

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