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Reactive Power-Voltage Integrated Control Method Based on MCR

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Abstract*—In power system, the voltage pulsation and deficiency or surplus of reactive power will have a great effect on the quality of electric power supply. Dynamicly local reactive power compensation is one of the best methods to reduce the power network loss and improve the efficiency of transmission and distribution.Through the effective methods of compensation, we can keep the balance of reactive power in the maximum degree by the maintenance of acceptable voltage. This paper firstly describes the principles of synthetic compensation of reactive power and voltage then analyzes the principle of magnetically controlled reactor-MCR in detail and derives the characteristics, secondly analyses the disadvantages of the conventional reactive power compensation devices and the advantages of MCR, thirdly on this basis designs a control strategy of reactive power and voltage which is based on MCR,so as to achieve the goal of dynamic reactive power compensation. At the end of paper, simulator and experimental research are carried out for the model of compensation method; the results accord with the theoretical analyses done before. So the compensation method is proved to be accurate in theory and feasible in practice.

***Keywords*—reactive power compensatio, MCR, Inverse voltage control**

I. INTRODUCTION

Reasonable reactive power compensation is an important guarantee for the power system security, economic, high-quality way to run. With the reform and development of the power network, the amplitudes of voltage and reactive power are increasing while load is at the highest or lowest level. The traditional method of reactive power compensation is mainly implemented by switching the capacitors and adjusting the taps of transformers, which mainly exists the following problems:

a. the switching and adjusting times of capacitors and transformers have the limitation, which cannot satisfy the requirement of reactive voltage control;

b. switching capacitors and change the taps could cause the reactive power discreted, which might even lead to cutting oscillation while adjusting the voltage and reactive power at the qualified edge;

c. switching capacitors can easily cause overvoltage and threaten the safety and stable operation of the system.

While the magnetically controlled reactor—MCR developed from the foundation of magnetic amplifiers [1], the Soviet scholars proposed the principle of magnetic-valve controlled reactor in 1986 [2-3], namely changing the core saturation by controlling the loop dc current excitation ,so as to achieve the goal of smoothly changing the impedance.

MCR has many advantages, such as flexible control method, fast response time.It can not only smoothly regulate the reactive power to implement the flexible power transmission but also inhibit the power frequency overvoltage and switching overvoltage, reduce the loss of line, greatly improve thetability and security of electric power system.

This paper presents the reactive power-voltage integrated control method based on MCR to solve the problems in the traditional method, which include the stepped power adjustment and throw in-of oscillation.

II. SIGNIFICANCE OF REACTIVE POWER-VOLTAGE INTEGRATED CONTROL

Power system voltage is one of the important indicators to measure the power quality. The common electrical power equipments including asynchronous motor,all kinds of electric equipment,lighting lamps and the increasing number of household appliances in recent years,which will run best at rated voltage. When voltage offset is too large, it will affect the life and efficiency of electrical equipments, in serious cases, can even cause great harm to the stability and economic operation of power network. However, the operating voltage level depends on the balance of reactive power. When reactive power is not enough,it will make the voltage at the low level, on the contrary, the voltage would be too high. Effective voltage control and reasonable reactive power compensation not only ensure the voltage quality, but also improve the stability and security of power system, which give full play to economic efficiency. Therefore, there is a close relation between the voltage and reactive power regulation in power system operation.

III. THEORY OF REATIVE POWER-VOLTAGE INTEGRATED CONTROL

There are several methods to control the reactive power and voltage in power system,such as changing the generator voltage, changing on-load transformer tap, adding reactive power compensation devices, etc. When the transmission line is not long and the voltage loss is not significant, the generator voltage regulator can normally be carried out to meet the requirements, but for the longer lines, the other two methods are widely used[4].

The basic principle of the on-load transformer is leading a number of taps from the transformer coil, then changing one tap from the other one by on-load tapping switch without cutting off the load current,which changes the transformation ratio of transformer. This method has several advantages,low materials cost,small occupied area, high output voltage and large output capability.

The reactive power compensator based on MCR is made of a capacitor in parallel with a controlled magnetic reactor.Since capacitors can product reactive power, and the reactor can absorb reactive power. Reactive power compensator is just a Combination of the above two things and some appropriate control devices which can smoothly product(absorb) the reactive power. Its most important function is changing the reactive power with power system to maintain the line voltage constant. The reactive power compensator based on MCR can quickly and smoothly adjust the reactive power in order to meet the requirements of dynamic reactive power compensation.The advantages of such compensator is that more simple operation and maintenance, less power loss,provide phase-splitting compensation to adjust the unbalanced load changing between each phase and impact load.

In this paper, regulating on-load transformer taps and the reactive power compensator based on MCR are the means to control reactive power and voltage. Although both have the effect to adjust the voltage, but their roles and principles are different. Voltage and reactive power compensation device is the utilization of these two means to achieve voltage qualified and reactive power balance.

IV. PRINCIPLE AND CHARACTERISTICS OF MCR

A. Principle of MCR

Figure 1 shows the structure chart of shunt MCR and figure 2 shows cross-section diagram of the core and windings of Single-phase MCR. Shunt MCR commonly used double-coil structure, which separates the working windings from control windings to achieve electrical isolation between the two windings and to ensure that the work of MCR safety and reliability. The figure I, II shows the core, III, IV shows the return yoke, V and VI shows the upper and lower iron yokes; winding 1,2 are the AC controlled working windings, winding 3,4 are the DC control windings.The dotted terminals of working windings (the figure for the A, X) directly connect with power network in parallel; control windings with DC control voltage reversely in series with each,then connect with DC control power Ek (figure Ek +, Ek-).

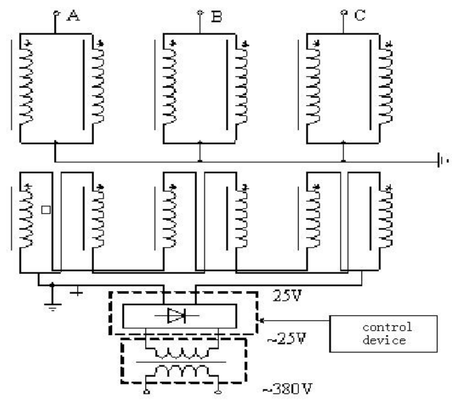


Fig. 1 Structure chart of Shunt MCR

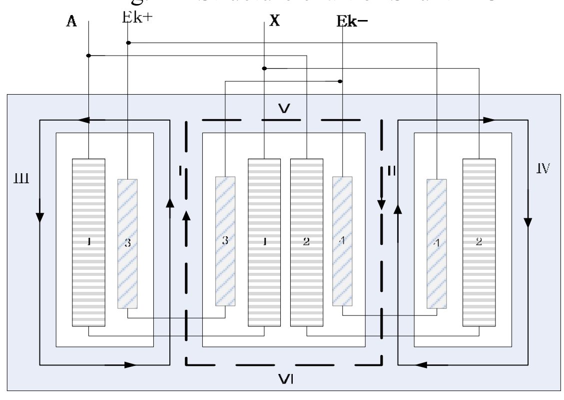


Fig.2 Cross-section diagram of core and windings

Inductance of MCR is:

$$L = \frac{\mu N^2 A}{l} \quad (H) \tag{1}$$

Where, μ is magnetic permeability, N is the number of the winding turns, A is the cross section area of the magnet core, l is the air gap length of magnetic circuit.

By equation (1) we can know, inductance value L of MCR is directly proportional to the magnetic permeability μ , winding turns N , cross sectional area A and inversely proportional to the air gap length of magnetic circuit l. In the practical application,the geometry dimensions of magnet core and winding parameters are not easy to change, so we only consider the inductance value related to the core permeability in the designment.While the core permeability changes, the inductance value follows with it[5].

We can change the permeability μ by adding a DC component B_0 to the alternating flux density $B = B_m \sin \omega t$ which is generated by the working voltage. By adjusting the size of B_0, we can adjust the equivalent permeability of magnet core. Shunt MCR just controls the voltage E_k of control windings to change the excitation current i_k of control windings. Exciting current i_k can changes the the magnetic saturation level of core to make the equivalent permeability μ changed, thus the equivalent inductance of core has been changed.As the operating voltage is unchanged, the bigger the exciting current i_k ,the smaller μ and the smaller L, which makes the output capacity of MCR bigger [6]. The relationship between the reactance value of MCR and the degree of core magnetic saturation is shown in figure 3.

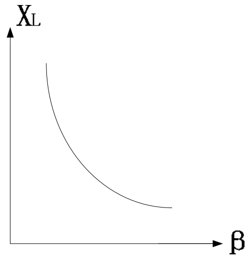


Fig.3 The relationship between reactance value and the degree of saturation

B. Caracteristics of Shunt MCR

1) Harmonic characteristic

The respective amplitude of harmonic components of MCR is[7]:

$$I_{(2n+1)} = \frac{2}{\pi}\int_0^{\pi} \frac{l}{2N}\{f[B_1(\omega t)]+f[B_2(\omega t)]\}\cos[(2n+1)\omega t]d(\omega t)$$

n=1,2,3… (2)

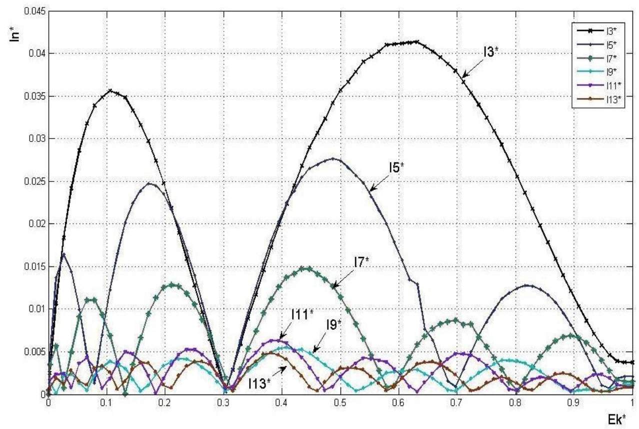


Fig.4 Harmonics of MCR at rated voltage

From figure 4 we can see that for MCR, when the AC working voltage is the rated value, increasing the DC control current value can make the core saturation increased.Each harmonic current changes pulsantly, and the pulsation frequency increases with the increase of the number of harmonics. The N-th harmonics of Current Controlled Reactor has n zero values and n-1 extreme points. The extreme points presented a symmetric distribution with Ek*= 0.3 as the center point.With this control voltage, the core saturation level of MCR is just in a semi-saturation condition. The biggest extreme points of each harmonics appear within the scope of Ek*= 0.3-0.7.

2) Control characteristic

The change of DC control voltage Ek of MCR can directly affect its capacity. When MCR operating voltage is the same, its capacity increases as the DC control voltage increases. Figure 5 shows the relationship between the output current I * of MCR and control voltage value Ek * in per-unit system , the baseline values are taken from the corresponding nominal value of the working state.

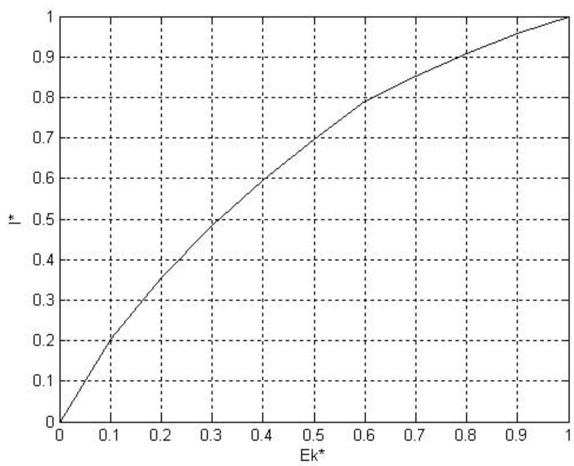
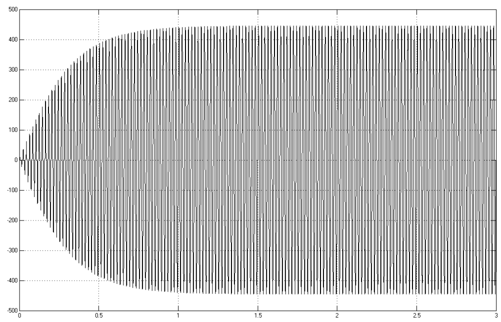


Fig.5 Control characteristic curve of MCR

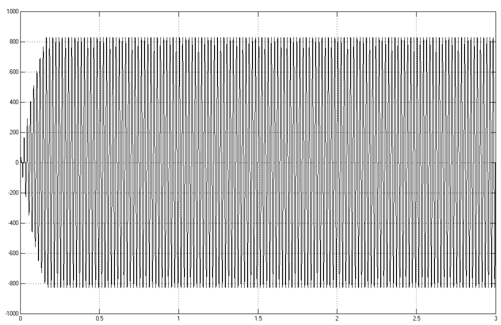
In figure 5, as the control current Ek * increases, the saturation of magnetic core of MCR increases, and the fundamental component of output current increases nonlinearly. Therefore, we can change the DC control voltage of MCR by the control characteristic curves to adjust its capacity rapidly and smoothly, which can give a dynamic reactive power compensation[8]. When a failure appears in the line, adjusting the capacity of MCR rapidly to the maximum not only gives strong reactive power compensation for the lines, but also limits power frequency and switching overvoltage.

3) Characteristic of response time

The capacity of MCR is be directly proportional with DC current component B_d of magnetic core. The change rate of DC current component has a directly relation with the magnitude of the DC control voltage. Figure 6 shows the output current waveform of 110kV MCR when control voltage Ek *= 1 and Ek *= 5.



(a) when DC control voltage Ek *= 1



(b) when DC control voltage Ek *= 5

Fig. 6 The output current waveforms in different DC control voltages

From figure 6 we can know that when DC control voltage is up to 5 times of rated DC control voltage, the response time from the no-load state to the rated capacity of MCR can be reduced about 0.18 second. Therefore, increasing the DC control voltage can greatly improves the response speed of MCR. It is very favorable for inhibiting overvoltage which caused by the line failure, especially for the suppression of operation over-voltage with high amplitude and short duration[9].

V. CONTROL STRATEGY BASED ON MCR

In the substation, in general, on-load tap transformers and reactive power compensation equipments are equipped, and reactive power and voltage are automatically adjusted to make voltage quality and energy consumption achieve the best comprehensive indicator[10]. The specific requirements are as follows:

a. Maintain the substation bus voltage of the load side at the required level;

b. Use the shunt compensation devices and voltage adjust measures effectively to balance the reactive power locally and to reduce the net loss as much as possible .

c. Achieve reverse voltage adjustment, that is make the voltage higher when heavy duty; make the voltage lower when light load , which is conducive to system stability and reduce network loss.

According to the above requirements, optimizing scheme of reactive power and voltage control based on MCR is as follows:

A. Voltage Sub-time Control

Divide a typical load curve of a hub in substation into the peak and trough times, take a different voltage-controlled areas respectively, namely, set a higher upper and lower limits while there is heavy duty, set a lower upper and lower limits voltage value while light load happens, which mainly solves the problem that the voltage is too high and the system reactive power surplus during the night and early morning.

Under the actual condition of a 110kV substation, dividing a typical load curve of a hub into 20h ~ 6h and 6h ~ 20h 2 hours initially.Setting the upper and lower limits of 110kV bus control voltage to 115kV and 110kV at the 20h ~ 6h period and the upper and lower limits to 118kV and 112kV at 6h ~ 20h period. After voltage sub-time control, the voltage fluctuation range is controlled around 4% though the voltage fluctuation is wider. The control method is as shown in figure 7:

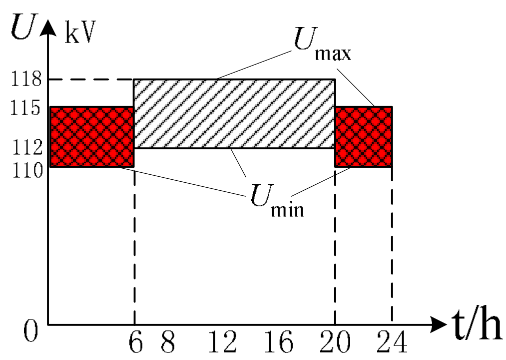


Fig.7 Schematic diagram of Voltage sub-time control

B. Inverse Voltage Control

In order to take full advantage of the quickly and smoothly adjustable features of output capacity of MCR and achieve the goal of inverse voltage control,this paper unifies voltage and reactive power control into the constant voltage regulation mode, which is shown in figure 8. Get a target value of system voltage control according to the system upper and lower limits. The relationship between them can be linear or non-linear.If the actual average merit value exceeds the upper limit, the target voltage is the upper limit value, if the actual average merit value is below the lower limit, then the target voltage is the lower limit value.

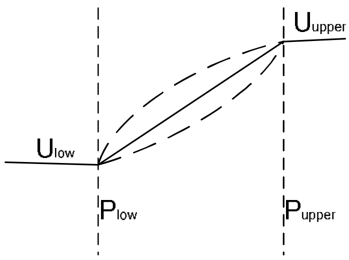


Fig.8 Relationship between the voltage and active power to achieve inverse voltage control

C. The Specific Control Mode of MCR

In order to make the system work in the best range, the measures to adjust the voltage and reactive power of the substation are needed:

a. MCR

b. Capacitor switching

c. OLTC control

Make sure the control goals of substation, firstly make the voltage meet the requirements: Voltage should operate between the upper and lower limits; Secondly, regulate reactive power on the basis of qualified voltage, so as to make the power factor meet the requirements.

Currently MCR、OLTC、capacitors、and switching reactor at low-voltage side are independently controlled, so we only consider controlling MCR, in the mean time the control device of MCR transferring the signal to the automatic switch device to adjust the transformer tap and swtich the capacitors [11-12]. The specific control strategy is shown in figure 9, in which we set the upper and lower limits of the voltage based on voltage sub-time control:

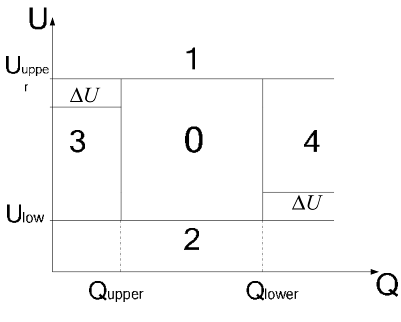


Fig.9 Voltage and reactive power relative to plan

District 0: voltage and reactive power are qualified, MCR does not act;

District 1: voltage is greater than the upper limit, MCR increases its capacity;

District 2: voltage is smaller than the lower limit, MCR reduces its capacity;

District 3: reactive power is greater than the upper limit, MCR reduces its capacity while voltage is qualified;

District 4: reactive power is smaller than the lower limit, MCR increases its capacity while voltage is qualified;

District ΔU : voltage micro-vibration area, no control.

VI. SIMULATION

The remarkable problem in high voltage substation is that the system voltage has some fluctuation and deviation from the standard limit. For example，the load of a 110kV substation fluctuates at 1s and lasts for 1 second, the load-side A-phase voltage amplitude changes is shown in Fig.10 while MCR is not installed.

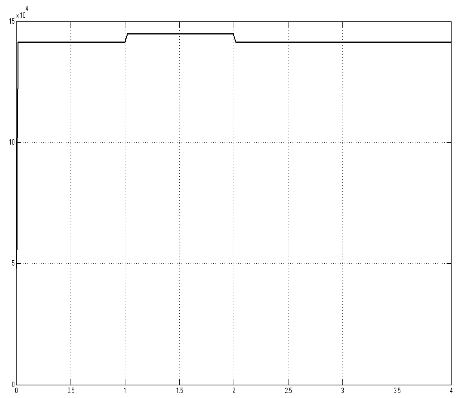


Fig.10 The voltage amplitude shown without MCR

As it can be seen from Fig.10, at 1s, the load-side voltage amplitude increased from 141.395kV to 144.7kV, the voltage variation is 3.305kV, when load fluctuation disappears at 2s, the voltage amplitude becomes 141.395kV again .

When three-phase Magnetically Controlled Reactor[13] with capacity of 200Mvar is installed as a controllable reactive compensation equipment, The reactor control system detects the voltage fluctuation exceeds the permitted range in 1s, it give direction to instruct the magnetron reactor into system, using look-up table method and the PI controller to reduce the voltage to allowable range in a short time. Load-side A-phase voltage amplitude is shown in figure 11, magnetic flux of A-phase of the reactor, output current and the excitation current is shown in figure 12.

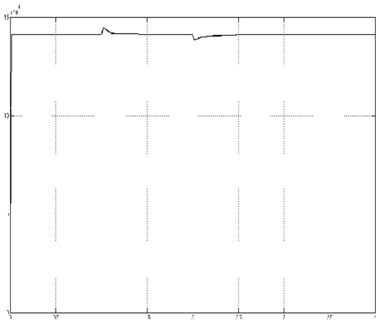


Fig.11 The voltage amplitude shown with MCR

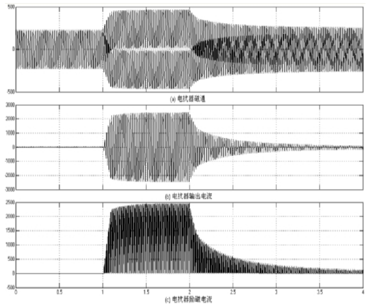


Fig.12 The sendouts of MCR

As it can be seen from figure 11, the original load-side voltage amplitude is 141.35kV, when the load fluctuation happens, and MCR is operated in time, the voltage can be maintained at 141.34kV, the process of voltage compensation is completed in 0.14 seconds. When control system detectes voltage drop as fluctuation disappears at 2s, then MCR is out of operation, the voltage recovers to 141.33kV. figure 12 shows the magnetic flux of MCR, output current and the DC excitation current waveform, which can explain it that reactive power and voltage control method based on Magnetically Controlled Reactor could meet the 110kV substation reactive power and voltage compensation .

VII. CONCLUSION

By using reactive power and voltage control method based on Magnetically Controlled Reactor can adjust reactive power continuously and smoothly, eliminate the reactive power which feeds back to system, improve power quality, and effectively reduce adjust times of the load tap and capacitor switchs to improve the life of the equipment which has obvious economic benefits. Besides, controlling MCR reasonably is also beneficial to limit the switching overvoltage and transient over voltage.

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