The Mechanism Analysis of Fault Current Limiter on Power System

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***Abstract*:** As a kind of new protection device，fault current limiter has been used in power system .When the fault occured in the circuit, the transient model based on FCL will have some influences on transient stability of power system, distance protection and voltage sag. The paper will study the mechanism of influence on power system, a new distance protection setting method proposed after FCL being input and using the models and simulations of PSCAD-EMTDC to test and verify FCL's influence on voltage sag. Analysis and simulation validation demonstrate that FCL not only improves transient stability of power system, but also reduce the influence of distance protection, as well as restrain the voltage sag effective.

***Index Terms*:** FCL；transient stability；distance protection；PSCAD；voltage sag；

I. INTRODUCTION

In recent years, with the capacity of power system increasing, short-current level in the grid also increases day by day，which set more critical requirement to the ability of cutting current by circuit breaker. The paper [1,2,3] pointed out that the maximum short-circuit current of high voltage grade in some areas of China such as Guangdong power grid, East China power grid, Jiangsu power grid has come close to or even more than the support limitation of the equipment.，and according to the data, the maximum short–circuit current of the Three Gorges hydropower plant would reach 300kA. However, now the international production of GIS(Gas Insulated Switchgear) only have 100kA for the limit, the short-circuit current problem has been very serious. The paper [4,5] point out that there are three methods to limit the short-circuit current levels at present, such as adjust the composition of network, change operating mode of system, install the current limit protection equipment and so on. Among them, connecting with the current limiting reactors (fault current limiter) in series of the power system is one of the excellent schemes to solve short-circuit current level. The paper [6] have used EMTP to simulate the level of using FCL to limit short-circuit current. This paper will first study the mechanism of influence on power system after FCL being installed on the basis of introducing transient model of FCL, and then study the influences to the distance protection's setting range of the high-voltage electric power system after FCL being input into the circuit, finally use PSCAD-EMTDC to simulate the influences of voltage sags after the installation of fault current limiter.

II.THE MECHANISM ANALYSIS OF FCL

A. simple equivalent transient model of FCL

The equivalent inductance of FCL almost closes to zero with no influences to the system while the system run in normal operation and before FCL being input into the short-circuit; However, when the fault occurred , FCL will being input into the circuit to limit current rapidly. The model of FCL can be shown in Figure 1, on the premise of ignoring electro-magnetic transient process of every element by FCL. In normal operation and before FCL operate when the fault occurred, switch S will keep in closed state; while the fault has lasting 5ms，switch off S , the current limit inductance L will be input into the system to limit the current.

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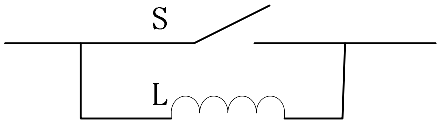


Figure 1.Simple equivalent transient model of FCL

B. FCL's influences on transient stability

A single power transmission system installing two FCLs on the Feeder terminal of lines is shown in Figure 2, which will analyze the mechanism of transient stability by power system, while a three-phase short-circuit fault occurred at the outlet of line.

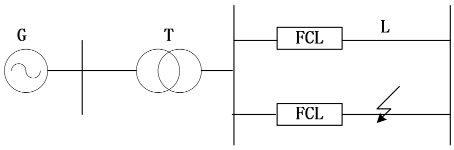


Figure 2. Transmission system with FCL

Through the electromagnetic power equation $P = \frac{E'U}{X_\Sigma}\sin\delta = P_m \sin\delta$, we can derive the power characteristics of the system in various situations as follows:

In normal operation:

$$X_{1\Sigma} = X'_d + X_T + X_L / 2 \tag{1}$$

Then $$P_I = \frac{E'U}{X_{1\Sigma}}\sin\delta = P_{1m}\sin\delta \tag{2}$$

FCL switch off, when fault occur:

$$X_{2\Sigma} = X'_d + X_T + X_L/2 + \frac{(X'_d + X_T)X_L/2}{X\Delta \to 0} = \infty \tag{3}$$

Then $$P_{II} = \frac{E'U}{X_{2\Sigma}}\sin\delta = 0 \cdot \sin\delta = 0 \tag{4}$$

FCL switch on, when fault occur:

$$X_{3\Sigma} = X'_d + X_T + 2X_L^2/(2X_L + X_{FCL}) + X_L X_{FCL}/(2X_L + X_{FCL}) + X_L X'_d / X_{FCL} + X_L X_T / X_{FCL} \tag{5}$$

Then $$P_{III} = \frac{E'U}{X_{3\Sigma}}\sin\delta = P_{3m}\sin\delta \tag{6}$$

After fault being cut off:

$$X_{4\Sigma} = X'_d + X_T + X_L \tag{7}$$

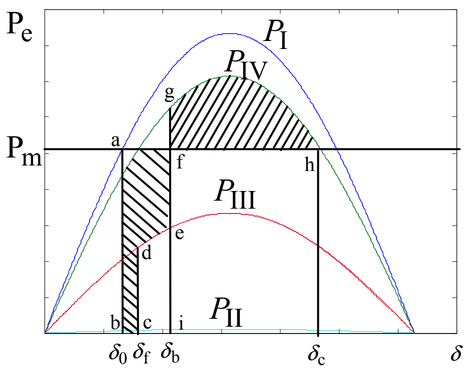
Then $$P_{IV} = \frac{E'U}{X_{4\Sigma}}\sin\delta = P_{4m}\sin\delta \tag{8}$$

From equation(1)~(8),we can draw:

$$\begin{cases} X_{1\Sigma} < X_{4\Sigma} < X_{3\Sigma} < X_{2\Sigma} \\ P_{1m} > P_{4m} > P_{3m} > P_{2m} \end{cases} \tag{9}$$

C. Power-angle characteristic analysis

From the above formula (9),we can draw the power-angle relationship of system in different situations, as shown in Figure 3. FCL's inputting into system make output electromagnetic power of Genenator increases and the accelerating area decreases, this is to say, it will reduce the accumulation of kinetic energy during the steam turbine rotor in fault, which will produce positively influence to transient stability of the system, increase the margins of generator 's transient stability ,decrease the possibility of desynchronization in the system.



δ_0 -power-angle in normal operation;

δ_f -power-angle at fault time;

δ_b -power-angle of FCL input;

δ_c -power-angle at clearing time of fault;

Figure 3. power-angle curve of system with FCL

In normal operation, the generator supply the active power Pe=Pm to infinite system ,with the input power of prime motor Pm ,while the generator runs stably at *a* point , with δ_0 power-angle. When three-phase short-circuit occurs instantaneously, power-angle curve of generator drop to P_{II} , with running state move to *b* point.. About 5ms later, running state will move to *c* point along with P_{II}, with δ_f power-angle. For the time being, FCL can be connected to the circuit in series, with power-angle curve becoming P_{III} , while running state change to *d* point correspondingly. When the running state move to *e* point, the fault will be cleared off, power-angle curve will become P_{IV}*, and the* running state will change to *g* point with δ_b power-angle, then running state will move to *h* point along with P_{IV} .By the graph, we can see, acceleration area of the system with FCL is *Sabcdef*; while the acceleration area of system with no FCL will move to *Sabcief* along with *a-b-c-i-e-f-g-h*. The method of connecting FCL to the circuit in series to reduce the acceleration area of system will play a positive effect to the transient stability of the system. Though the method is similar to the method of improving the stability of the system through increasing deceleration area of the system by automatic circuit recloser, FCL is more practical and effective to increase the transient stability of system comparing with case of worsening the transient stability of system by automatic recloser to reclose the permanent fault.

III. THE IMPACT OF FCL TO DISTANCE PROTECTION

A. The Operation characteristics of traditional Distance Protection

When the short circuit fault occurs, the FCL will be series connected in circuits automatically in order to restrict the short-circuit current. So the protection range of original distance protection of the system will be disrupted, but also the sensitivity of distance protection will be reduced.

Generally, the impedance relay with direction circle characteristics is used as measuring elements, and the operation characteristics of impedance relay is showed in Figure 4. Its absolute value comparison operation equation is：

$$\left| Z_m - \frac{1}{2} Z_{set} \right| \le \left| \frac{1}{2} Z_{set} \right| \qquad (10)$$

Where: Z_m is the measured impedance,

Z_{set} is the setting impedance.

When the FCL is series connected, the measured impedance Z_m may drop out of the circle, and the faults in circle will be not detected by direction impedance relay. The protections will failure. So it is necessary to set the setting impedance Z_{set} based on related parameters again before the FCL cascaded. And the setting value of the first segment is:

$$Z'_{set} = Z_{set} + Z_{FCL} \qquad (11)$$

Where: Z_{set} is the setting impedance,

Z_{FCL} is the impedance of FCL.

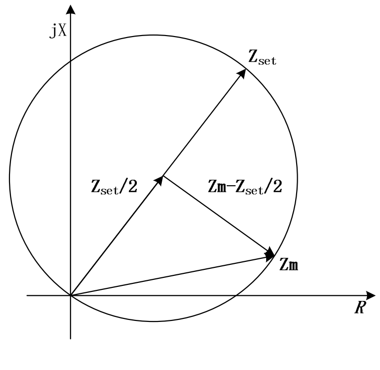


Figure 4. Operation Characteristics of Direction Impedance Relay before Correction

B. The Operation characteristics of Distance Protection after Correction

In order to make sure the direction impedance relay operates accuracy and rapidly but failure after the FCL cascaded, the new operation characteristics of direction impedance relay is showed in Figure 5:

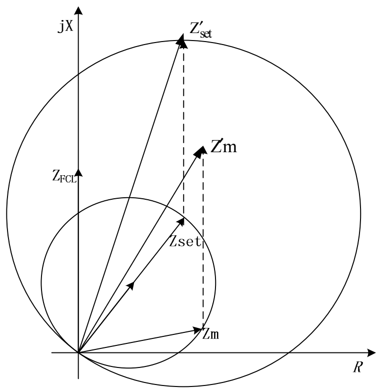


Figure 5. Operation Characteristics of Direction Impedance Relay after Correction

IV. THE IMPACT OF FCL TO VOLTAGE SAG

A. The definition of voltage sag

With the emergence of new technology industries, power quality has been paid more and more attention by power enterprises. Among them, the voltage sag has been considered as the foremost problem affecting normal and safe operations of many types of equipment. The International Electrotechnical commission (IEC) defines it as voltage sag, and the Institute of Electrical and Electronics Engineers (IEEE) defines it as voltage sag. The main parameters to measure the degree of voltage sag are the amplitude and duration of voltage sag. The essay [7] defines the voltage sag as the voltage RMS drops to 10 percent to 90 percent rapidly, and lasts 0.5 to 30 power frequency cycle.

Generally, voltage sag is caused by short-circuit faults of power system or the users themselves, and also may be caused by the wrong startup of large motors[8]. For example, when the short-circuit faults are caused by lighting strike or pollution flash over of insulators, the protections operate and cut them out, and then the auto-recloser successfully. So the users supplied by this fault line will undergo a short supply interruption and the users nearby supplied by the same busbar usually experience a voltage sag. If recloser unsuccessfully, the fault line breakout. So the users supplied by the fault line may be interrupted for a long time, more than 3 minutes, and the other users undergo voltage sag again.

B. Simulation Verification of FCL impact to voltage sag

The normal operation of electric equipments is affected seriously by voltage tip caused by short-circuit faults, and even huge economic losses. The installations of FCL between busbar and feeders to restrict short-circuit current and reduce voltage sags are studied in paper [9,10]. The effects of FCL to restrict voltage sag is analyzed below using PSCAD-EMTDC.

The artificial circuit of PSCAD is showed in Figure 6:

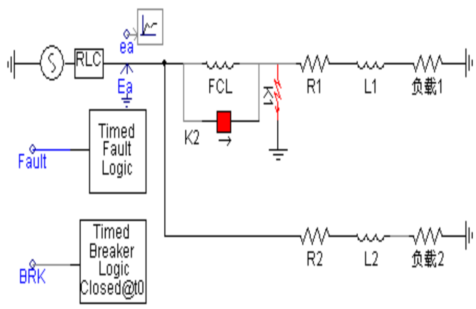


Figure 6. Simulation diagram of the impact of FCL to voltage sag

Where the terminal voltage U of generator is 10kv, the internal resistance R_s of the system is 0.3Ω, the internal impedance L_S is $1mH$, R_1、L_1、R_2、L_2 are the resistance and impedance of the branch 1st and 2nd, and their values are 0.39Ω and $1mH$, the equivalent load of branch 1st is 50Ω, and 10Ω in branch 2nd, the switch K1 is to imitate metallic grounding and K2 is for FCL cascaded.

The process of simulation is showed. When t is equal to $0.1s$, K1 switch off, and the single phase to earth fault occurs; when *t* is equal to 0.15*s*, K2 switch off, and FCL cascaded. The voltage waveform of busbar out of FCL is showed in Figure7and voltage waveform with FCL in Figure 8.

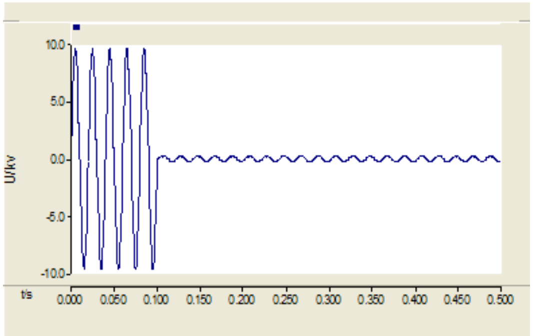


Figure 7. Voltage waveform of busbar out of FCL

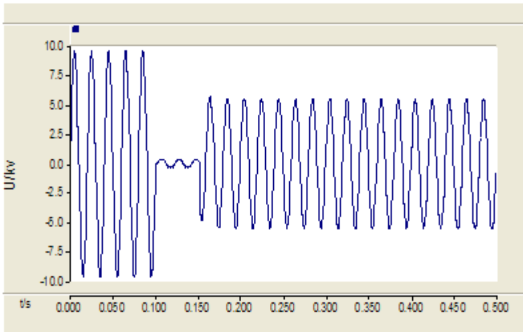


Figure 8. Voltage waveform of busbar with FCL

From Figure 7 and Figure 8, we can get the terminal voltage of busbar out of FCL is almost zero and with FCL is different. It based on the impedance of FCL. There is different degree of voltage sag in basbar. Within a certain range, the larger the impedance of FCL the better the restriction of voltage sag. In Figure 8, the voltage only drop to the half of the terminal voltage. Therefore, FCL can restrict voltage sag efficiently, as a result of reducing effects of voltage sag to the system.

V. CONCLUSIONS

The above analysis of simulations on the transient model of FCL prove that: The connecting of FCL to the circuit in series not only can improve the transient stability of system by reducing the acceleration area of generator, but also reduce the influence of distance protection, finally restrain voltage sag of the system effectively.

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