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Study on Suppression of Secondary Arc Current under Different Fault Locations for High Voltage Transmission Line

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ABSTRACT: In super/extra high-voltage systems, voltage levels are much higher and transmission lines are much longer, so it makes burning times of secondary arc current become longer, thus reduces the successful rate of single-phase auto reclosing. When single-phase grounding fault occurs in high voltage transmission line, secondary arc current and recovery voltage must be suppressed in order to ensure that single-phase auto reclosing operates reliably and successfully. This paper is a detailed study of the suppression of secondary arc current.

Keywords: High-voltage Transmission, single phase fault, single phase auto reclosing, secondary Arc current, shunt reactor, neutral small reactor.

I. INTRODUCTION

Based on past records of domestic and foreign countries high-voltage transmission lines, the statistical result shows that in extra high voltage (EHV) and ultra high voltage (UHV) systems, single-phase grounding fault is more than 90% of the total failure, of which nearly 80% are transient. The rapid single phase auto reclosing is generally used in extra or ultra high voltage system.

When the ultra-high pressure systems with single-phase automatic reclosing device, single-phase to ground, there may be breaking the single-phase state, it is normal operation mode.

Used in suppression at home and abroad arc current nowadays, there are two main suppression measures applied at home and abroad: high speed grounding switches (HSGS) and the shunt reactor with neutral small reactor, both methods are applied to suppress secondary arc current by reducing its amplitude and shortening its burning time. In Japan, because EHV lines are short and the lines are not transposed, it is not practical to use a small reactor to limit the secondary arc current. So Japan adopts the former way, yet the latter have been widely used in many countries. This paper, which is based on a 500kv high-voltage lines example, uses suppression method of shunt reactor with neutral small reactor and simulates suppression effect while fault point occurs in different locations [1].

Studies have shown that the amplitude of secondary arc current is an essential factor for the extinguishment of arc. The successful rate of single-phase auto reclosing depends largely on magnitude of secondary arc current at the fault point. With the voltage levels improving, the influence of the secondary arc on the system is more and more serious. If the secondary arc can not be extinguished promptly, the single-phase auto reclosing will be a failure [3]. It is common knowledge that extra high voltage and long distant transmission line join a shunt reactor and a neutral grounding via small reactor.

II. SINGLE PHASE AUTORECLOSER

Transient condition result in such arcing faults that if the fault energy in feed is interrupted for a short period, the arc extinguishes and the line can be re energized. This fact is employed as a basic for auto recloser scheme. In such scheme, after the relays at both ends of the line have pick up, the circuit breaker are tripped as for a possible at same time and reclosed after time has been allowed for deionization. The fault disappears if it transient, and line is fully restored to service after the recloser.

If the fault is not cleared after the first recloser, a double or triple attempt of isolation and recloser can be made. If the fault still persists, the breakers may permanently open till it is reset manually.

Autorecloser may be single or three phase type. Mostly single phase auto reclosing breakers are preferred as most of the transmission faults are single phase to ground faults. Auto reclosing in single phase also improves stability as the power remains transmitted through the two healthy phase, when one phase is interrupted.

The merits of single phase switching are following:-

1. The healthy phase continues to supply power and only faulty phase is opened.
2. Single phase reclosing further improves the power transfer limit.
3. The power transfer on fault can be substantially increased for single phase auto recloser scheme.

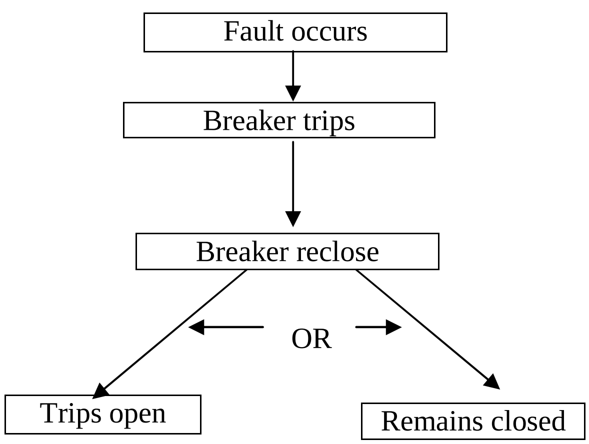


Fig.1. Block diagram of single phase autorecloser.

III. GENERATION THEORY OF SECONDARY ARC CURRENT

After the fault line is cut off because of single phase grounding fault, there is certain grounding current at fault location due to the coupling effects of inter phase of inductance and capacitance. This current is called secondary arc current, which is in the form of electric arc [5].

Secondary arc is an electromagnetic transient phenomenon generated in the process of Single-phase autoreclosing operation.

The generation theory is shown in Fig. 2. When the single phase (i.e. phase *C*) ground fault occurs, the breakers at both ends of the fault phase will be tripped and short-circuit current which is provided with power and system from both ends to the fault point will be cut off. But this time the healthy phases (phase *A* and phase *B*) are still running. There are loads Current (*Ia*, *Ib*) flows through, and the two phases still keep working voltage (*Ea* `*Eb*). Due to the function of inter-phase capacitance *CM* and mutual inductance *M*, the secondary arc current I*c* is generated at the fault point *Q*. It contains two parts: capacitive component and inductive component [2].

When a single phase grounding fault occurs on the ultrahigh voltage (UHV) transmission line, the short circuit current is cut off after the action of protection. At this point, there is still power flowing on the two healthy lines. If not suppressed of secondary arc current that is damaged our transmission system. The two healthy phases will provide secondary arc current to the fault point through the inter-phase electrostatic coupling (capacitive coupling) and the electromagnetic coupling (mutual inductance coupling), as shown in Fig. 2.

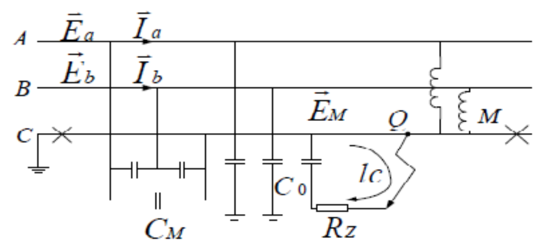


Fig. 2. The theory of secondary arc current.

IV. SHUNT REACTOR

In certain applications such as single-phase tripping on long overhead lines, it might be necessary to install shunt reactors on the line with a neutral reactor so that the zero-sequence impedance is greater than the positive-sequence impedance. A reactor intended for connection in shunt to an electric system for the purpose of drawing inductive current. The normal use for shunt reactors is to compensate for capacitive currents from transmission lines, cables, or shunt capacitors. The need for shunt reactors is most apparent at light loads.

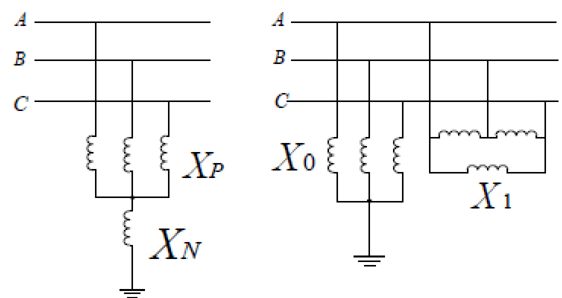
Shunt reactors are commonly used to compensate the capacitive reactive power of transmission lines and there by provide a means to regulate voltage levels in the network. These reactor can be applied directly to transmission level but the cost of switchgear, maintenance of oil cooled iron core reactors and possible saturation at high voltage levels favour the use of air core reactors at medium voltage.

Shunt reactors are provided at sending end and receiving end of long EHV and UHV transmission line. They are necessary when the line is to be charged or when the line is on low load. One primary reason for using shunt reactors on EHV transmission line is to control steady state over voltage when energized the long EHV lines or when operating under light load conditions.

Some high voltage, three-phase reactors are also designed to have higher $X0$ than $X1$. This is necessary in order to reduce the secondary fault current of such systems (i.e., the fault current that continues to flow after the faulted phase has been opened) in order to allow single-phase reclosing of the circuit breaker. This current is caused by the capacitive coupling between the open phase and the two remaining energized phases. With this additional neutral impedance, the reactor neutral point will have a potential to ground under both ground fault and single-phase open-pole conditions. This value ranges from 30–60% of phase-to neutral voltage on effectively grounded systems, depending on the neutral reactance. This, of course, might require greater insulation at the neutral end of the phase reactors as compared to the solidly grounded case, and it also usually will require the provision of surge protection for the neutral end insulation [4].

V. SUPPRESSION THEORY OF SHUNT REACTOR WITH NEUTRAL SMALL REACTOR

Capacitive component of secondary arc current can be eliminated partly or fully through rational choice for reactance of reactor. But it is difficult to eliminate inductive component. In secondary arc current, capacitive component makes up a larger proportion. To compensate for capacitance effect of transmission line and limit the rise of frequency voltage, in general, shunt reactors are installed in long-distance ultra-high single-circuit transmission lines. So it is convenient to set up small reactor at the neutral of shunt reactor to extinguish secondary arc current [2]. The method of connecting wire and equivalent circuit are shown in Fig. 3.



(a) Method of connecting wire (b) Equivalent circuit

Fig. 3. Theory circuit of shunt reactor with neutral small reactor.

Here are some equations as follow:

$$X_1 = \frac{X_P}{X_N}(X_P + 3X_N) \qquad (1)$$

$$X_O = X_P + 3X_N \qquad (2)$$

It is shown obviously that the circuit of shunt reactor *XP* with neutral small reactor *XN* grounding is equal to two equivalent circuits: Three-phase shunt reactor *X0* and three three phase interphase reactor $X1(X1= \omega\ LM)$. They respectively compensate for ground capacitance and interphase capacitance of transmission line. When equivalent interphase reactor fully compensate for interphase capacitance of transmission line, equivalent interphase inductive susceptance is equal to capacitive susceptance. In this case, Parallel resonance occurs.

It makes loop impedance of inductive component become infinite and thus eliminates effects of inductive component of secondary arc current. According to the analysis above, equations are shown:

$$B_{LM} + B_{CM} = 0 \qquad (3)$$

$$\frac{1}{\omega L_M} = \omega C_M \qquad (4)$$

However, under the conditions of full compensation, recovery voltage circuit of fault phase is equivalent to two parallel resonant circuits in series, so it easily leads to the danger of power frequency over-voltage. Therefore the system could not perform in this way.

VI. TIMING SEQUENCE AND PROCESS OF SINGLE-PHASE AUTORECLOSING OPERATION

In the process of fault occurs in power system, protection equipments of transmission line from response to accomplishment of autoreclosing operation ’corresponding timing sequence and process of single-phase autoreclosing operation are shown in table.1 The whole time from t0 to t6 is known as the reclosing time of single-phase autoreclosing. It is the time intervals between emergences of short-circuit current and comeback of system. The setting time of single-phase autoreclosing is determined according to it. In the context of maintaining a certain reserve, shortening the setting time can improve the transmission power.

Table 1. Single-Phase Autoreclosing Timing Sequence.

Timing Sequence	Process Description
*t*0	Single-phase grounding fault occurs in power system
*t*1	Breaking coil of breaker charges
*t*2	Main contact turns off; Short-circuit current is cut off.
*t*3	Fault phase separates from power system; Secondary arc in the process of self-extinguishing time
*t*4	Self-extinguishing moment
*t*5	Deionization time of secondary arc finishes
*t*6	Pre-breakdown moment after breakers at both ends of fault phase automatic switch-on

In our country, it is generally believed that the reclosing time which is set between 0.3s and 0.5s belongs to the quick closure, while those between 0.7 and 1s, even longer, and refers to the slow closure.

VII. CALCULATION OF SECONDARY ARC CUREENT

Example of these is a model EHV transmission line with double ended sources, whose frequency is 50 Hz and length is 300km. The impedance parameters of positive sequence and zero sequence at both ends.
The transmission line applies the measure of shunt reactor *LP* with neutral small reactor *LN* grounding at both ends to suppress secondary arc current. *K1* and *K2* are breakers at both ends of fault phase. Connect the fault point *Q* with the earth through Breaker *K3*. The equivalent circuit is shown in fig 4. Secondary arc current are measured using MAT LAB software.

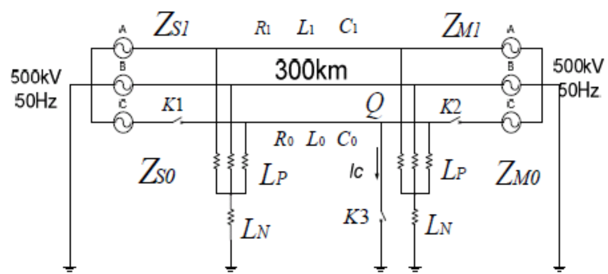
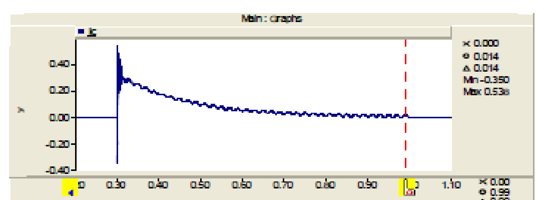
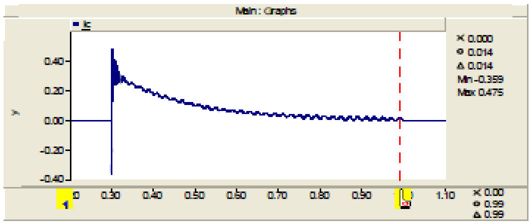


Fig. 4. Equivalent circuit of transmission line.

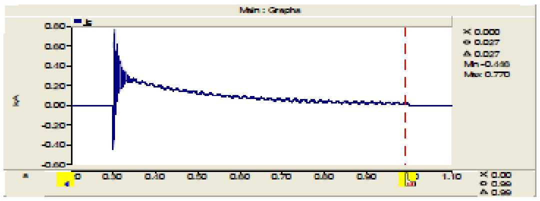
Simulation result are Change the locations of fault point, and set the distance between initiating terminal and the fault point as 150km, 200km and 300km. Corresponding waves of secondary arc current are shown in Fig. 5.



(a) 150 km



(b) 200 km



(c) 300 km

Fig. 5. The changing situations of secondary arc current under different locations of fault point.

VIII. CONCLUSION

This paper studies the suppression theory of shunt reactor with neutral small reactor toward secondary arc current. The factors affecting the secondary arc extinction, Shunt Reactor's role is the inductance which can use to compensate between line and line-to-ground capacitance, reducing the flow through line capacitance current, capacitance effect weakened. Adopt neutral point reactor small inductance to compensation phase capacitance between lines, can effectively suppress the vibration frequency of occurrence, and significantly reduces the arc current frequency amplitude. For shunt reactor with the no-load lines, its reclosing process happen single-phase line fault caused by single-phase refusing to move, and its equivalent circuit the job status to change is very complex. With industrial development, demand for power consumption increasing quickly. Construction of EHV and UHV can effectively solve this problem. But high voltage level will cause serious security risk of secondary arc current to the power systems. The suppression theory of shunt reactor with neutral small reactor toward secondary arc current

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