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Phenomenon of Secondary Arc Extinction in Circuit Breaker on Single Phase Tripping of the High Voltage Transmission Line

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ABSTRACT: 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. Shunt reactor joined in long distance EHV transmission line neutral grounding via small reactor. This paper review systematically possible condition of the frequency-regulating resonance over-voltage on single phase cut fault to refusing-shut of the 500kV extra high voltage transmission line which joins a shunt reactor. The system compose an complex series resonance circuits, and present a rational mode of reactive compensation. This paper review also build rational mathematic mode on systemic parameter of 500kV transmission line, and resolute detailed its power frequency component, low frequency component and its DC component of single phase cut fault voltage and secondary arc current by the mean of Laplacian transformation ruling formula. In the end, this system also implemented using MATLAB software, by simulation that transient process on single phase cut fault voltage and secondary arc current.

Keywords: shunt reactor, frequency-regulating resonance over-voltage, reactive compensation; secondary arc current, series resonance circuits, single phase cut fault.

I. INTRODUCTION

EHV Transmission line are usually access by shunt reactor. Shunt reactors are used for compensation of line capacitance in line. The breaking relative capacitance and capacitance of the reclosing phase and to-ground reactance of breaking phase may be composed of series resonant circuit, may lead to resonance over-voltage. Used in suppression at home and abroad arc current Nowadays there are two main reason 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. In this method Make single-phase opening, although the breaking phase lose power, but because of the other two-phase is still running, through the lines of non-fault phase and fault phase with the capacitive coupling between the electromagnetic coupling, in the fault phase is still a considerable number of current flow, at this time the current known as the arc current. This paper detailed review the size of fault generated voltage and arc current.

II. SHUNT REACTOR

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.

In certain applications such as single-pole 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.

III. STRUCTURE AND WORKING PRINCIPLE OF SINGLE PHASE LINE FAULT SYSTEM

Assume that the end off line shunt reactor to ground directly without small reactor, then switch on no-load line of single-phase system after refusing to move, the three-phase equivalent circuit show in Fig. 1. Due to the parallel slip potential CO and XO the reclosing phase (B-phase, C-phase) are being fixed, may cause resonance line components for the fault phase (A phase).

It is capacitance to ground CO, to non-fault phase single phase C12 to ground capacitance and the electric reactor zero-sequence inductance XLO, its equivalent circuit can be further simplified to Fig. 2(a).

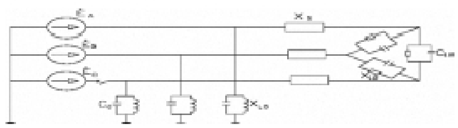


Fig. 1. Three phase system equivalent circuit diagram.

In this figure:
C_O -Line-to-ground capacitance
C_{12} -Phase capacitance
X_L, X L_O -Shunt Reactor inductance positive sequence, zero sequence inductance
X_n - Neutral point reactor inductance
r_s, x_s -Line resistance, inductance

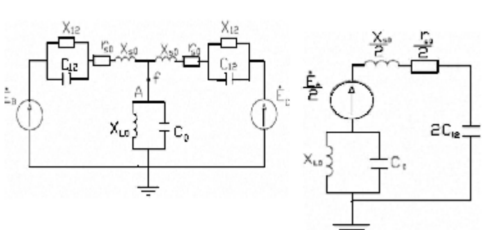
Taking into account the positive sequence inductance X_L of the three-phase reactor greater than zero sequence inductance X L_O, Equivalent circuits are required to add a calculated equivalent inductance X_{12}, X_L Size should satisfy the wiring method into a star with zero-sequence parallel value equal inductance X L_O Reactor positive sequence inductance, X_L that is:

$$\frac{1}{X_L} = \frac{1}{X_{L0}} + \frac{3}{X_{12}}$$

to

$$X_{12} = \frac{3X_L X_{L0}}{X_{L0} - X_L} \quad \dots (1)$$

For three single-phase reactor consisting of three-phase reactor, and its positive sequence inductance X_L equal its zero sequence inductance. Figure 2 (a) in f point is Open-phase fault point, application of the principle of equivalent generators, open the f point, at three single-phase shunt reactor circuit, near infinite large X_{12} can be omitted, single-phase equivalent circuit in Fig. 2 (b).



(a) **(b)**

Fig. 2. System equivalent calculation circuit diagram (a) equivalent calculation circuit diagram (b) single phase equivalent circuit diagram.

It is clear, breaking phase voltage $\dot{U}_A$ is:

$$\dot{U}_A = \frac{\dot{E}_A}{2} \frac{\frac{1}{j\omega C_0 + \frac{1}{j\omega X_{L0}}}}{\frac{1}{j\omega C_0 + \frac{1}{j\omega X_{L0}}} + \frac{1}{j2\omega C_{12}} + j\omega \frac{X_{s0}}{2} + \frac{r_{s0}}{2}} \quad \dots (2)$$

From this single-phase breaker when resonant conditions are:

$$\frac{1}{j\omega C_0 + \frac{1}{j\omega X_{L0}}} + \frac{1}{j2\omega C_{12}} + j\omega \frac{x_{s0}}{2} = 0 \quad \dots (3)$$

It can be seen above the resonance conditions and line-to ground capacitance C_0 , single phase capacitance C_{12} single-phase reactor zero-sequence-to-ground inductance X L_0 and zero-sequence inductance x_{s0} relevant. Above the resonance conditions can also be power reactor $Q_L = \frac{U_e^2}{X_L}$ capacity , and line charging capacity $Q_L = U_e^2 \omega C_1$ express , U_e is system nominal voltage, C_1 is line positive sequence capacitance. Because of the zero-sequence line inductance x_{s0} is small, so negligible, choose the line $C_0 = \frac{2}{3}C_1$, White line capacitance $C_{12}=(C_1 - C_0)/3$ By Type (2) the availability of single-phase resonant breaking when conditions are as follows:

$$Q_L = \frac{8}{9} Q_C \approx 0.9\ Q_C$$

Wish to restrict the occurrence of resonance, it would take the destruction of their resonant conditions, the methods are easy to take compensation for man-made device so that alternate routes were open state parameters, even breaking with zero voltage. Know from Figure 1 to prevent the resonance condition is:

$$\omega C_{12} = \frac{1}{X_{12}} \quad \dots (4)$$

Its physical meaning is to enable the interphase capacitance $\frac{1}{j\omega C_{12}}$ and capacitive reactance of the equivalent reactor components inductance j X_{12} parallel resonance, circuit impedance and white tends to infinity.

$$X_{L0} = \frac{1}{\frac{1}{X_L} - 3\omega C_{12}} \quad \dots (5)$$

To meet formula (5), Must have the condition XL_0 > X_L, it is impossible for three-phase or three single-phase reactor group, Currently widely used methods are at the neutral point reactor by the reactor small X_n to ground , At this point, the reactor zero-sequence reactance should be (XL_0 +3 X_n), the installation of small electric reactor X_n, the effect of which is generated equivalent white wire and white inductance compensation capacitor, and reactor are compensated positive sequence line wire capacitance, so small reactor are secondary compensation.

Here as 500kV EHV Transmission Line for an example, select the line parameters, proved the small neutral reactor grounding electric wiring on the single-phase line voltage fault.

The reactor zero-sequence impedance (XL_0+3X_n) into (1):

$$X_{12} = \frac{3X_L(X_{L0}+3X_n)}{[(X_{L0}+3X_n)-X_L]} = \frac{X_L(X_{L0}+3X_n)}{X_n} \quad \ldots(6)$$

Because of Line equivalent circuit is Increase of the equivalent reactance X_{12} ,so at this time the fault phase voltage of breaking phase $\dot{U}_A$ is:

$$U_A^{\cdot} = -\frac{\dot{E}_A}{2}\frac{\frac{1}{j\omega C_0+\frac{1}{j\omega X_{L0}}}}{\frac{1}{j\omega C_0+\frac{1}{j\omega X_{L0}}}+\frac{1}{j2\omega C_{12}+\frac{2}{jX_{12}}}+j\omega\frac{x_{s0}}{2}+\frac{r_{s0}}{2}} \quad \ldots(7)$$

Q are Separated into the type (2) and type (6) (7),The A-phase fault phase voltage can be calculate. And that the result are the increase in neutral grounding reactor can be very effective in reducing single-phase line of the phase voltage, and can effectively avoid the fracture occurrence of resonance over-voltage.

IV. SINGLE-PHASE LINE FAULT TRANSIENT PROCESS ANALYSIS BY LAPLACE TRANSFORMATION

During the transition process, because of the power to continue to supply energy, which is stored in the inductor or capacitor in the magnetic energy of the electrostatic field energy is released, or conversion, and its equivalent equivalent inductance L, capacitance C composition of the complex electrical circuit, resulting in an impact component in larger freedom. Established the original line for the no-load circuit, so the initial state for the fault relative to single phase capacitance and the basic energy storage capacitor to zero, of course, electric reactor storage energy also zero, fully available on the conditions shown in Figure 3 fault switching-off phases voltage Laplacian equivalent circuit diagram.

Because of the lines anti-electricity, circuit resistance is relatively small, in order to facilitate the analysis, in-the-Loop calculation be ignored

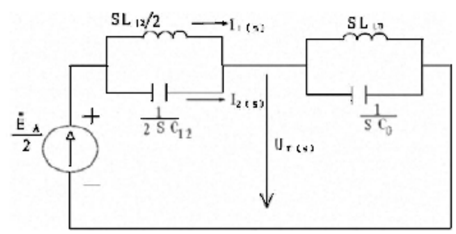


Fig. 3. Fault switching-off phase's voltage Laplacian equivalent diagram.

In the former, the fault port voltage has analyses -EA/2, so we can set up the equivalent power for $-\frac{U_n}{2}\sin(\omega t+\theta)$, therefore the fault port voltage for the Laplace transform is $V_f(s)$,*So :*

$$U_f(s) = \varepsilon\left[-\frac{U_n}{2}\sin(\omega t+\theta)\right]$$

$$= -\frac{1}{2}\frac{\omega cos\theta + ssin\theta}{s^2+\omega^2}U_n \quad \ldots(8)$$

Ignore the relatively small line resistance, available the following equation:

$$\begin{cases} \frac{1}{2}sL_{12}I_{1(f)} = U_{(s)} - U_{f(s)} \\ \frac{1}{2sC_{12}}I_{2(f)} = U_{(s)} - U_{f(s)} \\ I_{g(f)} = \left(I_{1(f)} + I_{2(f)}\right) \\ U_{f(s)} = \left(I_{1(f)} + I_{2(f)}\right)\frac{sL_{L0}}{s^2L_{L0}C_0 + 1} \end{cases} \quad (9)$$

Because of the impact of current DC, arc current arc extinguished the general admission happened at the nearest zero-axis current moment, when the check θ = o Into (8) (9) style.

Solution was:

$$U_{f(s)} = -\frac{\omega(s^2C_{12}L_{12}+1)}{(s^2+\omega^2)(s^2+\omega_z^2)(C_0+2C_{12})L_{12}}U_n$$

$$I_{g(f)} = \frac{\omega(s^2C_{12}L_{12}+1)(s^2C_0L_0+1)}{s(s^2+\omega^2)(s^2+\omega_z^2)(C_0+2C_{12})L_0L_{12}}$$

one of

$$\omega_z = \sqrt{\frac{L_{12}+2L_0}{L_{12}L_0(2C_{12}+C_0)}}$$

To type inverse transform was:

$$U_f(t) = k_1 Sin\omega t + k_2 Sin\,\omega_z t$$

$$k_1 = -\frac{\omega^2 C_{12} L_{12} - 1}{(\omega^2 - \omega_z^2)(C_0 + 2C_{12})L_{12}} U_n$$

$$k_2 = -\frac{\omega(\omega_z^2 C_{12} L_{12} - 1)}{\omega_z(\omega_z^2 - \omega^2)(C_0 + 2C_{12})L_{12}} U_n$$

So no-load circuit breaker reclosing happened single-phase refusing to move the fault voltage and arc current all contain the same frequency component and free weight. Frequency component is also a mandatory component, will continue to supply line fault with energy; freely component, and its oscillation frequency is self-loop frequency, size of 50 Hz.

V. EXAMPLE AND SIMULATION

Using MATLAB software by simulation to calculate the fault systems, setting fault happened at t = O.2s moment, can get no-load energy lines are not single-phase disconnection happened fault voltage and arc current transient waveform, see Figure 4. Of course fault voltage and the free components of current after a few cycles have been attenuated to a very small, the decay time of DC component is longer. Because of the system complexity of calculate, fault map does not take into account component and DC component Freedom attenuation, the fault transient wave reference only.

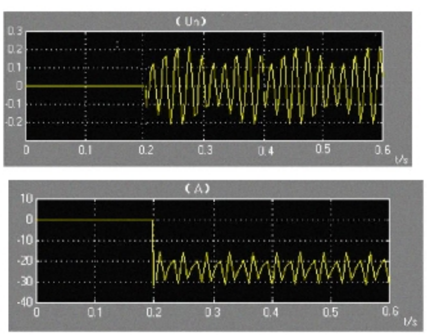


Fig. 4. Single phase no load transmission line refusing-closing faulting voltage and Secondary Arc Current waveform.

VI. CONCLUSION

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, If the reactive power compensation coefficient larger, equivalent capacitive reactance and inductance may be form a series resonant circuit.

In this paper a single-phase disconnection happen resonant Reactive power compensation factor is 0.9, so the general EHV transmission line reactive power compensation factor should be between 0.6 - 0.9. Adopt neutral point reactor small inductance to compensation phase capacitance between lines, can effectively suppress the vibration frequency of occurrence and significantly reduces the fault voltage and arc current frequency amplitude.

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