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Suppression of Secondary Arc Current in Extra High Voltage 765 KV Transmission Line of 4 Bus System

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Abstract: ***The effectiveness of single-pole auto reclosure (SPAR) in maintaining power system stability is largely determined by the speed with which secondary arc extinction, and hence auto reclosure, can be achieved. In this work there is approach to measure the suppression of secondary arc current by Neutral reactor (shunt reactor) which is applied widely in many countries. In this paper the different results of healthy 4 Bus system, faulted system, Breakers operation without Neutral reactor are compared with the Neutral reactor and Simulation studies were carried out in the MATLAB simulation environment to observe the secondary arc current suppression is achieved by the Neutral reactor is better as compared to without neutral reactor. For the simulation purpose, the model of two-machine 4-bus system with healthy operation, faulted system operation, breaker operation without Neutral Reactor and with Neutral Reactor operation is developed in MATLAB/SIMULINK using Simpower System (SPS) blockset.***

Keywords: Breakers, Neutral Reactor (Shunt Reactor), Secondary Arc, Single-Phase Grounding Fault, Test System Model, MATLAB/SIMULINK

1. Introduction

It is well realized that the transient faults which are most frequent in occurrence do no permanent damage to the system as they are transitory in nature. These faults disappear if the line is disconnected from the system momentarily in order to allow the arc to extinguish. After the arc path has become sufficiently de-ionized, the line can be reclosed to restore normal service. The type of fault could be a flashover across an insulator. Reclosing could also achieve the same thing with semi-permanent faults but with a delayed action, e.g., a small tree branch falling on the line, in which case the cause of the fault would not be removed by the immediate tripping of the circuit breaker but could be burnt away during a time delayed trip and thus the line reclosed to restore normal service.

Single phase to ground fault is the most common fault in power transmission systems. Single phase auto reclosing is used to improve system stability, power transfer, reliability, and availability of a transmission line during a single phase to ground fault. Soon after the fault, the two line end breakers will open (faulted phase only in this case) to isolate the fault. However, the other line (un-faulted phases) are still energized. There is inductive and capacitive coupling between the faulted line and the healthy phases, as well as between other conductors of parallel circuits (double circuit lines).

The Shunt reactors are installed to offset the capacitive effect of transmission lines and therefore improve the voltage profiles of transmission lines. Reactors can be placed on a section of the transmission line or on the adjacent bus. Current transformers (CTs) may be installed on the reactors, or the line protection devices may rely on bus CTs .In addition, they also help regulate the volt/VAR of power systems. Specific implementations of shunt reactors may greatly differ between utilities.

2. Generation Theory of Secondary Arc Current

Secondary arc is an electromagnetic transient phenomenon generated in the process of single-phase auto reclosing operation. The generation theory is shown in Fig.1. When the single phase (i.e. phase C) ground fault occurs, the breakers at both ends of the fault phase will be tripping 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 sound phases (phase A and phase B) are still running. There are loads current (I_a, I_b) flows through, and the two phases still keep working voltage (Ea, E_b). Due to the function of inter-phase capacitance C_M and mutual inductance M, the secondary arc current Ic is generated at the fault point Q. It contains two parts: capacitive component and inductive component.

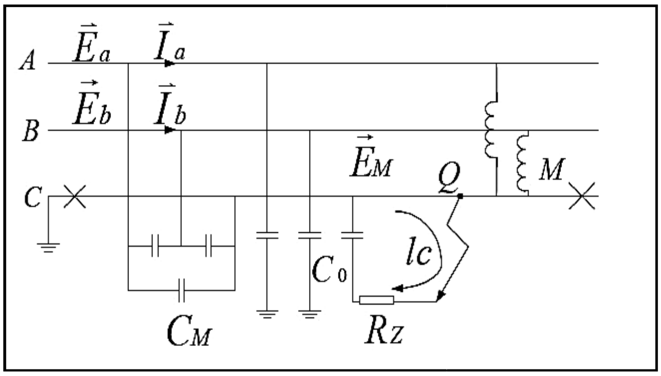

Figure 1: The theory of secondary arc current

Capacitive component is defined as a kind of capacitive current generated by sound phase voltage. It flows through inter-phase capacitance to the fault, and finally enters the earth via grounding arc. Its value is

$$(E_a + E_b)/X_c \text{ ------------------- (i)}$$

Where: $X_c = \frac{1}{\omega}\text{CM}$

As for certain distant transmission line, the value of capacitive component keeps constant and is not related to the exact location of fault point. Load current of sound phase through the mutual inductance M generates induced electromotive force EM on the fault phase. Its value is

$\omega M(I_a + I_b)$ ------------------- (ii)

The electromotive force provides fault point with induced current through the loop formed by transmission lines of fault phase, grounding arc, the earth resistance and earth capacity of fault phase. The induced current is inductive component. It can be seen that the inductive component is related to earth capacity of fault phase.

3. 4-Bus Test System (Healthy System)

A power system model with 4 bus test system is shown in figure 2 without any fault occurs in system (healthy system), the proposed single line diagram of 4 bus power system without faults, breakers and neutral reactor is shown in figure 2.

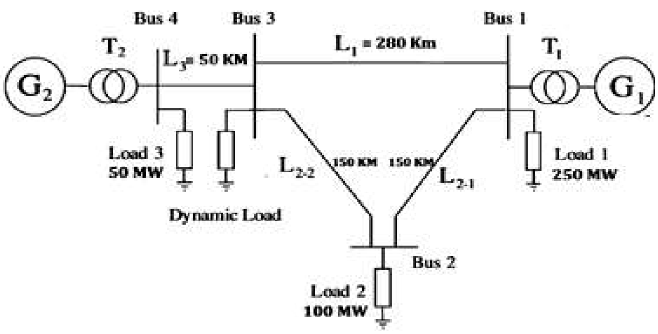

Figure 2: 4-Bus Test System Without Faults (Healthy Operating)

4. Simulation Model of 4-Bus Test System (Healthy System/without Fault)

The two source voltages of 13.8 kV are connected by a 330 km extra high voltage transmission line through two three-phase step-up transformers. The system consists of two output voltage of transformer is 765 KV equivalents, respectively 2100 MVA and 20,000 MVA connected by a 330km extra high voltage transmission line. The three loads having 50 MW, 100 MW, 250 MW and one dynamic load is connected at bus-3.

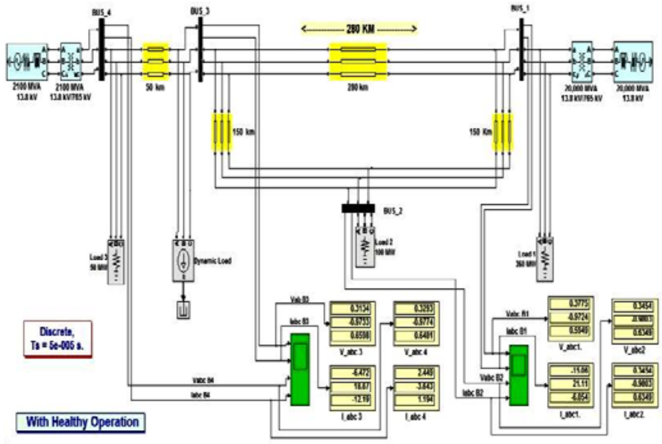

Figure 3: Simulink model of 4 bus system without fault (Healthy Operation)

5. Simulation Result of 4-Bus Test System (Healthy System/without Fault)

The healthy operation of 4 bus system without fault occurs in system is shown in figure 4 and figure 5, and having a no disturbances in the bus voltage and current waveform.

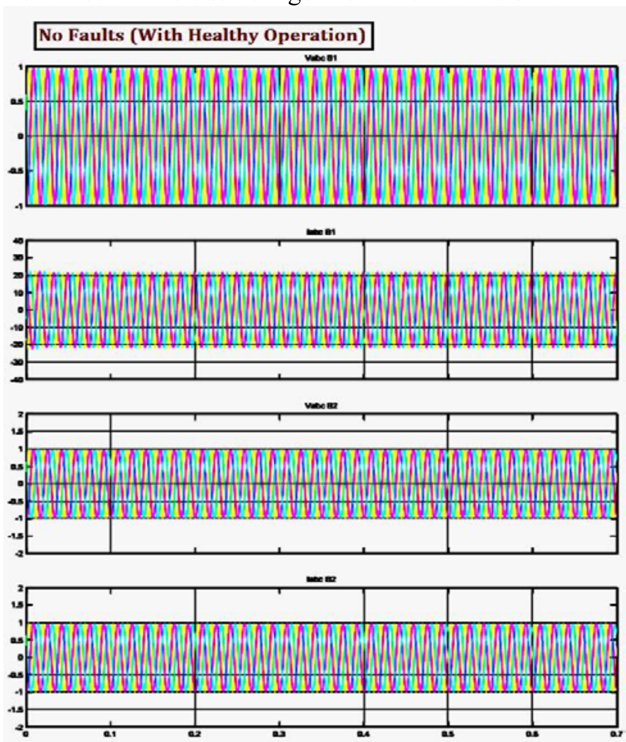

Figure 4: Bus 1 and Bus 2, voltage and Current result without disturbances (without fault)

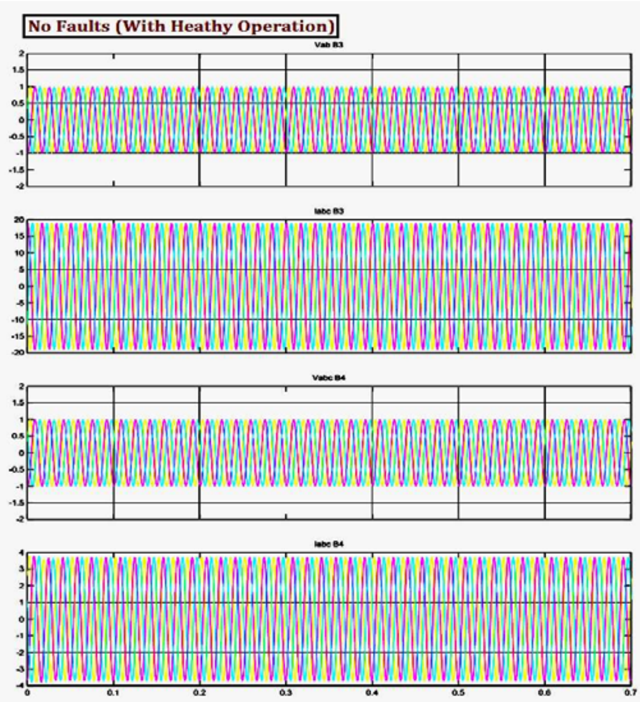

Figure 5: Bus 3 and Bus 4, voltage and Current result without disturbances (without fault)

6. Simulation Model of 4-Bus Test System (With Fault)

The proposed single line diagram of 4 bus test system model with phase to ground faults applied at the middle of 280 KM, 765KV extra high voltage transmission line connected between the Bus 3 and Bus 4. The two breakers are connected at the end of 280 KM line with the two neutral reactors is shown in figure 6.

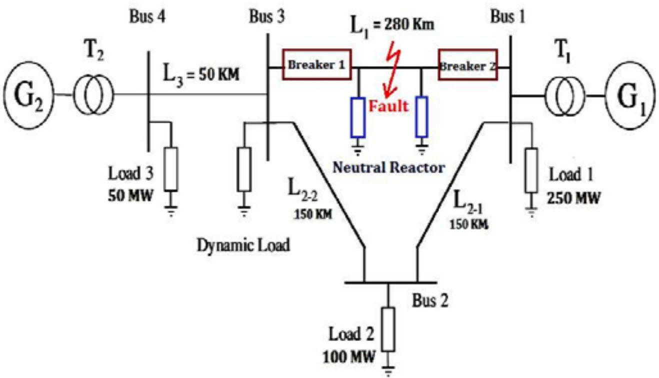

Figure 6: 4-Bus Test System with Faults (Fault is consider at middle of 280 KM line)

7. Simulation Result of 4-Bus Test System (With Fault)

The simulation model of 4 bus system with phase to ground fault occurs at the middle of 280 KM, 765 KV extra high voltage transmission line is to be considering in following three ways.

Simulation model with Fault on Phase A
Simulation model with Breakers operation (without Neutral Reactor)

8. Simulation model with Neutral Reactor

Simulation model with Fault on Phase A

A phase-to-ground fault is applied at the middle of line 280 km EHV line. In order to apply the fault along the line, this line is simulated in two sections of 140 km is shown in figure 7.

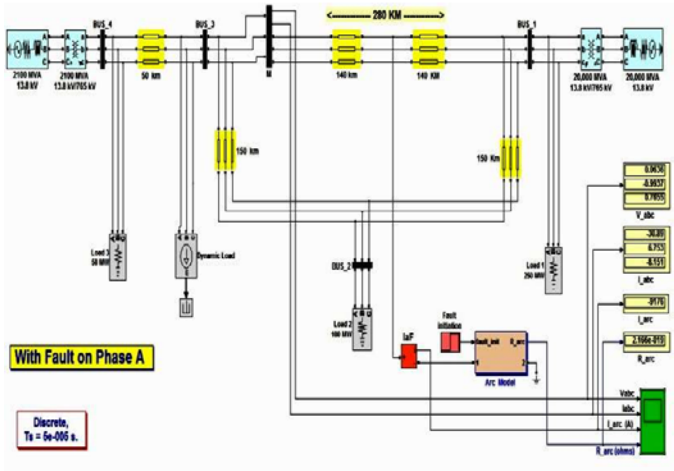

Figure 7: Simulink model of 4 bus system with fault (Without Healthy Operation)

9. Simulation Result with Fault on Phase A

The 4 bus system healthy operated up to the 1 cycle then the fault is applied at t = 1 cycle is shown in figure 8. Observe the three phase-to-ground voltages and currents at sending end of line 280km line and the current flowing into the fault. The line voltages and currents are measured with the 3-phase measurement bus of the Extras library.

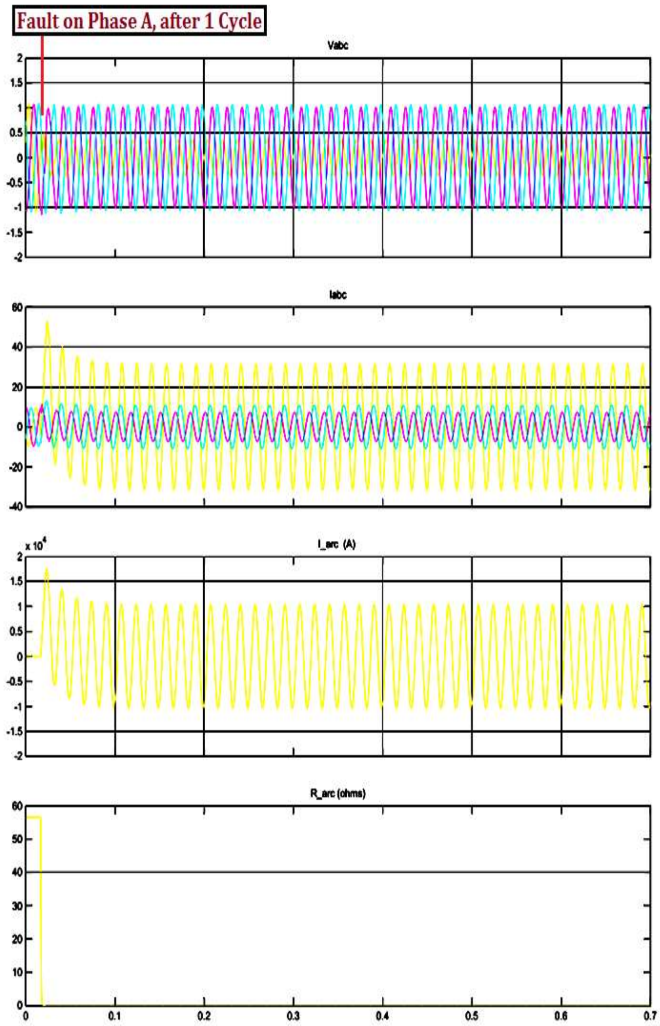

Figure 8: The 4 bus system healthy operated up to the 1 cycle and fault is applied at t = 1 cycle.

Simulation model with Breakers operation (Without Neutral Reactor)

As soon as the fault is detected by the protection relays (not simulated here), an opening command is sent to the two line breakers of the faulted phase.

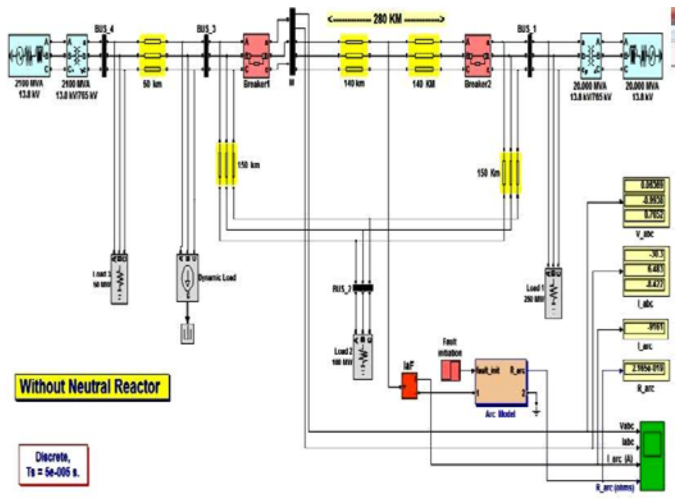

Figure 9: Simulink model of 4 bus system with Breakers Operation (Without Neutral Reactor)

10. Simulation Result with Breakers operation (Without Neutral Reactor)

The breakers are kept open during a certain 'dead time', during which the arc normally extinguishes, and then the two breakers are reclosed. When the two line breakers are tripped on the faulted phase, the fault current is interrupted but a small current will continue to flow through the arc. If this secondary arc current is too large, the arc cannot extinguish and the breaker will reclose on the fault.

The fault is applied at t = 1 cycle. Then, the opening command is sent to both breakers at t = 4 cycles (3 cycles detection + opening time). The two breakers are reclosed at t = 34 cycles after a dead time of 30 cycles (from the cycle 4 to cycle 34), during which the arc creating the fault should extinguish. The two breakers are reclosed at t = 34 cycles and generate the secondary arc current (arc current cannot be suppressed by the neutral reactor) is shown in figure 10.

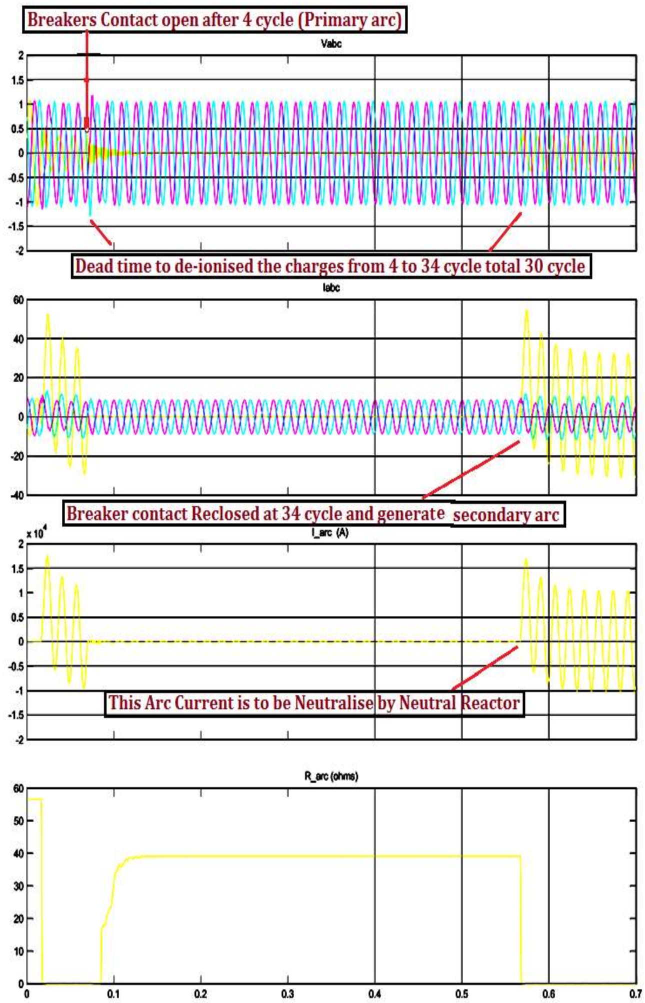

Figure 10: Simulation result with Breakers Operation (Without Neutral Reactor), the opening command is sent to both breakers at t = 4 cycles.

11. Simulation Model with Neutral Reactor

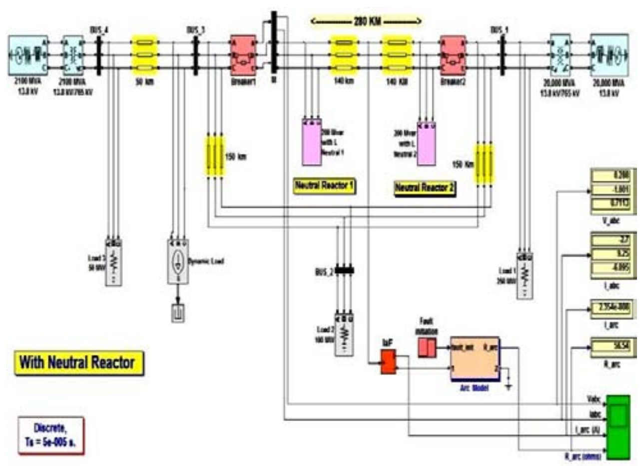

Figure 11: Simulink model of 4 bus system with Breakers and Neutral Reactor Operation

12. Simulation model Result with Neutral Reactor

The two breakers are reclosed at t = 34 cycles and generate the secondary arc current, this arc current suppressed by the two neutral reactor is shown in figure 12. According to the simulation diagram it is clear that the power system is in normal operation before 0.05s and the voltage is a standard sine wave, the power system happen circuit short fault at 0.1s but circuit breaker do not immediately trip, at this time it generates primary arc on lines and the voltage of primary arc much lower than the normal operation of the system voltage. Subsequently, circuit breaker trip and it generates secondary arc on lines and the voltage of secondary arc is less than primary arc. The secondary arc current contains a slowly decaying DC component and a fundamental component. The rms value is below 50 A, that's why the arc extinguishes at the first current zero crossing.

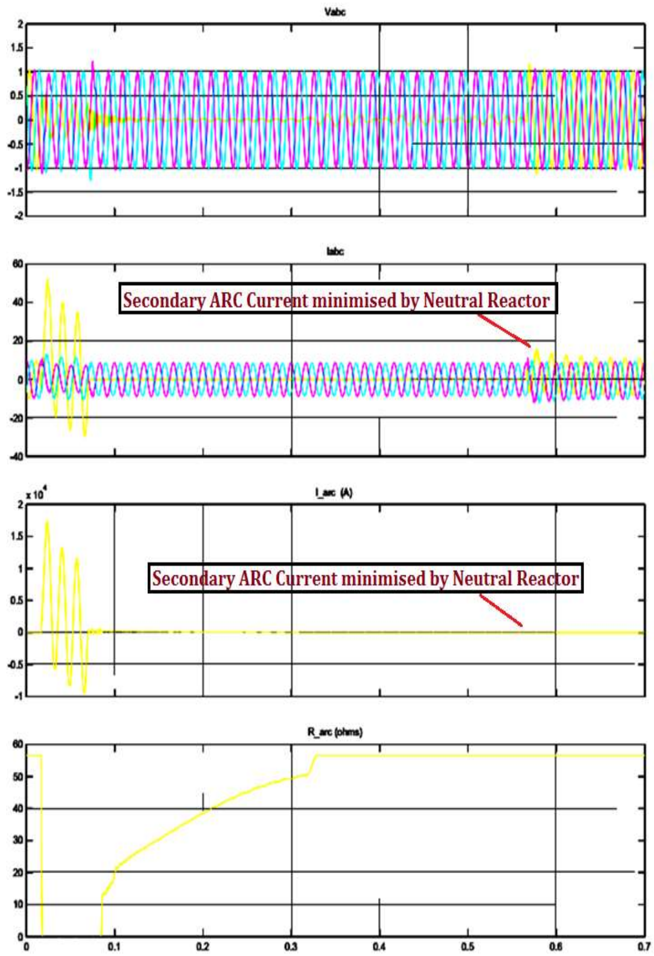

Figure 12: Simulation result with Neutral Reactor Operation, The secondary arc is suppressed by Neutral reactor at t = 34 cycles.

13. Conclusion

This work studies the suppression theory of shunt reactor with neutral small reactor toward secondary arc current, uses MATLAB/SIMULATION software to simulate the suppression effects of with and without neutral reactor finally gets the conclusion.

Due to highly random and complex behavior of secondary arc it is very difficult to reproduce the exact arc duration by digital simulation. However the model elaborated in this work can be employed successfully to examine the performance of arc suppression scheme in auto reclosure study.

This research is about the suppression theory of shunt reactor toward secondary arc current, the factors affecting the secondary arc extinction, shunt reactors role as inductance which can be used to compensate between line and line to ground capacitance, reducing the flow through line capacitance current, and weakened capacitance effect.

According to the simulation results, this measure can suppress secondary arc current effectively. It ensure success of single phase auto reclosing operation and finally achieve security and stability of power system using Neutral reactor.

Also adopting neutral point reactor (small inductance) to compensate phase capacitance between lines can effectively suppress the frequency of occurrence, significantly reducing the arc current amplitude. The Simulation uses system operation with and without neutral reactor for analysis purposes, and the application of reactor will be dependent over the arc current to be suppressed. A systematic procedure for modeling and simulink of neutral reactor used for improvement on suppression of secondary arc current was investigated in a two-machine 4-bus test system model. The simulation results reveal that the Neutral Reactorare more effective and betterly improve the secondary arc current in a power system as compared to without neutral reactor.

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