Selection of Neutral Grounding Reactor for Line to Ground Fault

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***Abstract*— Single line to ground faults are the most prominent faults in the power system. This may damage the generators and transformers in the system ultimately leading to its failure. Introducing a neutral grounding reactor between the neutral and ground in the high voltage system, will reduce the fault current and hence will protect the power system components. The paper will discuss the operation, application and selection of the neutral grounding reactor for power system devices protection and secondary arc quenching.**

Keywords*— *Neutral grounding reactor, single line to ground fault, neutral grounding transformer, single phase auto re-closure, secondary arc current.

[I] INTRODUCTION

Reactors are important part of distribution and transmission power system. Based on the application they may be connected in series or shunt in the power system network. In series configuration they are used for current limiting and in shunt configuration they are used for reactive power compensation. They are also used for other applications such as neutral grounding, harmonic reduction, reduction of flicker due to arc furnaces, reduction of switching transients.

Reactors for Neutral Grounding can be dry type or oil immersed, where dry type can be both iron cored and air cored. Air core reactors are oil free hence the maintenance, fire hazard risk, oil leakages and cost are less. Iron cored reactors are prone to magnetic saturation at high current levels, this limitation can be mitigated by the use of air cored reactors. Air core reactors show a linear characteristics of current and magnetic flux where as iron cored reactors show a linear relationship up to saturation knee point.

In 3 phase high voltage system, about 70-90% of the faults are line to ground faults. During line to ground fault, the fault current rises to abnormally high levels in the faulty phase which stresses the generators and power transformer winding. Mechanical forces on the windings which will develop due to this fault current , are proportional to the square of the fault currents. This may cause crushing, bending, stretching of conductors and insulation degradation, which ultimately results in failure of generators and transformer.

To raise the impedance of the fault path we can introduce a Neutral Grounding Reactor (NGR) between the neutral of generator or transformer and system ground.

In EHV and UHV three phase transmission lines when fault occurs on one of the three phase , opening all the three phases Circuit Breakers will interrupt the power flow which is not reliable. In such situations, single phase switching will be more reliable and economical solution to clear the single line to ground fault. In Single phase switching, the circuit breakers on the faulted phase at both the ends will isolate the faulted phase and then re-closes upon arc extinction.

[II] A. Analysis of Ungrounded and Neutral grounded system with Reactance Grounding using Neutral Grounding Reactor:

During line to ground fault, in an ungrounded system the fault current is majorly the charging current as shown in fig.1 [1]. The major component of fault current is capacitive in nature. Hence this current will lead the neutral to ground voltage of the faulted phase that is V_1 as shown in phasor diagram of Fig. 2[1].

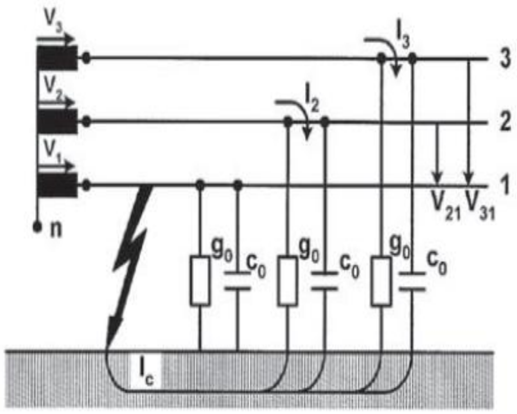

Fig 1: Single line to ground fault in an ungrounded system.

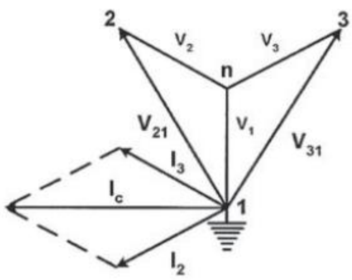

Fig 2: Phasor diagram for single line to ground fault in ungrounded system.

In reactance grounding , when NGR is added between the neutral and the earth in the fault path, the magnitude of fault current which will reduce will depend on the impedance of the NGR. NGR adds to the zero sequence impedance of the system and not to the positive sequence impedance. The effect of impedance of NGR is large for faults near the substation compared with the faults occurring further away from the substation. Grounding is said to be effective if the ratio of zero sequence impedance to positive sequence impedance of the system is less than or equal to three. As increase in zero sequence impedance greater than this value can cause transient over voltages . Due to this, single line to ground fault current has to be restricted to maximum 60% of the three phase fault current.

NGR's only provide protection against single line to ground faults. They are not useful during line to line fault. Line to ground faults if not cleared , it progresses to line to line fault if the fault side energy is high. Thus NGR indirectly reduces the number of line to line faults in the system.

Fig. 3[1] shows the NGR connected between the neutral and ground in the system which will provide the required inductive reactance to compensate the capacitive coupling which exists between the healthy and faulted phase, so that the arc current will be extinguished. The inductive current through the NGR should be equal in magnitude but opposite in phase to the charging current Ic , so that the arc current will be ideally zero as shown in the phasor diagram in fig 4[1].

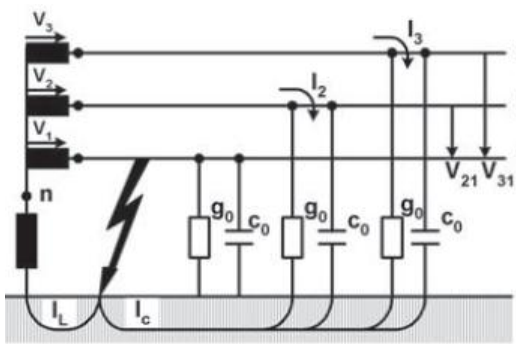

Fig 3: Single line to ground fault in a grounded system.

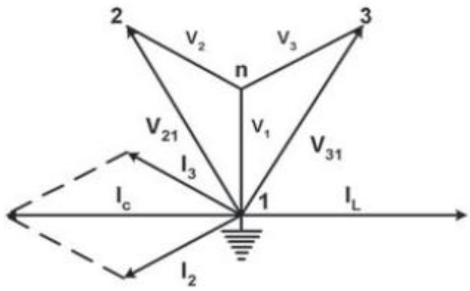

Fig 4: Phasor diagram for single line to ground fault in grounded system.

B. Transformer protection using neutral grounding:

The fault current flows from transformer winding, through line and then to the ground. Addition of NGR between the transformer neutral bushing and the substation ground mat increases the total impedance of the return path for the fault currents. This results in reduction of fault currents and protection of transformer winding from stresses. In the absence of neutral point as in delta configuration, a neutral grounding (a zig-zag or wye-delta) transformer is used for providing the artificial neutral for grounding purpose.

The neutral grounding reactance which needs to be introduced in the fault path to limit the fault current is equal to the difference between the total reactance as required to reduce the fault currents to desired value, and the existing reactance without NGR[2]. It can be calculated as:

$$X_{NGR} = (V_L /\sqrt{3}) [(1 / I_1) - (1 / I_0)] \quad (1)$$

X_{NGR} = Reactance of the neutral grounding reactor, Ω

V_L = System line to line voltage , kV

I_0 = Single line to ground fault current before introducing NGR in kA.

I_1 = Required single line to ground fault current after introducing NGR in kA.

While deciding the reactance of NGR the ratio of zero sequence reactance to the positive sequence reactance should not exceed critical value of 10 or else it results in transient over voltages on the healthy phases during fault conditions. Only one NGR is required per three phase transformer, whereas one current limiting reactor is required per phase. Thus the cost of installation of NGR is lesser than that of current limiting reactor.

C. Generator protection using Neutral Grounding Reactor:

NGR are used to protect Generators in special applications, in which Generators are connected to bus bars directly feeding single phase load. In generator the positive, negative and zero sequence reactance are not equal. When the neutral is solidly grounded the line to ground fault currents are usually higher than the 3 phase short circuit current. In solidly grounded neutral case, third harmonic currents reaches to the generator rated current .This large fault currents will damage the laminated core which increases cost of repair. Hence NGR need to be introduced between the neutral of Generator and the ground to limit this three phase short circuit current in thousands of Amps to hundreds of Amps [2].

The Reactance of the NGR must be selected such that it limits the single line to ground fault current to a value equal to the three phase short circuit current. It can be calculated as follows:

$$X_{NGR} = (X_d'' - X_0) / 3 \quad (2)$$

Where,

X_{NGR} is the reactance of Neutral Grounding reactor

X_d'' is the direct axis sub transient reactance of the Generator

X_0 is the zero sequence reactance of the Generator.

D. Effect of NGR on Secondary Arc Current during Single Phase Auto-reclosure :

In EHV and UHV transmission line, single phase auto reclosing is used to clear single line to ground faults, which increases system stability, reliability, and availability of line during fault condition. Single phase auto reclosing will be more effective with the use of NGR [3] [4].

Consider a three phase transmission line with three phase shunt reactor with a NGR connected between its neutral and ground as shown in fig 5 [4].A single L-G fault has been considered in this system by representing switch S_F in closed position. To isolate the faulted line the circuit breaker will be opened, represented by the open switch Sw.

When a single line to earth fault occurs, the circuit breaker at both ends of the faulty line are opened to extinguish the fault. But due to the inductive and capacitive coupling between the healthy and faulted phase the current tends to persist even after the circuit breakers at both the ends are opened. This fault current is called the Secondary Arc Current [5][6].

One of the means to reduce the secondary arc current in a line compensated by a three phase shunt reactor, is to add a NGR. Introducing the NGR between the neutral of the three phase compensating reactor and the ground, will provide inductive compensation to the capacitive secondary arc current. Hence the amplitude and time for which the secondary arc current persists will reduce and the fault current will be extinguished faster before circuit breakers are closed.

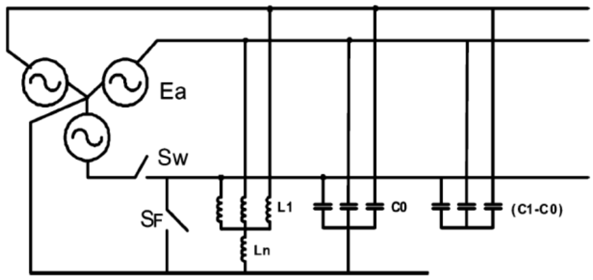

Fig. 5: Inductive and Capacitive Coupling between healthy phase and faulty phase.

L1 = Equivalent inductance of shunt reactor.

Ln = Equivalent reactance of NGR.

Sw = Circuit Breaker in open position on faulty line.

Sf = Representation of fault

C_0, C_1 = Zero and Positive Sequence Capacitances of the line respectively.

The reactance of NGR required for compensation of the capacitive reactance during fault condition as shown in Fig. 5, is given by the expression [4]:

$B_1 = \omega C_1$

$B_0 = \omega C_0$

$F = 1 / (Xr.B_1)$

$$X_{NGR} = (B_1 - B_0) / (3F.B_1.[B_0 - (1-F).B_1]) \quad (3)$$

Where,
B_0, B_1 = Zero and Positive sequence susceptance of line respectively.

Xr = Equivalent reactance of line shunt reactor.

F = Degree of Shunt Compensation.

If the degree of line compensation is higher then the reactance of NGR required for compensation will be lesser.

One important factor which needs to be considered while designing the NGR for the shunt compensation is its basic impulse insulation level (BIL) [7]. If the compensation degree is higher the BIL required for the NGR will be lower, so the cost of providing insulation will reduce, which makes the NGR design economical. For a 400kV line BIL of NGR is typically 350kV. Minimum BIL required for the NGR can be obtained from the relation [4] :

$$BIL_{NGR} = [X_{NGR} / (Xr + X_{NGR})] \times BIL_{Ph} \quad (4)$$

Where, BIL_{Ph} is the Basic Impulse Insulation Level of the phase.

[III] Fault Analysis :

A. Fault Current And Voltage Levels In Single Line To Ground In Ungrounded System:

Consider a single line to ground fault on a 11kV, 3 phase system, on phase A with a fault current of 3000 /-70 Amps. Considering a healthy grounded system with a ground impedance of 0.1/70 Ω for the fault path. Due to this fault current the drop in voltage across the ground will be 3000 /-70 x 0.1/70 = 300/0 V. This will cause the increase in voltages on the two healthy phases. Rise in voltage of phase B with respect to ground will be 6350.85 /120 - 300/0 = 6506.04/122.29V. Thus voltage of phase B has risen from 6350.85 to 6506.04V. The voltage rise of phase C can be calculated in a similar way and is 6506.04/-122.29V [8].

B. Fault Current And Voltage Levels In Single Line To Ground Fault In NGR Grounding:

Now to reduce the fault current a NGR of 0.35/70 Ω will be introduced in the system between the neutral and ground. This will raise the fault path impedance to 0.45/70 Ω. This increase in fault path impedance will reduce the fault current, which can be calculated from equation (1).The fault current thus obtained is 2575.1/-70 Amps, which shows a reduction in the fault current from 3000 /-70 Amps to 2575.1/-70 Amps. The voltage drop across fault path will be 2575.1/-70 x 0.45/70= 1158.79/0 Volts, causing the voltage of healthy phases to rise. The rise in voltage of phase B with respect to ground will be 6350.85/120 - 1158.79/0 = 7002.5/128.23 Volts. Thus the voltage in phase B has risen from 6350.85 Volts to 7002.5 Volts. This shows that the phase voltages have raised but the NGR has reduced the fault current levels.

CONCLUSION

Proper selection of Reactance and BIL is important for NGR applications discussed above. For generator grounding, the reactance value of the NGR should be such that line to ground fault current will be less than three phase short circuit current. Proper selection of NGR in case of shunt compensation, reduces the single line to ground secondary arc current and thus reduces the time for auto re-closure thereby making the system more reliable.

NGR has low resistance and hence does not dissipate a large amount of thermal energy. So in high voltage system, greater than 40kV this solution of Neutral grounding is more cost effective than resistance grounding. Neutral Grounding Air core type reactor will provide cost effective and maintenance free solution as compared to oil filled reactors.

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