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An Investigation of the Ability of Combined Zero – Sequence Cutoff Protection in Line High Voltage

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ABSTRACT
Zero-sequence cutoff protection has found extensive use in 110-400 kV power networks. Level of value protection settings a starting over-current relay is selected from the requirement of its adjustment out against three zero-sequence current on the end of protected line. Sensitivity of zero-sequence cutoff protection on line is function of equivalent zero-sequence impedance reduction to point bus-bars with disposition protection. Owing to availability of transformers with earthed neutrals at each substation of a 110-400 kV network which are the source of a zero-sequence current, the possibility exists of wide use of zero-sequence cutoffs and stepped zero-sequence protections practically on all lines of medium and large length. From these reasons propose is the use ``cutoff``` protection.
Keywords – cutoff, substation, simulation, protection, voltage

I. INTRODUCTION

The protection consists of over-current relay CR responding to an earth fault, power-directional relay CP determining the direction of the fault power flow, and time relay TR introducing a time delay into the protection operation needed according to the selectivity requirement, Fig 1.

The starting current relay and the current winding of the power-directional relay are connected into the neutral wire of the current transformers for current $3I_0$ [9,13] where as the polarizing (voltage) winding of the power relay is fed with voltage $3V_0$ from the broken delta connection of the voltage transformer [3,4].

The starting element of the zero-sequence protection features high sensitivity as it is not necessary to adjust the element out against load currents.

To speed up the clearance of faults to earth in circuits with solidly earthed neutral, use is made of cutoffs which respond to a zero-sequence current. Their operating principle is the same as that of the cutoffs responding to a phase current. Zero-sequence cutoffs are available in plain current and directional versions, with and without time delay.

II. DESCRIPTION OF COMBINED OVER CURRENT ZERO-SEQUENCE CUTOFF PROTECTION

The operating current of the starting relays of a zero-sequence over-current protection is selected from two condition:

-the requirement of reliable action of the protection in the event of a fault at the end of the adjacent (second) circuit section and

-from the requirement of its adjustment out against unbalance currents.

It is in this aspect that the directional cutoff fundamentally differs from the non-directional cutoff. The operating current of the directional cutoff is smaller than that of the non-directional one. That is why the zone of action of the first cutoff is much greater than that of the second zone. As a power relay features a dead zone, the directional cutoff should be used only in those cases when the plain cutoff fails to satisfy the sensitivity condition [6,7,8]. The directional instantaneous cutoff scheme differs from directional over-current protections, Fig. 1. in that it lacks a time relay. Combined over-current zero-sequence cutoff protection a) with voltage transformer, b) voltage transformer is absent, Fig. 1. a. and 1.b.).

The sensitivity of the zero-sequence protections can be small therefore. When a fault appears the zero-sequence impedance can be grows concerned with impedance under normal service, where zero-sequence of current grows, for examples a include line or transformer (or autotransformer) with neutral point.. This sensitivity can be grows bat widely used combined zero-sequence protection consist of two relays schemes [9,10]: zero-sequence over-current relay and zero-sequence voltage relay. Three schemes is represent in (Fig.1.a, b, c). The circuit is assumed to be a no-load circuit.

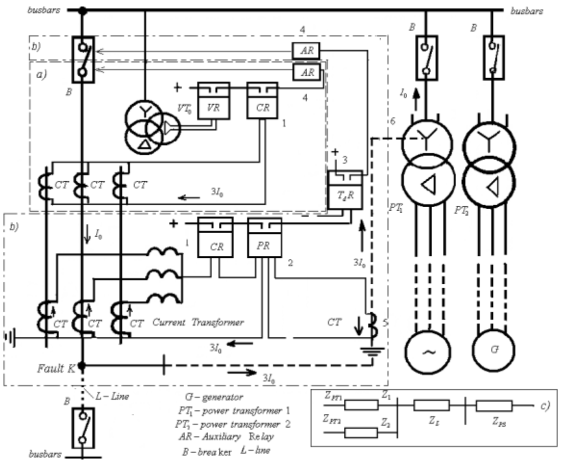

Fig.1: Combined overcurrent zero-sequence cutoff protection a) with voltage transformer, b) voltage transformer is absent, c). shows some cases of equivalent zero-sequence circuit current flow in certain parts of the circuit.

II.I. CALCULATION AND ANALYSIS

Fig 1.c, shows some cases of equivalent zero-sequence circuit current flow in certain parts of the circuit. The operating current of the directional zero-sequence cutoffs are adjusted out against current $3I_{0max}$ in the event of an earth fault (phase to ground or two-phase to ground fault) Line L on the busbars of the opposite substation (point) K according to the expression similar. It is assumed to include two transformer (PT_1, PT_2) with neutral point and current is:

$$I_{op.pr.A} = k_r 3I_{0.\max} \qquad (1)$$

$I_{0.\max} -$ maximum value of flowing zero-sequence current inside a line in considere transient conditions service substation in the event of an earth fault (phase to ground or two-phase to ground fault) line L on the starting busbar in point K and where PT_2 transformer is include (conditions of maximum current).

When is used combined zero-sequence cutoff protection bay diagram 1.a a) with voltage transformer and two relays: current relay CR and voltage relay VR it is necessary selected value of operating voltage relay of zero-sequence voltage VR to relation (because $Z_1, Z_2 -$ are parallel connection):

$$U_{op.pr.A} = k_{VR} 3I_{0.\max} \frac{Z_1 Z_2}{Z_1 + Z_2} \qquad (2)$$

$Z_1, Z_2 -$ zero-sequence impedance power transformers (PT_1, PT_2) in equivalent scheme zero-sequence, Fig.1.c).

The current operating of the current relay zero-sequence CR, represent in Fig. 1.a.,b. bay part a) it is needed from condition are adjusted out against current $3I_0$ in the event of an fault (phase to ground or two-phase to ground fault) Line Lon the busbars of the opposite substation (point) K according to the expression similar and assumed it is off duty one transformer, exemple PT_2 with neutral point.

$$I_{op.pr.A} = k_r 3I_{0.\min.out\ putPT2}. \qquad (3)$$

$I_{0.\min.out\ putPT2} -$ maximum value of flowing zero-sequence current inside a line in considere transient conditions service substation in the event of an earth fault (phase to ground or two-phase to ground fault) line L on the starting busbar in point K and where PT_2 transformer is off duty (coditions of minimum current).

Estimation of combined zero-sequence cutoff protection can by made with comparation under transient condition of a minimum value current and of a maximum value current in a fault scheme.

If a value operating current combined zero-sequence is considere from relation (3) small concerned magnitude operating current zero-sequence is considere from relation (1) should be coordinated so that the opera ting currents with sensitivity voltage relay k_{vr} combined zero-sequence protection. It is clear ,under transient condition of maximum value of current in bouth equivalent schemes on a combined zero-sequence cutof protection the operating current of current relay and operatin voltage of voltage relay thei have equal sensitivity. The operating curren t of a current relay and operating voltage of a voltage relay calculate from one equivalent scheme (under transient conditions where are include both transformers [2,3,4].

Under transient conditions of minimum value of current the sensitivity of voltage relay is bigger, bay relation (4),

$$\frac{k_{SV}}{k_{SC}} = \frac{3U_0 \cdot I_{op.pr.A}}{U_{op.pr.A} 3I_0} = \frac{3I_0 Z_1 I_{op.pr.A}}{3I_0 \cdot I_{op.pr.A} \dfrac{Z_1 Z_2}{Z_1 + Z_2}} = \frac{Z_1 + Z_2}{Z_2} \qquad (4)$$

Under transient conditions of minimum value of current the voltage relay have $(Z_1+Z_2)/Z_2$ time selectivity then current relays, bay circuit equivalent Fig. 1. c.

III. EVALUATION OF THE DIFFERENT COMBINED ZERO-SEQUENCE CUTOFF PROTECTION

The operating principle of protection is simple and reliable, which enables circuits with two-end supply to be protected selectively. A combination of combined cutoffs protection with a directional over-current protection provides a protection which in many cases provides fairly fast clearance of faults and sensitivity. Analyze and the service practice shows that the combined protection functions reliably [11,12,14].

The disadvantages of the protection are:
-long time delays, near the sources of supply in particular;
-insufficient sensitivity in circuits with large loads and relatively small fault current multiples;
- a dead zone in the event of three-phase faults;
-the possibility of the incorrect choice of the direction with the voltage circuit, feeding the power-directional relay, being damaged.

The directional over current protection is widely used as the main protection in networks up to 35 kV with two-end supply. In 110- and 220-kV networks, the classic directional overcurrent protection finds its application as a back-up protection, but sometimes, when combined with a cutoff, as the main protection.

The selection of operating current $I_{op.pr}$ according to the first requirement is made in the same way as for the over current protection, proceeding from the considerations set forth , by formula [1,3,4]:

$$I_{op.pr} = \frac{k_{sa1} k_{st} I_{mah}}{K_{rst}} \quad (5)$$

The maximum value of current I_{max} should be determined from the most severe but possible in service conditions. In ring circuits and in radial circuits with two-end supply (see Fig. 2.a and b) maximum loads develop on the lines upon disconnection them. For instance, if line L_{II} is disconnected in the circuit shown in Fig. 2..b, the load current on line L_I reaches its maximum.

In this case, the phases of the voltages applied to the protection are distorted and therefore the power-directional relay can close its contacts enabling the protection to operate even if the power flow is towards the busbars of the substation. According to the second requirement the operating current of the protection is derived from the formula: [2,3], :

$$I_{op.pr} = k_{saf} I_{h.ph} \quad (6)$$

where $I_{h.ph} = I_{ld} + kI_{sh-c}$ [3,4] , and safety factor k_{saf} is taken as 1.15 to 1.30 depending on how accurately the value of $I_{h.ph}$ is evaluated.. Taken as the final value of $I_{op.pr}$ is the greater magnitude derived from expressions (5) and (6).

As for protections in a circuit with small earth fault current (where $I_{h.ph} = I_{ld}$) and protections in a circuit with solidly earthed neutral which are interlocked in the case of earth faults, the operating current of starting relays is selected according to the first requirement only, i.e., by formula (5).

To provide selectivity, the sensitivity of the protections operating in one direction should be coordinated so that the operating currents grow as the power source is approached. Such coordination prevents the non-selective operation of the protection in the event of a fault current close in value to the operating currents of the protections. The aforesaid is illustrated by Fig.2.b. When a fault appears near the feeding busbars at point K_1 the ratio of fault currents I_{KA} and I_{KB} is inversely proportional to impedance $z`_{K1'}$ and z''_{K1}, i.e.,

$$\frac{I_{KA}}{I_{KB}} = \frac{z''_{K1}}{z`_{K1}} \quad (7)$$

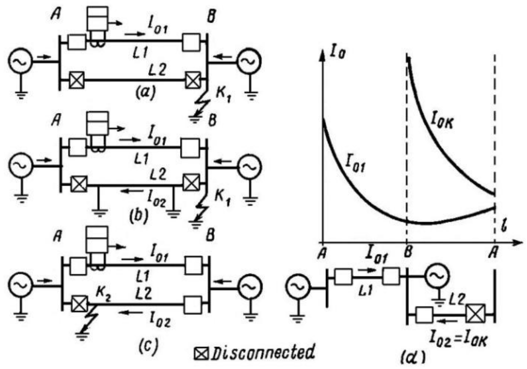

Fig. 2. Calculation of over current cutoff on parallel lines. Design schemes for selection of operating current of zero-sequence cutoffs on parallel lines (a, b, c) and nature of current I_{01} variation in the case of fault on parallel line L_2 disconnected on one side (d)

Consequently,, the operating current of a directional overcurrent cutoff is adjusted out against fault currents flowing from the busbars of the substation.

Under these conditions the impedance of operative line L_1 is reduced by mutual inductance due to current I_{02}, which involves an increase in design current I_{01} and voltage. Three schemes is represent in (Fig.2.c). (see simulation Fig.4.a,b,c).

Certain combinations of reactances x_o of parts of the network under consideration may be responsible for a maximum current rise in line L_1 not due to a fault on the busbars at point K_1 but on the parallel line at point K when this line is disconnected on one side (Fig.2.c). (see simulation Fig.4.a,b,c.)

Although the fault at point K_2 is more distant than that at K_1 current I_{01} in line L_1 may now happen to be greater in value due to a change of' current flow in the parallel branches of the network because of a reduction in the impedance of line L_1 caused by the strong mutual inductance from line L_2. Figure 2.d shows current I_{01} and full current I_{ok} at the point of a fault plotted against the location of the fault I_{0cal} is represented by the greater of the obtained values of I_{01} . Zero-sequence currents should be calculated for that kind of an earth fault wherein their value is greatest.

It is known from the fault current calculation theory that with equal total positive- and negative-sequence reactances of the equivalent circuit $[x_{1\Sigma} \le x_{2\Sigma}]$ current $I_0^{(1)} \ge I_0^{(1,1)}$ if $x_{0\Sigma} \ge x_{1\Sigma}$.

After calculation and correlation of $x_{0□ □}$with $x_{1□ □}$we find the calculated form of the fault (single-phase- or two-phase-to-earth faults).

IV. Analysis of the simulation results

The Distributed Parameter Line block implements an N-phase distributed parameter line model with lumped losses. The model is based on the Bergeron's traveling wave method usedb y the Electromagnetic transient program (EMTP) [2,5].

The breaker block implements a circuit breaker where the opening and closing times can be controlled either from an external Simulink signal (external control mode), or from an internal control timer (internal control mode). The arc extinction process is simulated by opening the breaker device when the current passes through 0 (first current zero crossing following the transition of the Simulink control input from 1 to 0). Specifies the number of phases, N=3, of the model.

Specifies the frequency used to compute the modal resistance R, inductance L, and capacitance C matrices of the line model. The resistance R per unit length, as an N-by-N matrix in ohm/km. For a 2-phase or three-phase continuously transposed line, you can enter the positive and zero-sequence resistances [R_1 R_0]. For a symmetrical six-phase line you can enter the sequence parameters plus the zero-sequence mutual resistance [R_1 R_0 R_{0m}]. For unsymmet rical lines, you must specify the complete N-by-N resistance matrix. The inductance L per unit length, as an N-by-N matrix in henries/km (H/km). For a symmetrical line, you can either specify the N-by-N matrix or the sequence parameters. The capacitance C per unit length, in farads/km (F/km). For a symmetrical line, you can either specify the N-by-N matrix or the sequence parameters. For a 2 or 3 phase continuously transposed line possible positive and zeo sequence (C_1, C_0). The line length, in km. (100km).

Measurements: Select Phase-to-ground voltages to measure the sending end and receiving end voltages for each phase of the line model. Multi-meter block in model to display the selected measurement during the simulation. This model does not rep- resent accurately the frequency dependence of RLC parameter of real power lines, because of skin effects in the conductor and ground, the R and L matrice exhibit strong frequency dependence, causing an attenuation of the high frequencies.

Example of simulation influence parallel line I and II.

The psbmonophaseline.mdl illustrate as a 100 km line connected on a pu(1), 50 Hz infinite source The line deenergized and reenenrgized after 2 cycles.The simulation is performed simultaneously with the distributed parameters line block in Fig. 3.

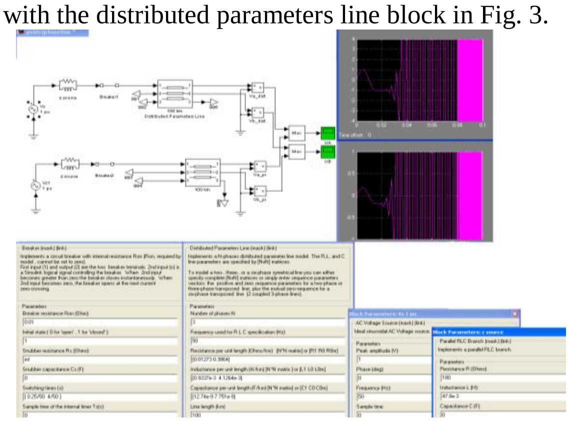

Fig. 3: The receiving end voltage obtained with distributed Parameter Line block. Phase (deg) 0, The influence phase (A) line I on phase (A) line II, closed Breaker 1 and 2

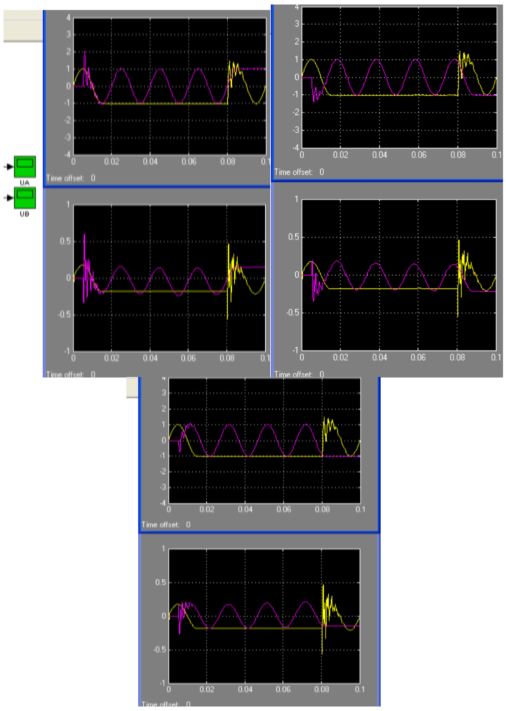

Fig. 4. a) Phase (deg) 0, simulation of influence phase (A) line I upon phase (A) line II, open Breaker 2 , AI-yellow, AII-pink., b) Phase (deg) +120, simulation of influence phase (A) line I upon phase (B) line II, open Breaker 2. A- pink, B yellow, c) Phase (deg) +120, simulation of influence phase (A) line I upon phase (C) line II, open Breaker 2. , A- pink, C yellow.

V. CONCLUSION

From increase sensitivity of protection in in protection from phase-to ground fault and two-phase to ground fault the combined zero-sequence cutoff protection is widely used as the main protection in network 110-400 kV.

Consequently,, the operating parameters of a current and voltage relays in combined zero-sequence directional overcurrent cutoff is adjusted out against fault currents flowing from the busbars of the opposite substation.

It is clear , from analysis, where is realized combined zero-sequence directional over-current and voltage cutoff is adjusted out against fault currents flowing from the busbars of the other lines with conditions selectivity of current and voltage relay.

The zero-sequence cutoff protection is widely used as the main protection in network 110-400 kV From increase of sensitivity in protection from phase-to ground fault and two-phase to ground fault. The operating principle of directional combined zero-sequence cutoff protection is simple and reliable, which enables circuits with two-end supply to be protected selectively.

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