

**Earth Fault Detection
Basics in Theory**

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Kempen, 16.04.2010

1. Star Point Treatment of Generators

Due to the fact that the outgoing utility transformers of power stations are delta connected, i.e. separated from the neutral earthing system of medium voltage side, the rating of earth fault currents of the MV - System only depends on the star point treatment of the generators.

The following star point treatments of generators are feasible:

1. isolated, i.e. unearthed star point
2. compensated star point, i.e. star point earthed via Peterson earth fault neutralizer
3. indirectly earthed star point, i.e.
 - a.) earthed via reactor or transformer or
 - b.) earthed via resistor
4. directly, i.e. solidly earthed star point.

This document is to compare the different methods of treating generator star points taking into account the requirements and conditions of the majority of power stations.

1.1. Isolated Star Point

The rating of the earth fault currents at isolated star points is mainly depending on the cable capacities of the network system, because of the fact that the earth fault circuit is only closed via cable capacities and earth fault location. Consequently, this method is only feasible, provided that the cable capacities within the network are relatively high and do not vary, which may particularly apply to cable network systems that are strongly intermeshed and quite complex. In most of the power stations, however, these conditions are not prevailing since the various existing operating modes and switching states on their own will result in very different network cable capacities. In case of an earth fault of one conductor, the system voltage of the remaining two healthy conductors against earth will increase by the factor $\sqrt{3}$, thus achieving the line-to-line voltage. The following shall apply:

$$I_E = 3 \cdot I_0 \approx \sqrt{3} \cdot U_\Delta \cdot \omega \cdot C_E$$

$$U_{\Delta, \text{healthy conductor}} \approx \sqrt{3} \cdot U_\Delta = U_\Delta$$

- with
- I_E : earth fault current at earth fault location
 - C_E : earthing capacitance = zero-capacitance of the network
 - ω : $2\pi f$ = angular frequency

1.2. Compensated Star Point

In this case, cable capacities of the entire network system are largely compensated through the inductance of a Petersen earth fault neutralizer. In case of an earth fault, the residual currents still available then, are very low. These currents are frequently detected by means of watt hour metering. This method of star point treatment is even more dependent on the cable capacities of the network system though the rating of cable capacities will additionally determine the rating of the Petersen earth fault neutralizer.

Consequently, this method of star point treatment is inapplicable, as well.

1.3. Indirectly Earthed Star Point

1.3.1. Earthed via Reactor or Transformer

By earthing the generator star point via reactor, it is possible to determine the value for the earth fault current. When this method is applied, the earth fault current will only depend on the network system's cable capacity as shown hereafter:

$$I_E \approx \sqrt{3} \cdot \underline{U}_\Delta j \cdot \left(\omega C_E - \frac{1}{3\omega L_D} \right)$$

$$\Rightarrow I_E \approx \sqrt{3} \cdot U_\Delta \cdot \left(\omega C_E - \frac{1}{3\omega L_D} \right)$$

$$U_{\Delta, \text{healthy conductor}} \leq 1.4 \cdot U_\Delta$$

with I_E : earth fault current at earth fault location
 L_D : inductance of reactor or transformer
 C_E : earthing capacitance of the network
 ω : $2\pi f$ = angular frequency

In case of an one phase earth fault the system voltage of the remaining two healthy conductors against earth will increase by approximation of a max. factor 1.4 due to earth fault factor f_E . It is also possible to connect a reactor or a transformer with the generator bus bar and operate the generator star points separately. The reactor (or the transformer) will then be acting as a so-called star point creator. In this case, it is necessary to determine a defined load for the reactor (or transformer).

This method of star point earthing via reactor or transformer is thus applicable for most of the power plant network systems.

1.3.2. Earthed via Resistor R_E

By earthing the generator star point via a resistor, it is possible to control the attitude of the protection system in comparison to the isolated star point method. The resistor defines the amount of the earth fault current and is only slightly dependent on the network system's cable capacities. The mostly low resistances R_N of a less extensive unmeshed network are usually negligible. The following shall apply:

$$I_E \approx \sqrt{3} \cdot \underline{U}_\Delta \left(\frac{1}{3R_E} + j\omega \cdot C_E \right)$$

$$\Rightarrow I_E \approx \sqrt{3} \cdot U_\Delta \cdot \sqrt{\left(\frac{1}{3R_E} \right)^2 + (\omega \cdot C_E)^2}$$

$$U_{\Delta, \text{healthy conductor}} \leq 1.4 \cdot U_\Delta$$

with

- I_E : earth fault current at earth fault location
- R_E : earthing resistance
- C_E : earthing capacitance of the network
- ω : $2\pi f$ = angular frequency

In that case, too, if there is an earth fault of one phase conductor the system voltage of the two healthy conductors against earth will increase by approximation of a max. factor 1.4 due to earth fault factor f_E . Proportionate to this, the load affecting the insulation of these conductors as well as connected voltage transformers etc. will increase accordingly. Therefore this method of star point treatment is also applicable.

1.4. Directly Earthed Star Point

By means of this star point treatment, in the event of external earth faults, high one phase short-circuit currents result, which might be a multiple of the generator's nominal current. These voltages are too high for the generator windings. The following shall apply:

$$I_{K,1P}'' \approx I_{K,3P}'' \cdot \frac{3}{2 + \frac{X_0}{X_1}}$$

at a ratio of $\frac{X_0}{X_1} \leq 5.2$ for the effectively earthed network.

1.5. Summary

After consideration of the different star point treatments of the generators, for the most power stations only the indirect methods turn out to be practicable such as

- earthing of the generator star point via an neutral earthing resistor R_E
- earthing of the generator star point via a neutral earthing reactor or neutral earthing transformer with a defined load
- earthing of the busbar of the generators via neutral earthing transformers as a star point creator with a defined load.

2. Star Point Treatment via Neutral Earthing Resistor R_E

When comparing the various possibilities of generator star point treatment dealt with in chapter 1, the way of earthing generator star points via a neutral earthing resistor seems to be the most practicable one since this method offers economic advantages and can normally rather easily be retrofitted and it is more independent with regard to subsequent system extensions or modifications.

In the figure 2-1 below, the star point treatment of the generator by means of a neutral earthing resistor R_E is illustrated in a diagram.

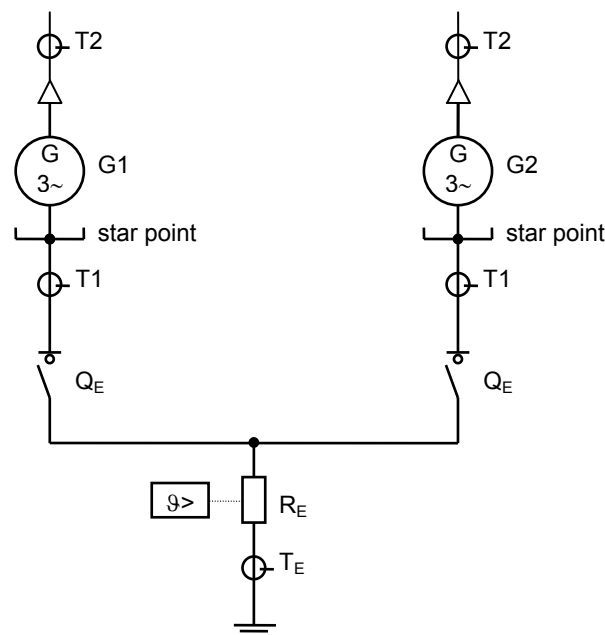


Figure 2-1 Diagram of the generator star point treatment via neutral earthing resistor R_E

with: R_E earthing resistance with temperature supervision $\vartheta >$

$R_E \approx 318 \Omega$, $I_{RE(10s)} = 20A$ rated for a period of 10s

and $I_{RE(cont.)} = 15A$ continuously, $U_{RE} = 11kV/\sqrt{3}$

Q_E : single-phase vacuum contactor of the series 12, 400A, with very short switching times

T_E : cable type current transformer for backup earth fault detection at neutral earthing resistor R_E

50/1A with 2.5VA, for max. 120min. at 10% I_N

$T1, T2$: cable type current transformers for earth fault detection within the generators (restricted earth fault: 64REF), data as T_E

In general, only one generator star point connected to the bus bar is grounded via the neutral earthing resistor. This applies to each MV busbar section.

With the aid of the appropriate single-phase vacuum contactor Q_E , the star point of the generator that was connected first to the MV switchgear, is switched to the neutral earthing resistor R_E . During this, only the star point of the generator that was initially connected will be earthed via the neutral earthing resistor R_E . In case that the generator circuit breaker of the generator whose star point was connected with, the neutral earthing resistor is switched off by the corresponding star point contactor and the neutral earthing resistor will be switched over to the contactor of that generator in operation, whose circuit breaker will be closed next.

As regards circuitry, it has to be ensured, that not more than only one generator star point will be earthed via the neutral earthing resistor since otherwise it might happen that transient currents of the third harmonic would flow between the generator star points.

To protect the system against ferroresonance (these are oscillations in electric circuits provoked by capacities and inductance in the iron core, whereby there is not always a stable operating point produced in the power voltage diagram, as the inductance depends on the current and therefore modifies the inherent frequency of the oscillating circuit!) in case of ungrounded generators (floating), the tertiary windings (open delta / e-n winding) of the voltage transformers are switched in an open triangle and are burdened with a resistor.

Protection in case of external earth faults

In the event of a station earth fault beyond the generator protection range, the earth fault current I_E that is primarily determined by the dimension of the neutral earthing resistance (and only secondary by the cable capacities of the network) will be flowing through the earth fault source. In case of selectivity, it is possible to separate the faulty segment by means of staggering and IDMT earth fault relays.

Protection in case of internal earth faults

In case of an internal earth fault, the stator earth fault relay of the defective generator will disconnect the defective generator only.

The cable type current transformers T1 and T2 are applied to detect earth faults within the generator's protection range, in particular for the detection of stator earth faults (ANSI - Code: 64REF).

These cable type current transformers must have the same transmission ratio and shall be connected anti-parallel, as shown in figure 2-2.

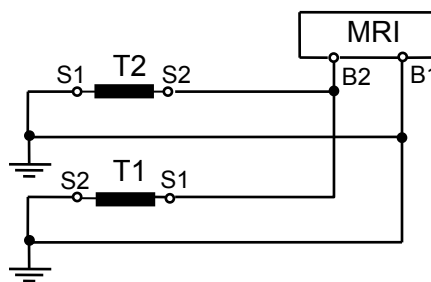


Figure 2-2 Diagram illustrating the wiring of stator earth fault protection devices

During faultless condition and in case of an earth fault occurring outside of the protection range of current transformers T1 and T2, the current rating is approximately the same. Anti-parallel connection of the transformers leads to the neutralization of the currents.

Earth faults within the protection range of both current transformers T1 and T2 result in the addition of the currents. For this purpose, the earth fault relays are adjusted as to disconnect the generator circuit breaker after maximum 10 sec. at detected currents of more than 5A or soonest possible at an earth fault current of more than 15A.

In case of a stator earth fault on an ungrounded generator the earth current limited by the resistor will flow to the grounded generator in operation. By interconnecting the ring core current transformer on the main connectors (L1, L2, L3) and the ring core current transformer on the star point side, only the earth current of the defective generator will be detected by its own earth fault relay.

The current on the earth fault relay of the non-defective but grounded generator is zero due to the anti-parallel connection of the ring core circuit transformers and does therefore not cause a fault.

Protection of the Neutral Earthing Resistor R_E

The cable type current transformer T_E is used to detect residual currents in the current path of the resistor. Should the preceding earth fault relays of the station not pick-up in case of an external fault, an appropriate earth fault relay has to be provided in order to prevent the neutral earthing resistor's overload. According to the rating of the neutral earthing resistor, this earth fault relay will be adjusted as to pick-up after 10s at the latest.

To protect the resistor from overheating, the neutral earthing resistor is furthermore equipped with an overtemperature detection facility. This element is another back-up protection that may only lead to tripping if no other earth fault relay picks-up.

A prerequisite for both, tripping of the back-up overload protection and tripping of the back-up overtemperature protection is the separation of the generator's star point from the neutral earthing resistor. In that case, the system earth fault protection should operate for a certain maximum time. After expiry of this time the generators should be isolated from the grid since earth fault protection can no longer be ensured.

Prerequisites for the use of star point treatment via Neutral Earthing Resistor R_E

- The generator star points have to be lead out and accessible.
- It is only permitted to earth that generator via neutral earthing resistor R_E which is connected first to the power station. It is never permitted to earth more than one generator star points via the earthing resistor R_E since this might lead to undesirable transient currents between the generator star points related hereto. Therefore the neutral earthing vacuum contactors have to be interlocked.
- All relevant network elements as insulation of conductors, voltage transformers etc. must be capable of withstanding the increased voltage generated between the healthy phases and earth during an earth fault.

3. Dimensioning of the Neutral Earthing Resistor R_E

The earth fault current which is defined by the neutral earthing resistor R_E is limited by the following circumstances:

- On one hand, the earth fault current within the total direct-connected network has to be at least high enough to energize the selective earth fault relays and the back-up protection relays.
- On the other hand, the earth fault current should be maintained low enough to avoid further damages resulting from the earth fault current.

This means that the rating of the neutral earthing resistance results from the current's pick-up values of the earth fault relay, taking into account the fact that earth fault currents must not become too high to maintain damages that might occur as slight as possible.

After due consideration on principles for the adjustment of these pick-up values there should be a minimal earth fault current of 80A. The earthing resistor has to be dimensioned for this earth fault current rating. The following shall apply:

$$R_E \leq \frac{U_{\Delta}}{\sqrt{3} \cdot I_{E_{\min}}}$$

⇒ $R_E = 318\Omega$ dimensioned for $I_E \approx 20A$ at 10sec. (15A continuously)

with R_E : rating of the neutral earthing resistance
 $I_{E, \min}$: minimum defined earth fault current
 U_{Δ} : 11kV

If vacuum contactors with low switching times far below 1s are selected for switching off the neutral earthing resistor, the resistor can be dimensioned for a load time of 10s (having regard to maximal staggering times of approximately 3sec.).

This information undergoes continuous further development and is subject to changes without prior notice. If you need any further information please contact:



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