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Impact of Shunt Circuit Breaker Technology on the Single Pole-to-Earth Fault Currents in Distribution Networks

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Abstract

In the paper a systematic view of the shunt circuit breaker technology as a relatively new concept of distribution system earthing is given. This technology is primarily intended to improve distribution system power quality by creating the conditions for the elimination of transient single pole-to-earth faults without the interruption of power supply. The paper starts with the explanation of the shunt circuit breaker operation. Additionally, a brief description of the faulted phase detection principle and the coordination with earth fault protection is given. Then the paper moves in the development of a mathematical model based on the theory of symmetrical components intended for the calculation of the fault current on the faulted point and shunt circuit breaker point when the shunt circuit breaker is activated. The model is then applied on a test distribution network with different basic earthings for the purpose of the analysis how the network parameters, fault location, basic earthing and other parameters affect the shunt circuit breaker operation. Moreover, the calculated values of faulted currents are compared with the one calculated when the shunt circuit breaker is inactive.

Keywords: Shunt circuit breaker; Earthing; Symmetrical components; Short circuit; Distribution network.

1. Introduction

Traditionally in distribution networks the following earthing methods are used: isolated neutral, resonant earthing, low-impedance or high-impedance earthing and compensated earthing (through fixed coil and resistance).

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A good review of existing distribution system earthing methods is given in [1-3]. According to [1] in a 20 kV Croatian distribution network the use of isolated earthing is recommended for capacitive currents up to 15 A, while high-impedance earthing (fault currents of 100 or 300 A) for capacitive currents up to 100 A. For capacitive currents higher than 100 A compensated or even resonant earthing is recommended. The best earthing system selection is based on many criteria which compromise studies of people safety in regard to the touch voltages, occurring overvoltages in the medium voltage network, power quality and economic aspects of the price of earthing in medium voltage substations [1-3]. With the opening up of the electricity market the power companies around the world are constantly faced with the challenge in increasing the quality and reliability of electrical energy [4-6]. One method for achieving this goal is the introduction of the shunt circuit breaker technology (combined with the existing earthing methods) as a new concept of earthing in distribution networks [7-8]. The basic objective of this improved earthing concept is to create conditions for eliminating transient single pole-to-earth faults without the interruption of power supply. In contemporary distribution networks without the shunt circuit breaker technology the transient single pole-to-earth faults (on overhead line feeders) are cleared with fast and slow automatic reclosing functions which cause short-term interruptions to consumers [9]. These short-term power interruptions (0,2 s – 1 s) are harmful for industrial consumers and distributed power plants connected to the distribution grid [10]. As emphasized by introducing the shunt circuit breaker in certain conditions transient single pole-to-earth faults are cleared without these short-term interruptions, which is also a primary advantage compared to automatic reclosing functions. According to many studies transient single pole-to-earth faults are the most common type of fault in distribution networks [11-12]. Thus, the justification of the shunt circuit breaker technology introduction is increased. Moreover, newer applications explore the possibility of a permanent single phase earthing archived with the shunt circuit breaker. However, this application is still in the phase of research and experimentation [8].

2. Basic concepts of shunt circuit breaker technology

2.1. Operation principle

The shunt circuit breaker differs from a feeder circuit breaker ([13-14]) in some constructional characteristics and in the connection method. This breaker enables the switching (opening/closing) of each of its poles and is connected between the main medium voltage busbar and the substation earthing. The idea of using the shunt circuit breaker technology lies in the fact that a part of a single pole-to-earth fault current is transferred from the fault location to the substation feeding the fault by temporarily (or even permanently) earthing the faulted phase. Additionally, when the shunt circuit breaker is activated the faulted phase has a voltage of approximately 0 V (if load and some impedances are ignored). This reduction of voltage and current at the fault location is advantageous with regard to the arc extinction [15-16]. Thus, if the fault is transient (self-extinguishing) it is cleared out without the fast automatic reclosing function, and consequently without costumers interruptions. In Figure 1 the operating principle of the shunt circuit breaker is presented for a distribution network with a compensated earthing system. Two stages may be seen. At the moment of a single pole-to-earth fault occurrence the relay take some time to determine the faulted phase. Thus, the network conditions are identical as without the shunt circuit breaker, and the single pole-to-earth fault current is consisted of a capacitive component (flowing through healthy phases), and a component passing through the compensated earthing elements (reactor and resistor). At the moment of shunt circuit breaker activation the fault current flowing through the shunt circuit breaker pole is divided a part of this current is flowing through the compensated earthing elements, while the other part represents the capacitive component. The shunt circuit breaker technology is used in distribution network with high-resistance, isolated or compensated earthing. In a distribution network with resonant earthing this solution is regarded as too expensive [3].

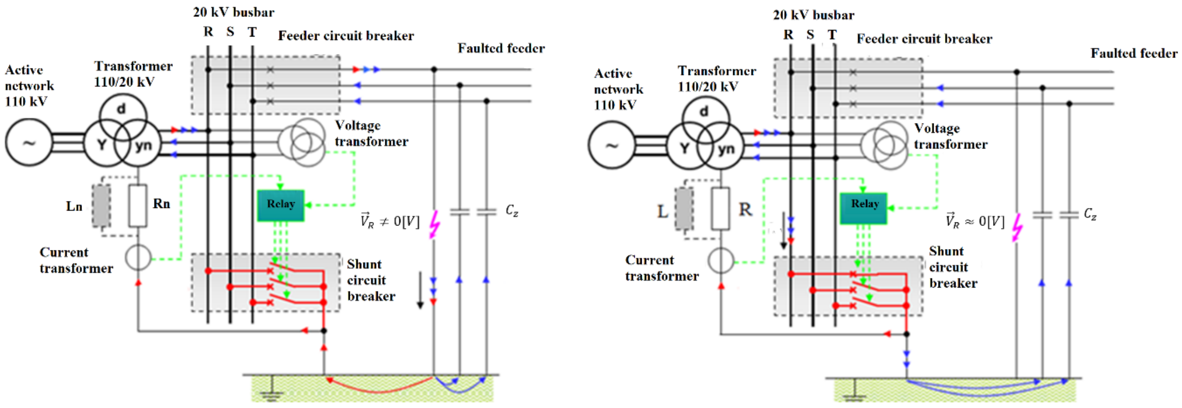

Figure 1: Operation principle of shunt circuit breaker left (off), right (on)

2.2. Model of shunt circuit breaker technology operation

The basic question concerning the shunt circuit breaker technology which arises is how much time the shunt circuit breaker should be activated to on the one hand allow the arc on the faulted location to extinguish and on the other hand to not exceed the requirements given for the touch voltages in medium voltage substations. Regarding the time needed for the arc to extinguish a time of 0,2-1 s is recommended. Usually, a time of 0,3 s is selected [7-8]. Regarding the determination of the touch voltages attention should be paid to sum up the activation (relay detection and earthing of the faulted phase) and operation time of the shunt circuit breaker [7]. If the feeder earth fault protection is blocked during the period in which the shunt circuit breaker is active than the operational time of the feeder earth fault protection should also be added to the previously mentioned summation. Regarding the shunt circuit breaker two models of earthing the faulted phase exists. In the first one the shunt circuit breaker is activated for a small amount of time (0,2-1 s), causing in this manner the reduction of fast automatic reclosing functions. In the second one the faulted phase is earthed long-term or even permanently. The long-term/permanent earthing is considered as a possibility to provide electricity to the consumers during the localization of a single pole-to-earth fault. This method regarding the touch voltages is safe to use only if the fault current is reduced enough and/or a proper values of earthing resistances are achieved in the medium voltage substations. Additionally, the activation of the shunt circuit breaker causes high temporary overvoltage’s, and during the fault localization complex control operations are needed [17]. Therefore, the introduction of long-term/permanent earthing is a very challenging solution to be carefully considered [8].

2.3. Coordination of shunt circuit breaker operation with earth fault protection

The main problem in the coordination of shunt circuit breaker with the earth fault protection is the activation and reset of the feeder relay [7-8]. The main objective is to avoid the situation in which the shunt circuit breaker is activated while the feeder relay trip and disconnects the feeder circuit breaker. Two different methods could be adopted to achieve this goal [7,8,18].

In the first method the earth fault protection is activated during the activation of the shunt circuit breaker. In this manner the disconnection of a single pole-to-earth fault is faster if the fault is not cleared by the shunt circuit breaker. Although, during the activation of the shunt circuit breaker the fault current seen by the feeder relay could be too small for its activation. This activation of the earth fault protection is difficult to achieve especially in regard to the sensitivity of common numerical relays and measurement transformers errors [19-20]. In addition the setting of the lowest activation current for earth fault protection is limited by the asymmetry of the feeder load [21].

The second method is based on blocking the earth fault current while the shunt circuit breaker is activated. This leads to a longer fault disconnection time which may cause problems regarding the touch voltages in the substation. The blocking of the feeder earth fault protection could be obtained in the secondary system or by an adequately high setting of the earth fault protection.

In Figure 2 for the first and second method the adequate coordination between the shunt circuit breaker operation and definite-time earth fault protection are shown.

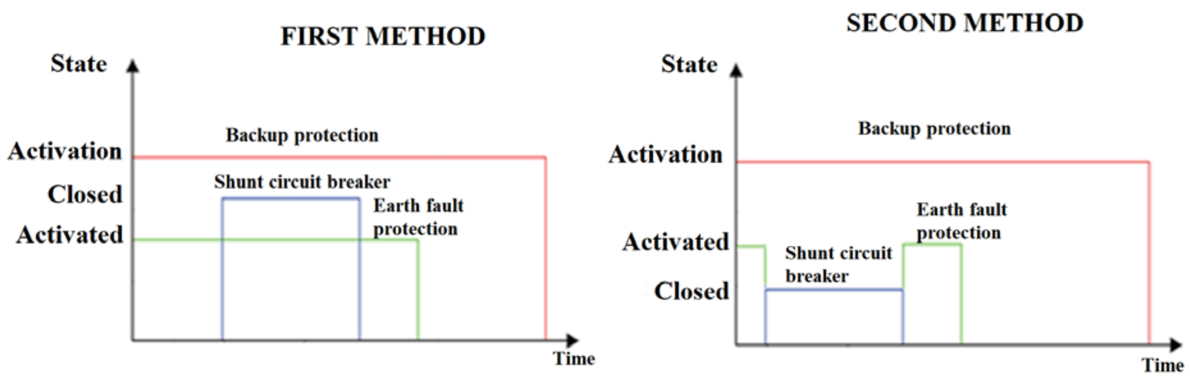

Figure 2: Coordination between the shunt circuit breaker operation and definite-time earth fault protection

2.4. Identification of the faulted phase

The identification of the faulted phase is required to determine which pole the shunt circuit breaker will connect to earth. Several different methods for the identification of the faulted phase have been developed. [8] Faulted phase detection is basically performed by measuring the busbar voltages of all three phases. When an ideal single pole-to-earth fault occurs (without the fault impedance) the voltage of the faulted phase falls to 0 V, and the voltages of the healthy phases increase to line to line voltages. Therefore, it is obvious that the faulted phase is the phase having the lowest voltage value. However, the above method is too simple, because in the event of higher fault impedance, it is possible that the voltage of the faulty phase is higher than the voltage in the phases (especially in network with isolated neutral). On the other hand, the shunt circuit breaker should never operate during multiple phase faults. For the aforementioned and other reasons, several additional criteria are used to prevent the malfunction of the shunt circuit breaker, which are also dependent on the basic earthing of the distribution grid. With the selection of the phase detection algorithm, it is possible to influence the safety of connecting the correct pole to earth, but also to limit the operating range of a shunt circuit breaker. Therefore, the faulted phase identification algorithms of a shunt circuit breaker should be carefully studied for a concrete distribution network.

3. Mathematical analysis of fault currents during the shunt circuit breaker operation

In this paper the steady-state is assumed, and for the calculation of fault currents during the shunt circuit breaker operation a method based on symmetrical components is used [22-23]. The analysis in symmetrical components is the same as for the case of two simultaneous single pole-to-earth faults in different parts of the network (also known as cross-country fault). This fact implies that activating the shunt circuit breaker is equivalent to causing two single pole-to-earth faults in different points of the medium voltage network, present in the same phase. This type of fault is more complex to analyze compared to a classical single pole-to-earth fault. The calculation used in this paper is based on references [7-8,22-23].

The first step for the analysis of the cross-country fault is to adequately group the direct, inverse, zero impedances. Three types of impedances are distinguished. The first type is common to both faults (represented with the index z). The second type is defined only by the first fault (represented with the index i). Finally the third one is defined by the second fault (represented with the index k). The node with index i represent the shunt circuit breaker position, while with index k the fault location. In addition the presented model takes into account a symmetrical line load with the impedance Z_l and with an open loop in the zero system. This open loop is due to an assumption that in the medium to low voltage substation the transformers have a connection type of Dyn5. The equivalent scheme of the direct, inverse and zero sequence impedances is presented in Figure 3.

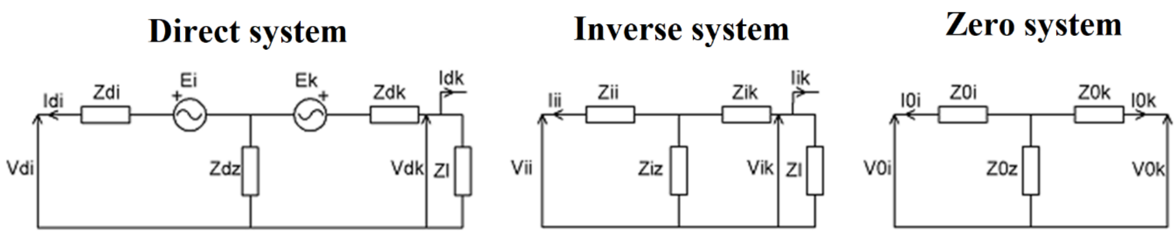

Figure 3: Equivalent scheme for the calculation of cross-country fault

The value of the sequence impedances during the shunt circuit breaker operation are described by the following equations:

$$\vec{Z}_{di} = \vec{Z}_{dk} = 0, \vec{Z}_{ii} = \vec{Z}_{ik} = \vec{Z}_{dl} \quad (1)$$

$$\vec{Z}_{0i} = 0, \vec{Z}_{0k} = \vec{Z}_{0l} \quad (2)$$

$$\vec{Z}_{dz} = \vec{Z}_{iz} = \vec{Z}_{dAM} + \vec{Z}_{dT}, \vec{Z}_{0z} = \left(\vec{Z}_{0T} + 3 \cdot \vec{Z}_n\right) || \left(\frac{1}{j \cdot \omega \cdot C_{SN}}\right) \quad (3)$$

Where: Z_{dl}, Z_{0l} direct and zero impedance of line, Z_{dAM} direct impedance of active network, Z_{dT} direct impedance of transformer, Z_{0T} zero impedance of transformer or grounding transformer, Z_n impedance dependent on the basic earthing, C_{sn} total zero capacitance of medium voltage network, ω angular frequency.

The impedance dependent on the basic earthing has a value according to Table 1. In Table 1 R_n and L_n represent the nominal values of earthing resistor and reactor. In Equation (3) the zero sequence impedance of the active network was neglected due to a small value in comparison to Z_{0T} and Z_n.

Table 1: Values of impedance dependent on the basic earthing

Type of basic earthing	Z_n
Isolated	∞
High or low resistance	R_n
Compensated	$R_n \| (\omega L_n)$
Resonant	ωL_n

If phase R is considered faulted the voltage and current conditions at the faulted locations can be expressed with the following equations:

$$\vec{V}_{di} + \vec{V}_{ii} + \vec{V}_{0i} = 3 \cdot R_{sh} \cdot \vec{I}_{di} \tag{5}$$

$$\vec{I}_{Si} = \vec{I}_{Ti} = 0 \rightarrow \vec{I}_{di} = \vec{I}_{ii} = \vec{I}_{0i} \tag{6}$$

$$\vec{V}_{dk} + \vec{V}_{ik} + \vec{V}_{0k} = 3 \cdot R_f \cdot \vec{I}_{dk} \tag{7}$$

$$\vec{I}_{Sk} = \vec{I}_{Tk} = 0 \rightarrow \vec{I}_{dk} = \vec{I}_{ik} = \vec{I}_{0k} \tag{8}$$

Where: V_{di}, V_{ii}, V_{0i},V_{dk}, V_{ik}, V_{0k}, direct, inverse and zero sequence voltages at fault locations i and k, I_{di}, I_{ii}, I_{0i}, I_{dk}, I_{ik}, I_{0k}, direct, inverse and zero sequence currents at fault locations i and k, I_{Si}, I_{Ti}, I_{Sk}, I_{Tk}, phase currents S and T at fault locations i and k, R_{sh} shunt circuit breaker resistance, R_f fault resistance.

If the sequence voltages are calculated according to Figure 3 and then substituted in Equation (5) and (7) then it is possible to calculate the currents I_{di} and I_{dk} and the fault currents I_{ki} and I_{kk} as follows:

$$\begin{bmatrix} \vec{I}_{ki} \\ \vec{I}_{kk} \end{bmatrix} = 3 \cdot \begin{bmatrix} \vec{I}_{di} \\ \vec{I}_{dk} \end{bmatrix} = 3 \cdot \begin{bmatrix} \vec{Z}_{11} & \vec{Z}_{12} \\ \vec{Z}_{21} & \vec{Z}_{22} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \vec{E}_i - \frac{\vec{E}_k \cdot \vec{Z}_{dz}}{k_d} \\ \frac{\vec{E}_k \cdot \vec{Z}_l}{k_d} \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} \vec{Z}_{11} & \vec{Z}_{12} \\ \vec{Z}_{21} & \vec{Z}_{22} \end{bmatrix} = \begin{bmatrix} \vec{Z}_{0i} + \vec{Z}_{0z} + \frac{k_{1d}}{k_d} + \frac{k_{1i}}{k_i} + 3 \cdot R_{sh} & \frac{\vec{Z}_l \cdot \vec{Z}_{dz}}{k_d} + \frac{\vec{Z}_l \cdot \vec{Z}_{iz}}{k_i} + \vec{Z}_{0z} \\ \frac{\vec{Z}_l \cdot \vec{Z}_{dz}}{k_d} + \frac{\vec{Z}_l \cdot \vec{Z}_{iz}}{k_i} + \vec{Z}_{0z} & \vec{Z}_{0k} + \vec{Z}_{0z} + 3 \cdot R_f + \frac{(\vec{Z}_{dk} + \vec{Z}_{dz}) \cdot \vec{Z}_l}{k_d} + \frac{(\vec{Z}_{ik} + \vec{Z}_{iz}) \cdot \vec{Z}_l}{k_i} \end{bmatrix} \tag{10}$$

$$k_d = \vec{Z}_l + \vec{Z}_{dk} + \vec{Z}_{dz} \quad (11)$$

$$k_i = \vec{Z}_l + \vec{Z}_{ik} + \vec{Z}_{iz} \quad (12)$$

$$k_{1d} = \vec{Z}_{di} \cdot \vec{Z}_{dk} + \vec{Z}_{di} \cdot \vec{Z}_l + \vec{Z}_{di} \cdot \vec{Z}_{dz} + \vec{Z}_{dk} \cdot \vec{Z}_{dz} + \vec{Z}_l \cdot \vec{Z}_{dz} \quad (13)$$

$$k_{1i} = \vec{Z}_{ii} \cdot \vec{Z}_{ik} + \vec{Z}_{ii} \cdot \vec{Z}_l + \vec{Z}_{ii} \cdot \vec{Z}_{iz} + \vec{Z}_{ik} \cdot \vec{Z}_{iz} + \vec{Z}_l \cdot \vec{Z}_{iz} \quad (14)$$

Where: E_i, E_k, phase voltage at fault locations i and k, Z_l, load impedance.

In this paper for the calculation according Equations (9) and (10) it is assumed that the voltages at the fault location (E_i i E_k) are equal to the normal operating phase voltages, while the load impedence Z_l is assumed to be located at the end of the line.

In the case that the load impedance is neglected (Zl→∞) the Equations (9) i (10) take the following forms:

$$\begin{bmatrix} \vec{I}_{ki} \\ \vec{I}_{kk} \end{bmatrix} = 3 \cdot \begin{bmatrix} \vec{I}_{di} \\ \vec{I}_{dk} \end{bmatrix} = 3 \cdot \begin{bmatrix} \vec{Z}_{11} & \vec{Z}_{12} \\ \vec{Z}_{21} & \vec{Z}_{22} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \vec{E}_i \\ \vec{E}_k \end{bmatrix} \quad (15)$$

$$\begin{bmatrix} \vec{Z}_{11} & \vec{Z}_{12} \\ \vec{Z}_{21} & \vec{Z}_{22} \end{bmatrix} = \begin{bmatrix} \vec{Z}_{0i} + \vec{Z}_{0z} + \vec{Z}_{ii} + \vec{Z}_{iz} + \vec{Z}_{di} + \vec{Z}_{dz} + 3 \cdot R_{sh} & \vec{Z}_{iz} + \vec{Z}_{dz} + \vec{Z}_{0z} \\ \vec{Z}_{iz} + \vec{Z}_{dz} + \vec{Z}_{0z} & \vec{Z}_{0k} + \vec{Z}_{0z} + \vec{Z}_{ik} + \vec{Z}_{iz} + \vec{Z}_{dk} + \vec{Z}_{dz} + 3 \cdot R_f \end{bmatrix}$$

(16)

With Equations (9) and (10) and (15) and (16) two mathematical models for the calculation of fault currents at the shunt circuit breaker (I_{ki}) and fault location (I_{kk}) point have been defined. The defined models allows the steady state analysis of the impact of the shunt circuit breaker on the fault currents. From the mathematical models it is possible to conclude that the fault currents are dependent on the network parameters and basic earthimg, location of fault, phase voltages, shunt circuit breaker resistance, fault resistance and in the general case on the line load. When the shunt circuit breaker is switched off the single pole-to-earth fault current is calculated as:

$$\vec{I}_{k1} = \frac{3 \cdot \vec{E}_d}{\vec{Z}_d + \vec{Z}_i + \vec{Z}_0 + 3 \cdot R_f} \quad (17)$$

$$\vec{Z}_d = \vec{Z}_i = \vec{Z}_{dAM} + \vec{Z}_{dT} + \vec{Z}_{dl} \quad (18)$$

$$\vec{Z}_0 = \left(3 \cdot \vec{Z}_n + \vec{Z}_{0T}\right) || \left(\frac{1}{j \cdot \omega \cdot C_{sn}}\right) + \vec{Z}_{0l} \quad (19)$$

Where: E_d, nominal (operating) phase voltage of the network.

4. Case study and results

4.1. Input parameters

The case study was conducted for a typical 20 kV distribution network taking into account only the main feeder branches, as presented in Figure 4. The network is consisted of a 110 kV active network, a transformer of nominal power of 20 MVA with the nominal ratio of 110/20, of three cable feeders with length of 20 km and of three overhead line feeders with length of 32 km. Regarding the analyzed basic case the values of parameters used for the calculation aside from the one shown on Figure 3 are presented in Table 2. In the results part if not differently noted the parameters used are equal to the one stated in Table 2. Three cases of basic earthing are analyzed: isolated, high-resistance and compensated earhing. All the results will be separately shown in the subsequent sections.

Table 1: Values of parameters for the basic case

Parameter	Value
Phase voltages (E_d=E_i=E_k)	21//√3 kV
Shunt resistance (R_{sh})	0,5 Ω
Fault resistance (R_f)	0 Ω
Fault location	5 km on Feeder 6
Impedance dependent on the earthing (Z_n)	Isolated Z_n =∞ Ω
	High resistance Z_n=40 Ω
	Compensated Z_n==(j·ω·615*10-3)‖240
Load (Z_l)	Z_l=∞ Ω
Total zero capacitance of the network (C_{sn})	$5{,}5582\cdot10^{-6}$ S

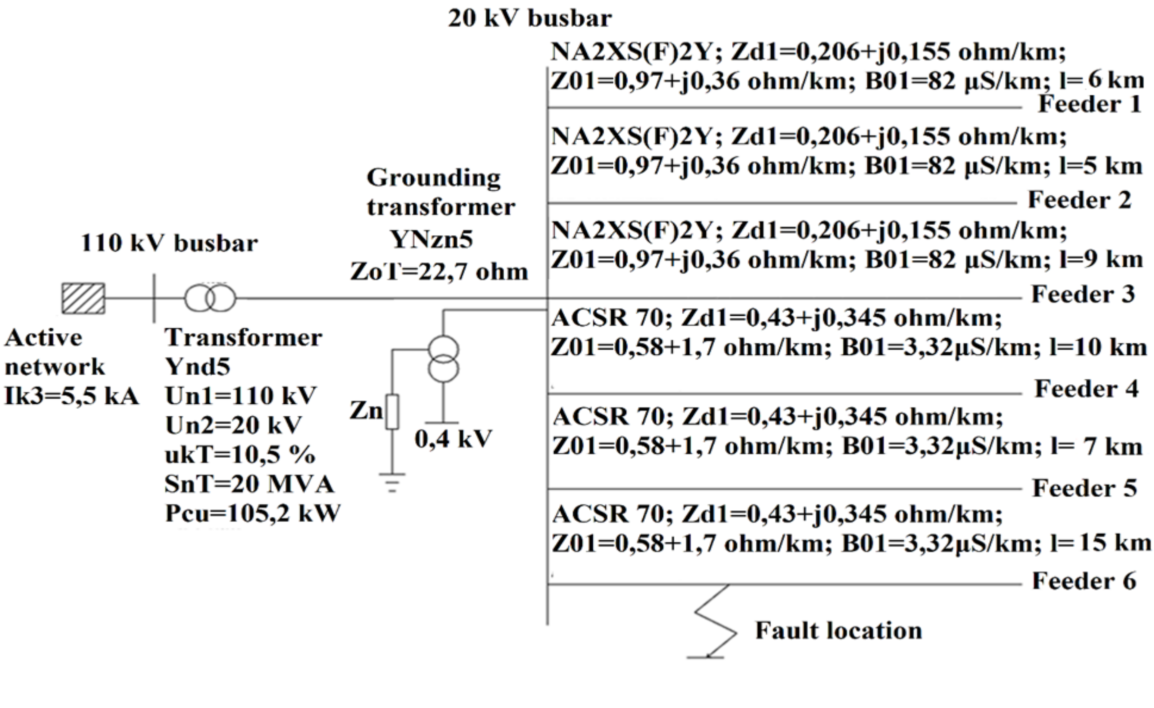

Figure 4: Case study 20 kV distribution network

4.2. Results for isolated network earthing

According to the basic case in the studied 20 kV distribution network the calculated values are:

- shunt circuit breaker switched on: I_{ki}=60,54 A, I_{kk}=6,5 A
- shunt circuit breaker disconnected: I_k= 64,4 A

Thus, during the operation of the shunt circuit breaker the current at the fault location is lowered from the value of I_k to I_{kk} which represents a decrease of 90 %. Although the current at the shunt circuit breaker point is lowered only for 6 %. In Figure 5 the dependences of the fault currents on the fault location, fault and shunt circuit breaker resistance are shown (the other parameters are as for the basic case). From Figure 5 can be concluded that the effectiveness of the shunt circuit breaker technology is lower for lower values of l and R_{sh}, and higher values of R_f, due to a small decrease in the current at the fault location I_{kk} compared to I_k. Although a decrease in the current I_{kk} rises the current I_{ki}. In the simulated cases the current ranges of I_{ki} and I_{kk} assume values from nearly 0 % to 100 % of the current I_k. The distance numerically has the biggest effect on the current I_{kk}, and thus on the shunt circuit technology effectiveness.

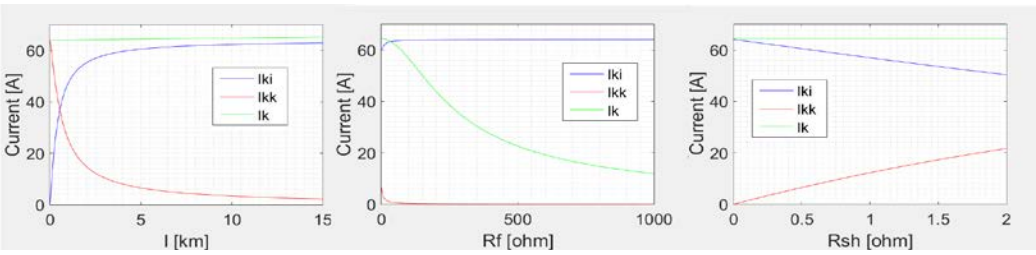

Figure 5: Dependences of the fault currents model without load - isolated network

In Figure 6 the load impact on the fault currents at different values of l, R_{sh}, R_f are shown (the other parameters are as for the basic case). From Figure 6 can be concluded that the load has a high impact on the current I_{ki}. Although this impact is much smaller if a relatively low R_f is present. Moreover, higher R_{sh} values minimize the effect of the load current. Regarding the current I_{ki} it is concluded that this current could be higher than the value of the single pole-to-earth fault I_k. This fact is dangerous in respect to the developed touch voltages in the feeding substation. In the simulated cases the current I_{kk} ranged from 0 % to 91 % of the current I_k, while the current I_{ki} from 43 % to 110 %. From all of this reasons while analyzing the shunt circuit breaker impact on the fault currents the line load should be considered.

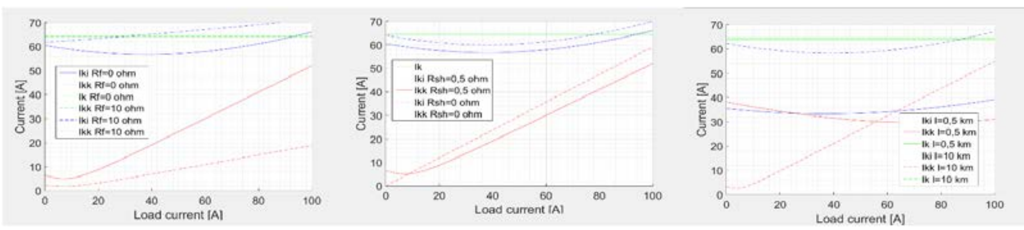

Figure 6: Dependences of the fault currents on line load - isolated network

4.3. Results for high-resistance network earthing

According to the basic case in the studied 20 kV distribution network the calculated values are:

- shunt circuit breaker switched on: I_{ki}=272 A, I_{kk}=31,26 A
- shunt circuit breaker disconnected: I_k= 274,97 A

In the basic case during the operation of the shunt circuit breaker the current I_{kk} is lowered for 90 %. Although the current at the shunt circuit breaker point is lowered only by 1 %.

Similarly as for the isolated network the dependencies of the fault currents on l, R_{sh}, R_f and the load impact are presented in Figure 7 and 8. On the one hand in the case of high-resistance earthing for the mathematical model without load similar conclusions as for the network with isolated neutral could be made. On the other hand the model with the load shows that the impact of the load on I_{kk} compared with I_k is low, but the current I_{ki} is raised above the nominal I_k (300 A) in some cases. This means that the shunt circuit breaker technology is more efficient in the network with high-resistance grounding (lower current I_{kk}), but the rise of I_{ki} over I_k should be considered in the calculation of the touch voltages in the feeding substation. In the simulated cases the current I_{kk} ranged from approximately 0 % to 100 % of the nominal current I_k (300 A), while the current I_{ki} from 0 % to 116 %.

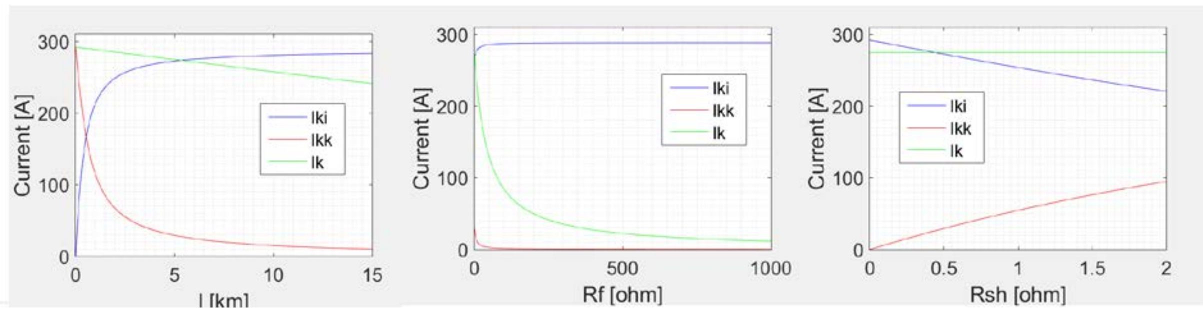

Figure 7: Dependences of the fault currents model without load - high-resistance network earthing

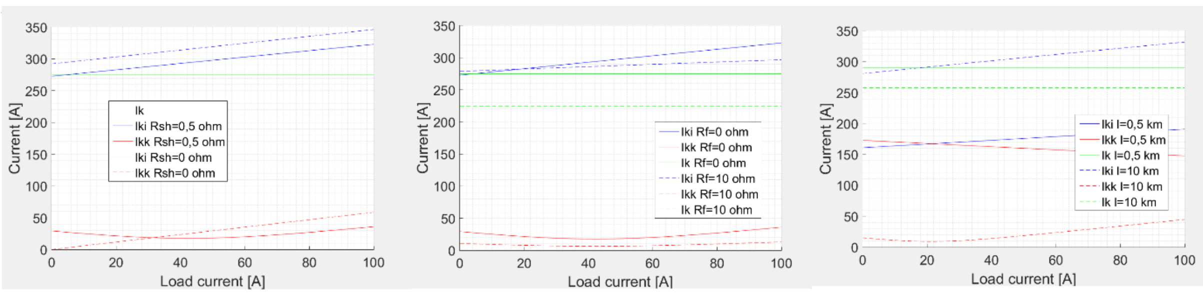

Figure 8: Dependences of the fault currents on line load - high-resistance network earthing

4.4. Results for compensated network earthing

According to the basic case in the studied 20 kV distribution network the calculated values are:

- shunt circuit breaker switched on: I_{ki}=44,06 A, I_{kk}=4,74 A
- shunt circuit breaker disconnected: I_k= 46,35 A

In the basic case during the operation of the shunt circuit breaker the current I_{kk} is lowered for 90 %, while the current at the shunt circuit breaker point is lowered only by 0,5 %.

Similarly as in previous sections the dependencies of the fault currents on l, R_{sh}, R_f and the load impact are presented in Figure 9 and 10. In the compensated earthing for the mathematical model without load similar conclusions as for previous earthing could be made. The model with the load shows that the impact of the load on $I_{kk,}$ and I_{ki} is high compared with the nominal I_k value of 50 A. In the simulated cases the current I_{kk} ranged from approximately from 0 % to 116 %,, while the current I_{ki} from 0 % to 206 %. This earthing method has the highest rise of fault currents over the nominal value of I_k. This should be taken into account for the calculation of touch voltages.

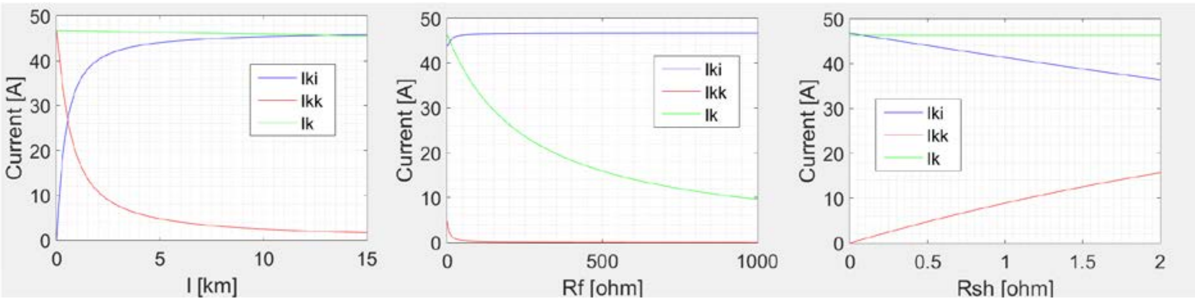

Figure 9: Dependences of the fault currents model without load - compensated earthing

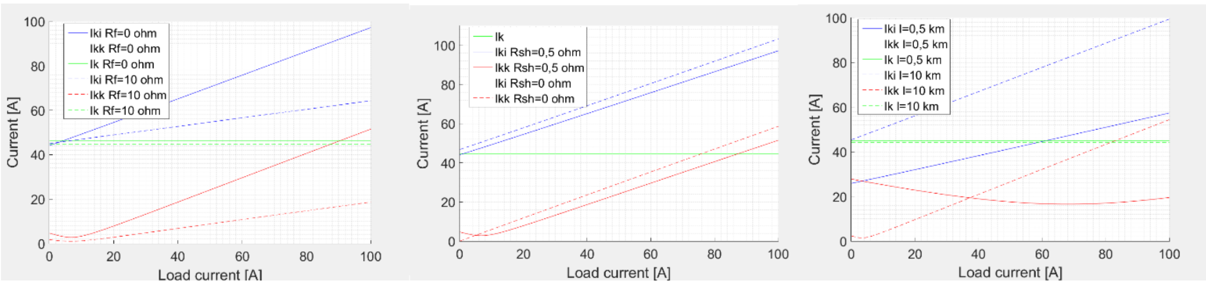

Figure 10: Dependences of the fault currents on line load - compensated earthing

5. Conclusion

The paper has shown with the steady-state analysis based on symmetrical components that during the shunt circuit breaker operation the fault currents I_{ki} and I_{kk} are aside from the network parameters (lines, transformers, active network) significantly dependent on the fault location, shunt circuit breaker resistance, fault resistance, and the basic earthing.

If the line load is neglected it was demonstrated that the shunt circuit breaker technology is inefficient for lower values of l and R_{sh}, and higher values of R_f, due to a rise of the current I_{kk} on the fault location. This fact is valid for all the basic earthings systems considered. The fault distance was identified as having the highest impact on the value of current I_{kk}.

The impact of the line load significantly complicates the whole picture of the impact that the shunt circuit breaker operation has on the fault currents I_{kk} and I_{ki}. This impact could significantly change the aforementioned conclusions. Although, the line load impact is smaller if some fault or shunt circuit breaker resistances are present. As demonstrated the line load could lead to a rise of the fault currents I_{kk} and I_{ki} over the nominal I_k. Thus, for the calculation of the touch voltages the worst case scenario of the maximum feeder load should be considered. According to the simulated cases the smallest impact of the load on I_{kk} is noticed in the network with high-resistance earthing, while the highest in the compensated earthing system.

Finally, the steady-state analysis results indicates that the shunt circuit breaker technology is not efficient in all cases because the decreases of I_{kk} is too small. In addition, steady-state analysis results indicate that in some cases the requirements for satisfying the touch voltages may be increased, which means better earthings in medium voltages substations or shortening the shunt circuit breaker operation. This may be problematic in terms of utilization, installation and cost-effectiveness of the technology itself. Therefore, without a detailed fault and steady-state analysis it is questionable whether the maximum utilization of this technology will be achieved, or if the security aspects of the touch voltages will be violated.

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