Residual overvoltage protection 59N Study of settings across leading protection relay manufactures

Lyudmil Kirilov
Faculty of Electrical Enegineering
Technical University of Sofia
Sofia, Bulgaria
l.kirilov96@gmail.com

Daniel Dobrilov
Faculty of Electrical Enegineering
Technical University of Sofia
Sofia, Bulgaria
dobrilow@tu-sofia.bg

Samet Omar
Faculty of Electrical Enegineering
Technical University of Sofia
Sofia, Bulgaria
somar@tu-sofia.bg

Adelin Antonov
Faculty of Electrical Enegineering
Technical University of Sofia
Sofia, Bulgaria
adelin.antonov@gmail.com

Slav Dimitrov
Faculty of Mechanical Engineering
Technical University of Sofia
Sofia, Bulgaria
sbd@tu-sofia.bg

***Abstract*— This paper presents a study focusing on the settings for residual overvoltage protection 59N within distribution networks MV and transmission networks HV. The research examines the practices employed by the leading relay protection manufacturers-Siemens, ABB, and Schneider Electric. The study delves into the principles underlying the operation of the 59N function and investigates the various methodologies utilized by these manufacturers to determine the zero-sequence voltage value.**

***Keywords*— Residual overvoltage protection, protection relay, settings, ground fault, zero-sequence voltage**

I. INTRODUCTION

The most common fault in an electrical network, regardless of its operational mode at the star point, is the connection between phase and ground. In Bulgaria, high-voltage transmission networks operate with an effectively grounded star point, and the current through the phase-to-ground connection point is of high magnitude, which is why this fault is called a single phase-to-ground short circuit. Distribution networks at medium voltage (MV) can operate with:

- Isolated star point;
- Star point grounded through an arc suppression coil (compensated networks);
- Star point grounded through active resistance;

The mentioned modes can be summarized as networks with an ineffective grounded star point, which are characterized by a lower current value through the phase-to-ground connection point. In this case, we have a ground fault.

The star point operating mode does not affect the production, transmission, and distribution of electrical energy, but it has a significant impact on the currents during ground faults and the accompanying overvoltages. To protect the equipment in the electrical power system from ground faults, ground relay protections are installed. Due to the low values of currents during ground faults, residual overvoltage protection is applied as a backup ground protection.

When a three-phase electrical system is symmetric and fault-free, the vector sum of the phase voltages is equal to zero because the vectors have the same amplitude and are phased 120° apart from each other. The appearance of a ground fault disrupts the symmetry between the vectors and changes their amplitudes, leading to the emergence of zero-sequence components. That's why in some literature sources and relay protection manuals, the function ANSI 59N is also referred to as overvoltage protection with zero-sequence voltage. In networks with an ineffective grounded star point, the change in the phase voltage vectors due to a ground fault leads to the displacement of the star point and a change in its potential. As a result of these phenomena, the protective function ANSI 59N can also be referred to as Neutral Voltage Displacement Protection. In addition to MV distribution networks, Residual Overvoltage Protection also finds application in the protection of electrical machines such as transformers and generators.

II. OPERATING PRINCIPLES

Modern digital relay protections offer the flexibility to choose the method of determining zero-sequence voltage either through internal software calculations based on phase voltage vectors or through direct measurement from the broken-delta winding of voltage transformers.

The connection between phase and ground is an asymmetric fault condition, and for its analysis, the method of symmetrical components is widely applied. This method views the asymmetric system as a combination of three symmetrical systems: positive-sequence (Fig. 1), negative-sequence (Fig. 2), and zero-sequence (Fig. 3).

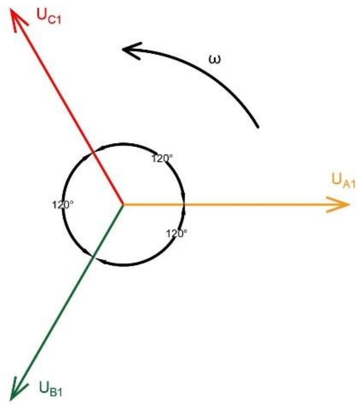

Fig. 1. Positive-sequence voltages

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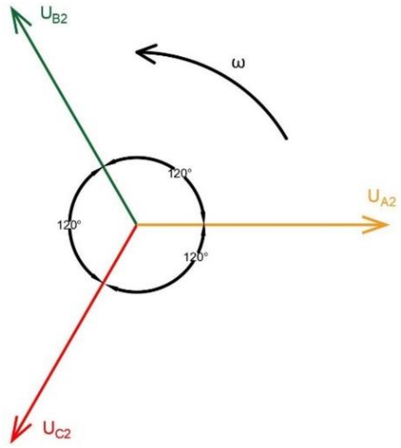

Fig. 2. Negative-sequence voltages

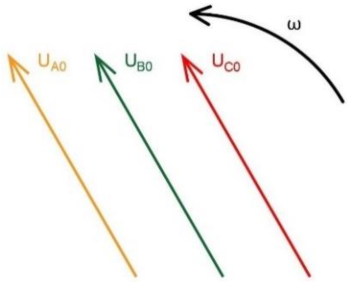

Fig. 3. Zero-sequence voltages

As seen from the figures, the positive and negative sequence systems are balanced and symmetrical. The zero-sequence system is not balanced, but since the vectors align in both phase and magnitude, the zero-sequence system is considered symmetrical. Therefore, the following relationship holds for the zero-sequence system:

$$\begin{vmatrix} U_A \\ U_B \\ U_C \end{vmatrix} = \begin{vmatrix} 1 \\ 1 \\ 1 \end{vmatrix} * U_0 \tag{1}$$

In the positive-sequence system, phase vector C is phased shifted by 120° relative to phase vector A. To align these two vectors, phase vector A needs to be multiplied by the operator $a=e^{j120°}$. Similarly, phase vector B is phased shifted by 240° relative to phase vector A, which means phase vector A should be multiplied by $a^2=e^{j240°}$. Considering the equal amplitudes of the three phases, the following relationship holds for the positive-sequence system:

$$\begin{vmatrix} U_A \\ U_B \\ U_C \end{vmatrix} = \begin{vmatrix} 1 \\ a^2 \\ a \end{vmatrix} * U_1 \tag{2}$$

The phase sequence is ACB for the negative-sequence system. Applying the reasoning from the positive-sequence system to the negative-sequence system results in:

$$\begin{vmatrix} U_A \\ U_B \\ U_C \end{vmatrix} = \begin{vmatrix} 1 \\ a \\ a^2 \end{vmatrix} * U_2 \tag{3}$$

Taking into account the matrix relations (1), (2), and (3), the matrix equation (4) is obtained for a random asymmetric system, which can be transformed into the system of equations (5):

$$\begin{vmatrix} U_A \\ U_B \\ U_C \end{vmatrix} = \begin{vmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{vmatrix} * \begin{vmatrix} U_0 \\ U_1 \\ U_2 \end{vmatrix} \tag{4}$$

$$\left| \begin{aligned} U_A &= U_0 + U_1 + U_2 \\ U_B &= U_0 + a^2 U_1 + a U_2 \\ U_C &= U_0 + a U_1 + a^2 U_2 \end{aligned} \right. \tag{5}$$

It is possible to solve (5) in terms of the positive, negative, and zero sequence components by considering the properties of the operator „a“. The equations (6), (7), and (8) are obtained, which are used in the analysis of unsymmetrical faults and applied in digital relay protections:

$$U_0 = \frac{1}{3} * \left(U_A + U_B + U_C \right) \tag{6}$$

$$U_1 = \frac{1}{3} * \left(U_A + a U_B + a^2 U_C \right) \tag{7}$$

$$U_2 = \frac{1}{3} * \left(U_A + a^2 U_B + a U_C \right) \tag{8}$$

In Fig. 4, the secondary diagram of a voltage transformer (VT) broken-delta winding is shown, which is used to determine zero-sequence voltage. In a balanced electrical network, the secondary voltage between the terminals of the broken-delta winding is very small and close to zero. However, in the presence of a single phase-to-ground fault, the secondary voltage can reach values up to 100V.

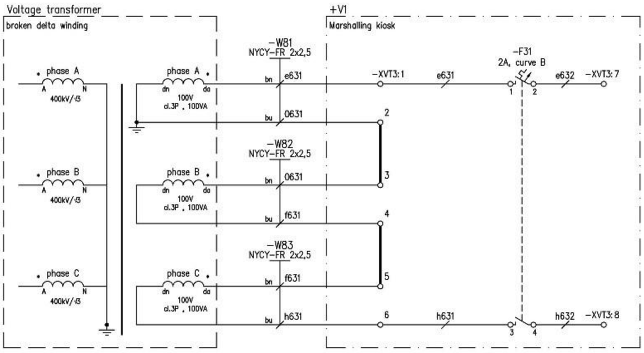

Fig. 4. Broken-delta winding

In networks with inefficiently grounded star point, overvoltages can occur during ground faults, which can reach up to three times the value of the phase voltage. Meanwhile, in networks with an effectively grounded star point, the phase voltages of the healthy phases will not exceed 80% of the line voltage. This necessitates the use of a rated secondary voltage of 100V for the broken-delta winding of voltage transformers installed in systems with an effectively grounded star point and 100/3V for systems with an inefficiently grounded star point.

It is important to note that the secondary voltage measured between the terminals of the broken-delta winding is not equal to the zero-sequence voltage. The actual relationship between the measured secondary voltage from the broken-delta winding $U_{da\text{-}dn}$, and the zero-sequence voltage U_0, can be accounted for by a coefficient k, which depends on the operational mode of the star point. This relationship can be represented by the following expression:

$$k * U_{da-dn} = 3U_0 \tag{9}$$

In the above expression, $3U_0$ is taken because during a single phase-to-ground fault, for example, on phase A, its voltage at the fault location is 0V. If we take (6), move the denominator 3 to the left side of the equation, and consider UA = 0, then the equation becomes:

$$3U_0 = U_A + U_B \tag{10}$$

Both primary operational modes of the star point will be considered to obtain the numerical value of the coefficient k.

A. Networks with an inefficiently grounded star point

The case of a network with an isolated star point is considered, as shown in Fig. 5. It is assumed that a metallic ground fault (R_{sc}=0Ω) occurs in phase A. In this case, the voltage U_{an} at the fault location becomes 0V. However, it is assumed that over the entire length of the line, we have 0V due to the low value of the ground fault current. Fig. 6 depicts the vectors of the secondary phase voltages before the occurrence of the ground fault with solid lines, while the same vectors after the occurrence of the ground fault are shown with dashed lines.

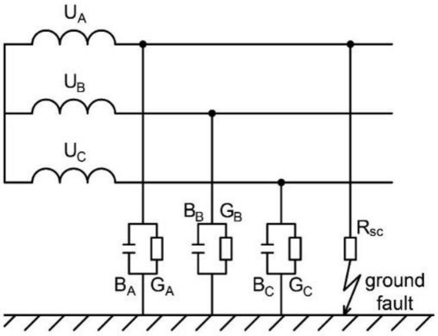

Fig. 5. Network with an inefficiently grounded star point (isolated system)

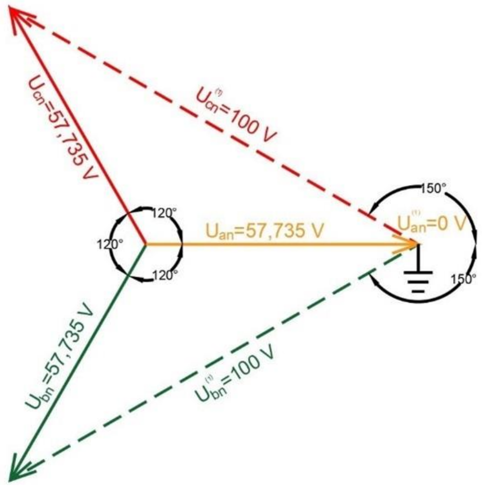

Fig. 6. Vector diagram of a ground fault in isolated system

The phase voltages of healthy phases B and C shift towards the potential of phase A, thus increasing their values to the line voltages of 100 V, and their phase angles become 150°. Consequently, the star point (neutral) attains the potential of phase A before the fault occurs, but with a negative sign:

$$U_N = -U_A \tag{11}$$

The vector sum of the secondary phase voltages U_B and U_C is shown in Fig. 7. As it's known from (10) the vector sum is equal to $3U_0$. Given that the zero-sequence voltage matches the voltage at the neutral point, it follows for the considered case that the secondary zero-sequence voltage is equal to the phase voltage of phase A before the occurrence of the ground fault. It is determined for the coefficient k that it has a value of 1.73 for networks with an isolated star point based on (9), the value of U_0=57.735V, and the measured voltage between the terminals of a broken-delta winding $U_{da\text{-}dn}$=100V.

$$k = \frac{3U_0}{U_{da-dn}} = \frac{3*57,735}{100} = 1.73 \tag{12}$$

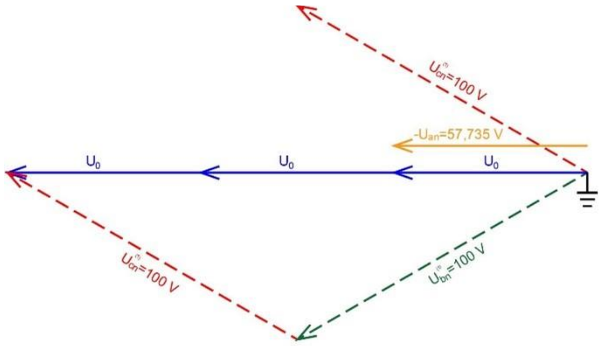

Fig. 7. Vector sum for ground fault in isolated system

The simplified analysis conducted above is identical for compensated networks and networks grounded through active resistance. It's important to note that in a real operating network, the voltage at the neutral point (U_0) is not equal to 0V due to the presence of the phase conductance of the insulation Y=G+jωB, where G is the active conductance of the insulation and B is the capacitive conductance. It is challenging to achieve completely identical voltages and conductance. Therefore, for the voltage at the star point, the following equation holds:

$$U_N = U_0 = -\frac{U_A Y_A + U_B Y_B + U_C Y_C}{Y_A + Y_B + Y_C} \tag{13}$$

If the ground fault is through a resistance R_{sc}, which is different from 0Ω, then (13) takes the following form:

$$U_0 = -\frac{\frac{1}{R} + U_A Y_A + U_B Y_B + U_C Y_C}{\frac{1}{R} + Y_A + Y_B + Y_C} \tag{14}$$

B. *Networks with an efficiently grounded star point*

This is a case of a network with a directly grounded star point without any load. In this type of network, during a ground fault, the current in the faulted phase is significantly higher than in networks with an inefficiently grounded star point, which is why the fault is called a single phase-to-ground short circuit short. Fig. 8 illustrates the vector diagram of a single phase-to-ground short circuit short in a network with a efficiently grounded star point. The depicted vector diagram is at the point of the fault.

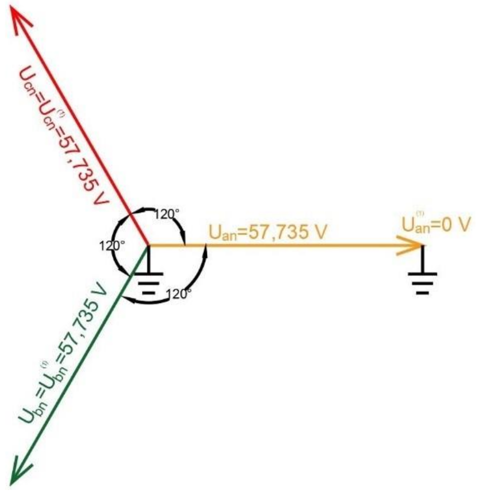

Fig. 8. Vector diagram of a single phase-to-ground short circuit short

The star point is directly connected to the ground, and in the presence of a short circuit on phase A, the end of vector U_A is also connected to the ground, meaning that the potential difference (the voltage of phase A) at the fault location is 0V. In this case, the secondary phase voltages of the healthy phases do not shift and maintain their value of 57.735V. Fig. 9 illustrates the vector sum of the voltages of the healthy phases.

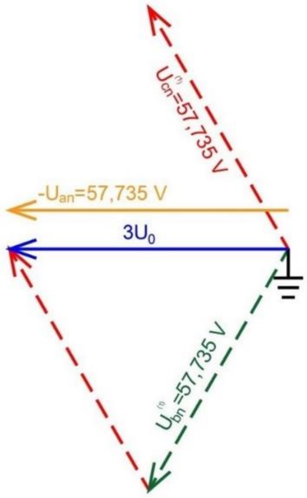

Fig. 9. Vector sum for single phase-to-ground short circuit short

Considering (10) and the vector sum from Fig. 9, the zero-sequence voltage is:

$$U_0 = \frac{1}{3}U_A = \frac{57,735}{3} = 19.245V \tag{15}$$

It is determined for the coefficient k that it has a value of 0.577 for networks with efficiently grounded star point based on (9), the value of 3U0=57.735V, and the measured voltage between the terminals of a broken-delta winding Uda-dn=100V:

$$k = \frac{3U_0}{U_{da-dn}} = \frac{57,735}{100} = 0.577 \tag{16}$$

While in the case of a single phase-to-ground short circuit, the vector of the zero-sequence voltage is in the opposite direction of the vector of the faulted phase but equal to 1/3 of its amplitude. In the case of a double-phase-to-ground short circuit, the vector of U_0 coincides in the direction with the vector of the healthy phase and is equal to 1/3 of its amplitude. These conclusions are confirmed by (6).

The determined zero-sequence voltage U_0, according to the simplified analysis, is at the fault location. Fig. 10 illustrates the actual decrease in voltage U_0 as you move away from the fault location. To determine the zero-sequence voltage at the point of the voltage transformer connected to the protective relay (IED = Intelligent Electronic Device), it is necessary to consider the zero-sequence impedance of the conductor from the point of the short circuit to the location of the voltage transformer.

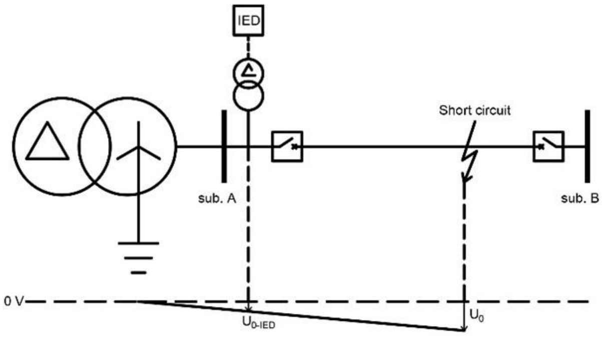

Fig. 10. Voltage U_0 decrease

For a system to be considered directly grounded, the grounding factor k_E should be equal to or less than 1.4. This factor decreases with an increase in the number of grounded neutrals on power transformers in the system. A high number of grounded neutrals leads to an increase in the value of the single-phase short circuit current $I^{(1)}_{SC}$, which can even be greater than the value of the three-phase short circuit current $I^{(3)}_{SC}$, which is used to size the equipment in the system. That's why only a certain number of neutrals are directly grounded to ensure that the conditions $k_E \leq 1.4$ and $I^{(1)}_{SC} < I^{(3)}_{SC}$ are met.

If the power transformer in Fig. 10 does not have a directly grounded neutral but is in a system that operates with an effectively grounded star point, a single phase-to-ground short circuit will activate both the relay protections at substations A and B. Both protections send tripping commands to their respective circuit breakers. It is assumed that the circuit breaker at substation B successfully trips, but the circuit breaker at substation A experiences a fault and cannot be switched off. Consequently, the power transformer has an ungrounded neutral, and it starts operating in a system with an isolated star point. If there are generating sources connected to the low voltage side of the power transformer, they will feed the ground fault through the power transformer, resulting in significant overvoltages. But the equipment insulation on the high side of the power transformer is not sized for these overvoltages. In this case, it is imperative to install residual overvoltage protection 59N on the high voltage side of the power transformer. The protection is required to send trip commands to the circuit breakers of the generating sources. It's important to note that both the zero-sequence voltage U_0 and the voltage $U_{da\text{-}dn}$ from the broken-delta winding will increase by 3. This will not lead to a change in the coefficient k=0.577.

III. SETTINGS ACROSS DIFFERENT MANUFACTURERS

The research is conducted for the leading manufacturers of digital relay protections: ABB, Schneider Electric, and Siemens. The settings for the residual overvoltage protection function of each manufacturer are described in detail. Three tests were performed with different settings for each of the studied digital protections. In each test, the pickup threshold for voltage is sought by gradually changing the voltage for 60 seconds (ramp test). In addition to each test, a voltage of 30V is applied to read the values for the voltage U_0 from the protection display. In the last test, voltages were applied to phases B and C, which were phase-shifted by ±150°. In the first two tests, the voltage U_0 is obtained from the broken-delta winding measurement, but with different values of the primary voltage of the voltage transformer. In the last test, a calculation of the voltage U_0 was set. The tests are conducted for the theoretical case of networks with an ineffectively grounded star point, which is the foundation of the algorithms for 59N in modern digital relay protections.

Two additional tests were conducted, which are not included in the results tables due to the similar responses of all studied objects. These two tests address cases where measured U_0 is specified but voltage is applied to the voltage analog inputs for the star winding, as well as when calculated U_0 is specified but voltage is applied to the voltage analog input for the broken-delta winding. In all three studied protections, there is no response, and they do not issue trip commands since the method for obtaining U_0 does not match the voltage analog inputs where voltage is applied.

A. ABB REF615

"PCM600" is the software used for configuring ABB protective relays. The investigated protection function 59N in ABB relays is denoted as "ROVPTOV." Access to the settings for this function can be found under "Application Configuration/ Protection/ Voltage protection/ ROVPTOV." The method for obtaining the value of U_0 is set using "U_0 signal Sel." The pickup threshold is configured in relative units of the secondary nominal voltage (100 V) and is entered in "Start value." The parameters for the voltage transformer windings are located in "IED Configuration/ Configuration/ Analog inputs." For the star winding, the submenu "Voltage (3U, VT)" is selected, and for the broken-delta winding - "Voltage (U_0, VT)".

TABLE I. TEST 1 FOR REF615

Applied voltage in U4 (broken-delta winding)	
U_0 signal Sel	Measured U_0
Primary voltage (U_0)	20kV
Start value	0.30xUn
Pickup result	**30.078V**
Display*: U_0-kV	**5.994kV**

TABLE II. TEST 2 FOR REF615

Applied voltage in U4 (broken-delta winding)	
U_0 signal Sel	Measured U_0
Primary voltage (U_0)	11.547kV
Start value	0.30xUn
Pickup result	**30.069V**
Display*: U_0-kV	**3.461kV**

TABLE III. TEST 3 FOR REF615

Applied voltage in U2-U3 (star winding)	
U_0 signal Sel	Calculated U_0
Primary voltage (U_0)	20kV
Start value	0.30xUn
Pickup result	**51.970V**
Display*: ZroSeq-kV	**3.456kV**

In test 1, the nominal primary voltage input is the line voltage - 20kV, and in test 2, it is the phase voltage - 11.547kV. In both tests, the protection operates at an applied secondary voltage of ~30V, which is quite expected considering that the setting is set in relative units from the nominal secondary voltage of 100V. The display values for the zero-sequence voltage U_0 are different for the two tests. In the theoretical case of networks with inefficiently grounded star point, it is known that the zero-sequence voltage U_0 is equal to the phase voltage. In this case, for ground faults in networks with a nominal voltage of 20kV, the zero-sequence voltage is 11.547kV. This value is taken as the base U_n. With a setting of $0.30xU_n$, the voltage threshold for zero-sequence voltage becomes 0.30*11.547=3.4641kV. When analyzing faults, the accuracy of the measured parameters is of paramount importance. Despite the identical secondary pickup voltages in the first two tests, the calculated voltage U_0 must correspond to the actual zero-sequence voltage. If the VT transformation ratios are calculated for both tests and multiplied by the applied secondary voltage of 30V, the values from the protection's display are obtained exactly:

$$U_{0-test1} = 30 * \frac{20000}{100} = 6000V \tag{17}$$

$$U_{0-test2} = 30 * \frac{11547}{100} = 3464V \tag{18}$$

From both display indications, it can be inferred that the protection relay assumes equality between the measured voltage of the broken-delta winding and the actual voltage of the zero-sequence. However, according to (12), the relationship between these two voltages is $1.73= \sqrt{3}$. The introduction of the phase voltage for the parameter "Primary voltage (U_0)" in the protection settings precisely establishes this relationship. These arguments are also confirmed by the protection manual, which specifies that when selecting the "Measured U_0" parameter, it is necessary to enter the phase voltage for the primary value of the voltage transformer.

In test 3, "Calculated U_0" is set as the method for obtaining the value of the zero-sequence voltage. The protection activates when the voltages of both phases are 51.97V with an angle of 60° between them (the vectors of the two phases are phase-shifted with respect to the vector of phase A by ±150°).

The vector sum of the voltages of phases B and C is 90.0147V in secondary values. In II. A, it is explained that this vector sum is equal to $3U_0$, which means that the secondary voltage of the zero-sequence is 30.0049V. The VT transformation ratio is 20000/100=200. The voltage U_0 in primary values is calculated by multiplying the transformation ratio by the obtained secondary value of U_0, resulting in 6000.98V. This value is confirmed by the display readings, noting that 30V with an angle of 60° between phases are applied (phase B and phase C). The vector sum for the experiment with 30V is 51.9615V, therefore, for U_0, resulting in 17.3205V in secondary values and 3464.1V in primary values. The results obtained from test 3 match the expected calculated values. However, it should be noted that the "Start value" setting is related to the line voltage of 20kV. When setting the protective function 59N in primary values of U_0, such as 3.464kV, it is essential to divide the desired set value by the line voltage of 20kV, yielding 3.464/20=0.1732. This value is entered as "Start value".

B. *Schneider Electric P3F30*

The software for configuring Schneider Electric digital relay protection devices is called "eSetup Easergy Pro." The method by which the digital relay protection determines the zero-sequence voltage U_0 is selected from the "General/ Scaling" menu through the "Voltage meas. mode" setting. If "3LN" is chosen for this setting, the digital protection will determine the voltage U_0 using internal software calculations, applying the method of symmetrical components, and utilizing the measured phase voltages from the star winding of the voltage transformer. To determine U_0 through measurement from the broken-delta winding, it is needed to set "3LN+U_0". The nominal secondary voltage of the broken-delta winding should be set to "VT_0 secondary". Configuring the 59N function is done through "Protection/ Neutral vol. displacement U0> 59N". The pickup threshold of the digital relay protection is set in percentage of the nominal secondary voltage (100V) using the "Pick-up setting [%]".

TABLE IV. TEST 1 FOR P3F30

Applied voltage in U4 (broken-delta winding)	
Voltage meas. mode	3LN+U_0
VT primary	20000V
Pick-up setting	30%
Pickup result	**30.192V**
Display*: U_0	**3463Vrms**

TABLE V. TEST 2 FOR P3F30

Applied voltage in U4 (broken-delta winding)	
Voltage meas. mode	3LN+U_0
VT primary	11547V
Pick-up setting	30%
Pickup result	**30.216V**
Display*: U_0	**1999Vrms**

TABLE VI. TEST 3 FOR P3F30

Applied voltage in U2-U3 (star winding)	
Voltage meas. mode	3LN
VT primary	20000V
Pick-up setting	30%
Pickup result	**30.259V**
Display*: U_0	**30%**

Table IV presents the results of test 1 for the Schneider Electric P3F30 protection relay. The obtained results match those in Table II for ABB REF615. While the REF615 considered the coefficient k=1.73 from (12) by setting the phase voltage for the nominal primary voltage, in the P3F30 protection, the line voltage is set. From this result, it follows that the Schneider Electric protection relay considers the coefficient k=1.73. The confirmation of this coefficient is also supported by test 2, where a nominal voltage of 11547V is set. To obtain the zero-sequence voltage, it is necessary to divide the entered voltage value by √3, resulting in 6666.66V. When set to 30% of this value, which equals 1999.99V, the display readings match exactly. The software's recognition of k=1.73 makes configuring the protection relay easier because it allows you to set the nominal voltage transformer parameters directly and because the percentage relationship between U_0 and the measured voltage in the broken-delta winding is the same.

The recognition of the coefficient k=1.73 also has a favorable impact on cases where U_0 is calculated (test 3). The vector sum of phases B and C (30.259V with a 60° angle between them) results in 52.41V. This yields a secondary voltage U_0 of 17.47V, and in primary values, by multiplying the secondary voltage by the transformation ratio of 200, it becomes 3494V, which represents 30.2% of the primary value of the zero-sequence voltage. Regardless of how the zero-sequence voltage is determined, it can be assumed that the pickup threshold setting for the P3F30 protection is given in percentages of the voltage U_0, with the anticipated secondary pickup voltage of the protection corresponding to the setting. These circumstances simplify the configuration and testing of this type of protection.

C. *Siemens 7SJ82*

The "Digsi 5" software is used to set up Siemens protection for the 5th generation (Siprotec 5). By default, in Siprotec 5, there are 3 voltage inputs set for the star winding. These 3 inputs are associated with "Meas. point V-3ph". If a fourth voltage input needs to be connected to a broken-delta winding, then a new "Meas. point V-1ph" must be made. This can be done from the "Voltage-measuring points" submenu under "Measuring-points routing", and it should be selected "VN broken-delta". The parameters for the VT windings are set in "Settings/ Power system". Accordingly, "Meas. point V-3ph" is selected for star winding and "Meas. point V-1ph" is selected for broken-delta winding. In "Meas. point V-1ph" there is a setting called "Matching ratio Vph/VN" which represents a coefficient. Siemens defines this coefficient as:

$$Matching \quad ratio = \frac{3V_{0\sec}}{V_{N\sec}} \tag{19}$$

The expression "$3V_{0\ \sec}$" refers to the value of the zero-sequence voltage, which the protection calculates by multiplying the "Matching ratio" coefficient by the measured voltage from the broken-delta winding ($V_{N\sec}$). It's evident that the defined equation from Siemens matches the theoretically derived (9).

The protection functions in Siprotec 5 are divided into functional groups. The "59 Overvolt.-V0" function from the Digsi 5 library must be added to the "VI 3ph" function group in order to implement the 59N protection, which is based on software calculations of the zero-sequence voltage. If 59N protection is required based on measurements from the broken-delta winding, it is necessary to first create a "VI 1ph" function group and then add the "59 Overvolt.-Vx" function to it. The pickup threshold is configured in the field next to "Threshold" for both functions.

TABLE VII. TEST 1 FOR 7SJ82

Applied voltage in U4 (broken-delta winding)	
Meas. point	V-1ph
Matching ratio	1.73
Rated primary voltage	20kV
Threshold	30V
Pickup result	**52.029V**
Display*: VI 1ph/V	**3.461kV**

TABLE VIII. TEST 2 FOR 7SJ82

Applied voltage in U4 (broken-delta winding)	
Meas. point	V-1ph
Matching ratio	1.73
Rated primary voltage	11.547kV
Threshold	30V
Pickup result	**52.058V**
Display*: VI 1ph/V	**1.997kV**

TABLE IX. TEST 3 FOR 7SJ82

Applied voltage in U2-U3 (star winding)	
Meas. point	V-3ph
Rated primary voltage	20kV
Threshold	30V
Pickup result	**52.035V**
Display*: Vseq:0	**3.462kV**

TABLE X. TEST 4 FOR 7SJ82

Applied voltage in U4 (broken-delta winding)	
Meas. point	V-1ph
Matching ratio	0.58
Rated primary voltage	20kV
Threshold	30V
Pickup result	**155.3V**

The results from the first test of the Siemens 7SJ82 protection relay are recorded in Table VII. The setting for the pickup threshold is input in secondary voltage (or primary voltage if "primary" is selected under "Edit mode" in „Settings/ Device settings“). This value pertains to the zero-sequence voltage U_0, which is used as the threshold. The protection relay multiplies the specified value "Threshold" by 3, and the resulting product is divided by the value of "Matching ratio Vph/VN." Accordingly, for test 1, with a set value of 30V, the protection is expected to operate at (3*30)/1.73, which equals 52.023V. The test conducted confirms that the expected value corresponds to the actual applied voltage. This algorithm is further validated by test 4 in Table X, where a "Matching ratio Vph/VN" value of 0.58 is specified. In this case, the expected pickup threshold is (3*30)/0.58=155.17V, which aligns with the actual applied voltage. The readings displayed on the protection relay are also accurate. In test 1, with 30V of secondary voltage input, a voltage of 3.461kV is recorded for U_0. If there is a requirement to set a 30V secondary measured voltage from the broken-delta winding, it is necessary to solve (19) with respect to $V_{0\,sec}$. It is determined that a value of 17.3V must be set for the "Threshold" setting to ensure the protection operates at an applied voltage of 30V.

The results of test 3 for the Siemens 7SJ82 perfectly match the results of test 3 for the ABB REF615. Unlike ABB, with Siemens, there is no need for recalculation of the setting since it is directly specified for the zero-sequence voltage U_0.

IV. CONCLUSION

For the purpose of locating and tripping ground faults in networks with an ineffectively grounded star point, the Residual Overvoltage Protection 59N is frequently used. The 59N function is useful in transmission networks with a star point that is effectively grounded as a backup protection against scenarios in which the primary equipment might enter an isolated neutral mode. The zero-sequence voltage U_0, a key requirement for the operation of this protection function, can be measured and calculated by modern digital protection devices.

Setting the phase voltage value to the nominal primary voltage is advised when measuring U_0, which is selected for ABB protection relays. On the other hand, Schneider Electric and Siemens protection relays require the desired tripping threshold to be set based on the U_0 voltage. In Schneider Electric protection relays, internal software compensation ensures that the entered setting matches the measured voltage from the broken-delta winding. The "Matching ratio" parameter, which is used in Siemens protection relays, specifies the relationship between the entered pickup threshold and the measured voltage. This parameter is used to adjust the pickup threshold based on the measured U_0 voltage.

When "Calculated U_0" is specified, based on the symmetrical components method, in ABB protections, an additional conversion of U_0 into relative units is required. In Schneider Electric and Siemens protections, the direct value of voltage U_0 is set.

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REFERENCES

[1] N. Nanchev, “Compensation of ground fault currents”, Sofia: Technika, 1963.

[2] L. Genov, “High-voltage engineering”, Sofia: Technika, 1979.

[3] N. Avramov, “Fundamentals of relay protection”, Sofia: Technika, 1984.

[4] L. Hewitson, M. Brown, R. Balakrishnan, “Power system protection”, ISBN 0 7506 6397 9, Elsevier, 2004.

[5] J. Blackburn, T. Domin, “Protective Relaying. Principles and applications. Third edition”, ISBN10: 1-57444-716-5, CRC Press, 2006.

[6] “615 series. Technical manual”, ABB, 2023.

[7] “Easergy P3F30. Feeder protection relay. User manual”, Schneider Electric, 2022.

[8] “Siprotec 5. Overcurrent protection 7SJ82/7SJ85. Manual”, Siemens, 2023.