



VEBKO ONLINE HELP

Distance Protection Voltage and Current Calculations in the Test Room

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In distance protection testing, an impedance relay is used to protect a line by calculating impedance using line current and voltage. The calculations in the distance room require injecting current and voltage proportional to the impedance of the relay. The training covers distance test calculations, along with proof for various fault types and testing methods. There are three common methods to calculate fault voltage and current for distance relay testing:

Constant Z-I Method

. Constant Z-I Method In this method, the fault current is considered constant, and the fault voltage is calculated by entering the impedance

$$V = Z I_{test}$$

Figure 1

In the Test Object window (Test Block), pay attention to the maximum test impedance ($\max(V)$), which depends on the maximum test voltage displayed in the table for various fault types under the ****Device Limits**** section.

Single phase fault	$Z_{L \max} = V_{\max} / \sqrt{3} \cdot (1 + K_L) \cdot I_{test}$
Two phase <u>fault</u>	$Z_{L \max} = V_{\max} / 2 \cdot I_{test}$
Three phase <u>fault</u>	$Z_{L \max} = V_{\max} / \sqrt{3} \cdot I_{test}$

Figure 2

Constant Z-V Method

In this method, the fault voltage is considered constant, and the fault current is calculated by entering the impedance.

$$I = \frac{V_{test}}{Z}$$

Figure 3

calculated by entering the impedance. In the Test Object window (Test Block), pay attention to the minimum test impedance ($Z_{L \min}$), which depends on the maximum fault current displayed in the table for various fault types under the 'Device Limits' section.

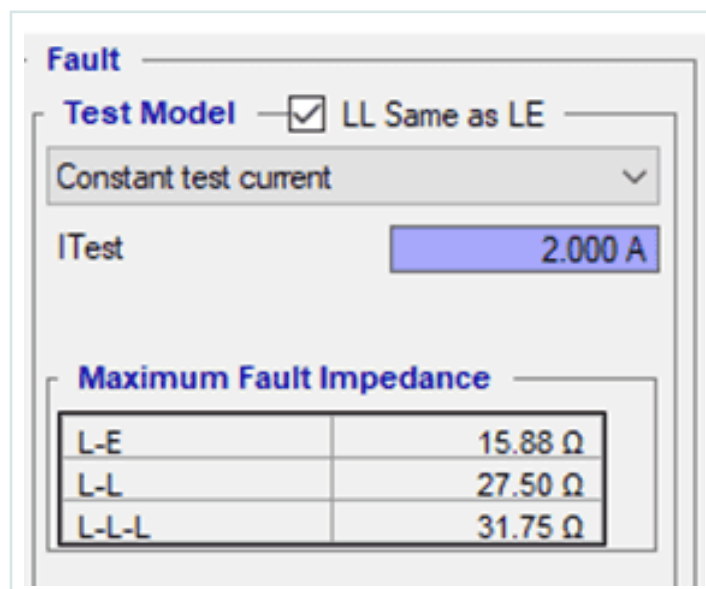
Single phase faults	$Z_{L \min} = \frac{V_{\text{test}}}{ 1+K_L \cdot I_{\max}}$
Two phase faults	$Z_{L \min} = \frac{V_{\text{test}}}{2 \cdot I_{\max}}$
Three phase faults	$Z_{L \min} = \frac{V_{\text{test}}}{I_{\max}}$

Figure 4

Constant Source Impedance Method

In this method, neither voltage nor current is considered constant, but instead, the fault voltage is calculated using the source impedance (Z_s) and the source factor (K_s). Information from the source may vary, but eventually, K_s and Z_s are converted into usable values for calculations. All of this data is related to source impedance and is finally used in calculations.

In the next step, based on the chosen test method, fault current and voltage can be calculated in the 'Distance Room' under the 'Setting' tab, 'Fault' subsection, and 'Test Model' group. Click on the sliding field to select the desired mode.



Maximum Fault Impedance	
L-E	15.88 Ω
L-L	27.50 Ω
L-L-L	31.75 Ω

Figure 5

Understanding the Concept of Source Impedance Ratio (SIR)

Consider a single-phase equivalent circuit of the network with a source or SV voltage. This network consists of the source impedance (Z_s) up to the relay installation location and the line impedance (Z_L), which the protection relay will monitor. The voltage measured by the relay is denoted as V_R .

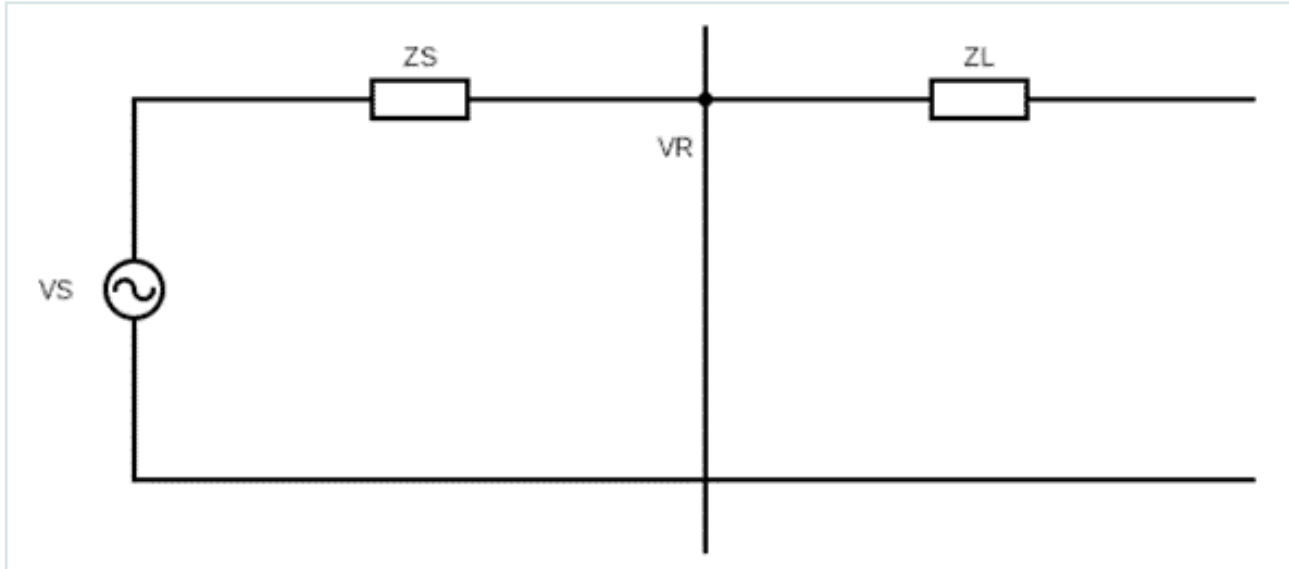


Figure 6

The system voltage seen by the relay is calculated using

$$V_R = \frac{Z_L}{Z_L + Z_S} V_S \xrightarrow{\text{Factor: } Z_L} V_R = \frac{Z_L}{Z_L \left(1 + \frac{Z_S}{Z_L}\right)} V_S \Rightarrow V_R = \frac{1}{1 + \frac{Z_S}{Z_L}} V_S$$

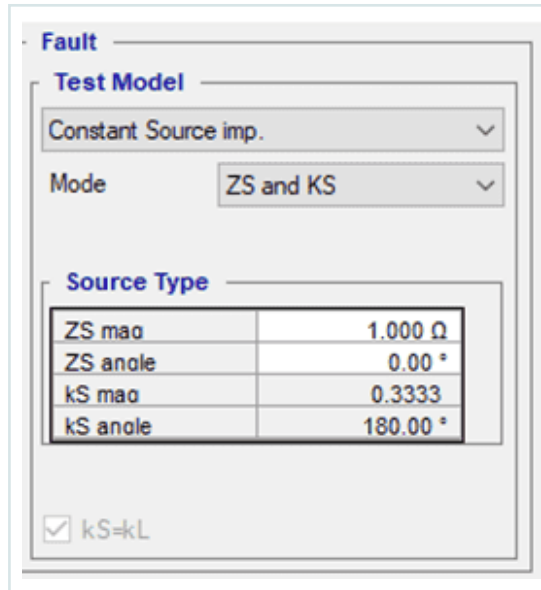
Figure 7

the ratio between Z_s and Z_L , known as the 'Source Impedance Ratio (SIR)', which is represented by the following equation:

$$SIR = \frac{Z_S}{Z_L} \Rightarrow V_R = \frac{V_S}{1 + SIR}$$

Figure 8

Also, using the following relationship, the voltage from the source to the short circuit level can be calculated as Therefore, the voltage measured by the relay during a fault depends on the SIR value and ultimately on the line impedance. Using the relationships for K_s and Z_s , fault voltage and current can be calculated for the test.



The screenshot shows the 'Fault' test model configuration. Under 'Test Model', 'Constant Source imp.' is selected. The 'Mode' is set to 'ZS and KS'. The 'Source Type' table is as follows:

Parameter	Value
ZS mag	1.000 Ω
ZS anole	0.00 $^\circ$
kS mag	0.3333
kS anole	180.00 $^\circ$

At the bottom, the checkbox 'kS=kL' is checked.

Figure 9

Z_S and K_S	Z_S امپدانس منبع K_S ضریب زمین
Z_{S1} and Z_{S0}	Z_{S1} امپدانس توالی مثبت Z_{S0} امپدانس توالی صفر
R_S, X_S $R_{SE}/R_S, X_{SE}/X_S$	R_S, X_S قسمت حقیقی و موهومی امپدانس منبع $R_{SE}/R_S, X_{SE}/X_S$ ضریب زمین به صورت نسبت قسمت حقیقی و قسمت موهومی
SIR and K_S	SIR نسبت امپدانس منبع به امپدانس بار K_S ضریب زمین
SSC and X/R	S_{SC} توان ظاهری اتصال کوتاه سه فاز تکفاز X/R نسبت بخش موهومی خط به قسمت حقیقی
ISC and X/R	I_{SC} جریان اتصال کوتاه در حالت سه فاز و تکفاز X/R نسبت بخش موهومی امپدانس خط به قسمت حقیقی
$Z_{S1} = Z_S$	
$K_S = (Z_{S0} / Z_S - 1) / 3$	
$Z_S = R_S + j X_S$	
$K_S * Z_S = R_E + j X_E = R_{SE}/R_S * R_S + j X_{SE}/X_S * X_S$	
SIR = $ Z_S / Z_L $, Z_L line length in Ohms set on Test object's "System Settings" Tab	
$S_{SC L-L} = \sqrt{3} V_{nom L-N}^2 / Z_S $	
$S_{SC L-N} = \sqrt{3} V_{nom L-N}^2 / Z_S * (1 + K_S) $	
$X/R_{L-L} = \tan(\angle Z_S) / \text{Re}(Z_S)$	
$X/R_{L-N} = \tan(\angle Z_S * (1 + K_S)) / \text{Re}(Z_S * (1 + K_S))$	
$I_{SC L-L} = \sqrt{3} S_{SC L-L} / Z_S $	
$I_{SC L-N} = \sqrt{3} S_{SC L-N} / Z_S * (1 + K_S) $	

Figure 10

Current and Voltage in Different Fault Types

So far, explanations have been provided regarding methods for impedance calculation. This section

discusses the relationships of fault current and voltage in the software using the equivalent circuit for single-phase, two-phase, and three-phase faults

Single-Phase Fault:

The figure below shows the equivalent circuit of the line in the case of a single-phase fault. For calculating the current and voltage of the faulted phase and the other phases, methods such as constant current, constant voltage, and constant source impedance are used, with the calculations for each provided separately.

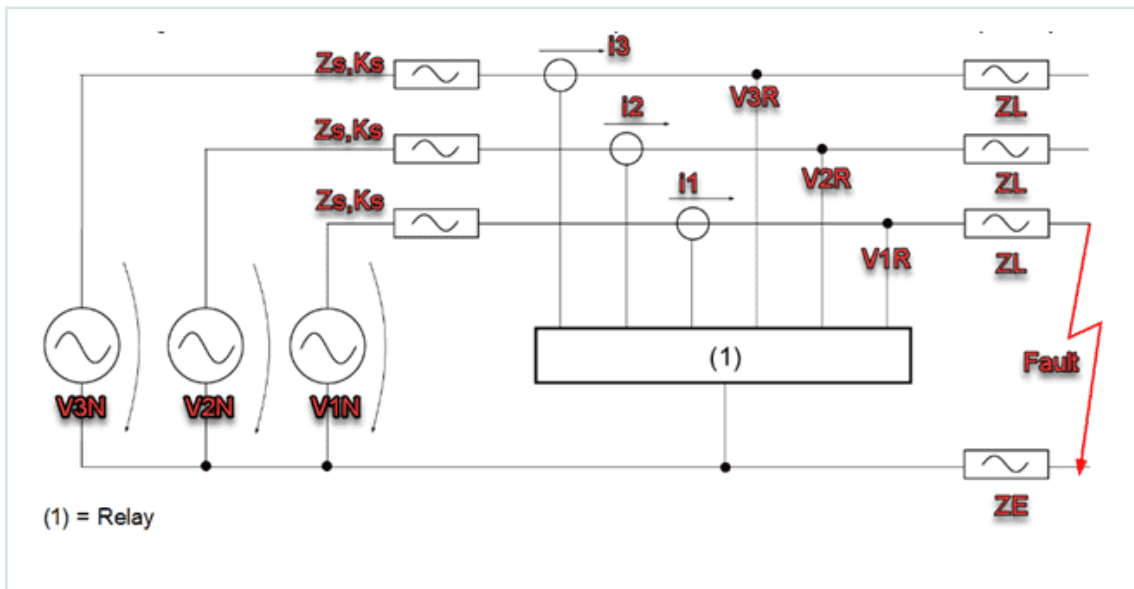


Figure 11

In Z-I Constant Method, the fault current (test current) is considered constant for all test points. Using the impedance and test current, the voltage is calculated as follows:

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} I_{\text{test}} \angle \phi_{(V_{1N})} - \phi_{(1+K_L)Z_L} \\ 0 \\ 0 \end{bmatrix}, \quad \begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} I_{\text{test}} \cdot |(1+K_L) \cdot Z_L| \angle \phi_{V_{1N}} \\ V_{2N} \\ V_{3N} \end{bmatrix}$$

Figure 12

In Z-V Constant Method the fault voltage (test voltage) is fixed for all test points. Using the impedance and test voltage, the current is determined by:

$$\begin{bmatrix} V_R \\ V_R \\ V_R \end{bmatrix} = \begin{bmatrix} V_{\text{test}} \angle \phi_{V_{1N}} \\ V_{2N} \\ V_{3N} \end{bmatrix}, \quad \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} \frac{V_R}{|(1+K_L)Z_L|} \angle \phi_{V_{1N}} - \phi_{(1+K_L)Z_L} \\ 0 \\ 0 \end{bmatrix}$$

Figure 13

In the Constant Source Impedance method, the fault current and voltage are calculated according to Kirchhoff's law as follows:

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} \frac{V_{1N}}{(1+K_S)Z_S + (1+K_L)Z_{test}} \\ 0 \\ 0 \end{bmatrix}, \quad \begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} i_1 (1+K_L)Z_{test} \\ V_{2N} - i_1 K_S Z_S \\ V_{3N} - i_1 K_S Z_S \end{bmatrix}$$

Figure 14

Proof of calculations in the Constant method:

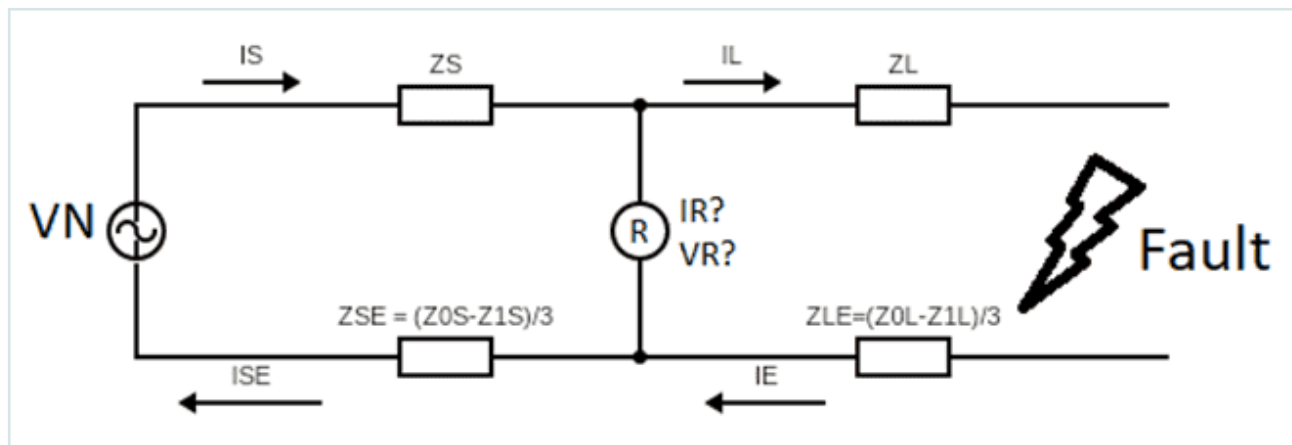


Figure 15

$$\begin{aligned} V_N &= Z_S I_S + Z_L I_L - Z_{LE} I_E - Z_{SE} I_E \xrightarrow{I=I_L=I_S=-I_E} V_N = I \overbrace{(Z_S + Z_L + Z_{LE} + Z_{SE})}^{Z_{Total}} \\ \Rightarrow \frac{V_N}{I} &= Z_{Total} \xrightarrow{factor: Z_L, Z_E} \frac{V_N}{I} = Z_S \underbrace{\left(1 + \frac{Z_{SE}}{Z_S}\right)}_{K_S} + Z_L \underbrace{\left(1 + \frac{Z_E}{Z_L}\right)}_{K_L} \\ \Rightarrow I_1 &= \frac{Z_S(1+K_S) + Z_L(1+K_L)}{V_N}, I_2 = 0, I_3 = 0 \\ V_{1R} &= I_1 \cdot Z_L \cdot (1+K_L), \quad V_{2R} = V_{2N} - I_1 \cdot K_S \cdot Z_S, \quad V_{3R} = V_{3N} - I_1 \cdot K_S \cdot Z_S \end{aligned}$$

Figure 16

. Two-Phase Fault

The equivalent circuit for a two-phase fault is shown below. For the faulted and healthy phases, methods like constant current, constant voltage, and constant source impedance are used, with each calculation presented separately

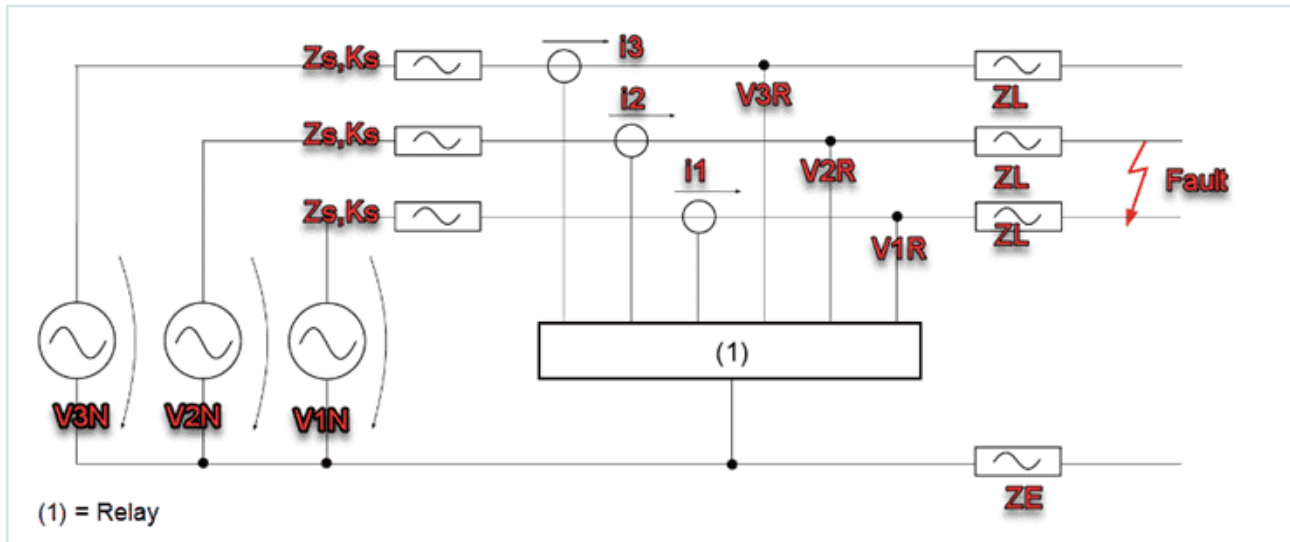


Figure 17

In Z-I Constant Method, the fault current remains constant across all test points and is the same for the two faulted phases but 180° out of phase. This results in the following relationships for current and voltage:

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} I_{\text{test}} \angle \varphi_{(V_{1N} - V_{2N})} - \varphi_{Z_{\text{fault}}} \\ i_1 * 1 \angle 180^\circ \\ 0 \end{bmatrix}, \quad \begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} Z_{\text{test}} i_1 - \frac{V_{3N}}{2} \\ Z_{\text{test}} i_2 - \frac{V_{3N}}{2} \\ V_{3N} \end{bmatrix}$$

Figure 18

Proof of calculations in the Z-I constant method:

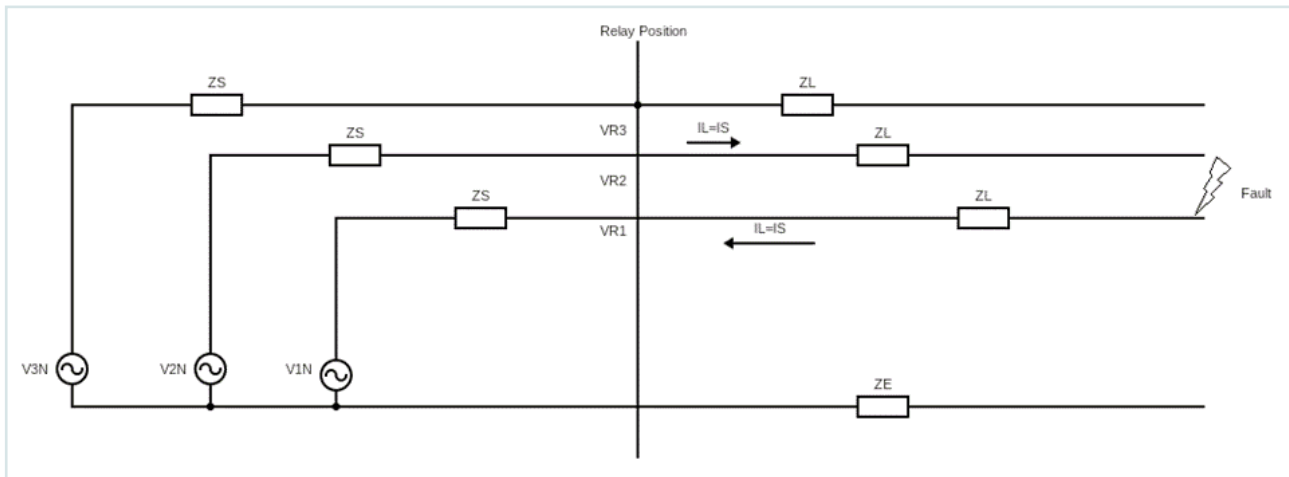


Figure 19

$$\begin{cases} V_{1N} = Z_S I_S + V_{R1N} \\ V_{2N} = -Z_S I_S + V_{R2N} \\ V_{3N} = V_{R3N} \end{cases} \xrightarrow{SUM} \begin{cases} V_{R1N} + V_{R2N} + V_{R3N} = 0 \\ V_{R1N} - V_{R2N} = 2Z_L I_L \end{cases} \xrightarrow{Sum} 2V_{R1N} + V_{R3N} = 2Z_L I_L$$

$$\Rightarrow V_{R1N} = Z_L I_L - \frac{V_{R3N}}{2} \quad [2]$$

$$[1] \Rightarrow V_{R2N} = V_{R1N} - 2Z_L I_L \xrightarrow{[1][2]} V_{R2N} = Z_L I_L - \frac{V_{R3N}}{2} - 2Z_L I_L$$

$$\Rightarrow V_{R2N} = -Z_L I_L - \frac{V_{R3N}}{2} \Rightarrow V_{R2N} = Z_L I_L - \frac{V_{R3N}}{2}$$

Figure 20

-In the Z-V constant method, the fault voltage for all test points is equal to the faulted two-phase line voltage ($V_{test} = V_{1N} - V_{2N}$). Given the fault impedance, the line current and voltage are obtained from the following relationships:

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} \frac{V_{test}}{2 \cdot |Z_{test}|} \angle \varphi_{(V_{1N} - V_{2N})} - \varphi_{Z_{test}} \\ i_1 * 1 \angle 180^\circ \\ 0 \end{bmatrix}, \quad \begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} Z_{test} i_1 - \frac{V_{3N}}{2} \\ Z_{test} i_2 - \frac{V_{3N}}{2} \\ V_{3N} \end{bmatrix}$$

Figure 21

Example: Two-Phase Fault (L1-L2) Assume a fault impedance of 1 ohm with an angle of 0° is used for testing. In this fault type, the angle between the line-to-line voltage and the corresponding current creates the desired impedance angle. The results for phase angles and magnitudes are:

PreFault:

$$\begin{array}{lll} V_{L1-L2} = 110 \angle 0 & , & V_{L1-E} = 63.51 \angle -30 & , & I_{L1} = I_{load} \angle 0 \\ V_{L2-L3} = 110 \angle -120 & , & V_{L2-E} = 63.51 \angle -150 & , & I_{L2} = I_{load} \angle -120 \\ V_{L3-L1} = 110 \angle 120 & , & V_{L3-E} = 63.51 \angle 90 & , & I_{L2} = I_{load} \angle 120 \end{array}$$

Fault(L1-L2):

$$V_{L1-L2} = V_{test} \angle 0$$

$$V_{L3-E} = 63.51 \angle 90$$

$$\rightarrow V_{L1-E} - V_{L2-E} = V_{test} \angle 0$$

$$\xrightarrow[\text{If } I_{test}=50]{\text{Sum}} 2 * V_{L1-E} = 50 \angle 0 - 63.51 \angle 90 \rightarrow V_{L1-E} = 40.41 \angle -51.79, V_{L2-E} = 40.41 \angle -128.21$$

Figure 22

In the Constant Source Impedance method, the fault current and voltage are obtained as follows according to Kirchhoff's law:

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} \frac{V_{1N} - V_{2N}}{2(Z_s + Z_{test})} \\ -i_1 \\ 0 \end{bmatrix}, \quad \begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} V_{1N} - i_1 Z_s \\ V_{2N} + i_1 Z_s \\ V_{3N} \end{bmatrix}$$

Figure 23

Three-Phase Fault

The equivalent circuit for a three-phase symmetrical fault is illustrated below. Faulted phase calculations are performed separately for constant current, constant voltage, and constant source impedance methods.

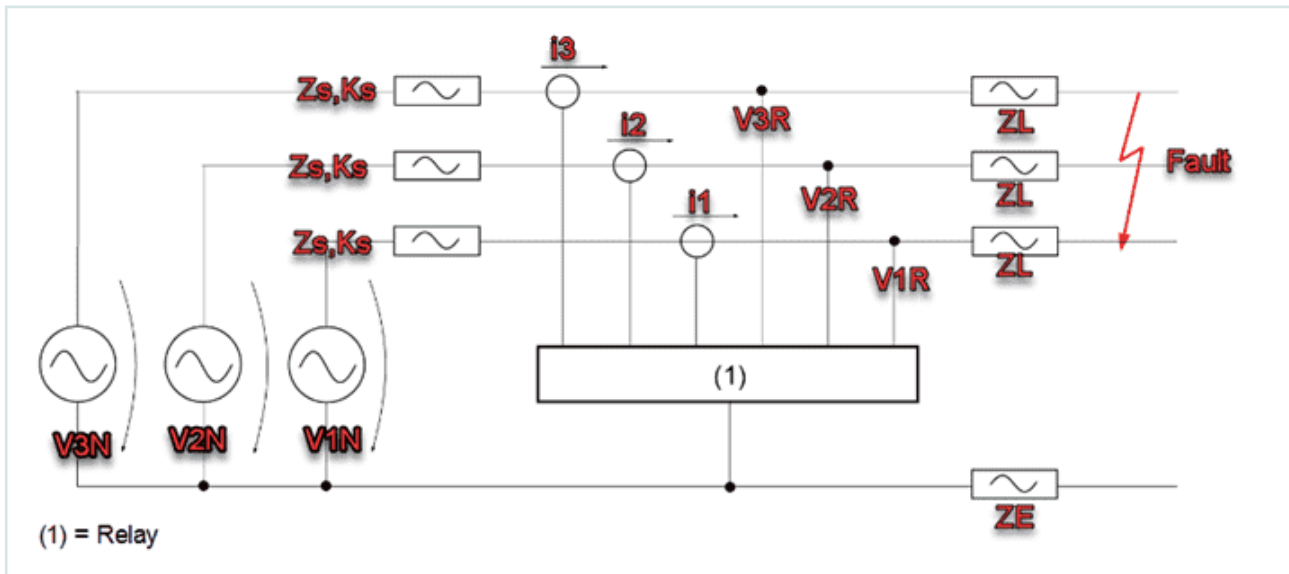


Figure 24

In Z-I Constant Method, fault current is fixed across all test points, and the fault voltage for all three phases is calculated using:

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} I_{test} \angle \phi_{V_{1N}} - \phi_{Z_L} \\ I_{test} \angle \phi_{V_{2N}} - \phi_{Z_L} \\ I_{test} \angle \phi_{V_{3N}} - \phi_{Z_L} \end{bmatrix}, \quad \begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} I_{test} \cdot |Z_L| \angle \phi_{V_{1N}} \\ I_{test} \cdot |Z_L| \angle \phi_{V_{2N}} \\ I_{test} \cdot |Z_L| \angle \phi_{V_{3N}} \end{bmatrix}$$

Figure 25

In the Z-V Constant Method the fault voltage is set equal to the phase-to-ground voltage for all test points. Fault currents for each phase are determined as:

$$\begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} V_{test} \angle \phi_{V_{1N}} \\ V_{test} \angle \phi_{V_{2N}} \\ V_{test} \angle \phi_{V_{3N}} \end{bmatrix}, \quad \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} \frac{V_{test}}{|Z_L|} \angle \phi_{V_{1N}} - \phi_{Z_L} \\ \frac{V_{test}}{|Z_L|} \angle \phi_{V_{2N}} - \phi_{Z_L} \\ \frac{V_{test}}{|Z_L|} \angle \phi_{V_{3N}} - \phi_{Z_L} \end{bmatrix}$$

Figure 26

In this method, both fault current and voltage are calculated using Kirchhoff's laws, considering the source impedance. The relationships for fault current and relay voltage are

$$\begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} \frac{V_{1N}}{Z_s + Z_{test}} \\ \frac{V_{2N}}{Z_s + Z_{test}} \\ \frac{V_{3N}}{Z_s + Z_{test}} \end{bmatrix}, \quad \begin{bmatrix} V_{1R} \\ V_{2R} \\ V_{3R} \end{bmatrix} = \begin{bmatrix} \frac{V_{1N} \cdot Z_{test}}{Z_s + Z_{test}} \\ \frac{V_{2N} \cdot Z_{test}}{Z_s + Z_{test}} \\ \frac{V_{3N} \cdot Z_{test}}{Z_s + Z_{test}} \end{bmatrix}$$

Figure 27

[jg1]Distance_Protection_Voltage_and_Current_Calculations_in_the_Test_Room