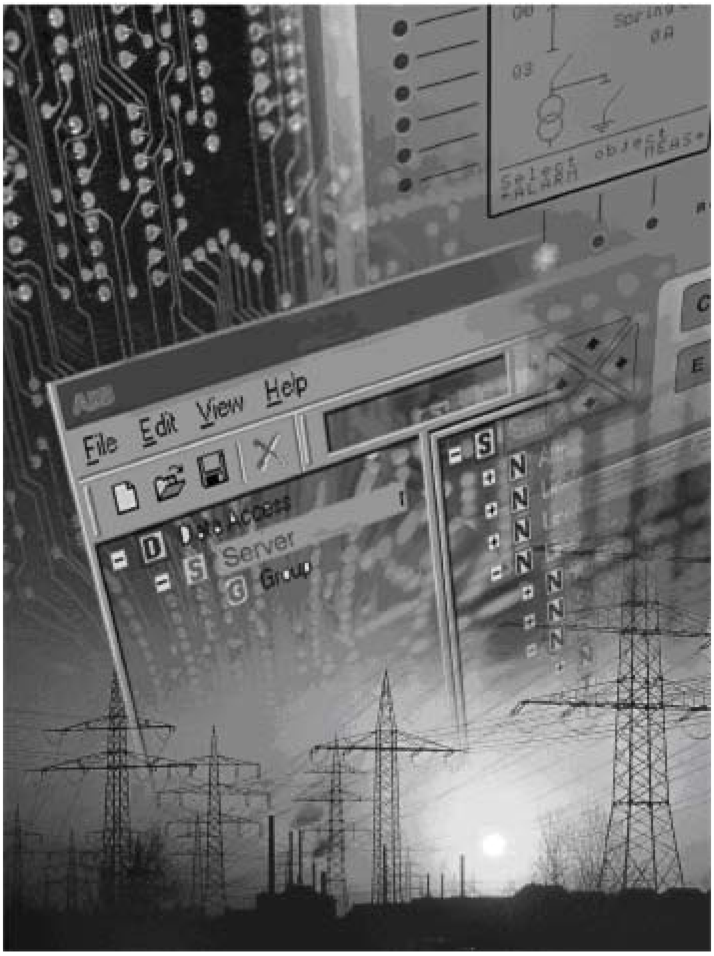
Multizone distance protection REF 542plus

Multizone Distance Protection

Application and setting guide



Contents

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1. Scope

This document introduces the application of the distance protection function in the REF 542plus feeder terminal. The distance protection function is designed to provide selective power system feeder protection. The protection zone can be defined by applying the value of the line impedance and the related directional criteria. As a consequence, the function enables a fast and selective detection and isolation of faults in a meshed medium-voltage (MV) power systems.

The distance protection function can be implemented for MV power system feeder protection regardless of the method for the neutral system earthing. It can be used in isolated neutral systems, in resonant earthed systems, that is, the systems where the neutral is earthed with an inductance (also known as arc suppression coil or Petersen coil) and in systems with low-resistance or reactance grounding.

The optimum operation time is about 30 to 35 milliseconds. This time setting is to be applied to avoid trip delays caused by the possible saturation of current transformers. The distance protection features up to 8 instances of zones, each of which can be used as zones either in the forward or backward direction or without direction.

When autoreclosing is used together with the distance protection, the used of one instances for operating as overreach zone can be provided to handle faults on the entire length of the line. In addition, different transfer trip schemes with the corresponding logical combination for the trip generation are provided.

The fault impedance is calculated by the distance protection. The value of the reactance can be displayed and used to determine the fault location. Once the distance protection has provided a trip signal, the value of the fault reactance is displayed on the HMI.

KEYWORDS: ***feeder protection***, ***selectivity***, ***distance protection***, ***backup protection***, ***fault locator by reactance value***

2. Introduction

The new multizone distance protection in REF 542plus provides up to eight zones to be applied. As other distance protection the following ancillary functions are possible:

- Fault detection start function
- Impedance calculation function
- Direction determination function with voltage memory
- Tripping logical scheme
- Transfer tripping scheme

The purpose of the start function is to check the system for system failures and to identify the type of fault that has occurred. The appropriate quantities to be measured for determining the impedance and the direction of the fault are chosen on the basis of the type of system fault. Once the direction and zone of a system fault have been determined, the trip logic determines from the status signals of all the applied zones the trip time according to the set impedance time characteristic.

Different transfer trip schemes are also integrated in the distance protection. This feature can be used to increase the selectivity of a relatively selective protection, like the distance protection, to an absolute selective protection scheme, like the differential protection.

The transfer trip scheme requires a communication link to be available for signal exchange between the distance protection devices at both ends of the line.

To limit and repair a possible damage and to restore the network operation, it is important to localize and isolate a fault as soon as possible. Because the MV systems usually cover wide areas, fault location information expressed as a reactive primary value in ohm is provided.

To assure the proper functioning of the distance protection, the CTs (current transformers) have to fulfill the requirements described in 4.3. about checking the CT requirements. Otherwise the correct functioning cannot be guaranteed. Besides, the fault location would not be calculated correctly by using the reactive value.

Once a system fault has been detected and isolated, the system operator needs information for fault analysis. Therefore, a disturbance recorder is provided, in which the sequence of appearance of the fault events are registered too. The fault recorder function can be started either by an external control signal, via a binary input or via an internal signal obtained from the distance protection. Either a general start or a general trip signal can be used for starting the fault recorder.

In a meshed network configuration, the fault reactance can only be used for finding the fault location correctly if the fault is located along the protected line. In case of applying an additional fault locator function block, it is recommended to trigger it by the trip signal of the first impedance zone or additionally by the overreach zone if available.

The distance protection measures the phase currents and phase voltages. Consequently, a measurement supervision scheme is needed to monitor the condition of the measured currents and voltages.

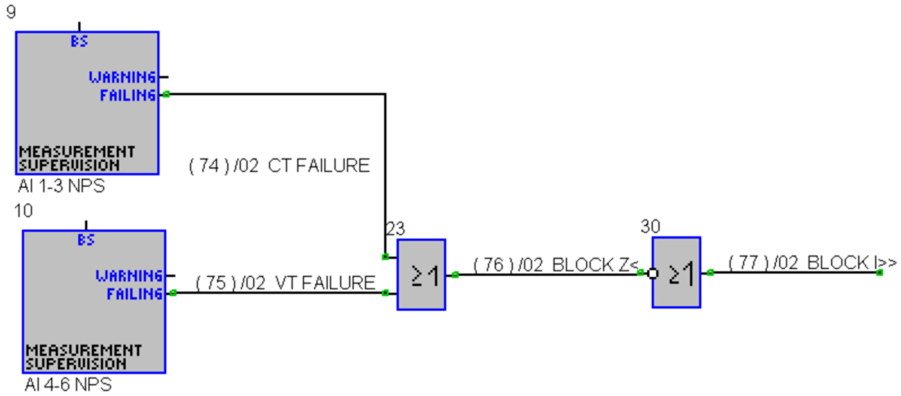

Fig. 2.-1 Supervision of the measured currents and voltages

2.-1 shows a measurement supervision scheme which can be configured by the FUPLA (FUnction plan Programming LAnguage). Both the currents connected to the analog input channels 1 to 3 and the voltages connected to the analog input channels 4 to 6 are supervised through a continuous calculation of the negative phase sequence. For example, if a fuse failure occurs, the supervision of the negative phase sequence voltage starts. When the delay time, which is normally set in the range of 5 to 10 seconds, has expired, a high signal to block the distance protection is generated. At the same time the blocking of the so-called emergency overcurrent protection is deactivated and the overcurrent protection can assume the function of a local emergency backup protection.

When the VT (voltage transformer) returns to a normal condition, the blocking of the distance protection is deactivated, that is, the distance protection returns to a normal operation and, consequently, the overcurrent protection operating as an emergency backup protection is no longer necessary. For this reason, the feeder protection scheme comprises a combined distance protection and overcurrent protection

3. Technical implementation

The distance protection is implemented as multizone instances. In 3.-1 the configuration of the distance protection can be seen. The first function block is used to define the common setting for the distance protection. The following zones, of which there can be up to eight, can be applied as required to set up the intended feeder protection scheme.

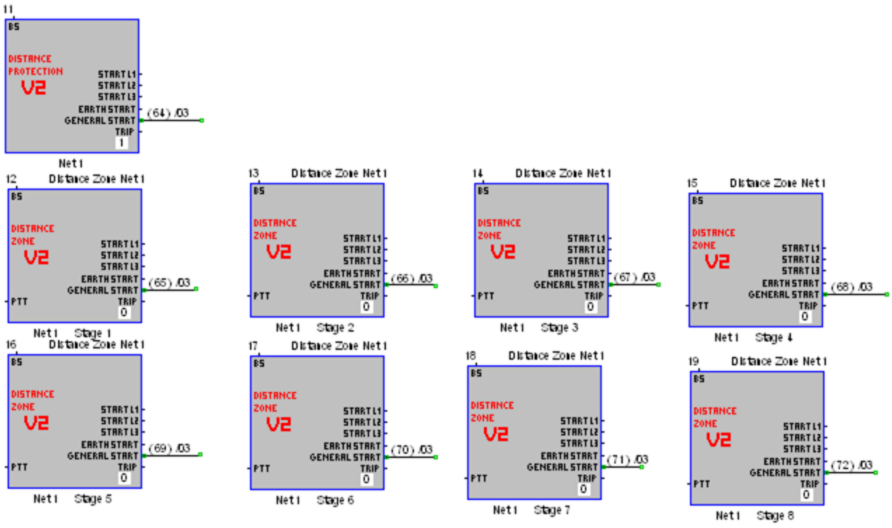

Fig. 3.-1 Configuration of an eight-zone distance protection

3.1. System fault detection

In case of a system fault, the distance protection must calculate the fault impedance. In addition, the distance protection is able to operate in the system with an isolated or earth fault-compensated neutral or in an earthed system where the neutral is connected to earth via resistance or reactance.

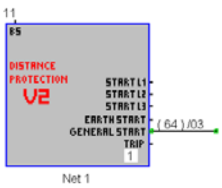

Fig. 3.1.-1 Function block for the general setting

To adapt to the different system condition, the first function block, which is shown in 3.1.-1 in FUPLA, is foreseen for the common setting of the distance protection. The block input BS can be used to block the entire operation of the distance protection by a logical high signal. Moreover, all status signals generated in subordinate instances for the zone impedances are collected here. For example, if in an instance used as the 1st zone a start and later a trip signal are indicated, the same signal with the related time stamping is forwarded here. The function block comprises of several tabs.

3.1.1. General

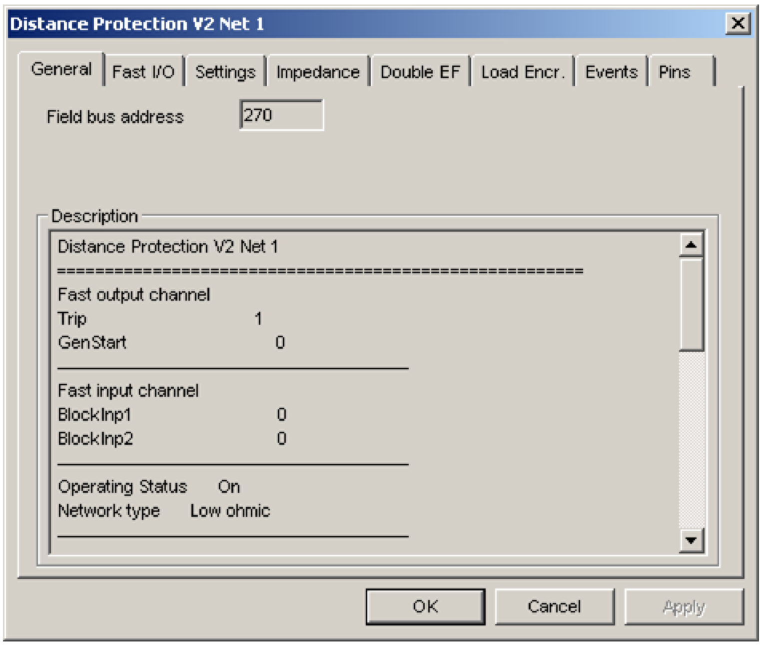

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Fig. 3.1.1.-1 General

Important settings are described here. The field bus address is used for communication with the upper level control system.

3.1.2. Fast I/O

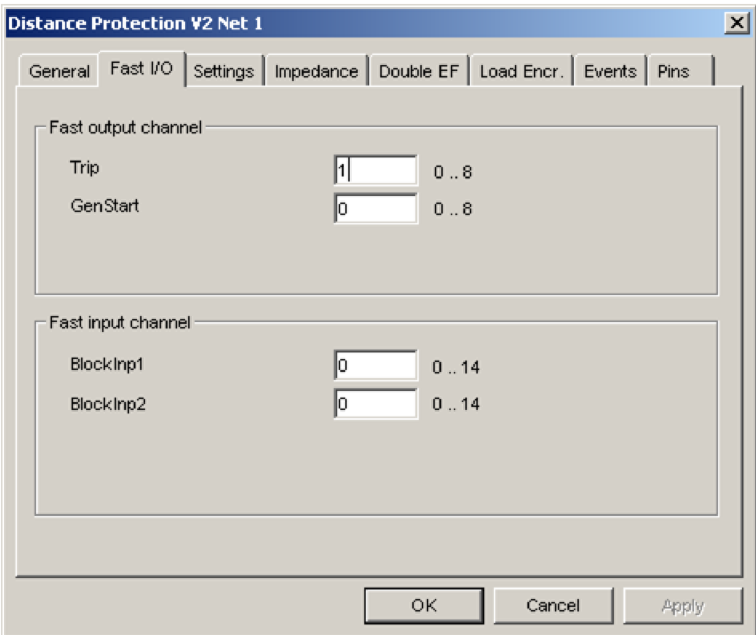

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Fig. 3.1.2.-1 Fast I/O

The fast I/O is meant for use of the transfer trip scheme. The fast output or input channel is activated if the related output or input channel different from 0 is used. As an example here, the trip is connected to the fast output channel 1. In this case the trip signal is directly executed to the binary output channel 1 by skipping the FUPLA cyclic evaluation. The same is valid for the execution of the block input signal by selecting the related fast input channel to block the operation of the distance protection, for example.

If a fast input or output channel is used, it is not necessary to wire the related input or output of the function block to the binary input or output channel in FUPLA.

3.1.3. Settings

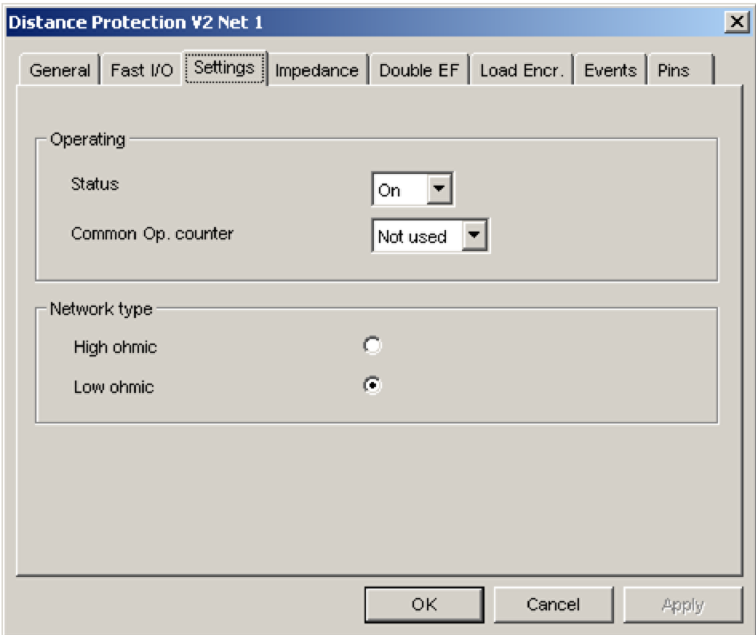

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Fig. 3.1.3.-1 Settings

As recommended by the communication protocol IEC 61850, the operating status is selectable. If the status is "On," the ancillary instances are released to operate. In case of setting the status "Off," the function of the entire multizone distance protection is out of order. The parameter "Common Op. counter" defines the start of the operation time of the multi-instance distance protection. If "Used" is selected, the operation time of the distance protection is started normally as soon as a fault is detected. If "Not used" is selected, only the operation time of the fault-involved zones is activated.

In a system with an isolated neutral an earth fault does not switch off the affected line. The system operation can be continued while the line affected by the earth fault is located. Then the needed reconfiguration of the electrical can be carried out without any supply interruptions. On the contrary, in a system with an earthed neutral a line affected by an earth fault must be switched off. As the distance protection operates both in a system with an isolated or an earthed neutral, the correct network type must therefore be selected by the related option button.

3.1.4. Impedance

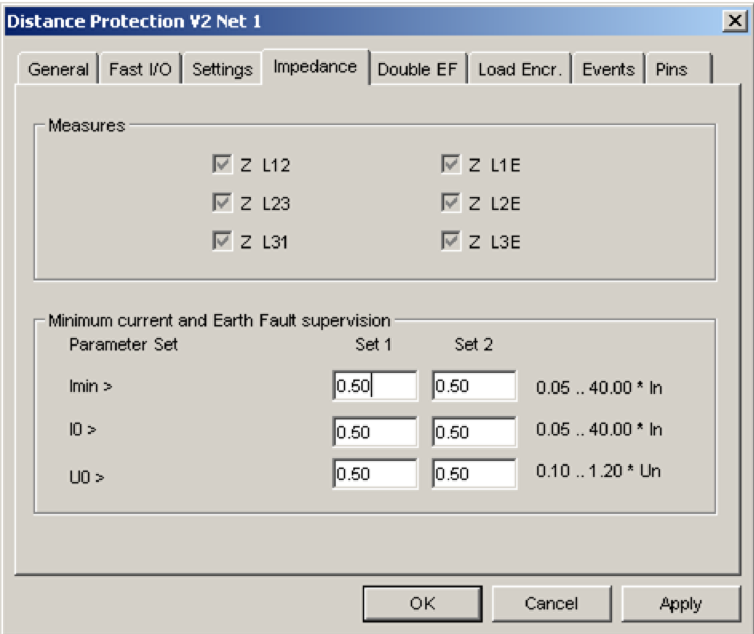

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Fig. 3.1.4.-1 Impedances

In the section for measures, the selected calculations of the impedance loops are shown. In a three-phase system where in each phase a CT and VT are provided, all six impedance loops are calculated. Therefore, the selection possibility is not provided. Only for application in a single-phase or two-phase system, like in a railway system, the impedance loops to be calculated can be selected according to the connection of the CT and VT to the related phases.

The lower section shows the setting for the minimum current and earth fault supervision. The impedance calculation is carried out if the corresponding phase current has exceeded the value of Imin>. The setting Io> and Uo> are used to detect an earth fault condition. In case of an earth fault the calculation is mainly performed on the phase-to-earth impedance loops Z L1E, Z L2E and Z L3E. If no earth fault is detected, the phase-to-phase impedance loops are calculated.

The calculation of the impedance loops for a phase-to-earth fault is performed if the following condition is valid:

Z_{LE} calculation if: Io> Λ Uo>

Provided in the corresponding phases the current has exceeded the threshold Imin>, the fault impedance Z_{LE} is then calculated with the equation:

$$\underline{Z}_{LE} = \frac{\underline{U}_{LE}}{\underline{I}_L + \underline{K} \cdot \underline{I}_E} \tag{1}$$

Whether $\underline{I}$E is the neutral or the residual current can be estimated with the equation:

$$\underline{I}_E = \underline{I}_{L1} + \underline{I}_{L2} + \underline{I}_{L3} \tag{2}$$

K is the so-called earth factor according to the equation:

$$\underline{K} = \frac{1}{3} \cdot \left(\frac{\underline{Z}_0}{\underline{Z}_L} - 1 \right) = \frac{1}{3} \cdot \left(\frac{\underline{Z}_0 - \underline{Z}_L}{\underline{Z}_L} \right) \tag{3}$$

The calculation of the impedance loops for phase-to-phase fault is performed if the above condition for earth fault is not valid. The fault impedance Z_{LL} is performed in the phases where the phase current has exceeded the threshold Imin>. The impedance is calculated with the equation:

$$\underline{Z}_{LL} = \frac{\underline{U}_{LL}}{\underline{I}_{LL}} \tag{4}$$

Therefore, U_{LL} is the line voltage and I_{LL} the so-called line current. The calculation scheme of the line voltage or line current is the same. For example, the line current I_{12} can be calculated with the equation:

$$\underline{I}_{12} = \underline{I}_{L1} - \underline{I}_{L2} \tag{5}$$

The same scheme is also used for calculating the line voltages.

3.1.5. Double earth fault

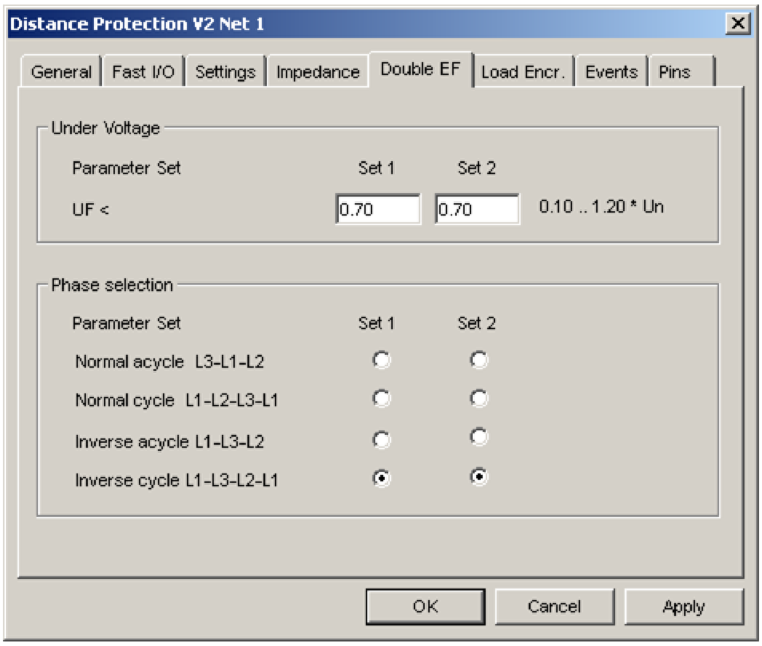

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Fig. 3.1.5.-1 Double earth fault

The double earth fault is a fault condition mostly occurred in an MV system with an isolated neutral or with an earth fault compensation by the Petersen coil. Due to this kind of system-neutral treatment, an earth fault can normally be ignored until the fault location is found. The necessary system reconfiguration can then be performed without causing any disturbances for the electrical power distribution.

It can take a relatively long time to find the earth fault location. Depending on the system configuration, the earth fault could therefore last for several hours in the electrical distribution system. During an earth fault, the voltage magnitude of the two sound phases grows to line voltages. Consequently, the probability for the occurrence of another earth fault at another location is relatively high. That kind of two-phases-to-earth fault on different locations is called the double earth fault or cross-country fault.

Therefore, it is required in case of a double-earth fault to switch off only one line affected by earth fault. To detect a double earth fault, the undervoltage condition of the line voltage is monitored. For example, as shown in 3.1.5.-2, the double-earth fault DEF involving an earth fault in phase L1-E and another earth fault in phase L2-E at another location can be detected by checking the following logical algebra:

$$\text{DEF (L1-L2-E)}=(U0> \wedge I0>) \wedge U12< \qquad (6)$$

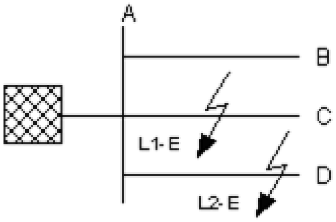

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Fig. 3.1.5.-2 Example of a double earth fault involving L1-E and L2-E

The generation of the trip command can be programmed by selecting the related option in the phase selection table. If, for example, normal acycle L3-L1-L2 is used, the earth fault in phase L1-E of the outgoing feeder C is cleared immediately by the distance protection, provided the fault impedance is within the fast tripping zone. The earth fault L2-E in the outgoing feeder D remains until disconnected by the network control center after successfully performing the system reconfiguration.

To enable the disconnection of one specific line section in a double earth fault, the distance protection systems of the entire electrical system must be configured with the same phase selection.

3.1.6. Load encroachment

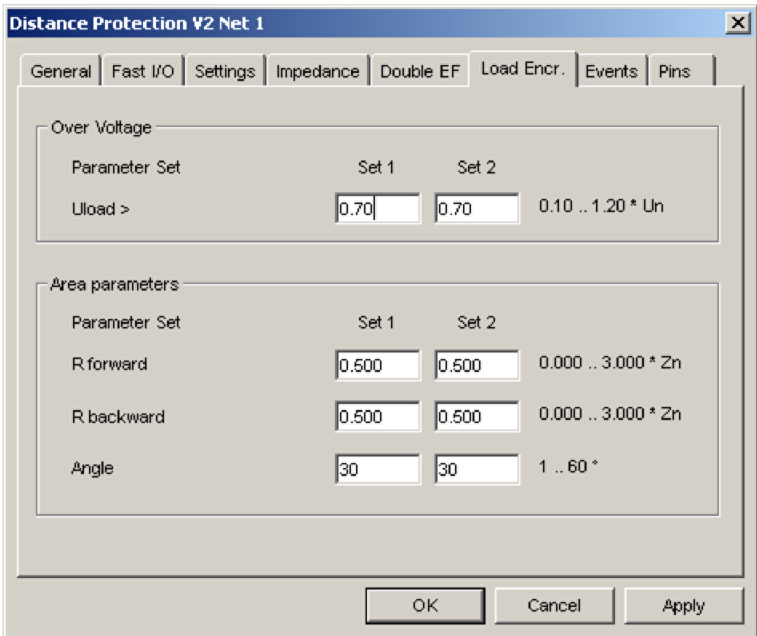

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Fig. 3.1.6.-1 Load encroachment

When using a zone to supervise the occurrence of a system fault, especially on a long, heavily loaded line, there is a risk that the load impedance enters the starting zone. To exclude the risk of an unwanted fault detection during the heavy load condition, a load encroachment characteristic can be set for the zone with a large value for reaches. If the calculated impedance values are within this load encroachment characteristic, the impedance calculation does not activate to prevent the zones from an unwanted tripping.

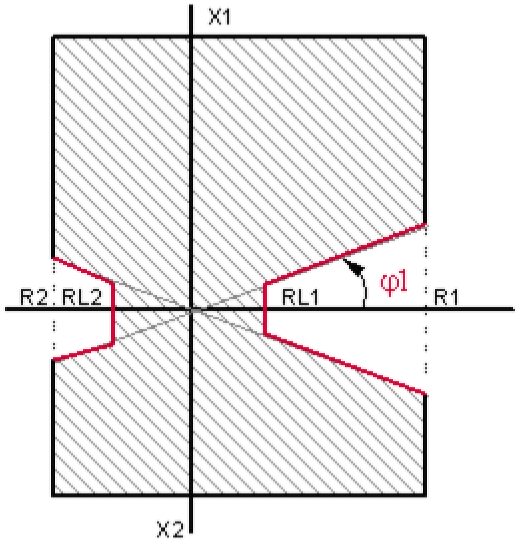

Fig. 3.1.6.-2 Zone with load encroachment

An example of a zone with load encroachment is shown in 3.1.6.-2. At first the reach of the zone for monitoring the electrical system is defined with the settings R1 and R2 on the horizontal axis and X1 and X2 on the vertical axis. To avoid unwanted tripping during heavy load condition, the load encroachment can be activated. The operation condition for the load encroachment is the value of the line voltages. Only if Uload> value is exceeded, the load encroachment becomes active. Otherwise a system fault is assumed and the appropriate impedance calculation is started. The setting of the load encroachment is defined with the setting of the angle φ1, R forward RL1 and R backward RL2. The resulting zone is shown in the above figure as the shaded area.

3.1.7. Events

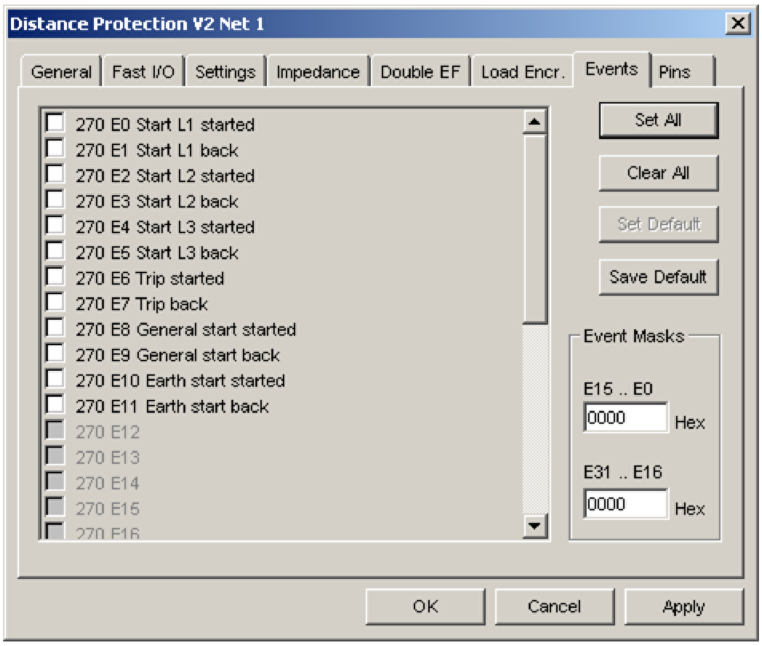

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Fig. 3.1.7.-1 Events

As other protection function in REF 542plus the events can be selected as needed. The main part in the tab is the list of events. The channel number over which the events are sent is shown in the left column near to the check box. To enable the individual events to be transmitted to the substation automation system, transmission of events must be generally enabled. By marking the adjacent check box, the event is generated and sent as required.

3.1.8. Pins

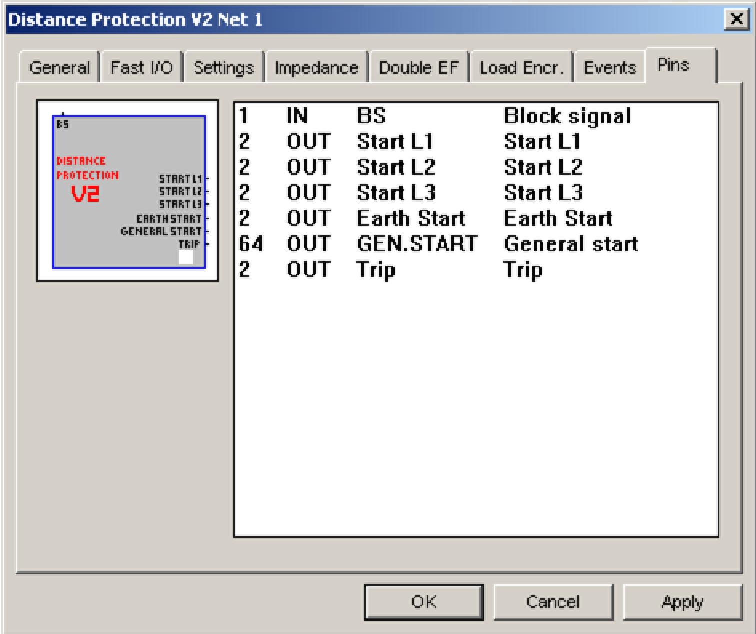

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Fig. 3.1.8.-1 Pins

In the tab a list of connections on the function block and information about the wire number connected to the pin can be seen. There is also information about the pin being an input or an output of the function block. The connection numbers 1 (on one input) or 2 (on one output) are displayed if the function block still has no connections made.

3.2. Setting of zones

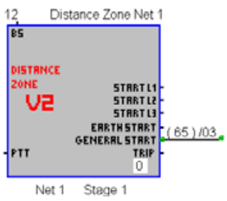

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Fig. 3.2.-1 Function block for a zone

After the common setting for the fault detection is finalized, the function blocks for the zone can be inserted in FUPLA. Depending on the intended scheme for the distance protection, the needed number of the impedances zones can be applied. In total, up to eight zones can be used. All function blocks have the same setting as described here.

The block signal input in this case, in contrary to the previously mentioned function block for the common setting, only blocks the related zone by connecting a high input signal. Moreover, an input PTT for a different protection transfer trip scheme is foreseen by comparing the related signals. If the input is high, the intended transfer trip is activated. The control of the transfer trip can be freely defined using a logical scheme in FUPLA. Note that the FUPLA cycle time, which is displayed on the HMI, must be considered accordingly in the intended control scheme. If a fast blocking or tripping in the transfer trip scheme is intended or required, the use of the direct channel is recommended.

3.2.1. General

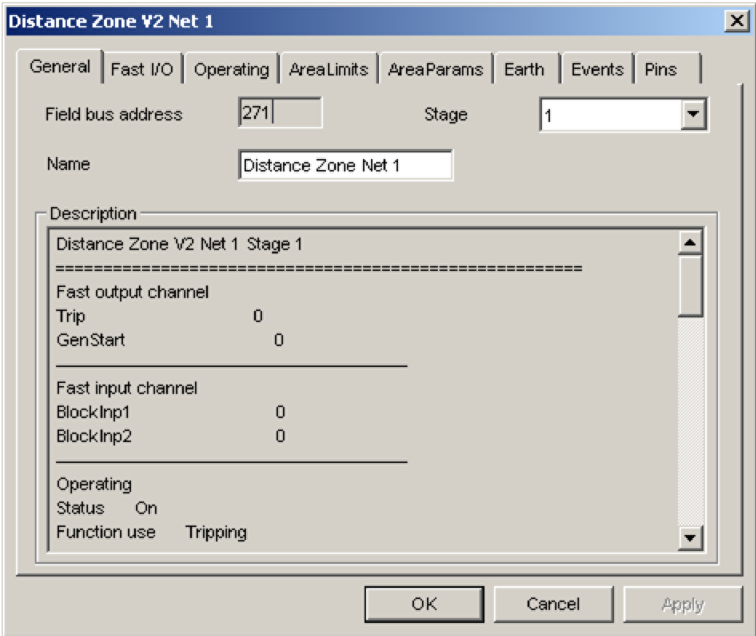

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Fig. 3.2.1.-1 General

In this tab, an overview of the used configuration can be seen. The zone can be named by the user. In this example, the zone is named Zone 1.

The name cannot be longer than 20 digits.

3.2.2. Fast I/O

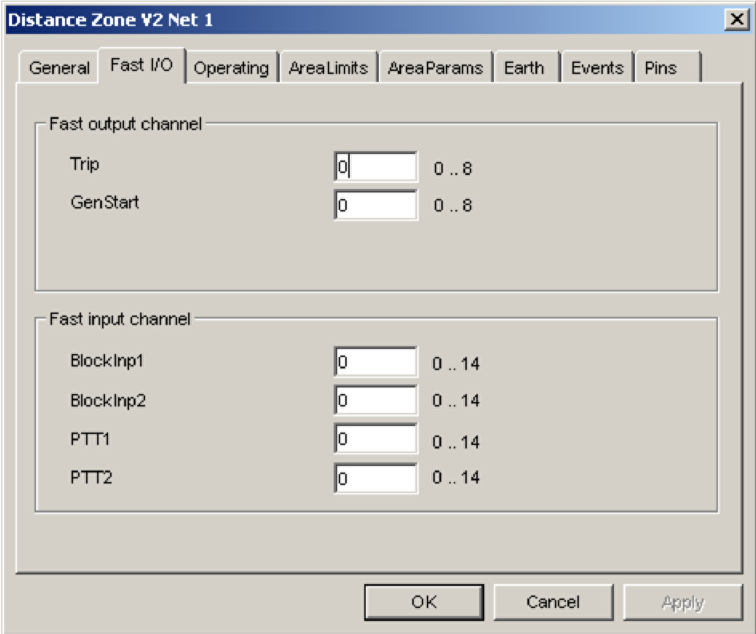

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Fig. 3.2.2.-1 Fast I/O

If a control scheme or a command is processed without consideration of the FUPLA cycle time, the fast I/O is applied. The fast output channel is foreseen for a trip or general start signal of the distance protection, depending on the needed scheme. By using the fast input signal, the corresponding signal is forwarded to the distance protection without any delay by the FUPLA cycle time. If, for example, a blocking scheme is required, the signal on the corresponding input is immediately used to block the zone.

The fast output or input is activated if the related output or input channel other than 0 is used. As an example here, the trip is connected to the fast output channel 1. In this case the trip signal is directly executed to the binary output channel 1 by skipping the FUPLA cyclic evaluation. The same is also valid for the execution of the block input signal by selecting the related fast input channel to block the operation of the distance protection, for example.

If a fast input or output channel is used, there is no need to wire the related input or output of the function block to the binary input or output channel in the FUPLA.

3.2.3. Operating

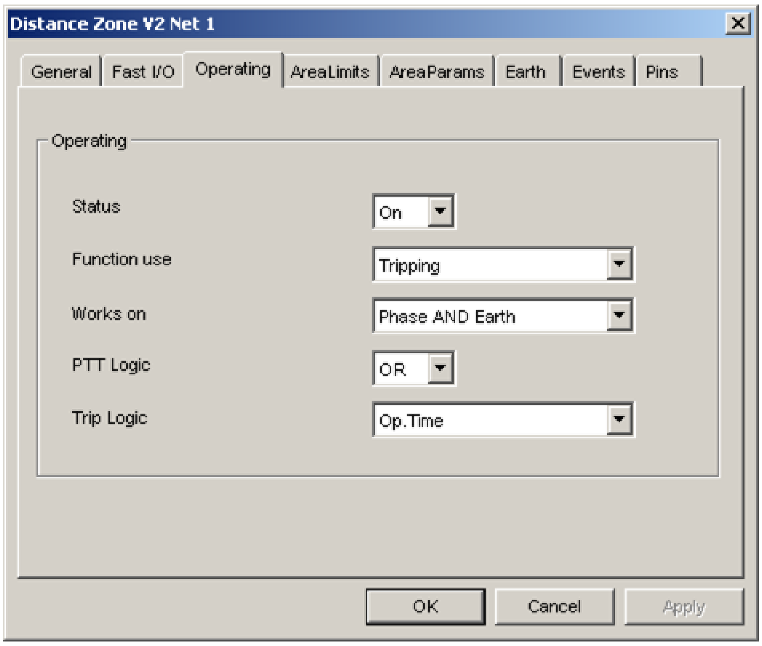

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Fig. 3.2.3.-1 Operating

Under the Operating tab, the required parameters are available. The status can be selected for “On” or “Off” as required by the new communication protocol IEC 61850. When the status is "Off," the zone is taken out of operation.

The function of each zone can be used for tripping or signaling or as the overreach zone, depending on the distance protection scheme to be used. However, in most applications the function tripping is applied. In some cases when the transfer trip scheme is applied, one of the zones is used for signaling to indicate where the system fault is. Depending on the used transfer trip scheme, it is necessary to apply the overreach zone which is also needed for operation with the function block for Autoreclose or Switching onto fault.

The "Works on" parameter defines the fault impedance to be calculated. There are three different setting for this parameter:

- Phase AND Earth
- Phase
- Earth

In a three-phase electrical system only the Phase AND Earth setting is the default setting because all possible system faults must be calculated, including earth fault, two-phase-to-earth fault, phase-to-phase fault and three-phase fault. The other settings, Phase and Earth, are reserved for the application of distance protection in a single- or two-phase system, like in a railway system, which is described in a corresponding application note.

The PTT Logic parameter is meant to improve the selectivity of the distance protection by transfer trip scheme. Therefore two setting, "OR" and "AND," are provided.

Trip Logic must be defined. There are four settings available.

- Operation Time
- Operation Time AND PTT
- Operation Time OR PTT
- PTT

3.2.4. Area limits

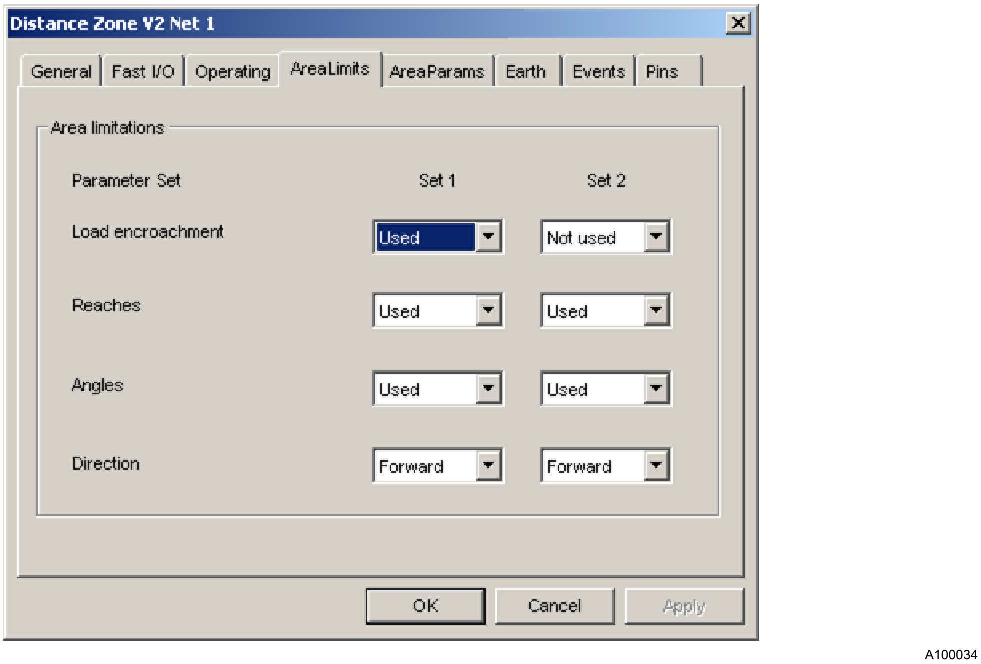

Fig. 3.2.4.-1 Area limits

The Area Limits tab defines the shape of the trip characteristic to be used. The settings of the tripping characteristic are located in the Area Params tab.

The load encroachment is used to avoid the start of the distance protection under heavy load condition. If the load encroachment is used, a certain area of the trip characteristic of the zone is blinded.

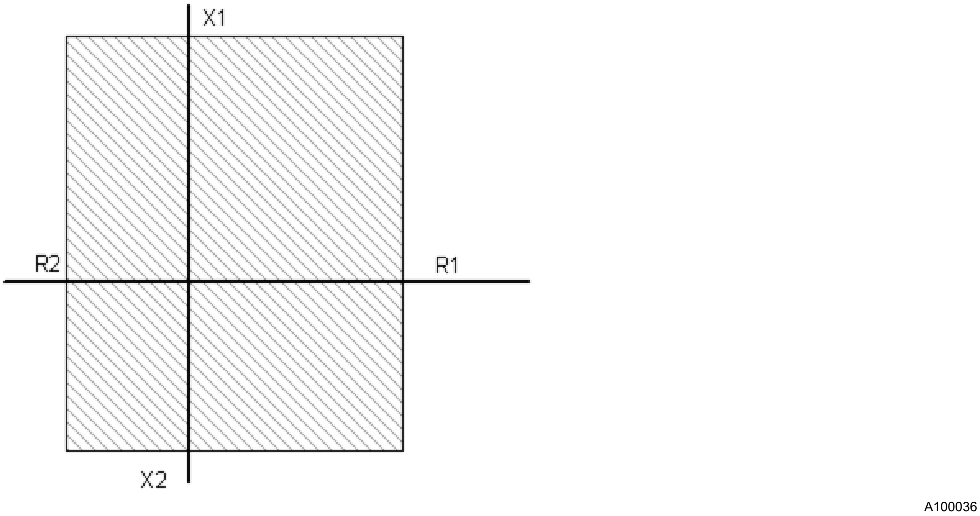

Fig. 3.2.4.-2 Rectangular characteristic defined by reaches only

For the operation of the distance protection, the Reach parameter is normally used. This parameter defines the limits of the zone on the impedance plane with the horizontal R and vertical X Axis. If only the reaches are used, the zone has a rectangular characteristic as shown in 3.2.4.-2.

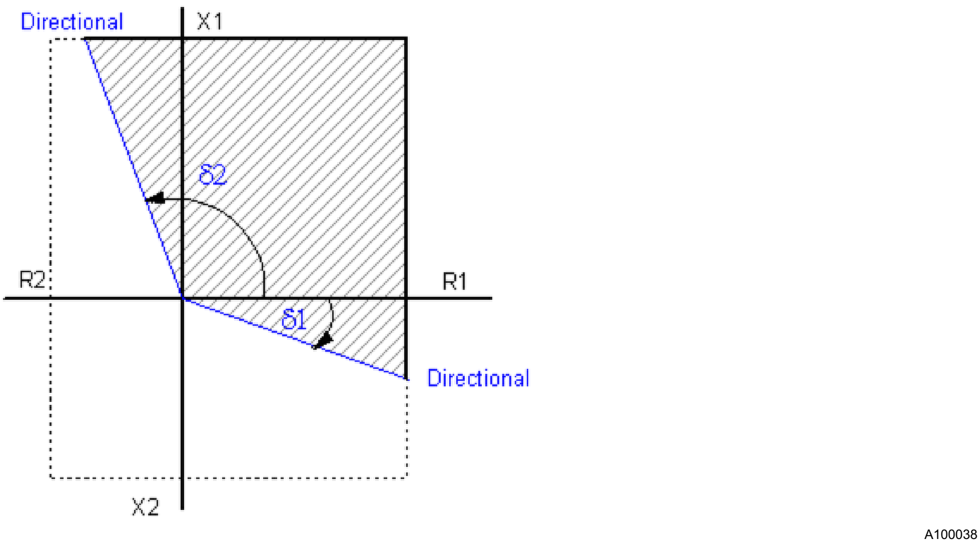

Fig. 3.2.4.-3 Polygonal characteristic defined by reaches and forward direction

The next two parameters are needed to limit the reaches by the directional characteristic, provided they are used. The rectangular characteristic is limited accordingly. 3.2.4.-3 shows the polygonal characteristic for forward direction as a result from the limitation of the rectangular characteristic by the forward directional setting.

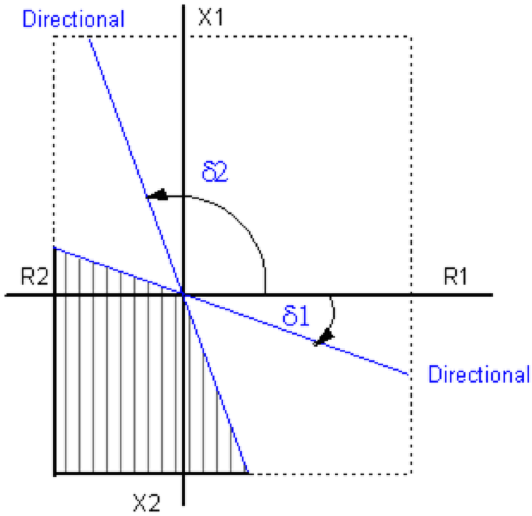

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Fig. 3.2.4.-4 Polygonal characteristic defined by reaches and backward direction

3.2.4.-4 shows the polygonal characteristic for backward direction as a result from the limitation of the rectangular characteristic by the backward directional setting.

It is recommended to use the direction and the angle simultaneously to define the forward or backward operation characteristic properly.

3.2.5. Area parameters

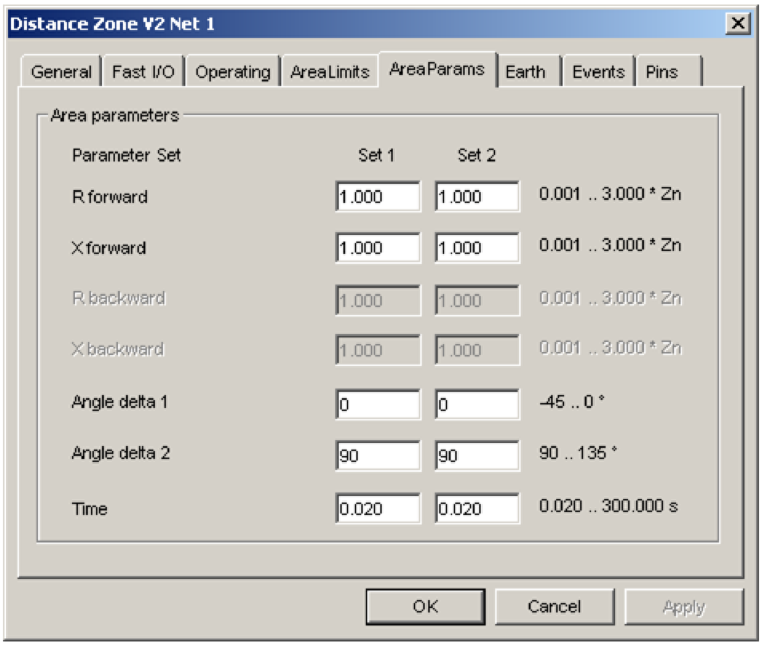

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Fig. 3.2.5.-1 Area parameters

The AreaParams tab describes the range of the setting value. The setting values of the reaches for the zones, Rforward, Xforward, Rbackward and Xbackward, are referred to as the rated impedance value Zn, which is defined by the rated value of the voltage transformer and the current transformers. If, for example, in the MV system a 10 Ω reactance is to be reached by a zone where the rated value for the VT is 20 kV and the CT 400 A, the setting value to be set is as follows:

$$\frac{Xset}{Zn} = \frac{10\Omega}{\dfrac{20kV}{400A}} \tag{7}$$

where Xset = 0.2 Zn.

The angles delta 1 and delta 2 are used to limit the rectangular operation characteristic of the zones by the directional setting.

The operation time can be set separately in each zone. As soon as a system fault is detected, the operation time of all the activated zones in FUPLA is started simultaneously.

3.2.6. Earth

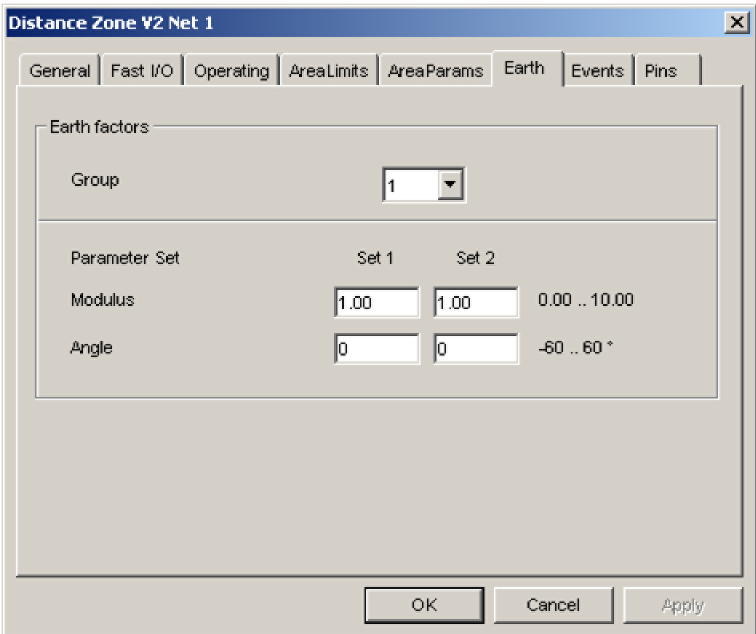

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Fig. 3.2.6.-1 Earth

In the Earth tab the setting of the so-called earth factor k is done. This correction factor is required to calculate the system fault to earth, like earth fault, double-earth fault or two-phases-to-earth fault.

Four earth factor group setting are provided in total. In each zone the correct earth factor group setting is defined accordingly. For example, zone Z1 uses the setting of group 1 and zone Z2 uses the setting of group 2.

3.2.7. Events

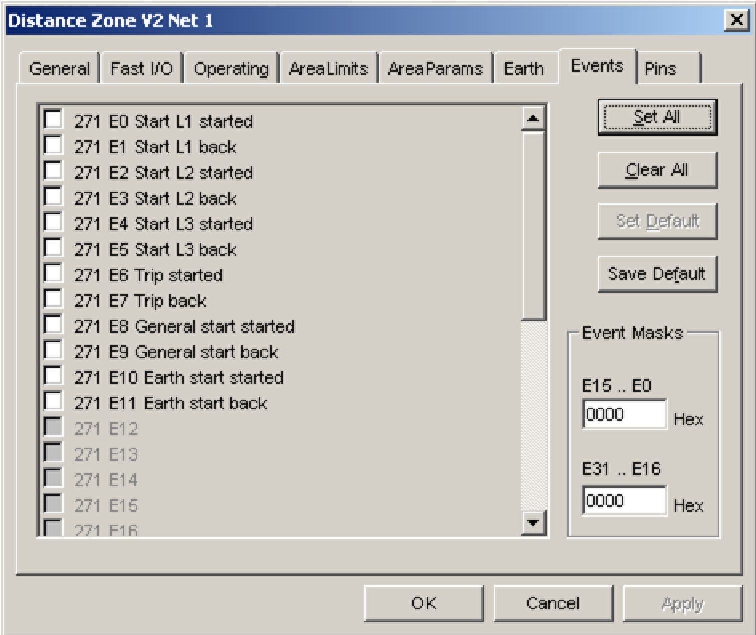

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Fig. 3.2.7.-1 Events

As other protection functions in REF 542plus, the events can be selected as needed. The main part in the tab is the list of events. The channel number over which the events are sent is shown in the left column near to the check box. To enable the individual events to be transmitted to the substation automation system, transmission of events must be generally enabled. By selecting the corresponding check box the event is generated and sent as required.

3.2.8. Pins

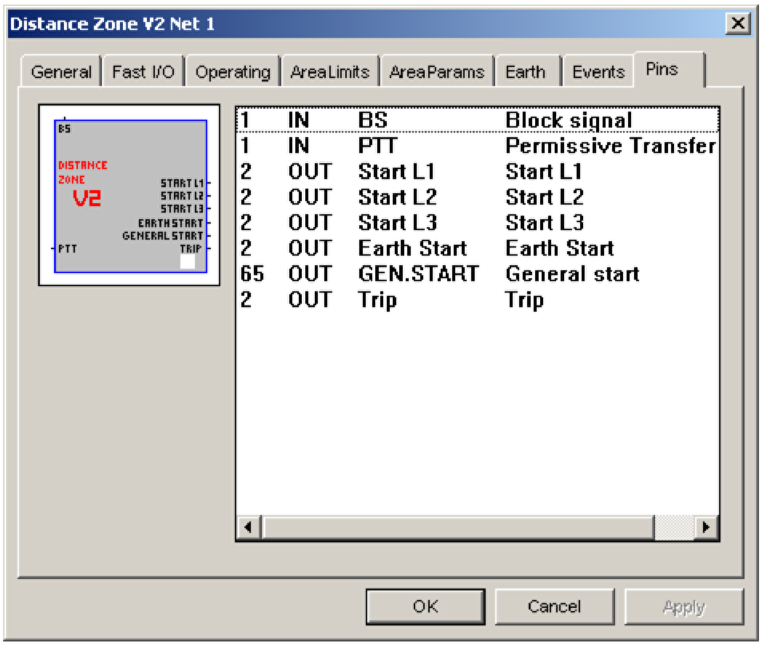

Fig. 3.2.8.-1 Pins

In the Pins tab a list of connections on the function block and information about the wire number connected to a pin can be seen. There is also information regarding whether the pin is an input or an output of the function block. The connection numbers 1 (on one input) or 2 (on one output) are displayed if the function block still has no connections made.

3.3. Direction estimation with voltage memory

The direction toward a fault location is normally derived from the result of the fault impedance calculation. The voltage related to the fault is used to determine the direction. However, if the fault occurs in the close-up area where the VT or the voltage sensors are installed, the determination of the direction to the fault location can be affected negatively by the resulting low level of voltage. For this reason a voltage memory is always used to enable the determination of the direction at close-up faults.

The voltage memory is activated if the measured voltage drops below about 10% of the nominal voltage ***U***n. All voltages (phase and line voltages) measured before the fault are saved in the voltage memory. At close-up faults, where the voltage drops close to zero, the memorized voltage measured before the fault is used for the determination of the direction. The memory function enables the distance protection to operate up to 300 seconds after a total loss of voltage. The prevailing voltage is applied again as soon as it exceeds 0.1 ***U***n for at least 100 ms. The memorized voltage is discarded when the measured voltage stays below 0.1 x ***U***n for more than 300 seconds.

When a fault occurs, a phase displacement with an angle of approximately ±30° between the corresponding phase voltages before and after the fault occurrence can take place. This can happen, for example, when the fault situation develops into a double-earth fault. This fact should be taken into account when the directional characteristic is to be set too close to the tripping area of the distance protection.

The tripping characteristic should be set as follows to obtain a permanent optimal determination of the direction:

In the 2nd quadrant:

- δ_2=90º+30º=120º

and in the 4th quadrant:

- δ_1=0º-30º=-30º

If the voltage memory is not available, for example during the energizing of a line where the voltage transformer is located at the line side, the directional estimation is due to electromagnetic disturbances not reliable. Therefore, if the related voltage measurement quantity is low, for example in the range of 1% to 2% ***U***n, a trip is forced to ensure that the fault on the energized line is disconnected. For this borderline case, an unselective trip is tolerated.

3.4. Switching onto fault

To cover all the possible faults during the system operation, it is recommended to apply the switching onto fault SOTF protection in addition to the distance protection. SOTF is designed as an independent function block and used to protect the line during the closing of the circuit breaker. If a fault on the protected line is detected, the switching onto fault protection trips the circuit breaker according to the operation time of the corresponding protection.

If the switching onto fault protection is in operation together with the distance protection V2, it is recommended to use its overreach zone as shown in 3.4.-1.

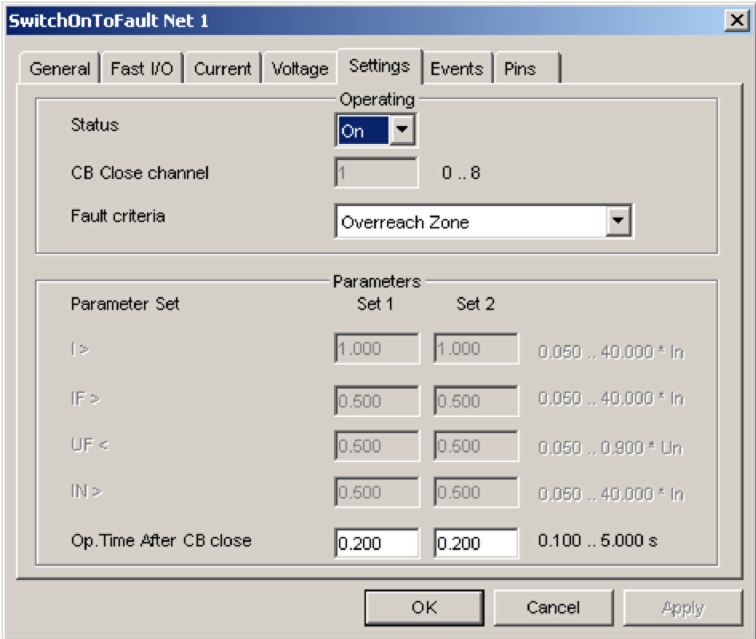

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Fig. 3.4.-1 Setting of STF inoperation with the distance protection V2

By using the fault criterion "Overreach Zone," all fault locations within the overreach zone are captured and switched off. The reach of the overreach zone is normally set to cover at least the whole length of the line. Consequently, all possible faults on the line are switched off by the operation time of the distance protection. The parameter "Op. Time After CB close" defines how long SOTF is activated after the CB has reached the closed position. Afterwards, SOTF becomes inactive again. In a modern installation, this parameter can be set to 1 second.

3.5. Protection transfer trip scheme

The transfer trip scheme is an additional feature to be used with the distance protection in order to improve the selectivity of the distance protection. In general, when using this scheme the distance protections installed at the end of the protected line exchange the status information with each other, for example the start, trip or directional status of the detected system fault. Another type of transfer trip scheme is to exchange the status information with other IEDs installed on the same busbar in the substation. By comparing the received status information, an absolute selective protection scheme can be achieved. The generally applied transfer trip schemes are described in the next sections.

3.5.1. Direct transfer trip

The direct transfer trip (TT) is an exception within the entire transfer trip scheme because in this specific case no further status information of the distance protection is required as in other signal comparison schemes. 3.5.1.-1 shows an example of the direct TT. Whenever a fault is detected in the fast trip zone, a signal is sent to the other distance protection located at the other end of the line. At the other end, the received signal initiates the CB trip immediately and without any further local protection criteria.

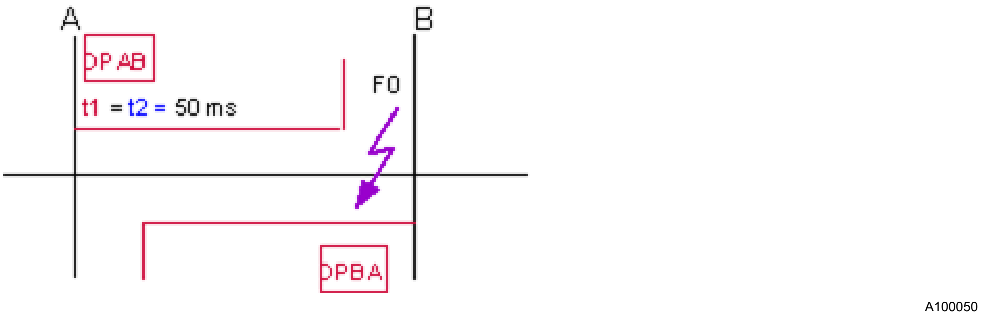

Fig. 3.5.1.-1 Direct transfer trip

In this example, DPAB is the distance protection for the protection of the line between station A and station B, while the distance protection DPBA is located at the other end of the same line. If a fault F0 occurs beyond the fast trip zone Z1 of the distance protection DPAB, like shown in 3.5.1.-1, the related trip is generated later when the operate time of the following zone Z2 has expired.

In order to get a fast tripping by the distance protection DPAB, the direct transfer trip scheme can be applied because the fault is detected by the distance protection DPBA in the fast trip zone Z1. In that case a transfer trip signal is sent to distance protection DPAB by the distance protection DPBA. Then the distance protection DPAB generates the trip command without checking any other fault condition as soon as the transfer trip signal is received.

The control scheme for the direct transfer trip can be defined as follows:

- Trip in the fast trip zone Z1 → send a TT signal
- Received TT signal → Generate protection trip

The fast I/O can be used for sending and receiving the TT signal if the delay by the FUPLA cycle is not intended.

3.5.2. Permissive underreaching transfer trip

The control scheme of the so-called permissive underreaching TT is similar to the direct TT as mentioned above. A TT signal is generated and sent by the distance protection DPBA if a system fault is detected in the fast trip zone Z1. After receiving the TT signal the distance protection DPAB can generate a trip, provided a start signal is present due to the detection of a system fault in the corresponding zone.

The control scheme for the permissive underreaching transfer trip can be defined as follows:

- Trip in the fast trip zone Z1 → Send a TT signal
- Received TT signal → Generate a protection trip command if the general start signal is available

It is recommended to use the common operation counter.

The fast I/O can be used for sending and receiving the TT signal if a delay by the FUPLA cycle is not intended.

3.5.3. Zone acceleration

The next control scheme is the so-called zone acceleration scheme. Zone 2 is an overreach zone Zov and is normally not in use. As soon as the distance protection DPBA detects a fault in the fast trip zone Z1, a TT signal is sent to the distance protection DPAB at the other end of the line. When the signal is received by the distance protection DPAB, the overreach zone Zov is activated, which again generates the trip within the related operation time.

The control scheme for the zone acceleration scheme can be defined as following:

- Trip in fast trip zone Z1 → Send a TT signal
- Received TT signal → Release overreach zone Zov for operation

The fast I/O can be used for sending and receiving the TT signal if a delay by the FUPLA cycle is not intended.

3.5.4. Permissive overreaching transfer trip

The overreaching scheme involves the operation of the overreach zone in parallel to the fast trip zone. But a trip of the overreach zone Zov can only be performed if a corresponding TT signal is received.

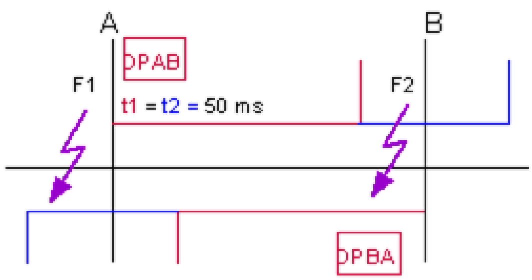

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Fig. 3.5.4.-1 Permissive overreaching transfer trip

3.5.4.-1 shows the operation principle of the permissive overreaching transfer trip. In this scheme the overreach zone Zov is used and in operation simultaneously with the fast trip zone. In this example, a fault F1 located beyond the reach of the fast trip zone Z1 of the distance protection DPBA is assumed, but inside the related overreach zone Zov. Therefore it is required that no trip can be generated by the distance protection DPBA because the fault is not detected by the distance protection DPAB. Only for the fault F2 the generation of the trip by the distance protection DPAB is possible because now the distance protection DPBA detects a fault inside the fast trip zone Z1 and also inside the overreach zone Zov. Consequently, a signal can be sent by the distance protection DPBA to release the trip of the overreach zone of DPAB.

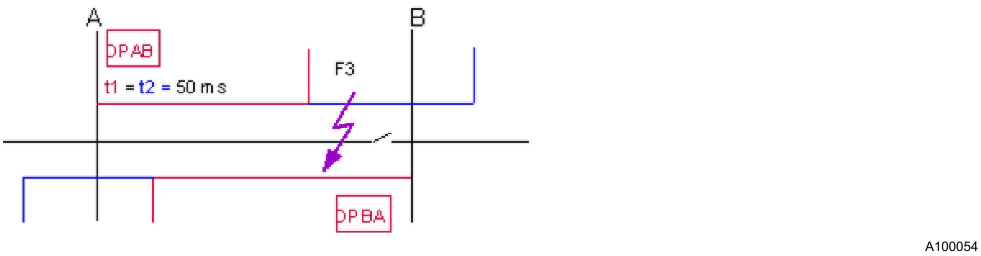

Fig. 3.5.4.-2 Echo signal for CB open

3.5.4.-2 shows how the protected line is open at one side because at station B the CB is switched off. As a consequence for fault F3 the distance protection DPAB would not generate a trip, neither with the fast trip zone Z1 nor with the overreach zone Zov, as the distance protection DPBA remains inactive due to an open CB status. In order to achieve a fast trip, it is necessary to receive a TT signal for the distance protection DPAB. If the CB is open, it is therefore necessary to generate an echo signal in the related distance protection.

If due to a system configuration or the CB open status the distance protection remained idle on a system fault condition, it is necessary to generate an echo of the received TT signal. The logical scheme for the generation of this echo signal must be defined accordingly in FUPLA.

The control scheme for the permissive overreaching transfer trip can be defined as follows:

- Trip in the overreach zone → Send a TT signal to release the trip of the overreach zone Zov of the distance protection at the other end of the protected line
- Received TT signal → Generate a trip if the fault is detected by the overreach zone Zov
- Received TT signal AND distance protection remain idle → Echo it back as a TT signal

The fast I/O can be used for sending and receiving the TT signal if a delay by the FUPLA cycle is not intended.

3.5.5. Blocking scheme

In the blocking scheme the overreach zone Zov is activated simultaneously with the fast trip zone Z1. However, the trip of the overreach zone Zov can only be generated if a related TT signal is not received. For this purpose the use of a zone in the backward direction is useful.

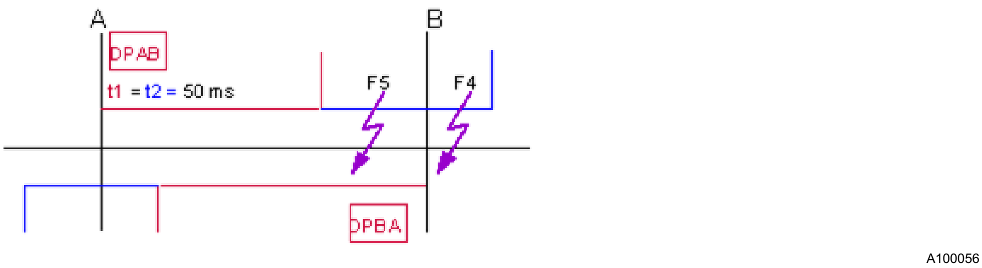

Fig. 3.5.5.-1 Blocking scheme

In 3.5.5.-1, an example of the blocking scheme is shown. The fault F4 is detected by the overreach zone of the distance protection DPAB. The trip can only be generated if a TT signal from the distance protection at the other end is not received after the related operation time has expired. Therefore, the distance protection DPBA is provided with a zone in the backward direction Zbk, which can be used to send a TT signal to block the trip by the overreach zone Zov of the distance protection DPAB.

If a fault is located in the overreach zone of one of the distance protections, for example fault F5 in the overreach zone of distance protection DPAB, neither of the distance protection, DPAB nor DPBA, sends a TT Signal. Consequently, the trip by the related overreach zone can be generated.

The control scheme for the blocking scheme can be defined as follows:

- Trip in the backward zone Zbk → Send TT signal to block the trip by the overreach zone Zov for the distance protection at the other end of the protected line
- Received TT signal → Block the trip of the overreach zone Zov for the distance protection

The operation time of the overreach zone for the blocking scheme must be set with sufficient delay in order to ensure the signal processing and transmission by the distance protection at the other line end. If the delay should be kept as short as possible, the use of fast I/O and fast transmission channel is recommended.

3.5.6. Backward interlocking

The backward interlocking is a signal comparison scheme normally used as a busbar protection. If a fault is detected in the fast trip forward zone Z1, all protections located at the same busbar are blocked. In case the fault is detected in the backward direction or in the backward zone Zbk, the trip can be generated when no blocking signal is received. The scheme operates with opposite directional zones than the blocking scheme does.

The control scheme for the blocking scheme can be defined as follows:

- Trip in the fast trip zone Z1 → Send TT signal to block the trip of the other distance protection located at the same busbar
- Received TT signal → Block the trip of the fast trip zone Z1 of the distance protection

The operation time of the overreach zone for the blocking scheme must be set with sufficient delay in order to ensure the signal processing in the distance protection at the other line end. If the delay is to be kept as short as possible, the use of a fast I/O and fast transmission channel is recommended.

3.6. Autoreclosure

The protection of overhead line generally requires an autoreclosure, AR. In case of a transient system fault caused by, for example, an atmospheric lightning, the fault is cleared after the affected line section is opened so that the system can be operated again as before. The setting for operating the distance protection V2 together with AR is shown in 3.6.-1.

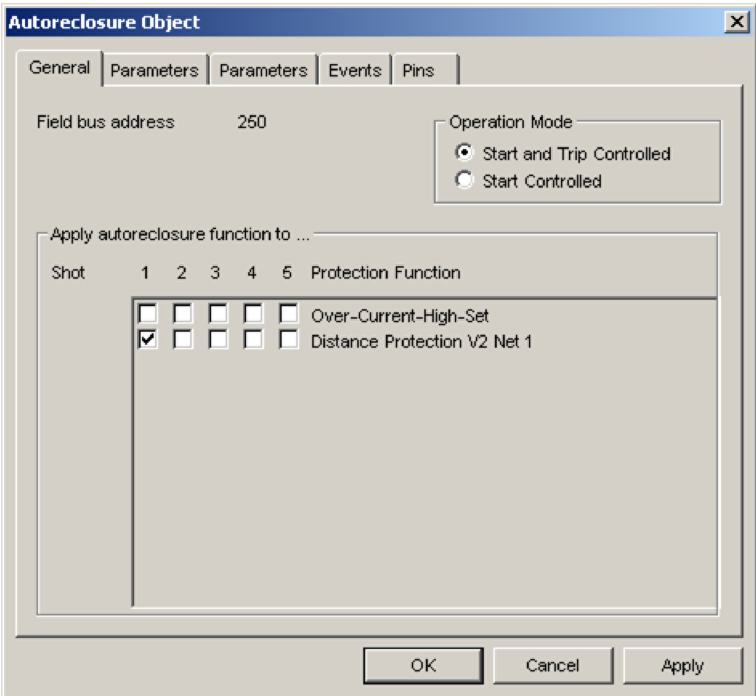

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Fig. 3.6.-1 Setting AR for distance protection V2

It is recommended to use the operation mode "Start and Trip Controlled" in AR. The number of shots is limited to 1 or at most to 2. By applying this setting, the distance protection uses the overreach zone to cover the system fault for the first shot. After this, the overreach zone is taken out of operation. In case of a persisting system fault, the trip of the distance protection is carried out by the corresponding zone. Consequently, the fault is cleared according to the time-grading scheme of the protection coordination.

4. Setting example

The setting of the distance protection requires detailed knowledge of the MV system. To achieve all the data needed, a comprehensive network analysis is recommended. Any possible power system configuration should be analyzed and the short-circuit currents for every possible fault condition should be calculated.

At least the maximum short-circuit current is needed for dimensioning the CT and the minimum short-circuit current, including the minimum residual current, for setting the threshold of the related zone to detect a system fault. Then the reaches of the zones can be derived from the impedance of the protected cable or overhead line.

4.1. Electrical power system

The analysis of the power system is not described in this example. The distance protection is assumed to operate under the following system conditions:

- 20 kV MV resonant earthed system
- Maximum short-circuit current I_{MAX} 25 kA at busbar in station A
- Network time constant for the decaying DC component 45 ms
- Maximum load current 400 A
- Minimum short-circuit current I_{MIN} = 200 A
- Minimum residua current I_{RES} = 100 A

Measurement transformer ratings:

- CT: 300 A/1 A
- VT: 20 kV/100 V

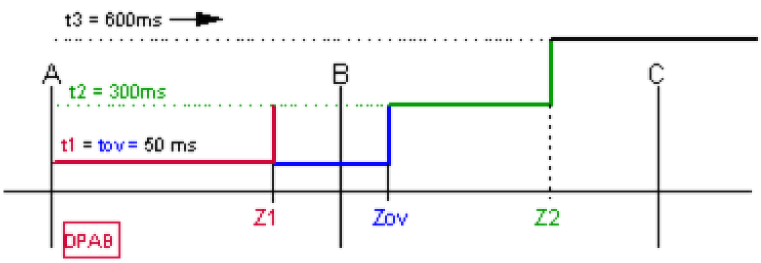

Fig. 4.1.-1 Coordination of the zone for line protection

A simple configuration of the line to be protected by the distance protection DPAB and the coordination of the related zones are shown in 4.1.-1. The distance protection DPAB is located at station A as protection for the overhead line L1 (A-B) to station B. Furthermore, the same distance protection operates as remote a backup protection for the overhead line L2 (B-C) between station B and station C and feeders far beyond station C.

The impedance values of the overhead line for the line to be protected by the distance protection are as follows:

Line 1 (A-B):

- Positive sequence $\underline{Z}_{L1} = 0.3\ \Omega + j\ 0.8\ \Omega$
- Zero sequence $Z0_{L1} = 1.4\ \Omega + j\ 4.0\ \Omega$

Line 2 (B-C):

- Positive sequence $\underline{Z}_{L2} = 0.8\ \Omega + j\ 2.5\ \Omega$
- Zero sequence $Z0_{L2} = 3.2\ \Omega + j\ 10.0\ \Omega$

The reach of the first zone Z1 is set to 0.9 $\underline{Z}_{L1}$ and the related operation time to 50 milliseconds. The reach for the zone Z1 is consequently:

- $Z1 = 0.9\ (0.3\ \Omega + j\ 0.8\ \Omega) = 0.27\ \Omega + j\ 0.72\ \Omega$
- $Z01 = 0.9\ (1.4\ \Omega + j\ 4.0\ \Omega) = 1.26\ \Omega + j\ 3.6\ \Omega$

The overreach zone Zov covers 0.2 of the length of line 2 (B-C) with the same operation time. The reach of the overreach zone can be calculated as follows:

- $Zov = (0.3\ \Omega + j\ 0.8\ \Omega) + 0.2\ (0.8\ \Omega + j\ 2.5\ \Omega) = 0.46\ \Omega + j\ 1.3\ \Omega$
- $Z0ov = (1.4\ \Omega + j\ 4.0\ \Omega) + 0.2\ (3.2\ \Omega + j\ 10.0\ \Omega) = 2.04\ \Omega + j\ 6.0\ \Omega$

The second zone as a remote backup protection covers up to 0.6 of the line B-C with a 300-millisecond operation time. The calculated reach for the zone Z2 is shown below:

- $Z2 = (0.3\ \Omega + j\ 0.8\ \Omega) + 0.6\ (0.8\ \Omega + j\ 2.5\ \Omega) = 0.78\ \Omega + j\ 2.3\ \Omega$
- $Z02 = (1.4\ \Omega + j\ 0.4\ \Omega) + 0.6\ (3.2\ \Omega + j\ 10.0\ \Omega) = 3.32\ \Omega + j\ 10.0\ \Omega$

The next zone Z3 with 600 milliseconds operation time is used as a further remote backup protection in the forward direction.

In addition, a zone as an underimpedance zone start is used as a non-directional backup protection with a 5-second operation time.

4.2. Setting of the analog inputs

For the proper operation of the distance protection, menu terminals/analog inputs are provided for three phase current transformers, three voltage transformers and one current transformer for the residual current.

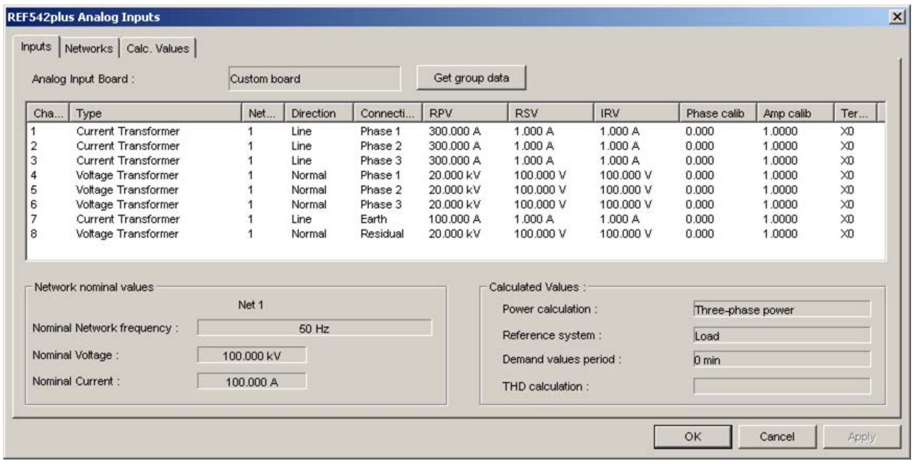

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Fig. 4.2.-1 Setting window of the terminal/analog inputs

If the rated secondary voltage of the voltage transformer is 110 VAC instead of 100 VAC, the RSV (Rated Secondary Voltage) value has to be changed accordingly. The IRV (Input Rated Value) value remains at 100 VAC.

4.3. Checking of CT requirements

Generally there is no special requirement for VT. The accuracy of the VT should be equal to or better than class 1. On the other hand, the CT has to be carefully dimensioned to avoid saturation.

The behavior of the distance protection depends on the quality of the measured currents. In case of CT saturation, the current waveform can be distorted so that the proper operation of the distance protection can be jeopardized. CT saturation can be caused by a slowly decaying DC component, which is the case if a system fault is initiated at or close to the zero crossing point of the system voltage. Consequently, the CT has to meet the specific requirements for operation with the distance protection to enable the distance protection to generate the required fast tripping. After the trip signal has been issued, the CT can be allowed to saturate. However, it should be considered that in such a case the accuracy of the fault impedance calculation in the fault locator is strongly affected by the saturation of the CT.

In principle, the distance protection of REF 542plus has been made insensitive to the CT saturation by design. With the implemented algorithm based on Discrete Fourier Transformation, unwanted tripping is unlikely to happen. On the other hand, the tripping time can be delayed so that the overall selectivity of the system might be endangered. When saturation of the current transformer cannot be avoided, a response time setting of 30 milliseconds is recommended for the first zone. This setting strategy is necessary to lower the requirements on CT as much as possible. With the above setting, CT needs to correctly reproduce the short-circuit current only for about the initial 25 milliseconds.

For the selection of CT, it must be assumed that the fault is located in the middle of the first zone of the distance protection. CT must be able to reproduce the symmetrical short-circuit current without saturating during the initial 25 ms. Under this condition, the distance protection would still generate a CB trip signal within 30 ms. This rule has been derived from the result of a computer simulation study shown in 4.3.-1.

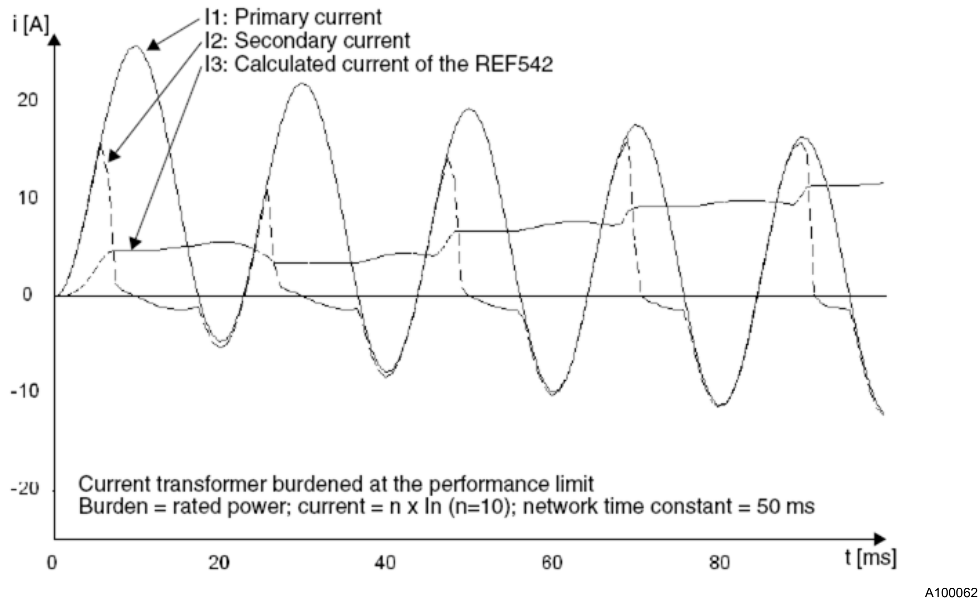

Fig. 4.3.-1 CB behavior recorded in computer simulation

Curve I1 denotes the primary current, I2 the CT secondary current and I3 the current calculated using an algorithm based on Discrete Fourier Transformation. Due to the CT saturation occurring during the first half, the result of the current calculation amounts to just 35% of the real short-circuit current. Resulting from this, the determined distance to the fault spot is inaccurate. The fault appears to be located about 3 times (100%/35%) farther, and consequently the trip command of the protection is delayed.

To ensure the proper operation of the distance protection and consequently the selectivity of the whole protection scheme of the electrical system, a comprehensive system analysis including short-circuit calculation has to be done. The maximum magnitude of the short-circuit current and the corresponding network time constant on every CT installation place is determined.

In this setting example, the maximum short-circuit current is assumed to be 25 kA. According to the related IEC 60255 standard, the thermal withstand current of the current input is 100 In (nominal current). Therefore, the lowest possible CT-rated current must not fall below 25 kA / 100 = 250 A. Accordingly, the selection of the primary rated current of 300 A is correct.

A comprehensive power system analysis is needed. At first the impedance angle φs of the current and voltage quantities under short-circuit conditions is calculated. In this example, the impedance angle can be calculated from the given value of the network time constant τ = 45 ms for the decaying DC component of the short-circuit current. Due to the relation:

$$\tau = \frac{Xs}{\omega Rs} \tag{8}$$

$$\tan\varphi s = \frac{Xs}{Rs} \tag{9}$$

the impedance angle can be determined by combining both equation as follows:

$$\varphi\text{s} = \arctan\omega\tau = \arctan(2\Pi \cdot 50\text{Hz} \cdot 45\text{ms}\,) = 85.95° \tag{10}$$

Then the source impedance of the incomer is to be estimated using the maximum short-circuit current on the busbar as follows:

$$Zs = \frac{U\text{r}}{\sqrt{3} \cdot I\text{sc}} = \frac{20\text{kV}}{\sqrt{3} \cdot 25\text{kA}} = 0.46\Omega \tag{11}$$

Based on the impedance angle, the reactance Xs and the resistance Rs can be estimated as follows:

$$X\text{s} = \text{Zs}\,sin\,\varphi\text{s} = 0.458\Omega \tag{12}$$

$$R\text{s} = \text{Zs}\,cos\,\varphi\text{s} = 0.032\Omega \tag{13}$$

The equivalent diagram for the incomer as shown in 4.3.-2 can be used for further calculations.

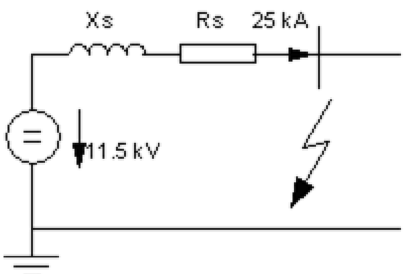

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Fig. 4.3.-2 Equivalent diagram of the feeder

The short-circuit current in the middle of the protected zone and the related time constant must be determined to be able to continue the dimensioning of CT. In Figure 4.3.-3 the equivalent diagram for the calculation of the fault current If can be seen.

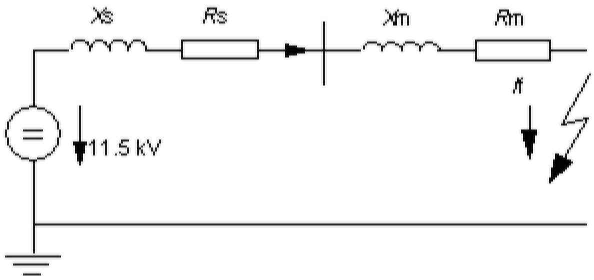

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Fig. 4.3.-3 Equivalent diagram for the calculation of the fault current

The total fault reactance ***X***f and resistance ***R***f are:

$$Xf = (0.458 + 0.40)\Omega = 0.858\Omega \quad (14)$$

$$Rf=(0.032+0.15)\Omega=0.182\Omega \quad (15)$$

The short-circuit current I_f is:

$$I_f = \frac{Ur}{\sqrt{3}\cdot\sqrt{(0.858^2 + 0.182^2}} = 13.2\text{kA} \quad (16)$$

and the related time constant τ_f

$$\tau_f = \frac{0.858}{0.182\omega} = 15\text{ms} \quad (17)$$

The calculation of the accuracy limit factor of CT is described in Reference [1]. To secure selectivity and fast tripping of the distance protection, the CT must be able to correctly reproduce the fault current containing a DC component during the first 25 ms. The diagram in 4.3.-4 shows the oversize factor K(ct) as a function of the network time constant for the decaying DC component needed for avoiding of the CT saturation during the initial 25 ms.

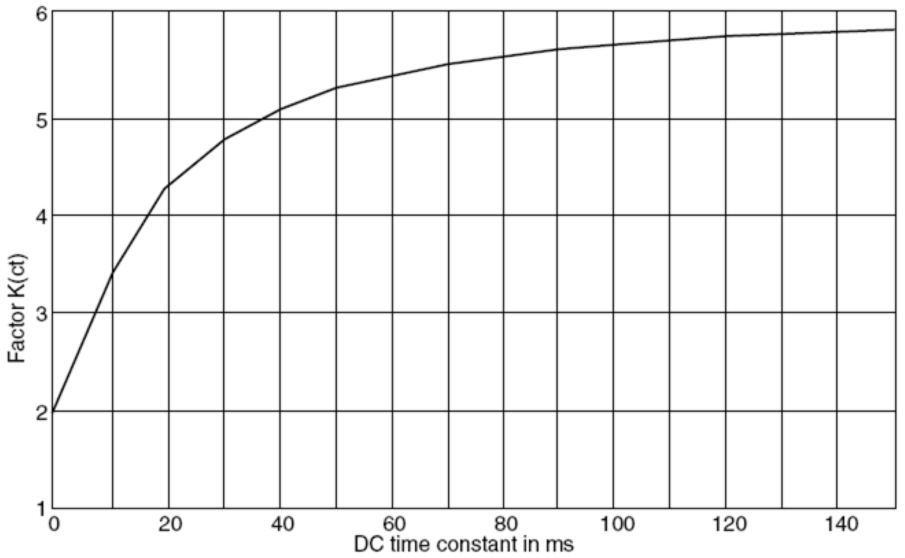


Fig. 4.3.-4 Oversize factor K(ct) to avoid the CT saturation during the first 25 ms

As shown in 4.3.-4, an additional oversize factor K(ct) of about 3.8 is needed. This means that CT must have an actual accuracy limit factor of

$$F_{\mathrm{A}} = \frac{13.2\mathrm{kA}}{300\mathrm{A}} 3.8 = 167$$

The accuracy limit factor is required to ensure that the distance protection is able to trip in 30 ms as set. If this condition cannot be fulfilled, the operation time can be delayed by at least five times the time constant. In this example, the operation time of the first zone could be delayed up to 75 ms, but then the accuracy limit factor $\boldsymbol{F}_{\mathrm{MIN}}$ must be at least greater than

$$F_{\mathrm{MIN}} \geq \frac{13.2\mathrm{kA}}{300\mathrm{A}} \geq 44 \qquad (18)$$

In this example, the internal burden of the 300/1 A CT is assumed to be 2.0 VA and the resistance of the wiring including the input transformer of the REF 542plus is assumed to be about 0.5 Ω, that is, an actual burden of 0.5 VA.

The equation for calculating the actual accuracy limit factor is as follows:

$$F_{\mathrm{A}} = F_{\mathrm{n}} \frac{S_{\mathrm{IN}} + S_{\mathrm{n}}}{S_{\mathrm{IN}} + S_{\mathrm{A}}} \qquad (19)$$

F_n	rated accuracy limit factor
F_A	actual accuracy limit factor
S_{IN}	internal burden of the CT secondary coil
S_n	rated burden of CT
S_A	actual burden of CT

If a CT with a rated accuracy limit factor of 20 is to be used, the rated burden of the CT must be at least

$$S_n = \frac{F_A}{F_n}(S_{IN} + S_A) - S_{IN}$$
$$= \left[\frac{167}{20}(20 + 0.5) - 0.5\right]\mathrm{VA} = 20.4\mathrm{VA} \qquad (20)$$

To ensure the correct operation of the distance protection, a CT with the following technical specifications is recommended:

300 A/1 A, 20 VA, 5P20

If the rated power of the CT has to be reduced, a higher rated primary current must be selected.

4.4. Setting the distance protection

Depending on the number of zones needed, the related function blocks must be activated in FUPLA by the configuration tool. The first function block is used for the common setting of the distance protection. Afterwards, the zones for START and, depending on the required Impedance-Time-Characteristic, the related number of function blocks for the zones are to be inserted.

4.4.1. System operation condition

The distance protection starts to operate if a certain current value is exceeded. Therefore, the setting Imin> is foreseen to define the minimum current flow. As mentioned above, the minimum short-circuit current is 200 A and the nominal value of CT is 300 A. Consequently, the setting of Imin> can be calculated by taking a safety margin 0.9 into account as follows:

$$\mathrm{Imin} >= 0.9 \cdot 200/300\,\mathrm{In} = 0.60\mathrm{In} \qquad (21)$$

Imin>	Minimum short-circuit current
In	Nominal current of the CT as reference value

In order to detect an earth fault in the system, the setting of the residual current Io> and the residual voltage Uo> are provided too. For this example, the minimum residual current is assumed to be 100 A. The setting of the residual current can be calculated as follows:

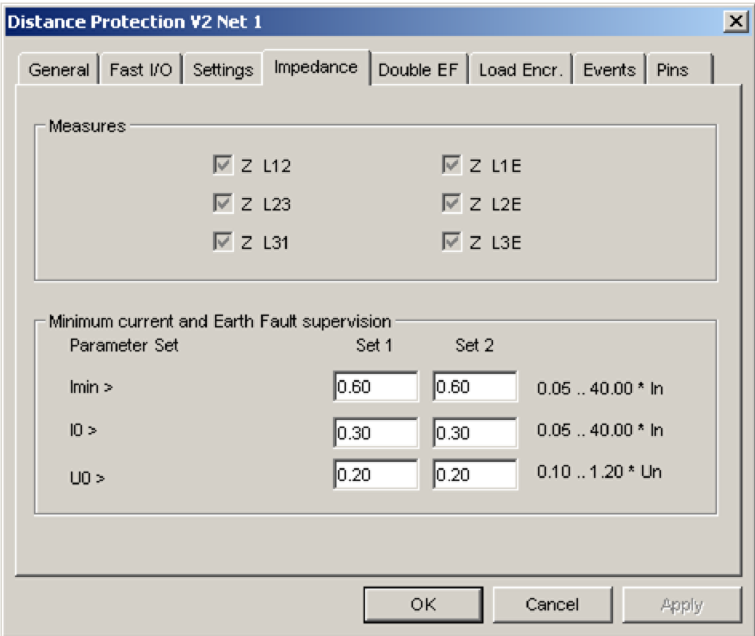
$$\mathrm{Io} >= 0.9 \cdot 100/300\,\mathrm{In} = 0.3\mathrm{In} \tag{22}$$

Io>	Residual overcurrent
In	Nominal current as reference value

The setting of the residual voltage for this example is assumed to be:

Uo> = 0.2 Un

Uo>	Nominal voltage as reference value



A100070

Fig. 4.4.1.-1 Setting for defining the operation condition

4.4.2. System neutral treatment

An important parameter to consider is the treatment of the system neutral which requires a specific behavior of the distance protection. In a system where the system neutral is effectively earthed, all kinds of faults - earth faults, two-phase faults, two phase-to-earth faults and three-phase faults - must lead to a trip of CB. But if the system neutral is isolated or earthed by an earth fault compensation coil, an earth fault does not cause an operation of the distance protection. The system is designed in a way that an earth fault does not affect the system operation at all. Only in the cases where an earth fault has become a double-earth fault (additional earth fault at another location), only one of the affected lines can be switched off. Since double-earth fault has changed to an earth fault, the system can be operated normally again.

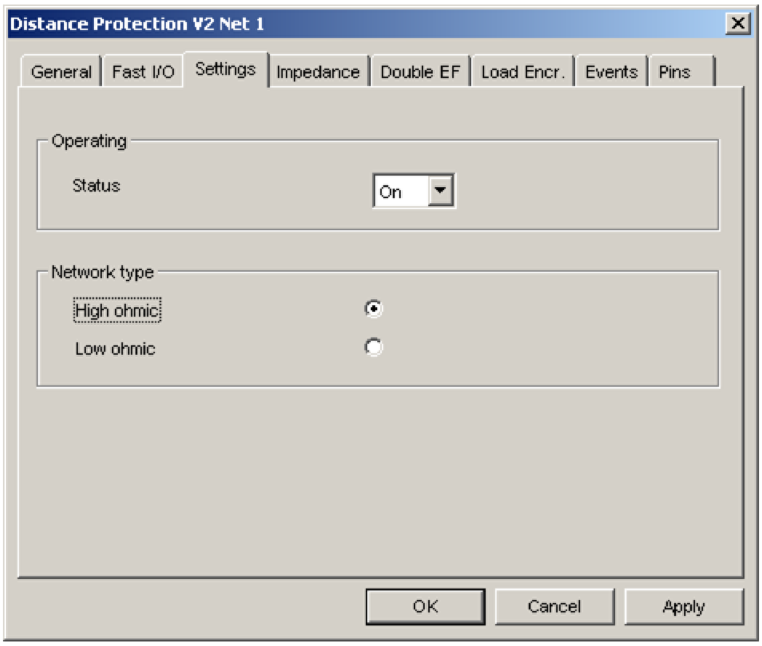


Fig. 4.4.2.-1 Setting of the network type

Here the distance protection operates in an MV system with an earth fault compensation. Therefore, as shown in 4.4.2.-1, high ohmic must be selected as the network type.

4.4.3. Phase selection

In a system with an earth fault compensation, it is required to have a specific behavior for switching off a double earth fault. From the system operation point of view, an earth fault can be tolerated. Thus, in case of a double earth fault, only one of the affected line sections with an earth fault must be isolated.

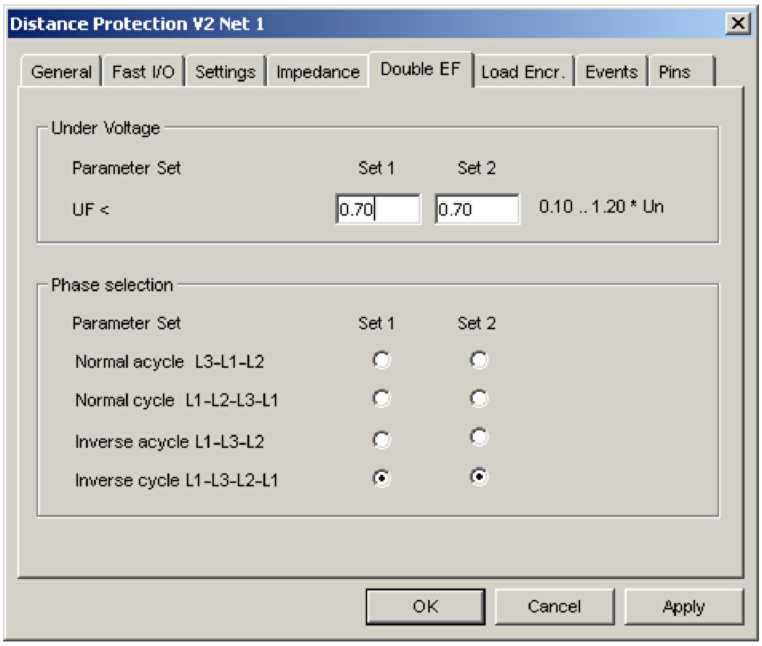


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Fig. 4.4.3.-1 Setting for double earth fault behavior

Therefore, the so-called phase selection program must be set accordingly, as shown in 4.4.3.-1. The same setting must be foreseen for all the protection devices installed in the system.

The following phase selections for switching off CB in case of a double earth fault are available:

- Normal acycle L3-L1-L2
- Normal cycle L1-L2-L3-L1
- Inverse acycle L1-L3-L2
- Inverse cycle L1-L3-L2-L1

For this example, the phase selection normal acycle L3-L1-L2 is set. By applying this setting, a double-earth fault involving the phases L2-E and L3-E causes a trip of the CB on the line section where the earth fault is located on phase L3. The operation of the power system can be continued, as the system is only affected by an earth fault on phase L2.

For the correct detection of the double-earth fault, the line voltages are supervised. By applying an undervoltage monitoring function, it can be detected in which phases the double-earth fault has occurred. A double-earth fault is present if the value of one line voltage is low. For this example it is assumed that during the system operation the lowest value of the line voltages could be down to 0.8 of its nominal value. Therefore by taking a safety margin of 0.9 the value for the undervoltage monitoring is set as high as possible as follows:

$$\mathrm{UF} <= 0.9 \cdot 0.8\mathrm{Un} = 0.72\mathrm{Un} \tag{23}$$

UF<	Undervoltage monitoring of the faulty line voltage
Un	Nominal line voltage as reference value

4.4.4. Load encroachment

The maximum load current in this example is greater than the minimum short-circuit current. Consequently, it is necessary to have the load encroachment activated to avoid an unwanted operation of the distance protection during normal load condition. The area to be blinded is defined by the parameter Rforward, Rbackward and the angle according to the power factor.

The reach for Rforward and Rbackward in this example is assumed to be the same and it needs to be estimated. The maximum load current referred to the nominal value of the CT is 400A / 300 A = 1,33 In. Under consideration of the lowest operation voltage of 0.8 Un, the calculation with a 0.9 safety margin can be performed as follows:

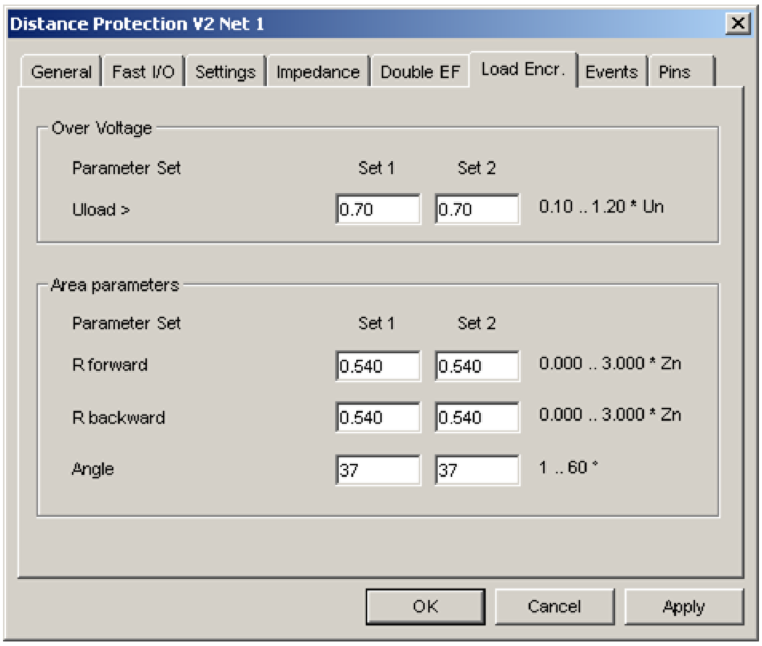
$$\mathrm{Rforward} = 0.9(0.8\mathrm{Un})/(1.33\mathrm{ln}) = 0.54\mathrm{Zn} \tag{24}$$

As during the load condition the power factor can be 0.8, the angle for the load encroachment is set as follows:

$$\Phi = \mathrm{arc}\ cos\, 0.8 = 37° \tag{25}$$

The load encroachment is only required during normal operation condition. Consequently, the line voltages must be in a symmetrical condition and exceed the overvoltage threshold Uload>. If the line voltages are not in a symmetrical condition or below the threshold value of Uload>, it is assumed that a system fault is present. In that case, the load encroachment is taken out of operation. The threshold for the Uload> is set with a safety margin of 0.9:

$$\mathrm{Uload>} = 0.9 \cdot 0.8\mathrm{Un} = 0.72\mathrm{Un} \tag{26}$$



A100076

Fig. 4.4.4.-1 Setting for the load encroachment

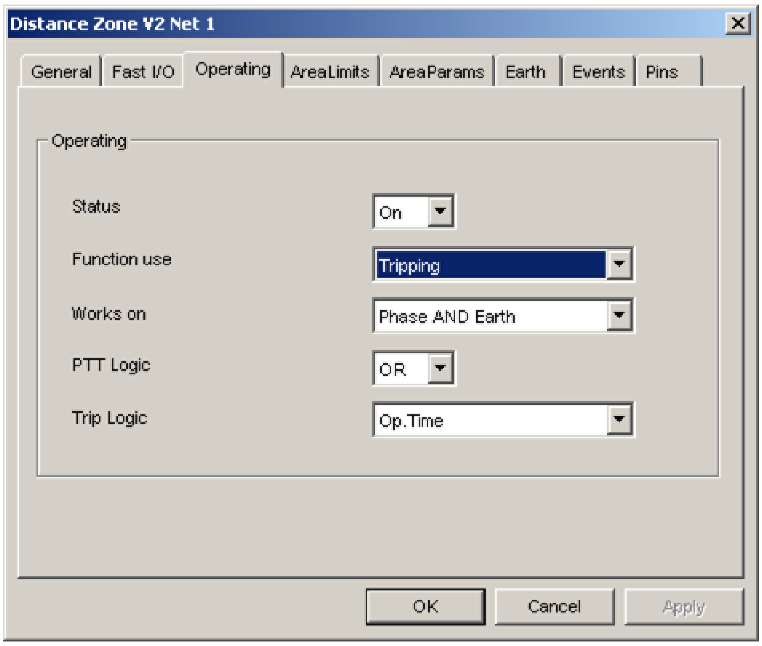
4.4.5. Underimpedance start zone

The new multizone distance protection can be designed for use with up to eight zones. Each zones is always activated as soon as the minimum current is present. Therefore, an underimpedance start zone, as used in the past to start the operation of the distance protection, is not needed anymore.

From the selectivity coordination point of view, the distance protection can be used as a remote backup protection. Therefore, in most cases the start zone of the distance protection is used as a non-directional backup protection. Besides, the start signal is used for indication of the existing system fault.

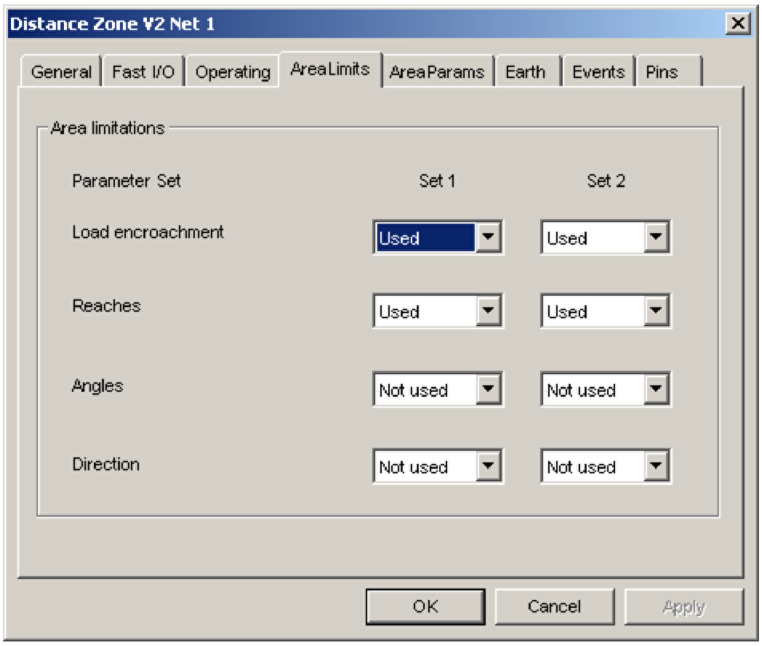
For this example, one of the distance protection zones is used as an underimpedance non-directional backup zone. The setting of the zone is defined with the minimum short circuit current to be covered and the maximum operating voltage. As in this example with the minimum short-circuit current being (200 A / 300 A) In and the maximum operation voltage 1.1 Un, by taking into account a factor of 0.9 as a safety margin the reach for the operation characteristic can be calculated as follows:

$$\begin{aligned} &\text{Xforward} = \text{Rforward} = \text{Xbackward} = \text{Rbackward} \\ &= 1.1\text{Un} \big/ \left[\left(2/3\text{In} \right) 0.9 \right] = 1.83\text{Zn} \end{aligned} \qquad (27)$$



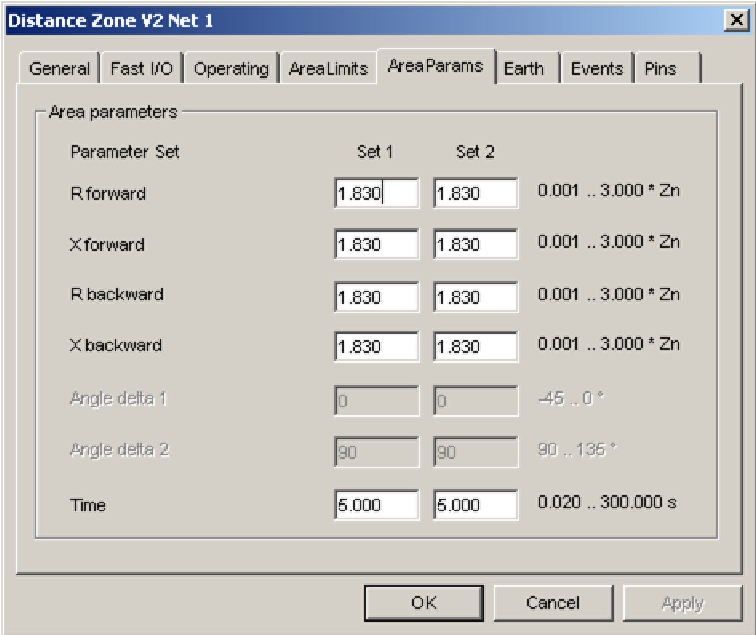
A100078

Fig. 4.4.5.-1 Setting for the operation of the zone start



A100080

Fig. 4.4.5.-2 Setting for the area limits of the zone start



A100082

Fig. 4.4.5.-3 Setting for the area parameters of the zone start

In 4.4.5.-1, 4.4.5.-2 and 4.4.5.-3 the setting for the underimpedance start zone are displayed. The characteristic is rectangular with the load encroachment. The operation time for the non-directional backup functionalities is set to be five second. The operation characteristic is similar to the one displayed in 3.1.6.-2.

4.4.6. Impedance zones

Reach of the first zone Z1 is set as follows:

- Z1 = 0.27 Ω + j 0.72 Ω
- Z01 = 1.26 Ω + j 3.6 Ω
- The related operation time 50 milliseconds

For the setting of the impedance zone, the reactance is essential. As for other settings in protection functions, the reference value for the impedance is the nominal impedance, which can be defined by the primary nominal value, provided that the setting of the analog inputs in 4.2. is done correctly.

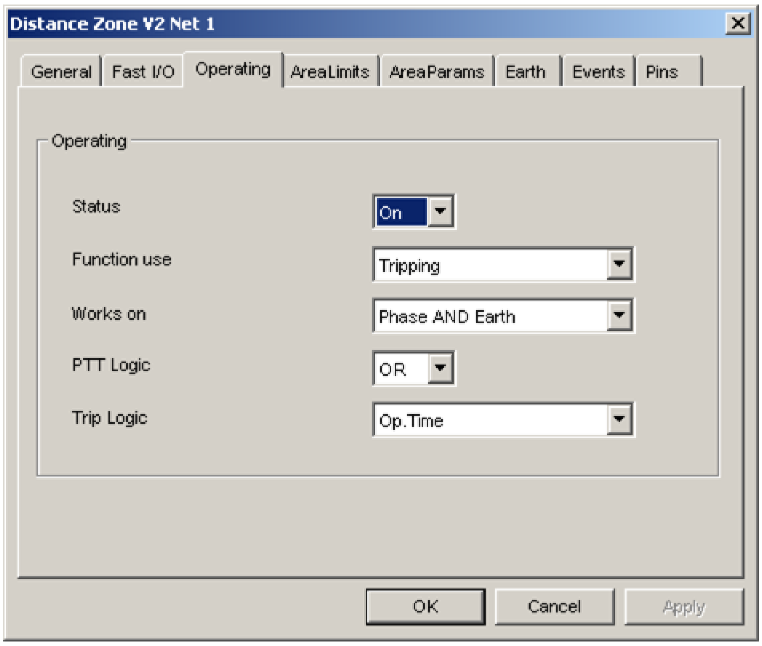
$$\mathrm{Zn} = 20\mathrm{kV}/300\mathrm{A} = 66.67\Omega \tag{28}$$

The reach Xforward for the first zone Z1 can be calculated as follows:

$$\mathrm{Xforward} = \mathrm{Z1} = \left(0.72\Omega/66.67\Omega\right)\mathrm{Zn} = 0.011\mathrm{Zn} \tag{29}$$

Rforward can be set according to the need for covering the possible high-resistance fault. In this example, it is assumed that the resistance to be covered is 1.5 Ω. So the setting value is:

$$\mathrm{Rforward(Z1)} = \left(1.5\Omega/66.67\Omega\right)\mathrm{Zn} = 0.022\mathrm{Zn} \tag{30}$$



A100084

Fig. 4.4.6.-1 Setting for the operating of the impedance zone Z1

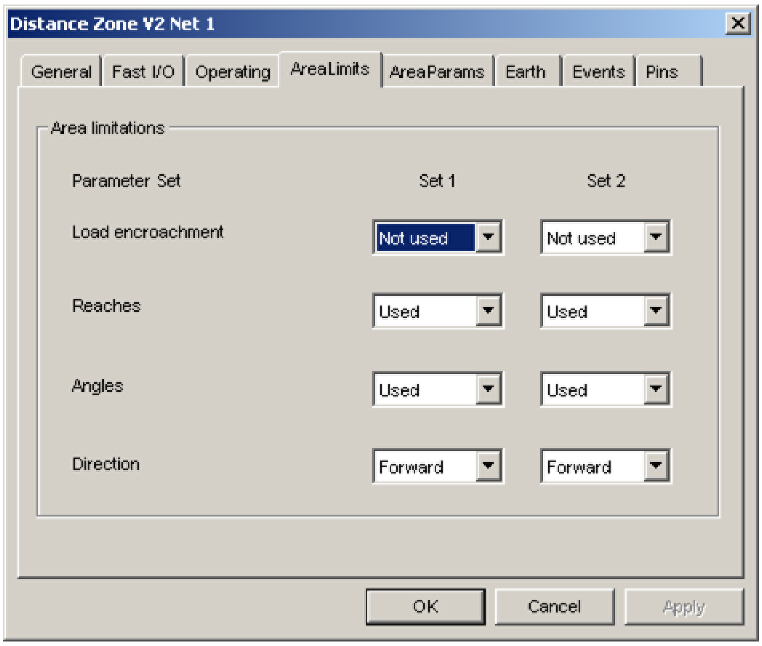


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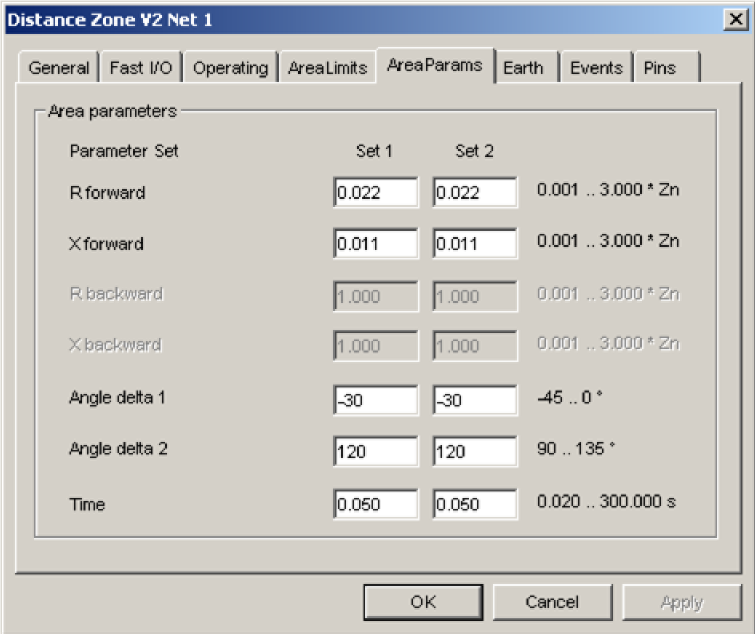
Fig. 4.4.6.-2 Setting for the area limits of the impedance zone Z1



A100088

Fig. 4.4.6.-3 Setting for the area parameters of the impedance zone Z1

Several parameters must be configured. 4.4.6.-1, 4.4.6.-2 and 4.4.6.-3 show the setting of the zone Z1. As the reach is relatively low, no load encroachment is needed. The zone Z1 protects the related line section in the forward direction, therefore the angles delta1 and delta2 must be configured accordingly. It is recommended to use the setting as described in 3.3. Direction estimation with voltage memory. The operation time for the first zone is set for 50 milliseconds. The operation characteristic is similar to the one shown in 3.2.4.-3.

Value lower than 30 ms is not recommended because the algorithm for the impedance calculation needs at least one period to perform the calculation accurately.

For the impedance calculation of fault-to-earth, the so-called earth factor must be estimated according to the equation below:

$$\underline{k} = \frac{1}{3} \cdot \left(\frac{\underline{Z}_0}{\underline{Z}_L} - 1 \right) = \frac{1}{3} \cdot \left(\frac{\underline{Z}_0 - \underline{Z}_L}{\underline{Z}_L} \right) \qquad (31)$$

The value of the line impedance ZL and the zero sequence impedance for the reach to be covered by zone Z1 is listed below:

- Z1 = 0.27 Ω + j 0.72 Ω
- Z01 = 1.26 Ω + j 3.6 Ω

The calculation can be done as below:

$$\underline{Z}_{01} - \underline{Z}_1 = \left[(1.26 - 0.27) + j(3.6 - 0.72)\right]\Omega = (0.99 - j2.88)\Omega \tag{32}$$

After conversion in the polar coordinate, the result for

Modulus (Z01 – Z1) = 3.04 Ω

Angle (Z01 – Z1) = 71°

The same can be done for Z1 to concert in the polar coordinate.

Modulus (Z1) = 0.77 Ω

Angle (Z1) = 69°

Now the k faktor can be estimated:

Modulus (k for Z1) = (1/3) (3.04/0.77) = 1.31

Angle (k for Z1) = 71° – 69° = 2°

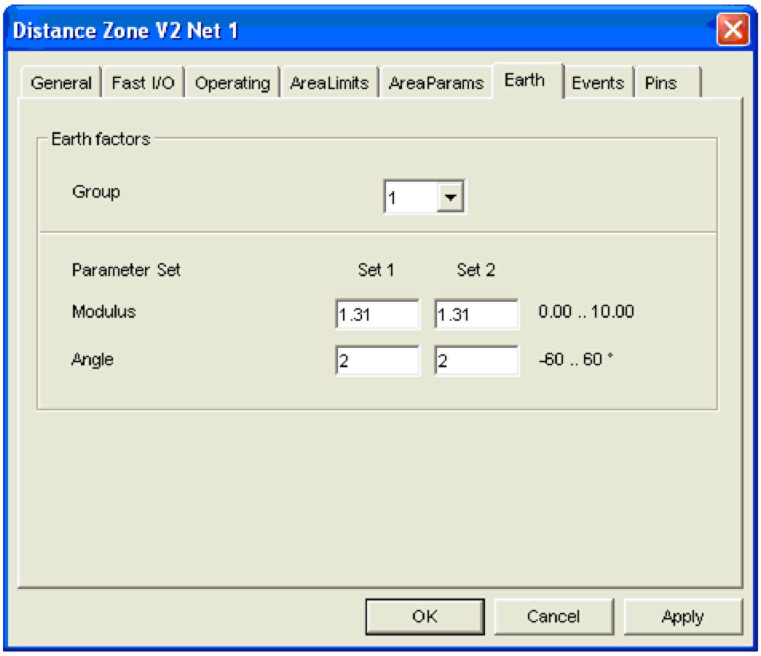


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Fig. 4.4.6.-4 Setting for the earth factor of the impedance zone Z1

The setting for the k factor for Zone Z1 can be seen in 4.4.6.-4. In total, up to four earth factor groups can be applied. The needed earth factor group for each zone can be selected accordingly. In this example for zone 1, the earth factor in group 1 is used.

The setting for the overreach zone Zov and the second impedance zone Z2 can be done similarly. That is why the setting calculation is not described anymore.

The Zone Z3 is used as a directional remote backup protection. The same setting as for the zone start, which is used as a non-directional backup protection, can principally be used. Because the forward direction is to be applied, the settings are shown in 4.4.6.-5, 4.4.6.-6 and 4.4.6.-7.

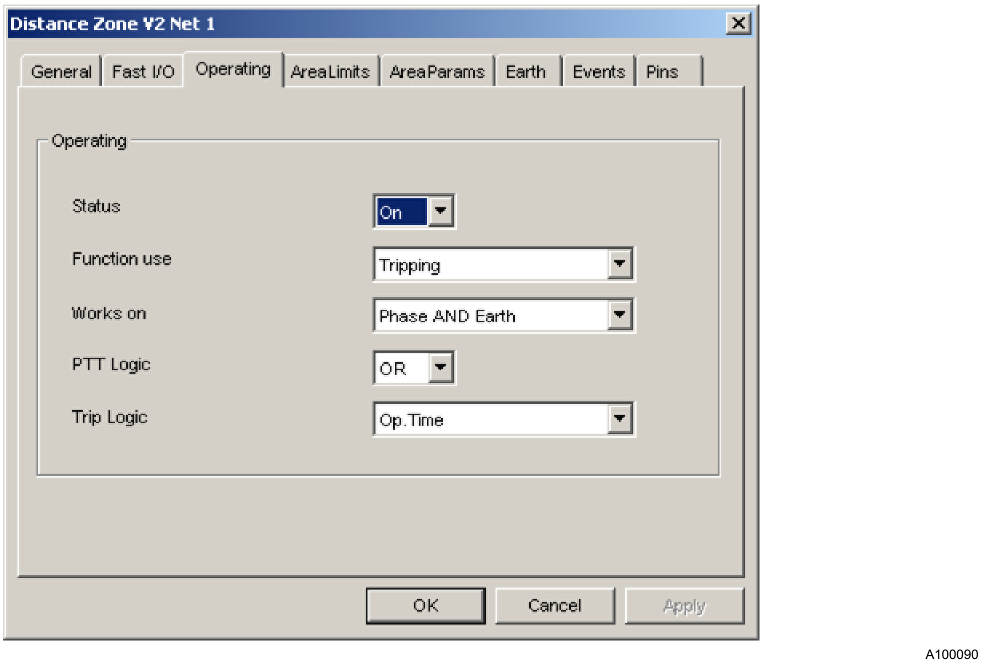

Fig. 4.4.6.-5 Setting for the operating for the zone-directional backup

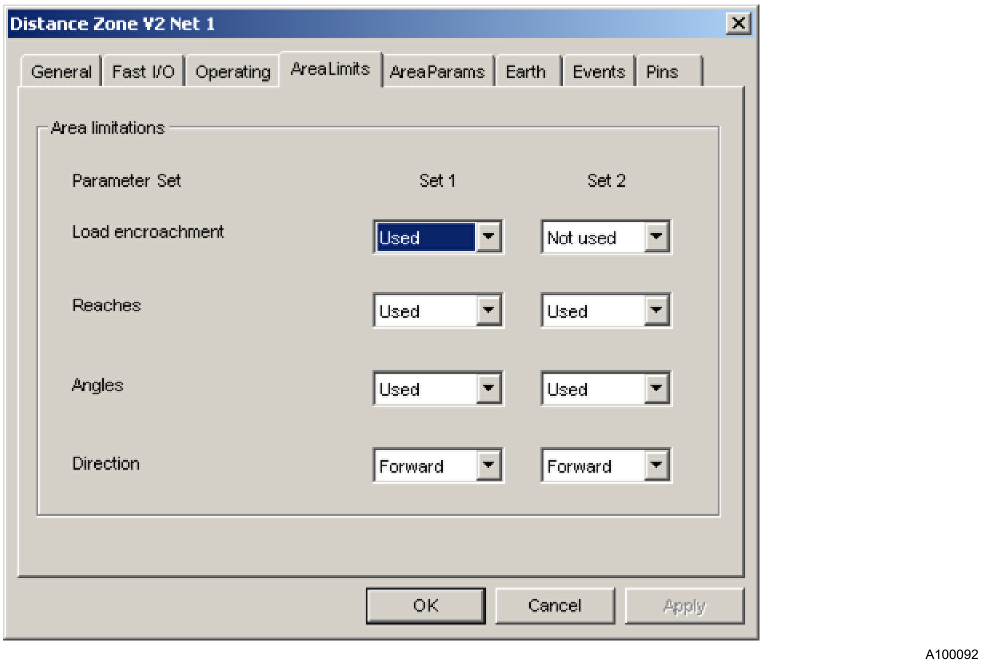

Fig. 4.4.6.-6 Setting for the area limits for the zone-directional backup

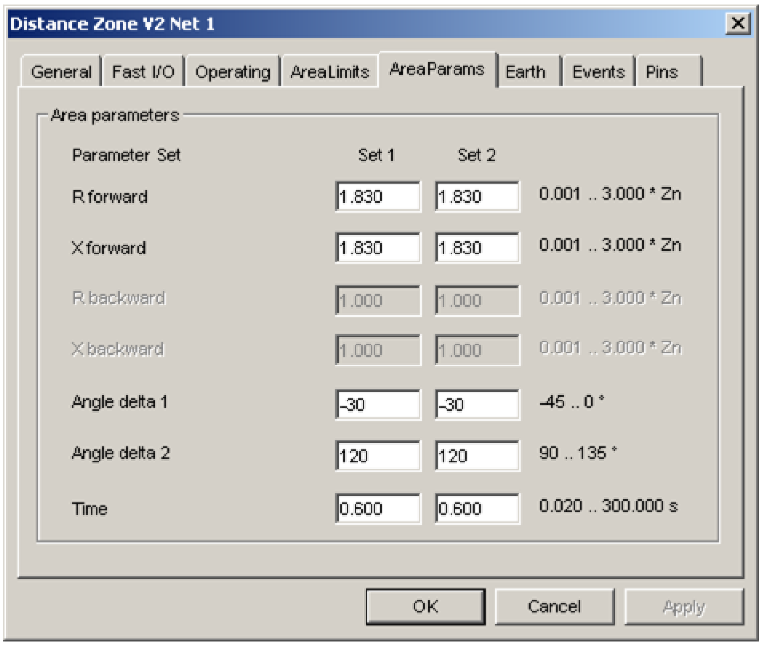

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Fig. 4.4.6.-7 Setting for the area parameters for the zone-directional backup

5. Summary

The operation principle of the distance protection is explained. The distance protection incorporates the following functions:

- Adaptation to system-neutral treatment
- Load encroachment to avoid unwanted operation during heavy load condition
- Protection of up to eight independent zones
- Simultaneous calculation of system faults in all activated zones
- Four earth factor groups can be applied
- Directional detection by using voltage memory
- Different transfer trip scheme foreseen

In the setting example all the needed setting parameters are explained. Also the needed CT ratings are calculated.

6. Abbreviations

Abbreviation	Description
AR	Autoreclosure
CB	Circuit-breaker
CT	Current transformer
DEF	Double earth fault
FUPLA	Function block programming language; Functional programming language; Function plan; Function chart
I/O	Binary input and output
IED	Intelligent electronic device
IRV	Input rated value
MV	Medium voltage
PTT	Protection transfer trip scheme by comparison of the related signals
RSV	Rated secondary value
SOTF	Switching onto fault
TT	Transfer trip
VT	Voltage transformer

7. References

[1] 1MRS755481	Calculation of the Current Transformer, Accuracy Limit Factor, ABB Application Note
[2] 1MRS755860	Protection Functions, Configuration and Settings
[3] 1MRS756571	Autoreclosing REF 542plus

8. Connection diagram

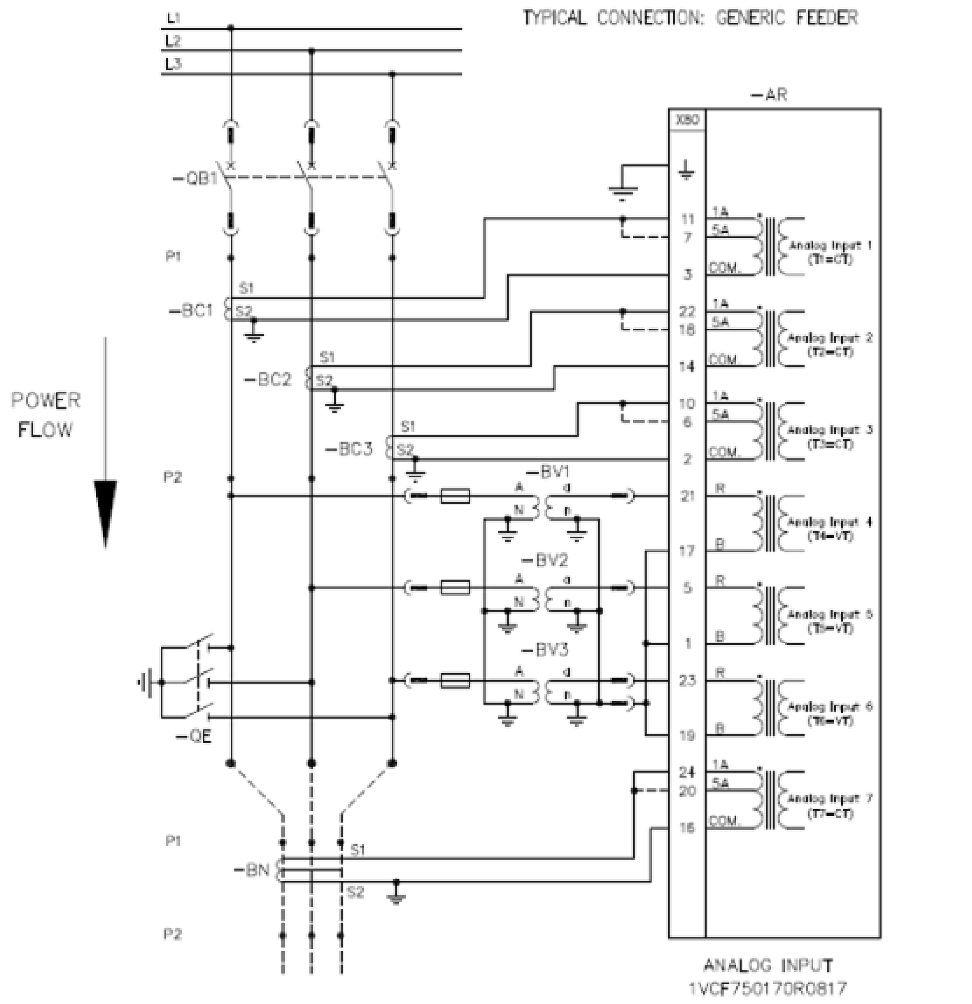

Fig. 8.-1 Connection diagram for REF 542plus

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