7SR242 Duobias

Multi-Function 2-Winding Transformer Protection Relay

Document Release History

This document is issue **2010/06**. The list of revisions up to and including this issue is:

2010/06	Revisions to trip/close circuit supervision diagrams
2010/02	Document reformat due to rebrand
2010/02	Third issue. Software revision 2662H80001 R4c-3
2008/07	Second issue. Software revision 2662H80001R3d-2c.
2008/05	First issue

Software Revision History

2010/02	2662H80001 R4c-3	Revisions to: VT ratio settings, 87BD 1st bias slope limit setting increments, CB fail function, LED CONFIG menu, DATA STORAGE menu. Added: Open circuit detection (46BC), CONTROL MODE menu, Close circuit supervision (74CCS), Measured earth fault undercurrent (37G), Pulsed output contacts.
2008/07	2662H80001R3d-2c.	Demand metering. Optional DNP3.0 data comms.
2008/05	2662H80001R3-2b	First Release

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Section 1: Common Functions

1.1 Multiple Settings Groups

Alternate settings groups can be used to reconfigure the relay during significant changes to system conditions e.g.

Primary plant switching in/out.

Summer/winter or day/night settings.

switchable earthing connections.

Allowable short term overloads.

Loss of Grid connection (see below)

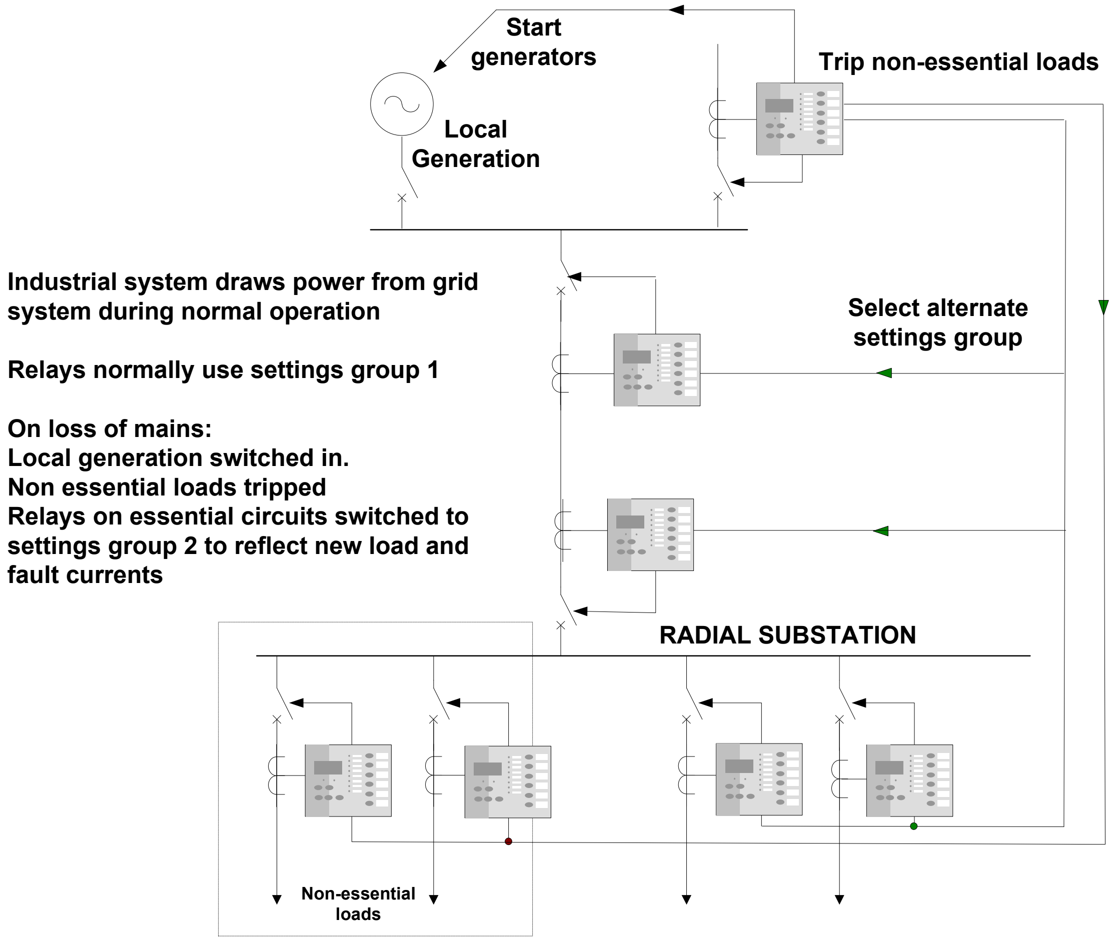


Figure 1-1 Example Use of Alternative Settings Groups

1.2 Binary Inputs

Each Binary Input (BI) can be programmed to operate one or more of the relay functions, LEDs or output relays. These could be used to bring such digital signals as Inhibits for protection elements, the trip circuit supervision status, autoreclose control signals etc. into the Relay.

Alarm and Tripping Inputs

A common use of binary inputs is to provide indication of alarm or fault conditions e.g. transformer Buchholz Gas or Buchholz Surge conditions. The Binary Inputs can be mapped to LED(s), waveform storage trigger and binary outputs.

The inputs can also be mapped as 'General Alarms' – this allows user defined text to be displayed on the LCD when the BI is energised. Inputs used in this way are programmed using:

INPUT CONFIG>INPUT MATRIX>***General Alarm n*** – Assigned to BI.

INPUT CONFIG>GENERAL ALARMS>***General Alarm n*** – 16 character string.

Where transformer outputs require high speed tripping, such as a Buchholz Surge, these should be wired to a binary input to provide LED indication and also have a parallel connection wired to directly trip the circuit via a blocking diode, see fig. 1-2:

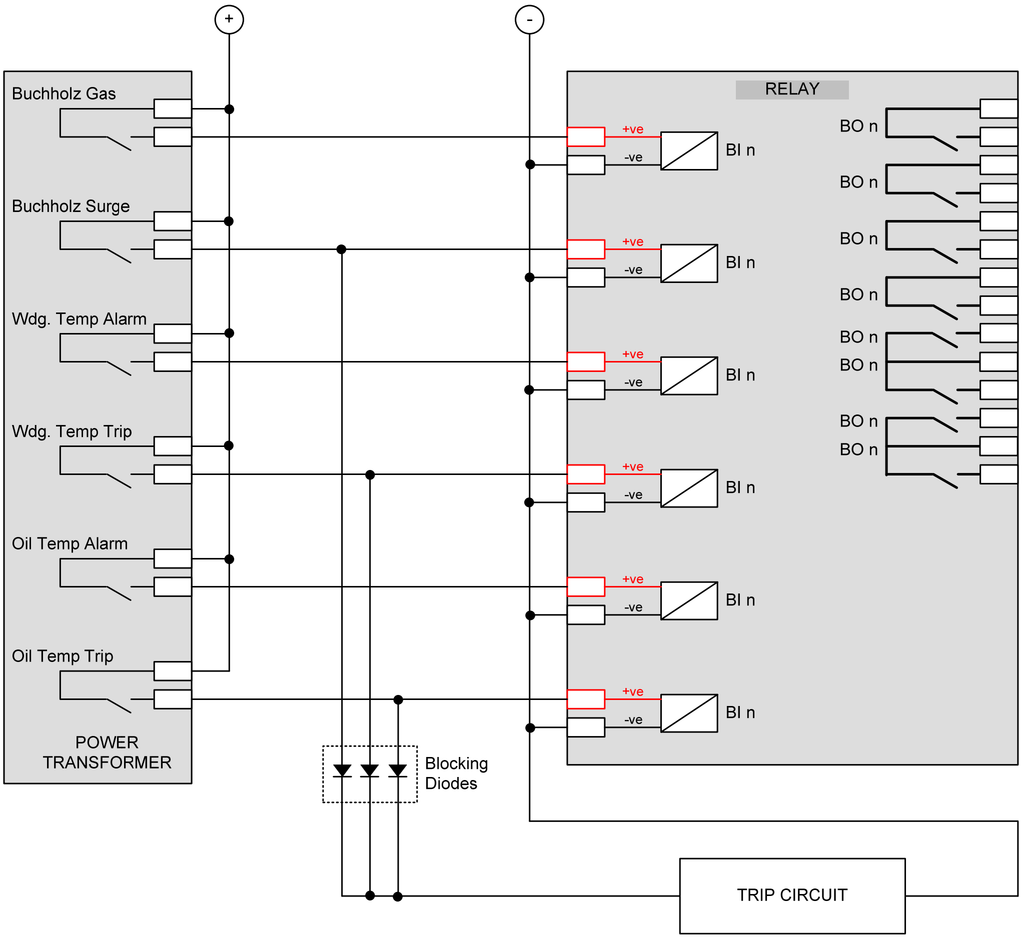


Figure 1-2 Example of Transformer Alarm and Trip Wiring

The Effects of Capacitance Current

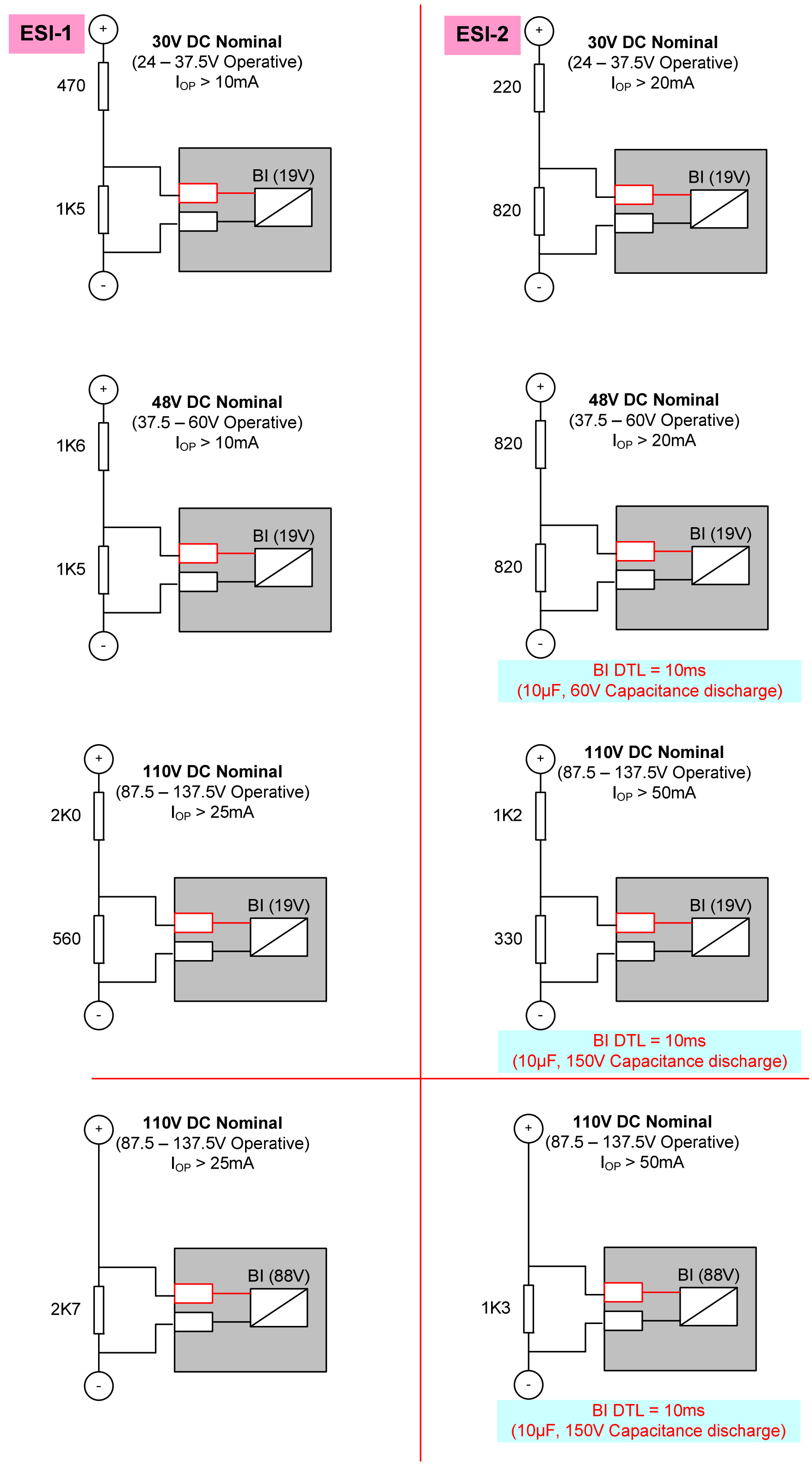
The binary inputs have a low minimum operate current and may be set for instantaneous operation. Consideration should be given to the likelihood of mal-operation due to capacitance current. Capacitance current can flow through the BI, for example if an earth fault occurs on the dc circuits associated with the relay. The binary inputs will be less likely to mal-operate if they:

1. Have both the positive and negative switched (double-pole switched).
2. Do not have extensive external wiring associated with them e.g. if the wiring is confined to the relay room.

Where a binary input is both used to influence a control function (e.g. provide a tripping function) and it is considered to be susceptible to mal-operation the external circuitry can be modified to provide immunity to such disturbances, see fig 1.3.

AC Rejection

The default pick-up time delay of 20ms provides immunity to ac current e.g. induced from cross site wiring.



Resistor power ratings:	30V DC Nominal	>3W
	48V DC Nominal	>3W
	110V DC Nominal	>10W (ESI- 1)
	110V DC Nominal	>20W (ESI-2)

Resistors must be wired with crimped connections as they may run hot

Figure 1-3 – Binary Input Configurations Providing Compliance with EATS 48-4 Classes ESI 1 and ESI 2

1.3 Binary Outputs

Binary Outputs are mapped to output functions by means of settings. These could be used to bring out such digital signals as trips, a general pick-up, plant control signals etc.

All Binary Outputs are trip rated

Each can be defined as Self or Hand Reset. Self-reset contacts are applicable to most protection applications. Hand-reset contacts are used where the output must remain active until the user expressly clears it e.g. in a control scheme where the output must remain active until some external feature has correctly processed it.

Case contacts 26 and 27 will automatically short-circuit when the relay is withdrawn from the case. This can be used to provide an alarm that the Relay is out of service.

Notes on Self Reset Outputs

With a failed breaker condition the relay may remain operated until current flow in the primary system is interrupted by an upstream device. The relay will then reset and attempt to interrupt trip coil current flowing through an output contact. Where this level is above the break rating of the output contact an auxiliary relay with heavy-duty contacts should be utilised.

1.4 LEDs

Output-function LEDs are mapped to output functions by means of settings. These could be used to display such digital signals as trips, a general pick-up, plant control signals etc.

User Defined Function LEDs are used to indicate the status of Function Key operation. These do not relate directly to the operation of the Function Key but rather to its consequences. So that if a Function Key is depressed to close a Circuit-Breaker, the associated LED would show the status of the Circuit-Breaker closed Binary Input.

Each LED can be defined as Self or Hand Reset. Hand reset LEDs are used where the user is required to expressly acknowledge the change in status e.g. critical operations such as trips or system failures. Self-reset LEDs are used to display features which routinely change state, such as Circuit-Breaker open or close.

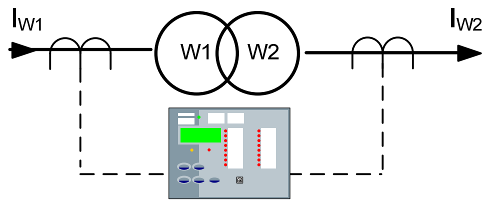
The status of hand reset LEDs is retained in capacitor-backed memory in the event of supply loss.

Section 2: Protection Functions

This section provides guidance on the application and recommended settings of the 7SR24 protection functions.

2.1 Overall Differential Protection (87)

This section covers the transformer overall differential protections – the biased differential and high-set differential elements. Transformer design limitations necessitate that the protection CTs are located on the line side of the HV and LV windings, therefore the zone of differential protection covers both transformer windings.



The application of differential protection to transformers is complicated by:

- The current magnitude change introduced by the transformer HV/LV turns ratio. The current ratio may also be variable due to the presence of an On-Load-Tap-Changer (OLTC).
- The transformer connections which may introduce a phase change between the currents flowing into each winding of the transformer.
- Magnetising inrush current which flows in only one winding of the transformer when energised.

Generally the procedure to calculate relay settings is carried out in the following order:

Establish System Parameters
Transformer rated power
Transformer impedance
Transformer rated voltage
Winding Connections
Transformer OLTC range
HV CT ratio
LV CT ratio

↓

Calculate ICT Settings
ICT Multiplier
ICT vectors

↓

Establish Required Protection Settings
87BD
87HS

Calculate Required Relay Settings
87BD Initial
87 Bias Slope 1

Figure 2-1 Procedure for calculating Overall Differential Protection Settings

2.1.1 ICT Settings for Current Magnitude Balance

Internal current multipliers are used to adjust the CT secondary currents to accommodate for any mismatch between the winding 1 and winding 2 CT ratios.

For load or through fault conditions the output of the ICT Multiplier for each winding must be equal, notwithstanding variations in the OLTC position. Where possible the output of each ICT Multiplier is set to 1A at transformer full load rating when the transformer OLTC is on its mid-tap position. At mid-tap a balanced relay should have virtually no differential currents, the bias currents will vary with the load level.

Balancing ICT Multiplier outputs (ICT_{OUT}) to 1A at transformer rating ensures that the relay operates at the levels indicated by its differential protection settings. However achieving balance at ICT_{OUT} = 1 is not always possible, here the effects on settings must be taken into account. The effect of applying ICT_{OUT} < 1 is to de-sensitise current dependent differential settings, applying ICT_{OUT} > 1 makes the effected elements more sensitive. To compensate for the resultant ICT_{OUT} value the following settings must be multiplied by ICT_{OUT}:

87HS Setting

87BD Initial

87BD 1st Bias Slope Limit

See examples in sections 2.1.5 and 2.1.6.

2.1.2 ICT Settings for Vector Group Correction

Internal interposing current transformers are used to correct the CT secondary current phase relationships in line with any phase change introduced by the transformer connections.

As a general rule, the phase angle ***ICT Connection*** setting to correct the phase angle difference is applied to the star side winding. A table showing the settings to apply for all standard transformer vector groups is included on the following page. The table assumes that all line CTs are ‘star’ connected.

Note that the choice of interposing CT vector group will modify the effective operating levels of the protection due to the current distribution for the various fault conditions – the effects on settings must be taken into account - see section 2.1.5.1.

Settings examples included in section 6 cover selected non-standard connection arrangements e.g. where the primary connections within the protected zone are crossed.

Interposing CT Selection Guide

Power Transformer Vector Group	HV Interposing CT Selection	LV Interposing CT Selection
Yy0, YNy0, Yyn0, YNyn0, Ydy0, Yndy0, Ydyn0, Yndyn0, Dz0	Ydy0,0°	Ydy0,0°
Yd1, YNd1	Yd1,-30°	Yy0,0°
Yd1, YNd1 + Earthing Transformer	Yd1,-30°	Ydy0,0°
Yy2, YNy2, Yyn2 YNyn2, Ydy2, YNdy2, Ydyn2, Yndyn2, Dz2	Ydy2,-60°	Ydy0,0°
Yd3, YNd3	Yd3,-90°	Yy0,0°
Yd3, YNd3 + Earthing Transformer	Yd3,-90°	Ydy0,0°
Yy4, YNy4, Yyn4, YNyn4, Ydy4, YNdy4, Ydyn4, Yndyn4, Dz4	Ydy4,-120°	Ydy0,0°
Yd5, YNd5	Yd5,-150°	Yy0,0°
Yd5, YNd5 + Earthing Transformer	Yd5,-150°	Ydy0,0°
Yy6, YNy6, Yyn6, YNyn6, Ydy6, YNdy6, Ydyn6, Yndyn6, Dz6	Ydy6,180°	Ydy0,0°
Yd7, YNd7	Yd7,150°	Yy0,0°
Yd7, YNd7 + Earthing Transformer	Yd7,150°	Ydy0,0°
Yy8, YNy8, Yyn8, YNyn8, Ydy8, YNdy8, Ydyn8, Yndyn8, Dz8	Ydy8,120°	Ydy0,0°
Yd9, YNd9	Yd9,90°	Yy0,0°
Yd9, YNd9 + Earthing Transformer	Yd9,90°	Ydy0,0°
Yy10, Yny10, Yyn10, YNyn10, Ydy10, YNdy10, Ydyn10, Yndyn10, Dz10	Ydy10,60°	Ydy0,0°
Yd11, Ynd11	Yd11,30°	Yy0,0°
Yd11, Ynd11 + Earthing Transformer	Yd11,30°	Ydy0,0°
Dy1, Dyn1	Yy0,0°	Yd11,30°
Dy1, Dyn1 + Earthing Transformer	Ydy0,0°	Yd11,30°
Dy3, Dyn3	Yy0,0°	Yd9,90°
Dy3, Dyn3 + Earthing Transformer	Ydy0,0°	Yd9,90°
Dy5, Dyn5	Yy0,0°	Yd7,150°
Dy5, Dyn5 + Earthing Transformer	Ydy0,0°	Yd7,150°
Dy7, Dyn7	Yy0,0°	Yd5,-150°
Dy7, Dyn7 + Earthing Transformer	Ydy0,0°	Yd5,-150°
Dy9, Dyn9	Yy0,0°	Yd3,-90°
Dy9, Dyn9 + Earthing Transformer	Ydy0,0°	Yd3,-90°
Dy11, Dyn11	Yy0,0°	Yd1,-30°
Dy11, Dyn11 + Earthing Transformer	Ydy0,0°	Yd1,-30°

1. Y or y denotes an unearthed star connection on the HV or LV side of the transformer.
2. YN or yn denotes an earthed star connection on the HV or LV side of the transformer.
3. D or d denotes a delta connection on the HV or LV side of the transformer respectively.
4. Z or z denotes a zigzag connection of the HV or LV side of the transformer respectively

2.1.3 Biased Differential (87BD) Settings

The 87BD elements provide differential protection for phase and earth faults. The limiting factors for protection sensitivity are dictated by the need to ensure protection stability during load or through fault conditions.

Magnitude restraint bias is used to ensure the relay is stable when the transformer is carrying load current and during the passage of external (out of zone) fault current. As the bias current increases the differential current required for operation increases.

Harmonic bias is used to prevent relay operation during magnetising inrush current into one winding when the transformer is first energised.

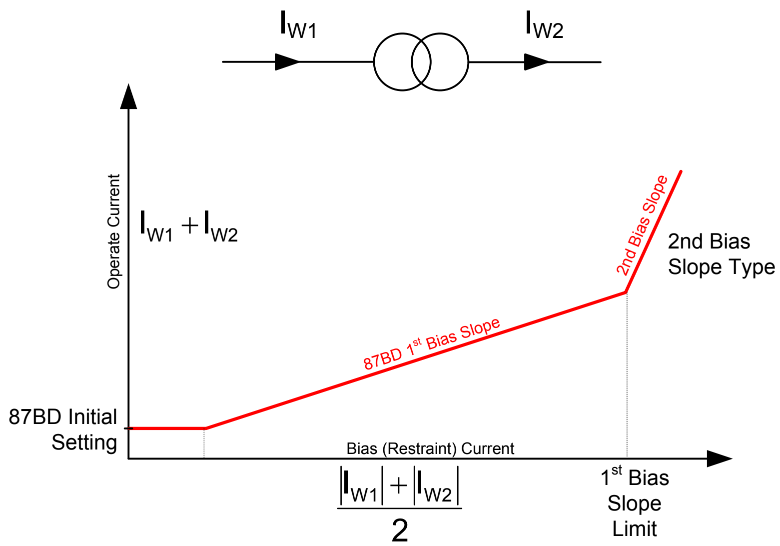


Figure 2-2: 87BD Characteristic

87BD Initial Setting (0.1 to 2.0 x In)

This setting is selected to ensure stability in the presence of CT and relay errors when low levels of bias current are present i.e. low load levels.

This is the minimum level of differential current at which the relay will operate. Typically this setting is chosen to match the on load tap-change range. For example if the tap change range is +10% to –20%, a setting of 0.3In is selected.

87BD 1st Bias Slope Setting (0.0 to 0.7)

Steady state unbalance current will appear in the differential (operate) circuit of the relay due to the transformer tap position, relay tolerance and to CT measurement errors. The differential current will increase with increasing load or through fault current in the transformer so, to ensure stability, the differential current required for operation increases with increasing bias current. The bias slope expresses the current to operate the relay relative to the biasing (restraint) current.

The Bias slope setting chosen must be greater than the maximum unbalance, it is selected to ensure stability when through fault or heavy load current flows in the transformer and the tap changer is in its extreme position.

The recommended setting is 1 x the tap change range. As the protection is optimised around the centre tap position then using the total tap change range includes for a 100% safety margin, this provides contingency for CT and relay tolerances. For example if the tap change range is +10 to –20%, the overall range is 30% so a 0.3x setting is chosen.

87BD 1st Bias Slope Limit Setting (1 to 20 x In)

Above this setting the ratio of differential current to bias current required for operation is increased.

When a through fault occurs, saturation of one or more CTs may cause a transient differential current to be detected by the relay. The bias slope limit is chosen to ensure the biased differential function is stable for high through fault currents coincident with CT saturation. This setting defines the upper limit of the bias slope and is expressed in multiples of nominal rated current i.e. the lower the setting the more stable the protection.

The three phase through fault current can be estimated from the transformer impedance. For a typical grid transformer of 15% impedance, the maximum through fault will be 1/0.15 = 6.66 x rating. A setting value is chosen that introduces the extra bias at half of the three phase through fault current level of the transformer, so 6.66/2 = 3.33 and a setting of 3 would be selected as the nearest lower setting available.

87BD 2nd Bias Slope Type (Line, Curve)

87BD 2nd Bias Slope Setting (1.0 to 2.0 – applied to 'Line' only)

These settings are chosen to ensure the biased differential function is stable for high through fault currents coincident with CT saturation.

87BD Inrush Action

Harmonic bias is used to prevent relay operation during magnetising inrush current into one winding when the transformer is first energised.

The recommended setting is **ENABLED** - see section 5.1.

87BD Overfluxing Action

This setting can be used to prevent operation of the 87BD elements in the presence of allowable over-fluxing conditions - see section 5.2.

87BD Time Delay Setting

A 5ms setting is recommended where the circuit is cabled to ensure stability during resonant conditions.

2.1.4 Differential Highset (87HS) Settings

The element operates on the differential current measured by the relay.

The 87HS element is generally applied as an unrestrained differential element to provide fast tripping for heavy internal faults.

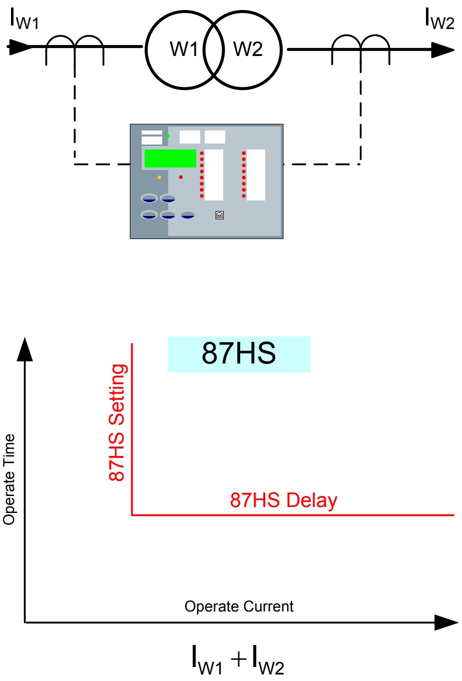


Figure 2-3: Differential Highset Characteristic

87HS Setting (1 to 30 x In)

The 87HS element is set as low as possible but not less than the maximum three phase through fault current and not less than half the peak magnetizing inrush current.

For almost all applications a setting of 7 or 8 x In has shown to be sufficiently sensitive for internal faults as well as providing stability during external faults and transient system conditions.

A Differential Highset Setting of 7 x In will be stable for a peak magnetizing inrush levels of 14 x rated current.

Smaller transformers generally will have lower impedance and therefore greater three phase through fault levels and magnetizing inrush currents. A setting of 8 x can be used as *CT saturation is reduced as system X/R is usually very low and* the peak level of magnetising current does not usually ever exceed 16 x rating.

87HS Delay Setting

A 5ms setting is recommended to compensate for transient overreach.

87HS Inrush Action

87HS Overfluxing Action

These functions are set to 'Disabled' unless specifically required by the application.

2.1.5 Example 1 – New Installation

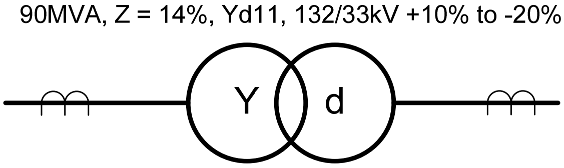


Figure 2-4 New Transformer Application

The required AC connections to the 7SR24 are shown in fig. 2.1-5

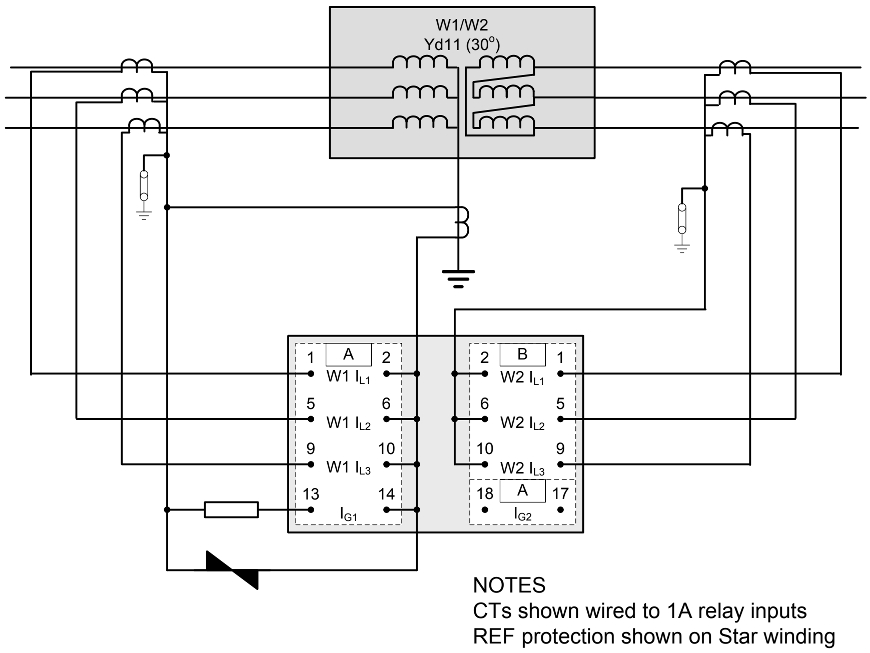


Figure 2-5: AC Connections - Example 1

Step 1 – Selection of Line CT Ratios

CTs with a secondary rating of 1A are preferred as the burden imposed on the CT by the secondary wiring is reduced in comparison with a 5A rated secondary.

HV load current = $\dfrac{90 \times 10^6}{\sqrt{3} \times 132{,}000} = 393.7\text{A}$ A CT ratio of 400/1A is chosen.

LV load current = $\dfrac{90 \times 10^6}{\sqrt{3} \times 33{,}000} \times 0.95 = 1495.7\text{A}$ A CT ratio of 1600/1A is chosen.

Note, the 0.95 factor relates to the tap changer at mid-tap position.

Step 2 – Selection of ICT Multiplier Settings

The outputs of the interposing CTs (ICT_{OUT}) must be balanced for system healthy conditions - where possible the balance is set at 1.00A at transformer rated current/mid-tap position.

HV Secondary current = $\dfrac{393.7}{400} = 0.98\text{A}$ HV ICT Multiplier = 1/0.98 = 1.02

LV Secondary current = $\dfrac{1495.7}{1600} = 0.93\text{A}$ LV ICT Multiplier = 1/0.93 = 1.07

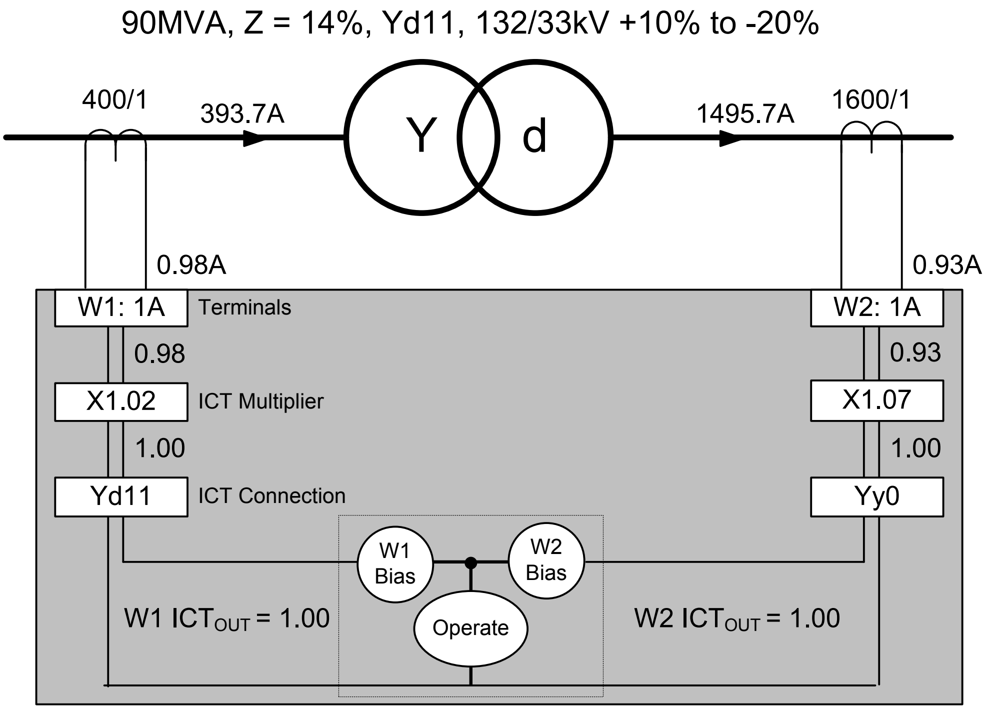


Figure 2-6 ICT Settings – Example 1

Summary of Required Settings

CT/VT CONFIG >

W1 Phase Input	1A
W1 Phase CT Ratio	400:1
W2 Phase Input	1A
W2 Phase CT Ratio	1600:1

FUNCTION CONFIG>

Gn Differential	Enabled
Gn Inrush Detector	Enabled

DIFFERENTIAL PROT'N >

Gn W1 ICT Multiplier	1.02
Gn W1 ICT Connection	Yd11
Gn W2 ICT Multiplier	1.07
Gn W2 ICT Connection	Yy0

(Note that the above settings produce ICT_{OUT} = 1.00)

DIFFERENTIAL PROT'N > 87BD >

Gn 87 BD Element	Enabled	
Gn 87BD Initial:	0.3 x In	*(0.3 x ICT_{OUT})*
Gn 87BD 1st Bias Slope:	0.3x	*(OLTC = +10% to -20%)*
Gn 87BD 1st Bias Slope Limit:	4 x In	*(1/0.14 x 0.5 = 3.6 x ICT_{OUT})*
Gn 87BD 2nd Bias Slope Type:	Line	*(Default value)*
Gn 87BD 2nd Bias Slope:	1.5x	*(Default value)*
Gn 87BD Delay:	0.005s	
Gn 87BD Inrush Action:	Inhibit	
Gn 87BD Overfluxing Action:	Off	

DIFFERENTIAL PROT'N > 87HS >

Gn 87HS Element	Enabled	
Gn 87HS Setting:	8 x In	*(> $I_{3PH\ THRU\ FAULT}$ i.e. 1/0.14 = 7.14 x ICT_{OUT})*
Gn 87HS Delay:	0.005s	
Gn 87HS Inrush Action:	Off	
Gn 87HS Overfluxing Action:	Off	

SUPERVISION > INRUSH DETECTOR >

Gn81HBL2 Element	Enabled	
Gn 81HBL2 Bias	Cross	*(Default value)*
Gn 81HBL2 Setting	0.2 x I	*(Default value)*

OUTPUT CONFIG>OUTPUT MATRIX>

87BD	BOn, Ln
87HS	BOn, Ln

OUTPUT CONFIG>BINARY OUTPUT CONFIG>

CB1 Trip Contacts	BOn
CB2 Trip Contacts	BOn

2.1.5.1 Example 1 – Further Analysis

Having established settings to ensure stability under load, transient and external fault conditions the following considers the operating levels for internal faults. The 'fault setting' for internal fault conditions is affected by the ***ICT Multiplier*** and ***ICT Connection*** settings applied:

W1 Internal Earth Fault

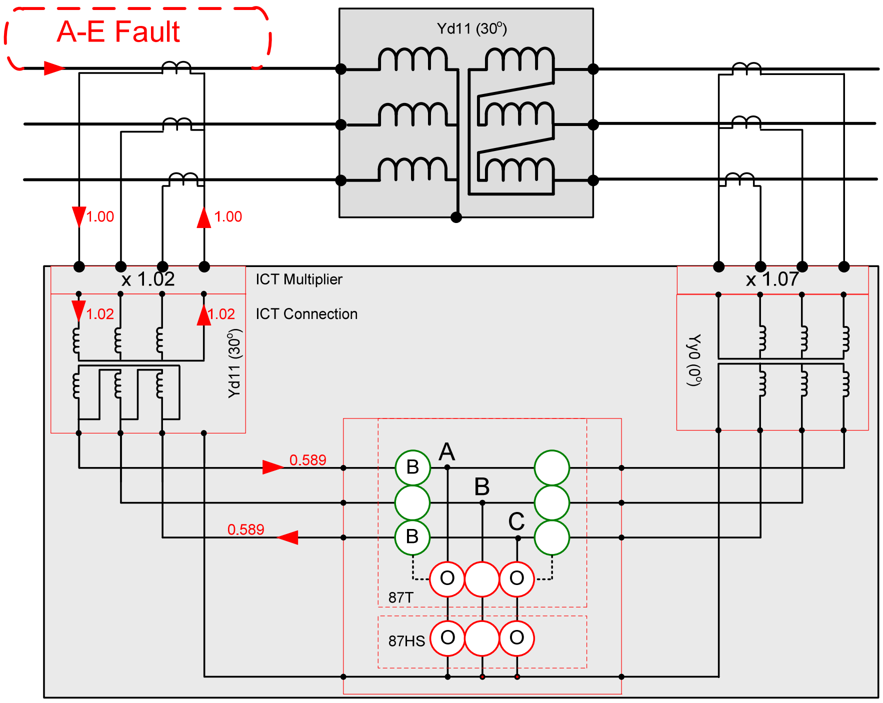


Figure 2-7: Relay Currents - Star Winding Internal Earth

<u>Notes</u>

A- E fault causes current to flow in the A and C elements

The Yd ICT connection reduces current flow by a factor of 1/√3

Relay may indicate A and C faults

W1 Internal Phase-Phase Fault

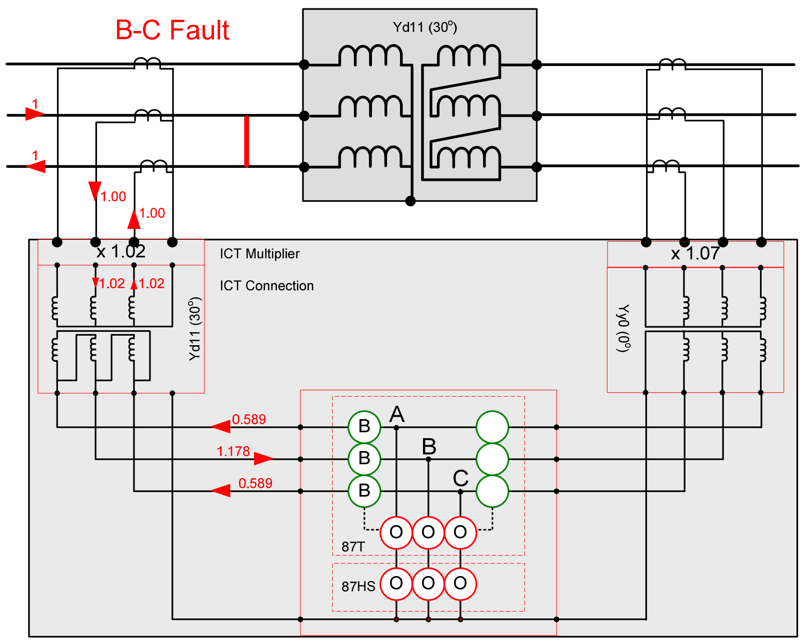


Figure 2-8: Relay Currents - Star Winding Internal Phase Fault

<u>Notes</u>

B - C fault causes current to flow in the A, B and C elements

The Yd ICT connection causes a 1:2:1 current distribution and introduces a 1/√3 multiplying factor.

Relay may indicate three phase fault

W2 Internal Earth Fault

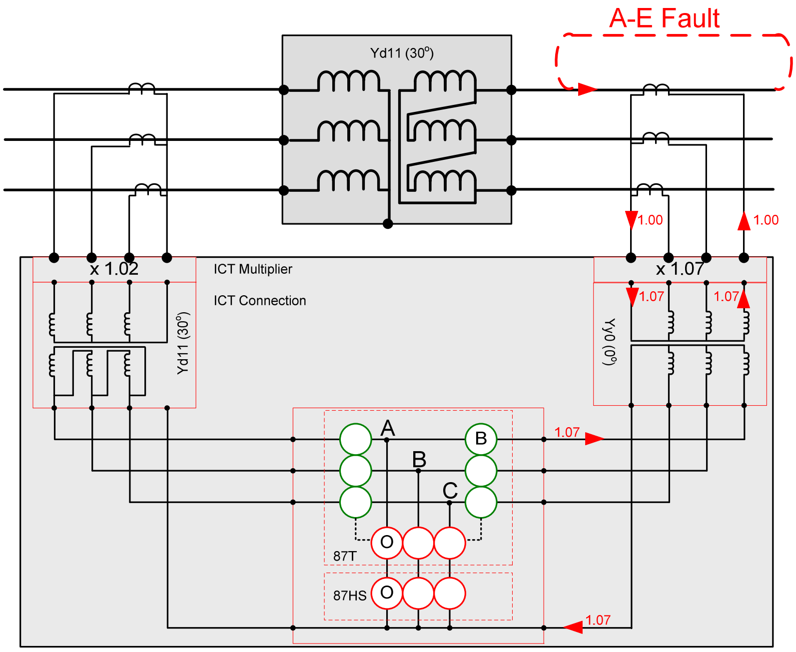


Figure 2-9: Relay Currents - Delta Winding Internal Earth Fault

W2 Internal Phase-Phase Fault

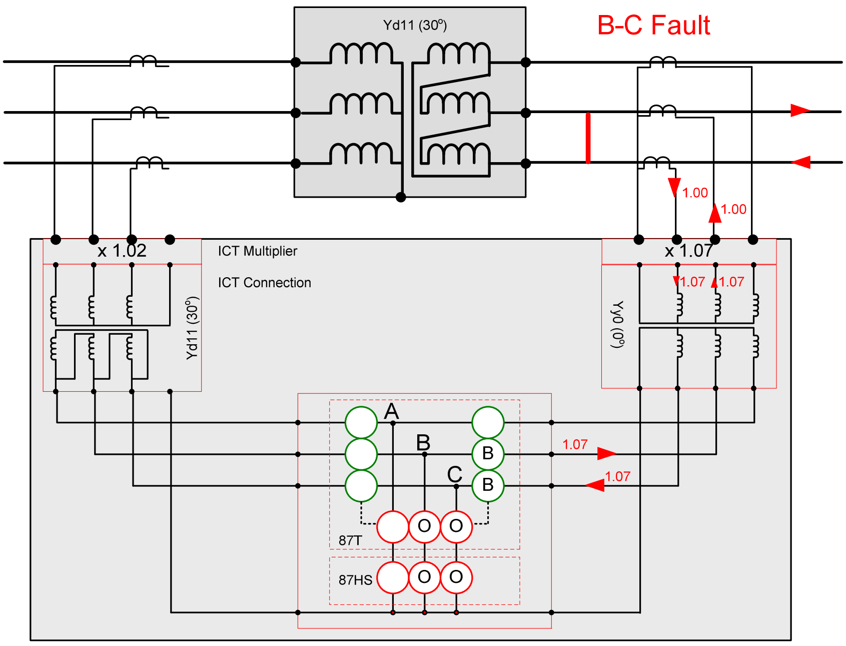


Figure 2-10: Relay Currents - Delta Winding Internal Phase Fault

Table 2-1 summarises the implications of using Yd or Yy interposing CTs.

Table 2-1 The Effect of ICT Selection on Protection Settings

CT Secondary Current	**HV (ICT: Yd11, x 1.02) W1 ICT_{OUT} =**	**LV (ICT: Yy0, x 1.07) W2 ICT_{OUT} =**
3-Phase		
A = 1A	A = 1.02A	A = 1.07A
B = 1A	B = 1.02A	B = 1.07A
C = 1A	C = 1.02A	C = 1.07A
B – C		
A = 0	A = 0.589A	A = 0
B = 1A	B = 1.178A	B = 1.07A
C = 1A	C = 0.589A	C = 1.07A
A – E		
A = 1A	A = 0.589A	A = 1.07A
B = 0	B = 0	B = 0
C = 0	C = 0.589A	C = 0

The above analysis covers current distributions for internal faults. The table illustrates that the Yd ICT has the effect of:

Modifying the amplitude of the ICT_{OUT} currents

Changing current distribution

The above factors must be considered during any analysis of protection operations and indications.

A similar analysis can be carried for external (through) fault conditions. However as the protection settings already ensured stability for the maximum through fault condition (3-phase fault) this is not necessary.

2.1.6 Example 2 – Relay Replacement Using Existing CTs

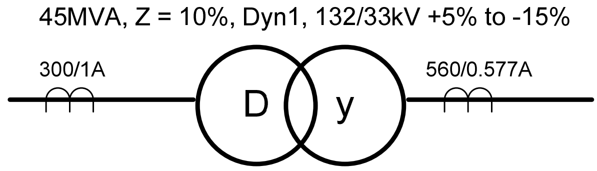


Figure 2-11 Relay Replacement

It is recommended to wire all line CTs in star when connecting to the 7SR24 relay. Where the 7SR24 is used to replace an older biased differential relay the existing CTs will often be re-used, it is recommended that any line CTs connected in 'delta' are reconnected as 'star'.

Usually the interposing CTs associated older schemes can be removed as both the vector group and current magnitude compensation functions are carried out within the 7SR24. This requires ICT settings to be programmed into the relay to correct for differences before the currents are applied to the differential algorithm. When the relay is in balance the phase angle of the currents applied to each phase of the differential algorithm will be in anti-phase.

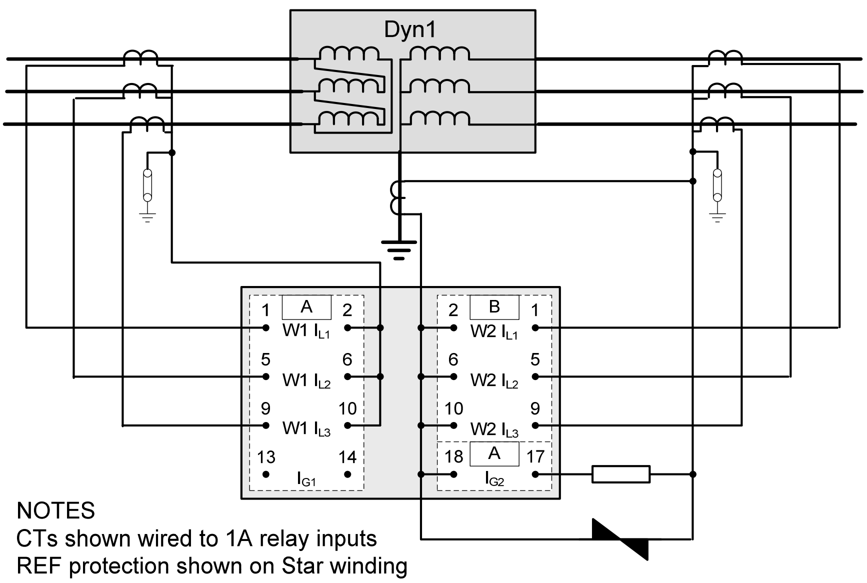


Figure 2-12: AC Connections - Example 2

Step 1 – Connection of CTs

Remove all interposing CTs from the secondary circuit. Connect all line CT secondary wiring in star.

HV load current = $\dfrac{45\times10^{6}}{\sqrt{3}\times132{,}000}=196.8\text{A}$ Re-use 300/1A CTs.

LV load current = $\dfrac{45\times10^{6}}{\sqrt{3}\times33{,}000}\times0.95=747.9\text{A}$ Re-use 560/0.577A CTs.

Step 2 – Selection of Interposing CT Multiplier Settings

HV Secondary current = $\dfrac{196.8}{300}=0.66\text{A}$ HV ICT Multiplier = 1/0.66 = 1.54

LV Secondary current = $\dfrac{747.9}{560/0.577}=0.77\text{A}$ LV ICT Multiplier = 1/0.77 = 1.30

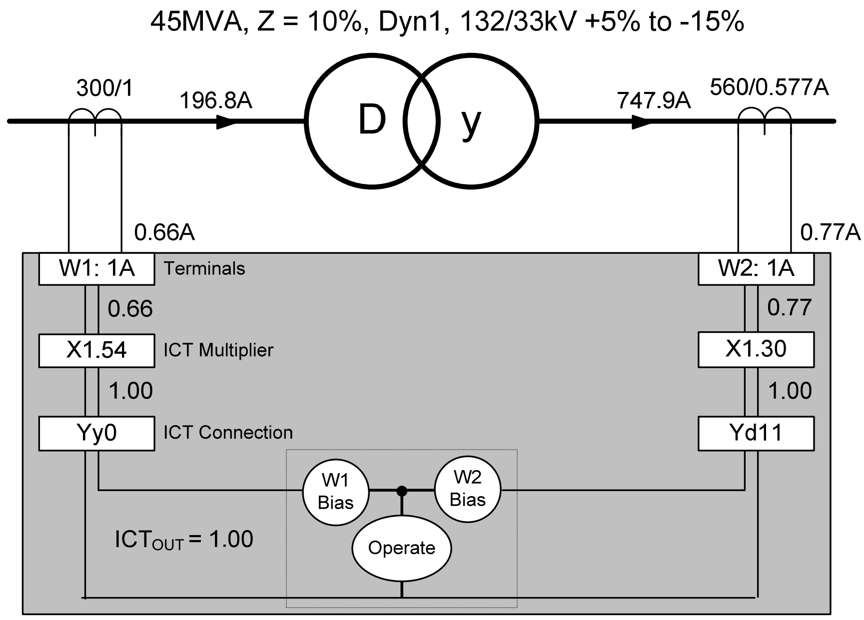


Figure 2-13 Summary of ICT Settings

Summary of Protection Settings

CT/VT CONFIG >

W1 Phase Input	1A	
W1 Phase CT Ratio	300:1	
W2 Phase Input	1A	
W2 Phase CT Ratio	560:0.58	

FUNCTION CONFIG>

Gn Differential	Enabled	
Gn Inrush Detector	Enabled	

DIFFERENTIAL PROT'N >

Gn W1 ICT Multiplier	1.54	
Gn W1 ICT Connection	Yy0	
Gn W2 ICT Multiplier	1.30	
Gn W2 ICT Connection	Yd11	

(Note that the above settings produce ICT_{OUT} = 1.00)

DIFFERENTIAL PROT'N > 87BD >

Gn 87 BD Element	Enabled	
Gn 87BD Initial:	0.2 x In	*(0.2 x ICT_{OUT})*
Gn 87BD 1st Bias Slope:	0.2x	*(OLTC = +5% to -15%)*
Gn 87BD 1st Bias Slope Limit:	5 x In	*(1/0.1 x 0.5 = 5 x ICT_{OUT})*
Gn 87BD 2nd Bias Slope Type:	Line	*(Default value)*
Gn 87BD 2nd Bias Slope:	1.5x	*(Default value)*
Gn 87BD Delay:	0.005s	
Gn 87BD Inrush Action:	Inhibit	
Gn 87BD Overfluxing Action:	Off	

DIFFERENTIAL PROT'N > 87HS >

Gn 87 HS Element	Enabled	
Gn 87HS Setting:	10 x In	*(> $I_{3PH\ THRU\ FAULT}$ i.e. 1/0.1 = 10 x ICT_{OUT})*
Gn 87HS Delay:	0.005s	
Gn 87HS Inrush Action:	Off	
Gn 87HS Overfluxing Action:	Off	

SUPERVISION > INRUSH DETECTOR >

Gn 81HBL2 Element	Enabled	
Gn 81HBL2 Bias	Cross	*(Default value)*
Gn 81HBL2 Setting	0.2 x I	*(Default value)*

OUTPUT CONFIG>OUTPUT MATRIX>

87BD	BOn, Ln	
87HS	BOn, Ln	

OUTPUT CONFIG>BINARY OUTPUT CONFIG>

CB1 Trip Contacts	BOn	
CB2 Trip Contacts	BOn	

2.2 Instantaneous OC/EF (50/50G/50N)

Instantaneous overcurrent can be applied to protect the HV terminals against high fault currents. The current setting applied must be above the maximum 3-phase through fault level of the transformer to ensure grading with the LV overcurrent protection.

Where the setting applied is below the magnetising inrush current of the transformer then inrush blocking (81HBL2) should be enabled.

2.3 Time Delayed OC/EF (51/51G/51N)

The time delayed element can provide a number of shaped characteristics. The selectable Inverse definite minimum time lag (IDMTL) and Definite Time Lag (DTL) characteristics provide protection for phase and earth faults.

As these protections are used as back-up protections discrete relays are often installed. To reduce cost and complexity it may be considered acceptable to implement the backup protection using elements within the main protection relay. The relay is self supervised and this can be used as justification for allowing the backup protection to be included as part of the main differential protection relay.

The following elements can be included:

- Three phase over current with IDMTL (IEC or ANSI) or DTL operate characteristic (51)
- Derived earth fault with IDMTL (IEC or ANSI) or DTL operate characteristic (51N)
- Measured earth fault with IDMTL (IEC or ANSI) or DTL operate characteristic (51G)

Each of the above elements can be selected to winding 1 or winding 2 CT inputs.

The time delayed characteristics are used to provide grading with other relays or fuses.

Earth fault elements can be used to provide system protection or standby earth fault protection of an earthing resistor.

2.3.1 Selection of Over-current Characteristics

Where the relay operate time must be co-ordinated with other time delayed relays on the system, the operating characteristic is selected to be the same type as the other relays. Often a normally inverse (NI) characteristic is applied, however extremely inverse curves (EI) can provide improved grading with fuses or moulded case circuit breakers.

To optimise the grading capability of the relay additional time multiplier, ‘Follower DTL’ (Fig. 2.1-1) or ‘Minimum Operate Time’ (Fig. 2.1-2) settings can be applied.

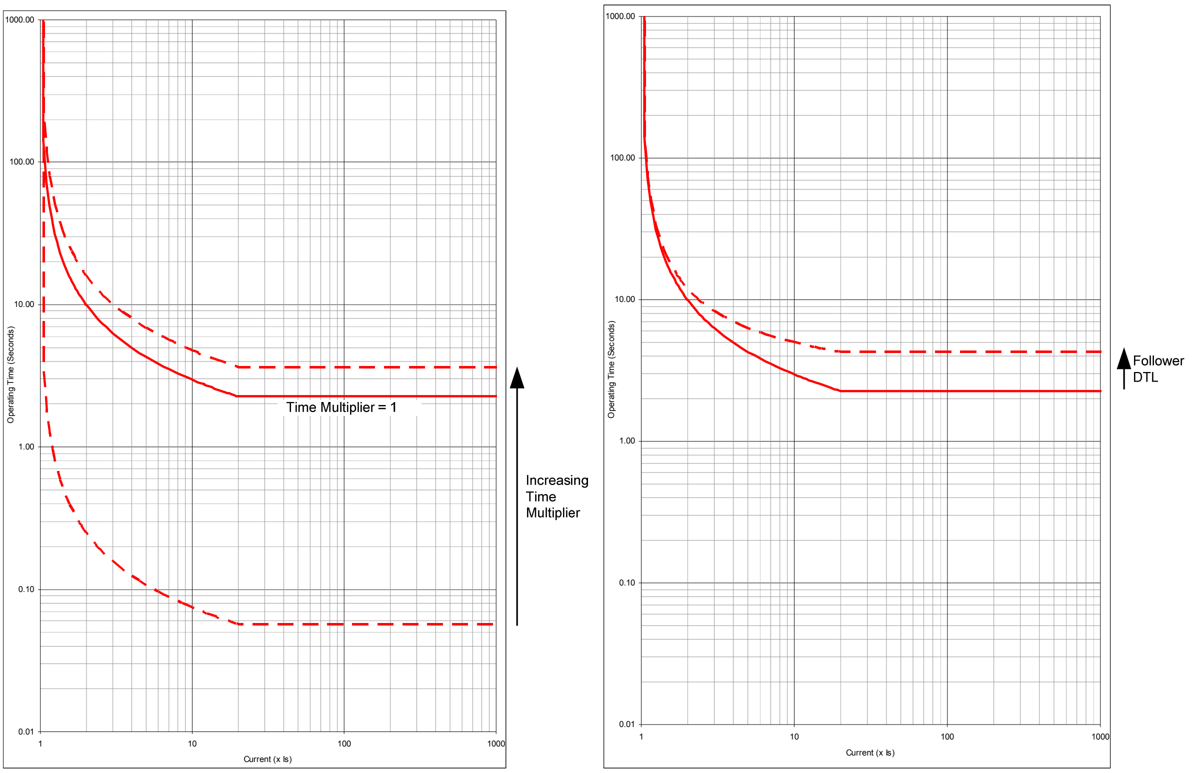


Figure 2-14 IEC NI Curve with Time Multiplier and Follower DTL Applied

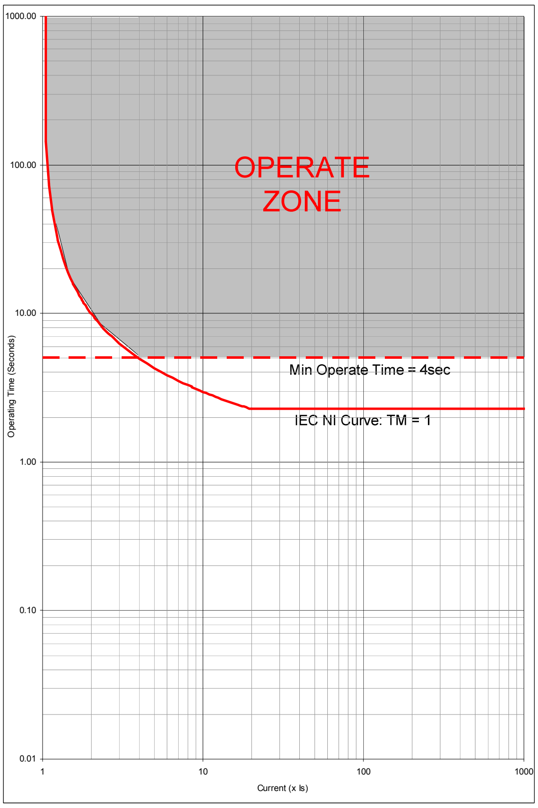


Figure 2-15 IEC NI Curve with Minimum Operate Time Setting Applied

2.3.2 Reset Delay

Faults in plastic insulated cables or compound-filled joint boxes can be intermittent or ‘flashing’ faults – the insulant melts and temporarily reseals the fault for a short time after which the insulation fails again.

The repeating process of the fault often causes electromechanical disc relays to “ratchet” up and eventually trip the faulty circuit if the reset time of the relay was longer than the time between successive flashes.

To ensure time grading is maintained with other relays on the system a DTL or shaped (ANSI only) reset characteristic can be selected for all overcurrent and earth fault elements.

Where the substation feeds an outgoing overhead line network, particularly where reclosers are installed, instantaneous resetting is desirable to ensure that, on multiple shot reclosing schemes, correct grading between the substation incomer relays and the relays associated with the reclosers is maintained.

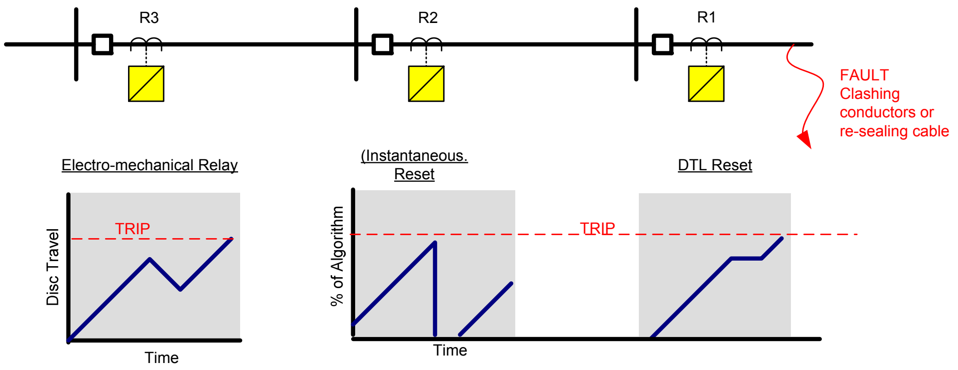


Figure 2-16 Overcurrent Reset Characteristics

2.4 High Impedance Restricted Earth Fault (64H)

Restricted earth fault (REF) protection can be applied to either or both windings of the transformer. The 7SR24 provides a high impedance REF (64H) element for each transformer winding. Low leakage reactance CTs (Class PX) are required for use with high impedance protection systems.

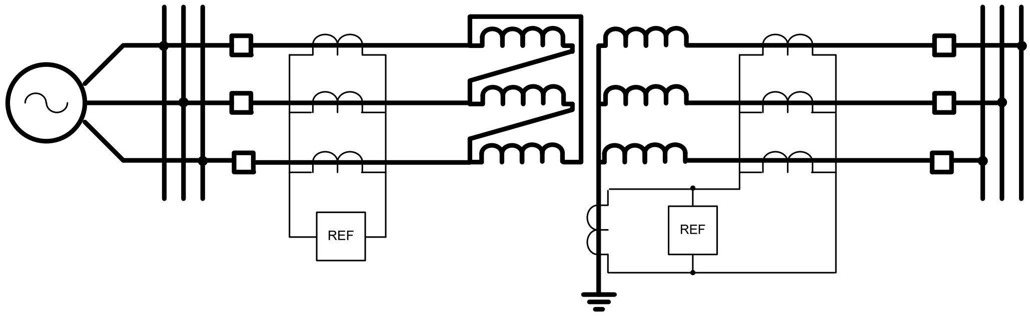


Figure 2-17: REF Protection Applied to a Delta/Star Transformer

The zone of REF protection is defined by the position of the CTs and/or the transformer winding. REF protection provides a low operate current (fault setting) for in zone earth faults and stability during external faults.

REF is more sensitive than overall biased differential protection (87BD) to earth faults it can protect against faults for a greater portion of the transformer windings or where the impedance in the earth fault path is relatively high. For a solidly earthed star winding, the REF function is roughly twice as sensitive in detecting a winding earth fault, than biased differential protection.

The stability of high impedance REF schemes depends upon the operate voltage setting being greater than the voltage which can appear across the element during the maximum assigned through fault conditions. To provide the required operating voltage an external 'stabilising' resistor is wired in series with the 64H current measuring input. A non-linear resistor is connected in parallel to protect the relay circuit against high over-voltages. REF connections are shown in fig. 2.4-2.

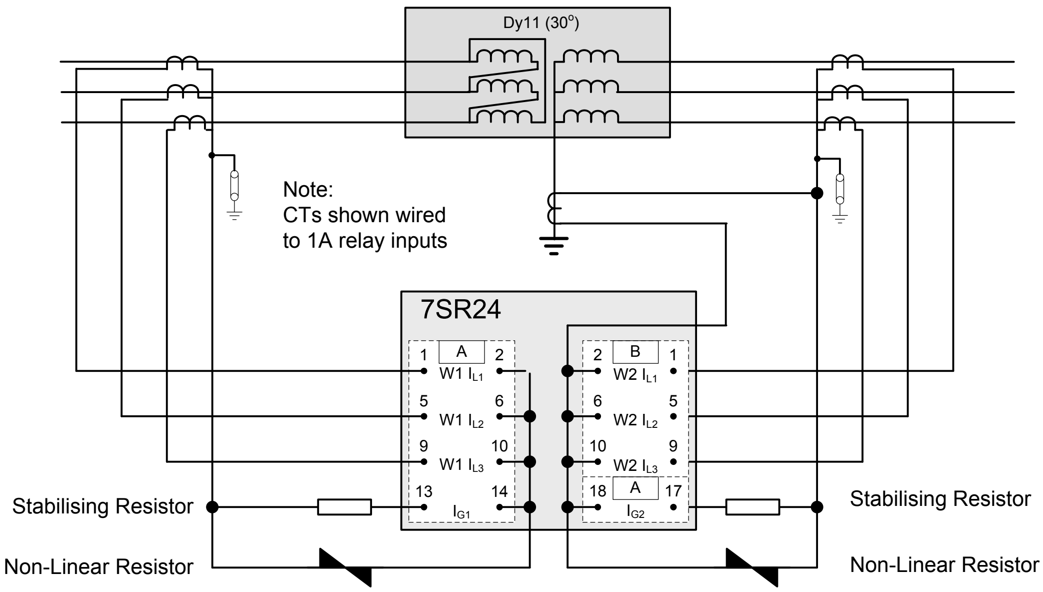


Figure 2-18: AC Connections: REF

The operating voltage of the relay/stabilising resistor combination is calculated taking into account: the r.m.s. value of the symmetrical component of the transformer through fault current

The relay current setting is calculated taking into account: the required operate level for in-zone earth faults (fault setting).

Determination of Stability

The stability of the high impedance REF scheme depends upon the operate voltage setting being greater than the maximum voltage which can appear across the element/stabilising resistor during the maximum assigned through fault conditions. It is assumed that any earthing resistor can become short-circuit.

This maximum voltage that can appear across the relay circuit can be determined by a simple calculation which makes the following assumptions:

One current transformer is fully saturated making its excitation current negligible.

The remaining current transformers maintain their ratio.

The resistance of the secondary winding of the saturated CT together with the leads connecting it to the relay circuit terminals constitute the only burden in parallel with the relay.

The minimum required relay operate voltage setting (Vs) is given by:

(1) $V_S \geq I_{MAX}(R_{CT} + R_L)T$

Where:

I_{MAX} = Maximum steady state through fault current of the transformer

R_{CT} = CT secondary winding resistance

R_L = Lead loop resistance between the CT and the relay circuit terminals

T = Turns ratios of the CTs

Establishing the Primary Operating Current (Fault Setting)

The required relay setting current is given by:

(2) $I_S = \frac{I_F}{T} - \left(\sum I_{mag} + I_{NLR}\right)$

Where:

I_S = Relay setting current

I_F = Required primary operate current (fault setting)

I_{mag} = CT magnetising current at Vs

I_{NLR} = Current through the non-linear resistor at Vs (usually small and often may be neglected)

Equation (2) should properly be the vector sum, however arithmetic addition is normally used.

Establishing the Required Stabilising Resistor Value

The required resistance value is given by:

(2) $R = \frac{V_S}{I_S}$

The exact resistance value is not necessary, a higher resistor standard value may be chosen provided that the resultant voltage setting (Vs) is less than 0.5 x Minimum CT Knee Point Voltage.

Thermal Ratings of Relay Circuit Components

The required Watt-Second ratings of the stabilising resistor and the non-linear shunt resistor are established at setting (continuous rating) and at the maximum fault rating (short time rating).

Resistors should be mounted vertically in a well ventilated location and clear of all other wiring and equipment to avoid the effects of their power dissipation.

2.5 Open Circuit (46BC)

Used to detect an open circuit condition e.g. an OLTC failure.

There will be little or no fault current and so differential elements will not detect the condition. However the condition can be detected because there will be a high content of NPS (unbalance) current present.

An NPS / PPS ratio > 50% will result from an open circuit condition.

A time delay can be applied to prevent operation for transitory effects.

2.6 Negative Phase Sequence Overcurrent (46NPS)

The Negative Phase Sequence (NPS) over current is intended to be used to detect uncleared system faults and conditions such as broken primary connections that may produce significant NPS current.

This unbalance may cause rotating plant such as generators or motors to overheat and fail.

This may also be used to monitor the state of the tap changer and alarm for faults with diverter resistors or switches.

Typical Settings are 5 to 10% for Tap Changer alarm and 10 to 15% for system fault or broken conductor.

2.7 Undercurrent (37)

Where current decreases beneath defined levels this can indicate low load or CB open conditions, it can also be used to indicate that no current is flowing.

The undercurrent function is used:

As a fault current check i.e. that no fault current continues to flow and that an auto-isolation sequence may safely be initiated.

As a check that a CB has opened – this can be used in addition to or in place of CB auxiliary switch indications.

2.8 Thermal Overload (49)

Thermal protection is provided to supplement the Winding Temperature device. This function provides a general overload thermal protection i.e. not a winding hot spot protection.

Outputs can be assigned to both alarm and trip levels. The default settings are recommended if transformer data is not available, these settings correspond to the lowest level of thermal withstand for an oil filled transformer.

Transformer overloading can result in:-

- Reduced transformer life expectancy.
- Lower insulation voltage withstand due to degradation of the insulation.
- Increased mechanical stress due to expansion.
- Gas bubble production in the mineral oil at extreme levels of overload.

2.8.1 Settings Guidelines

49 Overload Setting

The ***49 Overload Setting*** is expressed as a multiple of the relay nominal current and is equivalent to the factor $k.I_B$ as defined in the IEC255-8 thermal operating characteristics. It is the value of current above which 100% of thermal capacity will be reached after a period of time. This setting should be set to 110% of the secondary current flowing when the transformer is at its full rating and on its minimum voltage tap position.

49 Time Constant Setting

A transformer may be required to temporarily run overloaded e.g. 150% of rating for two hours or 200% of rating for one hour.

The thermal time constants required to match these specifications are:

150% for two hours	Time constant = 178 minutes
200% for one hour	Time constant = 186 minutes

These times are applicable to an overload occurring from no load with the transformer at ambient temperature.

The actual tripping time will depend on the loading level prior to the overload occurring.

The operate time can be calculated from:

Time to trip $t(\text{mins}) = \tau \times \ln\left[\dfrac{I^2}{I^2 - (I_\theta)^2}\right]$

The steady state % thermal capacity used can be calculated from:

$$\%\ \text{thermal capacity used} = \left[\frac{I^2}{(I_\theta)^2}\right] \times 100$$

Where:

I = applied current in terms of x I_n

I_Θ = thermal pick-up setting x I_n

49 Capacity Alarm Setting

This setting can be used to provide an alarm prior to a thermal trip occurring and is typically set to about 80 to 90 % of thermal capacity. The thermal capacity alarm can be mapped to a binary output wired to the control system.

Example

45MVA, Z = 10%, Dyn1, 132/33kV +5% to -15%

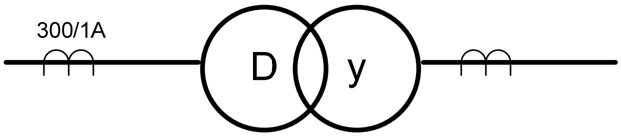


Figure 2-19 Thermal Overload Settings

1. In fig. 2-19 the direction of power flow is HV to LV. If W1 input is connected to HV CTs (as is usual) then set ***49 Select*** = **W1.** The transformer loss current and harmonic currents are then included in the thermal calculation.

2. **FUNCTION CONFIG>***Gn Thermal:* Enabled
CURRENT PROT'N>THERMAL>*Gn49 Thermal Overload:* Enabled.

3. **CURRENT PROT'N>THERMAL>*49 Overload Setting***:

   Maximum Primary Full Load current = $\frac{45000}{\sqrt{3}\times 132\times 0.85} = 231.5A$

   Secondary Current = 231.5A/300 = 0.772A. The thermal function should not trip for currents below this value.

   A setting of 110% is used to include a margin of safety.

   Therefore ***49 Overload Setting*** = 0.85 x I_n (I_θ) (1.10 x 0.772)

4. The time constant to apply will depend upon the transformer overload specification, but in this case it was decided to set a time constant of 178 minutes. This will allow an overload of 150% from ambient for about two hours before a trip is issued.

5. The capacity alarm is a useful function and therefore it is set to 90%. The current required to reach this 90% figure should be calculated. It is important not to alarm for current within the normal loading range of the transformer.

   The steady state thermal capacity = I^2 / I_θ^2 x 100%

   For this example: 90% = I^2 / I_θ^2 x 100%. I = 0.806 x I_n and this level is above the maximum full load current of 0.772 x I_n.

The above provides guidelines only as setting philosophies differ. Alternative protection setting groups may be used to match transformer loading for temporary or emergency overloads, wide variations in winter/summer loading or if a cooling failure (pump or fan) occurs. The thermal settings applied will differ in each Setting Group and will be made appropriate to the specific load conditions.

2.9 Under/Over Voltage (27/59)

Power system under-voltages may occur due to:

System faults.

An increase in system loading,

Non-energized power system e.g. loss of an incoming transformer

During normal system operating conditions regulating equipment such as transformer On Load Tap Changers (OLTC) and generator Automatic Voltage Regulators (AVR) ensure that the system runs within acceptable voltage limits.

7SR24 undervoltage/DTL elements can be used to detect abnormal undervoltage conditions due to system overloads. Binary outputs can be used to trip non-essential loads - returning the system back to its normal operating levels. This ‘load shedding’ should be initiated via time delay elements so avoiding operation during transient disturbances. An under voltage scheme (or a combined under frequency/under voltage scheme) can provide faster tripping of non-essential loads than under-frequency load shedding so minimising the possibility of system instability.

Where a transformer is supplying 3-phase motors a significant voltage drop e.g. to below 80% may cause the motors to stall. An undervoltage element can be set to trip motor circuits when the voltage falls below a preset value so that on restoration of supply an overload is not caused by the simultaneous starting of all the motors. A time delay is required to ensure voltage dips due to remote system faults do not result in an unnecessary disconnection of motors.

To confirm presence/loss of supply, the voltage elements should be set to values safely above/below that where a normal system voltage excursion can be expected. The switchgear/plant design should be considered. The ‘Dead’ level may be very near to the ‘live’ level or may be significantly below it. The variable hysteresis setting allows the relay to be used with all types of switchgear.

System over-voltages can damage component insulation. Excessive voltage may occur for:

Sudden loss of load

A tap changer run-away condition occurs in the high voltage direction,

Generator AVR equipment malfunctions or

Reactive compensation control malfunctions.

System regulating equipment such as transformer tap changers and generator AVRs may correct the overvoltage – unless this equipment mal-functions. The 7SR24 overvoltage/DTL elements can be used to protect against damage caused by system overvoltages.

If the overvoltage condition is small a relatively long DTL time delay can be used. If the overvoltage is more severe then another element, set at a higher pickup level and with a shorter DTL can be used to isolate the circuit more quickly. Alternatively, elements can be set to provide alarm and tripping stages, with the alarm levels set lower than the tripping stages.

The use of DTL settings allows a grading system to be applied to co-ordinate the network design, the regulating plant design, system plant insulation withstand and with other overvoltage relays elsewhere on the system. The DTL also prevents operation during transient disturbances.

The use of IDMTL protection is not recommended because of the difficulty of choosing settings to ensure correct co-ordination and security of supply.

2.10 Neutral Overvoltage (59N)

Neutral Overvoltage Displacement (Residual Overvoltage) protection is used to detect an earth fault where little or no earth current flows.

This can occur where a transformer feeder has been tripped at its HV side for an earth fault, but the circuit is still energised from the LV side via an unearthed transformer winding. Insufficient earth current would be present to cause a trip, but residual voltage would increase significantly; reaching up to 3-times the normal phase-earth voltage level.

If Neutral Overvoltage protection is used, it must be suitably time graded with other protections in order to prevent unwanted tripping for external system earth faults.

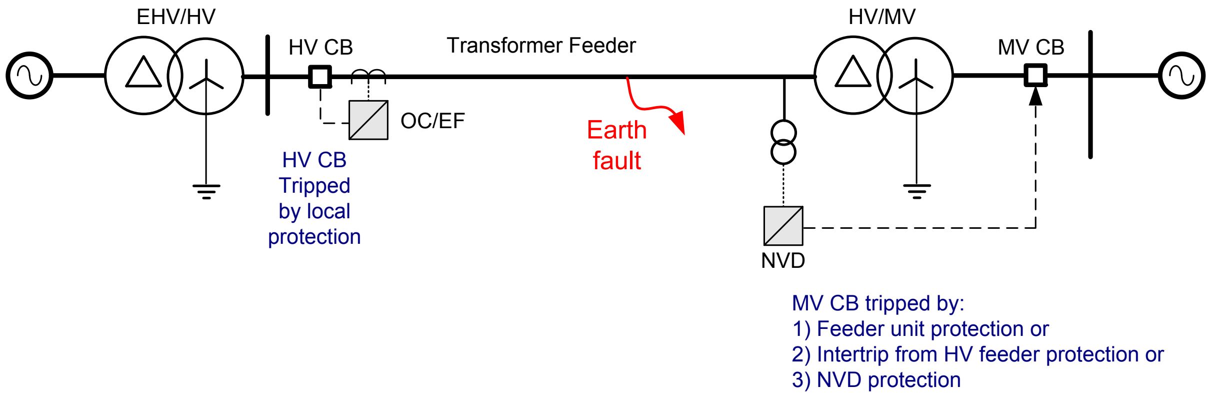


Figure 2-20 NVD Application

Typically NVD protection measures the residual voltage ($3V_0$) directly from an open delta VT or from capacitor cones – see fig. 2.13-2 below.

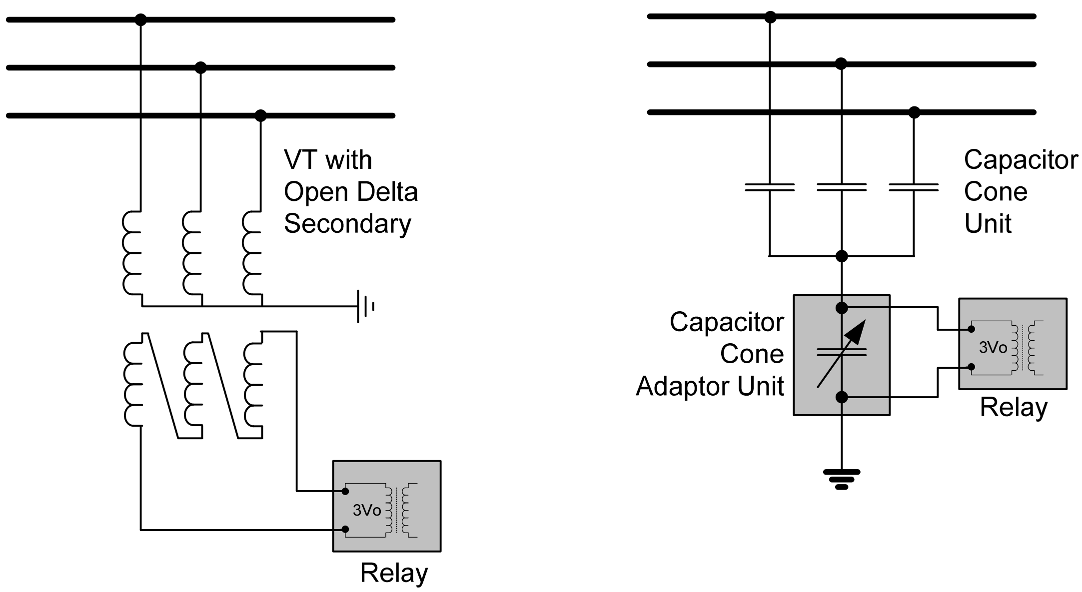


Figure 2-21 NVD Protection Connections

2.10.1 Application with Capacitor Cone Units

Capacitor cones provide a cost effective method of deriving residual voltage. The wide range of capacitor cone component values used by different manufacturers means that the relay cannot be connected directly to the cones.

The external adaptor unit contains parallel switched capacitors that enable a wide range of values to be selected using a DIL switch and hence the Capacitor Cone output can be scaled to the standard relay input range.

2.10.2 Derived NVD Voltage

Alternatively NVD voltage can be derived from the three phase to neutral voltages, this setting is available within the relay. Note with this method the NVD protection may mal-operate during a VT Fail condition.

2.11 Under/Over Frequency (81)

During normal system operation the frequency will continuously vary over a relatively small range due to the changing generation/load balance. Excessive frequency variation may occur for:

> Loss of generating capacity, or loss of mains supply (underfrequency): If the governors and other regulating equipment cannot respond to correct the balance, a sustained underfrequency condition may lead to a system collapse.
>
> Loss of load – excess generation (overfrequency): The generator speeds will increase causing a proportional frequency rise. This may be unacceptable to industrial loads, for example, where the running speeds of synchronous motors will be affected.

In the situation where the system frequency is falling rapidly it is common practise to disconnect non-essential loads until the generation-load balance can be restored. Usually, automatic load shedding, based on underfrequency is implemented. Underfrequency relays are usually installed on the transformer incomers of distribution or industrial substations as this provides a convenient position from which to monitor the busbar frequency. Loads are disconnected (shed) from the busbar in stages until the frequency stabilises and returns to an acceptable level.

The 7SR24 has six under/over frequency elements.

An example scheme may have the first load shedding stage set just below the nominal frequency, e.g. between 49.0 - 49.5Hz. A time delay element would be associated with this to allow for transient dips in frequency and to provide a time for the system regulating equipment to respond. If the first load shedding stage disconnects sufficient plant the frequency will stabilise and perhaps return to nominal. If, however, this is not sufficient then a second load shedding stage, set at a lower frequency, will shed further loads until the overload is relieved. This process will continue until all stages have operated. In the event of the load shedding being unsuccessful, a final stage of underfrequency protection should be provided to totally isolate all loads before plant is damaged, e.g. due to overfluxing.

An alternative type of load shedding scheme would be to set all underfrequency stages to about the same frequency setting but to have different length time delays set on each stage. If after the first stage is shed the frequency doesn't recover then subsequent stages will shed after longer time delays have elapsed.

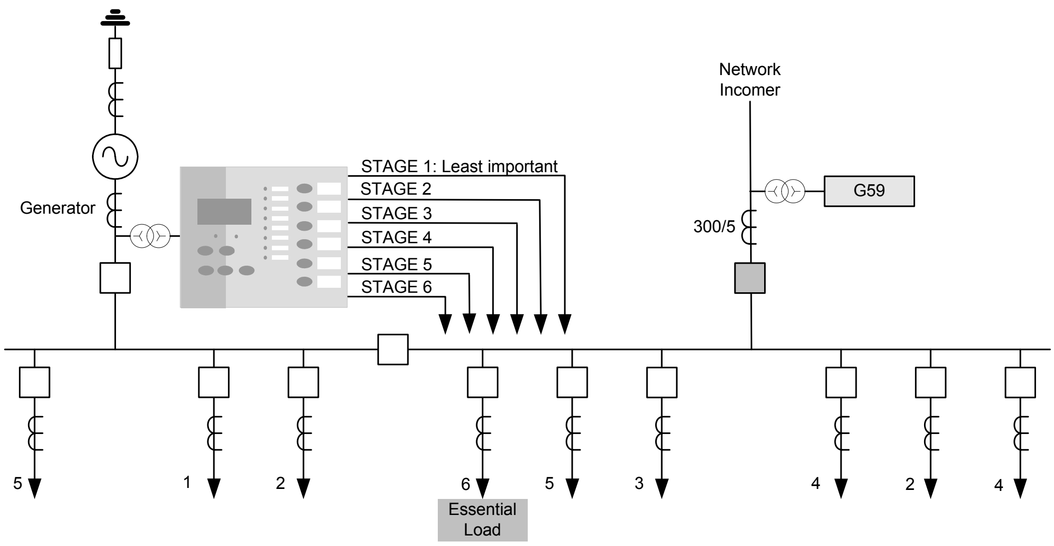


Figure 2-22 Load Shedding Scheme Using Under-Frequency Elements

2.12 Over Fluxing Protection (24)

An underfrequency condition at nominal voltage can cause over-fluxing (or over-excitation) of the transformer. Excess flux can cause transformer core saturation and some of the flux will radiate as leakage flux through the transformer tank. This leakage flux causes eddy currents and the I^2R losses from these currents heat the transformer tank and can cause overheating.

Overfluxing protection is applied to generator step-up transformers and other plant which may be subject to this condition.

This function measures the ratio of voltage to frequency (V/f) applied the transformer to determine operation.

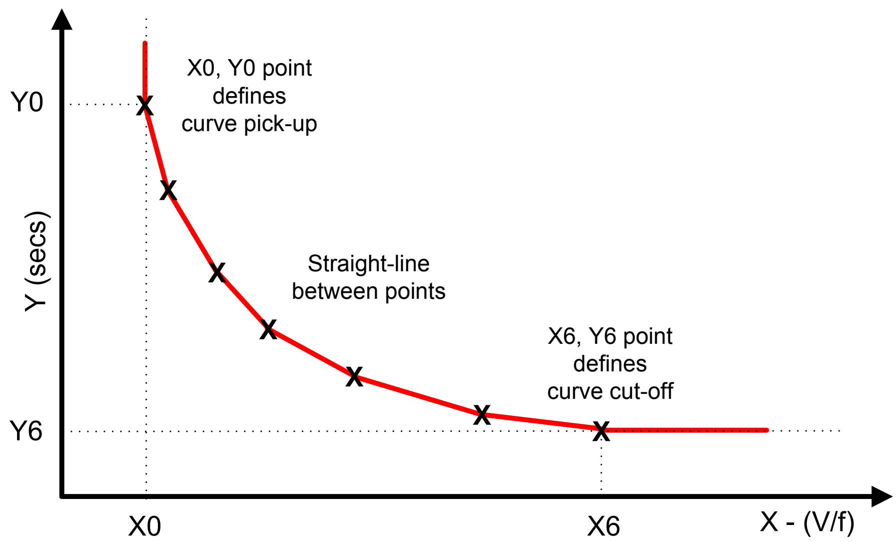
The relay has two types of V/f characteristics:

- User Definable Inverse curve
- Two Independent Definite Time Lag elements(DTL)

User Definable V/f Curve

As the leakage flux will cause overheating, an inverse type curve provides an appropriate match to the over fluxing withstand characteristics of a transformer.

The relay includes a user definable curve. Where the transformer manufacturer has provided an over-fluxing withstand curve the user can define up to seven points to provide correlation between the relay characteristic and transformer withstand curves.



Two Stage DTL Over fluxing

In addition to the inverse curve, two independent DTL V/f elements are included and are used where the over excitation withstand curve of the transformer is not known. In this case the inverse V/f curve should be set to [Disabled] and both DTL elements should be set to [Enabled]. The default DTL settings are adequate to protect almost all transformer designs, and can be used with confidence.

Section 3: CT Requirements

The specification of CTs must meet the requirements of all protection functions utilised e.g. overall differential, REF and backup over current protections.

The relay has 1A and 5A rated terminals for each CT input and any combination of these may be used. 1A rated CTs can be used on one winding and together with 5A rated CTs on the other.

3.1 CT Requirement for Differential Protection

The quality of CTs will affect the performance of the protection system. The CT knee-point voltage (V_k) is a factor in assessing protection performance.

If a high level internal short circuit occurs the dc offset in the primary fault current may produce transient CT saturation. This is more likely to occur if the CT knee-point is low and/or the connected burden is high. Saturated CTs produce high levels of even harmonics which may increase the operate time of the biased differential function where harmonic restraint or inhibit is applied.

A highset differential element (87HS) can be used without harmonic restraint this can reduce the overall operating time of the differential protection.

Restricted Earth Fault protection helps ensure fast tripping as its speed of operation is not affected significantly by CT saturation.

For high speed operation:

$$\mathbf{Vk \geq 4 \times I_{FS} \times (A + C)}$$

Where:

Vk = CT knee point voltage.

I_{FS} = Max. secondary 3-phase through fault current (as limited by the transformer impedance).

A = Secondary winding resistance of each star connected CT.

C = The CT secondary loop lead resistance.

Where the CTs used have a lower knee point voltage e.g. half that calculated in the expression above the biased differential elements may have a slightly longer operate time. To ensure stability during through fault conditions the biased differential settings should be increased by 10%.

Advice on CT Selection.

1A rated CT secondaries are preferred to 5A CTs as the CT VA burden is reduced by a factor of 25.

Line current transformer ratios should be selected to match the main transformer rating and ratio. However the ***ICT Multiplier*** adjustment can be used to compensate for non matched ratios. Choose a CT ratio that produces at least 0.33 x nominal secondary rating, when based on the transformer is at nameplate rating i.e. within the range of the ***ICT Multiplier*** setting.

Where long secondary lead lengths are required measures can be taken to reduce the burden imposed on the CTs:

Use high CT ratios to reduce the secondary current. Compensate the low secondary current using the ICT Multipliers..

Parallel CT secondary cable cores to reduce lead resistance.

Worked Example

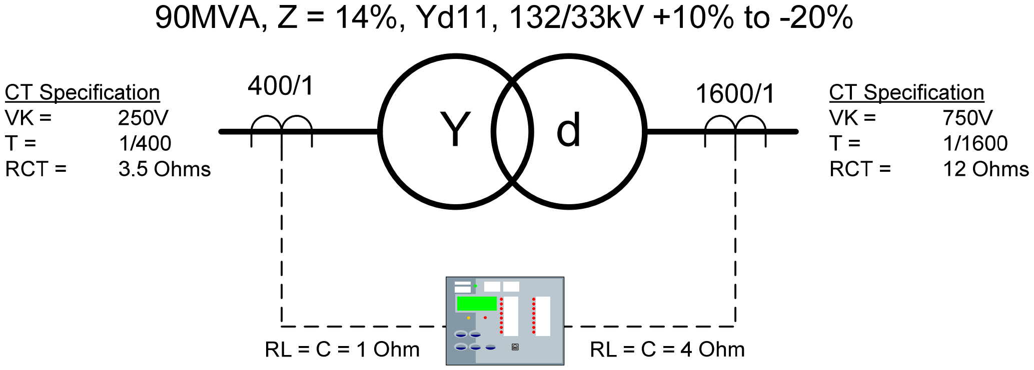


Figure 3-1 CT Requirements

Suitability of HV Current Transformers:

$$V_K \geq 4 \times \frac{90 \times 10^6}{\sqrt{3} \times 132 \times 10^3 \times 400 \times 0.14} \times (3.5 + 1) = 126.5\text{V} \text{ i.e. less than 250V}$$

Suitability of LV Current Transformers:

$$V_K \geq 4 \times \frac{90 \times 10^6}{\sqrt{3} \times 33 \times 10^3 \times 1600 \times 0.14} \times (12 + 4) = 449.9\text{V} \text{ i.e. less than 750V}$$

An indication of the suitability of a protection class CT e.g. class 5P to IEC60044 classification can be obtained. The product of its rated burden expressed in ohms and the secondary current equivalent of its accuracy limit primary current will give an approximation of the secondary voltage it can produce while operating within the limit of its stated composite error.

3.2 CT Requirements for High Impedance Restricted Earth Fault (64H)

For high impedance REF protection:

Low reactance CTs to IEC Class PX must be used, this allows a sensitive current setting to be applied.

All current transformers should have an equal turns ratio.

The knee-point voltage of the CTs must be greater than 2 x 64H Setting Voltage (Vs) – see section 2.4.

A full explanation of how to specify CTs for use with REF protection, and set REF relays is available on our Website: www.siemens.com/energy .

Section 4: Control Functions

4.1 User Defined Logic

4.1.1 Auto-Changeover Scheme Example

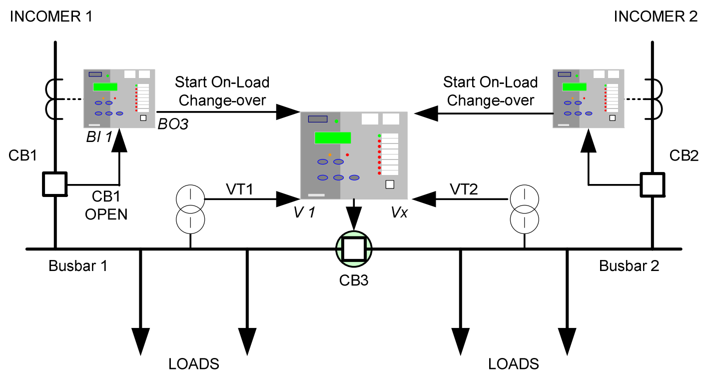


Figure 4-1 Example Use of Quick Logic

The MV installation illustrated above is fed from two incomers. To limit the substation fault level the busbar is run with CB3 open. When a fault occurs on one of the incomers it is isolated by the circuit protection. To re-supply the disconnected loads from the remaining incomer CB3 is closed.

If the line fault occurs on incomer 1 it must be confirmed that CB 1 has opened before CB3 can be closed. The relay on incomer 1 confirms that a trip has been issued to CB1 (e.g. Binary Output 2), that CB 1 has opened (e.g. Binary Input 1) and that no current flows in the circuit (e.g. 37-1 = Virtual 1):

Incomer 1 Relay is Configured:

CB1 Open auxiliary switch wired to B.I. 1

Trip output to CB1 = B.O. 2

OUTPUT CONFIG>OUTPUT MATRIX: ***37-1*** = **V1**

OUTPUT CONFIG>OUTPUT MATRIX: ***E1*** = **BO3**

CONTROL & LOGIC>QUICK LOGIC: ***E1*** = **O2.I1.V1**

The output from Incomer 1 (BO3) relay is input to the relay on CB 3 (Binary Input 1). A panel switch may be used to enable the On-Load Change-over scheme (Binary Input 2). Before Closing CB3 a check may be made that there is no voltage on busbar 1 (27/59-1 = Virtual 1). CB 3 is closed from Binary Output 3.

CB3 Relay is Configured:

Panel switch (ON-Load Change-over Enabled) wired to B.I. 1

OUTPUT CONFIG>OUTPUT MATRIX: ***27/59-1*** = **V1**

OUTPUT CONFIG>OUTPUT MATRIX: ***E1*** = **BO3**

CONTROL & LOGIC>QUICK LOGIC: ***E1*** = **I1.I2.V1**

If required a time delay can be added to the output using the CONTROL & LOGIC > QUICK LOGIC: ***E1 Pickup Delay*** setting.

Section 5: Supervision Functions

5.1 Inrush Detector (81HBL2)

87 Inrush Element (Enable, Disable)

When a transformer is energized transient magnetizing inrush currents flow in each phase of the energised winding. Inrush currents only flow into one transformer winding and the resulting unbalance can be sufficient to cause mal-operation of the biased differential elements. To prevent the relay operating for this non-fault condition, the presence of even harmonics in the current is used to distinguish between inrush currents and short circuit faults.

The inrush restraint detector can be used to block the operation of selected elements during transformer magnetising inrush conditions.

The ***81HBL2 Bias*** setting allows the user to select between, **Phase, Sum** and **Cross** methods of measurement. Each of the three selections has a specific application.

Phase – The even harmonic content in each phase is measured independently and compared to the total operate current in its own phase i.e. each phase of the biased differential elements is blocked by even harmonic content in its own phase only.

This method is used exclusively where large transformers are manufactured with three separate phase tanks each containing a phase core. This construction facilitates transportation. Each of the phase cores is not magnetically affected by the flux in the other phase cores.

These large single phase transformers are often auto-transformers used on EHV transmission systems. A typical setting level for this application is 18% of Id.

Cross – Each phase is monitored and if the even harmonic present in any phase exceeds the setting then all three phases are blocked. This method is used for the majority of applications of the relay to power transformers.

Generally the default setting of 0.20 x Id provides stable operation.

Sum – The level of even harmonic current (2nd and 4th) in the differential signal for each phase is measured. The square root is taken of each of these even harmonic currents and these three values summated. This single current level is then divided by the Inrush Setting to arrive at the Harmonic Sum with which each of the phase currents are compared.

If the operate current in any phase is greater than this Harmonic Sum then its differential element will operate.

The advantage of this method is it allows fast operation of the biased differential element if the transformer is switched onto an internal phase to earth fault. The cross method may suffer from slowed operation for this situation, as healthy phase inrush may block all three phases (including the one feeding the fault current) from operating. Where REF is used to protect the winding, the slowed operation is not critical as the REF will operate very fast, typically in about 20ms for this rare condition.

The Sum method is not slowed down when switching onto an in zone earth fault, as the Harmonic Sum is reduced by the presence of the fault current and therefore allows relay operation.

Typically the Sum method will allow the biased differential elements to operate in the normal time of about 30ms, if a transformer earth fault occurs when it is energised.

This setting is recommended if REF is not used to protect the windings for earth faults on effectively earthed power systems. The recommended setting that offers a good compromise between stability for typical inrush currents and fast operation for internal faults is 0.15 x Id.

87 Inrush Setting (0.1 to 0.5 x Id)

This defines the levels of inrush used in each of the above methods.

The setting applied will determine the level of even harmonic (second and fourth) content in the relay operating current that will cause operation of the relay to be inhibited. The lowest setting of 0.1 x Id therefore represents the setting that provides the most stability under magnetising inrush conditions.

The recommended settings for each method are:

Phase – 0.18 x Id

Cross – 0.20 x Id

Sum – 0.15 x Id

These setting provide a good compromise between speed of operation for internal faults and stability for inrush current. Generally the above values will be stable for most cases, but in rare cases may not prevent relay operation for all angles of point on wave switching, and the setting may require being lower slightly. If the relay operates when the transformer is energised, the waveform record should be examined for signs of fault current and the levels of harmonic current.

Set to 0.20 x Id unless a very rare false operation for inrush occurs. In which case a lower setting should be adopted after checking the waveform record for the presence of fault current.

5.2 Overfluxing Detector (81HBL5)

An increase in transformer or decrease in system frequency may result in the transformer becoming over-excited. The 81HBL5 element can be used to prevent protection operation e.g. prevent differential protection operation during acceptable over-excitation conditions.

5.3 Circuit Breaker Fail (50BF)

Where a circuit breaker fails to operate to clear fault current the power system will remain in a hazardous state until the fault is cleared by remote or back-up protections. To minimise any delay, CB Failure protection provides a signal to either re-trip the local CB or back-trip the next 'upstream' CB.

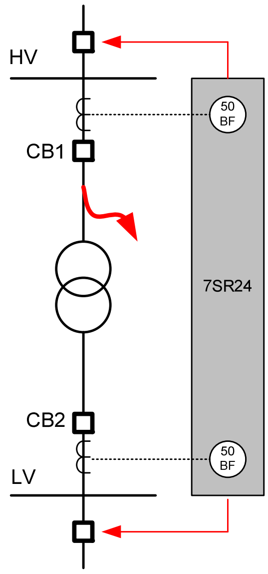


Figure 5-1 - Circuit Breaker Fail

The CBF function is initiated by the operation of either:

Protection functions that operate binary outputs mapped as **OUTPUT CONFIG>BINARY OUTPUT CONFIG>***CBn Trip Contacts,* or

A binary input mapped as **INPUT CONFIG>INPUT MATRIX >***C50BF-n Ext Trip*

Each 50BF uses phase segregated current check elements and two timers.

Current in each phase is monitored and if any of the 50BF current check elements have not reset before the timers have expired an output is given. Typically a single stage scheme is used, DTL1 is wired to back-trip the adjacent CBs e.g. via the busbar protection system. Alternatively the first timer output can be wired to re-trip the failed CB through a different trip coil, and the second timer output is wired to trip the adjacent CBs.

Practical time sequences for single and two stage 50BF applications are illustrated below.

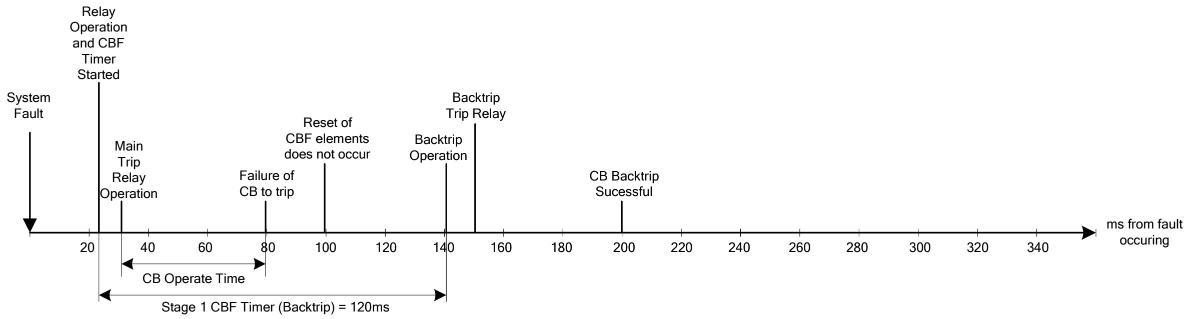


Figure 5-2 - Single Stage Circuit Breaker Fail Timing

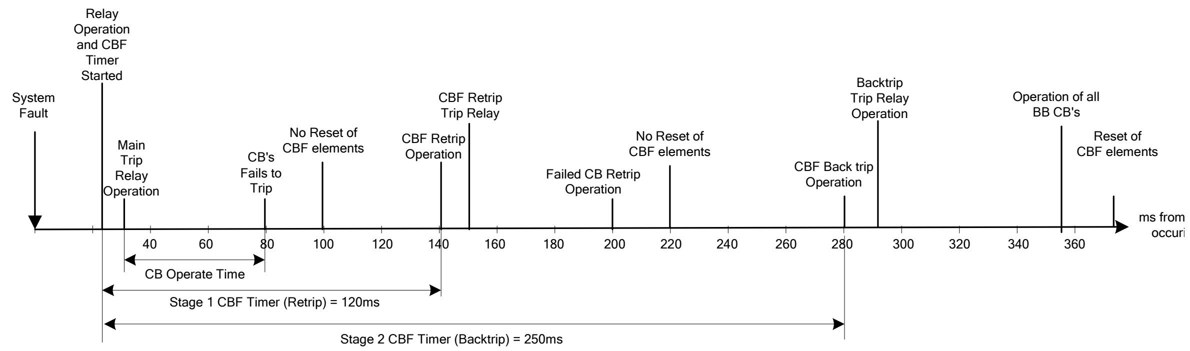


Figure 5-3 - Two Stage Circuit Breaker Fail Timing

Example of Required Settings (e.g. HV CB)

FUNCTION CONFIG>

Gn CB Fail	Enabled

SUPERVISION > CB FAIL > 50BF-1

Gn 50BF-1 Element	Enabled
Gn 50BF-1 Setting	0.2 x In
Gn 50BF-1-1 Delay	120ms
Gn 50BF-1-2 Delay	250ms

INPUT CONFIG>INPUT MATRIX>

50BF-1 Ext Trip	BIn

OUTPUT CONFIG>OUTPUT MATRIX>

50BF-1-1	BOn, Ln
50BF-1-2	BOn, Ln

OUTPUT CONFIG>BINARY OUTPUT CONFIG>

CB1 Trip Contacts	BOn

The above based on:

First Stage Backtrip (or Re-trip)	*Typical Times*
Trip Relay operate time	*10ms*
CB Tripping time	*50ms*
DUOBIAS-M Reset Time	*30ms*
Safety Margin	*30ms*
Overall First Stage CBF Time Delay	*120ms*

Second Stage (Back Trip)	
First CBF Time Delay	*120ms*
Trip Relay operate time	*10ms*
DUOBIAS-M Reset Time	*30ms*
CB Tripping time	*50ms*
Margin	*50ms*
Overall Second Stage CBF Time Delay	*260ms*

5.4 Trip Circuit Supervision (74TCS)

Binary Inputs may be used to monitor the integrity of the CB trip circuit wiring. Current flows through the B.I. confirming the integrity of the auxiliary supply, CB trip coil, auxiliary switch, C.B. secondary isolating contacts and associated wiring connected to that BI. If the current flow ceases, the B.I. drops off and if it is user programmed to operate one of the output relays, this can be used to provide an alarm. In addition, an LED on the relay fascia can be programmed to operate. A user text label can be used to define the operated LED e.g. “Trip CCT Fail”.

The relevant Binary Input is mapped to 74TCS-n in the INPUT CONFIG>INPUT MATRIX menu. To avoid giving spurious alarm messages while the circuit breaker is operating the input is given a 0.4s Drop-off Delay in the INPUT CONFIG>BINARY INPUT CONFIG menu.

To provide an alarm output a normally open binary output is mapped to 74TCS-n.

5.4.1 Trip Circuit Supervision Connections

The following circuits are derived from UK ENA S15 standard schemes H5, H6 and H7.

For compliance with this standard:

> Where more than one device is used to trip the CB then connections should be looped between the tripping contacts. To ensure that all wiring is monitored the binary input must be at the end of the looped wiring.
>
> Resistors must be continuously rated and where possible should be of wire-wound construction.

Scheme 1 (Basic)

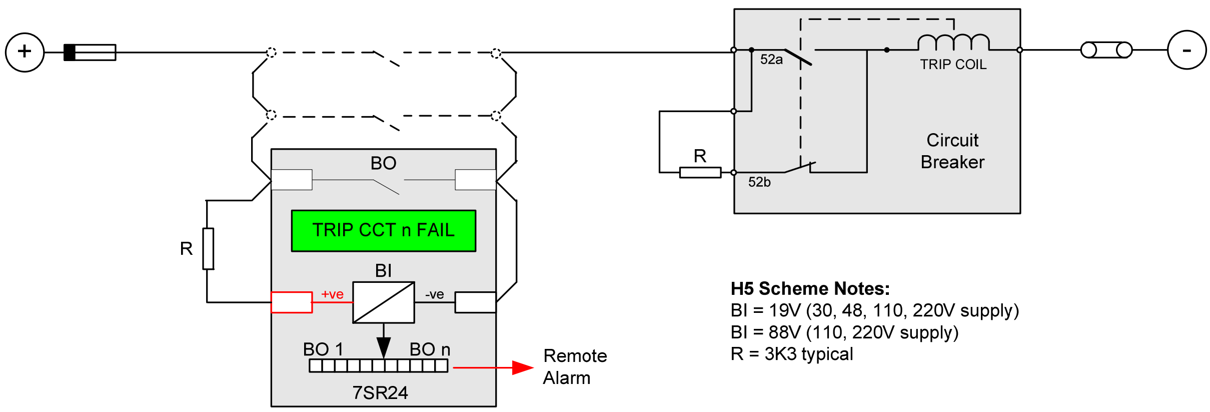


Figure 5-4: Trip Circuit Supervision Scheme 1 (H5)

Scheme 1 provides full Trip and Close supervision with the circuit breaker Open or Closed.

Where a ‘Hand Reset’ Trip contact is used measures must be taken to inhibit alarm indications after a CB trip.

Scheme 2 (Intermediate)

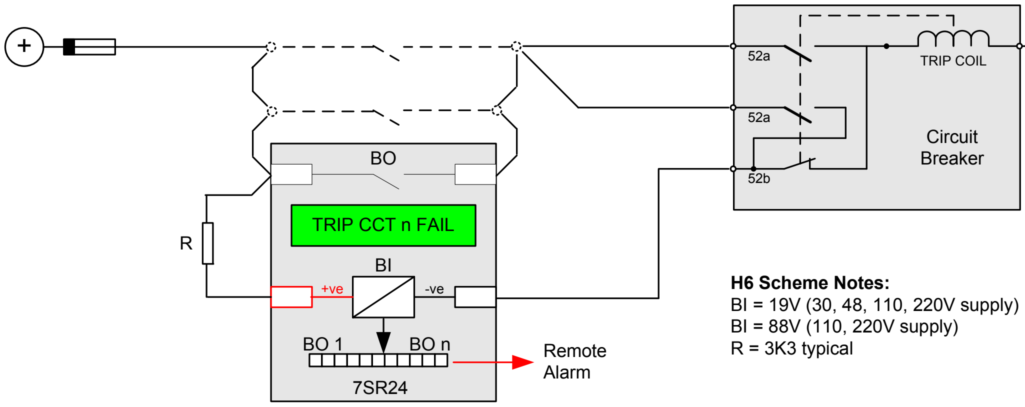


Figure 5-5: Trip Circuit Supervision Scheme 2 (H6)

Scheme 2 provides continuous Trip Circuit Supervision of trip coil with the circuit breaker Open or Closed. It does not provide pre-closing supervision of the connections and links between the tripping contacts and the circuit breaker and may not therefore be suitable for some circuits which include an isolating link.

Scheme 3 (Comprehensive) – 19V Binary Input Only

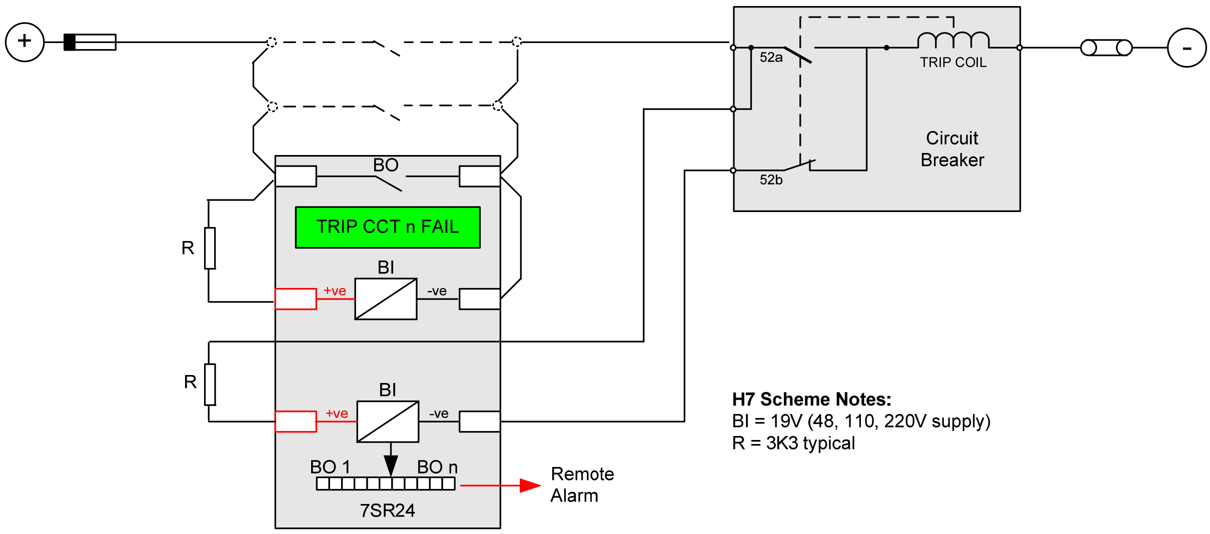


Figure 5-6: Trip Circuit Supervision Scheme 3 (H7)

Scheme 3 provides full Trip and Close supervision with the circuit breaker Open or Closed.

5.4.2 **Close Circuit Supervision Connections**

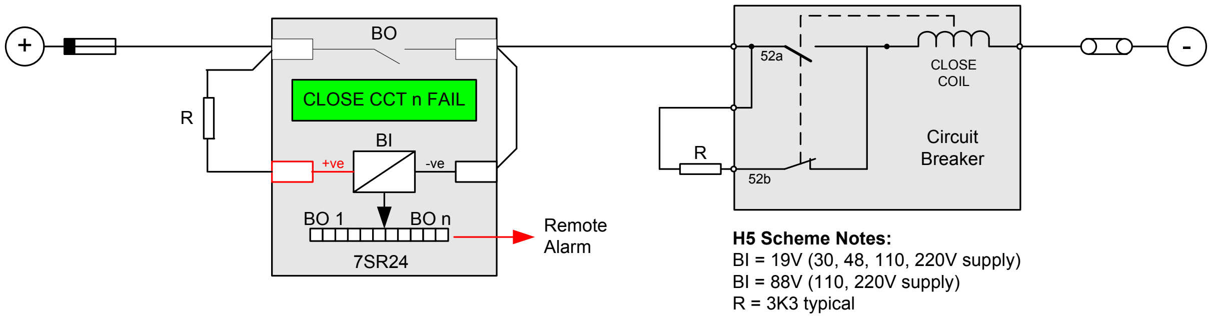


Figure 5-7 Close Circuit Supervision Scheme

Close circuit supervision with the circuit breaker Open or Closed.

Section 6: Application Considerations and Examples

6.1 The Effects of An In Zone Earthing Transformer

The in zone earthing transformer is a source of zero-sequence fault current. An earth fault on the delta side of the transformer external to the differential protection zone will cause zero sequence currents to flow in the CTs on the delta side of the transformer without corresponding current to flow in the line CTs on the star side of the transformer. If these zero sequence currents are allowed to flow through the differential elements they may cause undesired tripping.

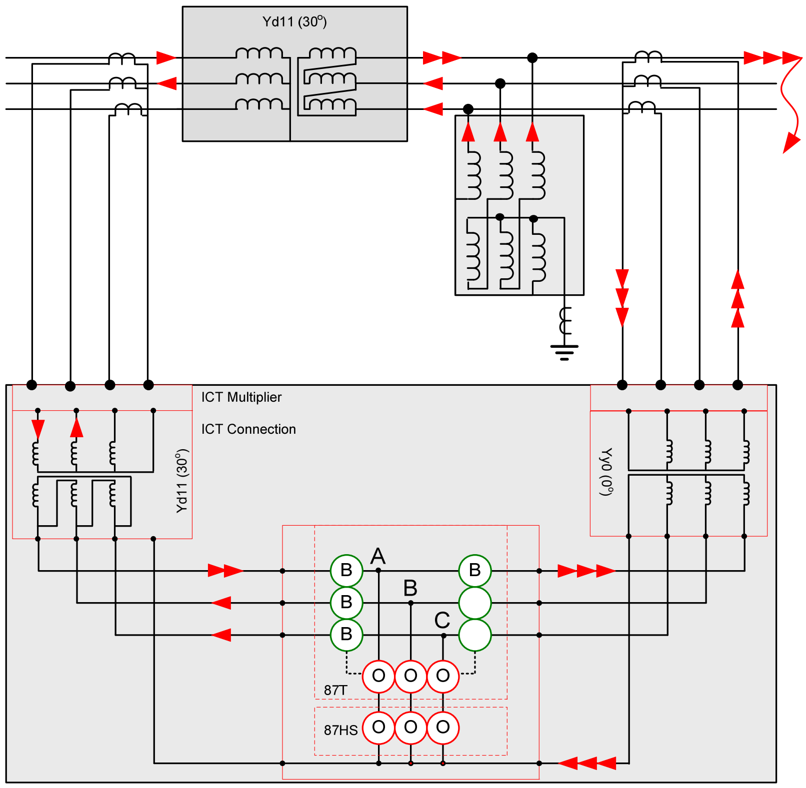


Figure 6-1: Relay Currents – External Earth Fault with In Zone Earthing Transformer

To prevent undesired tripping the ICT connections should be such as to cause the zero sequence currents to flow in a closed delta CT secondary connection of low impedance instead of in the differential relay operating coil. As we have already corrected for the transformer vector group on the star side a Ydy0 ICT is used on the delta side winding.

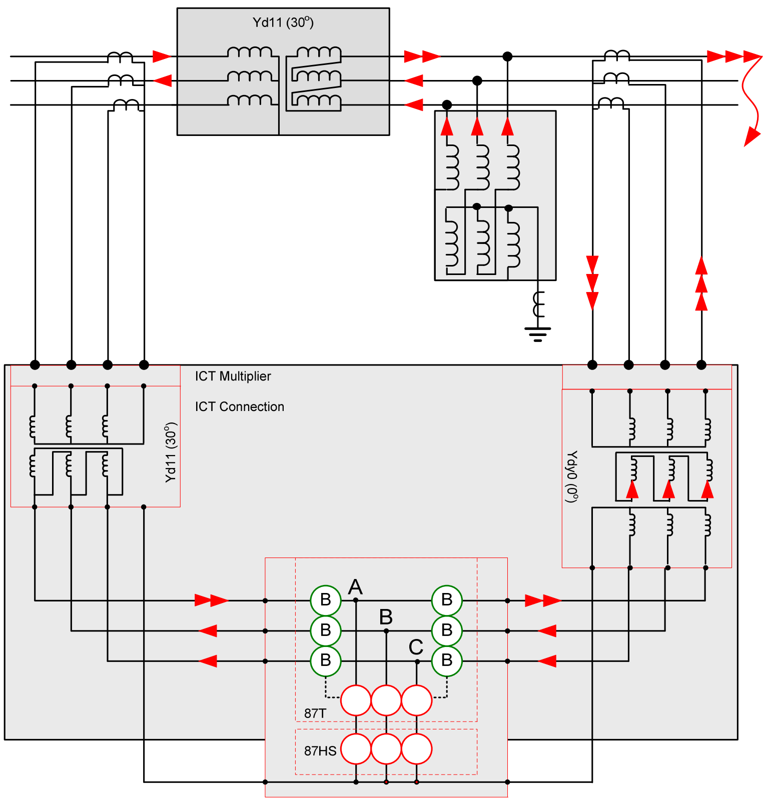
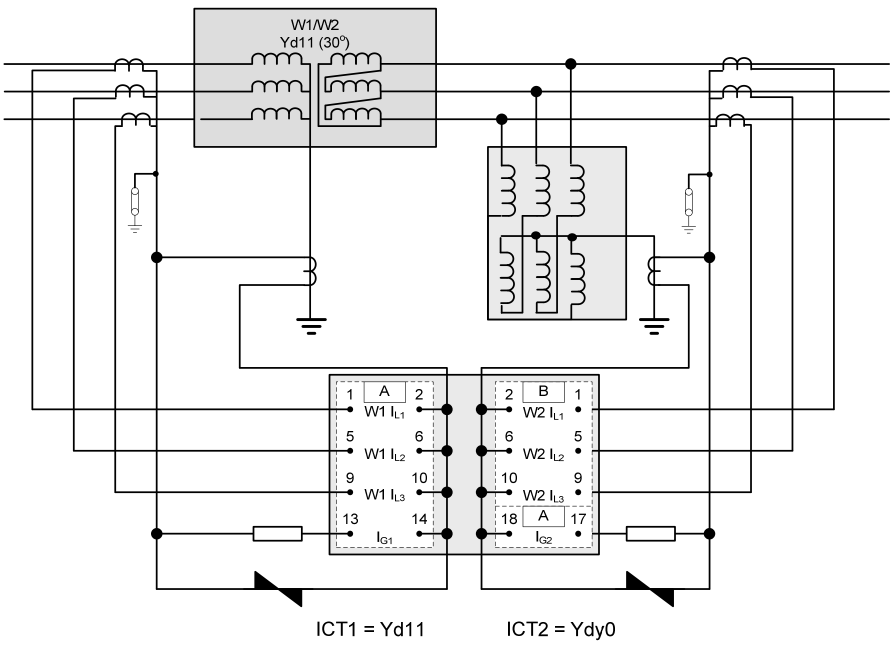


Figure 6-2: Relay Currents – External Earth Fault with In Zone Earthing Transformer



NOTES
CTs shown wired to 1A relay inputs

Figure 6-3 7SR24 Applied to Yd Transformer with an In Zone Earthing Transformer

6.2 Protection of Star/Star Transformer With Tertiary Winding

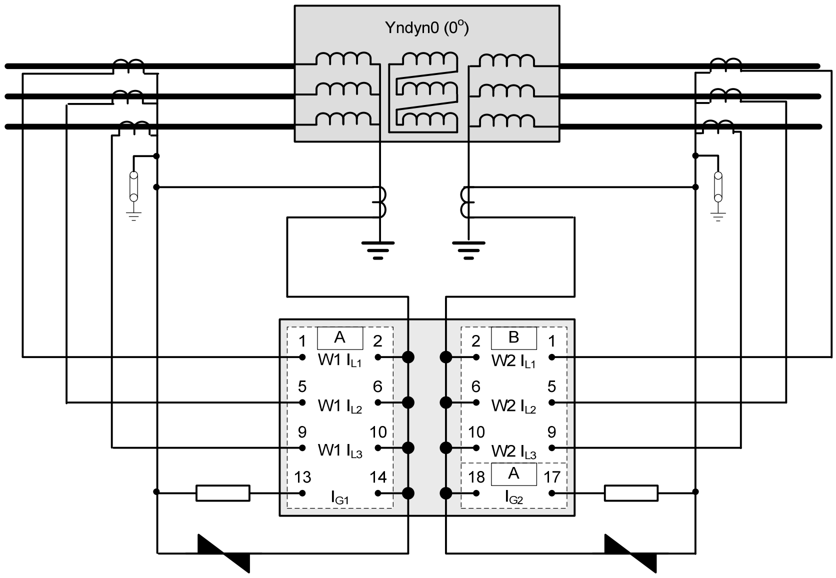


Figure 6-4: Protection of Star/Star Transformer with Tertiary

The provision of the tertiary winding in star/star transformers both stabilises the neutral potential and can allow earth fault current to flow in the secondary connections i.e. reduces the zero sequence impedance. An earth fault on the LV side of the transformer external to the differential protection zone will cause zero sequence currents to flow in the CTs on the LV side without corresponding current to flow in the line CTs on the HV side. If these zero sequence currents are allowed to flow through the differential elements they may cause undesired tripping.
The transformer has a phase shift of zero. To prevent undesired tripping for external faults a zero sequence shunt is required, this is implemented by selecting star/delta interposing CT settings. The Interposing CT Connection setting on all sets of current inputs must be set to the same Yd setting e.g. all Yd1, -30° or all Yd11, 30°.

6.3 Transformer with Primary Connections Crossed on Both Windings

Yd11 Transformer Connected as Yd9 (90^0)

The phase-shift between the W1 and W2 primary systems may necessitate that primary connections to each winding of the transformer have to be crossed. Fig. 6.4-1 shows a typical arrangement where a Yd11 transformer is arranged to give a primary system phase-shift of 90° by crossing of its main connections. There are two optional methods of configuring the 7SR24 relay.

Solution 1

Fig. 6.4-1 shows W1 and W2 CT secondary wiring crossed over to replicating the crossovers on the transformer primary connections:

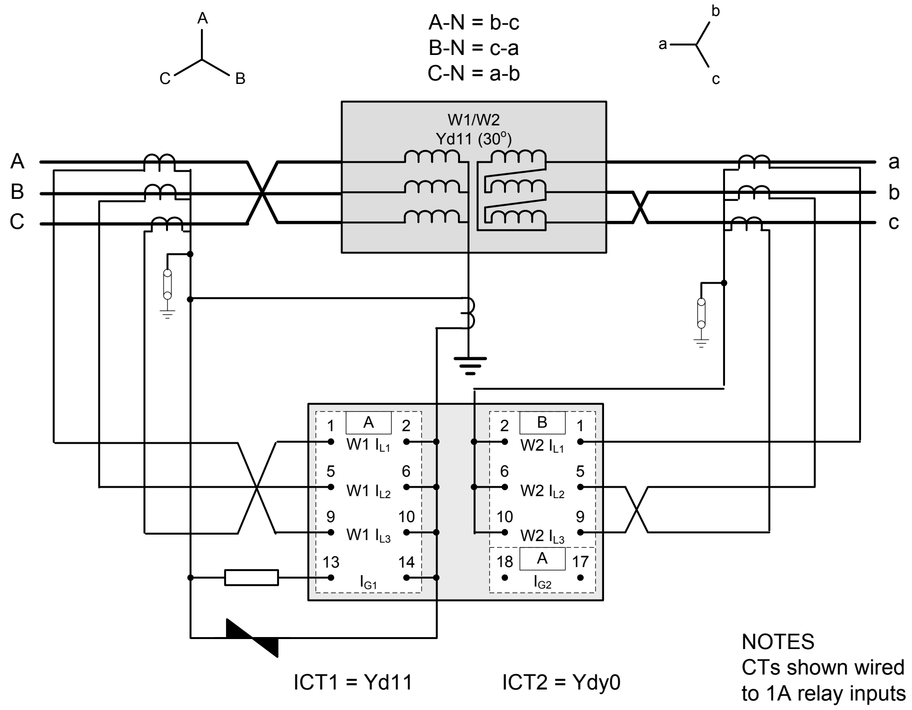


Figure 6-5 – AC Connections: Yd9, 90^0 Transformer – Non-standard Secondary Connections

Notes:

An advantage of the above is that the 7SR24 relay can be set to correspond to the vector group shown on the main transformer rating plate i.e. Yd11, +30° simplifying installation. This approach is also applicable where the transformer is used to reverse the system phase sequence – see section 6.5.

A disadvantage is that 'non-standard' secondary wiring connections are used.

Relay instruments will indicate 'transformer' quantities rather than system quantities.

Solution 2

Figure 6.4-2 shows use of the ICT Connection settings to correct for the phase shift introduced by the transformer connection i.e. ***ICT1 Connection*** is set to to Yd9, -90° and ***ICT2 Connection*** is set to Ydy0, 0°.

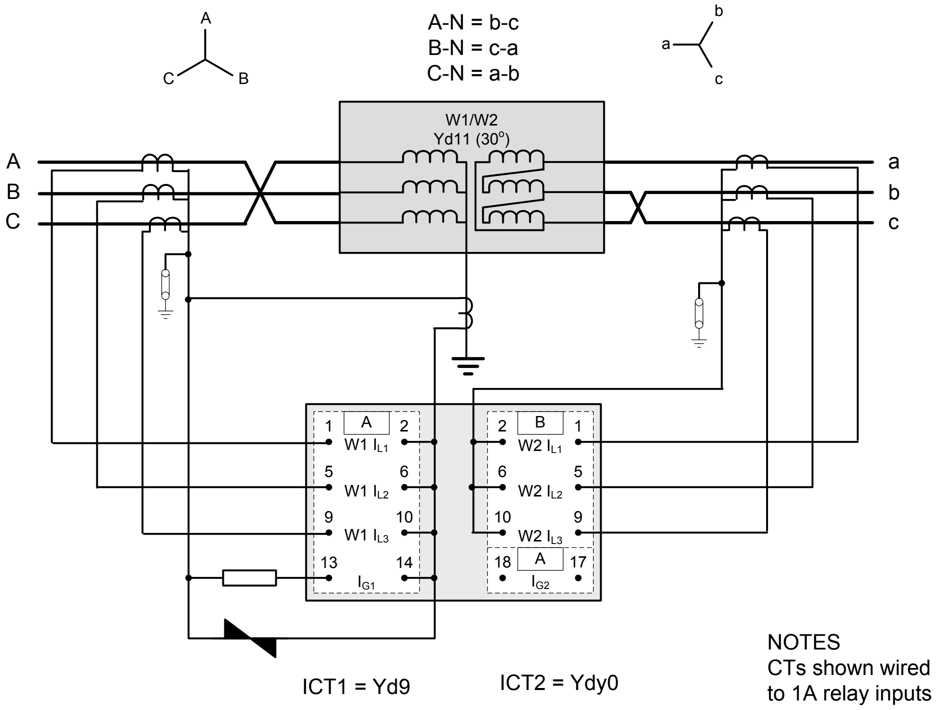


Figure 6-6 AC Connections: Yd9, 90^0 Transformer – Standard Secondary Connections

Notes:

An advantage of the approach above is that 'standard' secondary wiring connections are used.

The 7SR24 relay setting correspond to the power system vector relationship i.e. Yd9, 90°.

Relay instruments will indicate 'system' quantities rather than transformer quantities.

6.4 Transformer with Primary Connections Crossed on One Winding

Reversing the connections on only one side of the transformer will reverse the phase sequence of the system. For this arrangement W1 and W2 CT secondary wiring must be crossed over to replicate the crossovers on the transformer primary connections – see fig. 6.5-1.

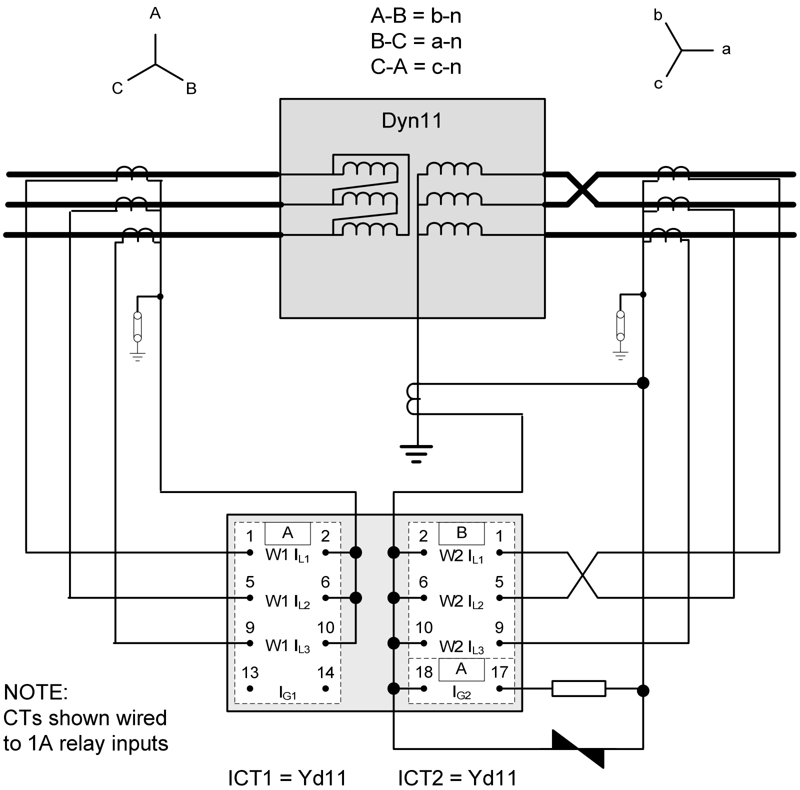


Figure 6-7 Dyn11 Transformer with Reverse Phase Notation

Notes:

The 7SR24 relay is set to correspond to the vector group shown on the main transformer rating plate i.e. Dy11, +30°.

Relay instruments will indicate ’transformer’ quantities rather than system quantities.

6.5 Protection of Auto Transformers

The transformer has a phase shift of zero. To prevent undesired tripping of the overall differential protection for external faults a zero sequence shunt is required, this is implemented by selecting star/delta ***ICT Connection*** settings. The ***ICT Connection*** setting on all both sets of CT inputs must be the same e.g. all Yd1, -30° or all Yd11, 30°. The inrush inhibit (81HBL2) must be Enabled as the magnetising inrush currents in each phase will not balance.

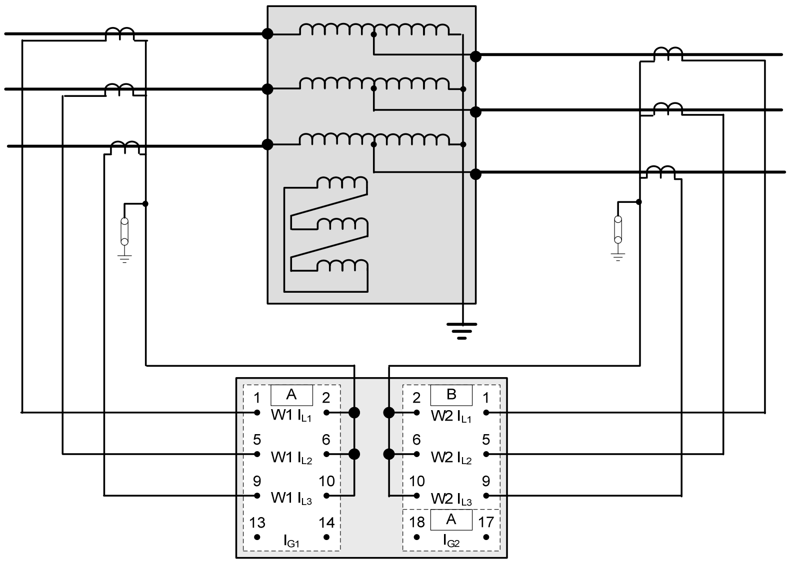


Figure 6-8: AC Connections for Auto-Transformer Overall Protection

REF protection can be applied if a neutral CT is available and all CTs have the same ratio:

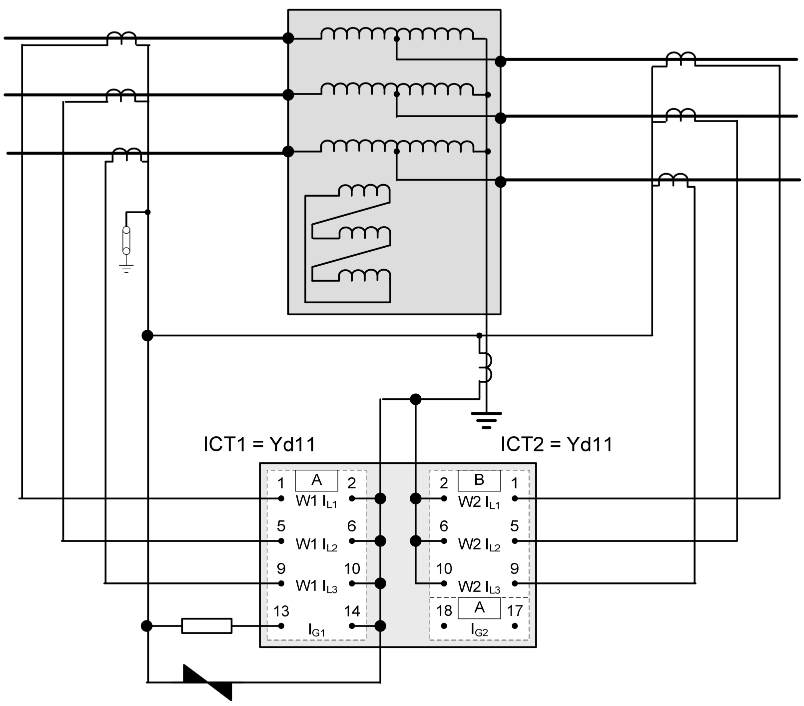
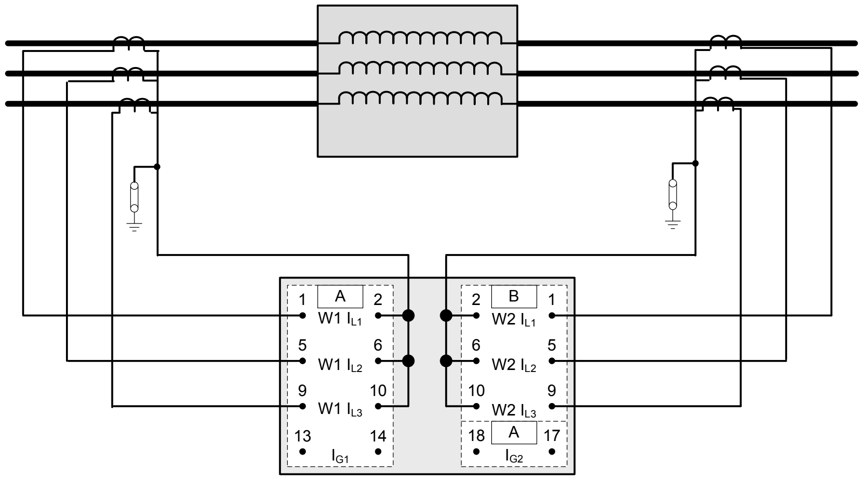


Figure 6-9: AC Connections for Auto-Transformer Overall and REF Protection

6.6 Reactor and Connections Protection



ICT1 = Yy0 ICT2 = Yy0

Figure 6-10 AC Connections for Reactor and Connections Protection

Settings must take into consideration:

Connections: High internal and through fault currents.

Series reactor: Through fault current limited by reactor.

Shunt reactor: Single end fed faults only.