7SG14 Duobias-M

Transformer Protection

Document Release History

This document is issue 2010/02. The list of revisions up to and including this issue is:
Pre release

Revision	Date	Change
	2010/02	Document reformat due to rebrand
R1	26/09/2006	Revision History Added. Reformatted to match other manual sections.

Software Revision History

Contents

FIGURES

Abbreviations

ALF	Accuracy Limiting Factor
CT	Current Transformer
HS	High set setting
I_B	Secondary line current produced by CT with circuit/transformer at full rating
I_F	Maximum fault current
I_N	CT Secondary nominal rating, typically 1A or 5A
N	CT Ratio
R_B	Rated value of the secondary connected resistive burden in ohms
R_{CT}	Secondary winding d.c. resistance in ohms
R_L	CT secondary lead resistance
V_k	CT knee point voltage
VT	Voltage Transformer
τ	Time Constant

1 Introduction

The ‘Modular II’ Duobias-M builds on the success of the Duobias-M ‘Modular I’ numerical relay. The differential algorithm of the previous relay has been retained as it was found to be stable for transformer through faults and transformer magnetizing inrush current, whilst allowing fast operation for internal faults. The Duobias-M has a long service history compared with other numerical relays of a similar type, with the first one entering service in 1988. This has enabled Reyrolle Protection to accumulate many years of field experience to date. This knowledge is incorporated into our latest modular II relays.

The main advantages of the new Duobias-M-200 series relays are flexibility in the hardware (case size/ number inputs and outputs) and the inclusion of backup protection functions. The modules that comprise the relay can be withdrawn from the front.

The Modular II relays can be purchased in 3 case sizes:

- E8 – half of 19” x 4U
- E12 – three quarters of 19” x 4U
- E16 – 19” x 4U

Generally, the three case sizes are envisaged to be used in the following applications:

- **E8 – 2 winding** Retrofit differential protection for transformers, generators, motors and reactors. This size relay case provides five output contacts and three status inputs. LED flagging of the operation of external devices such as Buchholz, is therefore limited to three, making this relay suitable for use for retrofit where existing flag relays are to be retained. The relay has 16 LED’s that may be programmed to any internal or external protection.

- **E12 – 2 or 3 winding** differential protection for grid transformers and auto transformers with the Duobias-M providing LED flag indication. The number of output contacts and status inputs can be varied to suite the application. The number of status inputs provided can be 3, 11 or 19 and the number of outputs can be 5, 13 or 21. This relay size case has 32 programmable LED’s that cab be used to flag internal (e.g. biased differential) or external (e.g. Buchholz or Winding temperature) protection.

- **E16 – 2 to 5 winding/input** applications at EHV or where voltage inputs are required for voltage, frequency functions and Ferro-resonance detection. Low impedance Busbar Protection for up to 8 sets CTs. This relay is suitable for single bus, mesh and 1.5 CB sub-station layouts. The relay is NOT suitable for double bus applications. This size relay case has 32 LED’s that may be used to flag the operation of internal or external types of protection.

These relays allow a very flexible way of meeting varying customer requirements in terms of the functionality, number inputs and outputs relays and number and type of analogue CT/V.T. inputs.

1.1 Standard Functions:

- Biased Differential – 87T
- Highset Differential – 87HS
- Flag indication for the operation of all internal and external (e.g. Buchholz) transformer protection and alarm functions
- Fault Recording
- One Front (25 pin RS232) and two Rear (ST Fibre optics) Communications ports
- Trip Circuit Supervision (H6) -74
- Programmable Scheme Logic (ReylogiC).

1.2 Optional Functions:

- Restricted Earth Fault per winding – 87REF
- Over fluxing - Inverse and 2 stage DTL – 24ITL, 24DTL#1 and 24DTL#2
- IDMTL (IEC&ANSI) and/or DTL Backup Over Current - 50/51
- IDMTL (IEC&ANSI) and/or DTL Backup Derived Earth Fault - 50G/51G
- Measured IDMTL/DTL Earth Fault - 50N/51N
- Thermal Overload – 49
- Over/Under Voltage (4 stage) - 59/27
- Over/Under Frequency (4 stage) - 81 O/U
- Stage IDMTL/DTL Standby Earth Fault – 51N SBEF
- Neutral Voltage Displacement – 59N
- Negative Sequence Over current – 46

This list of additional functions is not limited, and functions in addition to those listed may be included upon request.

A spreadsheet of standard relay models is included in the Description of Operation Section of this Technical Manual.

New models with different mixes of protection functions can be made available upon request.

The Duobias-M relay enables all/any of these functions to be performed within one relay case, with the additional capability of allowing remote interrogation of the settings and of the stored fault data. These notes give guidance on the application of the Duobias-M relay and make reference to the Commissioning Chapter that deals with setting-up instructions and testing.

The next section deals with the Standard Features included in all Duobias-M-200 series relays. This range of relay can be identified using their article number, as they all will have a DU3- article number. The rest of this number relates to an individual model.

2 Standard protection functions

2.1 Differential Protection

The word “Duobias” literally means two (duo) types of relay bias are used to make the relay stable. The two types of bias used are magnitude restraint (load) and harmonic content (inrush). The magnitude restraint bias is used to make the relay stable for external (out of zone) through faults as it increases the differential current required for operation as the current measured increases. The harmonic bias is used to prevent relay operation due to flow of pulses of magnetizing inrush current into one winding when the transformer is first energized.

Differential protection applied to two and or more winding transformers is slightly more complicated by the way transformer windings (e.g. Yd1) are connected. This can lead to a phase change between the currents flowing at either side of the transformer. The current entering the zone will also be changed in magnitude before it leaves the zone by virtue of the ratio of turns on the transformer H.V. and L.V. windings.

Considering the change in current magnitude first of all; if the transformer ratio is fixed i.e. it does not have a tap changer, then this can be compensated for in the choice of H.V. and L.V. CT ratios. For example, a transformer of ratio 132/33kV (4/1), would have L.V. CTs with four times the ratio of the H.V. CTs. In this way the H.V. and L.V. primary currents result in identical secondary currents and there is no differential current either under load or through fault conditions.

However, if the transformer is fitted with an on-load tap changer, its nominal voltage ratio can be varied, typically, over a range of +10% to -20%. Since it is not practicable to vary the CT ratios to follow that of the transformer, any deviation from nominal tap will result in the measurement of some differential current. This will reach its maximum when the tap changer is in its extreme position, in this case 20%. In this position, a secondary current equivalent to 20% of the load or through fault current will flow in the differential circuit.

To minimize the differential current measured due to on-load tap changer position, the relay should balance at to the mid-point of the tapping range. For the +10% to -20% example, the CT ratios would be chosen to give balance at the -5% position so that the maximum deviation and differential current should be 15%. The example below shows a single line diagram of a typical transformer with the calculation of the optimum CT ratio.

The Settings to be chosen for this type of protection are:

- Interposing CT Multiplier Settings for each set of inputs to balance the secondary currents
- Interposing CT Connection Settings for Vector Group (phase) Correction.
- Biased Differential Characteristics
- Differential Highset
- Harmonic Restraint level

2.1.1 Magnitude Balance – CT Ratio’s and Multiplier Settings

The relay has 1A and 5A rated terminals for each set of line CTs and any combination of these may be used. The Interposing CT Multiplier range is 0.25 to 3.00x. These facilities provide a wide accommodation for the choice of CT ratios.

In new installations, the CT ratios should be selected so that the secondary currents fed into the relay are as close as possible to the relay nominal rating (1A or 5A), when the transformer is at its maximum nameplate rating. The Interposing CT Multiplier settings can be set to balance the relay when the tap changer is at its middle tap position.

When replacing an older biased differential relays such as C21 with a Duobias-M, existing CTs will normally be re-used. Usually the interposing CTs associated with the old scheme can be removed as the vector group compensation and current magnitude compensation is done by the Duobias-M software settings. Any sets of CTs connected in 'Delta' should be reconnected is 'star', as the standard Duobias-M connection is to have all CTs in 'star'. This helps simplify the a.c. scheme.

The Interposing CT (ICT) multiplier settings range of 0.25 to 3.00 and 1/5A rated inputs per winding, can be used to achieve perfect balance in almost all cases. A perfectly balanced relay should have virtually no differential current and nominal bias current, when the transformer is at full load rating and the tap changer is at its middle tap position. By balancing the relay bias current to nominal, the relay biased differential characteristics are matched for transformer through faults, and therefore relay sensitivity is optimized for internal faults. If an internal fault occurs the relay will measure sufficient operate current to ensure a fast operate time.

The fact the ICT Multiplier may be selected to 3.0 allows a CT ratio to be selected to produce a secondary current of 0.33 x In, for a load current of full transformer rating. This assists if the in reducing the CT burden should the differential zone cover a long section of the system. Circuits of up to 4.5km are currently protected by Duobias-M. If the zone is long (greater than 1km) it is recommended to used 1A rated CTs as this will also assist in keeping the CT burden down.

2.1.1.1 Example 1 – New two winding application

132/33KV 90MVA Yd11 Transformer
Tap Changer range: +10% to -20%

Step 1 – Choice Line CT Ratio's
If possible 1A rated CTs should be used, as the CT burden is much less than if a 5A CT is used.

HV load current = 90 MVA / (√3 x 132kV) = 393.65A
Standard CT ratio of 400/1A selected.

LV load current = 393.65 x 132/33 = 1574.59
Standard CT ratio of 1600/1A chosen

Step 2 – Selection of Interposing CT Multiplier Settings
The Duobias-M multiplier settings can now be chosen

HV Secondary current = 393.65/400 * 1/0.95 = 1.036A
HV ICT Multiplier = 1 /1.036 = 0.97

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

LV Secondary current = 1574.59/1600 = 1.02
LV ICT Multiplier = 1 /1.02 = 0.98

Both HV and LV secondary wiring should be connected to 1A rated input terminals on the relay.

2.1.1.2 Example 2 – Retrofit of a two winding application

45MVA, 132/33kV Dyn1Transformer with 300/1A HV and 560/0.577A CTs.
Tap Changer range: +5 to –15%

Step 1 – Connection of CTs

The older schemes using relays such as the Reyrolle C21 to 4C21 often required HV CTs to be connected in 'star' and LV CTs in 'delta' (or vice-versa). The relays also used external interposing CTs to correct for phase shift across the transformer. The Duobias-M uses software settings to replace the interposing CTs. It uses all CTs connected in star as its standard. It is common practice to re-use existing CTs when upgrading protection.

Remove Interposing CTs from the secondary circuit.

Connect all CT secondary wiring in star.

Nominal HV load current = 45 MVA / (√3 x 132kV) = 196.82A

Re-use 300/1A CTs.

Nominal LV load current = 196.82 x 132/33 = 787.28

Re-use 560/0.577A CTs.

Step 2 – Select Interposing CT Multiplier Settings

The Duobias-M multiplier settings can now be chosen

HV Secondary current = 196.82/300 * 1/0.95 = 0.69A

HV ICT Multiplier = 1 /0.69 = 1.45

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

LV Secondary current = 787.28 x 0.577/560 = 0.81A

LV ICT Multiplier = 1 /0.81 = 1.23

Both HV and LV secondary wiring should be connected to 1A rated input terminals on the relay.

2.1.1.3 Example 3 – Retrofit of a three winding application

It is worth looking at the application of the relay to three winding transformers. The balance of the relay is slightly more difficult as all of the windings usually have different ratings. To work out the CT ratios to use and ICT multiplier settings to apply the highest rated winding is used.

Three winding 60/40/20MVA 66/33/11kV YNyn0d11Transformer with a +10 –20% OLTC.

66kV rated current at middle tap = 60MVA / (66kV x √3 x 0.95) = 106.32A

CT ratios of 200/1A are present and are to be reused.

W1 (66kV) secondary currents = W1 rated / W1 CT ratio = 106.32/200 = 0.875A

W1 ICT Multiplier = 1/0.875 = 1.14 x

The currents in the 33kV and the 11kV windings will combine and will balance the currents in the 66kV winding. Therefore the relay balance is based on 60MVA of transformed power.

33kV rated current = 60MVA / 33kV x √3 = 1049.73A

The existing CTs with a ratio of 600/1A are to be used.

W2 (33kV) secondary current = W2 rated / W2 CT ratio = 1049.73/600 = 1.75A

W2 ICT Multiplier = 1/1.75 = 0.57 x

11kV rated current = 60MVA / 11kV x √3 = 3149.18A

The existing CTs with a ratio of 1600/1A are to be used.

W3 secondary current = W3 rated / W3 CT ratio = 3149.18/1600 = 1.97A*

W3 ICT Multiplier= 1/1.97 = 0.51 x

Transformer Ynyn0	W1	W2	W3
Voltage (kV)	66	33	11
Rating (MVA)	60	40	20
CT Ratios	200/1	600/1	1600/1
ICT Multipliers	1.14	0.57	0.51
ICT Connection	Yd11	Yd11	Yy0

* the relay inputs have a continuous rating of at least three times the rating of the input.

2.1.2 Interposing CT Connection Setting (Vector Group Correction)

A table showing the settings to apply to for all of the possible transformer vector groups is included on the following page. This provides a quick method of choosing the correct settings. If further clarification of the purpose of this setting is required please read further.

The phase angle of line currents flowing on either side of a power transformer may not be the same due to the connections adopted on the transformer windings. This requires an Interposing CT connection setting to be programmed into the relay to correct this difference in angle. Once corrected the phase angle of the ICT Relay Currents per phase should be in anti-phase.

The sets of line CTs forming the differential zone of protection should all be connected in ‘star’. Sometimes Phase crossovers will occur within the zone of protection and this is best corrected by rotating the secondary phase wiring to mirror the primary connections.

The addition of an earthing transformer on the LV side of transformer provides a path for earth fault current to flow. Usually this earthing transformer is within the zone of the differential protection. If an external earth fault occurs, the flow of fault current may lead to the differential function operating for an out of zone fault. To prevent this false operation, a Ydy0 setting is selected on the LV side (W2) input. This removes the zero sequence current from the differential measurement and makes the differential stable.

As a general rule, transformer windings connected as Yd or Dy have the phase angle ICT Connection setting to correct the phase angle difference, applied to the star side winding.

Some specific examples are included in the Appendices at the end of this section. These applications deal with the more complicated connections and vector group settings in some detail. The current distribution is shown to clarify the way the relay balances for an external fault. This may be used to explain relay indication when an operation has occurred.

2.1.3 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	Yd1,-30°	Yd1,-30°
Yd1, YNd1	Yd1,-30°	Yy0,0°
Yd1, YNd1 + Earthing Transformer	Yd1,-30°	Ydy0,0°
Yy2, YNy2, Yyn2 YNyn2, Ydy2, YNdy2, Ydyn2, Yndyn2, Dz2	Yd3,-90°	Yd1,-30°
Yd3, YNd3	Yd3,-90°	Yy0,0°
Yd3, YNd3 + Earthing Transformer	Yd3,-90°	Ydy0,0°
Yy4, YNy4, Yyn4, YNyn4, Ydy4, YNdy4, Ydyn4, Yndyn4, Dz4	Yd5,-150°	Yd1,-30°
Yd5, YNd5	Yd5,-150°	Yy0,0°
Yd5, YNd5 + Earthing Transformer	Yd5,-150°	Ydy0,0°
Yy6, YNy6, Yyn6, YNyn6, Ydy6, YNdy6, Ydyn6, Yndyn6, Dz6	Yd7,150°	Yd1,-30°
Yd7, YNd7	Yd7,150°	Yy0,0°
Yd7, YNd7 + Earthing Transformer	Yd7,150°	Ydy0,0°
Yy8, YNy8, Yyn8, YNyn8, Ydy8, YNdy8, Ydyn8, Yndyn8, Dz8	Yd9,90°	Yd1,-30°
Yd9, YNd9	Yd9,90°	Yy0,0°
Yd9, YNd9 + Earthing Transformer	Yd9,90°	Ydy0,0°
Yy10, Yny10, Yyn10, YNyn10, Ydy10, YNdy10, Ydyn10, Yndyn10, Dz10	Yd11,30°	Yd1,-30°
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°

Notes

1. Y or y denotes an unearthed star connection on the HV or LV side of the transformer respectively.
2. YN or yn denotes an earthed star connection on the HV or LV side of the transformer respectively.
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

2.1.4 Biased Differential Characteristic

87 Inrush Element (Enable, Disable)

When a transformer is energized it will experience a transient magnetizing inrush currents into its energised winding. These currents only flow into one transformer winding and the level would be sufficient to cause the biased differential relay to falsely operate. To prevent the relay operating for this non-fault condition, the presence of even harmonics in the wave shape can be used to distinguish between inrush currents and short circuit faults.

For most transformer applications this setting must be selected to [Enabled]. For certain applications of the relay to auto-transformers, shunt reactors and busbars the [Disable] setting may be selected.

87 Inrush Bias (Phase, Cross, Sum)

This setting defines the method of inrush inhibit used by the relay. Each of the three selections has specific reasons why they are chosen. The relay setting is expressed as the percentage of the even harmonic (2nd and 4th) divided by the total r.m.s. current in the differential signal.

If the relay does not have this setting available in it menu, the relay uses the cross method.

The definition of the methods and their use are as follows:

Phase – The even harmonic content in each phase is measured and compared to the total operate current in this phase. Therefore the 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 containing a phase core. This is done to make transportation to site easier. Each phase cores are therefore 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 will be used for the vast majority of applications of the relay to power transformers. This method is identical to that used in the original Modular 1 Duobias-M relay.

Most existing Duobias-M transformer differential relays use this method, and are stable when set to 0.20 x Id.

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 method works in a similar way to the C21 range of Reyrolle relays. 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 10% therefore represents the setting that provides the most stability under magnetising inrush conditions. In practice nearly all Modular I Duobias-M numerical relays were set to the default of 20% and to date no false operations due transformer magnetizing inrush current of any description have been reported. This is real proof of the design of the inrush inhibit or restraint used in these relays is technically sound as these relay have in service experience since 1988.

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 of 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 20% unless a very rare false operation for inrush occurs. In which case a lower setting should be adopted after checking the Duobias-M waveform record for the presence of fault current.

87 Biased Differential, Initial Setting (0.1 to 2.0 x In)

This is the level of differential current, expressed as a percentage of the chosen current rating, at which the relay will operate with the bias current around normal load levels. This setting is selected to match the percentage on load tap-change range. For example if the tap change range is +10% to –20%, a setting of 30% would be chosen.

Differential, Bias Slope Setting (0.0 to 0.7 x In)

Some unbalance current will appear in the differential (operate) circuit of the relay for predictable reasons, e.g. 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 maintain stability, the differential current required for operation must increase proportionately with bias current. The bias slope expresses the current to operate the relay as a percentage of the biasing (restraint) current. The Differential, Bias slope setting chosen must be greater than the maximum predictable percentage unbalance.

A setting based on the tap change range plus a small CT error must be made. For example if the tap change range is +10 to –20%, the overall range is 30%. The relay and CT composite error may be 2%, so this produces and overall requirement for 32%. The relay is set in 0.05 x In steps so a 35% setting should be adopted.

Differential, Bias Slope Limit Setting (1 to 20 x In)

The purpose of this setting is to ensure the biased differential function is stable for through faults. It does this by increasing the ratio of differential current to bias current required to operate the relay above this setting.

When a through fault occurs, some CT saturation of one or more CTs may cause a transient differential current to be measured by the relay. This setting defines the upper limit of the bias slope and is expressed in multiples of nominal rated current. A setting value must be chosen which will ensure the bias slope limit introduces the extra bias at half of the three phase through fault current level of the transformer.

If an infinite source is considered connected to the transformer, the three phase through fault level can easily 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.

The setting should be selected to half of this value, so 6.66/2 = 3.33 and a setting of 3 would be selected as it nearest lower available setting. The Bias Slope Limit is set in the range of 1 to 20 x In. The lower this setting is selected to the more stable the biased differential function becomes.

Differential Highset (1 to 30 x In)

This is an unbiased differential setting with a range of settings expressed as a multiple of the nominal current rating. This element is use to provide very fast clearance of transformer terminal faults. It also helps in reducing the kneepoint voltage requirements of the CTs.

It is NOT a highset Overcurrent element, as it operates on the differential current measured by the relay.

This function should always be used, as it provides very fast operation for terminals faults. It also is used to calculate the CT requirements.

The Differential Highset setting must consider the maximum through fault and the level of magnetising current. The high set should be 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 a good compromise between sensitivity for internal faults and stability for external faults. Only in very rare cases will a higher setting be required. A Differential Highset Setting of 7 x In will be stable for a peak magnetizing inrush levels of 14 x rated current. Smaller rated transformers will have greater three phase through fault levels and experience larger magnetizing 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.

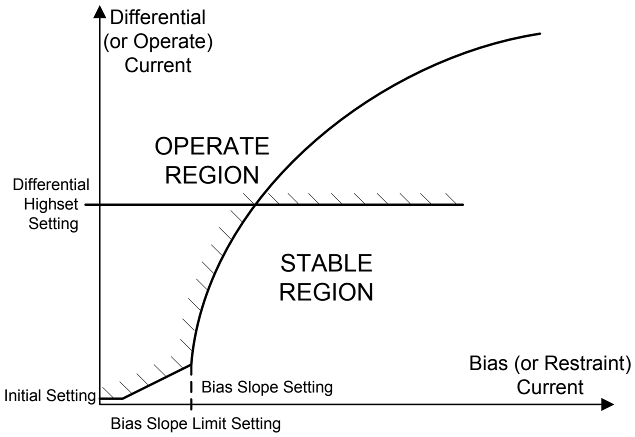


Figure 1- Biased Differential and Highset Differential Characteristics

2.2 LED Flag Indication

The Duobias-M relay has 16 (E8 case) or 32 (E12 and E16 cases) LED’s to provide indication of the operation of internal protection functions, and the external protection devices fitted to the transformer. These external devices may include Buchholz Trip (Surge), Winding Temperature Trip and Pressure Relief Device. The alarm and trip indications can be flagged on the front of the relay. This saves the cost of flag relays and engineering. The other advantage is these external trip signals can be programmed to trigger waveform storage. This allows an easy method of checking for the presence of fault current. An LED Menu is included in the relay so that any protection function or Status Input can be mapped to any LED. The LED Labels may be changed very easily, as the paper slips may be removed. They are accessed by opening the front fascia door.

The recommended method for connecting external devices that trip circuit breakers should be connected as shown on the connections diagram at the end of this section. Each external tripping device requires a blocking diode. These segregate the LED flag indications and provide a direct trip should the Duobias-M supply be lost. The Status Inputs used to indicate trips may be programmed to operate the Duobias-M trip contacts to back up the tripping through the blocking diode. The alarm indications do not normally require a blocking diode.

2.3 Trip Circuit Supervision (TCS)

Any of the Status Inputs may be used to monitor the state of a trip circuit.

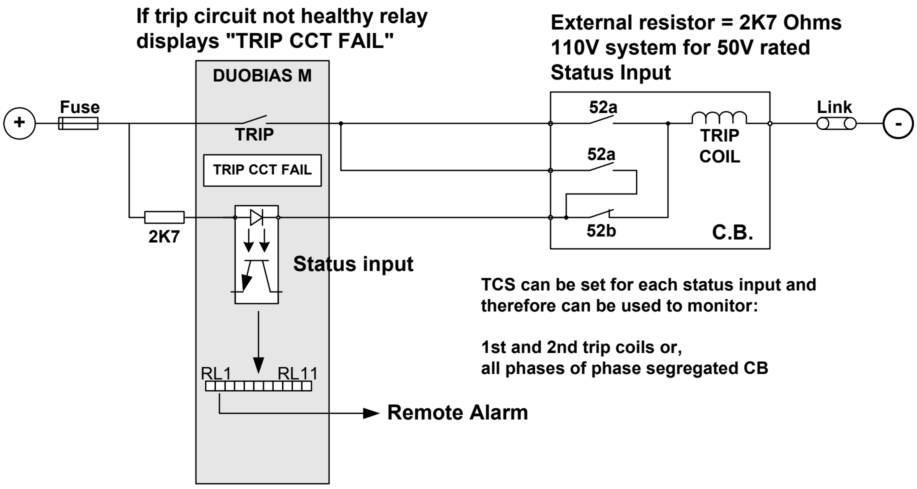


Figure 2 - Trip Circuit Supervision Connections

The 2K7 resistor is only needed to drop the dc voltage from 110V to the 48V rating of the status input. The relay may be purchased with 110V status inputs.

To use a Status Input for Trip Circuit Supervision Monitor:

Select that Input to “Trip Circuit Fail” and “Inverted Input” in the STATUS INPUT MENU. An automatic 400ms delay on pickup time delay is included when a Status input is allocated as a “Trip Circuit Fail” Input. A normally open output contact should be mapped to the Trip Circuit Fail Status input to provide an alarm contact to a remote point. The TCS alarm operation will also be logged as an IEC event.

Where strict compliance with the BEBS S15 Trip Circuit Supervision Standard is required, the relay must be specified with 48V rated status input. The 2K7 dropper resistors will then be required for the status inputs with a standard 110v dc tripping system.

Revision 14 and newer software relay models have a more flexible trip circuit supervision scheme which allows for multiple blocking inputs for each trip circuit that is supervised.

3 Optional protection functions

The Duobias-M relay can be specified to include the following optional protection functions:

- Restricted Earth Fault
- Over fluxing/Excitation
- Backup Over Current and Earth Fault (Measured or Calculated from Line CT inputs)
- Thermal Overload
- Circuit Breaker Fail
- Under and Over Voltage
- Under and Over Frequency
- Negative Sequence Over current

3.1 Restricted Earth Fault (REF)

The REF protection provides an extremely fast, sensitive and stable method of detecting winding earth faults. It is a unit type of protection and will only operate for earth faults within its zone of protection. It is inherently more sensitive and provides greater degree of earth fault protection to the transformer winding than biased differential protection. For a solidly earthed star winding, the REF function is roughly twice as sensitive in detecting a winding earth fault, than biased differential protection. Therefore its use is highly recommended and is the reason why is present in the Duobias-M range of relays.

Note REF protection is not slowed down at all if the transformer is switched onto an in zone fault, and will assist in providing high speed fault clearance for all fault conditions.

The Restricted Earth Fault (REF) must remain stable under switching and through fault conditions. This is achieved with by including stabilizing resistors in series with the REF current measuring input. The combination of the relay setting and value of resistor form a stability voltage setting. The REF input may also be used as a balanced earth fault (BEF) protection for ‘delta’ connected windings or a Sensitive Earth Fault (SEF) element.

As of May 2006 the Duobias-M REF input was altered to allow the same sensitivity as the original Modular 1 relay, i.e. a 0.005 x In setting. This new type was named SREF (sensitive restricted earth fault). This type of module will be supplied on all subsequent relay.

The normal REF input has a setting range of 0.020 to 0.960 x In for pickup and 0 to 864000 seconds for time delay. The time delay would only normally be set when the element is used for SEF protection.

Note where 5A rated line CTs are used for REF protection the recommendation is to use the 1A rated REF input so that sensitive settings and small setting steps are possible.

The procedure for establishing the relay settings and resistor values is explained in our publication "Application Guide, Restricted Earth Fault". This may be downloaded from our web site; www.reyrolle-protection.com, (Publications-> Technical Reports)

3.2 Over fluxing Protection (Volts/Hertz)

This type of protection should be included on all generator step-up transformers. Other types of power transformer that may have to withstand a sustained application of system over voltage should also be protected against over fluxing.

This type of function is necessary to protect the transformer from excessive heat generated when the power system applies excessive voltage to the transformer. The transformer core will saturate and some of the magnetic flux will radiate as leakage flux through the transformer tank. This leakage flux causes eddy currents to be induced into the transformer tank. The I2R losses from these currents heat the transformer tank. As this condition causes overheating of the transformer tank and core, an inverse V/f protection characteristic best matches the transformer over-excitation withstand.

This function uses the ratio of voltage to frequency (volts per hertz) applied the transformer to determine operation. The V/f ratio relates directly to the level of flux produced.

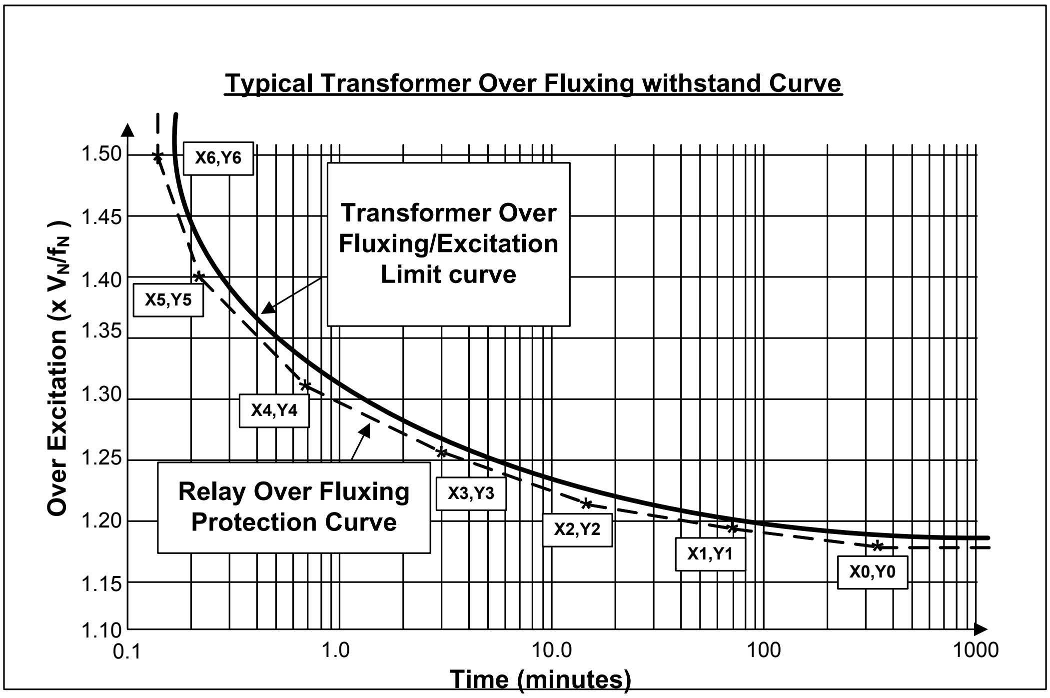
The relay has two types of V/f characteristics:

- 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 will be used to match the over fluxing protection characteristic of the relay with the withstand limit of a particular transformer. Therefore the relay includes an easy to set user definable curve if the Volts per Hertz withstand is known. The over excitation withstand curve can be obtained from the transformer manufacturer. The use of the inverse curve allows for the maximum scope for some limited over fluxing occurring whilst preventing damage.

Unfortunately withstand curves provided by transformer manufacturers have the V/f applied shown on the Y axis and the time on the X axis. Protection relays have this in reverse so it is necessary to tabulate the points required that approximates to the user definable curve. The advantage of using these seven points it makes it very easy for the inverse V/f curve to be matched to the transformer withstand curve, without the need for equations or a spreadsheet.



	Y (seconds)	X (x V_N/f_N)
X0,Y0	20000	1.17
X1,Y1	480	1.19
X2,Y2	780	1.22
X3,Y3	180	1.26
X4,Y4	39	1.31
X5,Y5	13	1.40
X6,Y6	8	1.50

Note the transformer withstand is normally shown with the applied over fluxing/excitation variable on the Y axis and the wihstand time on the X axis. Protection characteristics are always drawn with the time on the Y axis and the V/f on the X axis. The table to the left indicates the values applied to the protection characteristic.

Figure 3 - Inverse V/f Over Excitation Protection

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.

3.3 Backup Over current and Earth Fault (50/51/50N/51N/50G/51G)

These elements are often supplied as separate backup relays for the HV and LV side of the transformer circuit. To reduce cost and complexity some customers will accept the backup protection as part of the main protection relay. The relay is fully supervised and will alarm for a loss of its auxiliary dc supply or if a hardware fault is detected. This supervision feature provides 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 one IDMTL (IEC or ANSI) and three DTL/instantaneous elements (50/51)
- Derived Earth Fault with one IDMTL (IEC or ANSI) and three DTL/instantaneous elements (50G/51G)
- Measured Earth Fault with one IDMTL (IEC or ANSI) and three DTL/instantaneous elements (50N/51N)
- Standby Earth Fault with two IDMTL (IEC or ANSI curve) or DTL elements. (50SBEF, 51SBEF)
- Sensitive Earth Fault with two DTL elements (50SEF, 51SEF)

These elements can be selected to any or all of the sets of CT inputs.

Voltage controlled elements can be realized by using an under voltage element to supervise an over current or earth fault element. The simple logic scheme can be written in ReylogiC script for the relay.

Grading between other relays and fuses is always possible as all of the IEC and ANSI inverse curves are available. Often highset over current protection on the HV side of a transformer is arranged to trip the LV circuit breaker first and then a short time later the HV circuit breaker in a two stage Overcurrent protection.

Multiple stages of backup over current and earth fault functions can very easily be included. The derived earth fault function is useful where a dedicated neutral CT is not provided or available.

3.4 Over and Under Voltage (27/59)

There are four elements (1-4) included in this function. Any of them can be selected to either under or over voltage. Each element can be applied in the following way:

Voltage Stage (1-4)	Enable/Disable
Voltage Stage (1-4) Operation	Under/Over
Hysteresis (Drop off as % of Pickup = 1 – Hysteresis setting)	0 to 80%
Setting	0.01 to 2.5 x Vn
Time Delay	0 to 240 hours

These elements can be used to protect the insulation if excessive voltage is applied. The excessive voltage may occur if a tap changer runs away in the high voltage direction, if the AVR generator equipment malfunctions or if control of reactive compensation malfunctions. Voltage elements may also be graded with other voltage protection devices such as arcing horns and surge arrestors.

A non-energized power system can be detected by an under voltage element set with a large hysteresis setting. Another application of an under voltage element is for voltage control of over current elements.

Some utilities are also starting to adopt a four-stage under voltage as oppose to under frequency load shedding scheme, as it allows feeder tripping to be faster. Other utilities are now implementing a combined under frequency and voltage scheme to reduce the time required for each load shed stage.

The faster the power system can be brought into balance between generation and load, the greater the chance the system will stabilize.

3.5 Under and Over Frequency (81 U/O)

There are four elements or stages included in this function. Any of them can be selected to either under or over frequency. Each element can be selected to the following settings:

Frequency Stage #	Enable/Disable
Frequency Stage # Operation	Under/Over
Hysteresis (Drop off as % of Pickup = 1 – Hysteresis setting)	0 to 80%
Setting	0.01 to 2.5 x fn
Time Delay	0 to 240 hours

The main application of these elements is for load shedding. The transformer incomers provide a convenient position from which to monitor the balance between load MW demand and generated Mw's. The power system frequency will drop if the

The Duobias-M relay can be supplied with extra output contacts (up to 29) for direct tripping of the outgoing feeders at each stage of the load shed. A load shedding scheme with an under voltage and under frequency setting per stage is now being adopted to provide a faster method of balancing load and generation. It is possible to combine relay outputs to do a four stage Under Voltage and Under Frequency load shedding scheme that is favoured by some utilities.

Over frequency protection is usually used on generator protection. A short-circuit fault generally cause the generator to increase frequency as the real power demand from the fault will be less than when feeding a normal load.

3.6 Thermal Overload (49)

Transformer design has changed over the years, with less and less metal being used per MVA of transformed power. This has reduced the withstand time a transformer can be allowed to be run in an over loaded state. It is becoming more important to provide an additional thermal protection to supplement the Winding Temperature device. A thermal protection function within the Duobias-M can be used to provide alarm and trip stages. Global warming and high peak ambient temperatures also can impinge on the thermal capacity of a given transformer design.

The difficulty in using these types of functions is arriving at suitable settings. Thresholds for both alarm and trip levels are included in the Duobias-M relay and the default settings are recommended if transformer data is not available. These default setting correspond to the lowest level of thermal withstand for an oil filled transformer

This function provides a general overload and not a winding hot spot protection functions, as it does not contain a hot thermal curve. Thermal overload protection is not provided by over current type protection, as these elements do not track the thermal state during normal load conditions.

The costs of overloading transformers are:-

- Reduced life expectancy. The insulation will chemically degrade at a faster rate for an increase in the working temperature of the windings.
- Lower insulation voltage withstand.
- Increased Mechanical stress due to expansion.
- Mineral Oil will degrade at faster rate and has a lower flashpoint.
- Gas bubble production in the mineral oil has been known to occur at extreme levels of overload.

Primary Plant items such as transformers, cables, reactors and resistors are recommended to have some type of thermal protection.

Setting the Thermal Overload Function.

The method of setting this function would be as follows.

1. Select Source side winding

For Grid Transformers the source side will normally be the HV side (normally W1 inputs).

For Generator Step up Transformers the source side will be the LV side (normally W2 inputs).

The Duobias-M relay has windings allocated Winding 1(W1), W2 etc, as up to 5 sets of CTs may be connected. Normally the highest voltage winding is connected to W1 set inputs and so on. The W1 input is marked as AN1 (Analogue 1) on the rear of the relay.

2. Enabled the Thermal Overload Function

The Thermal Overload Function has a Default setting of [Disabled]. It must be set to [Enabled].

3. Calculate the Overload Pickup Setting (I_Θ)

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.

4. Select the Thermal Time Constant Setting (□)

This is the most difficult part of setting this function. As a general guide, most Grid Transformers are specified to run at 150% of Full Rating for two hours or 200% of rating for one hour. Utilities will differ as to the level of overload their transformers are specified to withstand.

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 $t(mins) = \tau \times \ln\left\{\frac{I^2}{I^2 - (I_\theta)^2}\right\}$

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

$$\%\ thermal\ capacity\ used = \left(\frac{\mathrm{I}^2}{(\mathrm{I}_\theta)^2}\right)\times 100$$

Where:

I = applied current in terms of x I_n

I_Θ = thermal pick-up setting x I_n

5. Capacity Alarm

This setting provides a means to alarm prior to a thermal trip occurring. This setting will usually be set to about 80 to 90 % of thermal capacity. The trip function operates at the point when 100% thermal capacity used is reached. The thermal capacity alarm will usually be mapped to a normally open output contact wired to the control system.

Example

45MVA Grid Transformer, 132kV/33kV, +5% to –15% Tap Changer, HV CTs 300/1 A

1. As the transformer is a Grid Transformer the direction of real power flow will be HV -> LV. If W1 input is connected to HV CTs (as is usual) select W1 for the current measurement.

2. Set Thermal Overload to [Enabled].

3. The Overload Setting is calculated as follows:

   Maximum Primary Full Load current = 45000/(132 x 0.85 x √3) = 231.5A

   Secondary Current = 231.5A / 300 = 0.772A. The thermal function should never trip for currents below this value.

   A setting margin of 110% is included to add a margin of safety.

   The Overload Setting to apply (I_θ) = 1.10 x 0.772 = 0.85 x I_n

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 settings are guideline only and setting philosophies do differ. Matching the Thermal Protection of the transformers lends itself well to the presence of setting groups in the relay. The Duobias-M relays have four settings groups. These may be used to match transformer loading for temporary emergency term overloads, wide variations in ambient (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 tailored to meet specific loading scenarios.

3.7 Circuit Breaker Fail (50BF)

The Circuit Breaker Fail functions were traditionally only implemented at transmission voltages to limit fault damage and to help avoid instability. As the circuit breaker logic is now implemented in numeric type protection relays CBF is becoming more widespread at distribution voltages also.

At transmission voltages circuit breaker fail was often implemented to ensure the power system will remain stable if the circuit breaker fails to trip and limit fault damage. Three-phase faults and to a less extent phase to phase faults can cause generators to fall into an unstable out of step state, that may damage the generation equipment.

It is therefore essential to remove either of these fault types before a critical fault clearance time is reached. Circuit breaker fail provides a solution by re-tripping the circuit breaker or back-tripping upstream circuits such as bus zones.

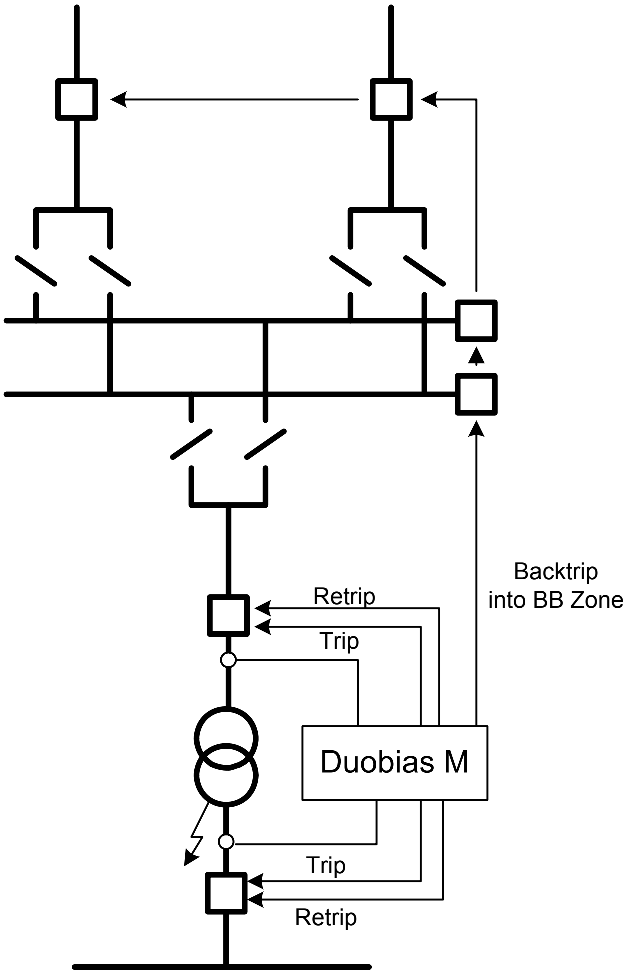


Figure 4 - Circuit Breaker Fail

The circuit breaker fail (50BF) feature uses a very sensitive three phase over current element and two stage timer. The REF elements are also included in the CBF logic as they may sense an earth fault beneath the over current sensitivity.

The CBF function is initiated by the tripping signal from the short circuit protection elements. The detector will then sense current in each phase and if all three 50BF element have not dropped off or reset the timer will expire. The first timer output is usually wired to re-trip the failed circuit breaker on a different phase, and the second timer output is wired to trip the upstream Busbar zone.

The time delays to apply to each stage are critical for the correct operation of the scheme. These should be calculated as follows:

First Stage (Retrip)	Typical Times
Trip Relay operate time	10ms
Duobias-M Reset Time	20ms
CB Tripping time	50ms
Safety Margin	40ms
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	20ms
CB Tripping time	50ms
Margin	60ms

Overall Second Stage CBF Time Delay 260ms

The safety margin is extended by 1 cycle for the second CBF stage as this will usually involve a back-trip of a Busbar zone-tripping scheme.

The sequence of operation and timing for each stage of the circuit breaker fail function are displayed below.

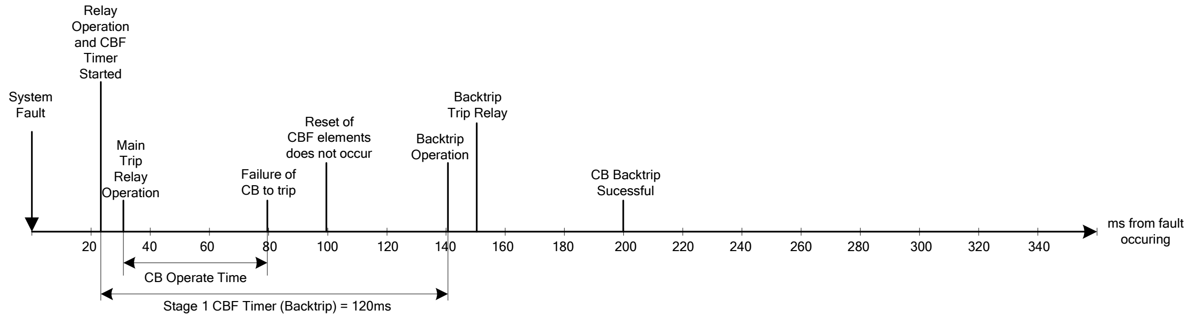


Figure 5 - Single Stage Circuit Breaker Fail Timing

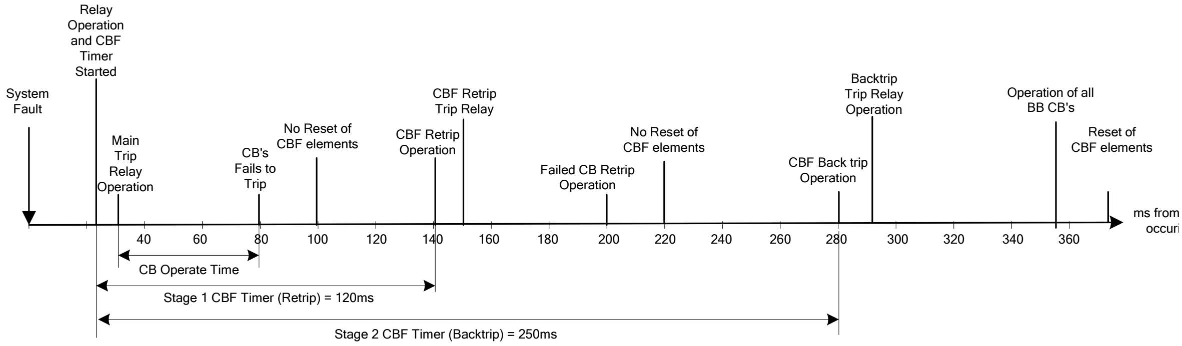


Figure 6 - Two Stage Circuit Breaker Fail Timing

3.8 NPS Over Current (46)

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.

4 Programmable Inputs and Outputs

The relay can be mapped with the use of its settings and does not rely on access to software packages to configure the relay I/O. This is an advantage in saving time and simplifies the setting of the relay. In rare occasions where more complex logic is required a software package called ReylogiC can be used. This allows the user to define logic scripts within the relay.

The Duobias-M-200 series of relays have from 5 to 29 output relays, all of which are "voltage-free" contacts and relays one, two and three have changeover contacts. It also has provision for receiving operating signals from 3 to 27 external contacts; these are referred to as the d.c. Status Inputs. Each of these Status Inputs can be programmed to operate one or more of the output relays. Similarly, the protection functions of the Duobias-M relay can each be programmed to operate one or more of the output relays. The output contacts can be programmed either to follow the status inputs i.e. be self-reset, or to Hand Reset in their operated state. If programmed to be latched, they will remain operated after their associated Status Inputs have reset and will stay operated until the 'Reset' button is pushed or a remotely initiated reset signal is received. The Commissioning Chapter describes the method of programming the output relay configuration.

The amount of I/O to include in the Duobias-M relay should be considered when the application engineering is being carried out. The total protection and alarm requirements of the installation should be assessed so that the relay can be fully exploited. The Relay Settings Chapter shows the relay configured for a typical transformer installation. The Matrix Planner shows how the d.c. Status inputs have been allocated to the various trip and alarm sources. It also shows how they have been programmed to operate one or more output relays so enabling one alarm source to initiate a discrete alarm plus a grouped alarm; and one tripping source to operate its appropriate tripping relay plus an alarm output. If there are spare Status Inputs and spare output relays more alarm or trip sources can be connected. For example, if the transformer has H.V. or L.V. electro-mechanical or static type over current relays, these can be connected to spare d.c. Status Inputs and programmed to initiate the appropriate alarm and trip output relays. Similarly, if the transformer cooler control scheme is arranged to initiate a "cooler fail" alarm, this can be added and programmed to initiate a discrete and/or a grouped alarm.

Where the transformer is part of an installation that is equipped with auto-switching, i.e. auto-isolation and auto-reclosing, the tripping output relays will probably require to operate separate, latched tripping relays which will then provide the various contact inputs to the auto-switching equipment. The same applies if a number of local and remote circuit breakers have to be tripped as is the case with certain designs of mesh substation. Where these constraints do not apply, the output relays can be arranged to operate the circuit breaker trip coils direct so long as the trip coil current is broken by a circuit breaker auxiliary switch and the 'make and carry' currents are not exceeded. A remote risk with this arrangement is that of the "stuck-breaker" condition which will probably result in damage to the output relay contacts. When the output relay is arranged to drive an external latched tripping relay, this risk is transferred to the tripping relay contacts and it is a matter of judgement as to which arrangement is most acceptable.

5 Current transformer requirements for transformer applications

The specification of CTs must meet the requirements of all the protection functions used on an application. If REF protection is used, the CTs must meet both the biased differential requirement and the REF requirement. If the CTs meet the requirement for the differential elements, they also will be suitable for all other current measuring functions such as backup over current and earth fault and overload protections.

5.1 CT Requirement for Differential Protection

The quality of CTs will always affect the performance of any protection system to a lesser or greater extent. The kneepoint voltage (V_k) a CT can deliver is one of the main criteria for assessing its performance. For biased differential relays the CTs kneepoint voltage is particularly important. All relays of this type have some form of harmonic restraint or inhibit to prevent operation from the flow of magnetizing inrush current when a transformer is energized.

If a high level internal short circuit occurs the dc offset in the primary fault current may push the CTs into transient saturation. This is more likely to occur if the CT kneepoint is low and or the burden is high. Saturated CTs produce high levels of even harmonics and this may slow down the operate time of the biased differential function. To overcome this, the CTs kneepoint voltage must be chosen to maintain high-speed operation of the biased differential element. A non-harmonically restrained highset differential element is included to cut off this slowed operate time of the biased element. The use of Restricted Earth Fault also helps ensure fast tripping as it is not slowed significantly by CT saturation.

The guidance on CT requirements is that the CT knee-point voltage must be equal to, or exceed

$Vk = 4 \times HS \times I_B \times R_B$

This equation is suitable for use if Restricted Earth Fault is not used to protect all windings.

Where REF is used to protect all transformer windings the CT requirements can be lowered to:

$Vk = 2 \times HS \times I_B \times (R_{CT}+R_L)$

It is always advised to use REF protection, as it is a very sensitive, very stable and very fast. Usually one set of current transformers is used for both Differential and Restricted Earth Fault protections they must meet the requirements for both protection systems.

A typical highset differential setting to use is 7 x I_n. Smaller transformers below 5MVA will require the highset differential to be set to 9 x I_n. Line current transformer ratios should be selected to match the main transformer rating and ratio. Other ratios can be used provided these are in the range of the relay current multiplier adjustment and do not exceed the current transformer and relay ratings.

Advice on CT Selection.

If possible use 1A rated secondary CTs instead of 5A CTs. The CT burden is 25 times (I2) less by using a 1A rated CT rather than using 5A rated CT.

Choose a CT ratio that produces at least 1/3rd (eg 0.33A if 1A CT are used) of the nominal secondary rating, when based on the transformer is at nameplate rating.

Use REF to lower the CT requirement

Where long secondary lead lengths must be used, choose CT ratios to produce about a secondary current of 0.35 x I_n. ICT multiplier settings of up to 3x can then be used to increase the relay currents to about 1 x I_n. This reduces burden imposed on the CT. Two cores per phase may also be used to half the lead resistance.

Typical Example

Taking the previous 45MVA 132/33kV Transformer with 300/1A CTs:

Secondary at transformer rating = 0.66A

Differential Highset (87HS) setting to 7 x I_n

A – 3.5 ohms

C - 2.5 ohms

V_k should equal or exceed 111 volts if REF is not used and 66 volts if REF is used to protect all windings.

An indication of the suitability of a protective CT whose performance is defined by a B.S.3938 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. However this is an approximation and should not replace the recommended method.

5.2 CT Requirement for Restricted Earth Fault

For Restricted Earth Fault protection it is recommended that all current transformers should have an equal number of secondary turns. A low reactance CT to IEC Class PX is recommended, as this will allow a sensitive current setting to be adopted. The low reactance CT will limit the magnetizing current drawn by the CT at the REF setting voltage. The CT kneepoint voltage must be sufficient to allow a stable voltage setting to be selected. It is recommended to use and specify 1A rated CTs for REF protection as a sensitive setting is more easily obtained. Line and neutral CT ratios must be identical and it is also best to have similar magnetizing characteristics.

A full explanation of how to specify CTs for use with REF protection, and set REF relays is available on our Website: www.reyrolle-protection.com (Publications->Technical Reports)

6 Secondary Connections

The a.c. connections to use for specific applications must be considered.

Two and three winding transformer applications with a set of line CTs per winding will be the most common type of application of the relay. Most applications are simple, but some are more complicated due to primary connections:

- Mixture of 5A and 1A CTs
- Cross over of the primary connections of two phases.
- Phase Rotations between HV and LV primary connections.
- Two sets of inputs per winding e.g. Teed Circuits, Meshes and 1.5 CB applications.
- Reversed primary connections
- Multiple Winding Transformers (3 Windings or more)

6.1 Mixing 5A and 1 A CTs

As discussed on the section on CT requirements, 1A rated CTs are always technically superior to 5A rated CTs in terms of protection performance. However sometime because of space limitations and re-use of existing CTs, 5A CTs must be accommodated. All Reyrolle numerical protection relays have 1A and 5A rated terminals for connection to each CT. It is therefore very easy for example to use 1A rated CTs on the HV side and 5A rated CTs on the LV side.

6.2 Parallel Connection of Two Sets of CTs into one winding

It is important that the relay connections are chosen to suite the application of the relay. Modern digital relays offer the option of multiple current inputs that allows the relay to be specified with a set of current inputs for each set of CTs that can greatly enhance stability for external through faults.

Sometimes two sets CTs would be connected in parallel into one relay input, as shown in Figure 7 below. Often the two CTs sets will use different core steel, have different kneepoint voltages and lead burdens. Therefore a through fault may cause transient saturation to different degrees which may lead to a false relay operation. The main reason for this is the fact that during a through fault the majority of the current (when the CTs are not saturated) only flows in the CT wiring and not in the relay input. The biasing affect of current from these CTs is lost.

Therefore it is not technically sound to parallel two sets of CTs together and connect them to one relay input.

The difference between the secondary currents in each set of CTs will flow into the relay as a pulse of differential current that may cause a false trip.

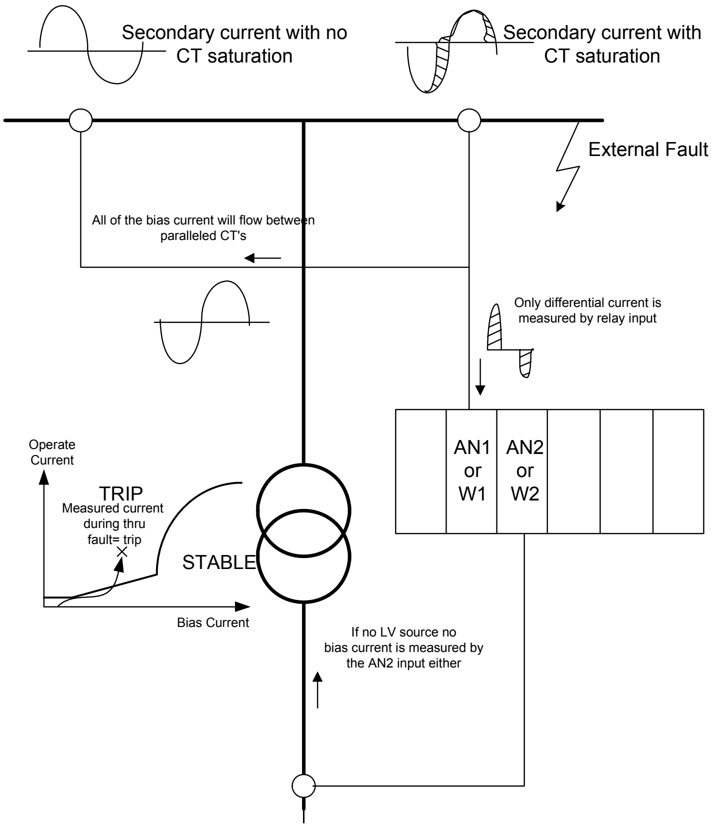


Figure 7 - Incorrect relay connections using parallel connected CTs into one relay input

It is better to use separate relay inputs for each set of CTs, as shown in Figure 8 below, as a greater bias current will be measured by the relay making it much more stable for through faults.

This is now easily dealt with as the Duobias M relay may be specified with up to 5 sets of CT inputs. As the relay input modules are referred to as windings W1, W2 etc the inputs can now be connected to any set of CT inputs.

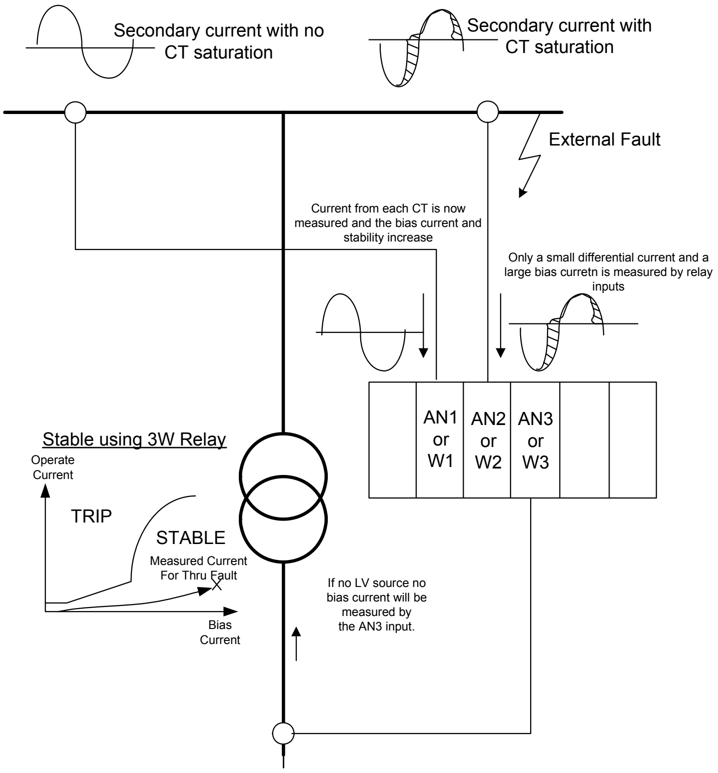


Figure 8 - Correct Method of Protection using a 3-winding relay

6.3 Differential Connections

As discussed above the relay is supplied with between 2 and 5 sets of CT inputs. Therefore almost all primary configurations, vector groups and CT locations can be catered for.

Historically a differential relay would be connected with external interposing CTs to correct for vector group and CT ratio mismatch and to compensate for zero sequence current removal to ensure stability for all through fault conditions.. Figure 9 is quite important in terms of understanding how this type of protection works. The relay bias windings are shown as circles and the relay differential elements as A, B and C. The differential relay measures operate current if a difference in the secondary currents as fed to it from the interposing CTs exists. Because the transformer delta connected secondary does not permit the transfer of zero sequence components and because an earthing transformer provides an in zone path for zero sequence currents to flow then it is important that these are removed from the currents applied to the relay. In this diagram this is done using a Ydy0 interposing current transformer.

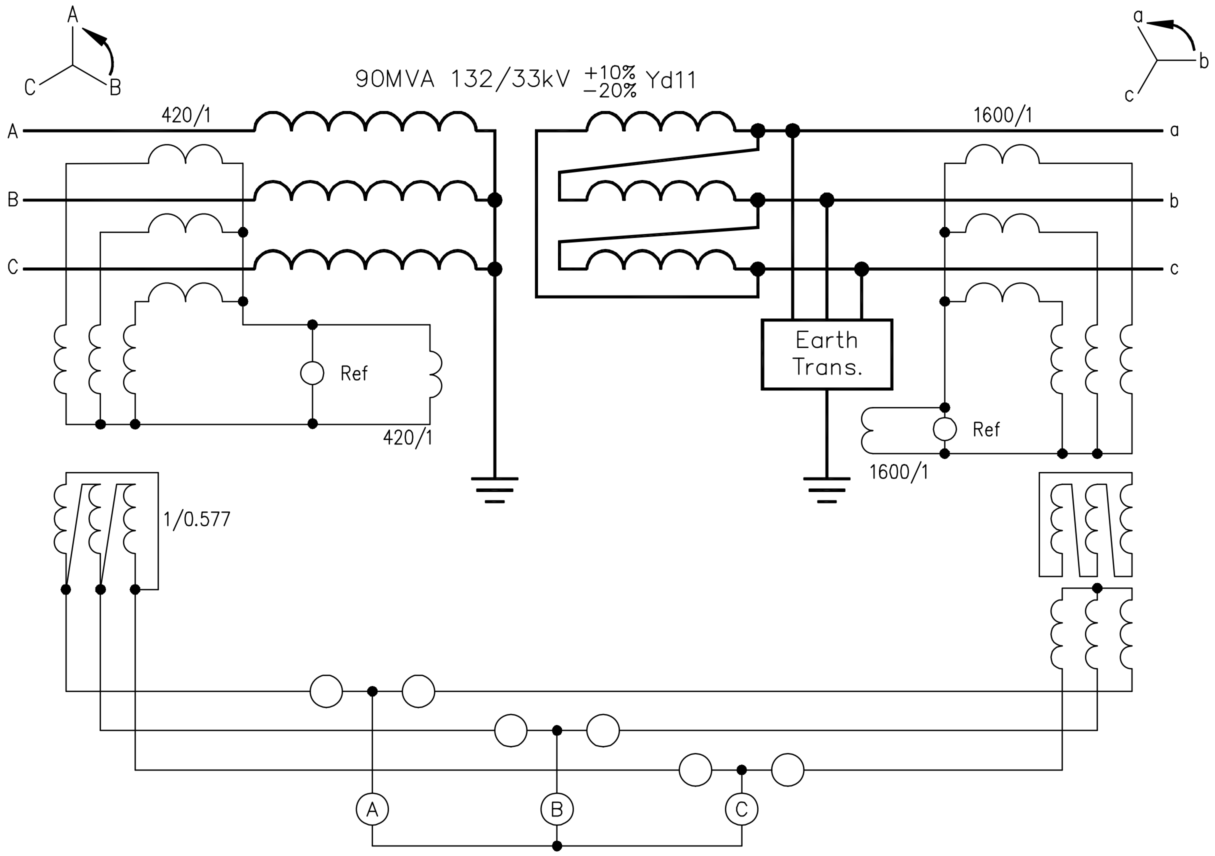


Figure 9 - with dedicated Biased Differential, HV & LV REF and associated Interposing CTs.

The numerical equivalent is shown in Figure 10, and is more abstract in terms of understanding how this protection works.
Here the vector compensation, matching of the current magnitudes and zero sequence current removal is done mathematically by the relay algorithms.

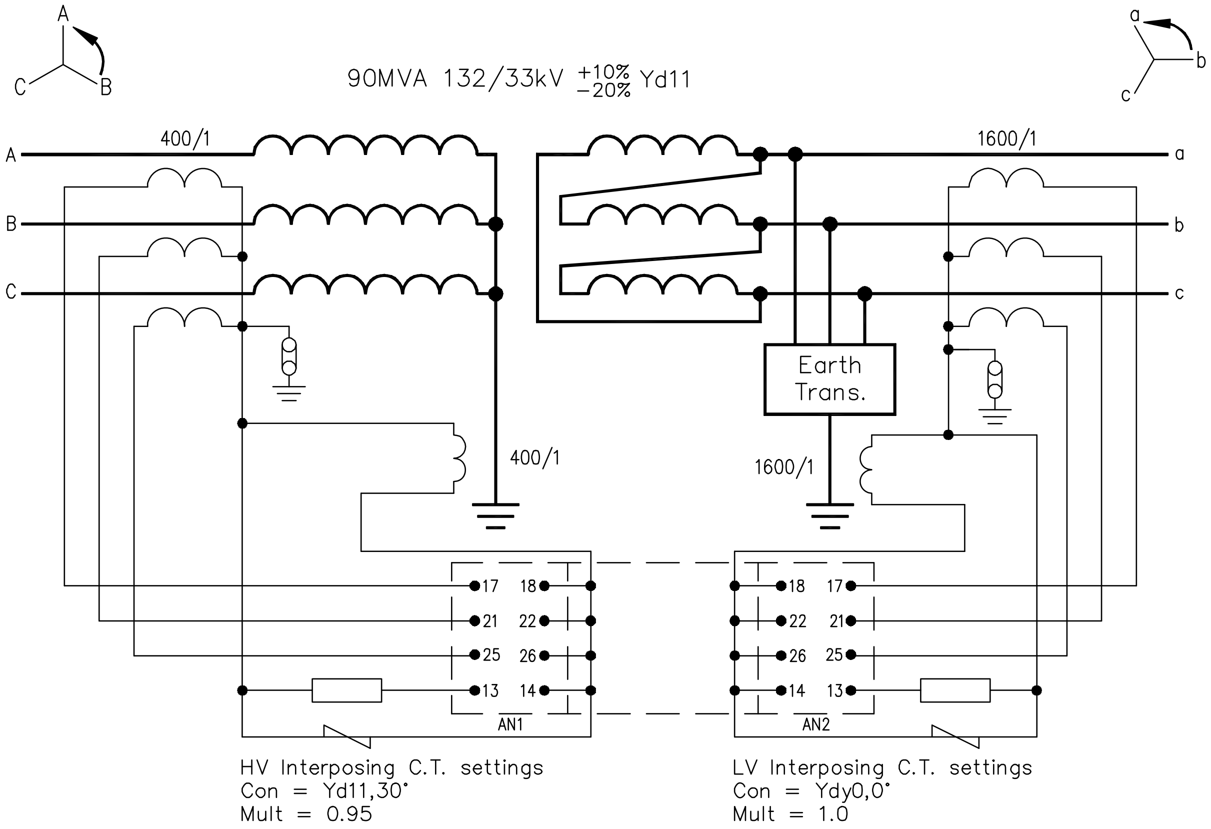


Figure 10 - Yd11 Transformer with Duobias-M protection applied

6.4 Phase Crossovers and Rotations

An example of the complication produced by primary connections is shown below in Figure 11. This has a rotation on the HV side and a crossover on the LV side.

6.4.1 Protection of a transformer with 90° phase shift

132/33KV 90MVA Yd11 +10% -20% Transformer

Where the phase-shift between the W1 and W2 primary systems is such that main connections have to be crossed, for example Figure 11 shows a typical arrangement where a Yd11 transformer is arranged to give a primary system phase-shift of +90° by appropriate crossing of its main connections. There are two optional methods of setting up Duobias-M protection.

One solution is shown in Figure 11 shows the H.V. and L.V. CT secondary wiring replicating the main connection crossovers with the 'A' phase connected to terminal 25, the 'B' phase to terminal 21 and the 'C' phase to terminal 17. The L.V. 'B' and 'C' connections are similarly crossed over. With this arrangement, the Duobias-M relay can be set to correspond to the vector group of the main transformer. i.e. Yd11, +30°.

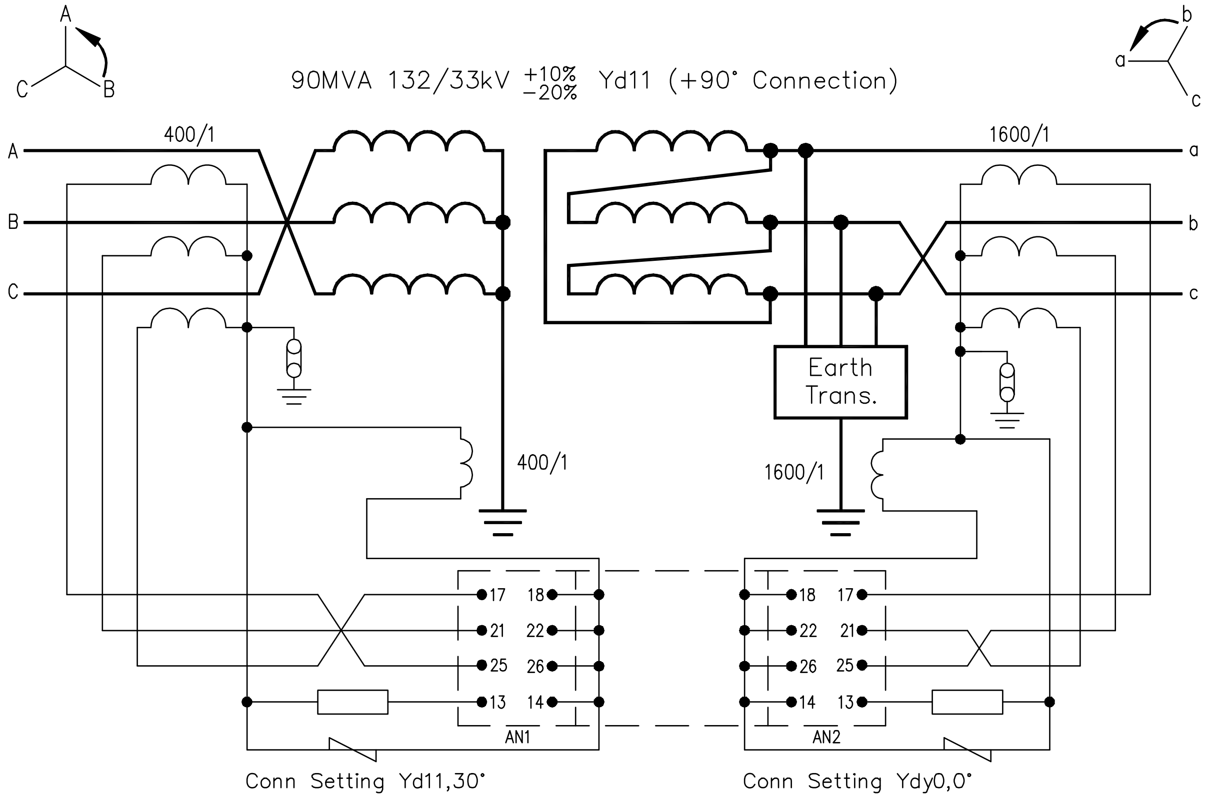


Figure 11 - Yd11 transformer connected as Yd9, +90 with crossover corrected at relay terminals.

In the second solution shown in Figure 12 the function of the interposing CTs is carried out within the relay by setting the H.V. interposing CT connection to Yd9, +90° and the L.V. interposing CT connection to Ydy0, 0°.

The secondary CT wiring is connected to a Duobias-M relay in the conventional way with the 'A' phase CT connected to terminal 17, the 'B' phase to terminal 21 and the 'C' phase to terminal 25. With this method, the H.V. interposing connection must be set to Yd9, 90°.

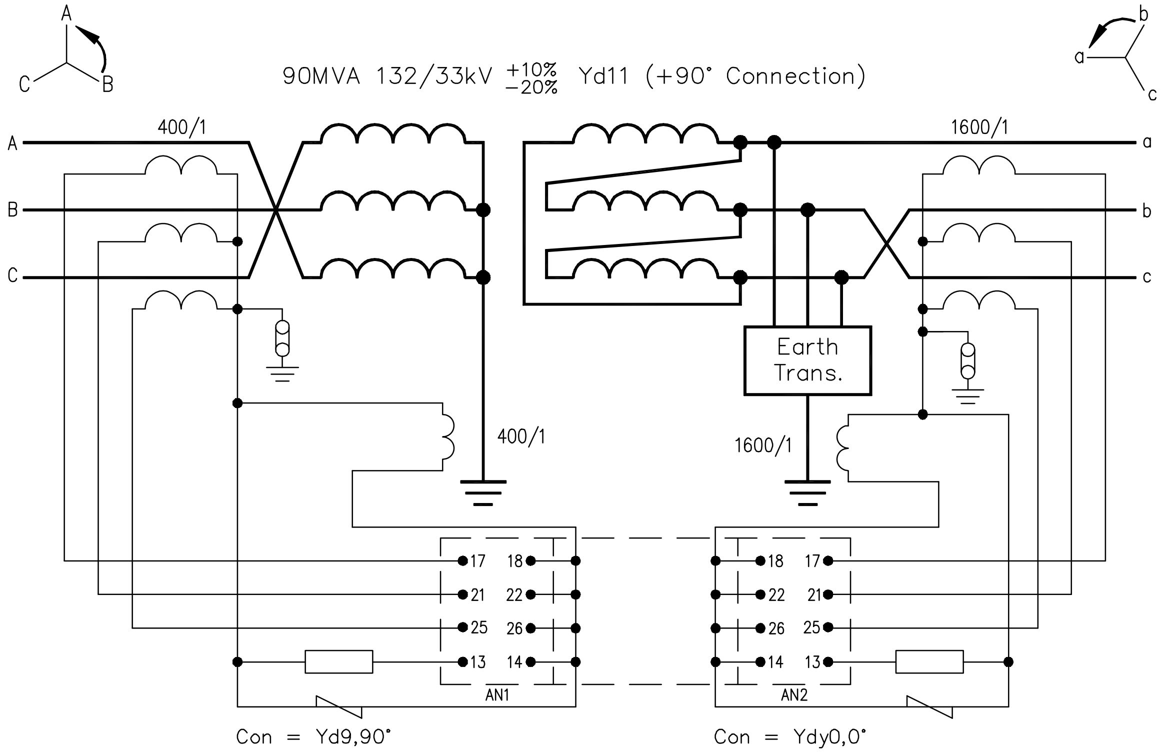
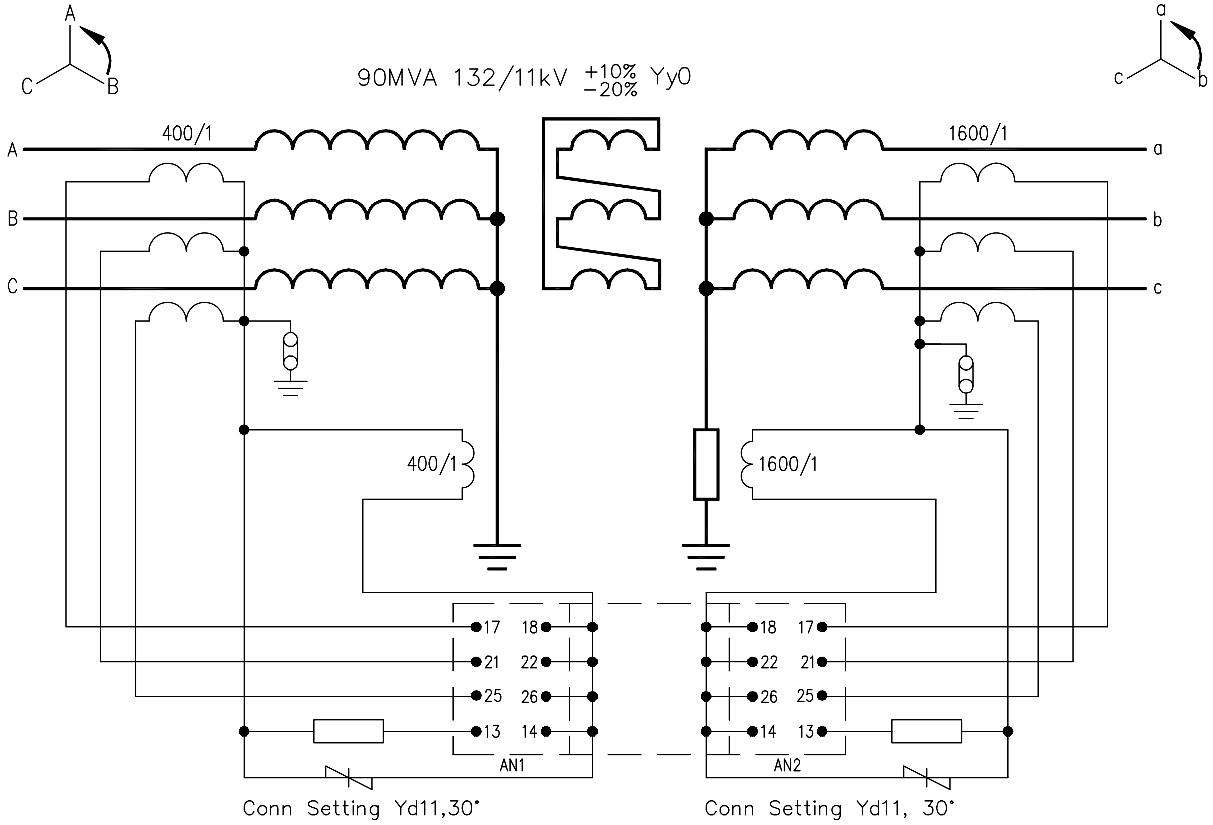


Figure 12 - Yd11 transformer connected to produce Yd9, +90^0 with correction using relay settings

7 Specific relay applications

7.1 Protection of Star/Star Transformer



Note: the settings can also be Yd1,−30° but both sides must be the same.

Figure 13 – YNdyn0 Transformer with Biased Differential and Restricted Earth Fault

The star/star transformer shown in Figure 13 has a phase shift of zero but still requires the zero sequence shunt which, in the dedicated relay arrangement, is provided either by delta connected main CTs or by selecting a star/delta interposing CT setting on the Duobias-M relay. The Interposing CT Connection setting on all sets of current inputs must be set to the same Yd setting. They can all be either Yd1, -30° or Yd11, 30°, but the H.V. and L.V. must have the same setting for the relay to balance.

Note 1 The connection setting can also be Yd1, -30° but both sides must be the same

Note 2 The HV and LV CTs must be of appropriate ratio for their associated system voltage and the transformer MVA rating.

Note 3 The change in transformer ratio due to the tap changer must be taken into account and the interposing CT multipliers set accordingly.

Note 4 The effect of the tap changer and of magnetising inrush current must be taken into account when setting the bias and the differential high set Overcurrent.

7.2 Protection Of Three Winding Transformers

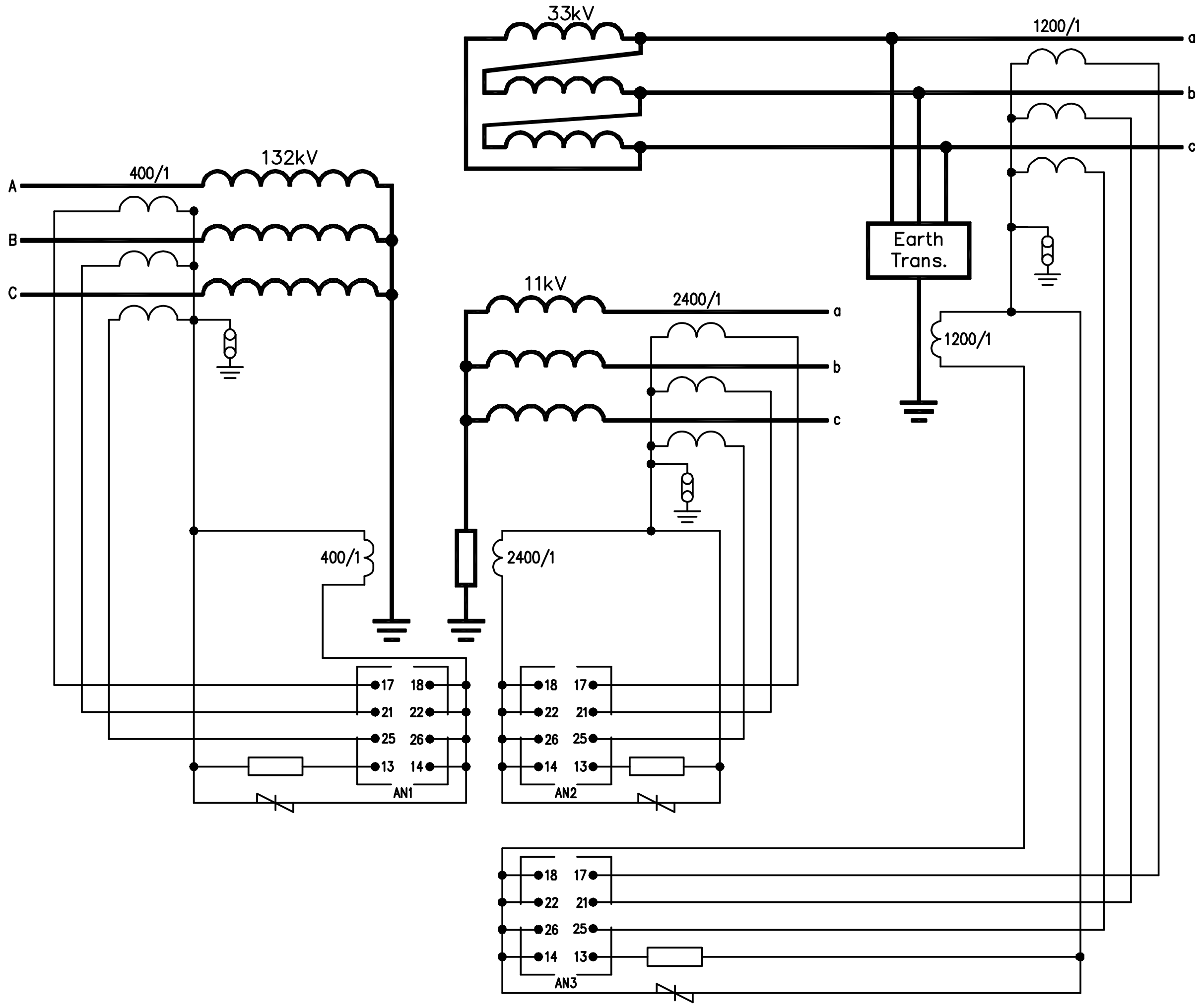


Figure 14 - Application to three winding transformer

Transformer: -
132/33/11KV 90MVA Yd11y0.
33KV DELTA WINDING 60MVA.
11KV STAR WINDING 30MVA.
TAPPING RANGE +10% TO -20%.

Figure 14, shows Duobias-M protection applied to a three winding transformer. The example chosen shows a 90MVA transformer. Its H.V. winding is rated at 132kV and is star connected, it has two L.V. windings, one star connected rated at 30MVA, 11kV and the other delta connected rated at 60MVA, 33kV. The H.V. winding has an on-load tap changer with a tapping range of +10% to -20%. The procedure to determine the CT ratios and protection settings is as follows.

Each combination of H.V./L.V. winding, i.e. 132/llkV and 132/33kV must be treat separately and the settings determined as shown in earlier examples. The H.V winding is common to both combinations so its settings must obviously be compatible for each arrangement. Considering the 132/33kV arrangement first. This is the same as that shown in Figure 10 and the same CT ratios and protection settings can be chosen. The L.V. CT ratio must be four times the H.V. ratio of 400/1, i.e. 1600/1, because the main transformer voltage ratio is 132/33kV, i.e. 4/1. Because the H.V. CT ratio was chosen to be appropriate to 90MVA, this means that the 33kV ratio selected of 1600/1 is also appropriate to 90MVA.

Since the 33kV winding is rated at 60MVA, the use of lower ratio CTs may be preferred; this can be achieved conveniently by suitable selection of the L.V. interposing CT multiplier setting. In this example, the CT ratio chosen is 1200/1A for the 60MVA winding. This is used in conjunction with an L.V. interposing CT multiplier setting of 0.75 giving an effective ratio of 1600/1 for protection balancing purposes.

Considering the 132/llkV arrangement, this is the same as that shown in Figure 13 for a Yy0 transformer and the same settings can be chosen. Once again, a more suitable 11kV. CT ratio of 2400/1 can be used in conjunction with the minimum L.V. interposing CT multiplier of 0.5 giving an effective ratio of 4800/1.

It can be seen that the H.V. interposing CT connection settings required for the 132/33kV. The 132/11kV arrangements are compatible so the settings shown in Fig.6 would be applied. If the three winding transformer shown was re-arranged to be of vector group Yd1y0, then the H.V. interposing CT connection and the 11kV, L.V. interposing CT connection would both have to be set to Yd1, -30.

The settings must, of course balance when the L.V. winding combination is treated as a two winding transformer and the procedure described above will produce the correct settings. In the Fig.7 example, if the 11/33kV combination is viewed as a Y/d11 transformer, the connection settings will be seen to correspond with those for the Y/d11 example shown in Fig.4B and the CT multiplier settings will also be seen to produce the required balance with effective CT ratios of 4800/1 and 1600/1 reflecting the voltage ratio of 11/33kV.

When applying the three winding Duobias-M relay to transformers where the rated voltage and therefore CT ratio of transformer windings differ greatly most of the ratio correction must be achieved by the appropriate selection of the CT ratio as the interposing CT multiplier is limited to 0.25 to 3.0. The appropriate CT ratio’s to be used can be found by calculating primary currents to a common MVA base (usually the highest MVA rated winding).

132/33KV 90MVA Yd11 +10% -20% Transformer

The function of the interposing CTs is now carried out within the relay by setting the H.V. interposing CT connection to Yd11, 30° and the L.V. interposing CT connection to Ydy0, 0°. The preferred ratio of 400/1 can now be used for the H.V. CTs and the optimising of the ratios carried out by setting the H.V. interposing CT multiplier to 0.95.

7.3 Protection of Auto Transformers

In the past the main protection applied to large auto-transformers would be overall high impedance with three phase sets of line CTs on all of the terminals of the winding. This arrangement is shown below.

The discussion of biased differential protection has, up to this point, been confined to two and three winding transformers. However, it is possible to treat an auto-transformer in the same way as normal two winding transformer. The Duobias-M can be supplied with two to five sets of CT inputs for unit protection of a transformer.

Two common arrangements are shown in Figure 15 and Figure 16. It can be seen that the need for neutral and connection CTs can be eliminated but at cost. The H.V. and L.V. and neutral end CTs must now have ratios appropriate to the rated voltage of their associated windings and the ratios must be optimized as shown in Figure 17.

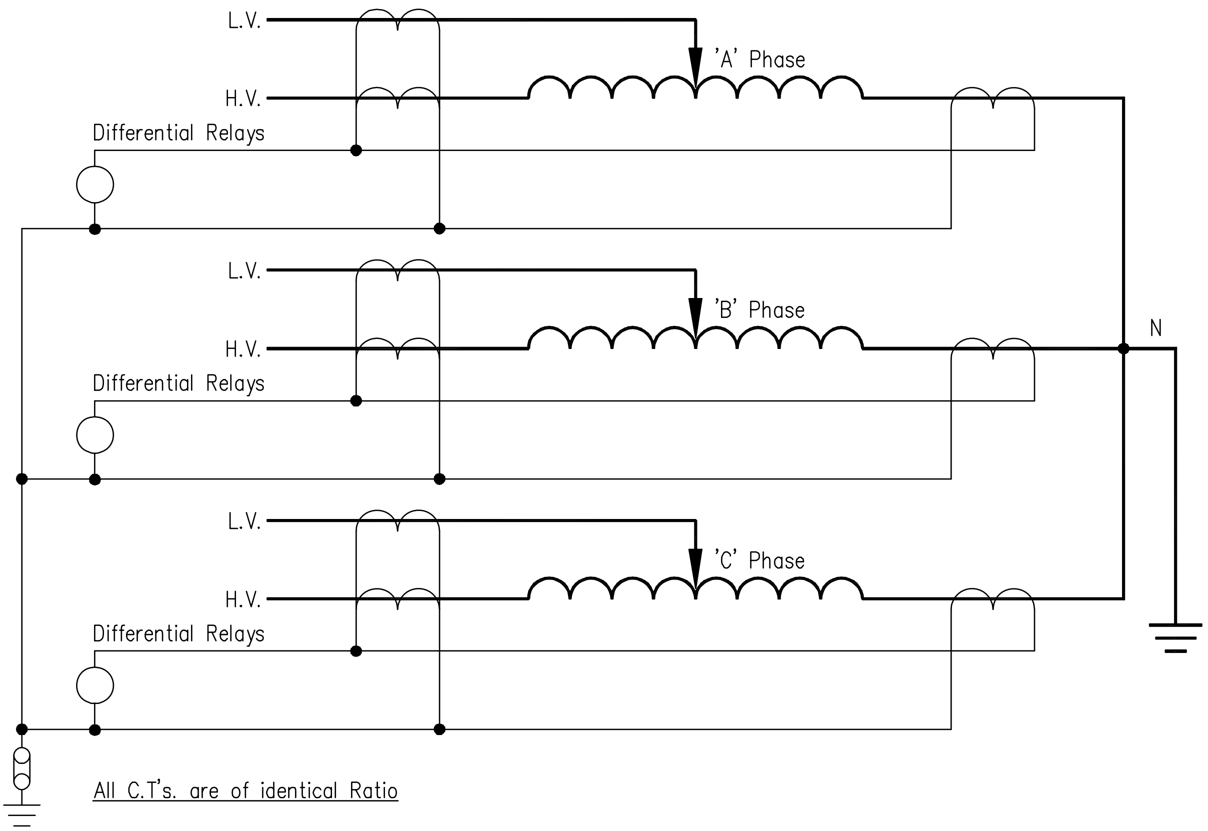


Figure 15 - Traditional High Impedance Transformer Protection

These relays would typically be static type relays.

The use of numerical biased relays to replace static high impedance relays offers a number of benefits:

- Supervision of relay power supply.
- Supervision of the relay hardware.
- Remote Communications.
- Lower CT requirements.
- Relay Instruments make commission easier.
- LED's provide flagging of all external protection devices such as Buchholz relays etc via the relay status inputs.
- Waveform Recording for the operations of all external and internal protection functions
- The existing CTs may be re-used in most cases

7.3.1 Preferred Application to Auto Transformers

The Duobias-M relay may be used to protect auto-transformers. The settings and connections will depend on the presence and location of CTs. Line CTs will always be required but the magnetising inrush settings to use will be depend on the neutral end CTs. If a three-phase set of CTs is neutral end CTs are available the Magnetizing Inrush may be set to [Disabled]. In this case the magnetizing inrush will balance out between the CTs as only one winding is present and all terminals have CTs.

The scheme uses the W1 REF to provide a high speed overall earth fault differential zone of protection. Overall EF provides sensitive earth fault protection for earth faults near to the neutral end of the winding. High speed protection (15 to 25ms) for all fault levels is provided.

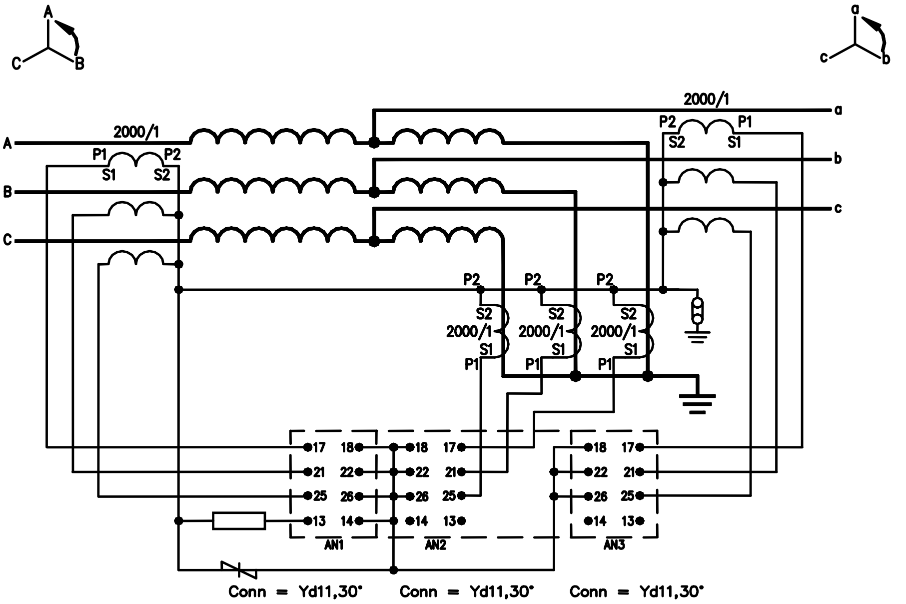


Figure 16 - Recommended Method of Auto Transformer Protection

7.3.2 Alternative Applications to Auto Transformers

An alternative scheme for auto transformer protection is shown in Figure 17. This scheme gives REF protection and hence is more comprehensive than the Figure 18 scheme but all line and neutral CTs must have the same ratio. The interposing CTs in the Duobias-M must have the ratio of the primary voltages. For instance, with a 400/275 kV auto transformer, the interposing CTS on module B (HV) should be set to a ratio of 1.45/1 and on Module C (LV) should be set to 1/1. These interposing CTs must be configured in a star/delta mode as indicated above. Where only one neutral CT is present as shown in Figure 17, the Magnetizing Inrush Inhibit must be set to [Enabled] as the magnetizing inrush currents in each phase will not balance. The overall earth fault high impedance zone can still be used.

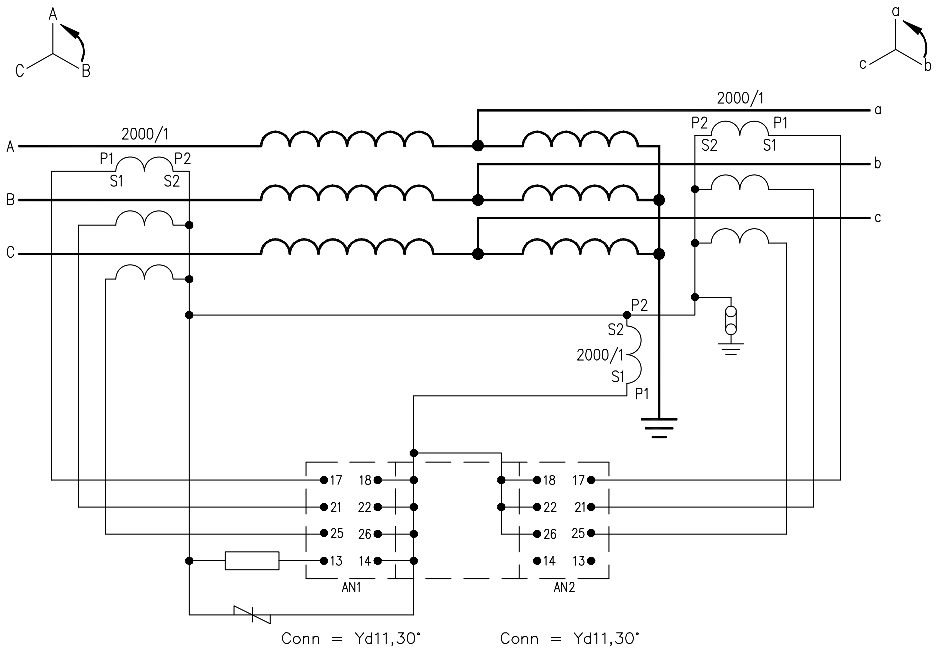


Figure 17 - Alternative Application to an Auto Transformer

The auto transformer shown in Figure 18 can be treat in the same way as the double wound, star/star transformer shown in Figure 13 and will have the same interposing CT connection settings. It is not equipped with neutral CTs however so it cannot have R.E.F. protection.

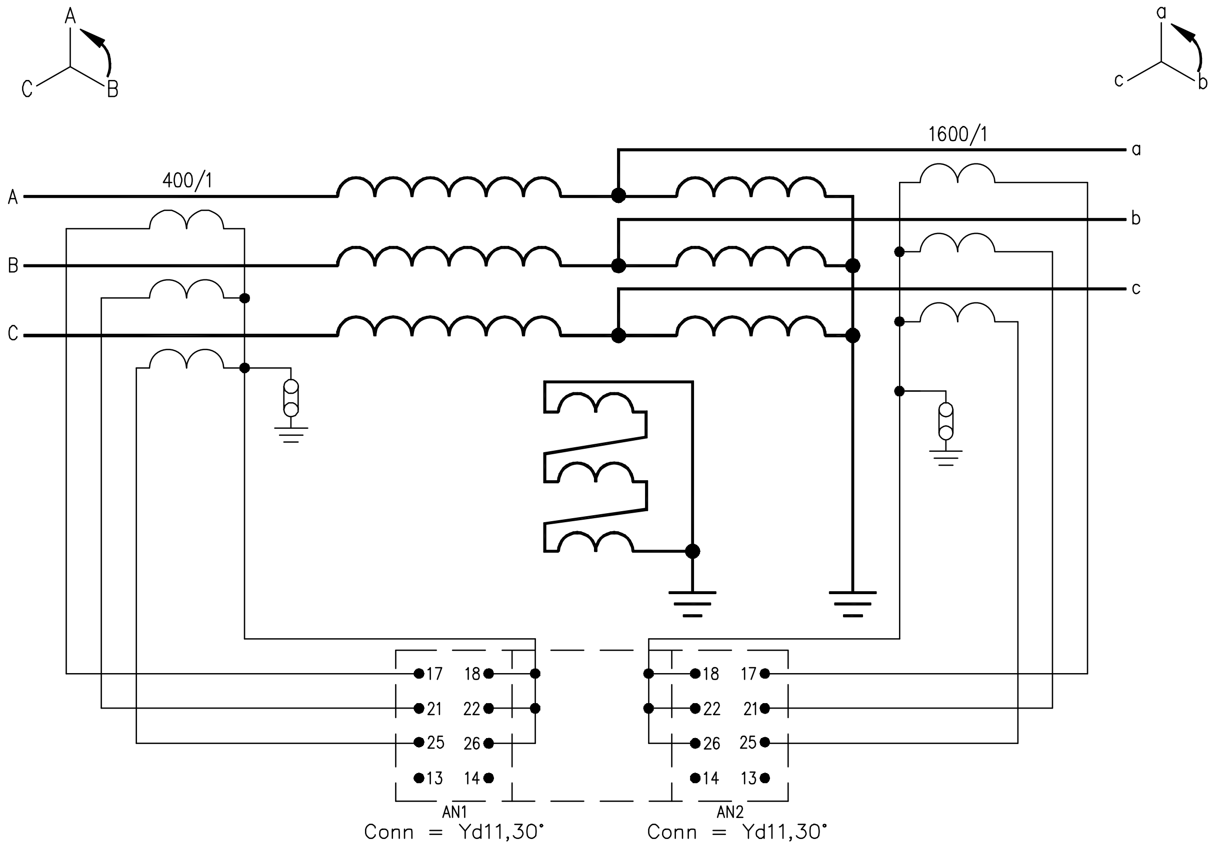


Figure 18 - Autotransformer with Biased Differential Protection

8 Appendix 1 – Application to YNyn6yn6 Transformer (3 winding)

8.1 Introduction

Relay settings appropriate for the protection of a Yyn6yn6 transformer where the red phase is at 8 o’clock (transformer phase C) on the primary winding and at 10 o’clock (transformer phase B) on the secondary windings.

8.2 Design considerations

The transformer connection implies a 60 degree phase shift between the primary and secondary windings i.e. the transformer is overall a Yy2y2 connection.

This at first suggests protection by using Yy2 interposing connection on the HV interposing current transformers and Yy0 on the LV interposing transformers.

However the HV winding is not earthed and therefore zero sequence currents seen by the LV current transformers will not be seen by the HV current transformers and such a selection would result in maloperation of the protection. The answer is therefore to remove the zero sequence components seen by the LV current transformers.

This could be done in several ways.

- Using delta connected current transformers on all windings.
- External zero sequence shunts in current transformer circuit.
- Star delta star interposing current transformers, externally or internally to the Duobias M relay on the LV side.
- Inserting a delta circuit by means of similar star delta interposing current transformations to both sides of the transformer. This may be done typically by means of a Yd1 connection LV side and an additional Yd1 on the HV side also i.e. Yy2 + Yd1 = Yd3 connected on the HV side. This is the method recommended.

8.3 Design calculations

Note: All calculations assuming no tap changer fitted.

HV rated current = 60MVA / 66kV x Ã3 = 524.86A

HV secondary currents = HV rated / HV CT ratio = 524.86/600 = 0.875A

LVA rated current = 60MVA / 11kV x Ã3 = 3149.18A

LVA secondary current = LVA rated / LVA CT ratio = 3149.18/1500 = 2.099A

LVB rated current = 60MVA / 11kV x Ã3 = 3149.18A

LVB secondary current = LVB rated / LVB CT ratio = 3149.18/1500 = 2.099A

Minimum multiplier which can be applied on LVA/B sides is 0.5x.

Therefore after interposing CT correction,

LVA relay current = LVA CT secondary current x 0.5 = 1.05A

LVB relay current = LVA CT secondary current x 0.5 = 1.05A

HV multiplier = LVA relay current / HV CT secondary current = 1.05/0.875 = 1.2x.

Transformer Yy6y6	HV	LVA	LVB
Voltage (kV)	66	11	11
Rating (MVA)	60	30	30
CT Ratios	600/1	1500/1	1500/1

Multipliers	1.20	0.50	0.50
Interposing CT Connection	Yd3	Yd1	Yd1

9 Appendix 2 – Application to Dyn11 Transformer with primary crossover

9.1 Introduction

Relay settings appropriate for the protection of a 66/11Kv transformer with reverse phase rotation.

9.2 Scheme details

Reverse phase rotation requires phase reversal at the transformer. This necessitates careful consideration of the selection of interposing CTs to maintain balance. A number of possible solutions are possible.

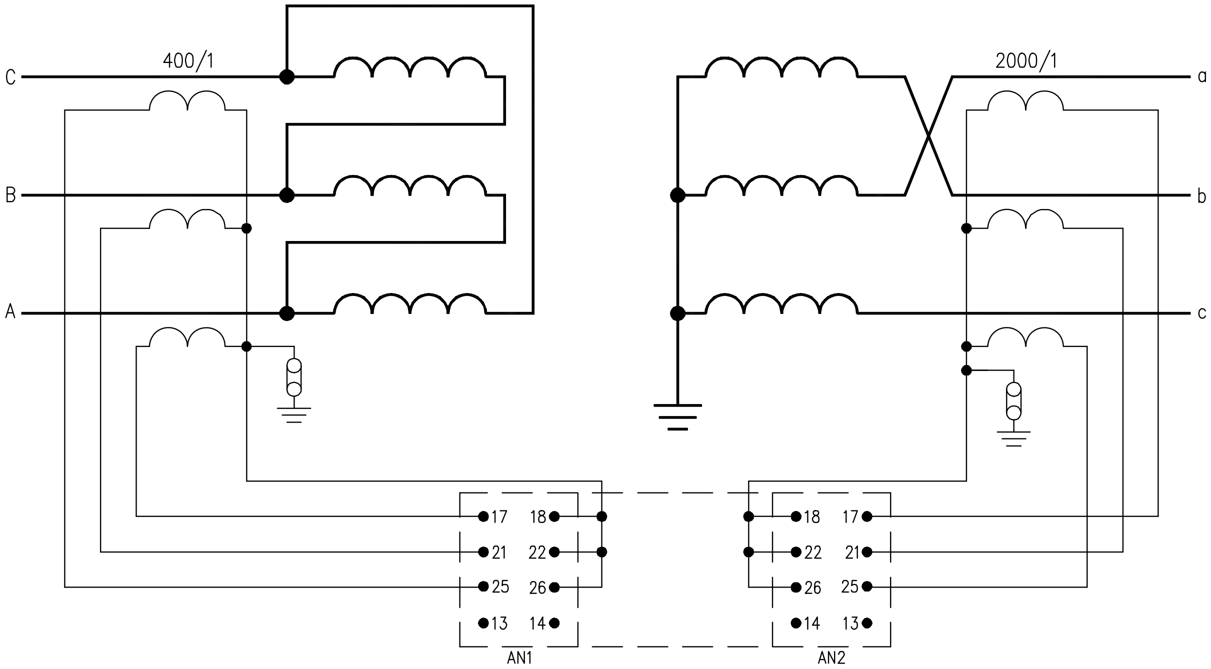


Figure 19 - Dyn11 Transformer with reverse phase rotation

9.3 Duobias-M settings

Differential Initial Setting: 20%

This is chosen to take account of the percentage tolerance difference of line CTs. This setting should be the same as that for the Differential Bias Slope.

Differential Bias Slope: 20%

This setting is selected to maintain balance when through fault or heavy load current is passed through the transformer when the tap change unit is in its extreme position. Recommend setting to be 1x tap change range (+5% to –15%).

Differential Bias Slope Limit: 4x

The bias slope limit is chosen to protect against CT saturation under through fault conditions. The lower the setting the more stable the protection.

Differential High Set Overcurrent: 8

This is set above the maximum through fault with the tap changer in the extreme position. The setting to be as low as possible but not less than the maximum three phase through fault or not less half of the peak maximum magnetising inrush current whichever is greater. A value of 8 x In is used as this equates to a transformer impedance of 12.5%.

Magnetising Inrush Restrain: 20%

A safety factor of 2 times the expected inrush secondary current is used. This commonly gives a factor of 20%. Note that the lower the setting the more stable the relay because this level represents the level of second harmonic which will cause the relay to be inhibited.

W1 (HV) Interposing CT multiplier: 1.14
W1 Interposing CT connection: Yd5

Taking account of scheme connection resulting in equivalent Yd5 transformer.

W2 (LV) Interposing CT multiplier: 1.00
W2 Interposing CT connection: Ydy0

Yy0 for Yd5 transformer but transformer still Dyn11 therefore zero sequence currents have to be removed from the LV side due to star connection and earth path.

HV rated current:	40MVA / 66kV x √3 = 349.9A
HV CT ratio:	400/1
HV CT secondary current:	349.9A/400 = 0.8747A

Transformer ratio at mean tap of tap changer range (+5% to –15%) is –5%±10. The mean tap is chosen in preference to the nominal tap thus avoiding larger unbalance at the extremes of the tap changer range. Although this may result with a small operate current at the nominal tap this is quite acceptable and does not cause any problem or burden. This also takes account of the difference to the voltage range. Reyrolle do not recommend using the nominal tap position in this calculation because balance cannot be guaranteed at the limit of the tap changer range.

66kV x 0.95/11kV = 5.7

LV rated current at mean tap:	349.9A x 5.7 = 1994.43A
LV CT ratio:	2000/1
LV CT secondary current:	1994.93/2000 = 0.9972A

Current input amplitude correction by W1 CT multiplier and W2 CT multiplier to balance HV and LV inputs. The ICT settings to apply to the relay should aim to adjust the relay currents to as close to 1 x in as possible.

0.8747 x W1 ICT = 0.9972 x W2 ICT = 1 x In for balance

Set W2 ICT multiplier = 1/0.9972 = 1.00, since CT ratio of 2000/1 is closest to relay 1A input terminal rating.

W1 ICT = 1/0.8747 = 1.14

9.4 Determination of interposing CT balance

9.4.1 Incorrect interposing CT selection

HV interposing CT	Yd5
LV interposing CT	Yy0

This example shows the flow of current for a through fault condition. Unbalanced loads produce the same effect.

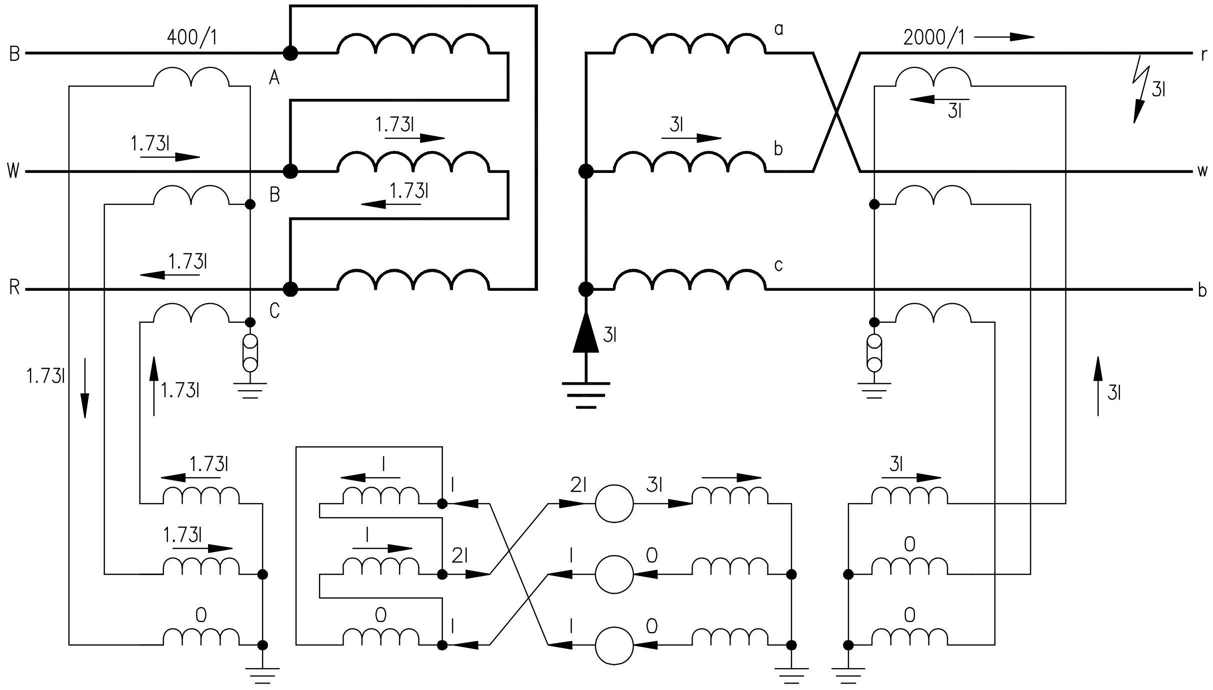


Figure 20 - Effect of incorrect interposing CT selection

9.4.2 Correct Interposing CT Selection

HV interposing CT	Yd5
LV interposing CT	Ydy0

This example shows the flow of current for a through fault condition.

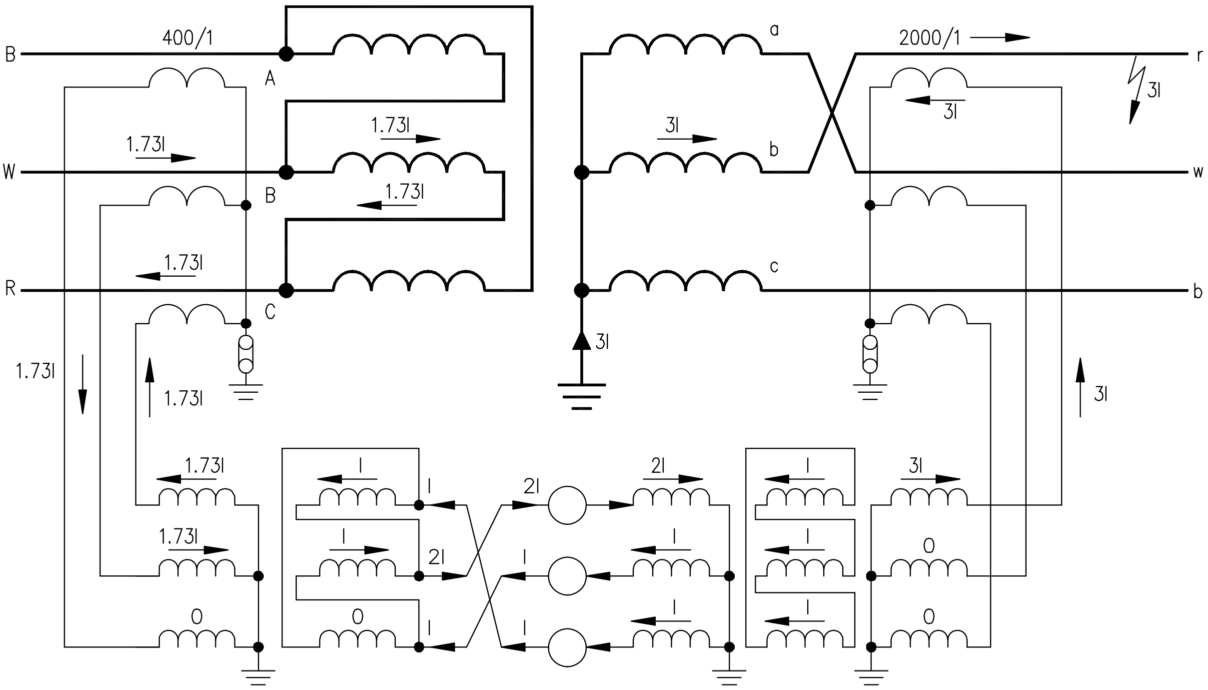
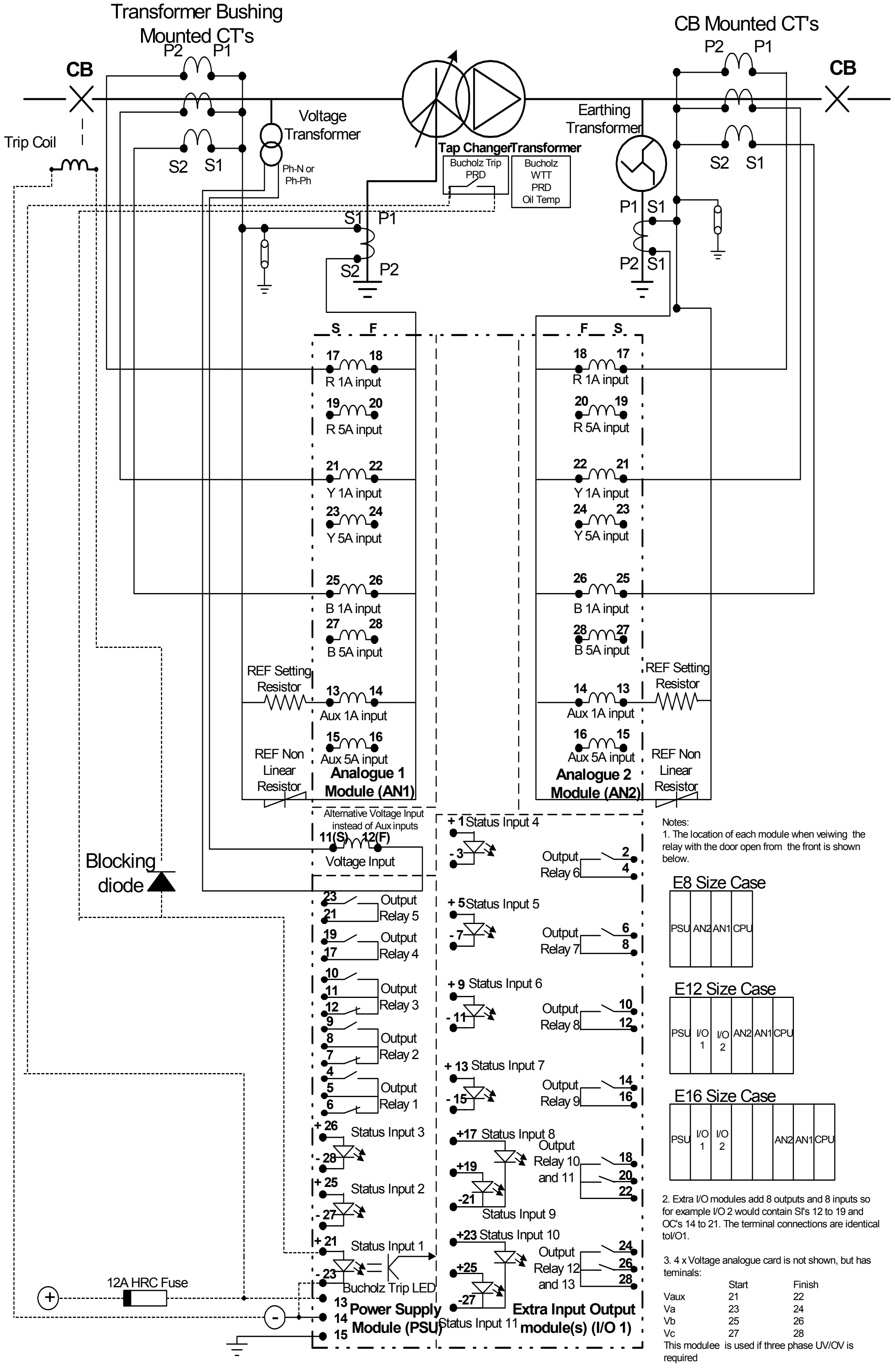


Figure 21 - Correct Interposing CT selection

10 Appendix 3 – Two winding connection diagram



Notes:

1. The location of each module when veiwing the relay with the door open from the front is shown below.

2. Extra I/O modules add 8 outputs and 8 inputs so for example I/O 2 would contain SI's 12 to 19 and OC's 14 to 21. The terminal connections are identical toI/O1.

3. 4 x Voltage analogue card is not shown, but has terminals:

	Start	Finish
Vaux	21	22
Va	23	24
Vb	25	26
Vc	27	28

This modulee is used if three phase UV/OV is required

Figure 22 - Two Winding Connection Diagram

10.1 Notes on Diagram

The module types are standardised and can be multiplied to give extra digital input and output contacts and analogue measurement cards to suite the application.

1.The type of Analogue modules available are:

- 4 x current inputs – 1A and 5A inputs per phase and earth input.(4I module)
- 3 x currents + 1 x voltage. (3I+1V module)
- 4 x voltages (4V module)

2. The types of input and output (I/O) modules available are:

- Standard I/O on Power supply module - Outputs - 3C/O + 2NO + 3 Status Inputs.

- Additional Standard I/O Modules provide 8 status inputs and 8 output relays.

  There are two variations in the type of outputs for each additional I/O module:

  8 Normally Open

  4 Normally Open and 4 Normally closed.

  The ordering table in the Description of Operation provides details of the hardware variants that may be ordered. This table includes the rating of power supply and status inputs.

  An Input module type with 16 status inputs may be ordered, if a particular scheme requires more logic inputs. This may be of use if ReylogiC is used to provide a bespoke control scheme.

  An Output module with 16 output contacts may also be specified.

11 Appendix 4 – Low impedance busbar protection

The Duobias-M relay has been used for the protection of generator station and single bus busbars in the past. It provides a low cost solution to Busbar protection for the simpler layouts. The relay is NOT suitable for double bus sub-station layouts, as there are no facilities to switch current inputs between differential groups.

11.1 Application

The modular II relay has up to five sets of inputs for the protection of various types Busbar layout:

Applications include:

- Distribution Single Bus substations.
- Generator Station Isolated Phase Bus Systems.
- Bus Protection for 1.5 CB Layouts.
- Mesh Corner Protections.

The relay when applied as a Busbar protection relay must be set in a different manner to other applications. The differential current produced for an internal Busbar fault will always be substantial and the relay can be set in a more stable manner. The relay could also be supplied with one input as an REF type, and this could provide sensitive earth fault Busbar protection. This may be useful if a system is non-effectively earthed using neutral earthing resistors or reactors.

The relays can use a mix of 1A and 5A rated CTs as both are provided on the relay. CTs of 1A rating are preferred however as they produce 25 times less burden on the CT at nominal current. The CT quality will determine the settings to apply to the relay. Generally the poorer the CTs are in terms of kneepoint voltage the higher the biased setting must be raised to ensure stability.

11.2 Settings

When the relay is used for Busbar protection the following settings should be adopted:

Initial Bias	50%
Bias Slope	70%
Bias Slope Limit	2x
Differential Highset	15 to 20 x In (used for phase fault tripping only)
Inrush Inhibit	DISABLED

All Interposing CTs settings should be set to Yy0. Using the 1/5A inputs and Interposing CTs Multiplier Setting (0.25 to 3.0) all the inputs can be adjusted to balance the relay to rated current when the Busbar is at its full continuous rating.

11.3 CT Requirements

For Biased Differential Protection using the above settings the CTs must meet the minimum:

$$V_k > 2 \times I_B \times I_f / N \times R_B$$

e.g.

600/1A 15VA 5P20 Protection CTs $R_{CT} = 2.5$ ohms and $R_L = 1.5$ ohms, applied to a 33kV bus substation. Maximum Fault levels are 15.1kA for three phase and phase to and 11kA for earth faults.

The CT knee point V_k can be estimated using:

$V_k \approx VA \times ALF / I_n + ALF \times I_n \times R_{ct}$

In this case the Vk is approximately = 15 x 20 / 1 + 20 x 1 x 2.5 = 350 volts.

The quality of this CT with respect to use with the Duobias-M BB Protection must be assessed.

Vk > 2 x 15100/600 x (2.5 + 1.5) = 201 volts

Therefore this CT may be used with the relay BB default settings. If the Vk requirements are not quite met, the bias settings should be adjusted to produce a more stable relay and the relay may also operate slightly slower.

11.4 High Impedance EF Busbar Zone Protection

It is possible to include one input on the relay as a high-impedance earth fault input. A fast and sensitive EF Busbar scheme can be included if earth fault levels are very low.

If the residual connection from each set of line CTs are used to form a high impedance type zone the magnetizing currents of the CTs become important in terms of sensitivity and low reactance type PX CTs must be used. It is advised to use a dedicated set of CTs, if the high impedance earth fault input is used. The CTs may saturate on internal earth faults and affect the performance of other earth fault relays. The relay must be ordered with one of the inputs as an EF type, and therefore only seven sets of line CTs may be accommodated in the relay.

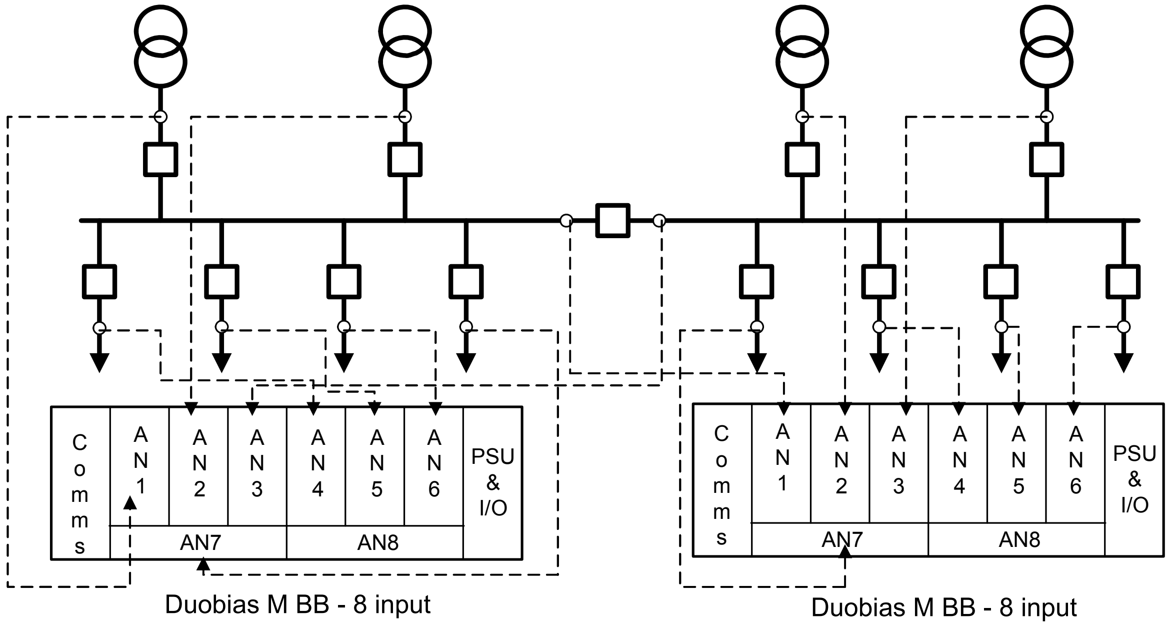


Figure 23 - Typical Application to Single Bus Substation