7PG21 Solkor Rf

Feeder Protection

Document Release History

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

Pre release

02/2010	Document reformat due to rebrand

Software Revision History

Contents

1 General

Solkor R & Solkor Rf are well established pilot wire feeder differential protections operating on the current balance principle. It is suitable for application on privately owned 2 core pilots with loop resistance up to 2000ohms to protect 2 ended feeder circuits up to 20km in length. Two identical relays are used as a pair with one relay connected to current transformers at each end of the feeder respectively.

Additional external Pilot Supervision equipment can be supplied to detect pilot cable open circuit which can lead to protection operation. Solkor relay trip contacts can be connected in series with those of an Overcurrent Guard relay to avoid operation for damaged pilots during normal load levels. Additional Intertripping equipment can also be supplied which utilises the pilot connection to initiate a protection operation at the remote end.

The Solkor R/Rf relay has an insulation level of 5kV between pilot connections and the local ground to withstand voltages induced on the pilot cable due to coupling with the fault current flowing in a parallel path and to withstand differential ground voltages caused by the flow of fault current. This is generally adequate for distribution feeders but for higher voltage systems where feeders may be longer and fault levels higher, an additional external isolation transformer is available for use with the relay in Rf mode to increase the voltage withstand to 15kV. One transformer should be fitted at each end of the pilot connection.

The R/Rf relay is primarily intended for use in the Rf mode which has the advantage of increased operating speed but can be simply changed to R mode for compatibility with pre-installed remote end relays which are older 5kv Solkor R type relays. The Solkor R/Rf relay is not compatible with the older 15kv Solkor R.

2 Information Required when ordering

Solkor Protection relay

- CT secondary Current Rating
- Case Styles
- Insulation level (5/15kV)
- Set as R or Rf mode

Pilot Supervision

- Case Styles
- System Frequency (50/60Hz)
- Send or Receive End
- Insulation level (5/15kV)
- Auxiliary DC supply

Guard Relays

- CT secondary Current Rating
- Case Styles
- System Frequency (50/60Hz)
- Not compatible with Intertripping
- Auxiliary DC supply (for numeric types)

Intertripping

- Not compatible with Guard Relays
- 1 way or 2 way intertripping
- Auxiliary DC supply
- R or Rf mode
- Insulation level (5/15kV)

3 Equipment Options

The following equipment lists provide an overview of the equipment normally required, highlighting differences for the various scheme options. These lists should be used in conjunction with the diagrams that follow.

3.1 Solkor Plain Protection Schemes

Solkor R/Rf relay (5kV), 1 per feeder end

15kV isolation transformer, 1 per feeder end if required

3.2 Pilot Supervision

3.2.1 5kV Schemes

3.2.1.1 Send End

Pilot Supervision Send End relay (transformer+rectifier), 1 per circuit
B22 AC Supply Supervision relay, 1 per circuit

3.2.1.2 Receive End

Pilot Supervision Receive End relay (B74 & B75), 1 per circuit
Note: Although the 5kV scheme utilises a combined B75/B74 unit, the additional isolation requirements at 15kV necessitate that separate units must be used.

3.2.2 15kV Schemes

3.2.2.1 Send End

15kV Pilot Supervision Send End relay (transformer+rectifier), 1 per circuit
B22 AC Supply Supervision relay, 1 per circuit. 5kV insulation as this is not connected to the pilots.

3.2.2.2 Receive End

15kV B75 relay, 1 per circuit
B74 relay, 1 per circuit
Note: Although the 5kV scheme utilises a combined B75/B74 unit, the additional isolation requirements at 15kV necessitate that separate units must be used.

3.3 Injection Intertripping 5kV or 15kV

(Equipment listed is for single ended intertripping for 2 ended intertripping, double quantities are required).Sustained intertripping will require one additional 300ohm 18W economy resistor per inverter.

3.3.1 R mode

Inverter for Solkor R
TEC relay

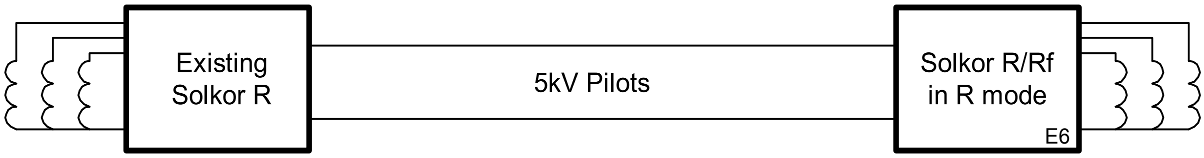
3.3.2 Rf mode

Inverter for Solkor Rf
TEC relay
B34 relay

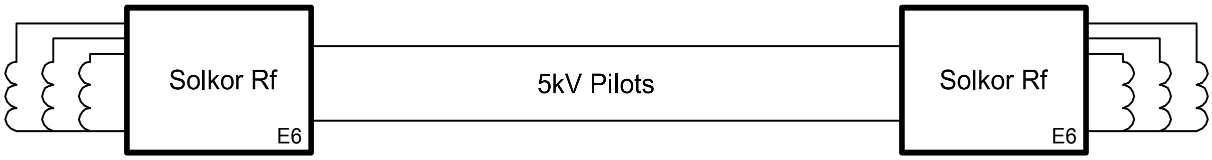
3.4 Overcurrent Guard Relay

Argus 1 or B69, 3P Overcurrent, or 2P Overcurrent + 1P Earth Fault relay

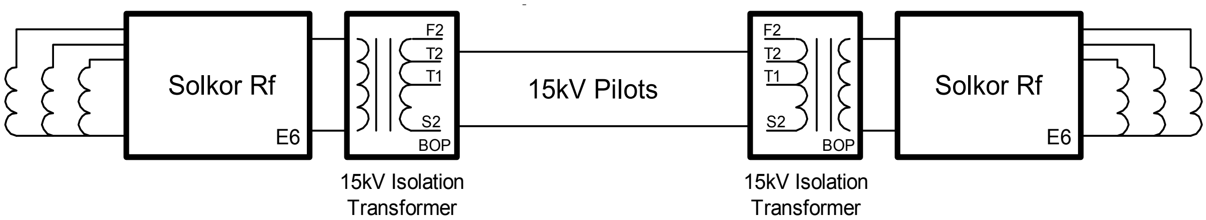
Installation with Existing Solkor R relay.



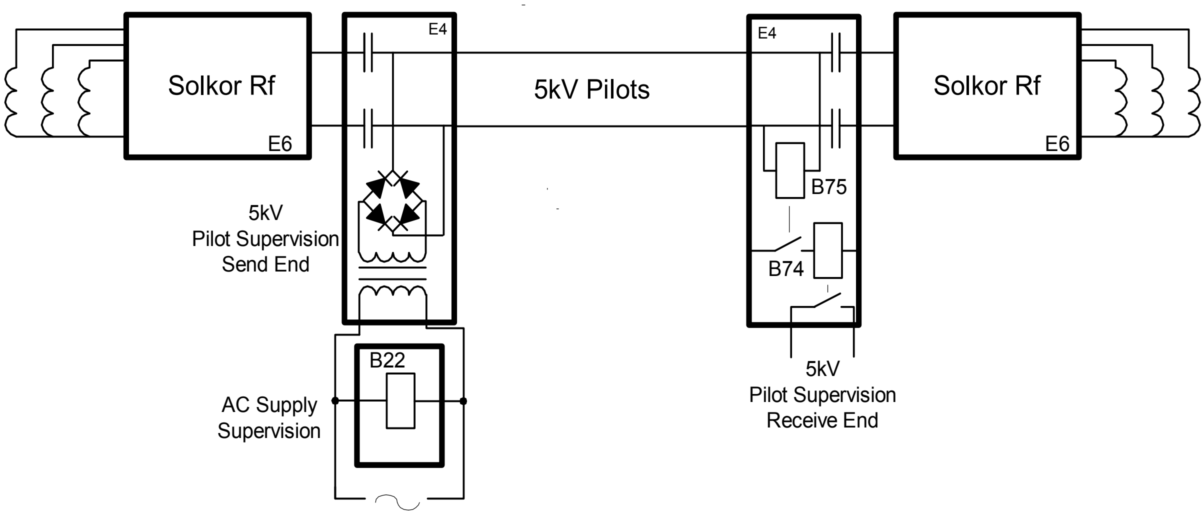
Standard 5kV Plain Solkor Rf.



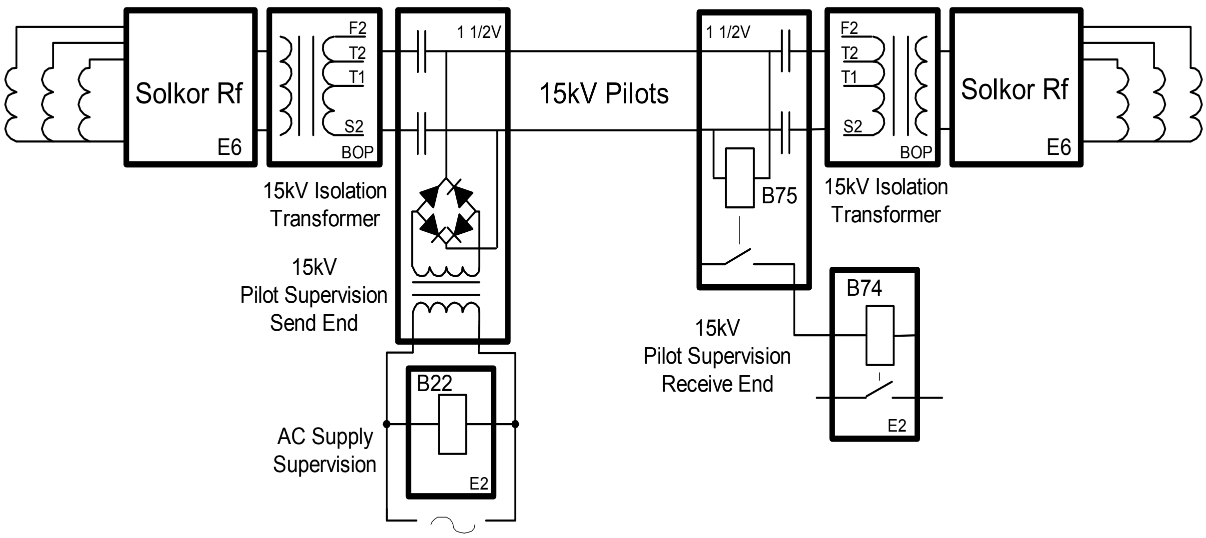
Standard 15kV Plain Solkor Rf.



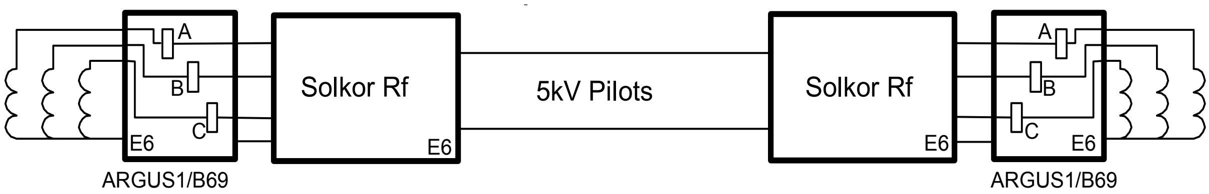
5kV Solkor Rf with Pilot Supervision.



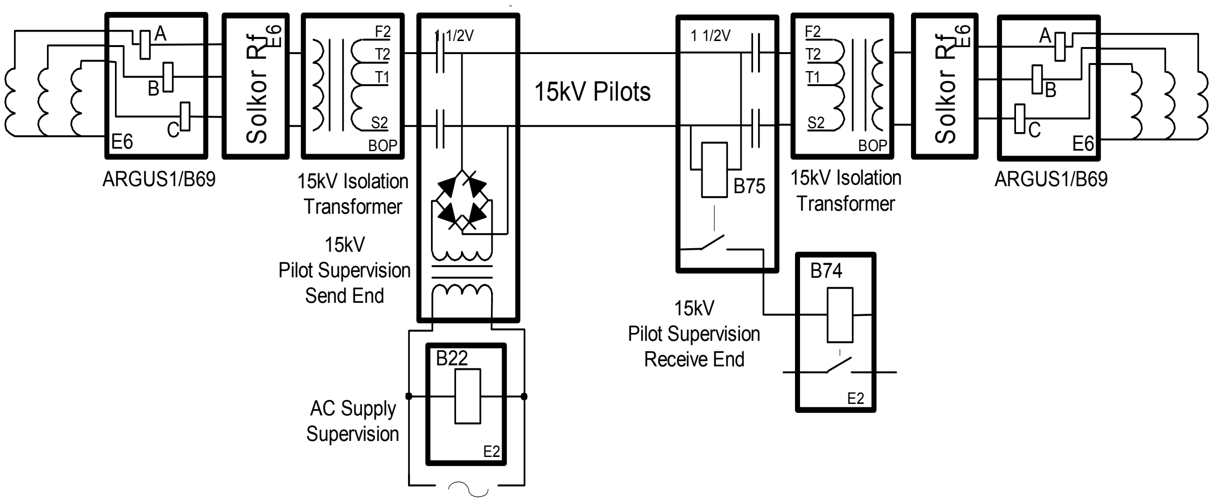
15kV Solkor Rf with Pilot Supervision.



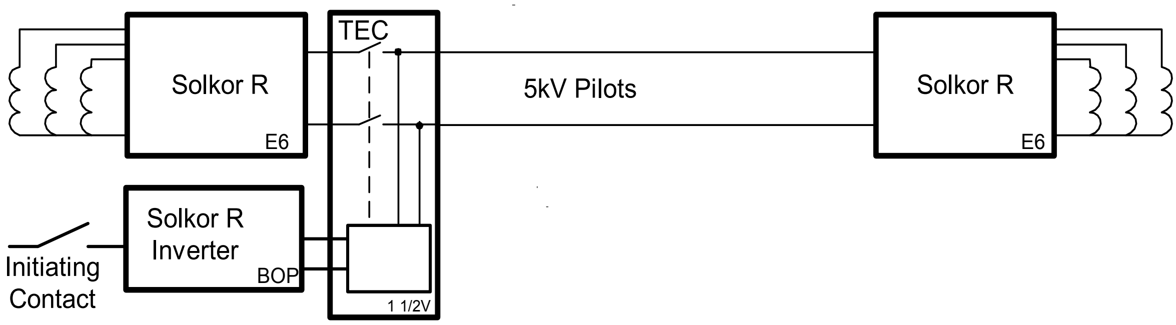
5kV Plain Solkor Rf with Overcurrent Guard.



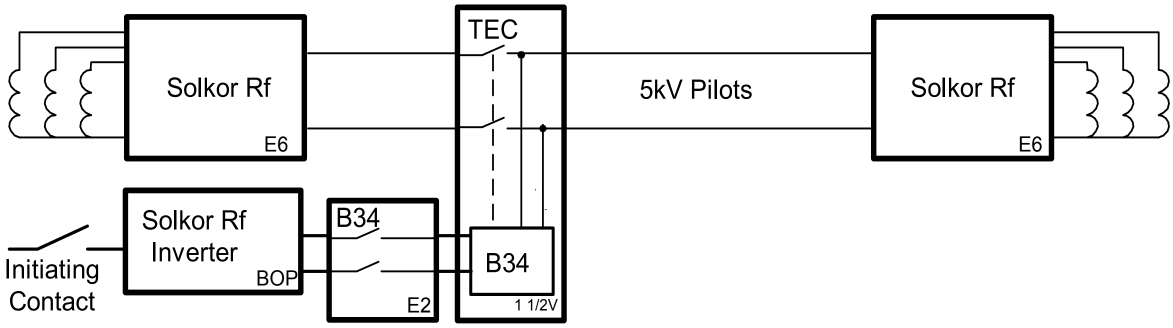
15kV Solkor Rf with Pilot Supervision and Overcurrent Guard.



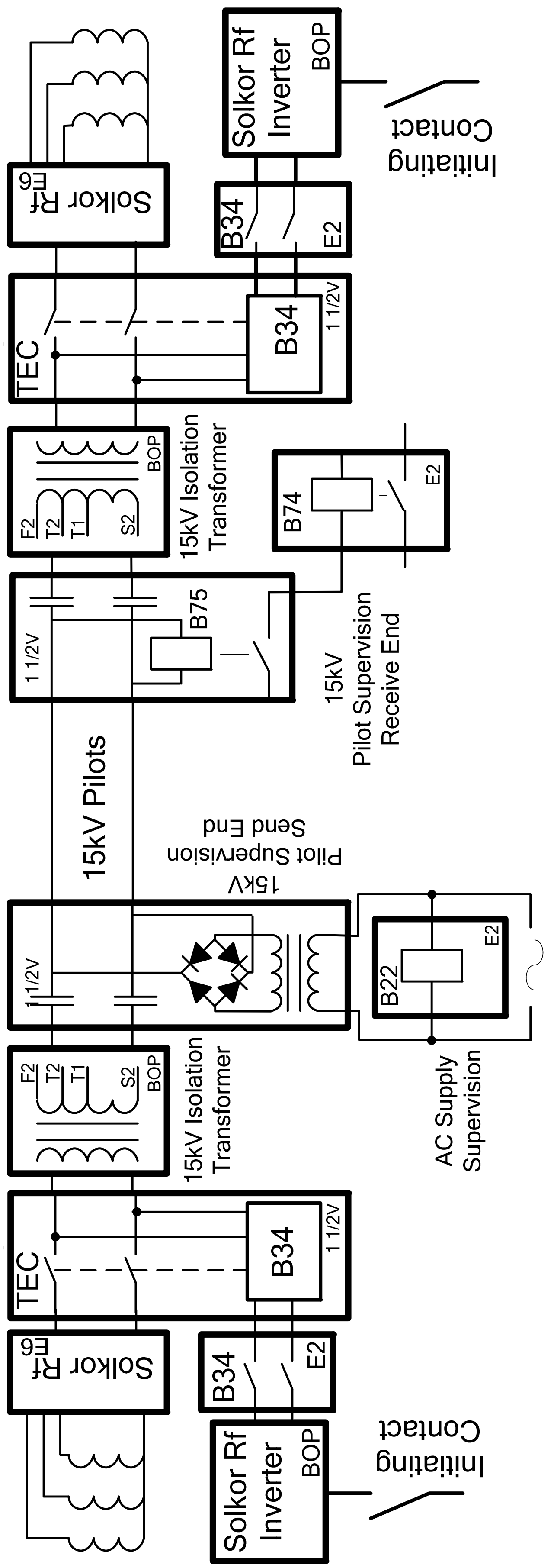
5kV Solkor R mode with One Way Injection Intertripping.



5kV Solkor Rf mode with One Way Injection Intertripping.



15kV Solkor Rf with Pilot Supervision and 2 Way Injection Intertripping.



4 5/15Kv Isolation Voltage

Any electrical current which flows in a path parallel to the pilot cable will cause a voltage to be induced along the pilot cable. This voltage can become significant for large values of current, long lengths of parallel path and higher mutual coupling factors caused by poor screening or close proximity of current paths. This voltage can lead to flashover inside of the relay case from the circuits connected to the pilots to the relay case and local ground. The problem can be worsened by ground voltage shift between the two substations at the feeder ends due to earth fault current. Earth shift voltage is often ignored in cable power systems because of the high percentage of the earth fault current which returns through the cable sheath and armouring, however with overhead line systems the earth shift voltage can be as significant as the induced longitudinal voltage.

The Solkor R/Rf relay will withstand 5kV rms voltage. This can be increased to 15kV by the addition of an isolation transformer.

5kV isolation is usually acceptable for 11kV cable distribution systems where zero sequence currents are relatively low and protected feeder lengths and therefore parallel runs are relatively short. For higher voltages where longer feeder lengths are common15kV insulation may be required but 5kV may be acceptable if fault levels are low or feeder lengths are short.

The pilot cores should be allowed to 'float' with neither core earthed at either end. Capacitive coupling to the local ground along the cable length will ensure that voltage at either end will cause the pilot voltage to remain symmetrical to the ground voltage such that the withstand requirement at each end is approximately half of the longitudinal induced voltage.

Induced voltage is proportional to parallel length, maximum parallel current and the coupling or screening factor between the pilot and the current path. This can be very difficult to assess accurately by calculation and cannot generally be measured.

The maximum current is generally accepted as the EARTH fault level for an out of zone fault. Although a phase-phase or 3-phase fault may have a higher fault current, the fault current for these faults will return locally in a parallel path in the opposite direction i.e. in the other phase(s). With an earth fault, the return path may be distant or non-parallel with the pilot such that the net current which couples to the pilot can be considered maximum for the earth fault. The through fault current level is used in combination with the total feeder length as a worst case scenario because although an internal fault may have a greater fault current, the parallel path will be shorter by definition.

5 Pilot Cables

The above considerations of insulation and balance between cores, it is evident that pilot cables for use with pilot wire current differential feeder protection are required to have special consideration when long lengths and high fault currents are involved. It is also apparent that the effects are not easily analysed or modelled and thus in-service experience is the most reliable basis in deciding which types of pilot will be satisfactory.

The UK has vast experience of the use of pilot wire differential feeder protection and the UK supply industry specification on multipair cables, ESI Standard 09-6 is therefore particularly applicable as a reference for pilot wire requirements.

It should be noted that the voltage between cores in the pilots is limited by the non-linear resistors which are connected across the summation transformers in the Solkor relays at the ends. Also note that any induced voltage will be at an equal level per unit length in all cores and screen. Thus it is possible to use pilots with 500v grade insulation between cores and core to screen. The 5 or 15kV insulation requirement exists only between 'internal cores and screen' to the local earth. Similar considerations should be observed at any cable terminations where standard 500v terminals can be used but the whole terminal block should be mounted on an insulating baseplate to comply with insulation requirements to the local ground. Terminals should be shrouded and clearly marked since during a system fault (included a fault on any parallel feeder, not only the protected circuit) the induced voltage may pose a serious risk to health. Inside of the protection panel, the insulation to local earth and segregation of wiring for health and safety purposes may be more easily achieved by the use of separate cable trunking which can be routed independently and clearly marked rather than by the use of special cabling inside of the panel. Special precautions will be required when terminating or handling pilot connections.

Pilot inter-core capacitance has the effect of shunting the relays in the current balance scheme. As the capacitance increases a point is reached where the shunt impedance has a significant effect on the relay settings. This produces a maximum limit for pilot capacitance which can be used with the relay. With the relays in the Solkor R connection mode the pilot capacitance maximum limit is 2.5μF and with the Solkor Rf connection mode this limit is 0.8μF. These limits can be increased for the Solkor Rf mode by the use of transformer tappings if the

15kV isolation transformers are used. The limits are 1μF, 2μF and 4μF which impose accompanying pilot LOOP resistance limits of 1760Ω, 880Ω and 440Ω respectively.

The pilot resistance is used in conjunction with settable padding resistance to achieve the stability biasing of the relay. The padding resistance must be set in series with the pilot resistance to achieve a standard value. There is a therefore a maximum value for the pilot resistance for which the padding should be set to zero. The maximum value of pilot LOOP resistance for the Solkor R mode is 1000Ω and for the Solkor Rf mode the maximum LOOP resistance is 2000Ω. When 15kV isolation transformers in the Rf mode the maximum LOOP resistance will be reduced to 1760Ω to compensate for the transformer winding resistance and if the transformer taps are used to compensate for the effects of pilot capacitance the maximum LOOP resistance is reduced further to values of, 880Ω and 440Ω depending on the tap used. The actual pilot resistance must be referred through the transformer at the chosen tap to give an equivalent pilot resistance value to which the padding should be added.

Thus the padding resistance R = (Sv-Rp)/(2T)

Where Rp = Pilot LOOP resistance

Sv = standard value

=1000Ω for Solkor R mode (T=1)

=2000Ω for 5kV Solkor Rf mode (without transformers) (T=1)

=1760Ω for Solkor Rf with 15kV transformers using tap 1 (T=1)

=880Ω for Solkor Rf with 15kV transformers using tap 0.5 (T=0.5)

=440Ω for Solkor Rf with 15kV transformers using tap 0.25 (T=0.25)

6 Pilot Supervision

Pilot supervision is used to detect failure of the pilot connection. Open circuit Pilots will lead to a loss This is often applied as standard with the Solkor system but may considered unnecessary at lower voltages or in an interconnected system where unnecessary tripping of an un-faulted feeder may be tolerated due to limited consequences in terms of loss of supply and relatively low probability of pilot damaged or failure when compared to the additional equipment cost.

The Pilot Supervision system uses DC injection which cannot pass through a transformer. For this reason the Pilot Supervision must be applied at the pilot side of the 15kV isolation transformers if fitted and therefore the devices must have an isolation level to suit. The Send End unit and B75 Receive End must have 15kV insulation. The B22 Supervision Relay and B74 Repeat Relay are not connected to the pilots directly and no special isolation requirements apply to these devices.

7 Overcurrent Guard Relays

Overcurrent Guard relays are connected to the same CTs as the Solkor relay. The output contact is connected in series with the Solkor Rf such that a Solkor differential operation will not cause a CB trip if the current in the guard relay (and therefore the local end) is below setting. A separate Solkor contact should be wired an alarm to indicate that the pilots may be damaged. Care should be taken when applying guard relays that the fault infeed will be available to operate the guard relay. Application to radial systems may be limited.

Phase fault Guard relays should be set to at least 150% of maximum load current for stability but less than 50% of the minimum expected phase fault current. These 2 requirements may conflict and a compromise may be required.

Earth fault guard relays should be set to less than 50% of the minimum earth fault but more than 150% of the maximum residual expected due to load imbalance. It is important to note that if an electromechanical, variable setting relay is used as a guard relay, if a low setting is selected the AC burden at rating will be increased. This is not the case when a modern numerical relay is used as a Guard relay since this will have a fixed burden independent of the relay setting. The lower burden of the numeric relay may be a major advantage in this application.

If a numeric Overcurrent guard relay is used, a spare contact from the Solkor can be wired to a binary input of the Guard relay and used to trigger a waveform record such that the waveform recording for a Solkor operation is added to the scheme. This function can be extremely useful in identifying the cause of operations caused by pilot disturbance.

8 Injection Intertripping

Injection intertripping is used to force the remote end circuit breaker to trip for local protection operation. This is generally started by protection other than the Solkor system since a differential protection system will generally trip on differential current at both ends regardless of the local current level. Injection Intertripping functions by injecting AC onto the pilots to simulate a local single end fed fault detection which causes a remote end differential trip. This achieves intertripping of the remote end circuit breaker without the requirement of a dedicated additional communications channel or intertrip receive equipment and associated trip relay at the remote end. Additional equipment (TEC/B34) is required to disconnect the local end relay and apply suitable delays to achieve the best attainable compromise of remote end operation time when the injection signal is compared to the full range of possible measured remote end current.

Injection Intertripping is generally difficult to apply successfully in conjunction with Overcurrent Guard relays since the remote Guard relay will block operations resulting from intertrip injection if the remote end CT current is below the Guard setting.

Inputs to the Injection intertripping are supplied for pulsed and sustained intertrip. A 2 second self resetting intertrip pulse is usually specified to operate the remote relay. A sustained intertrip is often specified to cause a persistent trip at the remote end which will stop auto-reclose and prevent manual close at the remote end for a fault which is identified as permanent at the local end.

When sustained intertripping is applied, the inverter output can be reduced to a level which will hold the remote Solkor in the operated condition, after the initial higher level has been used to ensure high speed operation. This Two Stage Intertripping is achieved by switching an external resistor into the inverter circuit after a 2 second time delay following an intertrip initiation. For this purpose a TEC relay with an additional 2s time delayed element providing a normally closed output contact is available. The connection arrangement is shown in the Diagrams section of this manual.

9 Capacitive Charging Currents

Significant electrical capacitance exists between HV primary conductors and the adjacent earth such that a capacitive charging current will exist with any energised line. The level of current is dependent on the system voltage, the feeder length and the construction including materials and proximity of earthed conductors. The highest levels are found in separate phase, individually screened and armoured conductors with lowest levels found on overhead line feeders. These currents are generally supplied from one end only as balanced 3 phase and as such constitute a differential current to the relays but is usually significantly lower than relay 3P setting.

During out of zone earth faults however, the voltage on the faulted phase may be significantly depressed such that the charging current is reduced. The Solkor summation transformer will measure charging current on two phases only and interpret this as a residual differential current for which relay settings are significantly lower than for 3P balanced differential current. This issue is compounded in systems which are not solidly earthed because the unfaulted phase voltage may increase, leading to increased charging current on these phases, during an earth fault. The transient switching of charging current limits the maximum charging current to 1/3 of the most sensitive earth fault setting for solidly earthed systems or 1/9 of the most sensitive earth fault setting for resistance earthed systems.

On higher voltage systems, where separate single phase cables are more commonly used and feeders are generally longer it is common to find phase segregated Solkor Rf systems where 3 separate Solkor relays are fitted at each end, each connected to a separate pairs of pilots with one phase of the system CT connected to each relay. This avoids the problem of summation of charging currents.

10 N/N1 Setting

The N1 tap can be used to increase the relay sensitivity to earth faults by lowering settings for these faults without affecting the phase fault settings. This may be particularly desirable for the 15kV scheme where all settings are naturally raised by the increase in energy required to drive the additional isolation transformers. It must be noted that the use of the N1 tap will increase the burden on the CT and therefore should only be used if the CT knee point voltage Vk easily exceeds the minimum requirements stated below, which is often the case with modern CTs. Prior to the introduction of cold rolled iron in CT design, the CT magnetising current effects could cancel out any reduction in setting by increasing the excitation currents required at the higher level of relay burden. Care should be taken when applying the N1 tap to older designs of CT with limited Vk.

The Primary in Zone Capacitance may also limit the use of the N1 tap as loss of charging current may lead to mal-operation at the lower earth fault setting as described above.

11 In-Zone Tapped Load

The relay is able to tolerate a limited amount of tapped off balanced load within the zone of protection based on the relatively insensitive level of fault setting for balanced 3P differential current. The typical setting is 72% for 3P faults or differential load current. To allow for switching transients of the tapped load a factor of 3 is advisable. The steady state feeder charging current and CT inaccuracy will also erode the stability margin resulting in a maximum bleed off of 10-20% of rated load current. Zero sequence infeed during out of zone earth faults from any transformer connected at the tapping point must be less than the minimum earth fault sensitivity of the relay at the feeder end. If a 20% tap off consists of a single large transformer, time lag relays may be required between the Solkor trip contact and the CB coil to improve stability by allowing for inrush conditions due transformer excitation.

If the feeder is teed at the substation, with an additional CT fitted to the tee-off, the two CTs should be connected in parallel. To minimise excitation caused by transient spill current the CTs should be connected by the shortest electrical path. Care should be taken in CT specification to ensure that CT mismatch or saturation is not significant for the out of zone fault path where the fault current is not limited by the protected impedance. Fault current passing in and out of the paralleled CTs will fail to cancel if the CTs are mismatched or if saturation occurs to different extents. This current may be higher than the through fault level upon which the CTs are usually sized.

12 Current Transformer Requirements

The main requisite is that the saturation voltage of the current transformers should not be less than that given by the formula:

$$V_k = \frac{50}{I_n} + \frac{I_F}{N}\left(R_{CT} + 2R_L\right)$$

Where I_n = Rated current of Solkor Rf relay.
I_F = Primary current under maximum steady state THROUGH FAULT conditions.
N = Current Transformer ratio.
R_{CT} = Secondary resistance of the current transformer
R_L = Lead resistance between the current transformers and the Solkor R/Rf, per phase.

For the above purpose the saturation voltage i.e. the knee point of the magnetising curve, may be taken as that point on the curve at which a 10% increase in output voltage requires 50% increase in magnetising current.
To ensure good balance of the protection the current transformers at the two ends should have identical turns ratios. Close balance of the ratio is provided by current transformers to IEC60044: pt1, class px, whose ratio error is limited to ±0.25% and these CTs are recommended to meet the above requirements.

It is recommended that no other burdens should be included in the current transformer circuit, but where this cannot be avoided the additional burden should be added to those listed when determining the current transformer output voltage required.

In addition to the above, the secondary magnetising currents of the current transformers at different ends of the feeder should normally not differ by more than $I_N/20$ amperes for output voltages up to 50/I volts where I = rated current of Solkor Rf relay. This criteria is applied to quantify matching of the transient response of the two CTs so that relay operations do not occur due to differing responses of the CTs to normal load switching or the incidence and clearance of out of zone faults. This condition is usually easily satisfied by modern CTs of similar size since the magnetising current is usually a lower value. Care should be taken when applying a new CT to be paired with existing CT and also when interposing CTs are required to match CT ratios.

The fault current used for the above calculation should be the THROUGH FAULT level. This condition must be considered to ensure that the relay will not be caused to operate for through faults due to secondary differential current being created by the failure of the CT to measure correctly due to core saturation. During a high level internal fault the relay will operate before the saturation effect becomes significant. The THROUGH fault level is often not readily available and may be significantly different to the source Busbar fault level which is commonly quoted incorrectly based on switchgear rating rather than on the actual current level which is limited by system impedances. The remote end fault level will be distorted by any parallel infeed or backfeed and is only equivalent to the through fault level for truly radial systems.

The following example shows a simple through fault current estimate based on Busbar levels and commonly available data.

Example

33kV Overhead line

10km long

X_L = 0.28978 ohms/km R_L= 0.07765 ohms/km (Primary)

CT ratio = 400:1

R_{CT} = 2 ohms

CT wiring resistance, R_L, 30m long 7/0.67mm 2.5mm sq. at 7.4 ohms/km = 0.22 ohms

VT ratio 33000:110V

Maximum X/R ratio at source busbar = 20

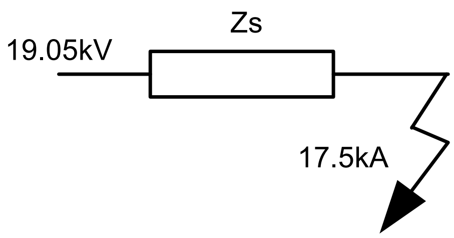
Maximum 3P fault level at busbar = 1000MVA

Consider 3P fault level based on maximum busbar levels.

V_{Ph} = 33000/√3 = 19.05kV

Fault level per phase = 1000/3 = 333MVA

$$I_F = \frac{333x10^6}{19.05x10^3} = 17.5kA$$

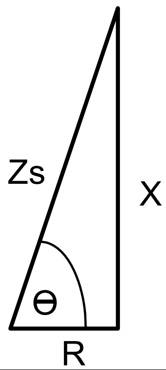


$$Z_S = \frac{19.05x10^3}{17.5x10^3} = 1.089\Omega$$

Also, since X/R at the busbar = 20,
We can evaluate the source impedance:

$$\theta = Tan^{-1}\left(\frac{X}{R}\right)$$

$$\theta = 87^\circ$$



$$R_S = Z_S \cos\theta = 00544\Omega \quad \& \quad X_S = Z_S \sin\theta = 1.0876\Omega \quad \text{(Primary)}$$

R_L= 0.07765 ohms/km (Primary)
R_L = 10 x 0.07765 = 0.7765Ω (Primary)

X_L = 0.28978 ohms/km
X_L= 10 x 0.28978 = j2.8978Ω (Primary)

Total impedance for a through fault at the remote busbar =

$Z_S + Z_L = (R_S + R_L) + (X_S + X_L)$

(0.0544 + 0.7765) + j(1.0876 +2.8978)

Z_F = 0.8309 + j3.9854 ohms

$$|Z| = \sqrt{R^2 + X^2}$$
$$|Z| = \sqrt{0.8309^2 + 3.9854^2}$$

<u>Z_F = 4.071 ohms</u>

Through Fault Current =

$$I_F = \frac{19.05x10^3}{4.071} = 4.68kA$$

Through fault current = 4.68kA compared to 17.5kA Busbar fault current due to the effect of the line impedance.