INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

OUT OF STEP RELAYING SYSTEMS

This instruction leaflet describes the various solid state out of-step relaying systems that are available. Before proceeding with the tests described, it is recommended that one become familiar with the instruction leaflets relating to the individual relays and system involved.

APPLICATION

The development of disturbing forces in a system that are in excess of the restorative forces the system can produce, causes instability. This unstable relationship is referred to as an OS (out-of-step) condition. It can be caused by a fault, circuit switching, or by deficient voltage level.

The following combinations of OS sensing elements are covered by this instruction leaflet.

System	Other devices required	Comments
1. SKSU	SKDU - zone 2 relay Ground Relay SRU	Provides OS blocking of SKDU-3Ø element and optionally allows delayed zone 1 tripping on OS.
2. SDBU-1	SRU SIU	Provides OS tripping following blinder reset
3. OS-2	SDBU-2 SRU SIU	OS-2 logic is located in the SRU. It provides a) OS blocking of SKDU-3Ø b) OS tripping on outer blinder reset. All tripping, OS indication and reclose blocking auxiliaries are provided in the SRU relay.

System Description

The three systems described in this instruction leaflet utilize the same fundamental concept for detecting a OS condition. They all respond to the changing ohmic value they "see" as an OS condition progresses. As instability evolves the voltage at the relay decreases, and the current increases until the ohmic value "seen" by the relays reaches a minimum. At this point the voltage at the relay begins to increase, and the current begins to decrease. Detection of the OS condition is accomplished by identifying the sequence in which elements in the system respond to the ohms applied to them.

SKSU System

This system is the concentric circle scheme. The distance element of the SKSU relay is set so its characteristic circle on a resistance-reactance plot is concentric with and greater in diameter than the characteristic circle of the 3Ø (3 phase) unit of the zone 2 SKDU relay. An evolving OS condition manifests itself as a changing ohmic value as "seen by" distance relays. Operation of the SKSU distance element 45 milliseconds or more ahead of 21-2 (the zone 2 3Ø unit) is characteristic of an OS condition. Operation of the SKSU distance element essentially simultaneously with 21-2 3Ø unit is characteristic of a fault condition.

To make the system as secure as possible against falsely identifying an OS condition, constraints are imposed in the logic that require that:

1) SKSU Z element operates 25 to 45 (adjustable) milliseconds before 21-2 3Ø unit.

2) The ground relay does not operate.

3) 21-2 3Ø unit does operate after the time relay.

Once the OS condition is identified, the tripping output of one or more SKDU relays is blocked and a reclose blocking output is produced by the SRU. This is to prevent reclosing if any element in the system can produce tripping following the OS condition such as, for example, a SKDU ØØ (phase-to-phase) unit trip for a fault occurring during the OS condition.

Two factors favor the use of the optional zone 1 3Ø unit tripping on OS conditions. 1) Virtually all system swings capable of producing operation of a zone 1 distance relay will subsequently prove to be unstable and 2) OS tripping <u>must</u> take place somewhere. Figure 1 shows that OS blocks zone 1 tripping temporarily. A memory circuit holds the information that zone 1 operated after zone 1 resets. Tripping is then initiated 0 to 1.0 second (adjustable) after Z resets.

The purpose of delayed tripping is to minimize the recovery voltage across the breaker contacts when tripping during an OS condition.

SDBU-1 System

Figure 2 shows the logic for the single blinder scheme. AND 1 and AND 2 serve to identify the origin of the swing as the right or left side of the resistance-reactance plot. If it is the right side blinder 1 operates well ahead of blinder 2. The logic requires that the ohmic value "seen by" the blinder relay 1) operate both blinder elements for 20 milliseconds 2) emerge on the side opposite entry and 3) cause reset of the blinder units sequentially with at least 20 milliseconds between their resetting.

The distinguishing factors between faults and OS conditions are that for faults the ohmic value seen by the blinders emerges on the same side as it enters, and that resetting is essentially simultaneous for both blinder units or fault clearing. For an OS condition, the ohmic value seen by the blinder units appears first on one side of the resistance-reactance plot and then progresses to the other.

To avoid the possibility of false trip due to load pick up, an overcurrent unit in the SIU ($I_{A\text{-}OS}$) is used to supervise OS tripping. This unit is set low and blocks tripping unless current substantially exceeds line changing current or terminal transformer exciting current.

OS-2 System

This is the dual blinder scheme. The SDBU-2 relay contains the two blinder units (providing 4 blinder lines). The OS-2 logic is incorporated in the SRU relay. The nature of the logic shown in Figure 3 is that 21B-O (the outer blinder) must operate 50 milliseconds or more ahead of 21B-I (the inner blinder), and then 21B-I must operate for 20 milliseconds or more in order for an OS condition to be identified. For OS blocking of 3Ø units of SKDU relays to take place the OS trip block switch on the SRU must be in the "On" position.

In the "Phase III" logic (not shown), an output is provided to the SKDU relay (s) if 1) the inner blinder operates and 2) an OS condition does not exist. This output supervises 3Ø unit tripping in the SKDU.

In the "Phase IV" logic shown in Figure 3 an output is provided to the SKDU relay (s) if an OS condition does exist. This output blocks 3Ø unit tripping. The inner blinder unit output of the SDBU-2 is fed directly to the SKDU. "Phase IV" is the standard OS-2 logic.

For OS tripping to take place the OS trip switch on the SRU must be in the "On" position. Tripping is initiated 1) after the OS condition is detected, 2) after 21B-O resets and 3) after 20 milliseconds have elapsed. An output continues for use in a breaker failure detecting scheme for 480 milliseconds following trip initiation.

The SDBU-2 relay in addition to controlling the OS logic also may be used to supervise distance relay tripping. Phase distance relay tripping cannot take place unless 21B-I operates. This prevents operation of the distance relay on load.

A supervising input to the OS-2 logic is provided to prevent the possibility of tripping on load pick up. This supervising unit is an overcurrent unit in the SIU (I_A-OS).

It is given a low setting, and it blocks OS tripping unless the transmission line current substantially exceeds line changing current or terminal transformer exciting current.

line length.

The distance element of the SKSU must be set so its characteristic circle is concentric with and larger than the zone 2 relay 3-phase characteristic. Also, its circle radius must be sufficiently larger than that of the zone 2 relay 3-phase unit circle that the fastest out-of-step swing expected will operate the SKSU distance element 45 milliseconds (adjustable to 25 milliseconds) or more, sooner than the zone 2, 3-phase unit. In general a 2 ohm (secondary) larger radius will suffice, but larger accelerating torque and low machine inertia for particular system conditions may force the use of larger settings and/or shorter logic times.

SDBU-1 System

Refer to Figure 4. If the SDBU-1 relay is used to supervise tripping of the 3Ø unit of SKDU relays the blinder units must be set sufficiently far apart to accomodate the maximum fault arc resistance.

A reasonable approximation of arc resistance at fault inception is 400 volts per ft. If a maximum ratio of (line voltage/(spacing) is 10,000 volts per ft. for a high voltage transmission line and if a min. internal 3-phase fault current is calculated as:

$$I_{min} = \frac{E}{(Z_A + Z_L)\ \sqrt{3}}$$ where Z_A is maximum source impedance Z_L is line impedance, and E is line-to-line- voltage.

$$\text{Then: } R_{max} = \frac{400 \times \text{Ft.}}{I_{min}} = \frac{400 \times \text{Ft.}}{E} \sqrt{3}\,(Z_A + Z_L)$$

$$R_{max} = \frac{693}{10{,}000}(Z_A + Z_L) = .0693\,(Z_A + Z_L) \quad (1)$$

Adding a 50% margin to cover the inaccuracies of this expression.

$$R_{max} = 0.104\,(Z_A + Z_L) \text{ primary ohms}$$

This may be converted to secondary ohms and then to tap value as described in the SDBU-1 instruction leaflet. This is the minimum setting permissible where the blinder relay is used to provide a restricted trip area for a distance relay.

Another criterion that may be considered is based upon the rule of thumb that stable swing will not involve an angular separation between generator voltages in excess of 120 degrees. This would give an approximate maximum of:

$$Z = \frac{Z_A + Z_L + Z_B}{2\ \sqrt{3}} = .288\,(Z_A + Z_L + Z_B) \text{ primary ohms} \quad (2)$$

Where Z_B is the equivalent maximum source impedance at the end of the line away from Z_A.

This calculation establishes the maximum setting permissible.

A blinder setting between the extremes of (1) and (2) may be used. This provides operation for any 3-phase fault with arc resistance, and restraint for any stable swing. A large setting may be required for extreme OS swing rates.

Note that the setting of the blinder relay establishes the "reach" in a direction perpendicular to the relay characteristic line.

OS-2 System

The requirements for setting the blinder units in the SDBU-2 relay are:

1. Inner blinder must be set to accommodate maximum fault resistance for internal 3-phase fault.

2. Inner blinder should not operate on most severe stable swing.

3. Outer blinder must have adequate separation from inner blinder for fastest out-of-step swing to be acknowledged as an out-of-step condition.

4. Outer blinder must not operate on load.

Inner Blinder Setting

The first two requirements are fulfilled by setting the inner blinder as described above for the SDBU-1 relay.

Outer Blinder Setting

For slow out-of-step swings a reasonably close placement of this outer to the inner blinder characteristic is possible. The separation must, however, be based on the fastest out-of-step swing expected. A 50 millisecond interval is inherent in the out-of-step sensing logic, and the outer blinder must operate 50 ms or more ahead of the inner blinder.

Since the rate of change of the ohmic value manifested to the blinder elements is dependent upon accelerating power and system WR^2, it is impossible to generalize. However, based on an inertia constant (H) equal to 3 and the servere assumption of full load rejection, a machine will experience, assuming a uniform acceleration, an angular change in position of no more than 20 degrees per cycle on the first half slip cycle.

If the inner blinder were set for $0.104\ (Z_A + Z_L + Z_B)$ and the very severe 20 degrees per cycle swing rate were used, the simple trigonemetric manipulation of Appendix I reveals that the outer blinder should be set for approximately:

$Z_{outer} = 0.5 Z_T$ (primary) Where $Z_T = (Z_A + Z_L + Z_B)$

Note that the 0.104 Z_T expression includes Z_B which was not present in the minimum relationship. Using the actual minimum for the inner blinder setting provides further margin.

It will usually be possible to use the minimum blinder setting of 1.5 ohms (secondary). Based on the 20 ohm per cycle criterion and the logic requirement of 50 milliseconds, Appendix II and Appendix III show the method of calculating the outer blinder setting.

It should be recognized that with the OS-2 logic, no commitment to trip on out-of-step occurs until the inner blinder operates. Therefore, a stable swing for which the outer blinder operates imposes no problem.

Also it should be emphasized that if a distance relay were used to supervise the out-of-step relaying, the distance relay 3-phase element and the outer blinder would have to operate 50 milliseconds or more prior to the inner blinder. This may require a somewhat longer reach on the distance relay than would otherwise be required.

For the calculation of Appendix II or Appendix III the result is in terms of secondary ohms and corresponds to SDBU-2 T-tap plate setting without conversion. Use the next highest T-setting available.

TROUBLE SHOOTING PROCEDURE

Any misoperation should be explored first by performing the related functional tests. Evidence obtained from these tests can assist in pinpointing the source of difficulty. The general philosophy followed in trouble shooting is to begin at the point of a known malfunction and by process of elimination, locate the source.

RECOMMENDED TEST EQUIPMENT

1. Oscilloscope
2. TCT test meter unit

SKSU System

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
Pressing OS push-button at proper time in sequence does not operate OS light or RB blue light	Blown fuse	Functional Test Transformer Supply	Check fuses
	21-2 input not present	ØØ unit of 21-2 SKDU Relay	Check SKDU (21-2) ØØ output
		OS pushbutton	Check SKDU (21-2) input to the SKSU

SKSU System

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
	SKSU not performing correctly	SKSU Z unit or logic	Refer to SKSU instruction leaflet. Go through test points step by step to find faulty component
Pressing OS push-button at proper time in sequence operates one but not both OS light and RB light	OS lamp burned out	SRU lamp	Operate test reset switch on SRU to the test position. Lamp should come on until switch is released.
	RB lamp burned out	RB lamp	Check RB lamp
	SRU component failure	Relay or lamp driver	Refer to SRU internal schematic diagrams and check circuit involved.
OS lamp operates but block input not present at SKDU "AND"	SKDU not sensing input	OS block	Check test points on OS block board of SKDU
	SKSU not providing output	OS block	Check test points on OS block board of SKSU

SDBU-1 System

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
OS light does not turn on at proper point in sequence when OS pushbutton is pushed	Blown fuse	Functional test transformer supply	Check Fuses
	OS lamp burned out	SRU lamp	Operate test reset switch on SRU to the test position. Lamp should come on until switch is released.
	SRU component failure	Lamp driver	Refer to SRU internal schematic diagrams and check circuit involved
	SIU input not present	I_A-OS unit of SIU	Check I_A-OS output
	SDBU-1 logic not responding properly	SDBU-1	Refer to SDBU-1 instruction leaflet. Go through test points step by step to find faulty component

SDBU-1 System

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
Trip, BFI or RB lights do not turn on when OS light turns on	SRU Malf-unction	Trip, BFI or RB circuits in SRU	Refer to SRU internal schematic diagrams and check circuits involved

SDBU-2 System

Neither OS light nor RB blue light come on during sequence when OS pushbutton is pushed	Blown Fuse	Functional Test Transformer Supply	Check Fuses
	21B-O input not present	SDBU-2 outer blinder	Check SDBU-2 outer blinder
	21B-I input not present	SDBU-2 inner blinder	Check SDBU-2 inner blinder
		OS pushbutton	Check continuity through OS pushbutton when pushed
	21B-I input present too early	RST switch	Check to see that 21B-I input to the OS-2 logic is absent until the OS pushbutton is depressed
	OS-2 logic not responding correctly	Out-of-step PC boards in SRU	Refer to SRU internal schematic diagrams and check circuits involved
	SIU input not present	I_{A-OS} unit of SIU	Check I_{A-OS} output
RB light comes on but OS light does not	OS lamp burned out	SRU lamp	Operate test reset switch on SRU to the test position. Lamp should come on until switch is released
	SRU component failure	lamp driver	Refer to SRU internal schematic diagrams & check circuit involved

SDBU-2 System

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
OS light comes on but RB light does not	RB lamp burned out	RB lamp	Check RB lamp
	no RB contact closure	RB telephone relay or relay driver	Check to see that RB operates in response to the OS trip input to the SRU
No trip lights and no momentary BFI light	No input to the trip logic	OS trip switch	Make sure OS trip switch is in the "ON" position
		OS trip output	Refer to SRU internal schematic diagrams and check OS trip output circuit
Trip lights but no BFI light	No BFI output	SRU breaker failure circuits	Refer to SRU internal schematic diagrams and check BF circuits
		0/500 timer in OS-2 logic faulty	Refer to SRU internal schematic diagram and check duration of output of 500 ms timer following reset of 21B-0.

Appendix I Determination of Outer Blinder Setting with Inner Blinder set for 0.104 Z_T (where $Z_T = Z_A + Z_L + Z_B$ primary ohms)

1. Refer to Figure 5a.

2. Calculate θ

$$\theta = 2 \operatorname{Tan}^{-1} \frac{0.5 Z_T}{0.104\, Z_T} = 2 \operatorname{Tan}^{-1} 4.8$$

$$\theta = 2\,(78.2) = 156.4$$

3. Calculate swing angle with for example, a 20 per cycle swing rate and a 50 millisecond logic criterion, the limiting swing angle between the outer and inner blinder operations is 20 x 3 = 60 degrees

4. Calculate (θ - swing angle)

$$\theta - 60 = 156.4 - 60 = 96.4$$

5. Find B2 (refer to Figure 5b)

$$B_2 = \frac{Z_A + Z_L + Z_B}{2 \operatorname{Tan} (\theta - 60)/2} = \frac{Z_T}{2 \operatorname{Tan} 48.2} = 0.448\, Z_T$$

Use Zouter $\doteq 0.5\, Z_T$ primary ohms

This is the minimum setting of the outer blinder for a 20 degree per cycle swing rate

Appendix II Determination of Outer Blinder Setting with Inner Blinder set for 1.5 ohms

1. Determine $(Z_T R_C)/(3R_V)$ where $Z_T = Z_A + Z_B + Z_C$ primary ohms. R_C is C.T. ratio and R_V is P.T. ratio.

2. If ratio is less than 0.8 refer to Appendix III, if not continue to 3. At 20 degrees per cycle swing rate and 50 millisecond logic criterion, the limiting swing angle between blinder operations is 20 x 3 = 60 degrees.

3. Referring to Figure 5c, it can be seen that:

$$\operatorname{Tan} \left(\frac{\theta - 60}{2}\right) = \frac{Z_T}{2B_2}$$

$$\text{then } B_2 = \frac{Z_T}{2} \quad \frac{1}{\operatorname{Tan} (\theta/2 - 30)}$$

$$B_2 = \frac{Z_T}{2} \quad \frac{1 + \operatorname{Tan} \theta/2 \operatorname{Tan} 30}{\operatorname{Tan} \theta/2 - \operatorname{Tan} 30}$$

$$B_2 = \frac{Z_T}{2} \; \frac{1 + 0.577 \,\text{Tan}\, \theta/2}{\text{Tan}\, \theta/2 - 0.577}$$

$$B_2 = \frac{Z_T}{2} \; \frac{\sqrt{3} + \text{Tan}\, \theta/2}{\sqrt{3}\, \text{Tan}\, \theta/2 - 1}$$

but $\text{Tan}\, \theta/2 = \dfrac{Z_T R_C}{2\,(1.5)\, R_v} = \dfrac{Z_T R_C}{3\, R_v}$

Determine B_2

4. Use Z_{outer} (primary) = 1.1 B_2 to provide additional margin.

5. Calculate Z_{outer} (secondary) = 1.1 $B_2\, R_C/R_v$. This is the minimum setting of the outer blinder for 20 degree per cycle swing rate.

Appendix III Determination of Outer Blinder Setting With Inner Blinder set for 1.5 ohms (secondary) and $\dfrac{Z_T R_C}{3R_v} < 0.8$, where $Z_T = Z_A + Z_C + Z_B$ (primary ohms)

1. Calculate $\theta = 2\, \text{Tan}^{-1} \dfrac{Z_T R_C}{3\, R_v}$

2. Using maximum swing rate, K (degrees per cycle), calculate:

$$B_2 = \frac{Z_T}{2} \; \frac{1}{\text{Tan}\, 1/2\, (\theta - 3K)}$$

3. Set Z_{outer} (primary) = 1.1 B_2

4. Calculate Z_{outer} (secondary) = 1.1 $B_2\, R_C/R_v$

This is the minimum setting of the outer blinder for the maximum swing rate K.

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