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Edition 1

Out-of-step relay for synchronous machines

GENERAL

Out-of-step operation means that the machine with intact field is running out of synchronism with the network. During the out-of-step condition, the machine current varies heavily as the rotor (machine emf) angle varies cyclic with respect to the emf behind the source impedance of the network, as seen from the generator terminals.

A prolonged out-of-step operation will have harmful effects on the machine and mechanical equipment associated to it and may also severely disturb the operation of other parts, such as station auxiliary motors etc.

The conventional relaying approach to detect a loss-of-synchronism condition is to supervise the variation of the apparent impedance as seen from the generator terminals. Computer programs have been used to calculate the impedance vector variation, and impedance measuring elements with suitable operating characteristic together with sequential logic relays are used to distinguish between loss-of-synchronism conditions and recoverable swings.

Typical for the genuine loss-of-synchronism condition is that the apparent impedance crosses the X-axis rather close to the origin compared to the point where the impedance crosses the X-axis in case of recoverable swings.

DESIGN

The impedance measuring out-of-step relay is shown on drawing 7432 0105-AB.

The relay is built up in system COMBIFLEX with a test switch (101), a dc/dc converter for auxiliary supply (107), a static directional relay type RXPE 40 (125), an impedance measuring unit RXZF 2 (113) and aux. relays for tripping logic. The tripping relay (137) is of type RXME 18 with indicating flag and heavy-duty contacts.

MODE OF OPERATION

The RXPE 40 (125) directional relay is normally set to about 2 percent of rated current (100 mA for 5 A rated current). The relay is not operated when the generator is delivering active power or the motor is receiving active power.

With this low setting, the operating characteristic of RXPE 40 is nearly a straight line within the operating characteristic normally set on RXZF 2 when the voltage to the relay is more than some few percent of rated voltage, see Fig. 1.

With relay setting 2 percent, the operating time of RXPE 40 is less than 10 ms when the current is equal to or more than 30 percent of rated current.

The RXMA output relay (313) of RXZF 2 operates within 35-50 ms when the impedance phasor enters into the oval.

The relay RXMA (319) is drop-out delayed, approx. 50 ms, by a diode connected across the coil. This delayed drop-out will give a long trip impulse to the breaker coil.

At a nearby fault, the impedance relay will operate and its output relay picks up. If, after fault clearing, there will be a swing only, the impedance will pass out of the oval on the same side of the X-axis as it entered. If the fault results in a loss of synchronism condition, the impedance will pass out of the oval on opposite side of the X-axis, i.e. the active power flow will be in opposite direction to normal running. When passing the X-axis the directional relay RXPE 40 and aux. relay RXMA (319) pick up. Passing the X-axis will correspond to a rotor angle of more than 180°. <in order to have a safety margin and to give trip signal at a more favourable rotor and emf angle, the trip signal is not given until the impedance passes out of the oval, which corresponds to a rotor angle of 250-300°. When RXZF 2 resets, relay RXMA (313) will together with RXMA (319) give a trip signal to the breaker. After a delay of about 35 ms the relay RXME 18 (137) with signal flag and heavy duty contacts will pick up. As RXMA (319) is drop out delayed the breaker coil will receive an impulse of about 75 ms.

TECHNICAL DATA FOR THE MEASURING UNITS

The impedance unit is of static design and consists of a measuring element having a concentric operating characteristic which is an oval in the R-X plane, see Fig. 2.

The secondary reach $Z_{\alpha} = \frac{U_{relay}}{I_{relay}}$ in the reactive direction of the oval is according to the formula:

$$Z_{\alpha} = \frac{d \cdot q}{I_s} \text{ ohms/loop}$$

where d = 1, 1.5, 2, 3, 5, 6

q = 20, 21, 22, 23, 24, 25, 26, 27, 28, 29

I_s = rated current 1, 2 or 5 A

The formula gives the range of:

20-174 ohms/loop at 1 A rated current
10-87 ohms/loop at 2 A rated current
4-348 ohms/loop at 5 A rated current

The reach in the resistive direction is preset to about 0.5 times the reach in the reactive direction.

The primary impedance is converted to the secondary side of the instrument transformers by means of the formula:

$$Z_{sec} = Z_{prim} \times \frac{I_{prim}}{I_{sec}} \times \frac{U_{sec}}{U_{prim}} \text{ (ohm/phase)}$$

When connected to voltage between phases, the setting of the RXZF 2 relay is calculated acc. to the formula

$$Z_{\alpha} = Z_{sec} = \frac{d \cdot q}{I_n \times \sqrt{3}} \text{ (ohm/phase)}$$

Recommended setting is 0.4 pu (on machine base) in reactive direction (covering the transient reactive X'_d of the machine). Machines running under excited could require a closer setting.

Technical data for the standard RXPE 40 is given in Catalogue B03-3013. In this protection, a special fast version is used (time curve 7). The characteristic angle of RXZF 21 is 90° on the primary side when the relay is connected to phase current and voltage between phases. Technical data for the relay are given in Catalogue B03-3210.

TESTING AND COMMISSIONING

Equipment for the tests

For the test recommended here, the following equipment is suitable:

- Secondary injection testing set, e.g. type TURH, see Buyer's Guide B03-9540E
- 2 pcs multi-purpose instruments
- Test-plug handle type RTXH 18
- Trip-block plug type RTXB
- Ammeter test plug type RTXM

Check and testing

The following checks, settings and tests are made before the relay can be put into service:

- General inspection
- General check of connections
- Setting of the relay
- Secondary injection test of the relay
- Primary tests
- Test on dc circuits

General inspection

Check that all components according to the circuit diagram and apparatus list are included and that there is no visible damage on the relay, also check that the plug-in units have the correct data (rated voltages, current range for RXPE 40) acc. to the apparatus list.

General check of connection

Check that the external wiring is in accordance wit the circuit diagram. The polarity of the auxiliary voltage connected to the relay should be checked. Check also carefully that the phase current and the phase voltage are correctly connected to the relay.

Settings of the relay

The settings of the impedance relay RXZF 2 and the RXPE 4 directional over-current relays are preferably decided from computer studies of power swing and loss-of-synchronism conditions for the specific machine and network. However, if such data are not available, the following settings can be regarded as "normal" values.

RXPE 4: operate current 2 percent of rated generator current

RXZF 2: Z = 40 percent (0.4 p.u.) of rated generator load impedance

Example:

300 MVA generator with rated voltage 20 kV. CT ratio: 10 000/5 A VT ratio: $\frac{20}{\sqrt{3}} / \frac{0.1}{\sqrt{3}}$ kV.

Calculate the impedance relay setting, assuming Z_{α} =0.4 p.u. of rated load impedance.

Primary rated load impedance

$$Z_p = \frac{U^2}{S} = \frac{20^2}{300} = \underline{1.333 \text{ ohm/phase}}$$

Secondary impedance setting:

$$Z = 0.4 \times 1.333 \times \frac{0.1}{20} \times \frac{10000}{5} = \underline{5.33 \text{ ohm/phase}}$$

The operating value Z_{α} is set according to the formula

$$Z_{\alpha} = \frac{d \cdot q}{I_s \times \sqrt{3}}$$

where d = 1, 1.5, 2, 3, 5, 6

q = 20, 21, 22, 23, 24, 25, 26, 27, 28, 29

I_s = rated current 1, 2 or 5 A

Determine d, using the formula

$$d < \frac{Z_{\alpha} \times I_s \times \sqrt{3}}{20} = \frac{5.33 \times 5 \times \sqrt{3}}{20} = 2.3$$

Choose d = 2

Determine q, using the formula

$$q = \frac{Z_{\alpha} \times I_s \times \sqrt{3}}{d} = \frac{5.33 \times 5 \times \sqrt{3}}{2} = 23$$

Choose q = 23

Check the value

$$Z_{\alpha} = \frac{d \times q}{I_s \times \sqrt{3}} = \frac{2 \times 23}{5 \times \sqrt{3}} = \underline{5.31 \text{ ohm/phase}}$$

Secondary injection test

Set the RXZF 2 and the RXPE 4 relays to the correct operating value. Check the operating characteristic of the RXZF 2 relay by means of a suitable impedance measuring test set. If test set TURH is used, the connections between the test set and the relay are made up in accordance with Fig. 2.1 For further details, reference is made to Instruction RK 654 101E, Clauses 1, 2 and 4. The testing is performed with the selector switch F in position RST.

Test the function of RXZF 2 with the test switch Q in position 1 and 4 (no operation of RXPE 4) and with the H test switch Q in position 2 and 3 (function of RXPE 4). Check that correct function is obtained on the output relays, pos 313 and 321.

Observe that the switches S1 and S2 must not be in a position which gives too high current to the RXPE 4 relay.

Connect the variable resistor Rs in the resistor case of TURH between the voltage supply and the test set as indicated with dotted lines in Fig. 2. For relays with rated current 1 or 2 amps, the max. value of 50 ohms in resistor R_s may not be sufficient to reduce the current to a value below the operating value of RXPE 4, and an external resistor then has to be used.

Set the switches S1 and S2 to the lowest value and set the resistor to max. value. Set the selector switch Q in position 2 and set $G_x = F_x = 0$. Increase the current by reducing the value of the series resistance. Set the switches G_R in a position which gives about 10 percent of rated phase voltage when the current I_R is equal to the set operating current of the RXPE 4 relay. Check the operating value.

Remove the series resistor.

Find the setting of S1, S2 and G_R which makes the RXZF 21 relay reset when the setting F_R is increased from zero.

Set $F_R = 0$, increase the setting of F_R and check that tripping is obtained when RXZF 2 resets.

Test of dc circuits

A systematic check of the dc system should be carried out in order to discover any possible faults. The testing is carried out by operating the relays electrically or by hand and observing that signals and trip pulses are correctly obtained from the relay.

Primary test

Check with an instrument connected to the RTXM ammeter test plug that correct current is supplied to test terminals 3 and 4 on the RTXP 18 test switch when the generator is loaded. Check that correct voltage is supplied to test terminals 9, 11 and 12.

Insert the RTXB trip-block plug in test terminal 17 and check when the generator is delivering some active power that the RXPE 4 relay operates when the wires to terminals 111 and 221 on the relay are interchanged. Restore the original connections and remove the blocking pin.

Check with a phase angle meter that the angle between the current flowing into test terminal 3 and the voltage between test terminals 9 and 12 is the same as the angle between the generator voltage and load current, i.e. the voltage U9-12 is leading the current when the generator is delivering reactive power. Also check that the voltage between terminals 9 and 11 is lagging 30° behind the voltage between terminals 9 and 12.

Commissioning

When the above tests have shown that all functions are correctly performed, the relay can be put into service.

Finally check that:

- o the indicating flag is reset
- o the plastic covers are refitted

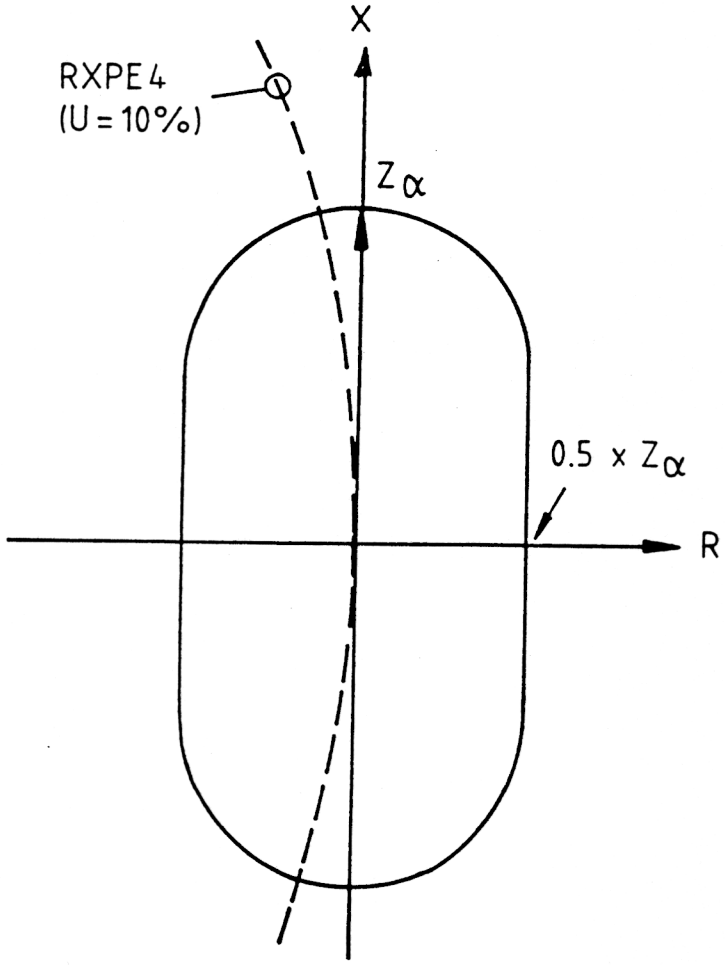

Fig. 1 Operate characteristic of the RXZF 2 and RXPE 4 relays

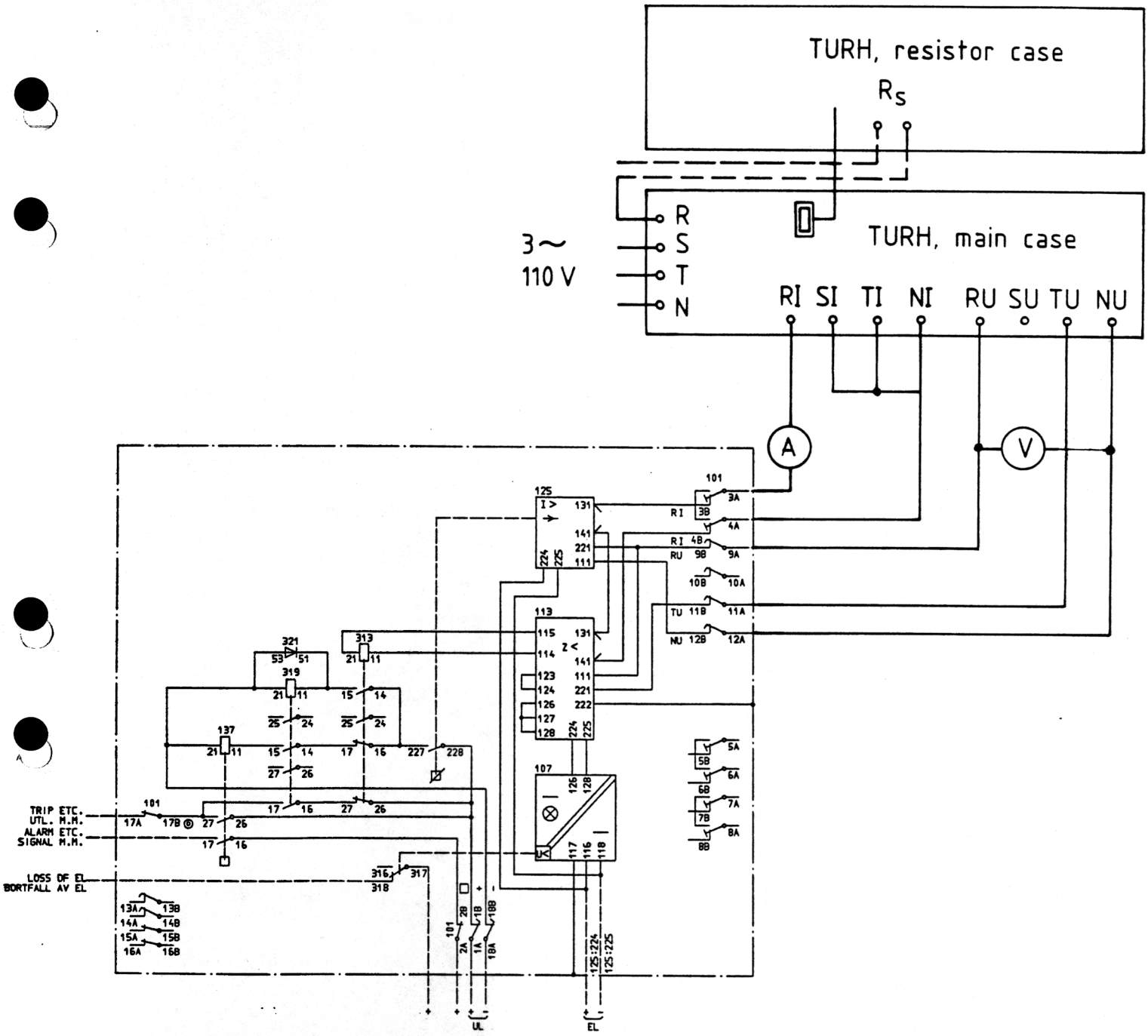

Fig. 2 Connection of TURH test set and instruments to the relay

Note: When RTXH test handle is inserted, the test set is connected to test terminals B (3B, 4B, 9B etc).