Instruction Manual

Description
Calibration

Excitation Sensor and Reverse Power Relay
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Introduction

Foreword
This manual contains instructions for installing, operating and maintaining Kato Engineering excitation sensor/reverse power relays.

Safety instructions
In order to prevent injury or equipment damage, everyone involved in installation, operating and maintenance of the equipment described in this manual must be qualified and informed of the current safety standards that govern his or her work.

While "common-sense" prevention of injury or equipment damage cannot be completely defined by any manual (nor built into any piece of equipment), the following paragraphs define warnings, cautions, and notes as they are used in this manual:

Warning: Warnings identify an installation, operating or maintenance procedure, practice, condition, or statement that, if not strictly followed, could result in death or serious injury to personnel.

Caution: Cautions identify an installation, operating or maintenance procedure, practice, condition, or statement that, if not strictly followed, could result in destruction of or damage to equipment or serious impairment of system operation.

Note: Notes highlight an installation, operating or maintenance procedure, condition, or statement and are essential or helpful but are not of known hazardous nature as indicated by warnings and cautions.

Purpose

The purpose of the excitation sensor/reverse power relay (ESRPR) is to monitor and detect problems in the excitation systems or motor drive systems of paralleled motor-generator (MG) sets. If problems are detected then the ESRPR boards will deliver an output signal via open drain MOSFETs or in the case of a reverse power condition a normally open relay contact will be closed. These signals typically drive external relays, which remove the ailing MG set from the paralleled bus thus protecting the system bus from failures of any one of the MG sets.

General Description

The ESRPR contains phase sensitive circuitry, which measures reactive current, real current, and bus voltage amplitude changes. Based on this information the ESRPR board will determine if the generator it is monitoring is over excited (voltage regulator is supplying too much field excitation), under excited (voltage regulator is supplying too little field excitation), or it is in a reverse power mode (generator is absorbing real current due to lack of prime mover power, which is typically caused by motor failure or loss of power to the motor). If any of these conditions persist longer than the preset time delays then the ESRPR will activate one of it's outputs which can be used to remove the MG from the paralleled bus.

To function properly, the ESRPR requires some external inputs. They include the following:
1. A 24 Vdc power supply (20 to 32 Vdc at < 150 mA)
2. A three-phase voltage input (24 Vac rms nominal)
3. A CT voltage input derived from a burden resistor and a CT mounted on the L2 phase of the generator.
4. A 24 Vdc inhibit signal to prevent other ESRPRs from tripping during bus transients (20 TO 32 Vdc at < 10 mA).
5. A system voltage offset signal from the system voltage control board used to trim the offsets in the ESRPR while the system voltage is deliberately altered (helps keep the excitation sensors calibrated when the system voltage is deliberately altered).

The ESRPR board also delivers three output signals. They include:
1. Two open drain MOSFETs pulled low for over excitation condition
2. Open drain MOSFET held low during normal operation and released to "float" high during under excitation conditions.
3. Normally open dry contact which is closed during reverse power conditions.

Refer to the ESRPR drawing appended to this manual to view the block diagram of the ESRPR control board. All of these input and output signals and how they are to be connected are shown on this drawing.

Components

External:
The three external components are shown on the ESRPR drawing and must be connected as shown for proper operation.

External CT:
The external CT and burden resistor (R1) should develop approximately a 3 to 5 Vac rms signal at full rated generator current. It typically will

consist of a CT with a secondary rated at 1 amp and a burden resistor between 3 and 5 ohms. A system using a CT rated at 5 A secondary current with a burden resistor of 1 ohm may also be used.

The voltage developed across the burden resistor must be connected as shown on the ESRPR drawing with the H1 and X1 leads of the CT also connected as shown (H1 toward the source and X1 connected to the burden resistor and terminal A18 of the ESRPR board). The X2 terminal of the CT must then be connected to the other end of the burden resistor and to the ESRPR terminal A20.

The CT must be mounted on the L2 or B phase of the system.

External potential transformer:

An external potential transformer (PT) will be required to transform the generator voltage to the right potential and also provide isolation. The potential (voltage) required at the ESRPR input terminals is approximately 24 Vac (this can range from approximately 18 to 30 Vac rms).

The phase leads must be connected as shown on the ESRPR drawing with L1 connected to terminal A12, L2 connected to terminal A14, L3 connected to terminal C14, and the neutral lead connected to terminal A2 (or any of those terminals shown 'as common with A2 - these terminals are the circuit board common).

External 24 Vdc power source:
An external 24 Vdc (20 to 32 Vdc) power source is required to power the ESRPR control circuits. It is usually derived from the control power bus in located in the MG set or the paralleling panel. The ESRPR board then takes this unregulated 24 Vdc power and regulates it to +15 and -15 Vdc power supplies which it uses to power the control circuits.

Internal:

Reverse power relay (RPR):

Circuit function:

A block diagram of the reverse power relay circuitry is shown within the dashed line on the ESRPR drawing (please refer to this drawing for additional information and understanding).

The reverse power relay consists of a multiplier (Mx), a couple of comparators (CP1 and CP2), a trip relay (TR), and a time delay circuit consisting of R68, R69, R70, and C29 (time delay selectable with SW7 and SW8).

The multiplier receives the L2 phase current from PT1 and multiplies it with the L2-N voltage from the EXT. PT. The resultant voltage from the multiplier will then be negative if the generator is delivering power (kW) or positive if it is absorbing power (reverse kW). As long as the generator is delivering power, then the non-inverting input of comparator CP1 will remain below the inverting terminal and the output of the comparator will remain low. If the generator begins to absorb power the output signal of Mx will become positive (proportional to the amount of reverse "real" current the generator is absorbing). The value of VREF (at the inverting input of CP1) is set so that the output of the multiplier will exceed VREF at approximately 5% of rated generator output power. This means that CP1 output will go high if the generator reverse "real" current exceeds 5% of the rating of the generator (the actual percentage is determined by the CT ratio).

Once CP1 output goes high, the voltage on C29 will rise depending on the time constant determined by the parallel combination of R68, 69, and R70 and the value of C29. The time delay combinations are shown below:

Calibration instructions:

The reverse power relay function on this circuit board is factory preset to trip at approximately 5% reverse power. The actual magnitude of the trip level is determined by the line voltage and the CT ratio and can not be adjusted without replacing components on the circuit board.

The time delay to trip can be adjusted by setting the switch 7 & 8 positions to the desired time delay shown in Table #1. This will be the delay to trip (energize the reverse power relay) following a reverse power detection by the ESRPR board.

Switch 7	Switch 8	Time Delay (S)
Open	Open	~ 6.0
Closed	Open	~ 2.5
Open	Closed	~ 1.0
Closed	Closed	~ 0.7

Table 1: Time delay switch settings

Excitation sensor (ES):

General overview: The excitation sensor portion of the ESRPR board monitors the generator voltage and current and the phase relationship between them. With this information it can determine if its generator's voltage is higher or lower than the system bus voltage. It also reads the difference in current between generators and the phase relationship between its own generator's current and voltage. This information is used to determine if its own generator is over or under excited and if it should be removed from the system bus.

Theory of operation:

In the back of this manual is (Figure 1) a block diagram of the ESRPR circuit board showing the major functions. Please refer to this diagram while reading the following few paragraphs (the excitation sensor circuit functions include all circuits outside of the blocked in "reverse power relay circuit" section).

When a generator is over excited and delivering reactive current to the system bus, the bus voltage will rise slightly. If a generator is under excited and absorbing reactive current from the system bus, then the bus voltage will decrease slightly. The magnitude of the change in bus voltage is determined by the system impedance and the amount of reactive current imbalance. The following is simplified example of how these excitation sensors determine which generator to remove from the system bus. In order for the excitation sensors to function properly they must all be calibrated to trip at the same point.

For example:
1. Two generators are paralleled to provide the system bus. The excitation sensors are calibrated to trip at 100 A reactive current error (this translates to a change in bus voltage of about 2 to 5% with this amount of reactive current error). The generators are rated to deliver 200 A at full load.
2. If generator #1 is over excited causing 100 A of reactive current to flow into the other generator, then the burden resistor voltages (from the cross current CTs) will be equal in magnitude but opposite in polarity. In generator #1 the voltage and current signal will add to produce a more positive voltage at amplifier A3 (shown on the attached block diagram). Conversely, the current signal of the second generator will subtract from the voltage signal thus resulting in a lower voltage at amplifier A3.
3. The key factor is that the system bus voltage is rising due to one of the generators being over excited (generator #1). This adds to the resultant voltage at amplifier A3 for both generators.

A simplified equation for this is shown in Equation 1:

$$A_1(BV + delta\ BV) + A_2\ (I_c) = \text{voltage at amplifier A3}$$

with: A_1 & A_2 = circuit gain constants
             BV = system bus voltage
             I_c = reactive current sharing error

Table 1: Time delay switch settings

This means that the excitation sensor for generator #1 will reach its over excitation trip point before the second generator reaches its under excitation trip point. This is because the over and under excitation trip magnitudes are symmetric. The over excitation trip level occurs at 5.0 Vdc. The under excitation trip level occurs at 2.5 Vdc. The center of the window is at 3.75 Vdc (the voltage output of A3 will be 3.75 Vdc when the generator is operating at rated voltage and approximately zero cross-current error). Therefore, there is +1.25 Vdc to reach the over excitation trip level and - 1.25 Vdc to reach the under excitation trip level. In all cases, the first excitation sensor to reach it's trip point will be the first to energize its output MOSFETs .

Circuit detail:

The excitation sensor circuit begins by taking output voltage of amplifier A2 which represents the differential voltage between phase A (LS) and phase C (L3) and adding it to the output voltage of amplifier Al. The output voltage of Al is derived from the current sourced by the phase B (L2) cross current CT and the burden resistor R1. It is then passed through a 1:1 isolation transformer PT1 and multiplied by the gain of Al.

The resultant of the addition of the Al, A2 voltages is then converted to dc and added to a voltage offset signal, which comes from the system voltage control board (This offset signal ensures that the excitation sensor remains calibrated if the system voltage is changed via the system voltage control board.). This resultant is then applied to another amplifier A3. The output voltage of A3 is then compared to the over excitation and under excitation trip references at comparators CP3 and CP4 respectively.

If the output voltage of A3 exceeds the over excitation trip reference, then the output driver following CP3 will be enabled and the time delay timer (TD) will be activated. Once the time delay has been satisfied, then the output driver will be enabled and the over excitation trip outputs will be pulled low (to circuit common). This will be the output signal given to the control panel to remove the generator from the system bus due to an over excitation fault.

The under excitation circuit function is essentially the inverse of the over excitation function. When the generator voltage is within approximately 10% of the rated voltage then the output voltage of A3 will rise above the under excitation setpoint and the comparator CP4 will energize its output driver which will ultimately turn on the under excitation trip output MOSFET. This means that during normal operation the under excitation output will be held low (pulled to circuit common). If the output voltage of A3 falls below the under excitation setpoint, then CP4 will enable its output driver and activate the time delay timer (TD). Once the time delay has been satisfied, then the output driver will be enabled and the under excitation trip output will be released to float high (if output relays are tied to this MOSFET then they will be de-energized).

Output inhibit: To prevent the outputs from changing state during transients, one can apply 24 Vdc to the Inhibit Input (A8). This will prevent the timer (TD) from timing out. This is usually accomplished through the use of a "change detector" board. You can also apply 24 Vdc to this inhibit input during the ESRPR calibration period to prevent the excitation sensors from initiating a trip while the set points are being adjusted.

Excitation sensor time delay:

The delay to trip time delay (TD) of the excitation sensor can be used to reduce the maximum bus voltage dip or overshoot during an excitation failure. Most excitation sensors will operate well with a 12 mS time delay programmed in. If the dip or overshoot exceeds customer specifications, then the time delay to trip may be reduced to 6 or 3 mS (this will trip the generator off line quicker thus reducing the maximum bus voltage dip and overshoot).

If synchronous motors are being used the time delay may have to be increased to 24 mS to allow the motors to "re-align" and prevent nuisance tripping during load transients. The excitation sensor time delay to trip can be set according to Table 2.

Switch 1	Switch 2	Switch 3	Switch 4	Time Delay (S)
Closed	Either	Either	Either	3 ms
Open	Closed	Either	Either	6 ms
Open	Open	Closed	Either	12 ms
Open	Open	Open	Closed	24 ms

Table 2: Time delay to trip

Excitation Sensor Calibration Instructions:

The excitation sensor uses a over/under excitation window which is symmetric around the nominal operating conditions. That is, under normal operation at rated voltage and zero cross-current error, the excitation signal (output voltage of A3) will be at 3.75 Vdc. Therefore, this circuit requires the user to null any offsets and calibrate only one of the trip points (over or under excitation trip level). The other trip point is automatically calibrated due to the symmetry of the circuits.

Calibration procedure:

1. Set dip switches on the ESRPR board prior to installing it into the card rack. The recommended starting switch settings are switch #3 and switch #7 closed and all other switches open (this yields a 2.5 S reverse power trip delay and a 12 mS excitation sensor trip delay).
2. Install the ESRPR board into the card rack and close calibration switch if provided (this will inhibit excitation sensors from tripping prior to being calibrated).
3. Fully calibrate the system voltage control (SVC) board if used including the excitation sensor offset adjustment (altering the bus voltage via the SVC should not change the voltage between TP4 and TP1 by more than 30 mV).
4. Bring one of the generators up to rated voltage (do not parallel with other generators yet).
5. Null the voltage between TP3 and TP4 by adjusting R15 (the voltage at TP3 should be approximately 3.75 Vdc).
6. Repeat steps 1, 2, 4, and 5 with the other generators in the system.
7. Place two or more generators in parallel on the bus.
8. Overexcite one of the generators to a predetermined level of circulating current (usually 25 to 40% of rated single unit output current).
9. Adjust R2 on the excitation sensor of the overexcited generator to achieve 5.00 ± 0.02 Vdc across TP4 and TP1 (voltage is positive at TP4).
10. Return the overexcited generator back to rated voltage and approximately zero circulating current.
11. Repeat steps 8, 9, and 10 with the other generators in the system.

Figure 1: Block diagram

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