TRANSmission and distRibutIon

Protection relay for capacitor banks

The RLC04 is a numeric, digital signal processor based, protection relay designed specifically to combine all functions required for comprehensive protection of medium and high voltage capacitor banks and filter installations.

Shunt capacitor and filter banks are used in medium and high voltage systems to provide power factor correction and reduce unwanted harmonics being fed back onto the mains grid. Any one of a number of standard circuitries can be used to provide capacitor or filter bank protection in a system. With its four analogue input elements, one digital input, five output relays for system protection, and one output relay for self-supervision purposes, the RLC04B can be programmed to handle any of these configurations.

The measured currents themselves, or several other values calculated from them, are compared to threshold values entered into the relay by the user. These can be alarm, low-set, or high-set thresholds, although not all threshold types are relevant to all functions. If a threshold value is exceeded, a start signal is immediately generated, which in itself can be used to activate one or more output relays, and a timer linked to that function starts running. Should the threshold remain exceeded for a specified time-out period, normally also entered by the user, an alarm or trip signal will be generated. The relay can be programmed to respond by switching any combination of the output relays for each particular signal/threshold combination.

The relay's functionality and programmable options adapt according to the type of circuitry being protected. We therefore need to describe the two major circuit groups separately in the following sections.

Normal mode

This mode is applicable to star, delta, and double star circuits.

Repetitive peak overvoltage protection

The dielectric of a capacitor bank is stressed by the repetitive peak voltage applied to it. According to recognised standards, a capacitor bank (and its individual elements) must be able to withstand an rms sinusoidal voltage of 110% of its rated voltage at rated frequency for extended periods. Thus a capacitor can withstand a repetitive peak voltage of 1.1√2 Un for extended periods.

A capacitor can withstand even higher voltages for short periods. The temporary overvoltage withstand curve defines the time the capacitor can survive such overvoltage before failure. The curve has been derived from the relevant ANSI and IEC recommendations.

In operation, the relay measures the fundamental frequency current flowing in the capacitor banks in each of the three phases, as well as any super-imposed harmonics (up to the 50th). These current measurements are then integrated to provide the repetitive peak voltages vc for each capacitor bank. This value vc, is then compared to three adjustable thresholds:

- The alarm threshold: vc(alarm), with an associated adjustable definite time-out period, vc(alarm>x), if vc exceeds the threshold for the time set, the alarm signal vc(alarm) is generated.
- The low-set threshold: vc(vcr). For voltages above this threshold, a starter signal, vc(start), starts a trip timer. The ANSI inverse time curve defines the time before the low-set trip signal, vc(trip), is generated, providing that the voltage still exceeds the threshold.
- The high-set threshold: vc(vc>vcr), with an associated adjustable definite time-out period vc(vc>vcr)>xt, is available to provide a high-set trip output vc(vc>vcr)>trip, if the associated threshold is exceeded for the definite time set.

Programmable vc>reset time

In the second situation above, when the low-set threshold vc(vc>vcr) is exceeded, the trip timer is started. If the overvoltage recovers to below the set threshold before the trip timer times out, no trip occurs but the trip timer is not cleared, but rather is held for a programmable reset time, vc>reset, before resetting. Should the threshold be exceeded again before expiry of this reset time, the trip timer starts incrementing from it's previous value. This means that a such a condition can still result in a trip because of the prior accumulated count value in the trip timer. This helps take care of the "memory effect" of capacitors. If this feature is not required, vc>reset can be set to zero.

The graphs in Fig. 2 show a sequence of intermittent overvoltages in a monitored circuit, with two different consequences for the relay condition dependent upon the vc>reset value chosen.

- a) The vc(vcr)/vc<vcr voltage ratio, occasionally exceeding the high-set trip threshold value.
- b) The accumulating trip timer value with a shorter vc>reset time, allowing an intermediate trip timer reset.
- c) The accumulating timer value with a longer vc>reset time, thus allowing no intermediate reset of the trip timer, and eventually creating a trip condition.

Thermal overcurrent protection

All of the components making up a capacitor bank/harmonic filter circuit, are stressed thermally by the current Irms which flows through them. This applies to all of the elements such as circuit breaker, feed cable, damping or filter reactors, and filter resistors, as well as the capacitors. Irms comprises both the fundamental and harmonic components. The relay protects the banks against such excessive temperature rise which would otherwise lead to damage of the components and cause a breakdown. According to recognised standards, a capacitor bank, and the capacitor units making up the bank, must be rated to withstand a continuous current of 130% of the rated current.

For each phase, the relay protects a capacitor bank/harmonic filter circuit from
excessive current stressing, by modeling the thermal response of the circuit to the total heating current, $I_{rms}$.

After a system has been running for a short while, it will heat up to a particular temperature. At any point before that steady state condition is reached, the lower temperature of the system so far attained could be said to be caused by a lower effective thermal current, represented as $I_{th}$, as shown in Fig. 2. When the system eventually reaches the steady state condition, $I_{th}$ equals $I_{rms}$. The time constant which determines how quickly this occurs depends upon the system.

Using advanced digital signal processing techniques $I_{rms}$ is continuously calculated from the measured line currents, both fundamental and harmonics (up to the 50th). A second order thermal model with an adjustable heating/cooling time constant $\tau$ is then used to continuously calculate the thermal current response, $I_{th}$, to the heating current $I_{rms}$. $I_{th}$ is continuously compared to the adjustable low-set and high-set thresholds, $I_{th}>$ and $I_{th}>>$, each linked to their corresponding trip signals $I_{th}>trip$, and $I_{th}>>trip$, which are generated, if the associated thresholds are exceeded for the definite times set. However, it is possible to set the low-set time-out period $I_{th}<$ to “Alarm”. The low-set function then acts purely as an alarm, and only the $I_{th}>start$ signal is generated, without a subsequent $I_{th}>trip$ signal.

Fundamental frequency star point unbalance protection

In a double star connected capacitor
compared to an adjustable alarm

The magnitude of

in capacitance has occurred.

Iub>start

Iub >

Iub:xt

Iub_al

respectively.

Ilub >>:xt

Io>:xt

Io>>:xt

Io>>trip

Irms>:xt

Irms>>:xt

For Ilub greater than Iub >, a starter signal, Iub:xt, is generated. In addition, low-set and high-set trip signals, Iub:trip and Iub>>:trip, are generated if the associated thresholds are exceeded for the definite times set.

The sensitivity of line current unbalance protection is limited by the effect of supply voltage unbalance on the line currents. Nevertheless, line current unbalance protection is useful as back-up protection to star point unbalance protection, as well as for early detection of filter resistor and reactor failures, and for early detection of capacitor element failures in smaller capacitor banks, in single star or delta connected arrangements, where star point unbalance protection is not provided.

Fundamental frequency earth fault protection

The relay calculates the fundamental frequency residual or earth fault current, I1, as the magnitude of the vector sum of the three fundamental frequency components of the three phase line currents. I1 is compared with two adjustable thresholds, I1:xt and I1>>:xt respectively. Where ΔI1 exceeds I1:xt for the definite time set, an alarm signal, I1:alarm, is generated. In addition, a starter signal I1:Trip as well as low-set and high-set trip signals, I1:trip and I1>>:trip, are generated if the associated thresholds are exceeded for the definite times set.

The advantage of star point unbalance protection is that, unlike line current unbalance, the magnitude and phase angle of ΔI1 is not influenced by any phase imbalances in the supply voltage. Therefore, the sensitivity can be much higher than line current unbalance measurement, without spurious tripping caused by unbalanced supply voltages. This sensitivity is often essential for adequate protection of larger capacitor banks with both internal, external and unfused capacitor units.

In addition, the star point unbalance protection function indicates the leg of the double star bank in which the change in capacitance has occurred. This is particularly convenient for larger capacitor banks with internally fused or un-fused capacitor arrangements, to speed up the identification of faulty capacitor units.

Note: If the natural unbalance has been compensated and the fundamental current in the reference phase drops below 10% of the nominal current I1, the star point unbalance protection functions are suspended, and the compensation vectors are ignored.

If the natural unbalance is not compensated and the fundamental current in the reference phase drops below 10% of the nominal current I1, the star point unbalance protection function operates only on the amplitude of the measured unbalance current—the phase angle will not be taken into consideration.

Fundamental frequency line current unbalance protection

The monitoring of fundamental frequency line current unbalance provides a means of detecting changes in impedance resulting from failures and faults within the capacitive, inductive and resistive elements of a capacitor bank/harmonic filter circuit. These faults or failures invariably result in an unbalance in the fundamental frequency component of the line currents.

The relay calculates the fundamental frequency line unbalance, Iub, from the fundamental frequency components of the three phase line currents. Iub is continuously compared with two adjustable thresholds, Iub:xt and Iub>>:xt, each with an associated adjustable definite time, Iub:xt and Iub>>:xt respectively. Where ΔIub exceeds Iub:xt for the definite time set, an alarm signal, Iub:alarm, is generated. In addition, a starter signal Iub:Trip as well as low-set and high-set trip signals, Iub:trip and Iub>>:trip, are generated if the associated thresholds are exceeded for the definite times set.

This enables the relay to stop the capacitor banks with both internal, external and unfused capacitor units.

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Nevertheless, line current unbalance protection is useful as back-up protection to star point unbalance protection, as well as for early detection of filter resistor and reactor faults, and for early detection of capacitor element failures in smaller capacitor banks, in single star or delta connected arrangements, where star point unbalance protection is not provided.

Fundamental frequency earth fault protection

The relay calculates the fundamental frequency residual or earth fault current, I1, as the magnitude of the vector sum of the three fundamental frequency components of the three phase line currents. I1 is compared with two adjustable thresholds, I1:xt and I1>>:xt respectively. Where ΔI1 exceeds I1:xt for the definite time set, an alarm signal, I1:alarm, is generated. In addition, a starter signal I1:Trip as well as low-set and high-set trip signals, I1:trip and I1>>:trip, are generated if the associated thresholds are exceeded for the definite times set.

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fundamental frequency component of the line current, \( I_1 \), is continuously compared with an adjustable undercurrent threshold, \( I_{1<} \), and associated adjustable definite time-out period, \( I_{1<x} \). With the capacitor bank/harmonic filter circuit breaker on, if the mains power supply fails, as indicated by a drop in \( I_1 \) below \( I_{1<} \) for longer than the definite time set, then the undercurrent trip signal, \( I_{1<trip} \), is generated.

**Breaker fail protection**

\( B_{fail1} \)

Any one of the following conditions can be selected to signal successful breaker operation:

1. \( \frac{I_{fund}}{I_n} < 10\% \): a drop in the fundamental currents below 10%
2. \( \text{Dig-Input} \): a change of the digital input from active to inactive
3. \( I_{fund} \text{ OR Input} \): logical OR combination of [1] and [2]
4. \( I_{fund} \text{ AND Input} \): logical AND combination of [1] and [2]

If the selected condition is not fulfilled within a programmable time-out period, \( B_{fail1:xt} \), after the relay issues a trip output, \( B_{fail1} \) signal is generated which can be allocated to one or more of the output relays. For selections which involve the digital input, the input function must be set to “Breaker-Bon” or else the release function will be default to \( I_{fund} < 10\% I_n \), \( B_{fail2} \).

In addition to the above, if \( I_1 \) remains above 10% of rated \( I_n \) for longer than the adjustable definite time-out period, \( B_{fail2:xt} \), after the breaker switches off (digital input set to “Breaker-Bon” – indicates the breaker open/close status), this indicates a major failure of the capacitor bank/harmonic filter circuit breaker, and the breaker fail signal, \( B_{fail2} \), is generated.

Both signals can be used to trip an upstream breaker.

**Capacitor bank re-switching protection**

When a capacitor bank/harmonic filter circuit breaker switches off for any reason, it should not be re-energized until the capacitor bank has discharged. This will prevent severe and stressful voltage and current transients due to the application of mains supply voltage onto a charged capacitor bank.

The relay provides the necessary logic, and a breaker enable output signal, \( B_{ena} \), to inhibit the re-energisation of the circuit breaker, for an adjustable definite time, \( B_{ena:xt} \), since de-energisation.

\( B_{ena} \) can be triggered by a choice of the following:

1. \( \frac{I_{fund}}{I_n} < 10\% \): a drop in the fundamental currents below 10%
2. \( \text{Dig-Input} \): a change of the digital input from active to inactive
3. \( I_{fund} \text{ OR Input} \): logical OR combination of [1] and [2]
4. \( I_{fund} \text{ AND Input} \): logical AND combination of [1] and [2]

**Event trip**

The relay offers the possibility to trip the relay from an external signal via its digital input. A precondition is that the digital input must be configured as an event trip input. If the digital input changes its state from inactive to active for the definite time-out period \( Event:xt \), the generated function, \( Event_{trip} \), can be used to operate any of the output relay(s).

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