



Instantaneous overcurrent element response to saturated waveforms in UR-series relays

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DESCRIPTION

This document examines minimum operate times of the instantaneous overcurrent elements of the UR-series relays and how elements perform on saturated waveforms as well as the minimum time to saturation that would guarantee instantaneous overcurrent operation for a given multiple of pickup.

The UR-series of relays uses a full-cycle Fourier filter for current phasor estimation. The current waveforms are pre-filtered using a modified MIMIC filter. The MIMIC filter is a Finite Impulse Response (FIR) filter that ensures accurate rejection of any DC components that may be present in the current signals. The filter guarantees that a transient overshoot in the estimated current magnitude is below 2% for any time constant of the DC component that may be contained in current signals. This allows for a very low security margin when setting an instantaneous overcurrent as far as the relay accuracy is considered. At the same time the filter has much better filtering properties for higher frequencies as compared with a traditional MIMIC.

The 100% settling time for the phasor magnitude is 1.33 of a power system cycle; that is, 22.1 ms for 60 Hz systems, and 26.6 ms for 50 Hz systems. Thus, for a multiple of pickup of 1.01 (i.e. when the current magnitude is only slightly higher than the pickup setting), it will take an instantaneous overcurrent 1.33 of a power system cycle to pickup and operate.

For any practical multiple of pickup, the response time may be approximated with reasonable accuracy by the following equation:

$$t_{pkp} = \frac{1.33}{MOP} \quad (\text{EQ 1})$$

where t_{pkp} is a pickup time in power system cycles and MOP is a multiple of pickup (actual current / pickup threshold).

Do not mistake the above equation for an operating time. The operating time is longer as it includes processing times and delays of CT/VT modules, the CPU,

and output contacts. The operating times are specified in the *Specifications* section of the UR-series manuals. The above equation specifies the minimum waveform duration that ramps up the estimate of the current magnitude to the pickup level, thus causing a pickup of the instantaneous overcurrent element, what is referred as “commit time” below.

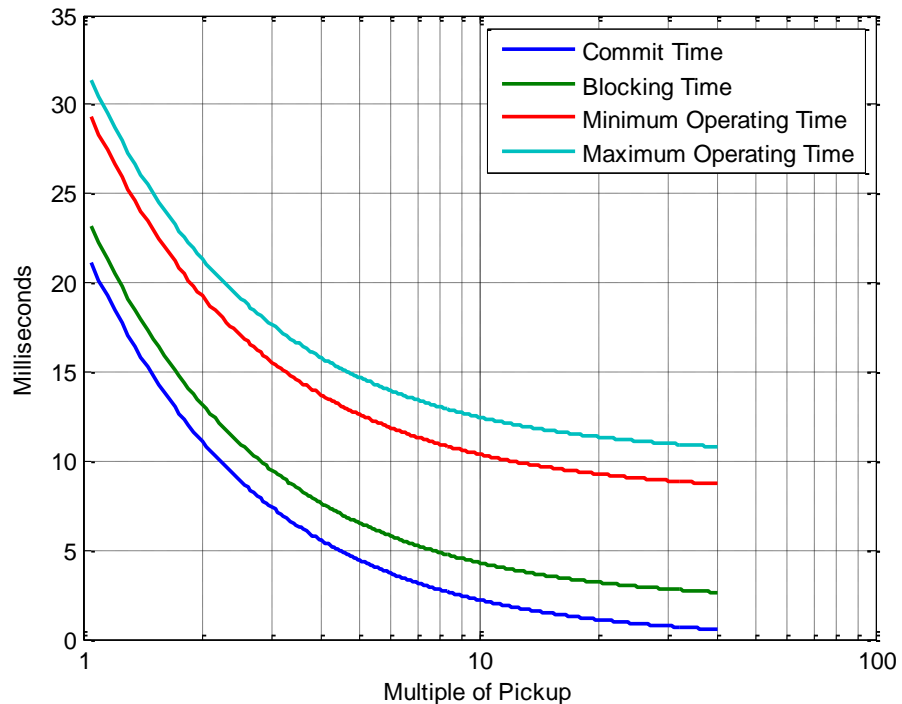


FIGURE 1. IOC timing curves with no intentional delay

IOC timing curves shown above specify the following:

- Commit time is the minimum time that current at this magnitude has to be applied to the relay that IOC “commits” the operation. This time excludes logic processing and delay variance due to fault inception instance
- Blocking time is the time when element still can be blocked even after committed operation. This time includes delays in data transfer from DSP to CPU and logic processing delays at CPU.
- Minimum operate time is the minimum operating time which includes blocking time and Form-A contact output operation
- Maximum operate time is the maximum operating time including logic processing delays, delay variance due to fault inception instance and Form-A contact output operation

Adding intentional delay will shift all curves up by this delay given that current magnitude is not changing during injection to the relay.

For example, for a MOP of 4, the magnitude estimated by a relay will reach a pickup level after $1.33 / 4 = 0.33$ of a power system cycle. Even if a main CT saturates after this time completely, the instantaneous overcurrent is guaranteed to operate. Consequently, the following equation describes a condition guaranteeing operation of an instantaneous overcurrent element before CT saturation for the UR-series of relays:

$$t_{pkp} < t_{sat} \quad (\text{EQ 2})$$

where t_{sat} is the time to saturation. The above equation may be re-written as follows:

$$\frac{1.33 \times T_1}{\text{MOP}} < -T_{DC} \times \ln \left[1 - \frac{(V_{sat} / (I_s \times R_s)) - 1}{\omega \times T_{DC}} \right] \quad (\text{EQ 3})$$

where T_1 is a power system cycle, V_{sat} is a CT saturation voltage, I_s is a CT secondary current, R_s is a CT secondary (total) resistance, and T_{DC} is a time constant of a DC component in a fault current.

EXAMPLE

Consider a system with the following characteristics:

- CT: 400 V, $R_s = 0.8$ ohm, 50% residual magnetism
- System: X/R ratio of 35
- Fault: $I_{fault} = 50$ A secondary
- Instantaneous overcurrent settings: Pickup threshold = 20 A secondary

Now, given a 400 V saturation voltage with 50% residual magnetism in a CT core, we have the CT saturation voltage as:

$$V_{sat} = 400 \text{ V} \times (1 - 0.5) = 200 \text{ V} \quad (\text{EQ 4})$$

The T_{DC} time constant is calculated as follows:

$$\frac{X}{R} = 35 \rightarrow \frac{L}{R} = \frac{35}{2\pi \times 60 \text{ Hz}} = 0.093 \text{ s} \rightarrow T_{DC} = 93 \text{ ms}$$

(EQ 5)

The multiple of pickup is:

$$\text{MOP} = \frac{50 \text{ A}}{20 \text{ A}} = 2.5 \quad (\text{EQ 6})$$

Now time to saturation = 11.3 ms, time to pickup = $\frac{(1.33 \times 16.66 \text{ ms})}{2.5} = 8.9 \text{ ms}$.

The instantaneous overcurrent will pickup before the CT saturates.

Once a main CT saturates, the waveform distorts and the magnitude of the fundamental frequency component is reduced. Having the saturation curve of the CT available, one may estimate the actual secondary current seen by the relay and confirm if a given instantaneous overcurrent would pickup on a saturated waveform.

For illustration the following figure shows a saturated waveform, the magnitude of the fundamental frequency component as measured by the UR-series relay and the true RMS value as measured by the UR-series relay.

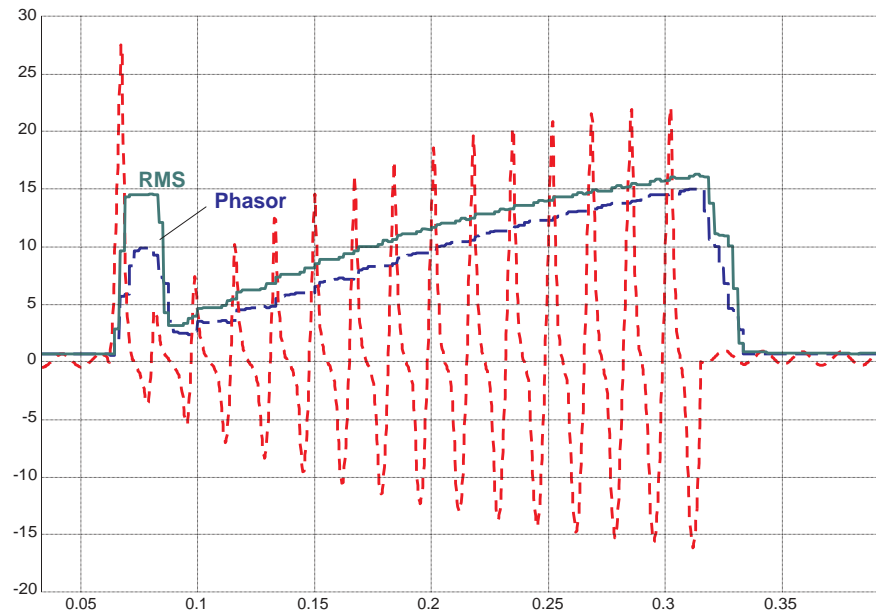


FIGURE 2. Sample CT saturated current: true RMS vs. phasor magnitude