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Inrush Restraint for Transformer Differential Protection with Current Waveform Analysis (CWA) in SIPROTEC 4 7UT6x

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SIPROTEC 4 Application

Inrush Restraint for Transformer Differential Protection with Current Waveform Analysis (CWA) in 7UT6x

APN-076, Edition 1

Content

1 Inrush Restraint with CWA for Transformer Differential Protection in 7UT6x

1.1 Introduction

During switching on of power transformers on no load or light loads, it is very common for the presence of high short-time inrush magnetizing currents which only enter the protected zone but do not exit it again. Figure 1 illustrates such a switching instance:

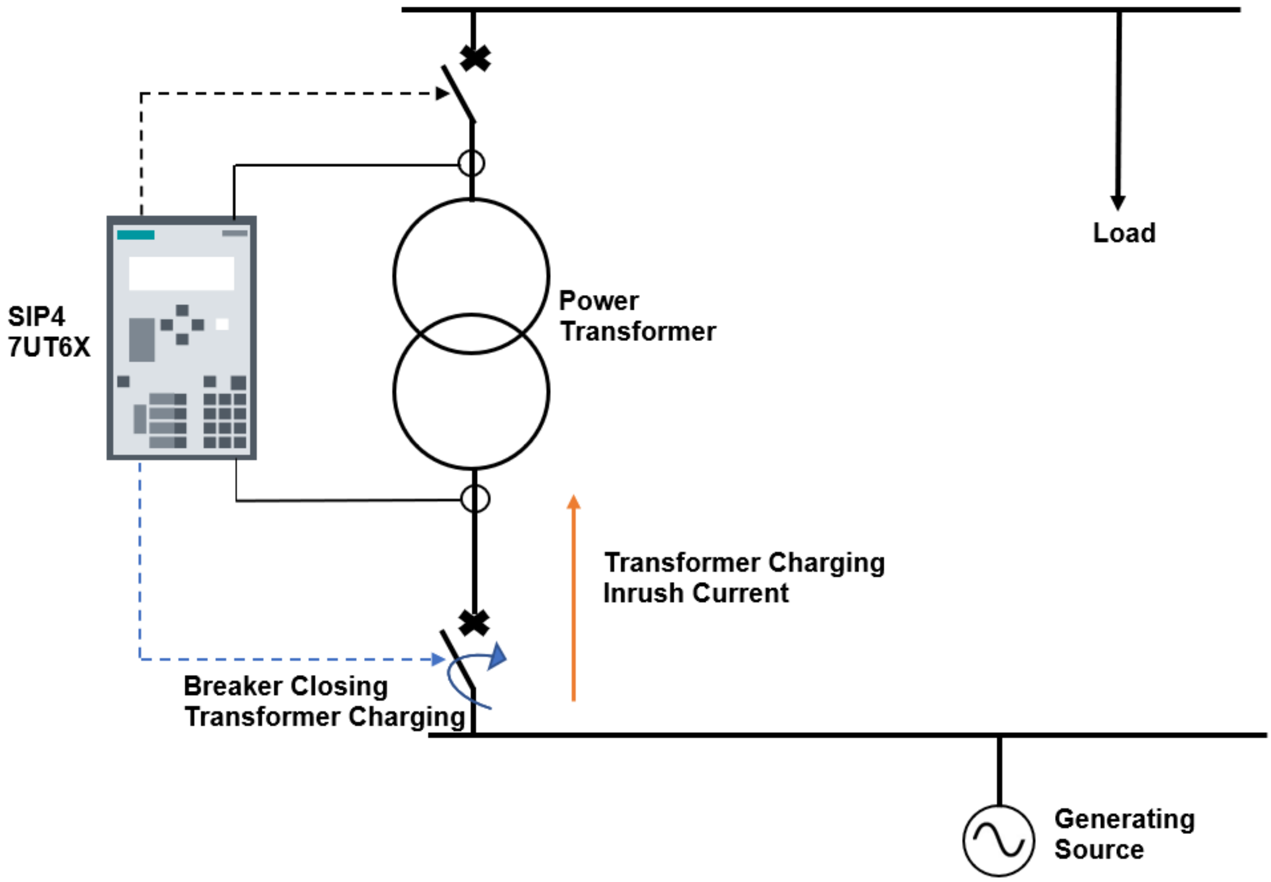

Figure 1: Schematic diagram of switching on an unloaded power transformer

Naturally these inrush currents will produce differential quantities as they seem like single end fed fault currents and thus can trigger the undesired operation of the differential protection.

These inrush currents are characterized by considerable 2nd harmonic content (double the nominal frequency) which is practically absent during short circuits. Using 2nd harmonic inrush restraint in 7UT6x, if the content of 2nd harmonic current exceeds a settable threshold then the differential protection is blocked. The harmonic restraint operates individually per phase therefore the differential protection is fully operative even when the transformer is switched on to a single-phase fault, whereby inrush currents may possibly be present in one of the heathy phases. It is however possible to set the protection in a way that when the permissible harmonic content in the current of only one single-phase is exceeded, not only the phase with the inrush current but also the remaining phases of the differential stage are blocked. This "cross-block" can be limited to a selectable duration with the help of a parameter called "Time for cross-blocking 2nd harmonic".

Besides detecting inrush currents using 2nd harmonic contents 7UT6x offers an alternate method called **Current Waveform Analysis (CWA)**. New transformer core materials, in order to reduce the noise level, and longer outage time of the transformer lead to a low content of 2nd harmonic current during energization (this means if a transformer is not energized for a long time, the first energization will not show enough 2nd harmonic content due to the magnetic flux). As a result, the lower content level does not reach the default threshold of 15% for 2nd harmonic restraint. The general approach to avoid a mal trip of the differential protection in such scenarios is to decrease the threshold to 12% and to enable cross blocking for 2nd harmonic to 8 cycles. But one must also consider 2nd harmonics during internal faults. This leads to a certain risk for an under function of the differential protection if the 2nd harmonic settings are set too low with long cross-block durations.

If CWA function is enabled this checks for any asymmetrical current waveforms and if any asymmetry exceeds a fixed level, then the differential protection tripping is blocked. The typical transformer energizing waveform (explained in **Section 1.3**) is unsymmetrical in nature. Therefore, CWA provides a suitable alternative for stabilization of differential protection against transformer charging inrush and mitigates the risk of under function of differential protection due to low parameterization of 2nd harmonic restraint.

1.2 Transformer Energizing Current Waveform

When energizing a transformer, one – sided over-excitation results due to remanence causing large magnetizing current flow (inrush current). For Remanence please refer Figure 2.

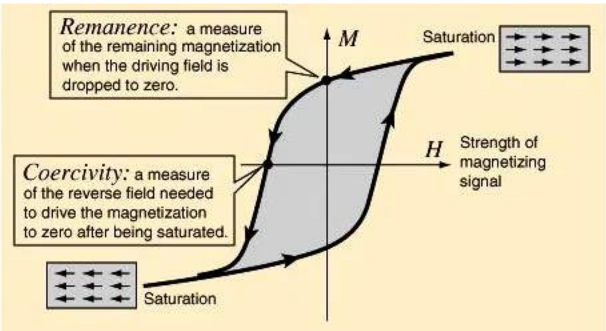

Figure 2: B-H Magnetizing Curve for any magnetic material

The flux does not return to zero when the transformer is switched off but remains at the remanence point Φ_{rem}.

When the transformer is re-energized, the flux increase starts from this point. Depending on the energizing instant on the sinusoidal voltage (point on wave), an offset course of the flux can result. For the large flux values in the saturation range, a very large magnetizing current is required, and cyclic current peaks will result. The curve form corresponds with the sinusoidal half waves of a simple half wave rectified AC current that decays with a large time constant as per Figure 3.

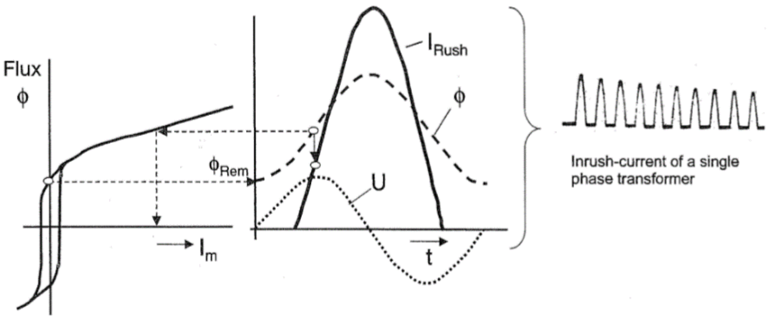

Figure 3: Origin of single phase magnetizing current waveform.

On three phase transformers, a three-phase inrush current will result depending on the vector group and method of star point earthing on the transformer. In general, two phases will saturate and draw large magnetizing currents. A typical inrush current for such scenarios is shown in Figure 4 which depicts the asymmetric nature of these currents.

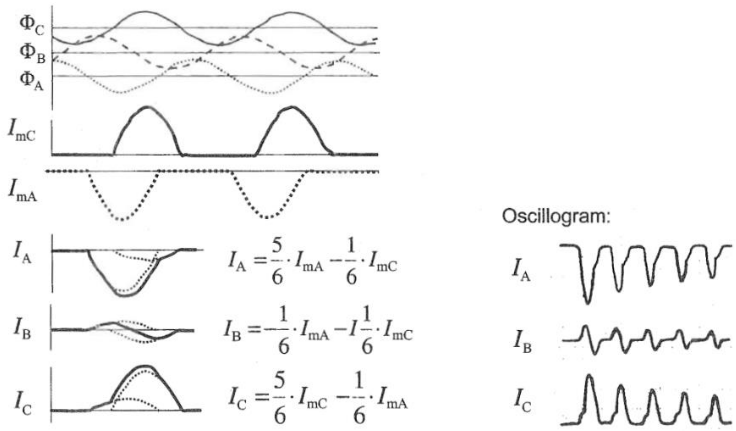

Figure 4: Origin of three phase magnetizing current waveforms with theoretical quantification.

1.3 Definitions

1.3.1 87 2nd Harmonic Content in I-DIFF (Addr. 1271):

This parameter sets the limit of the ratio of the 2nd harmonics to the fundamental current **(I_{2fN}/ I_{fN})**. If this ratio exceeds the value set at this parameter, then the differential protection will be blocked.

1.3.2 87 Time for Cross-blocking 2nd Harm. (Addr. 1272):

This parameter sets the time duration for which 2nd harmonic content overshoot beyond the settable limit in one phase can be extended to the unaffected phases. Therefore, for this set duration the differential protection in the unaffected phases will also be blocked.

1.3.3 87 Blocking with CWA (Addr. 1300):

If the parameter is set to "ON" then 7UT6x will use Current Waveform Analysis (CWA) in parallel with 2nd Harmonic content for detection of high magnetizing inrush currents.

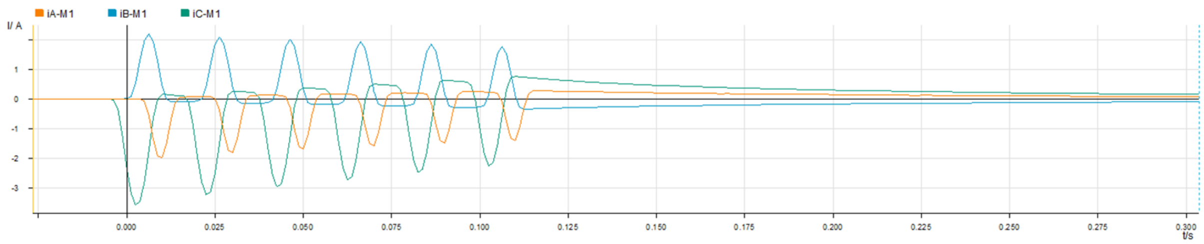

Figure 5: Typical transformer inrush current asymmetric waveform.

Typical for a transformer energizing process is the occurrence of asymmetry in the current waveform as explained earlier (see Figure 5). The CWA method works as a supplement to the 2nd harmonic and covers cases that are not controlled through the second harmonic restraint. As the name suggests this function is based on waveform analysis. The nature of the inrush magnetizing current is asymmetric, and this function is based on evaluation of the asymmetry in the differential current against fixed set internal thresholds. If the content of asymmetry in two phases exceeds the allowed degree of asymmetry, then differential protection is blocked.

In order to prevent a malfunction under some power system faults, eg. single phase earthed faults, etc. another degree of asymmetry – the max phase criterion is used to unblock this logic.

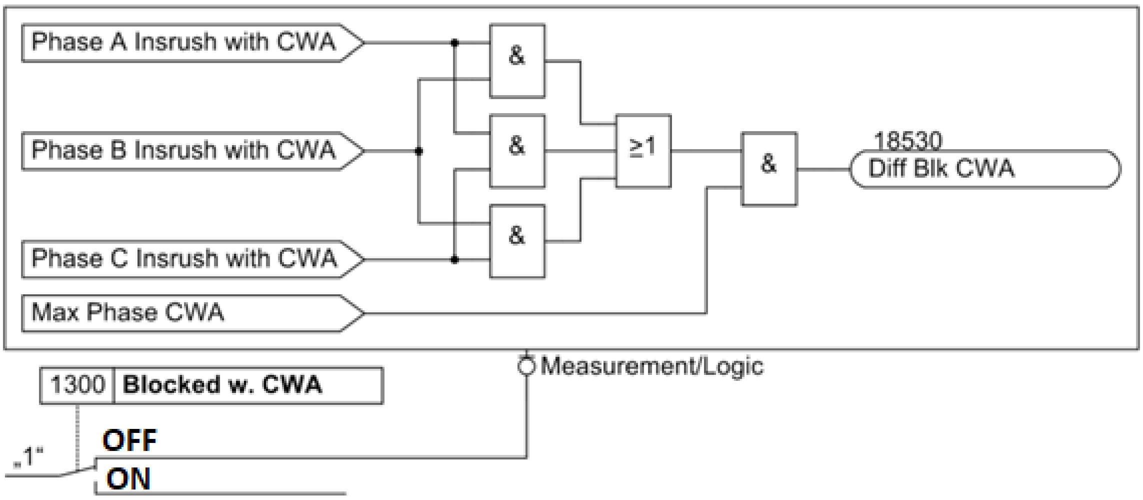

Figure 6: Logic for Current Waveform Analysis Restraint (CWA)

As with 2nd Harmonic content, CWA **does not restraint the stage I-DIFF>> (87 Stage 2 trip)**.

1.4 Device Configuration to enable Current Waveform Analysis (CWA)

The following parameter needs to be configured in order to enable CWA:

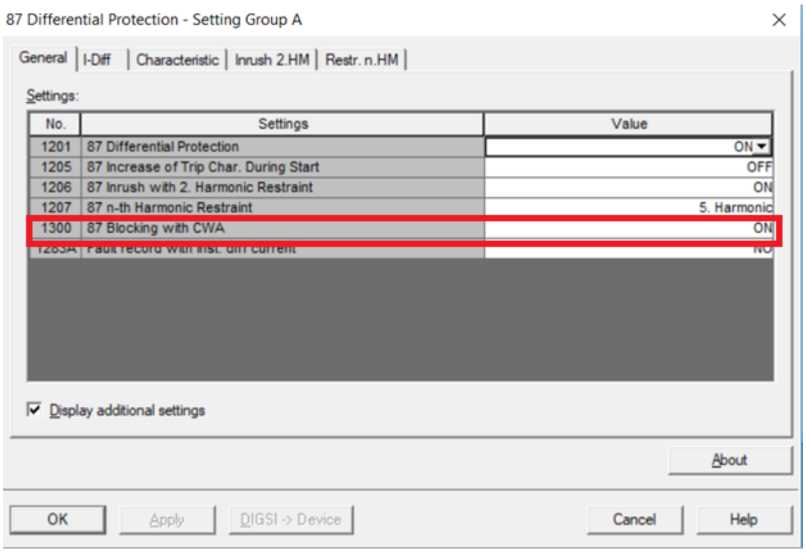

Figure 7: Setting parametrization required for CWA

As per Figure 7, setting parameter at address 1300 needs to be configured as “ON” for CWA to be activated.

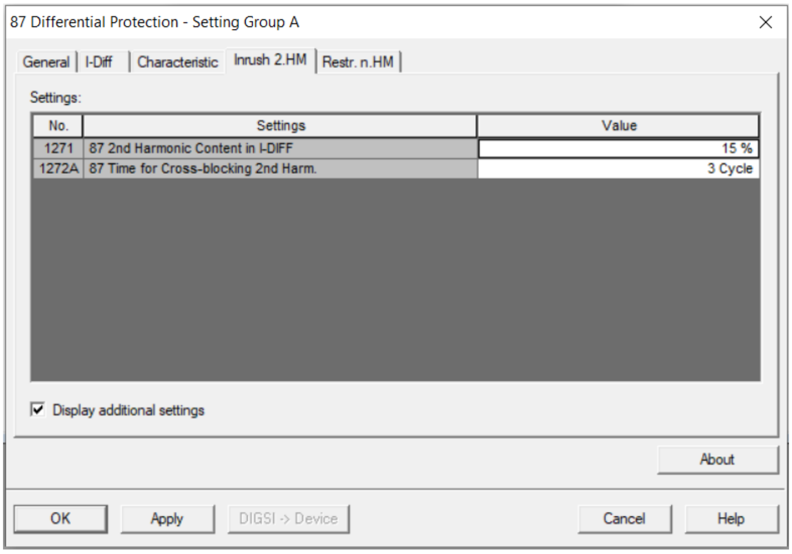

Figure 8: Setting parameterization for 2nd Harmonic Content in parallel with CWA.

In most applications and existing configurations, 2nd harmonic content is primarily used for inrush detection during transformer energization. The setting parameterization for this method includes setting the 2nd harmonic content at address 1271 and cross-block duration at address 1272 respectively. As per the example in Figure 8 these parameters as set as 15% and 3 cycles respectively.

CWA can also be adopted in parallel with 2nd harmonic to provide a more contingent solution for detecting magnetizing inrush currents during Transformer energizations as illustrated by the following simulation in **Section 1.6**.

1.5 Simulation of a Power Transformer Energization during Switch On

In this section we will demonstrate a typical no load or lightly loaded energization instant of a power transformer depicted in Figure 1 with the help of secondary injection to a SIPROTEC 4 7UT613 relay using Comtrade TransPlay.

Here two cases are simulated for the same current waveform to understand the relay behavior under the scenarios:

1. With only 2nd Harmonic Restraint and no CWA
2. With 2nd Harmonic Restraint as well as CWA

1.5.1 Simulation

The following current waveform is used for the secondary simulation:
(Note that the current waveform illustrated in Figure 9 used for the simulation is recorded while energizing a 220kV/33kV 160 MVA power transformer on no load by a prominent Power Transition Utility in Gujrat, India using a SIPROTEC 7UT633 relay)

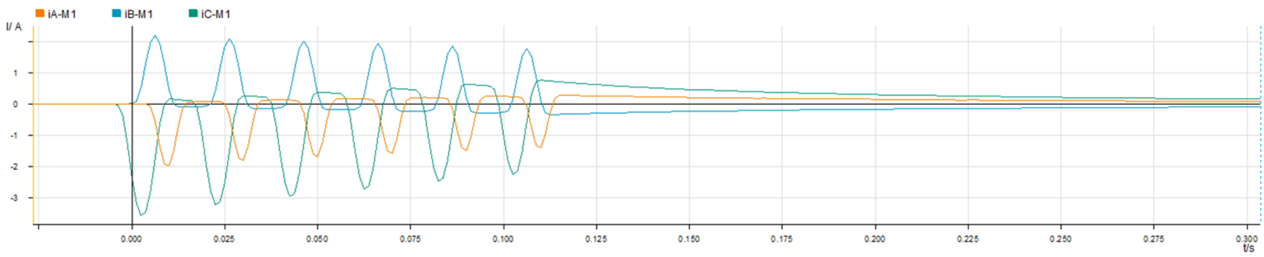

Figure 9: Current Waveform injected to the 7UT613 recorded in SIGRA

Case 1: With Only 2nd Harmonic Restraint and no CWA

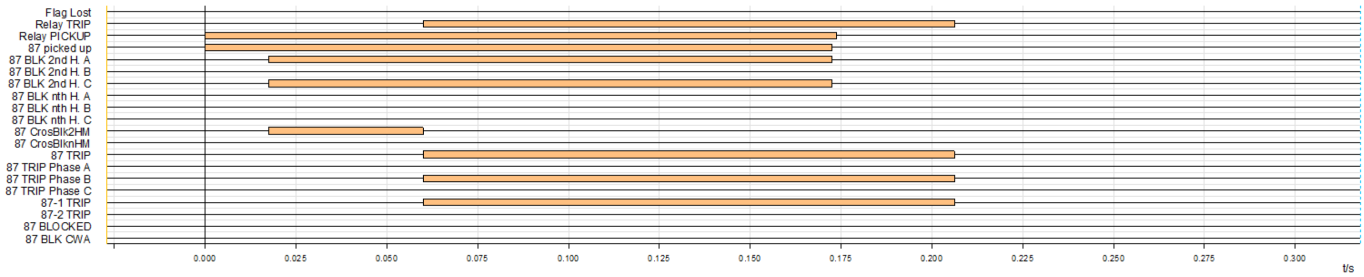

Figure 10: Events timeline in SIGRA generated by 7UT613 for case 1

Case 2: With 2nd Harmonic Restraint and CWA

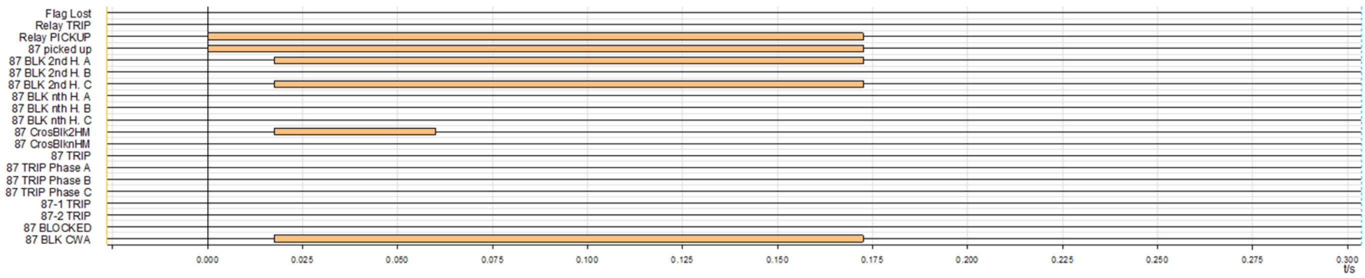

Figure 11: Events timeline in SIGRA generated by 7UT613 for case 2

(Note: SIGRA is a Siemens Comtrade Viewer used for Fault Record Evaluation.)

1.5.2 Observations and inferences

Case 1:

When only 2nd harmonic content is used for magnetizing inrush current detection then we observe the following with respect to the events timeline as per Figure 10:

1. The moment this unbalanced energization current is injected the differential protection is picked up. Also, after a delay inrush in phase A and phase C are also detected for as long as the inrush current in these phases are persisting.
2. No inrush is detected phase B. Also, cross block for 2nd harmonic is also activated for the duration of 60ms as per setting parameterization of Figure 8.
3. After the cross block for 2nd harmonic has elapsed, the first stage differential protection (87-1) in phase B is released due to the absence of 2nd harmonics in this respective phase.

When we investigate these observations, we find that inrush is detected only in phases A and C. No inrush detection in phase B leads to the release of differential protection trip in this phase after the expiration of cross block duration. This is undesirable during transformer energization and can happen in large power transformers where each transformer phase cores draw unequal and uneven magnetizing currents leading to cases where any one of the currents may remain undetected.

Case 2:

When both the 2nd harmonic content and CWA together are used for magnetizing inrush current detection then we observe the following with respect to the events timeline as per Figure 11:

1. The moment this unbalanced charging current is injected the differential protection is picked up. Also, after a delay inrush in phase A and phase C are also detected for as long as the inrush current in these phases are persisting.
2. No inrush is detected phase B. Also, cross block for 2nd harmonic is also activated for the duration of 60ms as per setting parameterization of Figure 8.

3. Unlike case 1, here along with the detection of the inrush current in phase A and phase C, CWA blocking of differential protection ("87 BLK CWA") is also generated and this signal is active for the entire duration the inrush currents persist. This signal prevents the operation of differential protection in phase B.

When we investigate these observations, we find that CWA has assisted 2nd Harmonic restraint and prevented an undesirable differential tripping while energizing a power transformer on no load or even lightly loaded without the need to modify any existing setting parametrization for inrush content ratio nor the cross block duration.

1.6 Conclusion

We hope with this application note the reader will understand Current Waveform Analysis (CWA) as a method for inrush restraint of transformer differential protection and how it can be used as a contingency along with 2nd harmonic content as a reliable method of inrush current detection in SIPROTEC 4 7UT6x devices.

Please note that the default threshold of 2nd Harmonic restraint is 15% and cross block duration recommendation is 3 cycles respectively when CWA is activated.

Also note that CWA is available with version **4.67** for **7UT613/63X**, **4.64** for **7UT612** and **4.80** for **7UT682/683**.

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