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Transformer differential protection with fuzzy logic based inrush stabilization ☆

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ABSTRACT

Second harmonic restraint is still commonly used to discriminate fault current and transformer inrush conditions. Such approach, however, has some disadvantages and limitations. Therefore various other criteria signals for power transformer inrush discrimination have been analysed. The paper presents a new multi-criteria stabilization algorithm that employs fuzzy reasoning technique for better discrimination of inrush conditions. The developed protection algorithm has been tested with EMTP–ATP generated signals as well as real-world data, proving to be reliable and much more sensitive than standard algorithms with traditional criteria and crisp settings.

1. Introduction

The differential protection has been successfully used for decades to protect power transformers against faults. Nevertheless, to assure proper operation the differential principle has to be supported by additional stabilization algorithms which are aimed at avoiding unwanted tripping during transformer magnetizing inrush. The second harmonic ratio restraint is the most common used principle to discriminate inrush conditions [4,13]. This approach has one critical drawback. Namely, it is impossible to determine the threshold which will be high enough to not deteriorate operation speed under internal faults (when content of second harmonic in fault current can be as high as in the magnetizing inrush current) and at the same time not too high to provide sufficient stabilization under transformer energization (in a modern large power transformer the level of second harmonic component in the magnetizing inrush current may be very low). Consequently, application of traditional second harmonic restraint stabilization method may lead to both misoperation under internal faults and maloperation during transformer energization. Thus, new techniques to improve security and dependability are reported in the recent literature. Those techniques mainly are based on: fuzzy logic [3,9,13,18], ANN approach [11,13,16], correlation analysis and waveform identification [1,2,6], wavelet transform [12,14,15], transformer magnetizing characteristics based [5], normalized grille curve [17].

Unfortunately, numerous transformer protection operation records show that the second harmonic restraint as well as other methods may not always be effective. Magnetic cores of modern transformers are made from amorphous materials, what may be a reason of low level of second harmonic ratio generated during energization, being insufficient for effective protection stabilization. Difficulties may also arise for the cases of loaded transformer energization (e.g. after fault clearing) and ultrasaturation conditions [7], when the level of stabilization signal is also very low. On the other hand problem of detection of turn-to-turn internal fault incepted during transformer energization is not discussed in the literature, while such disturbance is very likely.

Thus, in order to improve protection operation, especially for such difficult cases, new protection stabilization criteria would be required. The criteria signals should be selected to meet the following requirements:

- Immunity to magnetizing inrush conditions regardless of the second harmonic ratio.
- fast operation under internal faults even for severe faults when current transformer (CT) Saturation occurs.
- Sensitivity for low current internal faults (e.g. single turn-to-turn faults).

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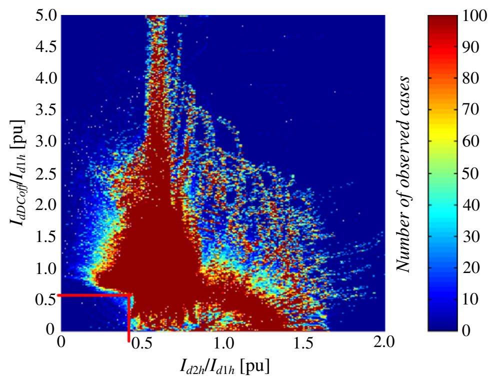

Fig. 1. Analysis of the relationship between magnitude of reconstructed value of the DC component ratio and second harmonic ratio for all generated cases of energization of the power transformer.

A number of suitable criteria signals had been investigated and discussed in [8], where also appropriate operation thresholds are recommended. Proposed criteria and their combinations reveal ability to ensure better stabilization for various energization situations. In [9] the first version of the fuzzy protection is described. This approach employs input signals proposed in [8] but still shows some problems with: fast tripping of high short-circuit current internal fault as well as identification of inter-turn faults. Since, this fuzzy protection system requires some improvements, here full version of the scheme is presented together with results of its thorough testing.

This paper presents original stabilization algorithm for transformer differential protection (Sections 2 and 3). Recommended criteria, their combinations and operation thresholds have been aggregated with use of fuzzy logic methods in multi-criteria system. Thorough statistical analyses of performance of the differential protection with application of the new stabilisation algorithm have been carried out (Section 4), with use of signals generated in prepared digital transformer model (ATP–EMTP) as well as with signals received from field measurements for various transformer types. Conclusions are provided in Section 5.

2. Stabilization algorithm – general information

In order to select optimal set of criteria signals for stabilization of the power transformer differential protection thorough statistical analysis has been performed [8]. This analysis encompassed behaviour of various criteria signals under wide scope of power transformer operating conditions. For this purpose, using EMTP model of power transformer, over 80 thousand various cases of internal and external faults as well as transformer energization have been generated. Simulating internal faults apart from terminal faults also turn-to-turn faults (especially these with low number of turns involved) have been taken into account. This base of signals has been used to determine criteria signals, their combinations (mutual relationships) and threshold values. Results of the analyses can be presented in form of histograms that illustrate distribution of the measured values at consecutive time instants. Using such histograms one can assess, for a given value of the criteria signal percentage, the number of cases for which, at a given time instant after inception of disturbance, the same or higher value was observed. In Fig. 1 the results of statistical analysis for cases of transformer energization for a given criteria signals.

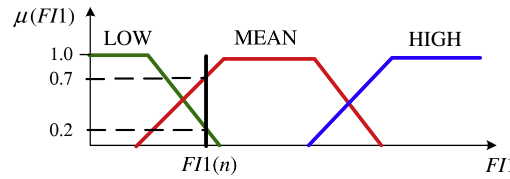

Fig. 3. Mapping crisp value into fuzzy sets – an illustration.

According to such analyses (for more details see [8]), for proper operation of proposed algorithm following criteria values are recommended:

- $K_{d1h} = I_{d1h}/I_n$ – ratio of magnitude of fundamental harmonic of the differential current and transformer rated current.
- $K_{d2h} = I_{d2h}/I_{d1h}$ – ratio of magnitudes of the second harmonic and fundamental harmonic of the differential current.
- $K_{DCoff} = I_{dDCoff}/I_{d1h}$ – ratio of reconstructed DC component and fundamental harmonic of the differential current.
- $K_{DCon} = I_{dDCon}/I_{d1h}$ – ratio of calculated DC component and fundamental harmonic of the differential current.
- D_{1d} – non-saturation interval distortion coefficient of the differential current, needed for better identification of turn-to-turn fault.
- D_{2d} – non-saturation interval distortion coefficient of the differential current, assuring operation speed-up for internal faults.

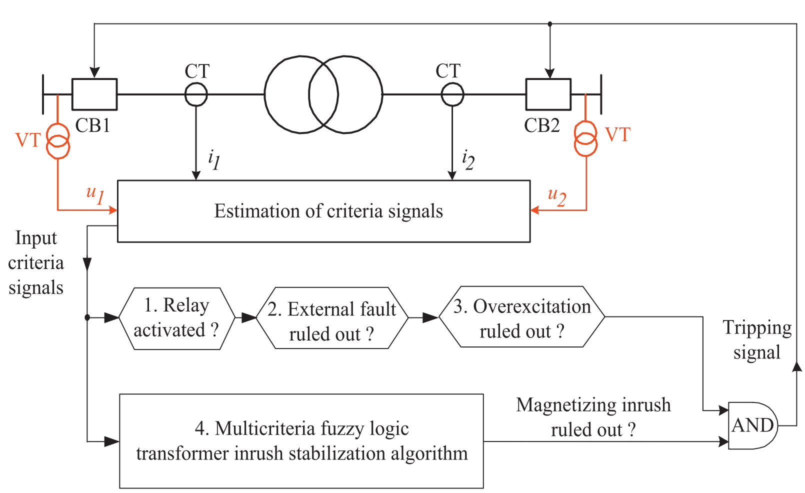

Fig. 2. Block scheme of differential protection with multi-criteria fuzzy logic magnetising inrush stabilization algorithm.