Electrical Power and Energy Systems 68 (2015) 294–303

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# Protection of power transformer using multi criteria decision-making

A. Rahmati [a,*], M. Sanaye-Pasand [b]

[a] School of ECE, College of Engineering, University of Tehran, Tehran 14395-515, Iran
[b] Control and Intelligent Processing Center of Excellence, School of ECE, College of Engineering, University of Tehran, Tehran 14395-515, Iran

ARTICLE INFO

*Article history:*
Received 17 December 2013
Received in revised form 18 December 2014
Accepted 24 December 2014
Available online 13 January 2015

*Keywords:*
CT saturation
Differential relay
Fuzzy logic
Inrush current
Multi criteria decision-making
Restricted earth fault relay

ABSTRACT

Power transformers are protected by different relays that operate independently. Malfunction of each relay has a major role in reducing the reliability of the protection system. In order to mitigate the main drawbacks of the power transformer relays, an overall protection scheme is presented in this paper. This scheme proposes a novel multi criterion algorithm using decision-making based on fuzzy logic. In this paper the outputs of restricted earth fault relay and a directional check unit, are combined with the output of the differential protection relay. Therefore, problems that are pertaining to independent operation of each relay have been mitigated and the relays cover protection blind spots of each other. The improved power transformer protection (IPTP) scheme enhances the sensitivity and reliability of the power transformer protection. Extensive simulations are used to measure the effectiveness and merit of the proposed IPTP relay. The above efforts result in a multi criteria approach for protection of power transformers.



## Introduction

Power transformers, as one of the vital components of electric power systems, require the protective system with high dependability (no missing operation), security (no false tripping), and quick speed of operation (short fault clearing time). For this purpose, a differential protection (DIFP) relay has served as the main protection of power transformers against faults on the windings for many years [1].

However, a DIFP relay suffers from difficulties due to several natural phenomena such as inrush current and saturation of instrument current transformers (CTs). These phenomena cause false differential currents and misoperation of the relay. These issues should be taken in consideration to design an efficient differential protection algorithm.

Extensive tries have been developed by different manufactures and researchers to provide more intelligent protective relays. Recently, different algorithms have been proposed to improve the operation of the DIFP relay. In general, one important key problem needs to be resolved by these efforts: how to immune the DIFP relay operation against the magnetizing inrush current and CT saturation condition.

Some methods [2–5] have been proposed to discriminate the magnetizing inrush current from the internal fault currents. Most of these algorithms are based on the harmonic contents of the inrush currents (mostly second harmonic), or specific pattern recognition of the inrush current waveform. The drawback of those methods, which are based on second harmonic restrain, is that the second harmonic component may also be generated during internal faults due to CT saturation. Delay in fault detection, maloperation during severe external faults and dependence of these methods on parameters of the power transformer are some shortcomings of wave shapes based algorithms. Consequently, these algorithms cannot distinguish between inrush currents and internal faults with high confidence.

Also, some algorithms [6–8] have been proposed to detect the CT saturation and enhance the stability of DIFP relay against heavy external faults. These algorithms have some deficiencies in CT saturation detection. They might not operate well for short-circuit currents due to the high decay DC component. In some other algorithms, the relay needs to be blocked for a fraction of a cycle after the fault inception and therefore, they take longer time to detect the CT saturation.

Another main drawback in the transformer protection is related to the development of the internal/external fault after an inrush current due to transformer switching. In this situation, the DIFP relay will be blocked due to its restrain criteria, and thus the internal fault might remain on the transformer winding for a long time[9].

* Corresponding author.
*E-mail addresses:* abouzar.rahmati@is-international.com, arahmati@ieee.org (A. Rahmati), msanaye@ut.ac.ir (M. Sanaye-Pasand).

http://dx.doi.org/10.1016/j.ijepes.2014.12.073
0142-0615/

Despite continuous research efforts on providing a perfect protection scheme, there is still no completely clear differentiation between the internal faults and other conditions. Some other relays such as restricted earth fault (REF) relay are used to overcome some of the DIFP relay problems. For instance, the REF relay is sensitive in low level internal earth faults (i.e. the faults occurring within 20–30% of the winding near the neutral point) while the DIFP relay cannot recognize this fault type [10]. Therefore, the REF relay covers these types of faults and it completes the DIFP relay protection zone.

In the current protection methods, each of the power transformer relays operates independently; i.e. each relay makes a decision only in accordance with its own logic and protection zone. Consequently, a false decision made by one relay while all other relays operate correctly would cause the transformer protection system to make a final false decision. In order to have a secure and reliable power transformer protection system, a multi-criteria algorithm using decision-making based on fuzzy logic is proposed. For covering the weaknesses of individual relays this method combines the REF relay and a directional check unit (DCU), with the DIFP relay. Superiority of the proposed IPTP relay in different transient conditions will be shown. This approach is considered as a multi-criteria method to provide reliable power transformers protection.

The proposed scheme is evaluated using extensive simulations, such as inrush conditions, internal fault, external fault combined with CT saturation, simultaneous inrush and internal fault, and simultaneous external fault and internal fault signals. The results demonstrate that the proposed IPTP relay provides an overall protection relay that improves the security and dependability of the power transformers protection.

## Relays modeling based on fuzzy logic

Fault uncertainty, which cannot be entirely eliminated from measurements, protective algorithms and modeling processes, and etc., must be adequately considered and reduced in the protective relays. Further improvement of the relays reliability could be achieved using simultaneous implementation of several protection principles. However, uncertainty and conflicts still may arise in doubtful cases which cause different relays make different decisions encountering the same disturbance. For instance, a relay may recognize a case as an inrush current or CT saturation while the other may consider it as an internal fault. Therefore, all relays do not provide a clear distinction between internal faults and other conditions with 100% accuracy. An effective approach is thus necessary to deal with these uncertainties. Fuzzy set theory offers a convenient means for considering inexactness and uncertainties. These uncertainties may be offset, if the relay signals are represented by fuzzy signals. Therefore, modeling of the relays using fuzzy logic approach is a reasonable way to reduce the uncertainty in decision-making. When fuzzy criteria are used for the relays their outputs are continuous logic values between 0 and 1. These 0 and 1 outputs correspond to decisions of the relay, “To Trip” and “To Block”, respectively. The fuzzy logic approach has been used in this paper to model the DIFP and REF relays [11].

To enhance the stability against CT saturation at heavy external faults, a directional check unit, DCU, is proposed. Its main duty is comparing the currents in two sides of the power transformer. An operation is only allowed if these currents are at least 160° apart. Fig. 1 shows the angle for an internal and an external two phase to ground ABG fault type.

Table 1 illustrates phase angle difference measured by DCU in some external faults combined with CT saturation. This table shows four samples of the phase angle difference from the

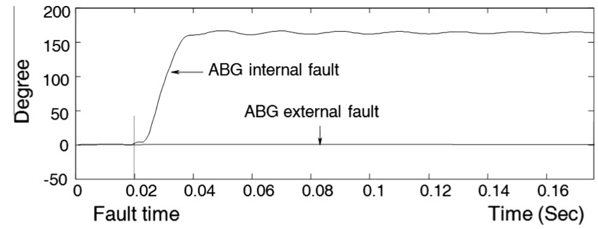


**Fig. 1.** Phase angle difference for ABG internal and external faults.

beginning of CT saturation. All faults are occurred at $t = 20$ ms. The maximum value of phase angle difference is shown in the last column. The maximum value is 48.34° in phase B for ABCG fault. In the AG fault, only the CT in phase B is saturated (Phase B saturation is due to the $Y/\Delta$ connection of the power transformer winding) and its saturation time is $t = 38$ ms. Therefore, the angle values only for phase B are shown in this table.

In addition to DIFP and REF relays, the DCU has also been modeled using fuzzy logic. The output of fuzzified relays are $P_{DIFP}, P_{REF}$ and $P_{DCU}$ that fall between “0” and “1”.

## Initial evaluation of various disturbances

In the proposed IPTP relay, decision making is made by the DIFP, REF and, DCU relays. These three relays are considered as the main relays in the proposed IPTP relay. Before making any decision by the main relays, an initial evaluation about the occurred disturbance is done by the three main relays as well as three auxiliary units. The auxiliary units are earth fault (EF) relay, inrush check unit (ICU) and external fault detector (EFD). These auxiliary units are only used for initial evaluation of the disturbance and are not directly involved in the final decision. In general, the proposed IPTP relay includes two stages. First, initial evaluation by the both main relays and auxiliary units and second, making the final decision by the only main relays. After the initial evaluation, three weighting factors are chosen and applied to the output of the main relays to make the final decision.

The weighting factors are usually determined based on the main relays historical operations. In other word, based on the historical operations of the relays in encountering with different disturbances it will be find out that which one of the main relays has had more number of successful operations for a specific disturbance. Let consider an inrush current as the disturbance. According to the relays historical operations the REF relay has had a high number of successfull operations in inrush conditions. The next number of successfull operations is related to the DIFP relay. Therefore, the higher weighting factor is chosen for the relay with the higher number of successfull operations. For example, for 10 times inrush current cases if the REF and DIFP relays have 8 times and 5 times successfull operations, then, the REF and DIFP weighting factors could be chosen as 0.8 and 0.5, respectively. The weighting factors shown in Table 2 are based on the historical operations of the relays for five different disturbances.

After initial evaluation of the disturbance the appropriate weighting factors related to the occurred disturbance are chosen. Initial evaluations of different disturbances are presented in the following.

### *Earth fault*

The EF relay is used to detect and evaluate all internal and external earth faults. This relay continuously measures the neutral current of the power transformer.