A Novel Methodology to Sense CT Saturation Using Numerical Protection Relays

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Abstract:- The necessity for dependability and safety in power system is rising at an alarming rate as the power system designs are getting more & more complex. In order to ensure maximum reliability, the numerical protection relays must receive accurate measurements. One of the most important input measurements desired by the relay is current. Nevertheless, the current measurements expected from current transformers (CTs) can be inaccurate due to occurrence of a phenomenon called as CT saturation. CT saturation causes distortion in the secondary current, which is not linearly proportional to the primary current, leading to mal-operation of protection devices. Therefore it becomes extremely vital that the numerical protection relay, also known as intelligent electronic device (IED) senses the CT saturation condition and blocks its operation so as to avoid mal-operation of the IED which may lead to supply interruption, further resulting in production losses and undesirable switching of the sensitive equipments affecting system reliability and customer satisfaction. This paper includes a review of the background about CTs & proposes a novel methodology to exclusively sense the CT saturation using the numerical protection relays reliably and cost effectively.

Keywords:- *IED, CT Saturation, Fast Fourier Transform (FFT).*

I. INTRODUCTION

The necessity for dependability and safety in power system is increasing at an alarming rate as the power system designs are getting more & more complex. The measurements from Current transformers (CTs) are one of the mainly significant constituents on which, working of a numerical protection relay is based. It is important that CT measurements are as accurate as possible as they are inputs for any protection function. However, fault currents of higher magnitude than the rated current of the CT frequently account for the distortion in the secondary side of the CT due to CT saturation. Distorted currents lead to inaccuracies in current measurement, resulting in mal-operation of protection relays [1]. Several methods have been developed to sense CT saturation phenomena. Majority of the methods are based on the protection function they are linked with. However, some degree of work has been carried out to bring up a standalone method to detect CT saturation using the CT measurements exclusively.

This paper proposes a novel methodology to detect CT saturation based on measurements taken solely from the current. Thus, the algorithm developed is completely independent of the type of protection function. To begin with, numerous existing methodologies to detect CT saturation have been studied and compared. The aim here is to develop an algorithm for CT saturation detection in an IED using combination of existing techniques and some new approaches to eliminate the limitations of the existing techniques. Thus, CT saturation can be sensed in a reliable and cost effective manner.

II. LITERATURE REVIEW

Many researchers have tried to sense CT saturation using diverse approaches. In practical applications, many relay manufacturers calculate harmonic content of the wave to detect CT saturation. A shortcoming here is that it needs minimum one cycle to detect CT saturation [8]. This technique is however vulnerable to detection around injection points.

Most algorithms detecting CT saturation are based on the associated protection function. For eg, differential-restraining curves in the operating region of differential current v/s restrain current are used to sense the CT saturation during external faults in differential protection [9]. One of the methodologies uses a cosine-peak adaptive filter with instantaneous overcurrent protection. This logic consists of a cosine filter with a peak detector. The transition from cosine filter to peak detector occurs when current distortion exceeds a set threshold level. Current distortion is found by comparing ratio of 2nd and 3rd harmonics to the fundamental component of current [3]. An innate shortcoming of the technique is that the threshold value needs to be cautiously set for precise operation of the algorithm. Another techniques makes use of diverse current magnitudes including differential currents, incoming and outgoing current etc. to recompense for CT saturation in busbar differential protection [10][12]. [11][13] use the verity that current waveforms change drastically during CT saturation, when compared to normal operation. This algorithm compares behavior of current wave with predefined constants and detects CT saturation.

[14] detects CT saturation using 3rd difference of the current. A benefit of this technique is being stand alone in nature, not requiring much of a information except the secondary current samples. But disadvantage is the sensitivity to noise and the need to carefully configure the threshold limit. [15] combines 2nd difference calculation and zero crossing detection to find the detection point of

CT saturation. ANN senses the CT saturation in [16]. In [17], a method is proposed using Euclidean distances to sense CT saturation.

III. BACKGROUND

A. Current Transformers (CTs)

Current transformer is used to reduce a high level current to a low level current of the power system to a magnitude which can be sensed by relays. Thus, CTs are the key equipments to measure the line currents where it is connected. A current transformer, as an instrument transformer is having the same principle of power transformer. It consists of primary and secondary winding. A current transformer is designed to produce the secondary current, which is proportional to the primary alternating current. While the alternating current flows through the CT, an alternating magnetic flux is produced.

For an ideal CT,

$$\frac{Ip}{Is} = \frac{Ns}{Np} = n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,
Ip = current flowing in primary
Is = current flowing in secondary
Np = number of turns on primary. In numerous cases, Np=1
Ns = number of turns on secondary

The primary side of CT is connected in series with network to measure the current flowing in network. This means that primary and secondary currents are not affected by secondary burden [2]. This helps in using a current source while making an equivalent CT circuit. However, not all current passes from the primary to the secondary side. Some current is consumed by the CT core. The CT core has active and reactive power losses represented by resistance, Rm and reactance, Xe of the core respectively. Fig. 1 shows a equivalent CT circuit diagram with core components included, where R´p and X´p is the primary winding resistance and reactance respectively referred to the secondary side. Rs and Xs is the secondary winding resistance and reactance respectively. Rb is secondary connected resistive burden.

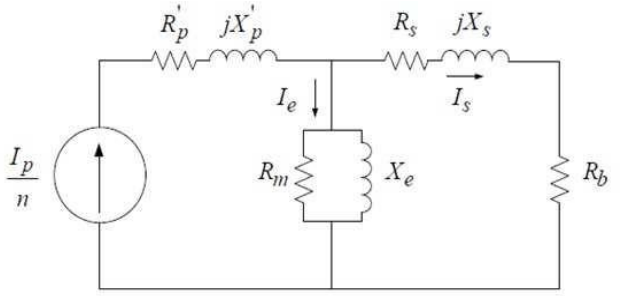

Fig. 1. Equivalent CT circuit referred to secondary side

The current passing through the CT core is exciting current Ie, which includes real and imaginary parts. Consequently, errors get introduced and tend to appear both in the phase and amplitude of the secondary current. Ratio error is the error in amplitude of the secondary current, while phase error or phase displacement is the error in phase of the secondary current. These errors are relatively miniature and declared by CT manufacturers as well as standardized by IEEE and IEC as accuracy class [2].

B. CT Saturation

A CT is said to be saturated if the primary current is not authentically reproduced in the secondary side of transformer. Applying Kirchoff's current law to circuit in fig 1, we get,

$$Is = \frac{Ip}{n} - Ie \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

During standard operations, Ie is a tiny percentage of entire current. However, CT saturation leads to passage of high current from the core, thus increasing the Ie. This reduces the secondary current as per equation 2. During faults, the current magnitude is very high than rated CT current. The fault current might also have significant quantity of DC components, alongwith the remanent flux in CT [4]. All these factors add to CT saturation. Fig 2 displays a typical secondary current wave with saturation as recorded by a protection relay.

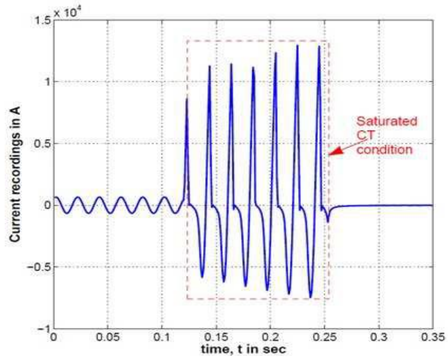

Fig. 2. Secondary side current recordings of CT from protection relay

IEC 61869-2 defines a few vital terms associated with CT saturation. It is essential to define them for a improved perceptive of CT saturation [5]. These are:

Saturation flux, ϕsat is the maximum value of secondary linked flux in a CT, corresponding to the magnetic saturation of the core material. Remnant flux, ϕr is the value of secondary linked flux which would remain in the core 3 min after the interruption of a magnetizing current of sufficient magnitude to induce saturation flux. Remanence factor, KR, expressed as a percentage, is the ratio of remnant flux to the saturation flux. Accuracy Limit Factor or ALF is the ratio of the value of primary current up to which the CT will comply with the requirements for composite errors to the rated primary current.

Various factors lead to CT saturation as well as influence time to saturation. These can be high remnant flux in the CT core, high primary current, high DC offset primary current, or high secondary burden [6].

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C. Power System Protection

The described CT behavior plays an vital responsibility in the performance of power system protection as it deals with the protection from unforeseen events which can create instabilities and physical damages in power system.

The protection system must fulfill basic necessities like reliability, selectivity, sensitivity and speed so as to successfully protect the system. A protection system is reliable only if, it operates all times whenever required. A protection system is selective, if it disconnects only the faulty element from healthy power system. Sensitivity is defined by how accurately the system responds to the change in parameters within power system, whereas speed is defined by the time the power system takes to respond whenever it detects a fault [7].

All the protection functions implemented by the IEDs need current input from CT. Thus, precise current measurement from CT has paramount importance. CTs are the most important equipments in a protection system as they perform three major operations in power system; metering, measurement and relaying. Metering is required for energy metering within the power system. Measurement is concerned with measuring current for monitoring purposes & alarming in case of any fault. Relaying is more associated with the numerical protection relays or IEDs. The secondary side current from a CT is used as an input to the relays. Therefore, it is tremendously vital that the secondary current from the CT is a excellent depiction of primary currents received by the CT. A saturated CT may compromise the reliability of power system protection as inaccurate current measurement values can be transferred from the secondary side to the IED. It is therefore required that CT saturation is sensed as early as possible so that the IED can act upon crucial alterations or amendments in the protection function.

In order to evade saturation, CTs can be over-sized, however, this can increase the expenditure and installation area requirement. A different approach is to operate the protection algorithm rapid enough so that tripping or blocking decision can be taken before the saturation phenomena occurs. However, this won't help in solving the trouble of mal-tripping, especially in case of differential protection, where tripping is not desired in the event of any external faults. Also, blocking is not desired in the event of internal faults. The CT also can saturate due to the external faults in differential protection resulting in mal-tripping.

IV. ALGORITHM

To study the harmonic contents in a saturated CT, a practical experiment was carried out. CT considered is a double ratio single core CT, the primary ratio considered for experiment was 30A accordingly the secondary connections was made. A numerical protection relay was connected at the secondary side of the CT. As per the manufacturing details of the CT will start to saturate or will go into temporary saturation only after the primary current of the CT exceeds 100A hence an momentary experimental current greater than 100A was passed through the CT and the harmonic content present in the CT secondary current was studied on Digital Storage Oscilloscope (DSO). The MATH function of DSO was enabled which directly analyze the harmonics content. Below are the observations & analysis:

- **CT is Unsaturated:** Current passed through the primary of the CT 30A; secondary waveform observed was pure sinusoidal. The harmonic analysis of the pure sine wave shows negligible presence of the harmonics.

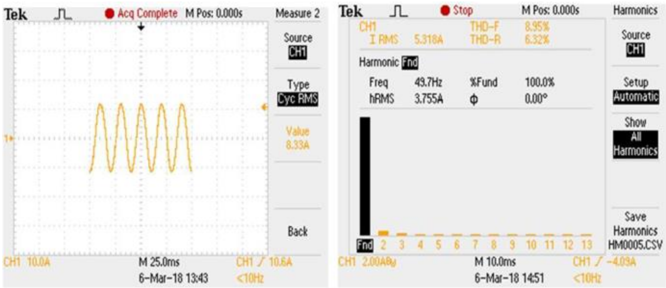

Fig. 3. Unsaturated CT Waveform

- **CT Saturation:** Current passed through the primary of the CT is 200A; secondary waveform observed was chopped. The harmonic analysis of the chopped waveform shows presence of the harmonics.

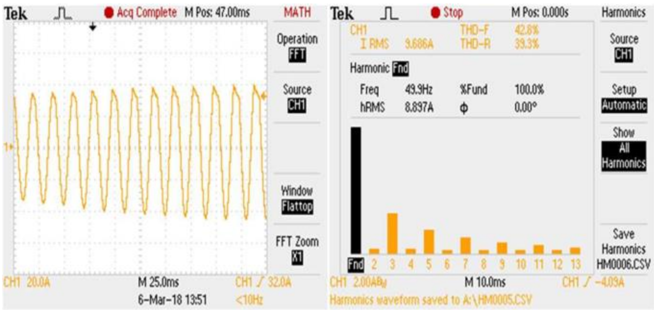

Fig. 4. Saturated CT Waveform

Looking at graphs, a conclusion as following can be drawn:

- The saturated waveform is rich in harmonics.
- Presence of the odd harmonics are predominant than even harmonics.
- Presence of 3rd harmonic is greater than 5th harmonics.

Presence of the odd harmonics is predominant can be justified as the saturation was a symmetrical saturation [reference].but in real life scenario the CT may have a symmetrical or asymmetrical saturation hence both even and odd harmonics needs to be taken in consideration while writing an CT saturation algorithm. Also, we cannot also ignore the fact that the 3rd harmonic in this case is predominant than 5th harmonic, so as in the method based on 2nd and 5th harmonic If we only consider 5th harmonic in CT saturation algorithm than there may be a case wherein the CT saturation has predominance of 3rd harmonic and the 5th harmonic is below the threshold value and the saturation may be left undetected.

Based on the practical experiment, it was concluded it is not preferable to consider only 2nd and 5th harmonic but to have a reliable and independent CT saturation detection algorithm total harmonic distortion (THD) needs to be considered.

V. ADVANTAGES

This algorithm can be used with any protection which requires to sense the CT saturation. Continuous work is being done so as to discover various ways to entirely make use of this design by combining it with diverse protection algorithms. This methodology can also be used with distance protection or differential protection to increase the reliability of these protection functions. An added attribute that can enhance the existing protection functions is to offer an alarm signal in case of CT saturation. This will definitely facilitate the end customer to come across the system for potential issues that could lead to CT saturation and help him in taking essential remedial measures.

VI. CONCLUSION

It can be concluded that this method is standalone as it considers only the CT secondary samples scaled to primary CT values and the rated CT as inputs. A natural benefit of this methodology is that it is not dependent on any particular harmonic, but considers the total harmonic distortion (THD). Since this algorithm has dependency on CT secondary current values and rated current only, it is feasible to use this methodology with any protection function. Furthermore, since the algorithm requires lesser inputs, the algorithm complexity gets abridged. This reduces the constraint in requisites of computing power. As the level of THD is greater the tripping time taken by the relay is lower. The algorithm powers the customer to enable / disable the protection & set threshold value depending on site conditions.

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