CT SATURATION SECONDARY WAVEFORM ANALYSIS

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ABSTRACT

Current transformers form an integral part of protective systems. Ideal Current Transformers (CTs) are expected to reproduce the primary current faithfully on the secondary side. Often, during fault conditions an important component of current is exponentially decaying DC offset current. Under such conditions the CT saturates, and hence it cannot reproduce the primary current faithfully. This paper comprises a study of the background about CTs and CT saturation and attempts to highlight the differences between symmetrical and asymmetrical saturation. When saturation occurs, the secondary current will not be linearly proportional to the primary current, which may lead to mal-operation of protection devices.

Keywords - *CT Saturation, Power system protection, harmonic, symmetrical and unsymmetrical fault*

1. INTRODUCTION

The faithful replication of fault current is an important requirement in relaying. Unless Current Transformer (CT) secondary replicates faithfully the fault current, relay's decision cannot be considered dependable, secure and accurate. This is particularly true for distance relaying or differential relaying schemes. For example, due to CT saturation, a distance relay may fail to detect the fault (lack of dependability) and a bus differential relay may operate on the external fault (lack of security). Thus, the relay should operate before the onset of CT saturation.

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2. LITERATURE SURVEY

Current transformer (CT) saturation is not a new topic, and there have been many papers, books, application guides, and tutorials written on the subject. Sorting through this vast array of information to piece together a complete understanding of the topic is a time-consuming task and may not be realistic with the schedules and demands placed on many practicing engineers. Because of this, engineers' level of understanding is often limited to the familiar CT excitation graph a consolidated information for practical answering of various questions like why CT saturates etc is available. [1] presents the transformer concepts that provide the fundamentals to understand the non-linear characteristics, accuracy ratings, and transient behavior of current transformers. The concept of CT and its modeling and knee point voltage concept can be understood from this paper [8]. The performance of current transformers(CTs) under the presence of geo-magnetically induced currents is analyzed [4]. Various standards and Guide for the Application of Current Transformers Used for Protective Relaying Purposes highlights the requirement of current transformers which are used in real world [2][9][12]. The analysis of some fault cases is discussed shows that the protective relaying will not operate, or will not operate properly, due to the saturated CTs [13]. Different protection schemes application like bus bar differential, line differential and transformer differential are shown and there CT requirement for proper operation of the protection function is discussed in [5][7][14]. Various tools available to analyze the CT secondary current such as MATHCAD, COMTRADE were studied [3].

3. CONCEPT OF CT SATURATION

CT saturation is a term used to describe the state where a CT is no longer able to reproduce an output current in proportional to its primary current or as per its ratio. The basic reason for CT saturation is due to number of reasons like large primary current, small DC current, high burden at the secondary and open circuit in the secondary.

The saturation is the concept related to property of magnetic materials used for the current transformer core. In usual the metering CT's core saturates for smaller multiples of the rated current. But protection and PS class CT's can be operated for a wide range of rated current. When the secondary induced EMF passes the level of knee point voltage (Vk) shown in fig. 1, the core goes for saturation. Measurement class CT's can't operate beyond the knee point, but the protection and PS class CT's can operate around the knee point depends on the class of CT.

Abnormal high magnitude primary current and high secondary burden these two results high flux density in the current transformer core. When the flux density reaches the designed limit of the core it results saturation. Fig.3 shows the result of saturation, the CT accuracy becomes poor, the secondary side output waveform becomes distorted; also the magnitude of secondary wave reduces due to core impedance.

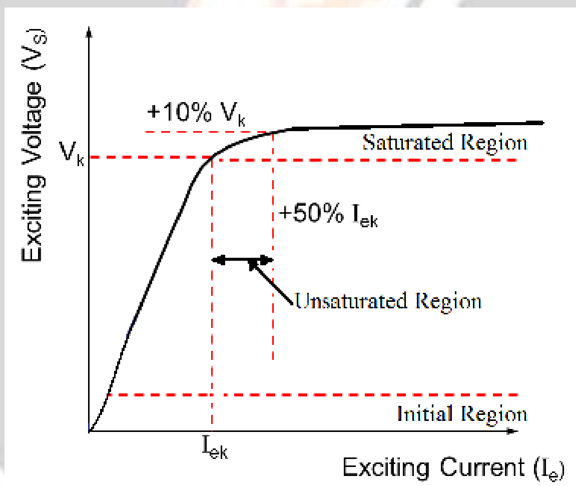

Fig -1 Secondary excitation curve representing knee-point

The fault current as seen by the current transformer primary winding is shown in fig. 2. CT saturation can occur in two forms: symmetrical saturation and asymmetrical saturation. These saturation types are explained in the following subsections.

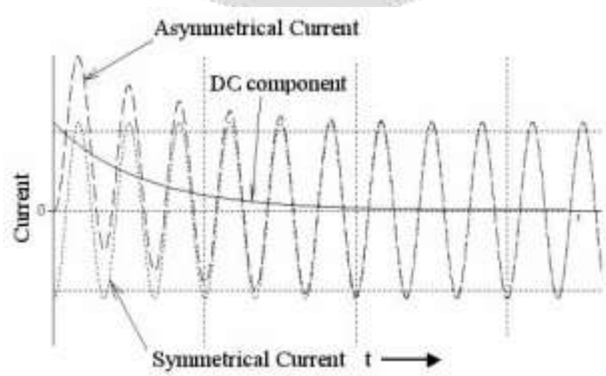

Fig -2 Fault current waveform

3.1 Symmetrical Saturation

Symmetrical saturation is the result of a symmetrical primary current being applied to the CT that is too large for the CT core to handle for a given burden. fig. 3 shows an example of the primary current (Ip) and secondary current (Is) of a CT during symmetrical saturation. Ideally, before the current is applied at Point *a*, the magnets in the core are aligned in random directions. Between Points *a* and *b*, as Ip starts to flow in the first positive half cycle, the magnets start to line up in the positive direction. Because there is a change in flux during this time, the current Is matches Ip exactly (assuming a CT ratio of 1:1). Before the positive half cycle is over, at Point *b*, all of the magnets available in the core are lined up in the positive direction, and the core has reached maximum flux density (saturation). At this point, even though Ip continues to flow, there is no more change in flux, Vs drops to zero, and Is drops to zero. Is stays at zero until Ip begins to flow in the negative direction, reversing the magnetic field. This negative flow, beginning at Point *c*, causes the magnets to begin aligning in the negative direction. This changing flux allows the generation of voltage Vs and allows Is to follow Ip again until all of the magnets are aligned in the negative direction at Point *d*. Because maximum flux density (saturation) has been reached again, Vs and Is again drop to zero. The example in fig. 3 shows the primary current decreasing in magnitude every cycle. The point of this is to show that if primary current magnitude decreases, the CT will have less saturation. The lower magnitude in the second cycle of fig. 3 generates a weaker magnetic field, requiring less flux density to replicate the current correctly. Because fewer magnets are used, Is reliably replicates Ip for a longer time until all the magnets are aligned. In the third cycle, the magnitude of Ip has been lowered to the point that the CT does not saturate and replicates current correctly.

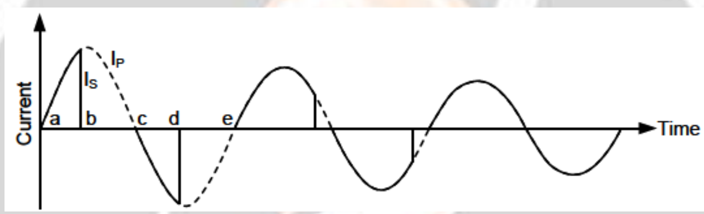

Fig -3 Primary and secondary currents, in the core during symmetrical saturation

3.2 Asymmetrical Saturation

The other form of saturation, asymmetrical saturation, results from high levels of dc offset in the primary sinusoidal current being applied to the CT. The current peaks are not symmetrical around zero. DC offset is when there is more area under the curve above the zero-crossing than there is below the zero-crossing (or vice versa). Fig. 4 shows how a waveform with high dc offset can cause a CT to quickly saturate. From points a to b, magnets are all lining up in the positive direction and the CT has not saturated. When Ip becomes negative, from Points b to c, magnets start changing directions and lining up in the negative direction. Because there is such a small amount of area under the curve between Points b and c, not very many of the magnets have lined up in the negative direction when the Ip current goes back above the zero crossing (Point c) and they are forced to start lining up in the positive direction again. Finally, at Point d, all of the available magnets are lined up in the positive direction and the core saturates. The dc offset—not the magnitude of the fault current itself—is what causes the saturation. The fact that Ip is not below the zero-crossing long enough to reset the magnets in the opposite direction is what causes saturation to occur. Notice that as the dc component decays, the CT starts to come out of saturation. A given CT can handle some maximum amount of flux before it saturates. This limit is defined by a symmetrical sine wave with a fixed voltage magnitude and fixed area under the curve in both the positive and negative directions. As long as the actual CT waveform does not exceed this positive or negative volt time area, the CT will not saturate. Consider the dc offset of the asymmetrical current in fig. 4. This dc offset will result in an accumulating positive volt-time area that eventually reaches the maximum that the CT can handle at Point d, where saturation occurs.

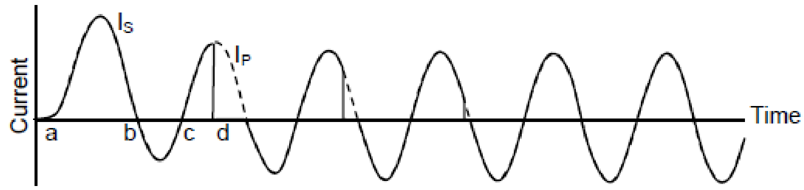

Fig -4 Primary and secondary currents in the core during asymmetrical saturation

The waveshape of secondary current IS during saturation also depends on the type of load connected. Fig.5 shows the waveshape with a purely resistive burden compared with a burden that has both resistive and reactive components of similar magnitudes. The difference in waveshape is because of the fact that current through an inductive load cannot change instantaneously, so it takes some time for the current to decay.

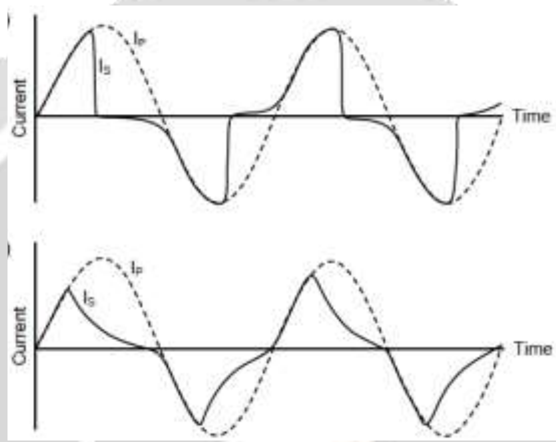

Fig -5 Saturated waveshapes for (a) resistive and (b) resistive-inductive loads

4. CONCLUSIONS

- There are two types of CT saturation: symmetrical saturation and asymmetrical saturation. Symmetrical saturation is caused by symmetrical fault currents high in magnitude, while asymmetrical saturation is caused by fault currents with dc offset.
- CT saturates faster in asymmetrical current than in symmetrical fault current.
- Connected load and burden affect the CT saturation characteristics. In case the burden is a mix of resistive and reactive component is more chopped than that of a pure resistive burden.
- When the CT secondary waveform when analyzed it can be characterized as a waveform which is chopped and rich in harmonics 3^{rd} and 5^{th} harmonics are predominant.

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6. REFERENCES

[1]. S.E. Zocholl, *Analyzing and Applying Current Transformers*, Schweitzer Engineering Laboratories, Inc., Pullman, WA, 2004.
[2]. IEEE Standard C37.110-2007, IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes.

[3]. D. Subedi and S. Pradhan, "Analyzing Current Transformers Saturation Characteristics for Different Connected Burden Using LabVIEW Data Acquisition Tool," *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, Vol. 9, Issue 10, 2015.

[4]. B. Kasztenny, N. Fischer, D. Taylor, T. Prakash, and J. Jalli, "Do CTs like DC? Performance of Current Transformers With Geomagnetically Induced Currents," proceedings of the 69th Annual Conference for Protective Relay Engineers, College Station, TX, April 2016.

[5]. M. Thompson and R. Folkers, "Secure Application of Transformer Differential Relays for Bus Protection," proceedings of the 58th Annual Conference for Protective Relay Engineers, College Station, TX, April 2005.

[6]. S. Hodder, B. Kasztenny, N. Fischer, and Y. Xia, "Low Second- Harmonic Content in Transformer Inrush Currents – Analysis and Practical Solutions for Protection Security," proceedings of the 67th Annual Conference for Protective Relay Engineers, College Station, TX, March 2014.

[7]. H. J. Altuve, N. Fischer, G. Benmouyal, and D. Finney, "Sizing Current Transformers for Line Protection Applications," proceedings of the 66th Annual Conference for Protective Relay Engineers, College Station, TX, April 2013.

[8]. S.E. Zocholl and D.W. Smaha, "Current Transformer Concepts," proceedings of the 46th Annual Georgia Tech Protective Relaying Conference, Atlanta, GA, April 1992.

[9]. IEEE Standard C57.13, IEEE Standard Requirements for Instrument Transformers.

[10]. Forest K. Harris, *Electrical Measurements*, John Wiley & Sons, Hoboken, NJ, 1952.

[11]. Ariana Hargrave, Michael J. Thompson, and Brad Heilman, Beyond the Knee Point: A Practical Guide to CT Saturation, 71st Annual Conference for Protective Relay Engineers (CPRE), 2018

[12]. IEEE Power System Relaying and Control Committee, "CT Saturation Theory and Calculator."

[13]. Pradeep Chawande, S.A. Soman, P.R. Apte & Shubha Pandit , "Experimental Evaluation of current transformer performance under saturation."