Performance of current transformer operate under harmonic condition and their effects on transformer differential protection

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Abstract. This paper focused to determine the performance of Current Transformer (CT) operates under harmonics condition and their effects on transformer differential protection. A laboratory test has been implemented to determine the error produced by both CT and power transformer when operating under harmonic condition. The test was performing with the actual condition, where the power transformer is connected to an adjusted nonlinear load, so that the test can be conducted with several levels of total harmonic distortion current (THD_i). The results shows, for THD_i ranging from 16.70% to 40.88% the maximum errors occurred on CT at secondary power transformers is 27.21% and CT at primary power transformers is 8.12%. This error resulted in differential current flow 0.17A and relay trip without any fault. In this study it was found that the relays started to operate incorrectly on THD_i 31.5%.

1. Introduction

The advanced technologies in power electronics development over the past decade, the application of power electronics in industrial, commercial, office building, educational institutions and residential areas have increase. Power electronic equipments are harmonic producing equipments due to its switching devices and called nonlinear load. Nonlinear loads are broadly classified as loads, which draw non-sinusoidal current even when the supply voltage is perfectly sinusoidal. Because of their extraordinary gains in efficiency and control, power electronics loads are expected to be significant in the future. Currently, power electronic loads can be found at all level of power system, ranging from low voltage appliances up to a high voltage converter. Non-linear load typically comprise more than 50%, and in some case as much as 90% of total building load [1]. Heavy use of power electronics equipment in the industrial, commercial and office building can lead to considerable harmonic distortions in the distribution feeder. The higher harmonic distortion level in the distribution system has caused a serious problem in power system quality and stability [2].

Increased the levels of harmonic currents in distribution systems, creating concern for electricity distribution network service providers will face malfunction of protection system components. Harmonics current and voltage can distort the operating characteristic of

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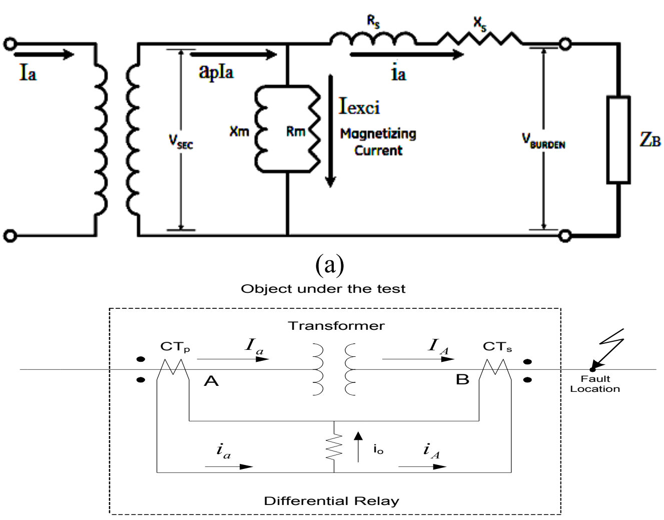
protective relays which is depending on the design features and principles operation of the relay [3]. During fault or normal conditions, the harmonic in distribution system might cause to miss operation of differential protection as well as relay calibrations inaccurate [4], [5], [6].

2. CT operates under harmonic condition

When a CT operates under harmonic condition, the distorted excitation current will flow in the excitation circuit, so that the secondary current produced by this CT will distorted as well. These phenomena will cause degradation of CT performance due to its core saturation. While CTs it self are constrained in their performance by the magnetic flux limitations of the core. Ferromagnetic materials cannot support infinite magnetic flux densities. High content of harmonic currents in power distribution systems will lead to the phenomenon of CTs saturation that can cause some errors in the operation of differential relays.

Two current transformers at both sides of protected equipment might not perform equally even when they are from the same brand, same ratio and type. The excitation current of both current transformer are also not identical due to remnant magnetic fluxes in the core may not identical. The different level saturation of both sides current transformers will affect to differential current, whether in normal condition or fault condition. The error signal produced by current transformer at both sides of protected equipment will cause to miss operation of differential relay.



(b)

Fig. 1. (a) Current transformer equivalent circuit , (b) Differential relay scheme for power transformer protection

Fig. 1 (a) shows current transformer equivalent circuit at primary side of power transformer (CT_p). The secondary current in the pilot wire of CT_p is equal to:

$$i_a = a_p I_a - I_{exci(p)} \quad (1)$$

where,
a_p is the transformation ratio of CT_p, I_a is line current at primary side of power transformer, $I_{exci(p)}$ is the excitation current of CT_p

For the current transformer at secondary side of power transformer (CT_s), the equation of secondary current in pilot wire of CT_s is equal to:

$$i_A = a_s I_A - I_{exci(s)} \qquad (2)$$

where,
a_s is the transformation ratio of CT_s, I_A is line current at secondary side of power transformer, $I_{exci(s)}$ is the excitation current of CT_s

Fig. 1 (b) shows single line diagram of a differential protection system under normal or external fault condition (no fault) [7]. It can be observed that the protection zone is delimited by a couple of CTs. Current entering the protected unit (I_a) would be equal to the current leaving protected unit (I_A). So the current i_a is equal to current i_A and differential current (i_d) is equal to zero (relay not operate). Assuming equal transformation ratios, a_p = a_s = a, the relay operation current i_o is given by:

$$i_o = i_a - i_A \qquad (3)$$

During normal system operation, subtitute (1) and (2) into (3):

$$i_o = -I_{exci(p)} + I_{exci(s)} \qquad (4)$$

The differential relay should not operate for this differential current.

For internal fault,

$$i_o = i_a + i_A \qquad (5)$$

Subtitute (1) and (2) into (5) :

$$i_o = a(I_a + I_A) - I_{exci(p)} - I_{exci(s)}) \qquad (6)$$

The differential relay must operate for this differential current.

3. Experimental results and discussion

Current Transformer Data:

Ratio	:15/1A	Acc.Class	:1
Rated Burden	: 5VA	Frequency	:50/60Hz
Voltage	: 0.72/3.0kV	Type	: SES

Fig. 2 shows experimental result of a CT by directly connected to system with 15.2 A line current. The secondary current error is 5.3% for THD_i 20%. As for the THD_i increased to 30% and 40% the secondary current deviations increase to 13.5% and 21.7% respectively. This clearly indicates that, the errors occur at the secondary side of CT as a result from the harmonics at the primary side of CT.

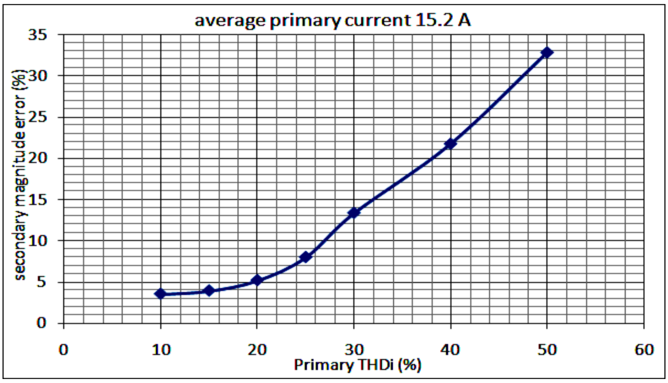


Fig. 2. Primary THD_i vs secondary current error for THD_i 10% to 50%

3.1 Performance of CT at primary side of power transformer

Table 1 (left side) shows the relationship between secondary current error of CT_p and THD_i at primary side of power transformer. The primary current of power transformer was remain constant at 15.2 A. In this experiment, CT_p has been connected to the primary sides of power transformer. The THD_i at primary side of power transformer increased from 16.7% until 32%. When THD_i at primary side increased until 32% the secondary current error occurs is 20.58%.

3.2 Performance of CT at secondary side of power transformer

Table 1 (right side) shows the relationship between secondary current error of CT_s and THD_i at secondary side of power transformer. The secondary current of power transformer was remain constant at 8.8 A. In this experiment, CT has been connected to the secondary sides of power transformer. The THD_i at secondary side of power transformer increased from 31.55% until 69.67%. With increasing of THD_i will cause to reduce the secondary current produced by current transformer. As THD_i at primary side of CT_s increased until 69.67% the secondary current error occurs is 55.77%.

Table 1. Percentage of CT_P and CT_S secondary current error

CT at primary transformer		CT at secondary transformer	
THD_i (%)	**Secondary current error (%)**	**THD_i(%)**	**Secondary current error (%)**
16.70	5.50	31.55	17.13
19.62	8.12	40.88	27.21
23.40	12.13	51.72	37.40
27.50	16.24	59.52	46.14
32.00	20.58	69.67	55.77

3.3 Effect to Differential Protection operation

Fig. 3 shows the characteristics of bias differential relay operate at purely sinusoidal. Without harmonics conditions, the internal fault operating point are in operation region, so the differential relay will trip. As for the external fault, the operating point of differential relay at restraining region, so the differential relay will not trip. At no fault conditions, current flow through operating coil is 0.006A and the operating point of differential relay is inside restrain region. So, it means the differential relay operates correctly.

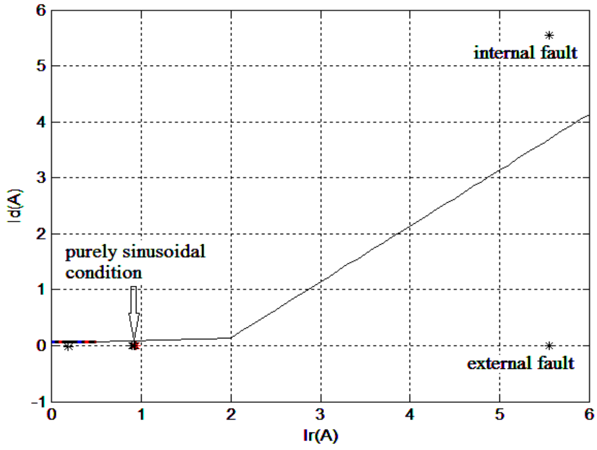


Fig. 3. Characteristics of biased differential relay operate under purely sinusoidal condition

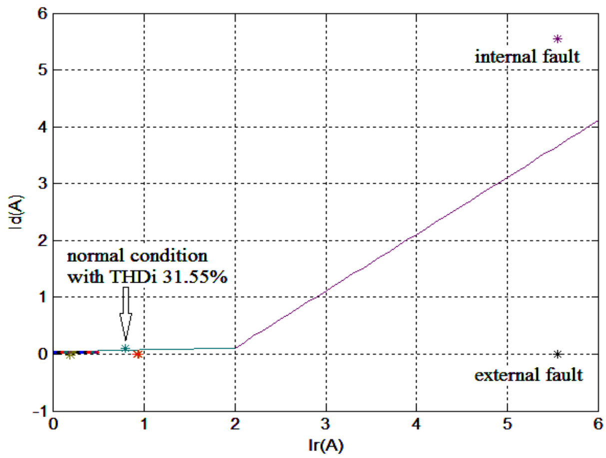


Fig. 4. Characteristics biased differential relay for normal condition with THD_i 31.55%

Fig. 4 shows the operating point of a differential relay at several conditions such as internal fault, external fault and normal condition. For internal fault that occurs at THD_i of 31.55%, the differential relay operating point is at operating region. As for external fault that occurs for THD_i of 31.55%, the differential relay operating point is at restraining region. These shows that the differential relays operate normally. However, when no fault occurs and the differential relay operates in harmonic condition for THD_i of 31.55%, the differential current flow is 0.109A. At this condition the operating point of the differential relay has been moved to the operating region. That means, the differential relay will trip at no fault condition (malfunction). This is something not allowed for the differential relay protection because the relay trip without any internal fault. At normal condition and THD_i 40.88%, differential current flow is 0.176A. The operating point of differential relay has been moved to operation region and then the differential relay will operate as shown in Fig. 5. It is evident that, this relay operate is caused by harmonics.

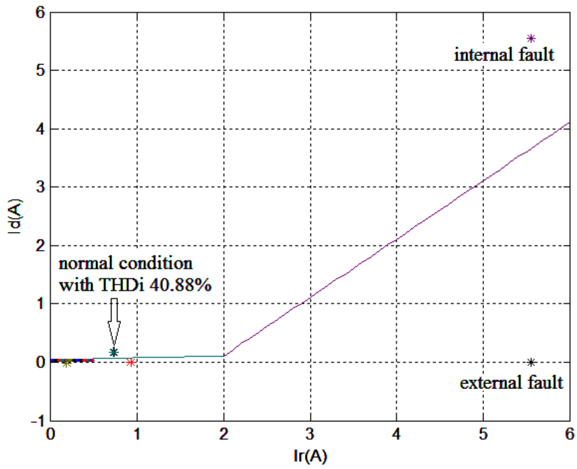


Fig. 5. Characteristics biased differential relay for normal condition with THD_i 40.88%

4. Conclusion

From the research that has been carried out can be concluded that an increasing of percentage THD_i in power system will increase the magnitude of current errors that occur on the secondary side of the CT. When THD_i at primary side power transformer increased until 32% the secondary currents errors on CT_p is 20.58% and if the THD_i on the secondary side power transformer rises to 40.88%, a secondary currents error on CT_s is 27.21%. This will result in reading error by the relay that connected to the CT. For THD_i at load side of power transformer of 31.55% and 40.88% and without an internal fault the differential current flow is 0.109A and 0.17A respectively which causes the relay to operate.

References

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