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The Restricted Earth Fault Relay Operation: Impact of Current Transformer Knee Point Voltages

Udoh, Benjamin E.
Department of Electrical/Electronic Engineering Federal Polytechnic Mubi Adamawa State, Nigeria

ABSTRACT
In this paper, the characteristic of current transformer (CT) magnetization curves are used to determine the performance of restricted earth fault (REF) relays. This study was carried out at the150MVA 330/132/33kV Gombe transmission substation. This is based on the field data obtained for the neutral current transformers (NCTs) servicing the 150 MVA 330/132/33kV and 15MVA 132/33kV power transformers at the substation. From the study, the knee-point voltages from the CT magnetization curves justify the voltage settings of the restricted earth fault relays.

Keywords: *Magnetization curve, Neutral current transformer, Restricted earth fault*

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I. INTRODUCTION

The magnetization currents of current transformers usually affect the overall setting of a protection system. The effect may not be significant in the case of over current relays, but the effect can be seen in earth fault relays and unit protection systems where large number of current transformers are connected together. Because of the low setting of the restricted earth fault (REF) scheme the effect of current transformer (CT) magnetization current is easily pronounced in the operation of its relays [1]. It is a well known fact that CT core saturation is brought about by CT magnetization current on application of a voltage, when such voltage exceeds its knee point value. Hence when considering the performance to be expected from a given CT, the exciting current can be measured at various values of EMF. For this reason it is usually more convenient to apply a varying voltage to the secondary winding, the primary winding being open circuited. Fig. 1 shows a typical relationship. The point K on the curve is called the 'Knee Point', and is defined as the point in which an increase of 10% in the exciting voltage of rated frequency produces an increase of 50% in the exciting current [2]. From the curve in Fig. 1 point 'A' is known as the Ankle Point and the linear portion of the curve is between points 'A' and 'K'.

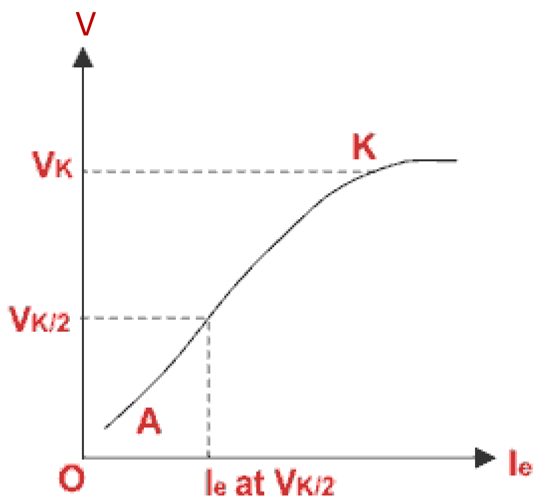

Figure 1: Typical CT Magnetization Curve

The restricted earth fault (REF) protection scheme refers to the differential protection of transformers against ground (earth) fault. It is called "restricted" because its zone of protection is limited only to the windings of the transformer. The restricted earth fault protection scheme is designed to take care of internal earth fault on transformer windings, which if omitted could cause the windings of such transformer to be damaged in the event of such fault. Since power transformers are one of the most important and most expensive components of transmission and distribution networks, it is very essential to prevent a scenario where this piece of equipment is being put out of service. If such an event occurs, the implication will be long period of power outage which according to [3] will generate unpleasant situations such as property loss and business disruption leading to loss orders, damaged to perishable goods and inventories for businesses. Since the issue of lack of adequate restricted earth fault for power transformer protection cannot be compromised, the REF relay must be made to operate satisfactorily by ensuring adequate setting of the relay voltage. The relay voltage must be made to fall within the linear portion of the CT magnetization curves for proper operation of the relays. In this regard, [4] pointed out that to ensure satisfactory operation of the restricted earth fault relay under internal fault conditions, the CT knee point voltage should not be less than twice the relay voltage setting. The relay will never operate with the required speed if the knee point voltage is just in excess of the relay voltage setting and not double the value at least [5]. The CT will normally transform the fault current of the electrical power system for operation of the protection relays connected to the secondary of that CT. If the core of the CT becomes saturated at a lower value of primary current, as in the case of metering CTs, the system fault will not reflect properly to the secondary terminals, which may cause the relays to remain inoperative even when the fault level of the power system is large enough. That is why the core of the protection CT is made in such a way that the saturation level of that core must be high enough, but still with a limit that is not too high otherwise, total transformation of primary current during huge fault may badly damage the protection relays.

The restricted earth fault (REF) protection schemes are particularly noted for their high speed of operation; hence they are readily applied in the protection of high voltage systems where fast fault clearing is a premium. This is made possible by the use of an instantaneous attracted armature type of relay. An internal earth fault within a transformer could cause serious damage to the system and this has to be cleared instantaneously [6]. Also high speed fault clearing is particularly beneficial for faults near large concentrations of generation and long intertie lines to remote sources of generation. This is so because fault causes strong angular acceleration to nearby generators, which in turn causes a reduction in plant output due to voltage suppression during fault [7]. Hence the knee point voltages of CTs servicing the REF relays protecting high voltage power transformers should be of higher values, which must be multiples of the relay voltage setting and must be carefully chosen so that the relay could function adequately in clearing its fault speedily. With high speed protection, it is desirable that the transformer should not saturate when carrying maximum current caused by a fault at the critical point of measurement. Where this is not possible, saturation would cause a reduction in the secondary current and therefore reduces the reach of the instantaneous relay [8].

II. RESEARCH METHOD AND ANALYSIS

The magnetization data for this study were obtained from the record of injection tests of the neutral current transformers (NCTs) servicing the two 150MVA 330/132/33kV and the two 15MVA 132/33kV power transformer at the substation under study. The data are presented in Tables (1) to (4). They were analyzed using an engineering software programme known as Micro cal – Origin 5.0 adapted for power system simulation.

2.1 Data Analysis

The principle of the high impedance (REF) scheme is applied, and to do so the following assumptions are made.

1. One current transformer (or set of it) completely saturates and ceases to transform any part of the primary fault current since its excitation impedance is negligible.
2. The whole of the primary fault current is perfectly transformed by the remaining current transformers.
3. The resistance of the secondary winding of the saturated current transformer together with the leads connecting it constitutes the only burden in parallel with the relay.

Consistent with the above assumptions, the maximum voltage across the relay is calculated using:

$$V_R = I_f\,(R_{CT} + 2R_L) \qquad (1)$$

Where:

I_f = Maximum through fault secondary current

R_{CT} = CT secondary winding resistance

R_L = Maximum lead resistance from CT to the relay circuit terminals

In order to ensure satisfactory operations of the relay under internal fault conditions the CT knee point voltage should not be less than twice the relay voltage setting, thus:

$$V_K = 2V_R \qquad (2)$$

Where: V_R = Relay voltage setting

The values of the knee point voltages are shown in Table 7 under the column "Calculated Value".

III. RESULTS AND DISCUSSIONS

Table 7 shows the relay voltage settings for the various power transformers and their corresponding knee point voltages based on equation (2). The Table shows the calculated and the actual values at the substation. The actual values are the minimum allowable setting values of the relays, in which case the values could be increased to meet the local condition to which the relays are operational. For example, the actual value of knee point voltage of 200V for the relay voltage setting of 100V as against 40V for the relay voltage of 20V (calculated value) with respect to the 330/132/33kV power transformers is practically chosen by the substation under study, as a means of preventing system mal-operation when fault occur outside the protected zone. This observation is in order because one of the benefits of the high impedance restricted earth fault relay operation, is the ability for the system to maintain stability when the voltage setting of the relay is greater than the maximum voltage which can appear under a given through fault condition [9, 10].

Figs. 2 to 5 give the magnetization curves for the neutral current transformers servicing the REF relays at the substation. The curves give a true picture of the magnetization characteristics from which the knee point voltages are estimated. From the magnetization curve of Fig. 2, the knee point voltage is about 450V as against the calculated value of 200V in Table 7. This knee point voltage of 450V estimated from the curve is a preferred value than the 200V calculated directly from equation (2), and gives a higher multiple of the 100V relay voltage setting. This shows that the performance of the neutral current transformer servicing the REF relay protecting the 150MVA 330/132/33kV power transformer is good because the 100V relay setting falls within the linear portion of the CT magnetization curve. From this it is quite certain that the neutral current transformer (NCT) will never get saturated in the event of any through fault condition or when there is an internal earth fault [8]. All the values of the neutral current transformers (NCTs) knee point voltages as estimated from the magnetization curves of Figs 2 to 5 are presented in Table 7. From the Table, the knee point voltage of the NCT servicing the REF relay protecting transformer T2A is lower than the rest. It is on record that the windings of that particular transformer were damaged some few years ago as a result of an inadequate restricted earth fault protection, which plunged the whole of the North East region into total darkness for a period of six (6) months. The whole set was replaced by the end of that year. It was the transformer failure that prompted this study.

It should be noted that the estimated values of the knee point voltages from the magnetization curves give the actual operational condition of the neutral current transformers (NCTs) at the substation. They also provide useful guides into the efficient operation of the REF relays in terms of speed [5]. On the other hand, the calculated values of the knee point voltages directly from the formula as presented in this paper are used as checks to determine the reliabilities of the estimated values from the curves. They do not describe the operating condition of the NCTs.

IV. CONCLUSION

The operational abilities of relays are sometimes affected by the magnetization characteristics of the CTs servicing such relays. In this study, the knee point voltages that were determined from the magnetization characteristics of the neutral current transformers have been found to be quite adequate in guaranteeing effective operation of the restricted earth fault relays. This is so because the neutral current transformers have favourable linear portion in their magnetization characteristics, which is a necessary requirement in the proper operation of the relays, especially when it has to do with high voltage power systems. From the observation made in this study, it will be safe to recommend that NCTs with high value knee point voltages should always be used to service REF relays protecting high voltage power systems.

Table 1: Magnetization Data for T1A 150MVA 330/132/33kV Transformer NCT

Neutral REF CT	**Slated Voltage (V)**	50	100	150	200	220	240	260
	Neutral Current (mA)	1.82	3.00	4.00	5.00	5.20	5.50	6.00

Table 2: Magnetization Data for T2A 150MVA 330/132/33kV Transformer NCT

Neutral REF CT	**Slated Voltage (V)**	50	100	150	200	220	240	260
	Neutral Current (mA)	1.75	2.50	3.25	4.25	4.50	5.00	5.50

Table 3: Magnetization Data for T1 15MVA 132/33kV Transformer NCT

Neutral REF CT	**Slated Voltage (V)**	50	100	150	200	220	233
	Neutral Current (mA)	4.00	7.00	9.75	12.25	13.25	14.00

Table 4: Magnetization Data for T2 15MVA 132/33kV Transformer NCT

Neutral REF CT	**Slated Voltage (V)**	50	100	150	200	220	233
	Neutral Current (mA)	5.00	9.00	12.75	16.00	17.40	18.30

Table 5: 150MVA 330/132/33kV Power Transformer Data

Secondary winding resistance (R_{CT})	5.8 Ohms
Maximum lead resistance (R_L) from CT to the relay tapping point	0.54 Ohms
Percentage reactance (X)	11.53%
Current Transformer ratio	800/1A
Type: Star/Delta/Star	

Table 6: 15MVA 132/33kV Power Transformer Data

Secondary winding resistance (R_{CT})	2.3 Ohms
Maximum lead resistance (R_L) from CT to the relay tapping point	0.4 Ohms
Percentage reactance (X)	5.17%
Current Transformer ratio	600/1A
Type: Star/Delta	

Table 7: Results of NCTs Knee Point Voltages Associated with the Power Transformers

Power Transformer	**Calculated Value**		**Actual Value**		**NCT Knee Point Voltage From Curve (V)**
	REF Relay Voltage (V)	**Knee Point Voltage (V)**	**REF Relay Voltage (V)**	**Knee Point Voltage (V)**	
T1A	20	40	100	200	450
T2A	20	40	100	200	280
T1	15	30	-	-	400
T2	15	30	-	-	480

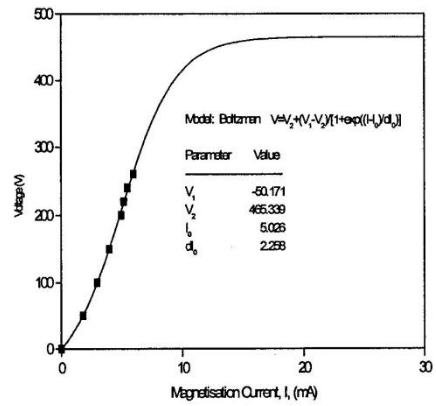

Figure 2: Magnetization curve for neutral CT of transformer T1A

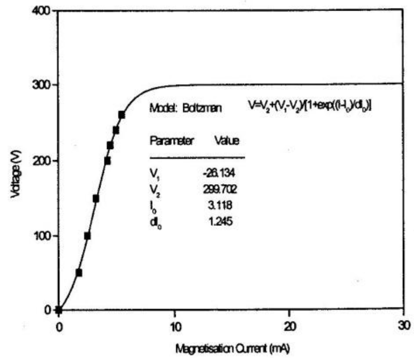

Figure 3: Magnetization curve for neutral CT of transformer T2A

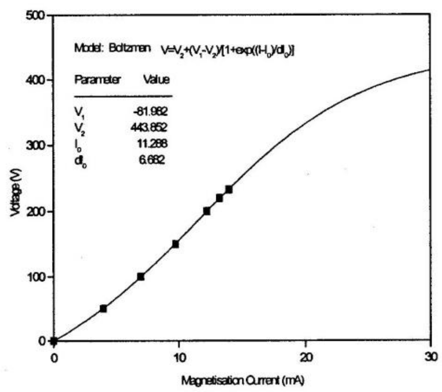

Figure 4: Magnetization curve for neutral CT of transformer T1

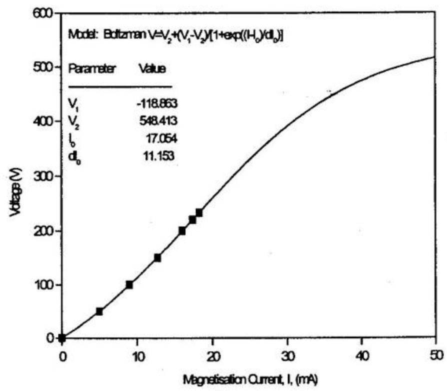

Figure 5: Magnetization curve for neutral CT of transformer T2

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