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EVALUATING PROTECTIVE SYSTEM'S RELIABILITY USING CURRENT TRANSFORMER BURDEN RATING

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ABSTRACT

Protective systems play vital roles in electricity supply and reliability; therefore, the protective system's performance/reliability should be evaluated to ensure the safety of the power system. A valuable method of evaluating this system's reliability is by the use of the burden rating of current transformers (CT) as they are found in almost all protective system as the first contact point between the power system and the protective system. By comparing the performance of four CTs (of different rating) feeding four different burden ratings with the same source/fault current (of 10,000A) with a program developed in MATLAB, the results show that the voltage required for driving the relay is independent of the relay rating but it is directly proportional to the connected burden on the CT. A 1200/5 CT when used with relays with ratings of C100, C200, C300 and C400 each posing an initial burden of 1.09Ω on the CT all require a driving voltage of 45.42V. As the burden begins to increase, the voltage required to drive the relay increases also to 50.07V, 104.10V, 153.80V and 206.10V for the respective relays. Hence, as the burden is increased, the required voltage to drive the relay also increases until it gets to the point where the current transformer saturates. This increase in the required voltage to drive the relay (that initiates tripping of circuit breakers/alarms and other protective gargets) reduces the sensitivity of the protective system thereby reducing its efficiency and reliability.

1. INTRODUCTION

Protecting power systems cannot be overemphasized as the system is prone to fault occurrences which may damage equipment the system is feeding power and even personnel operating the power system. Hence, a lot is being done and more research activities are still going on in trying to improve the existing protective mechanism. The major components of any power system protective system are the CTs (current transformers), PTs (potential transformers), relays, and CBs (circuit breakers). Proper operations of these components ensure the reliability and security of the power systems.

The reliability of protective systems can be enumerated by the sensitivity and probability of sending trip signal of a protective relay when the actuating signal gets to the predetermined value. This method is quite suitable as the relay is one of the most functional parts of any protective systems; however, when these relays are energized with actuating signals with some degrees of errors, the protective system reliability evaluation may not be free of errors; (Yip et al., 1984).

The use of fault tree analysis is another vital tool in evaluating protective system reliability; here, the contingency screening is conducted in the first step; the results are further classified into three clusters: normal, local trouble and system trouble in the second step. The fault-tree analysis is used to assess the reliability of the composite system in the third step. Lastly, Risk Reduction Worth is adopted as a measure of importance for identifying the crucial element that has significant impact on the reliability; (Singh and Patton, 1980); (McCalley and Weihui, 1999); (Ying and Lun, 2009). The use of a thorough, node-by-node top down analysis procedure inevitably led to logical loops arising from the highly interconnected nature of the system. These loops were not always obvious since they could involve very complex paths through the network. Another shortcoming of the method is that the fault tree analysis implies the use of routes throughout the network which will not be useable in practice. Lastly, the protective system components have no practical probability of success or failure values; they only have theoretical or assumed reliability data; hence, this method may not be practically correct.

Of all these components, the CT (or PT) is almost the first point of contact between the power system and the protective system; hence, its accurate operation goes a long way in determining the accuracy of the entire protective system. The CT is very prone to errors ranging from turn ratio errors (caused by inequality of transformation or actual turn ratio), resistivity and temperature coefficient of coils of the CT, and of the CT burden (which is the external load applied to the secondary of the CT); (Sawhney, 2008). Factors deciding the CT's accurate operations are much as compared to other components that make up the protective system (especially the relay where much emphasis is dwelt on). Hence, with all things being equal, the reliability of the CT is approximately equal to the reliability of the system; hence, evaluating the CT's reliability gives a closer evaluation of the complete system's reliability.

In this paper, the reliability of the protective system in a power system shall be analyzed in terms of the accuracy of the CT performance using the CT's burden rating. We shall see how the accuracy or reliability of the protective system is affected when the burden is changing with the fault current kept constant. The term burden is applied to the total external load connected to the terminals of a current transformer. Manufacturers' publications give the burdens of individual relays, meters, etc., from which, together with the resistance of interconnecting leads, the total CT burden can be calculated.

2. MATERIALS AND METHODS

The method used for this work will be mathematical modelling and simulations in MATLAB. The materials used in the work include CTs and relays of different ratings and MATLAB R2007b simulation software. A program developed in MATLAB was designed to operate on the principle that current transformers will not saturate if the relay rating of the current transformer is 2 times the voltage necessary to drive the maximum fault current through the burden connected. The program will determine for different current transformers the

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maximum required voltage to drive the relay for saturation to occur. This value is arrived at by increasing the value of the initial connected burden by 5% for a particular fault current; 10,000A was used for this study. This increment continues for as long as the condition – relay rating ≥ 2 times required voltage that will drive the relay – is satisfied. The program comes to an end when it has gotten to a point where saturation will begin. The burden at this point (saturation) and the corresponding voltage is given.

2.1 Effects of System X/R Ratio on CT's Saturation

CT performance is affected significantly by the dc component of the ac current. When a current change occurs in the primary ac system, one or more of the three-phase currents may contain some dc offset. This DC offset forms the necessity to satisfy two conflicting requirements that may occur:

(1) In a highly inductive network, the current wave must be near maximum when the voltage is at or near zero

(2) The actual current at the time of the change, which is determined by the prior networks conditions; (Al-Abbas, 2006).

During asymmetrical faults, the fault current I_f can be represented by two parts – the DC and AC components as follows:

$$I_f = I_{dc} + I_{ac} \tag{1}$$

The total fault current, I_f^T can be expressed as

$$I_f^T = \frac{V}{Z_b} = I_F\left[e^{-\frac{R}{L}t} - \cos\omega t\right] \tag{2}$$

Where I_F is the asymmetric fault current; Z_b is the burden impedance, and $R\ and\ L$ are resistance and inductance of the CT coil respectively.

The burden voltage can be expressed as follows

$$V = I_F Z_b\left[e^{-\frac{R}{L}t} - \cos\omega t\right] \tag{3}$$

However, V is related to the core turn N and the rate of change of the core flux by the induction as:

$$V = N\frac{d\varphi}{dt} \tag{4}$$

Therefore, the flux linkages in the core are given by the integral of Equation (4) where the flux is expressed as flux density B times the core cross sectional area A (Connor et al., 1975; Kojovic, 2002).

$$\varphi \mathrm{N} = \mathrm{B.A.N} = \int_0^t V.dt \tag{5}$$

Using the asymmetrical burden voltage Equation (3) and substituting in Equation (5), the limit of the resultant integral of the exponential term is the X/R ratio of the primary circuit. Since the limit integral of the cosine term is unity, we can write the equation as follows

$$B.N.\varphi.\mathrm{A} = \left|\frac{X}{R} + 1\right| I_F Z_b \tag{6}$$

Equation (6) expresses the C-rating voltage in terms of the physical parameters of the CT, namely the saturated flux density B, the turn ratio N, the core cross-sectional area A, and the system frequency f.

A different form of Equation (6) can be derived by recognizing that the rated voltage is 20 times the voltage across the standard burden at rated current; (Pascual et al., 2001). If we then express the fault current I_F as per unit of the rated current and the burden Z_b as per unit of the standard burden, Equation (6) becomes the simple IEEE Standard criterion to avoid saturation:

$$20 \geq \left|\frac{X}{R} + 1\right| i_f z_b \tag{7}$$

In the past, there has been an abiding interest in the application of current transformers for relaying, few written rules exist for selecting the ratings. To void AC saturation, the CT shall be applicable of a secondary saturation voltage

$$V_X \geq I_S Z_S \tag{8}$$

Current transformer secondary terminal voltage rating is the voltage that the current transformer will deliver to a standard burden at 20 times rated secondary current without exceeding 10% ratio correction (Zocholl et al., 1996), hence:

$$20 \geq i_f z_b \tag{9}$$

However, these rules result in impractically large current transformers most of the times, and they are not economically acceptable. This is true where small current transformers connected to a bus with high short circuit current that can exceed 200 times the current transformer primary current rating. IEEE Standard C37.110–1996 offers no guidance for other applications where those rules do not apply. High burdens, long leads (which also contribute to the total burden) and small cores etc leads to current transformer saturation; (Conroy et al., 1999).

3. RESULTS AND DISCUSSION

3.1. Simulation Results

A fault current (10,000A), initial connected burden (1.09Ω) and the increment of the burden (5%) were assumed to be the same for all cases the simulation.

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Table 1: Case 1 (Different CT ratings but the same relay rating)

CT Rating	Relay Rating	Initial Burden [Ω]	Initial Voltage [V]	Burden at Saturation [Ω]	Voltage at Saturation [V]	% Burden Increase
600/5	C200	1.09	90.83	1.20	100.15	10
1200/5	C200	1.09	45.42	2.50	104.10	129
1600/5	C200	1.09	34.06	3.35	104.62	207
2400/5	C200	1.09	22.71	4.95	103.05	354

Table 2: Case 2 (The same CT with different relay ratings)

CT Rating	Relay Rating	Initial Burden [Ω]	Initial Voltage [V]	Burden at Saturation [Ω]	Voltage at Saturation [V]	% Burden Increase
1200/5	C100	1.09	45.42	1.20	50.07	10
1200/5	C200	1.09	45.42	2.50	104.10	129
1200/5	C300	1.09	45.42	3.69	153.80	239
1200/5	C400	1.09	45.42	4.95	206.10	354

Table 3: Case 3 (Different CT ratings with different relay ratings).

CT Rating	Relay Rating	Initial Burden [Ω]	Initial Voltage [V]	Burden at Saturation [Ω]	Voltage at Saturation [V]	% Burden Increase
600/5	C200	1.09	90.83	1.20	100.14	10
1200/5	C100	1.09	45.42	1.20	50.07	10
1600/5	C300	1.09	34.06	4.95	154.58	354
2400/5	C400	1.09	22.71	9.79	204.03	798

3.1.1. Case 1

In this case, four current transformers with different CT ratings but the same relay ratings (C200) were used. From Table 1; it can be seen that the lower the CT ratings the higher the value of the initial voltage required to drive the relay. Also, the higher the CT rating the higher the percentage increase of the connected burden from the initial value to the value at saturation.

3.1.2. Case 2

In this case, a current transformer with CT rating 1200/5 with different relay ratings was used. It can be seen from the results in Table 2 that the initial voltage required to drive the relay is the same (45.42V). This quickly tells us that the voltage required to drive the relay is dependent on the burden; that is; as the burden increases, so does the voltage required to drive the relay. Also, it can be seen that the higher the CT rating, the higher the percentage increase of the connected burden from the initial value to the value at saturation.

3.1.3. Case 3

In this case, four current transformers with different CT ratings and relay ratings were used. From Table 3; it can be seen that the lower the CT ratings the higher the value of the initial voltage required to drive the relay. One can also observe that the higher the CT rating the higher the percentage increase of the connected burden from the initial value to the value at saturation.

4. CONCLUSION

From the cases above, it can be deduced that the voltage required to drive the relay is independent of the relay rating but it is directly proportional to the connected burden on the CT. That is, as the burden is increased, the required voltage to drive the relay also increases until it gets to the point where the current transformer saturates (that is the point where the condition; "relay rating ≥ 2 times required voltage that will drive the relay" no longer holds). At saturation, the optimal performance of the current transformer is no longer guaranteed and this phenomenon jeopardizes the function(s) of the protective relay connected to current transformer in particular and the power system in general. From the foregoing, it is glaring that burden plays a very vital role in current transformers' optimal performance.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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