Evaluation of Efficiency Reducing Factors in Power Transformers Winding Insulation

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Abstract-Instability in electric power system has been an aged-long problem in the power industries and to the end users devastating economic bottleneck. A lot of work have been carried out addressing this issue at the distribution levels but not in the transmission grid especially with respect to power transformer which is the primary component in the electric power system after generation. Switching effects in large high voltage power transformers may lead to power system instability and degradation of vital electrical power protection and control equipment, which will in turn affect the quality of power generated by the power systems network (Efficiency). Currently, researches are being carried to improve the reliability of existing power system infrastructure by minimizing some of these effects. This paper presents a concise investigation of the pertinent issues on the switching effects on power transformers due to inrush currents and reviews the state of art approaches to wards its mitigation leading to power and energy improvements. The result shows that the switching impact is found to be very high at the primary windings of the power transformers than any other part.

***Keywords**:* Intelligent switching, inrush current, power quality, power transformer, switching effects mitigation.

1. Introduction

Power infrastructure these days is burdened by the utmost need to deliver high quality power at a reduced cost of maintenance and high efficiency. However, due to the complicated nature of power system variables, this may not always be achievable. High voltage fluctuations, intermittent supplies, lightning, and transformer switching transients prove to be a major hurdle to overcome by the power system operators. Studies have shown that the peak value of the inrush current is related to switching instant of the terminal voltage here the generator step up unit (GSU), the characteristics of hysteresis curve (residual and saturation fluxes), the primary winding resistance and the primary winding air-core reluctance [S.J Chapman, 1999]. It was also emphasized that inrush currents are originated by the high saturation of the iron-core during switching in. Since the applied voltage to the transformer primary is the driving force of the inrush current, twice the steady state flux may buildup in addition to any residual flux. Super saturation also can lead to large current above normal excitation and rated current. The consequences being what the end users suffer today ranging from ill-operation of the protective overload to winding stresses and high harmonics at resonance [D. Povh Et al, 1978 & M.Nagpal Et al, 20060]. Thus, reliable tools and approaches augmented with modern state of art intelligent systems are desired.

1.1. Current state of the Art in Switching Effects (Inrush Currents) Mitigation

Several attempts have been made to study the likely effects of switching transformers and ways to minimize these persisting problem in a given power system network. In (H.W. Dommel & M.B. Selak 2001), the switching events in power transformers have been studied. Three core models for studying the switching events/effects of power transformers including the Low (Basic) frequency model, the Saturation effects model and the High frequency model were identified as vital models for describing a transformer switching problem.
Quantitative laboratory field studies (A. Ebner Et al 2008) have been carried out to investigate the effect of real time controlled switching factors using a systematic inrush current approach. Based on rapid and delayed closing strategy, it was discovered that acceptable tolerances for both strategies can be evaluated independent of the controlled switching strategy used by considering the inrush current of the first energized phase.
Brunke and Frohlich in (D.P. Balanchandran Et al 2012) developed three algorithmic strategies (rapid, delayed and simultaneous closing strategies) for controlled energization of most transformers in order to eliminate the inrush currents. Depending on strategy employed it was concluded that knowledge of some residual flux, independent pole breaker/control or model parameters of transformer transient performance studies may be required.

Fuzzy logic classifier has been developed in (J.N.Brunke and K.J.Frohlich 2012) to perform discrimination between the inrush currents and false currents with promising results. Ultra-low frequency power source for residual flux minimization in network transformers have been proposed in (B. Kovan Et al 2010). Using this approach, inrush currents reduction of more than 60% were reported.
In (B. Kovan Et al 2010, and A. Abdusaalam 2015) a technique have been developed for transformer inrush current detection using the second harmonic content principle. However, this does not scale well for modern transformers due to negligible second harmonic content that exist in such transformers.
While all these approaches seek to minimize if not eliminate the inrush switching current problem, there still remains the need to improve on existing technologies, in particular the full transition to intelligent computers by power system operators.

a) Inrush Current in a Power Transformer

Normally an inrush current occurs when a transformer is switched in on no-load (IEEE Std. 2002). This leads to swift rise in magnetization current due to large phase differentials of applied voltage. Accordingly, the applied voltage to a power generator step up unit (GSU) power transformer is expressed as (S.J Chapman, 1999):

$$V_{(t)} = V_{(m)} \sin(wt + \theta) \quad (1)$$

The corresponding net magnetic flux is given as:

$$Q_{net)} = Q_{(init)} + Q_{(m)} \quad (2)$$

where,

$$\phi(t) = \frac{1}{N_p}\int_0^{\pi/\omega} V_m \sin(\omega t)\partial t \quad (3)$$

If $Q_{(init)} = 0$ and $\theta = 90^0$

$$V_{(t)} = V_{(m)} \sin(wt + 90^0)$$
$$= V_{(t)} = V_{(m)} \cos(wt) \quad (4)$$

and,

$$\phi_m = \frac{V_{\max}}{\omega N_p} \quad (5)$$

However, for $\theta \ll 90^0$

$$\phi_m = \frac{nV_{\max}}{\omega N_p} \quad (6)$$

where n = 2 at $\theta = 0$.

As a result, a larger current flows due to increase in magnetization. In practice, *n* may be much greater than 2. Such excessive currents may lead to a wrong operation of the circulating current protection (IEEE Std. 2002, & F. Deleon Et al 2015), false tripping of breakers, fuse burn-out and distortions in the mains supply leading to a net degradation of the power system network.

2. Techniques for Mitigating Inrush Currents in Power Transformer

In this section we address some techniques for minimizing the residual flux and hence the magnetization current in a transformer. We also explore alternative ways existing infrastructure might be improved to maintain overall power system integrity.

a). False-Relay Prevention by Shunting with "Kick" fuses

Figure 1 shows a scheme for preventing false relay activation at high inrush currents using overcurrent inverse-time relays. This has the effect of diverting excessive current through the fuse elements. This is the blind spot approach. However, relay settings need to be increased each time to meet changing system requirements. Figure 1 is a false-relay prevention using a circulating current protection scheme with kick fuses.

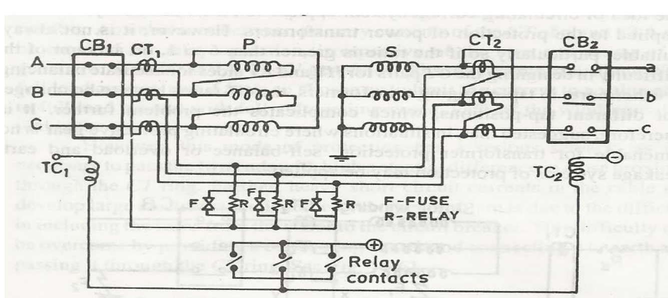

Fig.1 False relay, prevention Scheme. Source, [Gangadhar 2009]

b). Use of Digital Computer Program

This is based on computer algorithm embedded in specialized hardware for digitized control of the switching system. Several relays can then be coordinated effectively by the special digital program to minimize the inrush current flow through transformer primary.

c). Use of AI/Expert System

This employs state of art algorithms on artificial intelligence (AI) and Expert system. Several technologies exist but are not limited to fuzzy logic, genetic algorithms and Bayesian methods for the intelligent coordination and reliable operation of transformer inrush protection devices. The proposed method here involved the use of controllers concerned with isolation, demagnetization and current limiting algorithms based on the principle of variable voltage and constant frequency (VVCF) as presented in Fig. II. Here every trip from the generator triggers spontaneous isolation of the primary and secondary windings terminals of the transformer (GSU).

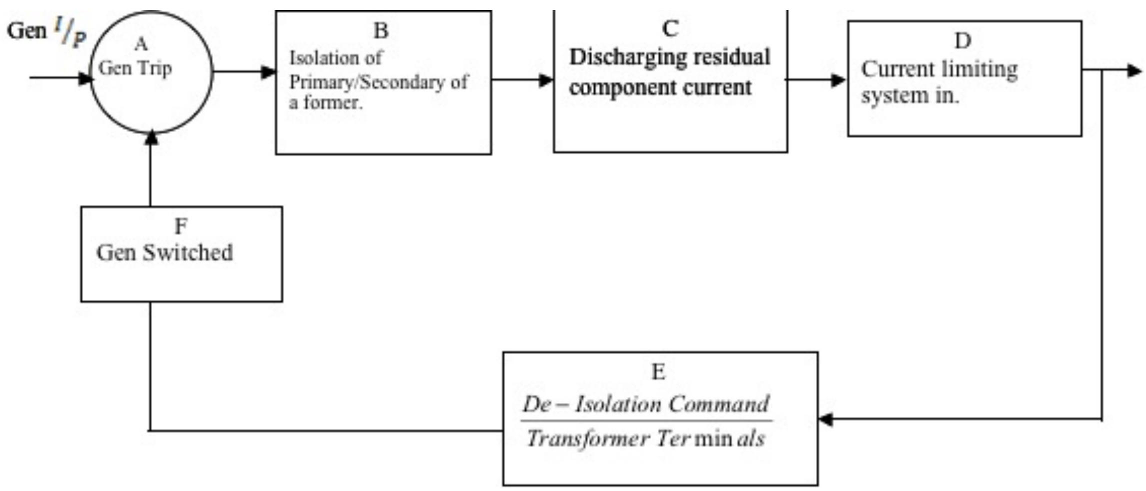

Fig. II. Block diagram showing Generator trips, transformer isolation and switching process.

The demagnetization of the transformer may be in combination of the technique as carried out by (F.Deleon Et al 2015) for a delta-star connection. Here the proposed method does not allow the occurrence of saturation by optimally controlling the magnetization process. But for any reason(s) there is occurrence, the electronic controller with the discharge pot eliminates it by eliminating the residual flux as shown in Fig. III.

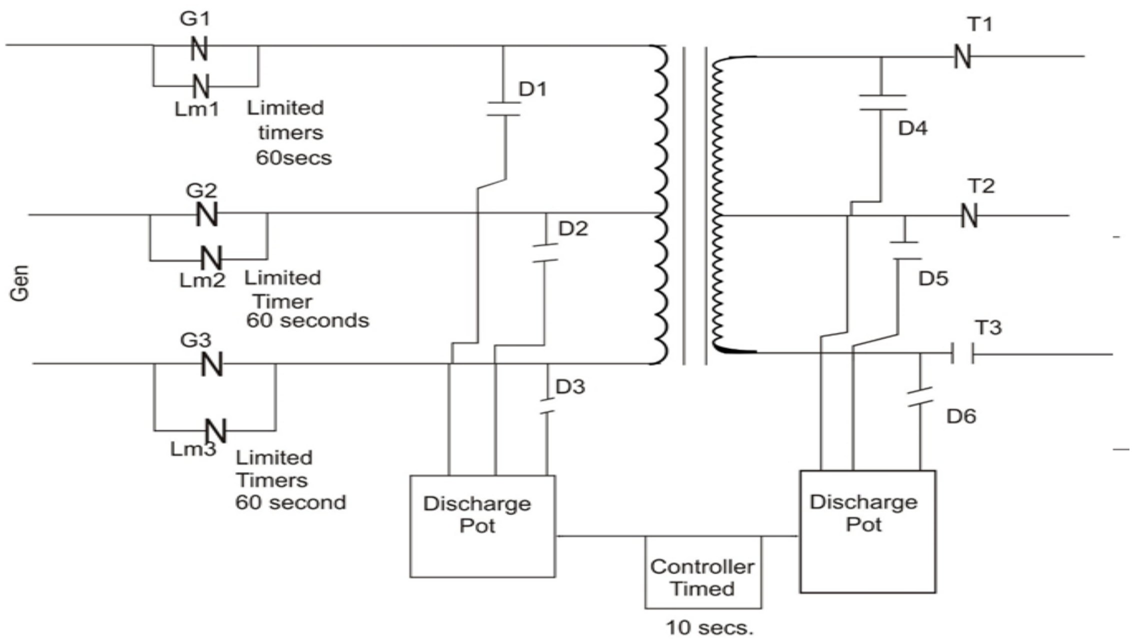

Fig. III: Control Circuit for the Tripping and Switching in Transformer Minimizing Inrush Current.

At the instant of Generator trips, the transformer as shown in Fig. III will be isolated both sides of Primary and Secondary winding terminals through the contacts G1, G2, G3, T1, T2, and T3. Also Lm1, Lm2, and Lm3 (current limiting relay contacts) opening. D1, D2, D3, D4, D5, and D6 closed bringing in the demagnetizing components (discharge pot). The demagnetization times out after 10 Seconds to open contacts. At this point the current limiting contacts at the primary winding closes to enable the primary winding to be powered with minimum current less than the rated value. After the pre-set time, here about 25 Seconds advocated. The primary main contacts will come in (G1, G2, and G3,) closing as well as the secondary terminals.

Limiters Lm1, Lm2, and Lm3 may not remain in circuit with the Generator set but must open at the point of trips.

3. Conclusions

The switching impact is found to be very high at the primary windings of the power transformers. Mostly at the trips of the generators before cruising to stop, there is always period of high speed and excitation producing high current to the primary windings. Thus it is our conclusion that the isolation, diversionary and the delaying approaches which will act as high current surge inhibitors be implored and effected at the primary windings of the transformers using described techniques. The essence of this will create power stability before the in-feed to the windings. This will also minimize the rate of power transformers from untimely explosion and damage.

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