Politeknik Dergisi
Cilt: 5 Sayı: 3 s. 221-225, 2002

Journal of Polytechnic
Vol: 5 No: 3 pp. 221-225, 2002

DECREASING THE EFFECT OF THE SECOND HARMONIC COMPONENT FOR POWER TRANSFORMER PROTECTION

Okan OZGONENEL
Ondokuz Mayis University, Engineering Faculty, Electrical & Electronik Eng.Dept.
Samsun – TURKEY

ABSTRACT

The transformer is one of the most expensive and important electrical equipment of a power distribution system and therefore the loss of such equipment through catastrophic failure can be very costly. Furthermore, repair or replacement is expensive and time consuming. To avoid this, methods and systems for monitoring and protecting of power transformers in service have been developed in recent years. To avoid the needless trip by magnetizing inrush current, the second harmonic component is commonly used for blocking differential relay in power transformers. This paper describes a new approach for power transformer differential protection that ensures security for inrush phenomenon during switching on. For this purpose, a new AC drive circuit is designed and implemented in a laboratory environment. Finally, we compare the behavior of this new drive for real cases of magnetizing inrush conditions.

Key Words: Transformer protection, inrush current, differential protection, zero crossing circuit.

GÜÇ TRANSFORMATÖRÜ KORUMASINDA İKİNCİ HARMONİĞİN ETKİSİNİN AZALTILMASI

ÖZET

Güç transformatörleri enerji sistemlerinin en pahalı ve vazgeçilmez elemanlarından biridir. Değişik tipte arızalar ile karşı karşıya kalırlar ve bunların etkileri de farklı şekillerde ortaya çıkar. Buna ek olarak, tamir ve arızaların giderilme aşamaları oldukça pahalı ve zaman gerektirmektedir. Bu durumdan kaçınmak için, çalışmakta olan güç transformatörlerinin korunması ve gözlenmesi amacıyla yeni yöntemler ve sistemler geliştirilmiştir. Ani mıknatıslanma akımı durumunda gereksiz açma sinyalinden kaçınmak amacıyla ikinci harmonik bileşeninin sınırlandırılması yöntemi güç transformatörlerinin diferansiyel korumasında en genel kullanılan bir yöntemdir. Bu çalışma güç transformatörlerinin diferansiyel korumasında ani mıknatıslanma durumunda güvenilir yeni bir yaklaşım sunmaktadır. Bu amaçla laboratuar şartlarında yeni bir AC sürücü düzeneği tasarlanmış ve uygulanmıştır. Sonuç olarak, bu tasarlanan sürücü düzeneği gerçek ani mıknatıslanma koşullarında denenmiştir.

Anahtar Kelimeler: Transformatör koruma, ani mıknatıslanma akımı, diferansiyel koruma, sıfır geçiş devresi.

1. INTRODUCTION

Power frequency harmonics exist in the distribution systems due to the prevalence of nonlinear loads. It is also known the non-load current of transformers contains several harmonics. This is primarily because of the nonlinear relationship between the flux density and the magnetic field strength in a transformer core.

However other factors, such as the stacking method, core material and the maximum allowable flux density influence the harmonic contents of the non-load current the transformer harmonics can cause the following effects:

- Disturb the proper functioning of upstream automatic network equipment,
- Interfere with the operation the telecommunication equipment,
- Increase the temperature of the delta connected windings due to the circulating triplen currents,
- Overload the neutral conductor of the star connected 4 wire windings,
- Cause the misoperation of the protective relays in power systems.

In order to deal with the problems of inrush and overexcitation conditions, designers of conventionals and digital relays have devised many solutions, of which two, harmonic restraint and voltage restraint relay models.

Harmonic restraint is based on the fact that the inrush current has a large second harmonic component, and the overexcitation current a large fifth harmonic component, which are used to restrain the relay from tripping during those two conditions, respectively (1).

In this work, the effect of the second harmonic component will be decreased by an AC control circuit. The following section describes the concept of magnetizing inrush current.

2. THE STUDY OF MAGNETIZING INRUSH

The phenomenon of magnetizing inrush is a transient condition, which occurs primarily when a transformer is energised. It is not a fault condition, and therefore does not necessitate the operation of protection, which, on the contrary, must remain stable during inrush transient, a requirement, which is a major limitation to the design of protective systems for transformers.

When an inductance is energised by a steady alternating voltage, the flux linking the inductive circuit varies from a peak negative value to an equivalent peak positive value during one half cycle of the voltage wave. The flux change of twice the maximum flux value is propotional the time integral of the voltage wave between successive zero points. On the switching at the zero point of the wave, the full flux change is required during the first cycle, but with the flux initially zero the maximum flux developed will be twice normal peak value.

Residual flux can increase the current still further. If the initial flux, instead of being zero, has an initial positive value, that is, an initial value in the same direction as the flux change, the increment of flux must remain the same, since it is proportional to the half cycle voltage drop, and the peak value attained may be of the order of the 2 – 8 times. The current wave, starting from zero, increases slowly. The time constant of the transients is relatively long, being from perhaps 0.1 second for a 100 kVA transformer and to 1.0 second for large units (2).

Figure 1 shows a typically inrush current of a labaratory transformer (220 / 220 V, 50 Hz, 1000 VA).

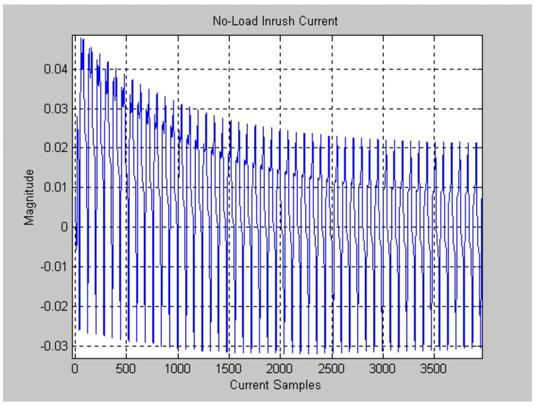

Figure 1. Inrush current of a model transformer.

The magnitudes and waveforms of inrush current depend on a multitude of factors, and are almost impossible to predict. The following summarized the main characteristic of inrush currents:

- Generally contain dc offset, odd harmonics and even harmonics,
- Typically composed of unipolar or bipolar pulses, separated by intervals of very low current values,
- Peak values of unipolar inrush current pulses decrease very slowly. Time constant is typically much greater than that of the exponentially decaying dc offset of fault currents,
- Second harmonic content starts with a low value and increases as the inrush currents decreases.

In the following section, simulation of model transformer with core saturation is described.

3. SIMULATION OF MODEL TRANSFORMER WITH CORE SATURATION

In this section, model transformer is simulated under Matlab environment by incorporating core saturation. Core saturation mainly affects the value of the mutual inductance and, to a much less extent, the leakage inductances. Core saturation behaviour can be determined from just the open circuit magnetization curve of the transformer.

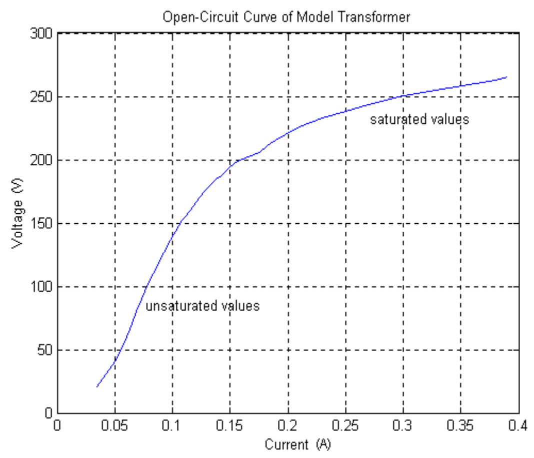

Figure 2. Open circuit curve of model transformer.

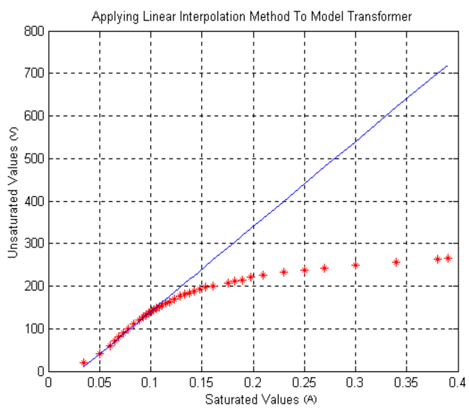

Figure 3. Unsaturated values of open – circuit curve versus saturated values.

As shown in Figure 2, for a given no-load current, i_1, we can determine the corresponding values of unsaturated flux linkage and saturated flux linkage. Repeating the procedure over the desired range for saturated flux linkage, we can obtain a sufficient number of paired values of unsaturated flux linkage and saturated flux linkage to plot the curve shown in Figure 3.

To achieve this goal, we proceeded to derive an algebraic expression for the calculation of $\bar{y}$ in terms of $\bar{x}$ and the values of x_k, y_k and x_{k+1}, y_{k+1}. The equation of the line through (x_k, y_k) and (x_{k+1}, y_{k+1}) is

$$y = y_k + \left(\frac{x - x_k}{x_{k+1} - x_k}\right)(y_{k+1} - y_k) \text{ so}$$

$$\bar{y} = y_k + \left(\frac{\bar{x} - x_k}{x_{k+1} - x_k}\right)(y_{k+1} - y_k). \qquad (1)$$

Applying equation (1) to open circuit curve, equation (2) is obtained and created a 2 x 82 matrix.

$$y = 2000x - 36 \qquad (2)$$

In digital simulation, the 2 x 82 matrix is written in look – up table module given in the Nonlinear Block Library in Matlab (3).

In digital simulation, we examined the inrush of magnetizing current in an unloaded transformer that is energised at the instant when

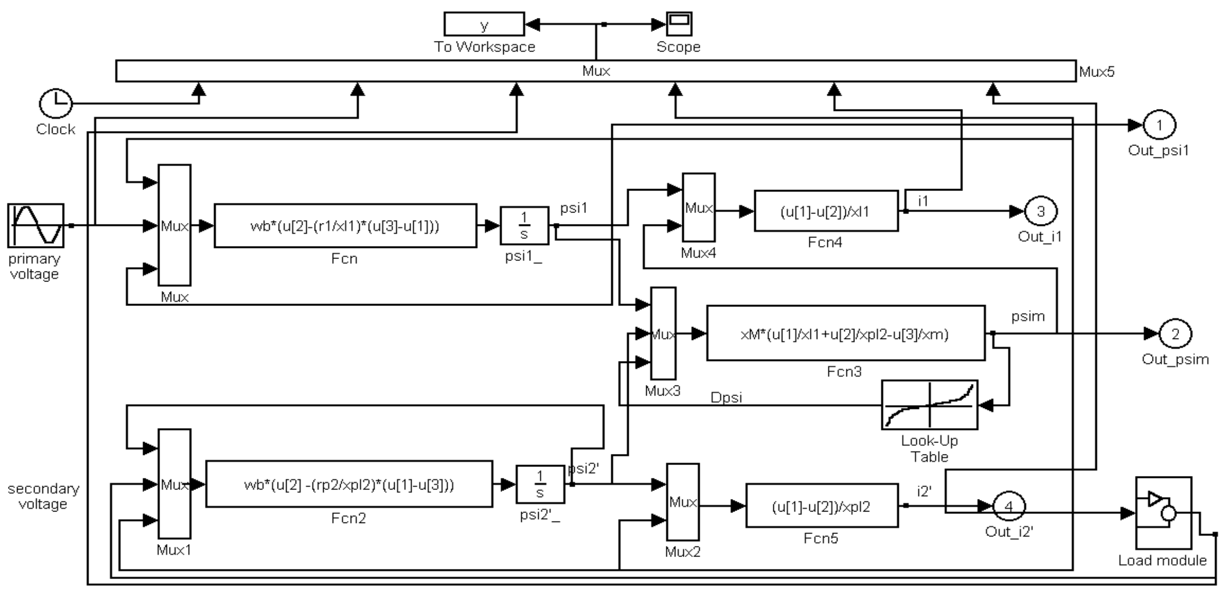

Figure 4. Simulation of model transformer in Matlab, Simulink environment [4].

the supply voltage and residual core flux are both zero.

Different phase angles of the supply voltage can also be examined by this simulation. This phenomenon is a focus point of this paper.

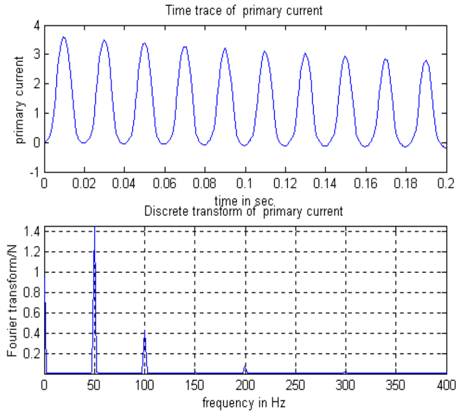

Figure 5. Inrush current and its harmonic contents of model transformer.

The following section describes zero crossing circuit design.

4. ZERO CROSSING CIRCUIT DESIGN

To get rid of unexpected effects of magnetizing inrush current, a zero crossing circuit is designed shown in Figure 6.

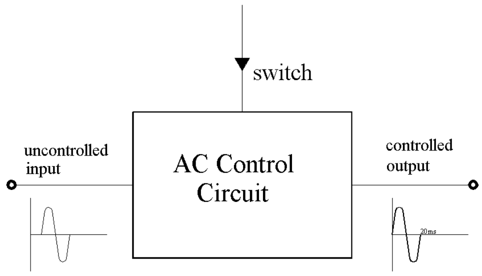

Figure 6. Zero crossing circuit design.

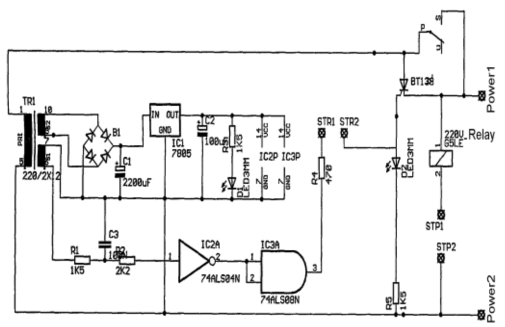

Figure 7. Inside the AC Control Circuit.

This is a low cost AC circuit that is simple to implement in a laboratory environment. When an input voltage is supplied then the output voltage will be zero until the switch is activated.

Furthermore, the phase angle of the input voltage is not important $(0^0....360^o)$, therefore we call it as *uncontrolled input*, the phase angle of the output voltage will be zero crossing (*controlled output*). Thus, the effect of inrush current as stated above will be minimized.

Figure 8. Experimental setup.

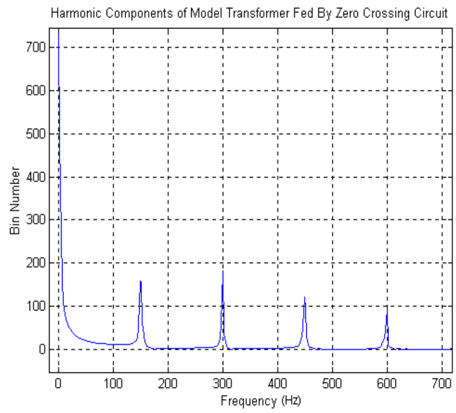

Figure 9. Harmonic contents of inrush current via zero crossing.

It is clearly seen from the Figure 9 that the ratio of 2^{nd} harmonic component to the fundamental harmonic component is decreased on a large scale. This circuit can be used for different kinds of transformer having with a convenient thyristor (SCR). In laboratory environment, since model transformer is 1000 VA and rated primary current is almost 4.54 A, a BT138A (SCR) is appropriate for this case study.

5. CONCLUSIONS

This paper presents a comprehensive simulation method for analyzing power transformers, which are amongst the most important components in a power system, and a zero crossing AC circuit that minimizes the effects of magnetizing inrush current.

The results from the experiment show that no-load current of the transformer fed by zero crossing circuit contains much less even harmonics including 2nd harmonic content.

This circuit can be applied any kind of transformer by using appropriate SCR's or solid state relays.

REFERENCES

1) A. Hassan, Al Haj, I. El-Amin, Factors That Influence Transformer No-Load Current Harmonics, IEEE Transactions On Power Delivery", Vol. 15, No.1, January, 2000.

2) Çiftçi Hakan, Implementation Of A Digital Feeder Overcurrent Protection Relay, Master Of Science, The Graduate School Of Natural and Applied Sciences, Middle East Technical University, May 1997.

3) J. Moscinski, Z. Ogonowski, Advanced Control With MATLAB And Simulink, Ellis Horwood Limited, Campus 400, Maylands Avenue Hemel Hempstead Hertfordshire, HP2 7EZ, 1995

4) Che – Mun Ong, Dynamic Simulation Of Electrical Machinery, Using Matlab / Simulink, Prentice Hall Ptr. , Upper Saddle River, New Jersey 07448, 1998.

APPENDIX

The layout of the electronic components can be seen in Figure 10. This circuit can be implemented to any kind of single phase transformer by choosing an appropriate thyristor (SCR).

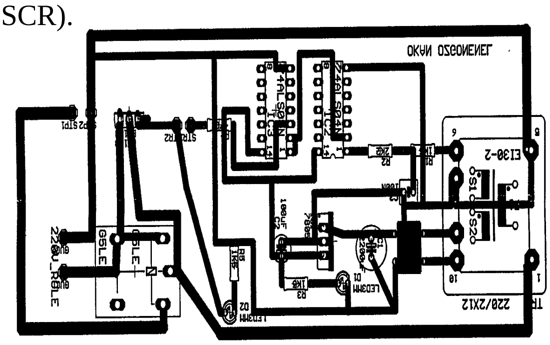

Figure 10. Layout of the components