ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

**International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering**

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 3, Issue 4, April 2014**

# A Study of Effect of Magnetizing Inrush Current on Different Ratings Of Transformers

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**ABSTRACT**: Transformer is a very important and major component in power system. It finds a major use in various sectors. In order to reduce the cost and the weight of the core, modern transformers are used at high saturation level which leads to harmonics in the voltage and the current .The resultant harmonics affects the performance of transformer and leads to increase in losses. So for a power system to work efficiently it becomes critically important to asses the harmonics that are generated .In this paper we simulate a power system using MATLAB Simulation. Here we compare the performance of différent rating of power transformers and study the effect of magnetizing inrush current at different switching angle.

**KEYWORDS:** Transformer, harmonics, Losses, Inrush.

## I.INTRODUCTION

One of the most important equipment in power system is the transformer that changes in size, types, and connections. A power transformer functions as a node to connect two different voltage levels. Therefore, the continuity of transformer operation is of vital importance for maintaining the reliability of power supply. Any unscheduled repair work, especially replacement of faulty transformer is very expensive and time consuming [1].
As a result, their protection is of great importance to assure stable and reliable operation of the whole system. The major concern in power transformer protection is to avoid the false tripping of the protective relays due to misidentifying the magnetizing inrush current. Magnetizing inrush currents may have a high magnitude, which is distinguishable from the traditional internal fault currents.
To avoid needless trip by magnetizing inrush current, the second harmonic component is commonly used for blocking differential relay in power transformers. In general, the major sources of harmonics in the inrush currents are a) nonlinearities of transformer core; b) saturation of current transformers; c) over-excitation of the transformers due to dynamic over voltage condition; d) core residual magnetization; e) switching instant [2].
The transformer inrush current flows in one winding only. This results in large differential currents. Similarly, over excitation causes highly distorted differential current. But above cases are not fault conditions, therefore, the relay must be able to properly discriminate inrush and over excitation Condition form internal fault condition [2].
Power Transformer is one of the most cost effective components in an electric power system. Any damage to it can cause irreparable damage resulting in replacement or high cost for repairs if possible. Thus protection of transformers becomes a critical issue related to power system. Thus it becomes very essential that the transformer is protected from various possible failures. Magnetizing inrush current of a transformer ranges between 01 to 05 % of the rated current whose first peak may reach as high as the rated current itself. Magnetizing inrush current find its presence in the initial stage when the transformer is energized and may last up to few mili seconds before the steady state is reached. This inrush current can cause the transformer to malfunction and thus leading to faulty operation of a power system. This inrush current tends to have a high magnitude and is rich in harmonics which may seriously reduce the life expectancy of the transformer. As the power system is subjected to varying magnitudes of load it automatically is subjected to varying inrush current every time the transformer is energized.
The magnitude of inrush current is usually 10 to 15 times the rated current due to which this inrush results in high level of harmonics which damages the insulation. On account of the insulation failure the temperature increases. The harmonics are reactive in nature and they generate a voltage drop across the network which leads to instability in the power system. The transformer design and the station installation affect the magnitude of the inrush currents. Therefore

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if becomes critically important to study the magnitude of harmonics of different order generated due to inrush current for different rating of the transformer. MATLAB Simulation is the most preferred software tool for determining the different order harmonics for different ratings of the transformer. In [6]a new simple and effective technique based on the instantaneous power computations for the detection of inrush currents from fault and load currents. Exhaustive investigations are carried out by simulating a single phase transformer for different fault and switching conditions. Simulation studies reveal that the proposed technique finds potential application in detection of inrush current in modern single phase transformers. In [5] an estimation of transients and method of elimination of decaying DC component for the purpose of power transformer protection is presented further, the presented strategy discriminates different harmonics generated during power transformer energization and distinguishes inrush from short circuit. The algorithm proposed in the relay logic disconnects the equipment reliably and accurately on sensing fault based on switching instance, switching angle of the circuit breaker and amplitude estimation of the current waveform generated during the fault. In [1] A statistical tool named maximum entropy method (MEM),which seems to provide a reliable and computationally efficient tool for identification inrush currents on twodifferent "C" core materials, SiFe and amorphous.

## II.INRUSH CURRENT

When a power transformer is switch on from primary side, with keeping its secondary circuit open, it acts as a simple inductance. When electrical power transformer runs normally, the flux produced in the core is in quadrature with applied voltage as shown in the figure below. That means, flux wave will reach its maximum value, ¼ cycle or π/2 angle after, reaching maximum value of voltage wave. Hence as per the waves shown in the figure, at the instant when, the voltage is zero, the corresponding steady state value of flux should be negative maximum. But practically it is not possible to have flux at the instant of switching on the supply of transformer. This is because, there will be no flux linked to the core prior to switch on the supply. The steady state value of flux will only reach after a finite time, depending upon how fast the circuit can take energy. This is because the rate of energy transfer to a circuit cannot be infinity. So the flux in the core also will start from its zero value at the time of switching on the transformer. [3]

According to Faraday's law of electromagnetic induction the voltage induced across the winding is given as e = dφ/dt. Where φ is the flux in the core. Hence the flux will be integral of the voltagewave.

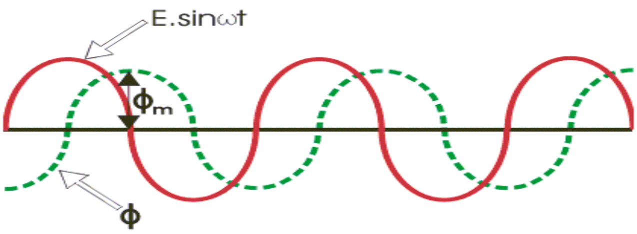


Fig 1 Voltage induced across the winding

$$e = E.sin\omega t = {d\varphi}/{dt} \Rightarrow \varphi = \int e.dt = E \int sin\omega t.dt$$

If the transformer is switched on at the instant of voltage zero, the flux wave is initiated from the same origin as voltage waveform, the value of flux at the end of first half cycle of the voltage waveform will be

$$\varphi_{m'=(E/\omega)}\int_0^{\pi} \sin\omega t.dt = \varphi_m\int_0^{\pi} \sin\omega t.d(\omega t) = 2\varphi m$$

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Where $\varphi_m$ is the maximum value of steady state flux. The transformer core are generally saturated just above the maximum steady state value of flux. But in our example, during switching on the transformer the maximum value of flux will jump to double of its steady state maximum value. As, after steady state maximum value of flux, the core becomes saturated, the current required to produced rest of flux will be very high. So transformer primary will draw a very high peaky current from the source which is called magnetizing inrush current in transformer **or simply** inrush current in transformer**.**

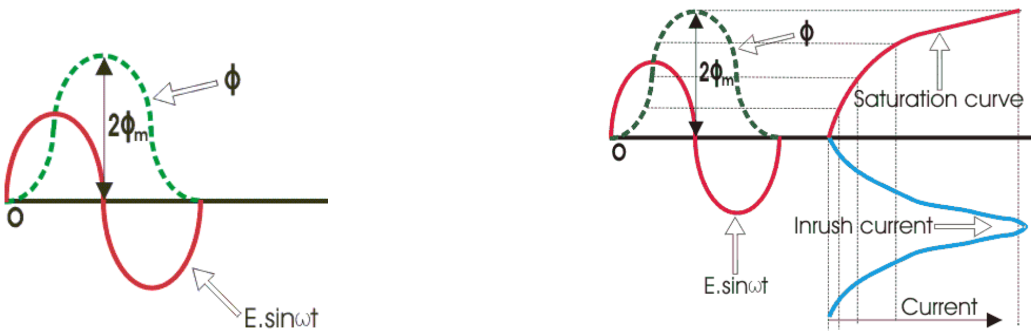


Fig 2 Waveform showing inrush current

Magnetizing inrush current in transformer is the current which is drown by a transformer at the time of energizing the transformer. This current is transient in nature and exists for few milliseconds. The inrush current may be up to 10 times higher than normal rated current of transformer. Although the magnitude of inrush current is so high but it generally does not create any permanent fault in transformer as it exists for very small time. But still **inrush current in power transformer** is a problem, because it interferes with the operation of circuits as they have been designed to function. Some effects of high inrush include nuisance fuse or breaker interruptions, as well as arcing and failure of primary circuit components, such as switches. High magnetizing inrush current in transformer also necessitate over-sizing of fuses or breakers. Another side effect of high inrush is the injection of noise and distortion back into the mains.

## III.HARMONICS

Harmonics are a mathematical way of describing distortion to a voltage or current waveform. The term harmonic refers to a component of a waveform that occurs at an integer multiple of the fundamental frequency [4].
Fourier theory tells us that any repetitive waveform can be defined in terms of summing sinusoidal waveforms which are integer multiples (or harmonics) of the fundamental frequency. For the purpose of a steady state waveform with equal positive and negative half-cycles, the Fourier series can be expressed as follows:

$$f(t) = \sum_{n=1}^{\infty} An \, . \sin\left(\frac{n\Pi t}{T}\right)$$

where
**f(t)** is the time domain function
**n** is the harmonic number (only odd values of **n** are required)
**An** is the amplitude of the nth harmonic component
**T** is the length of one cycle in seconds.
Understanding the mathematics is not important. What is important is understanding that harmonics are a steady state phenomenon and repeat with every 60 Hz cycle. Harmonics should not be confused with spikes, dips, impulses, oscillations or other forms of transients.

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A common term that is used in relation to harmonics is THD or Total Harmonic Distortion. THD can be used to describe voltage or current distortion and is calculated as follows:

$$THD(\%) = \sqrt{(ID_1^{\,2} + ID_2^{\,2} + ..ID_n^{\,2})}$$

Where,
***IDn*** is the magnitude of the nth harmonic as a percentage of the fundamental (individual distortion).
Another closely related term is Distortion Factor (DF) which is essentially the same as THD.

Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency being 50 or 60Hz (50Hz for European power and 60Hz for American power). For example, if the fundamental power frequency is 60 Hz, then the 2$^{nd}$ harmonic is 120 Hz, the 3$^{rd}$ is 180 Hz, etc. In modern test equipment today harmonics can be measured up to the 63$^{rd}$ harmonic. When harmonic frequencies are prevalent, electrical power panels and transformers become mechanically resonant to the magnetic fields generated by higher frequency harmonics. When this happens, the power panel or transformer vibrates and emits a buzzing sound for the different harmonic frequencies. Harmonic frequencies from the 3$^{rd}$ to the 25$^{th}$ are the most common range of frequencies measured in electrical distribution systems.

In today's environment, all computer systems use SMPS that convert utility AC voltage to regulated low voltage DC for internal electronics. These non-linear power supplies draw current in high amplitude short pulses. These current pulses create significant distortion in the electrical current and voltage wave shape. This is referred to as a harmonic distortion and is measured in Total Harmonic Distortion (THD). The distortion travels back into the power source and can effect other equipment connected to the same source.

Uncontrolled energization of large power transformers may result in large dynamic flux and saturation in one or more cores of the transformer. The saturation results in high amplitude magnetizing inrush current that are rich in harmonics and have a high direct current component. The amplitude of the magnetizing current depends mainly on two factors: the residual flux in the magnetic core and the transient flux produced by the integral of the sinusoidal supply voltage.
The magnitude of the magnetizing inrush current is in the range of the short circuit current and may occur severe dynamical stress in the transformer windings . The inrush current amplitude usually does not exceed the fault current withstand capability of the transformer, however the duration of these stresses are significantly longer and occurrence is more frequent than that of the short circuit which is cleared by the relay protection within some tens of milli seconds.

Besides the long duration exposure to the mechanical support structure of the windings, these currents reduce the power quality, because the voltage drop on the source impedance is considerable during the inrush period, which produces voltage swell in both side of the transformer. A high amplitude inrush current may cause false differential protection operations. Additionally, a false relay trip may result in dangerous over voltages if the inrush current is interrupted by a breaker having high current chopping level before the natural current zero.

The harmonic currents produce harmonic fields in the core and harmonic voltages in the windings. Relatively small value of harmonic fields generates considerable magnitude of harmonic voltages. These effects get even more pronounced for higher order harmonics. As these harmonic voltages get short circuited through the low impedance of the supply they produce harmonic currents. These currents produce effects according to Lenz's law and tend to neutralize the harmonic flux and bring the flux wave to a sinusoid. Normally third harmonic is the largest in its magnitude. In a single phase transformer the harmonics are confined mostly to the primary side as the source impedance is much smaller compared to the load impedance. The understanding of the phenomenon becomes clearer if the transformer is supplied with a sinusoidal current source. In this case current has to be sinusoidal and the harmonic currents cannot be supplied by the source and hence the induced EMF will be peaky containing harmonic voltages. When the load is connected on the secondary side the harmonic currents flow through the load and voltage tends to become sinusoidal. The harmonic voltages induce electric stress on dielectrics and increased electro static interference. The harmonic currents produce losses and electromagnetic interference.

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## IV.INVESTIGATION OF INRUSH CURRENT FOR DIFFERENT PARAMETERS

The inrush current phenomenon is investigated on a three phase transformer by using the MATLAB Simulink model for different ratings of transformers. The following simulation circuit is used to determine the magnetizing inrush current .

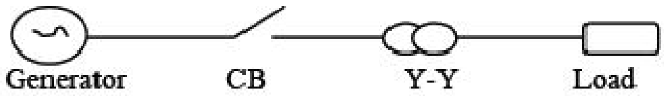


Fig 1 Single Line Diagram of the simulink model

## V. RESULT AND DISCUSSION

### Case I :

For a Three phase 250MVA, 22 KV / 220 KV Transformer is used at different switching angles, it gives the values of inrush current as shown in the table below . Here we observe that the the inrush current is minimum at the angle 90.

| Angle(degree) | Inrush Current (A) ( Peak value) |
|---|---|
| 0 | 1849.3 |
| 30 | 1534.7 |
| 60 | 695.87 |
| 90 | 26.2 |
| 120 | -159.29 |
| 150 | -156.6 |

Table 1 Investigation for three phase 250 MVA Transformer

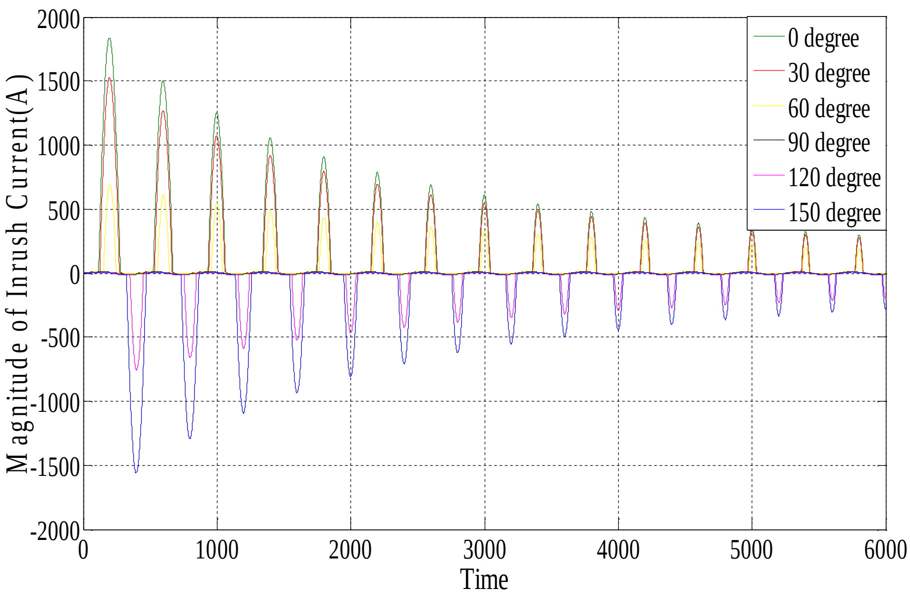


Fig 1 Magnitude of inrush current Vs time graph for 250MVA transformer.

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ISSN (Online): 2278 – 8875

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**Case II :**

For a Three phase 150MVA, 22 KV / 220 KV Transformer is used at different switching angles, it gives the values of inrush current as shown in the table below. Here also we observe that the inrush current is minimum at the angle 90.

| Angle(degree) | Inrush Current (A) ( Peak value) |
|---|---|
| 0 | 1741.8 |
| 30 | 1445.4 |
| 60 | 655.42 |
| 90 | 15.76 |
| 120 | -713.6 |
| 150 | -1478.1 |

Table II Investigation for three phase 150 MVA Transformer

**Case III :**

For a Three phase 100MVA, 22 KV / 220 KV Transformer is used at different switching angles, it gives the values of inrush current as shown in the table below. In this case also we observe that the inrush current is minimum at the angle 90.

| Angle(degree) | Inrush Current (A) ( Peak value) |
|---|---|
| 0 | 1849.3 |
| 30 | 1534.7 |
| 60 | 695.87 |
| 90 | 26.2 |
| 120 | -159.29 |
| 150 | -156.6 |

Table III Investigation for three phase 100 MVA Transformer

It is observed when the transformer is operated at an angle of 90 degree the value of the inrush current was found to be minimal.
Thus for all the three cases as presented above we found that the Inrush current is at its minimum value whenever the transformer is operated at an angle of 90 degree.

## VI.CONCLUSION

Thus the inrush current phenomenon is investigated on a three phase transformer by using the MATLAB Simulink model for different ratings of transformers. It is seen that the peak value of magnetizing inrush current is very high as compared to the normal magnetizing current and when the transformer was operated at an angle of 90 degree the value of the inrush current was found out to be minimal. During the investigation it was also found that transformer works best when it is being operated at its peak value of 22kv.

## REFERENCES

[1]Okan OZGONENEL, Ondokuz Mayis University,Caner AKUNER, Marmara University “A study on magnetizing inrush current of different core Materials”
[2]Omar A.S. Youssef, A Wavelet-Based Technique for Discrimination Between Faults and Magnetizing Inrush Currents in Transformer, IEEE Transactions on Power Delivery, Vol. 18, No. 1, January, 2003.
[[3] http://www.electrical4u.com/magnetizing-inrush-current-in-power-transformer
[4] http://literature.rockwellautomation.com/idc/groups/literature/documents/wp/mvb-wp011_-en-p.pdf
[5] Shantanu Kumar, *Member IEEE and* Victor Sreeram, *Member, IEEE* “Elimination of DC Component and Identification of Inrush Current using Harmonic Analysis for Power Transformer Protection “IEEE 2013 Tenecon – spring
[6]D P Balachandran, R Sreerama ,B Jayanand “Instantaneous Power Based Detection of InrusCurrents in Single Phase Transformers” 978-1-4673-1835-8/12 ©2012 IEEE

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

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*(An ISO 3297: 2007 Certified Organization)*

**Vol. 3, Issue 4, April 2014**

[8]S.P.Paraskar , M.A.Beg, G.M.Dhole "Discrimination between Inrush and Fault Transformer : ANN Approach" International Journal of Advancement in Technology Vol 2, No 2 (April 2011) ©IJoAT

[9] Dharmendra Kumar singh Dr.Moushmi Kar Dr.A.S.Zadgaonkar "Analysis of generated harmonics due to transformer load on power system using Artificial Neural Network" International Journal of Electrical Engineering and Technology (IJEET), Volume 4, Issue 1, January- February (2013), © IAEME

[10] A. Guzman, H. Altuve, D. Tziouvaras "Power Transformenr Protection Improvements with Numerical Relays" 2350 N.E. Hopkins Court • Pullman, WA 99163-5603.

[11] E.M. Tag Eldin, "A new algorithm for the classification of different Transient phenomena in power transformers combining Wavelet transforms and fuzzy logic" 0-7803-8294-3/04/ ©2004 IEEE

[12] Ouahdi Dris, Farag. M. Elmareimi, Rekina Fouad, "Transformer Differential Protection Scheme With Internal Faults Detection Algorithm Using Second Harmonics Restrain And Fifth Harmonics Blocking Logic"

[13] Spoljaric, Z[Eljko]; Jerkovic, V[Edrana] & Stojkov, M[Arinko] , " Measurement System For Transformer Inrush Current HigherHarmonics Determination" Annals of DAAAM for 2012 & Proceedings of the 23rd International DAAAM Symposium, Volume 23, No.1, ISSN 2304-1382

[14] Thiago Martins de Morais ,Carlos Alberto Canesin ,Fabio Toshiaki Wakabayashi "A New Three-Phase Transformer Modeling for Three-Phase Harmonic Analysis in Distribution Systems" 0-7803-9252-3/05©2005 IEEE.