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INRUSH CURRENT EFFECT TO REDUCE CORE LOSSES BY ADOPTING NEW MAGNETIC MATERIAL IN TRANSFORMER

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Abstract— Since independence in India there has always been shortage of electricity and at no point of time we have been able to meet the peak demand. The gap between the demand and generation can be bridged/ minimized by either improving the installed capacity or reducing the consumer demand. The gap between availability & demand is of order 6% as on date. If we take into account the issues like environment pollution and global warming, the preferred option is to increase the energy efficiency or minimize the consumer demand, as in the other alternative particularly in India where thermal generation dominates increased environmental pollution is inevitable. The paper covers design of transformer using a new technology superior magnetic material with thin sheets of lazer grade or amorphous core. Iron Boron Silicon amorphous alloy is a unique alloy whose structure of metal atoms occurs in random patters as opposed to conventional CRGO steel which has an organized crystalline structure. The paper covers design of distribution transformer using conventional material and the new technology improved core materials. The reflection on the no-load and load losses due to change in the material have been worked out. Commercial and technical feasibility for adoption of new technology core material has been detailed out and the payback period is quite attractive. By reducing the regular occurred power loss in the transformer, economy of the power sector and global environmental impact can be improved.

Index Terms— Core, Copper, Tank, Steel Radiator, Transformer Oil, Power Factor, Losses, Load Factor, Insulation Material. ,CRGO, Lazer Grade, Amorphous

I. INTRODUCTION

Power transformers are very efficient, with losses of less than 0.5% in large units. Smaller units have efficiencies of 97% or above. It is estimated that transformer losses in power distribution networks can exceed 3% of the total electrical power generated. In India, for an annual electricity consumption of about 500 billion kWh, this would come to around 15 billion kWh. Reducing losses can increase transformer efficiency. There are two components that make up transformer losses. The first is "core" loss (also called no-load loss), which is the result of the magnetizing and de-magnetizing of the core during normal operation. Core loss occurs whenever the transformer is energized; core loss does not vary with load. The second component of loss is called coil or load loss, because the efficiency losses occur in the primary and secondary coils of the transformer [1]. Coil loss is a function of the resistance of the winding materials and varies with the load on the transformer. In selecting equipments, one often conveniently avoids the concept of life cycle costing. But the truth is that even the most efficient energy transfer equipment like a transformer, concept of life cycle cost is very much relevant [2]. The total cost of owning and operating a transformer must be evaluated, since the unit will be in service for decades. The only proper method to evaluate alternatives is to request the manufacturer or bidder to supply the load and no-load losses, in watts [3]. Then, simple calculations can reveal anticipated losses at planned loading levels. Frequently, a small increase in purchase price will secure a unit with lower operating costs. The load profile of electronic equipment from the computer in the office to the variable speed drive in the factory drives both additional losses and unwanted distortion [4]. Transformers are one of the most important components in power systems. Security and stability of transformers are both important and necessary to system operation [5]. Magnetizing inrush is typically considered to occur when a de-energized transformer is energized; magnetizing inrush can also flow after system voltage dips and during post fault voltage recovery [6]. Inrush currents may last from tens of milliseconds to tens of seconds before the steady-state condition is reached. [7] The inrush current is asymmetric and unbalanced among the phases and may place a heavy stress on the network. The transformer inrush currents can have large magnitudes and rich harmonics, which can result in power system problems such as damage and decreased life expectancy of the transformer due to switching overvoltage .The overvoltage resulting from the inrush current could happen and cause serious damage to power apparatus.

INRUSH CURRENT THEORY

A. Inrush Current

The saturation of the magnetic core of a transformer is the main cause of an inrush current transient. The saturation of the core is due to an abrupt change in the system voltage which may be caused by switching transients, out-of-phase synchronization of a generator, external faults and faults restoration.

The energisation of a transformer yield to the most severe case of inrush current and the flux in the core can reach a maximum theoretical value of two to three times the rated flux peak how flux-linkage and current relates.

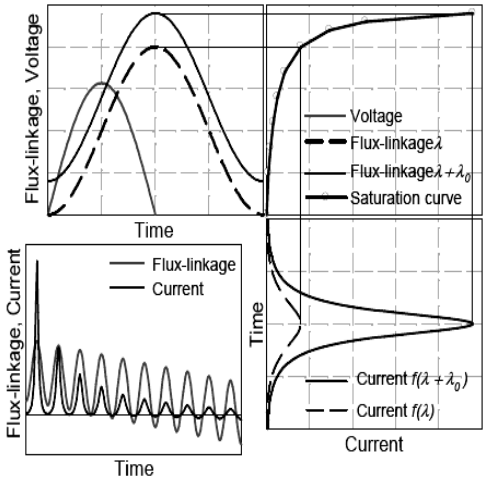

Fig. 1: Qualitative representation of the inrush current phenomenon and effect of the residual flux.

There is no direct evidence that the energisation of a transformer can cause an immediate failure due to high inrush currents. However, insulation failures in power transformers which are frequently energized under no load condition support the suspicion that inrush currents have a hazardous effect.

B. Inrush Phenomena

It has long been known that transient magnetizing inrush currents, sometimes reaching magnitudes as high as six to eight times

the rated current, flow in a transformer winding when switched on to an electric power network. It has not been generally appreciated, however, that the other transformers, already connected to the network near the transformer being switched, may also have a transient magnetizing current of appreciable magnitude at the same time. In order to understand how energizing of a transformer in a network affects the operating conditions of other transformers connected to the same network, consider a network as shown in figure1. When transformer B is switched on to the network already feeding similar transformers (C) in the neighborhoods, the transient magnetizing inrush current of the switched-on transformer also flows into these other transformers and produces in them a DC flux which gets superimposed on their normal AC magnetizing flux

C. Factors Affecting Inrush Phenomenon

a. Switching-on Angle

Inrush current decreases when switching-on angle (on the voltage wave) increases. It is maximum for α=0° and minimum for α=90°.

b. Residual Flux Density

Inrush current is significantly aggravated by residual flux density, which depends upon core material characteristics and the power factor of the load at interruption when a transformer was switched off. The instant of switching-off has an effect on residual flux density depending upon the type of load.

The total current is made up of the magnetizing current component and load current component. The current interruption generally occurs at or near zero of the total current waveform. The magnetizing current passes through its maximum value before the instant at which total current is switched off for no load, lagging load and unity power factor load conditions, resulting in maximum value of residual flux density as per B- curve .

c. Series Resistance

The resistance of line between the source and transformer has a predominant effect on the inrush phenomenon. Due to the damping effect, series resistance between the transformer and source not only reduces the maximum initial inrush current but also hastens its decay rate. Transformers near a generator usually have a longer inrush because of low line resistance .Consider a series circuit of two transformers, T feeding T1 as shown in figure 2.5. When transformer T1 is energized, transformer T experiences sympathetic inrush. Resistance between T and T1 contributes mainly to the decay of inrush of T1 (and T) and not the resistance on the primary side of T.

d. Inrush Under Load

If a transformer is switched on with load, the inrush peaks are affected to some extent by the load power factor. When it is switched on under heavy load (large secondary current) with the power factor close to unity, the peak value of inrush current is smaller, and as the power factor reduces (to either lagging or leading) ,the inrush current peak is higher .

D. Inrush Current Mitigation Techniques

The phenomenon of transient transformer inrush currents was first published by Fleming in 1892 .In 1988, the only method to reduce inrush currents was the installation of pre-insertion resistors. This is however not the best solution because they must be included in the circuit breaker design and need a lot of maintenance.

In1988, Moraw et al., introduced the first concept of addressing the cause of inrush currents with the strategy called "point-on-wave controlled switching" transformer is energized phase by phase at the corresponding voltage peak.

Assuming zero residual flux in the transformer core, the moment of energisation is optimal and no transient inrush current will arise. [2] There exists one drawback: The assumption of zero residual flux is slowly true; if the transformer will be de-energized under no-load and if there is no current chopping as well as the transformer has no magnetic coupling between the phases. Finally a much more flexible method called "controlled switching taking into account the residual flux" was presented by Brunke and Fröhlich. Real substations do not consist of ideal components and suffer real conditions.

E. Simulation Of Inrush Current Transients

The inrush current transient occurring at the energisation of a transformer is a highly nonlinear phenomena. The simulation of this behavior is rather complex and a transformer has to be modeled in great detail to represent the nonlinear behavior of the magnetization, losses, and saturation effects in the core.

The main difficulties in the simulation of transformer nonlinearities in EMTP [2] The Thevenin equivalent cannot always be determined due to possible floating network formation. A transformer model for inrush current simulation based on separate magnetic and electric equivalent circuits is proposed in the pscad. The three standard ATP/EMTP models BCTRAN, TRELEG and STC (saturable transformer component) are compared for the calculation of inrush current transients. [1]

REDUCTION OF LOSSES DESIGN STAGE

Design changes to reduce transformer losses, just as in a motor, always involve tradeoffs. For example, consider varying the cross-sectional area of the transformer core. An increase tends to lower no-load loss while raising the winding loss. An increase in volts per turn reduces winding loss.while increasing the core loss. Variation in conductor area and in the electric and magnetic circuit path lengths will affect efficiency in various ways, always leading the designer to seek a cost-effective balance

To raise transformer efficiency, core loss has probably drawn the most attention. Core construction permits two important energy-saving features not applicable to industrial motors. First, the inherent co linearity between lamination orientation and the magnetic field direction allows use of grain oriented steel for transformer laminations. That greatly reduces hysteresis loss in the core-the energy required to cyclically realign the "molecular magnets" within the steel, which are randomly positioned in a non-oriented material.

Second, because laminations are sheared or slit in strips rather than being punched with slots, much thinner material can be used in a transformer core than in a rotating machine. Whereas motor laminations are usually 0.014 to 0.025 inch thick, transformer lamination thickness may be as low as 0.006, with 0.009 to 0.012 being common. That lowers eddy current loss.

A further improvement appearing during the 1980's is amorphous core material. Resembling glas more than steel, this lamination material contains no granular structure at all. Laminations only 0.001 inch thick were used in the

first mass-produced distribution transformers (25 kVA) manufactured by Westinghouse in 1986. Many similar units have been put in service since then, along with some large power transformers. Typical core loss in such a transformer is only one-third of that in a conventional unit.
The design approaches for reduction of losses are well known and proven. They consists of

- Using more material
- Better material. New Material
- Improved distribution of materials
- Improvement in cooling medium and methods

Each design tries to achieve desired specifications with minimum cost of materials or minimum weight or volume or minimum overall cost of ownership. Worldwide, more and more consumers are now purchasing transformers based on the total ownership costs, than just the first cost.

A. Minimizing Iron Losses
a. Losses in Core
Choice of metal is critical for transformer cores, and it's important that good quality magnetic steel be used. There are many grades of steel that can be used for a transformer core. Each grade has an effect on efficiency on a per-kg basis. The choice depends on how you evaluate non-load losses and total owning costs. Almost all transformer manufacturers today use steel in their cores that provides low losses due to the effects of magnetic hysteresis and eddy currents. To achieve these objectives, high permeability, cold-rolled, grain-oriented, silicon steel is almost always used. Construction of the core utilizes step lap mitered joints and the laminations are carefully stacked.
The evolution of materials used in transformer core is summarized below
Table 1.Evolution of core material

Year	**Core Material**	**Thickness (mm)**	**LOSS (W/KG At 50 Hz)**
1910	Warm rolled FeSi	0.35	2 (1.5 T)
1950	Cold rolled CRGO	0.35	1 (1.5 T)
1960	Cold rolled CRGO	0.3	0.9 (1.5T)
1965	Cold rolled CRGO	0.27	0.84 (1.5T)
1975	Amorphous metal	0.03	0.2 (1.3T)
1980	Cold rolled CRGO	0.23	0.75 (1.5T)
1985	Cold rolled CRGO	0.18	0.67 (1.5T)
1995	Cold rolled CRGO	0.17	0.64 (1.5T)
2000	Cold rolled CRGO	0.15	0.63 (1.5T)
2005	Cold rolled CRGO	0.14	0.61 (1.5T)
2010	d rolled CRGO- Amorphous metal	0.13	0.59 (1.5T)
2013-14	d rolled CRGO- Amorphous metal	**=0.11**	**= 0.50 (1.5T)**

There are two important core materials used in transformer manufacturing. Amorphous metal and CRGO. It can be seen that losses in amorphous metal core is less than 25% of that in CRGO. This material gives high permeability and is available in very thin formations (like ribbons) resulting in much less core losses than CRGO.

The tradeoff between the both types is interesting. The use of higher flux densities in CRGO (up to 1.5 T) results in higher core losses; however, less amount of copper winding is required, as the volume of core is less. This reduces the copper losses.

In amorphous core, the flux density is less and thinner laminations also help in reducing core losses. However, there is relatively a larger volume to be dealt with, resulting in longer turns of winding, i.e. higher resistance resulting in more copper losses. Thus iron losses depend upon the material and flux densities selected, but affect also the copper losses.

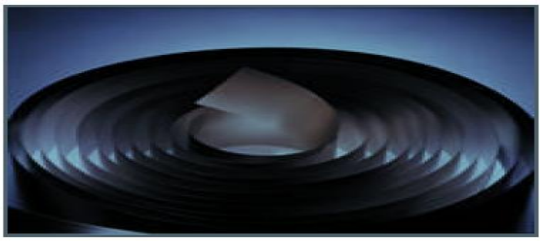

Fig.2. Amorphous core –ribbons

It becomes clear that a figure for total losses can be compared while evaluating operating cost of the transformers. The total operating cost due to losses and total investment cost forms the basis of Total Ownership Cost of a transformer.

B. Amorphous Cores

A new type of liquid-filled transformer introduced commercially in 1986 uses ultra low-loss cores made from amorphous metal; the core losses are between 60% to 70% lower than those for transformers using silicon steel. To date, these transformers have been designed for distribution operation primarily by electric utilities and use wound-cut cores of amorphous metal. Their ratings range from 10kVA through 2500kVA. The reason utilities purchase them, even though they are more expensive than silicon steel core transformers, is because of their high efficiency. The use of amorphous core liquid-filled transformers is now being expanded for use in power applications for industrial and commercial installations. This is especially true in other countries such as Japan.

Amorphous metal is a new class of material having no crystalline formation. Conventional metals possess crystalline structures in which the atoms form an orderly, repeated, three-dimensional array. Amorphous metals are characterized by a random arrangement of their atoms (because the atomic structure resembles that of glass, the material is sometimes referred to as glassy metal). This atomic structure, along with the difference in the composition and thickness of the metal, accounts for the very low hysteresis and eddy current losses in the new material.

At present, amorphous cores are not being applied in dry-type transformers. However, there is continuous developmental work being done on amorphous core transformers, and the use of this special metal in dry-type transformers may become a practical reality sometime in the future. If you're considering the use of an amorphous core transformer, you should determine the economic trade off; in other words, the price of the unit versus the cost of losses. Losses are especially important when transformers are lightly loaded, such as during the hours from about 9 p.m. to 6 a.m. When lightly loaded, the core loss becomes the largest component of a transformer's total losses. Thus, the cost of electric power at the location where such a transformer is contemplated is a very important factor in carrying out the economic analyses..

INRUSH CURRENT MEASUREMENTS

A. Test objects, configuration and measuring equipment

The test objects are three-phase oil-filled distribution transformers with a three legged core. The automated sequence of operations for the acquisition of in six repeating stages

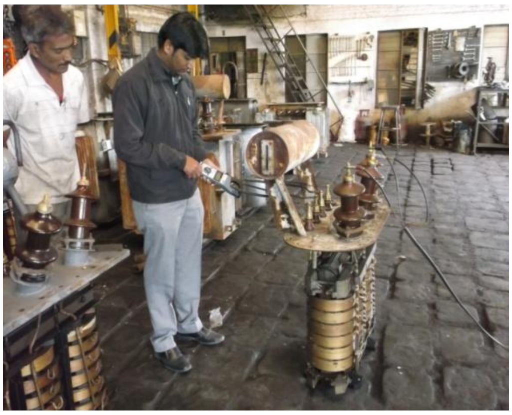

Fig.3. R,Y,B phase test of 63 KVA Transformer

II. SIMULATION RESULT

Using the magnetizing characteristic of the in-rush current for the test transformer was determined using the new model, when the supply voltage phase angle $\alpha = 0$ .The resulting transient is shown in figure 5.1 The peak in-rush current is 35.3 A, which is about 6 times the nominal load current. The transient decays during the relatively short time of about 0.25 sec, which may be explained by the high ratio of R0 to X0 in a small transformer. On the other hand, the peak magnetic flux is 0.0054 Wb, which is about 2.5 its nominal value. It's

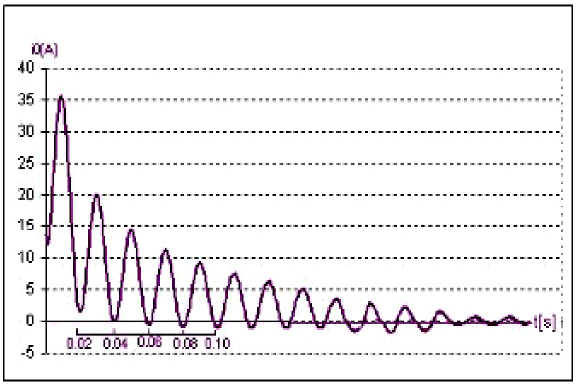

Fig.4. Simulated in-rush current and magnetic core flux for the laboratory transformer ($\alpha = 0^o$)

a periodic component decays within the same decaying time as the in-rush current.

Simulation of the laboratory transformer connected to the power supply at $\alpha = 90^o$ is shown in figure5.2. As expected, the current in this case settles immediately to its steady state value.

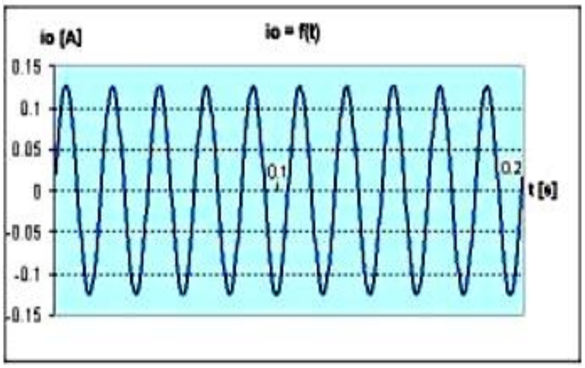

Fig.5. simulated in-rush current for the laboratory transformer ($\alpha = 0^o$)

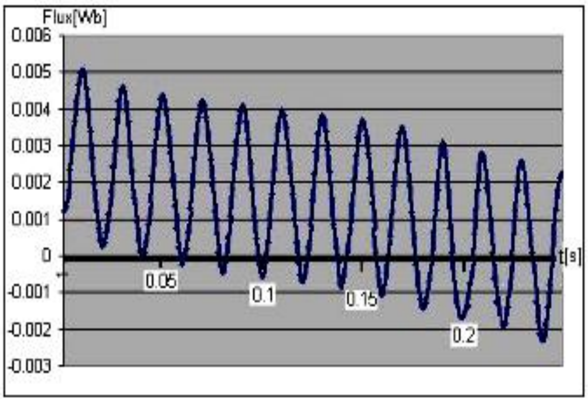

Fig.6. simulated in-rush current for the laboratory transformer ($\alpha = 90^o$).

III. CONCLUSION

I am conclude t he that how to reduce inrush current of transformer by using different mitigation method .Also measure simulation inrush current result and practical test of transformer in Emf control company.

Finally, I have changing core materials of the transformer which materials will be CRGO and Amorphous so Marge both materials we can gate good efficiency.

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