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AN ASPECT OF TRANSFORMER INRUSH CURRENT

SUMMARY

Paper analyzes a sparking phenomena that were observed on power transformers during their first few energizing. Sparks occurred on the flange between tank cover and tank side, in spite of the fact that a jumper (copper link) was used. The phenomenon was observed on transformers from different manufacturers, with various transformer ratings, three or five limb core.

Paper proposes a simple electromagnetic model for analyzing the phenomena. Three-phase power transformer is modeled in finite element method (FEM) magnetic software. Simplified 3D transformer model is used in order to simulate well known core saturation during the inrush current event. Voltages between tank cover and tank side are calculated for simulated conditions. The same model is used for calculation of possible currents flowing between tank cover and tank side, showing that a value of several kA can be reached.

In spite of the fact that the observed phenomenon is harmless mitigation measures are proposed. However, by doing nothing, sparking would disappear very soon.

Key words: Inrush current, core saturation, spark, copper jumper, tank coating

1. INTRODUCTION

Regardless the fact that power transformer inrush current phenomena (overcurrent, harmonics, noise, vibration, …) has been well known for last two decades, an additional strange and visually striking phenomenon was observed. During an inrush current event, visually strong sparks appeared between the tank cover and wall in spite of the fact that a jumper (copper link) was applied between the tank cover and wall. Complete visual appearance of the phenomenon sequence is shown in set of photographs in Figure 1.

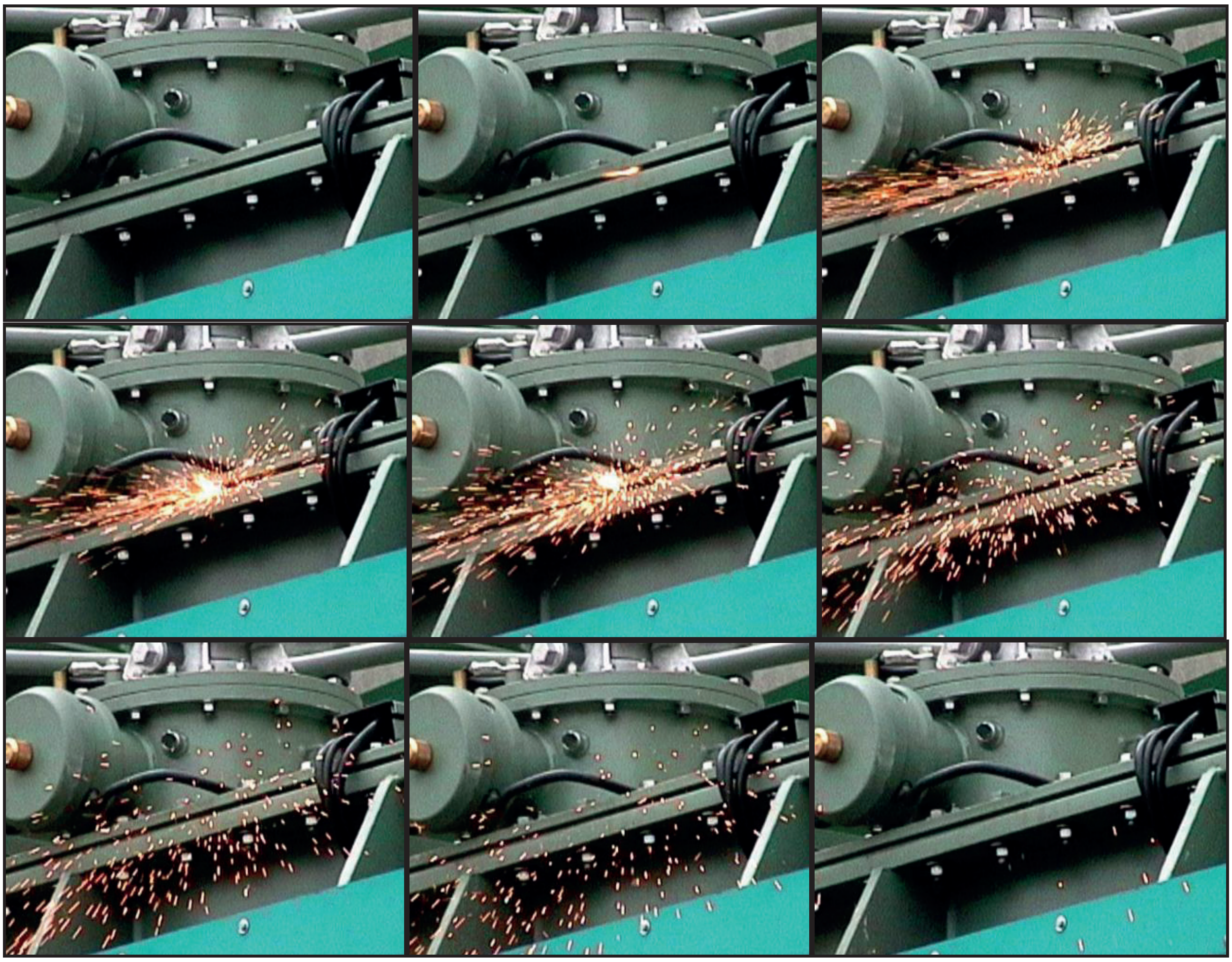

Figure 1: Sparks between tank cover and tank side (shown in detail) during inrush current event, autotransformer 220 MVA, 220 kV, sequence from left to right and from up to down

Entire phenomena in Figure 1 lasted in a range of a second. Such phenomenon was observed only on new transformers, mainly on one of the first several energizing or so, and shows a certain random behavior (in the same manner as inrush current), in a wide range of transformer power – from 40 to 500 MVA, and voltages – from 110 to 400 kV; transformers with three limb (3/0) and five limb (3/2) core type, so as from different manufactures. All observations were made on three phase transformers equipped with a bolted tank cover. It should be noted though that single phase transformers, so as three phase transformer with a bolted bell type tank, are much less abundant and this could be the reason why there has been no observations. Spark striking on 40 MVA 110 kV transformer is shown in Figure 2.

Figure 2: Sparks on tank during inrush current, transformer 40 MVA, 110 kV

Figure 1 and 2 show that the sparking may be fairly strong, astonishing the staff. Sparking does not appear on all new transformers. Moreover, it is a rare event observed only in several cases. In one case the phenomenon was observed on an about 30 years old but a completely refurbished transformer and it was also related to first energizing after refurbishment. No sparking striking events appeared on this transformer when it was new. In spite of this initial behavior, transformers operate perfectly without related complaints. Up to now there has been no evidence of any influence of the described phenomenon on dissolved gas analysis (DGA) results.

2. NUMERICAL ANALYSIS

The aim of this analysis is to find electromagnetic reasons for the reported phenomenon. First assumption is an inrush current event because the phenomenon coincides with it.

2.1. Proposed modeling approach

When switching on a transformer inrush current can drive the core into high saturation[1]. As saturation is approached, the flux is no longer confined only to the core. It is spilled to surrounding air and components. In such conditions it is quite possible that a substantial part of the flux will penetrate transformer's metal parts such as tank cover and induces eddy currents due to electrically conductive nature of tank material [2].

Closed paths of eddy currents are actually a result of different electric potentials induced by time varying magnetic flux in electrically conductive parts. However, conductive parts, such as tank cover and wall, do not have a strict electrical connection. At some places a single jumper (copper link) can be applied, but still not enabling the induced currents to have closed paths. The goal of the proposed modeling approach is to calculate differences between electric potential of the tank cover and wall at various positions on the flange. A model should include:

- 3D geometry of a transformer with modeled connections (jumpers) between tank cover and wall
- Inrush current (saturated) conditions in transformer core
- Time-varying voltage/current source

Considered three-phase 3/2 transformer model includes three basic parts; winding, core and tank (Figure 3). Tank is divided into two parts: the cover and the wall. These two parts are electrically connected only by a copper connection (jumper) and by another "test jumper" with a variable DC resistance. In order to approximate saturated conditions in the core, relative core permeability is substantially reduced to values equal or less than μ_r=100. Winding currents are given with their rated values. Model is solved in time-harmonic (quasi-stationary) sinusoidal domain in order to avoid computationally expensive time "step-by-step" (transient) calculation method.

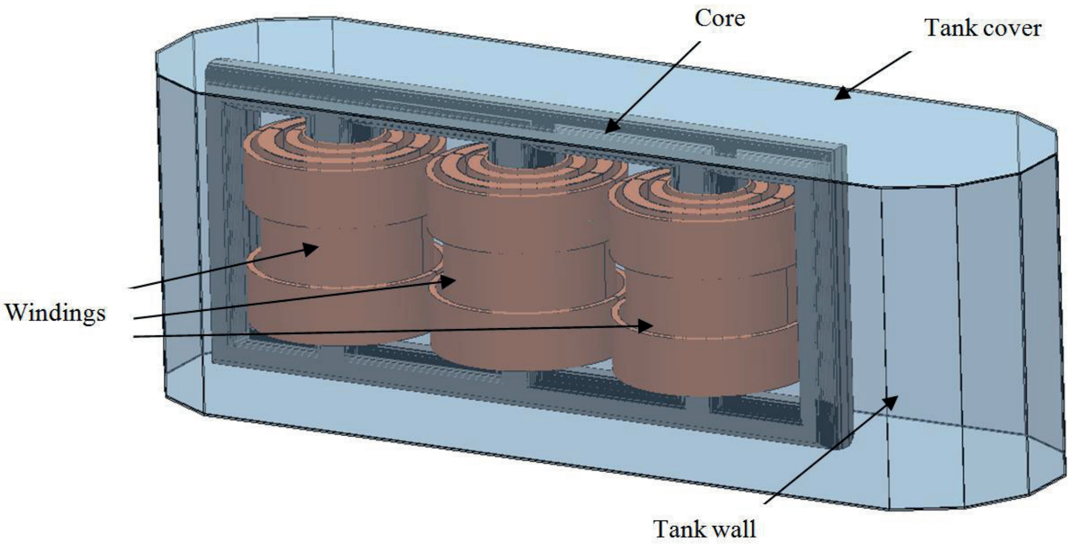

Figure 3 – 3D transformer model used in analysis

Test jumpers are placed at four different positions connecting the tank wall and cover. DC resistance of test jumpers is changed in order to observe values of currents passing through the jumper and evaluate voltage between the wall and cover at various positions. In the meantime the copper jumper has a fixed position as shown in Figure 4.

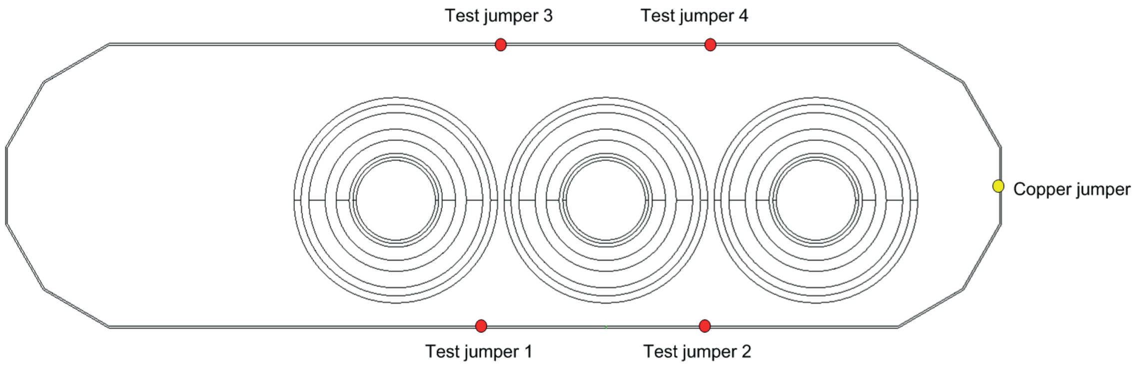

Figure 4 – Positions of test jumpers and copper jumper

2.2. Results and analysis

Several calculations have been done in MagNet [3] using FEM. Calculation model included different positions of test jumpers and different core relative permeability. Results are shown in Table I. Test jumper had a resistance of 10 kΩ. It is obvious that by reducing the permeability of the core to values close to air permeability, voltage at jumper terminals becomes higher resulting in values around 10 V. This could be considered as a voltage value that could lead to sparking at tank flanges.

Table I – Calculated voltage between test jumper terminals

Jumper	Core Rel. permeability	Voltage, V
1	100	0,652
2	100	1,397
3	100	0,361
4	100	0,990
1	1	11,811
2	1	13,484
3	1	7,997
4	1	9,515

Further on, if test jumper resistance is reduced to values of couple of mΩ, it is possible to evaluate the current flowing between the tank cover and wall. For example, test jumper 1 resistance is gradually reduced while current flowing through jumpers is observed. Results of this analysis are shown in Table II.

Table II– Calculated currents and voltages for various resistance of test jumper 1

Resistance, Ω	Current, A	Voltage, V
10000	0,001	11,89
1000	0,012	11,88
100	0,119	11,87
1	11,87	11,87
0,01	1115	11,15
0,001	8672	0,87

Results have shown that reducing the jumper's resistance, or just by short-circuiting the current path, values of currents flowing between cover and wall can go up to 10 kA.

3. SPARKING CAUSE

It is obvious that the currents calculated in previous chapter, for low jumper resistance, can have result in observed sparks but only if the majority of tank cover bolts are not able to carry the current (non-defined galvanized connection). This means that if many bolts are "insulated" from tank cover or side wall, current can become concentrated and have sparking as a consequence. This is a bit unusual because of a very high specific pressure between bolts and tank metal surface.

It is interesting to raise a question: why is this sparking happening and why has this phenomenon been recognized, by our knowledge, only for the last 15 years approximately? Actually we have no answer to this question, but some strong indication exists. According to our experience, tank coating quality (tank protection against corrosion) increased tremendously during the mentioned period. Today's tank coatings are so hard and firm providing no conductive path between the tank cover and wall in spite of the fact that all of them are properly tightened. This has been proven several times by low voltage resistance measurements performed during some other research. Because of that, the current could be concentrated (in similar manner as is simulated with a test jumper in previous chapter) and produce sparks on the "weakest place" between the tank cover and tank side wall. During transformer service, *caused by lot of similar effects*, a conductive connection between bolts and tank becomes much more likely and this side effect of inrush current event spontaneously disappears. This means that the sparking between the tank cover and wall is striking, but harmless, and will disappear quite soon in transformer service.

On the other hand, based on the facts mentioned above, the observed sparking can be understood as an unpleasant sign of a very good tank coating quality. Of course, we do not state that sparking on the tank is a desirable side effect of inrush current event.

Observed sparking can be prevented by the use of welded tank cover, but also by applying several more jumpers between the tank cover and tank side. However, by doing nothing, it will disappear soon.

4. CONCLUSION

In the paper a strange aspect of a power transformer inrush current event is explained. During this event, visually strong sparks appear between the tank cover and wall in spite of the fact that a jumper (usually copper link) between tank cover and wall is applied. Phenomenon is rare and mainly related to new transformers and transformers after detailed refurbishment which includes tank repainting. It is related especially to first several transformer energizing. There is no information about this phenomenon for (occurring on) transformers after a few months in service. Calculation revealed that during inrush current event, caused by core saturation, a huge magnetic flux may penetrate the tank. This flux may cause a very large current, up to 10 kA, between the tank cover and tank side.

This sparking seems to be caused by a large improvement in tank coating quality in last, fifteen years approximately. In that sense, observed sparking may be understood as an unpleasant sign of a very good tank coating quality, but of course, we do not state that sparking on the tank is a desirable side effect of inrush current event. We have no evidence that this phenomenon has a noticeable influence on transformer DGA results.

Observed sparking is a striking but a harmless phenomenon and can be prevented by using a welded tank cover and also by applying several more jumpers between tank cover and wall. However, by doing nothing, it will disappear very soon causing no damages.

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