A REAL CASE OF CURRENT CHOPPING OVERVOLTAGE

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Abstract - **This paper aims to present results associated to practical and computational studies carried out in order to investigate the reasons for a 30/33.6 MVA transformer insulation failures. This transformer is installed in a steel manufacture and it supplies a large load which consists in a 180 ton arc furnace. Besides field measurements and computational results, the paper goes towards the analysis of a proposition to eliminate the problem. A powerful computational tool to deal with power system time domain simulation known as SABER platform is highlighted during the discussions.**

Keywords: Transient Analysis, SABER Simulator, Current Chopping Overvoltage.

I. INTRODUCTION

This paper is mainly involved with the analysis of a practical case of transient overvoltage. This study was carried out in order to investigate the reasons for primary winding insulation failures in a 69 kV/450-310 V, 60 Hz, 30/33.6 MVA transformer. After two occurrences, followed by corresponding repairing procedures, it was found necessary to conduct measurements and investigations to identify the origin for the problems. In this way, two groups of studies were performed. The first was related to steady state operational conditions (voltage profile, harmonics, power loading, etc) and the second to transient situations (transformer or load switching). After a few set of measurement, it was possible to conclude that there were no problems associated to the steady state operation. The RMS voltage profile, the harmonic distortion and the transformer loading were found to be within normal conditions. However, the nature of the damage introduced into the transformer suggested they might be caused by transient overvoltage surges. Although a typical overvoltage protection equipment was installed, which consists of ZnO arresters, the occurrences have demonstrated they could not been acting in a proper way. With this in mind, to verify if this was the real reason for the failures, a few field switching were performed and monitored for the transformer and load. According to the recorded results this last hypothesis was found to produce expressive level of voltage surges. In this way, it appeared that the overvoltage protection was not responding to the transient. To support this thesis, computational investigations were carried out in the sequence. Again, it was found that the well known currrent chopping phenomenon could be the explanation for the transformer high voltage winding failure. Therefore, without going any further into the direction of the traditional and well established current chopping theory, this papers describes:

- First, the results obtained from site measurements under transformer and load switching conditions;
- Then, computational studies performed in order to support the above findings;
- Finally, the proposition and performance evaluation of a practical solution to eliminate the surges and protect the transformer against the current chopping overvoltages.

Thus, this paper is focused towards a practical case description then a new theory or approach. As already mentioned, this theory is quite well established [1,2] and will not be reviewed in this work.

II. THE SIMPLIFIED SYSTEM

Fig. 1 shows the simplified electrical diagram in the vicinity of the transformer/load.

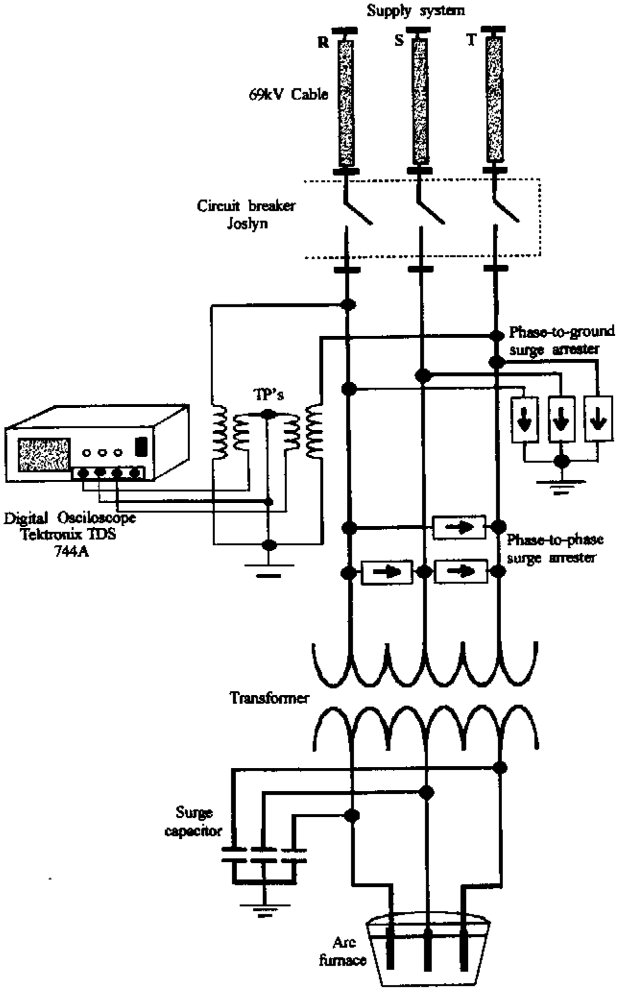

Fig. 1. Single line Diagram.

It can be seen that a 69 kV busbar feeds a transformer through a cable and a Joslyn circuit breaker. This specific breaker characteristics are necessary for this type of application. The overvoltage protection is offered by three phase-to-ground ZnO arresters and three phase-to-phase units. On the secondary side there are surge capacitors which, by the time of the measurements were out of order and disconnected from the system. Finally, the figure shows the load which consists of a 180 ton arc furnace. Besides these components, the figure also indicates the instrumentation location. It can be seen they have been installed on the primary side of the transformer. Therefore, the measurement results are related to the 69 kV busbar.

The main system parameters are given bellow.

Supply System

Voltage [kV]	**Short-circuit Level [MVA]**
69	400

Cable

Rated Voltage [kV]	**Length [m]**	**Cross Section [mm²]**	**R [Ω/km]**	**XL [Ω/km]**	**XC [Ω/km]**
69	950	185	0,09	0,12574	6724

Circuit Breaker Joslyn

Voltage [kV]	**Rated Current [A]**
69	400

Phase-to-Phase Surge Arrester

Disruptive Voltage [kV]	**Current [kA]**
120	20

Phase-to-Ground Surge Arrester

Disruptive Voltage [kV]	**Current [kA]**
72	20

Transformer

Connection	**Primary Voltage [kV]**	**Secondary Voltage [V]**	**X [%]**	**R [%]**
Δ - Δ	69	450-310	7.5	0.5

Secondary Surge Capacitor

Connection	**Phase Capacitance [μF]**
Y⏚	0.5

Arc Furnace

Rated Power [MVA]	**Rated Voltage [V]**	**Power Factor**
25	315	0.8

III. THE INSTRUMENTATION USED

Two equipment were used for site measurements. They are:

TYPE	**MANUFACTURE**	**MODEL**
DIGITAL OSCILLOSCOPE	Tektronix	TDS 744A
TRANSIENT RECORDER	Amprobe	LAS 800

IV. THE SOFTWARE

The software used is called SABER Simulator. It is a powerful computational tool originally developed and distributed by Analogy, Inc. (USA). It uses time domain strategy to study different circuit arrangements. Although the product was initially commercialised to cope mainly with electronic circuits, this programme was fully adapted to deal with power systems studies. This was a result of developments in the Electrical Engineering Department of the Federal University of Uberlandia and nowadays this programme has been successfully used for different studies related to general electrical engineering purposes. Several electronic and power system components are fully represented in the new SABER version. Amongst others, very complete models for non-linear transformers, overhead lines, cables, three phase induction motors, circuit-breakers, frequency converters, etc are ready for use. Besides, the integrated SABER structure offers a powerful graphic interface which is very helpful for users.

V. MEASUREMENT RESULTS

According to Fig. 1, the measurements were carried out on the 69 kV side. Three sets of transient operations were performed:

- Circuit-breaker opening manoeuvre under transformer load conditions;

- Circuit-breaker closing manoeuvre under no-load conditions for the transformer;
- Circuit-breaker opening manoeuvre under no-load conditions for the transformer.

For each situation, quite a few number of operations were made. However, only a small number of results are given in this paper. Fig. 2a and 2b are related to circuit breaker opening operation when the transformer is supplying the arc furnace. The first figure shows the complete waveform and the second gives a zoom in the region were the transient occurs. Two phase-to-ground voltages are given.

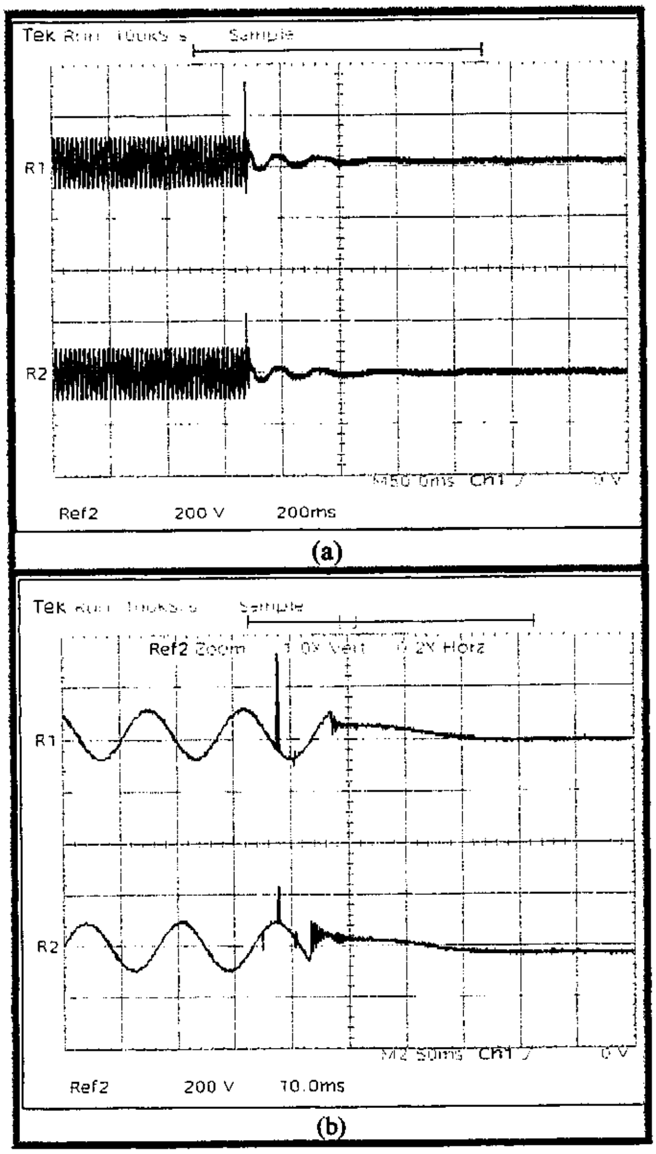

Fig. 2. Opening the circuit breaker under transformer load conditions.

(a) Complete oscillogram (b) Zoom

As illustrated by the above figures, a substantial overvoltage occurred during the specified manoeuvre. In fact, a deep analysis on the waveforms shows that besides the surge itself, a circuit breaker restrike phenomenon was also found. This may explain the reason the circuit breaker is requiring maintenance after say 40000 operations while the manufacturer states it is suitable to stand around 80000 manoeuvres. Another interesting aspect related to the recorded results is that the corresponding phase-to-phase voltage does not have the same overvoltage encountered for the phase-to-ground one. Therefore, it should not be expected the phase-to-phase arresters to operate. However, the measurements have demonstrated the phase-to-ground arresters, which should operated, did not respond to the registered surges. This could be caused by internal arrester problems or specification, as well as to ground connections, grounding impedance or other motive.

Following the sequence of switching, a set of situations involving circuit breaker closing under transformer no-load conditions were made. Fig. 3a and 3b give typical results derived from these manoeuvres.

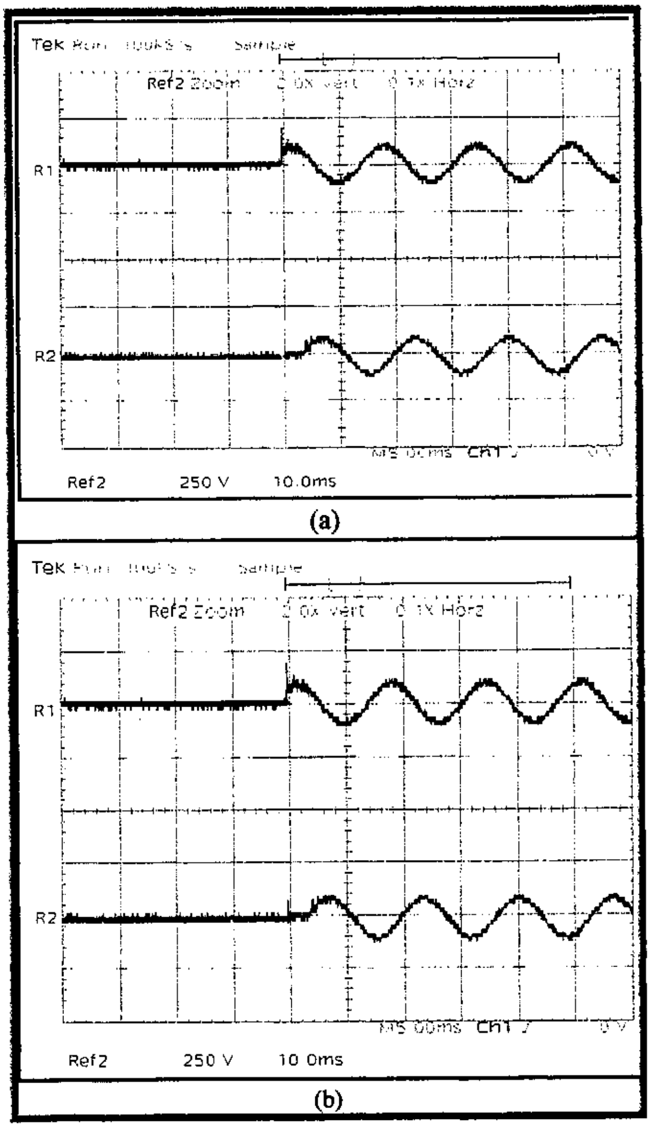

Fig. 3. Closing the circuit breaker under transformer no-load conditions.

(a) Complete oscillogram (b) Zoom

According to the above results no appreciable overvoltage occurred during the specified manoeuvre.

Finally, Fig. 4a and 4b illustrate two phase-to-ground voltage waveforms when the breaker is switched off under no-load conditions for the transformer.

Again, no further problems were found during this type of operation.

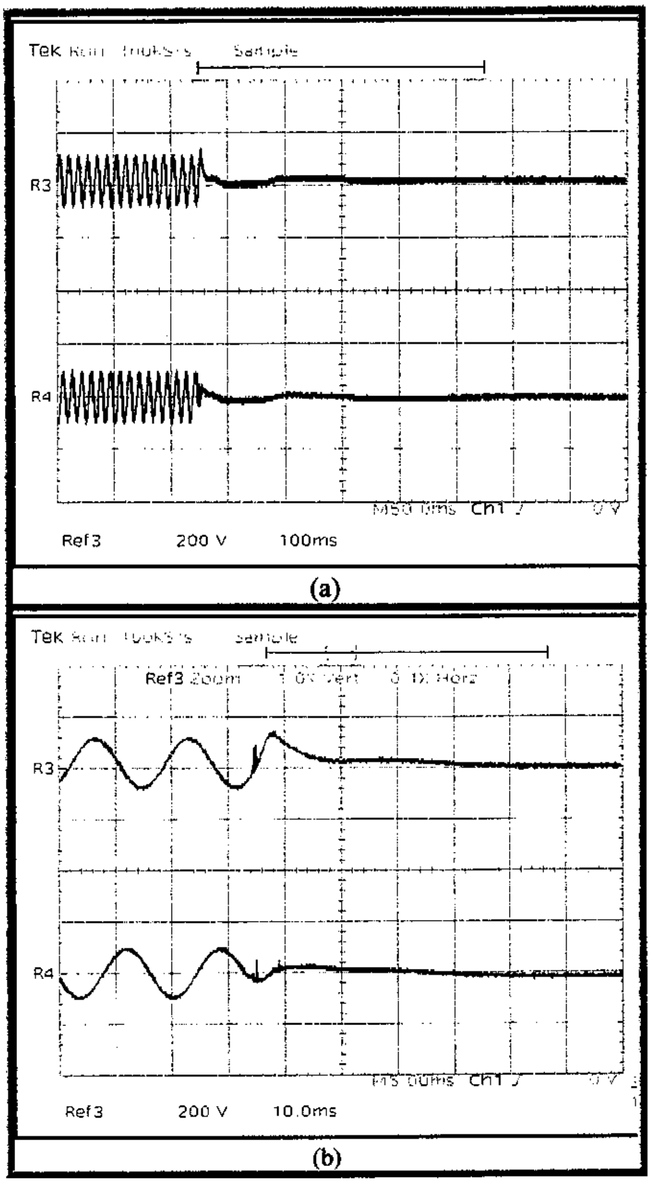

Fig. 4. Opening the circuit breaker under transformer no-load conditions.

(a) Complete oscillogram (b) Zoom

After monitoring all the above switching conditions, it was concluded that the transformer insulation failures on the high voltage windings could be attributed to the first type of manoeuvre, i.e. to the frequent switch off operation as necessary to unload the iron produced by the arc furnace. This happens several times per day. Also, as previously stated, it was observed that the transformer secondary winding surge capacitors were out of operation.

Without going into further theory, it can be said the overvoltage measured can be directly related to the abrupt arc furnace/transformer inductive current interruption. This is the well known Current Chopping phenomenon.

VI. COMPUTATIONAL RESULTS

In order to have an alternative way to support the previous conclusions, computational studies were then conducted to verify the occurrence of the current chopping effect for the given electrical system. Only the circuit-breaker switching off operation under load condition was considered and three cases were simulated:

- Switching off the system under load conditions with no arresters and no surge capacitors;
- Switching off the system under load conditions with the arresters and no surge capacitors;
- As above, including a new group of phase-to-ground surge capacitors. These are associated to the proposed solution and are to be installed on the primary side of the transformer. Again, the secondary side surge capacitors were disregarded.

The current chopping was taken when the load current assumed a value of 20 A. Naturally, any other current would result in similar waveforms but different level for the overvoltages.

The first case above mentioned aims to simulate the situation when, for any reason, the arresters do not act as it should be expected. This condition could arise from arrester failure or improper specification, as well as grounding connections problems or others. The three-phase to ground voltages are illustrated in Figure 5. Again, the overvoltage produced by the current chopping can be easily seen. In accordance with the results, the surge achieved more than twice the normal peak value. However, due to possible inaccuracy in the data supplied to the programme, the waveforms should be considered more qualitative than quantitative for analysis purposes.

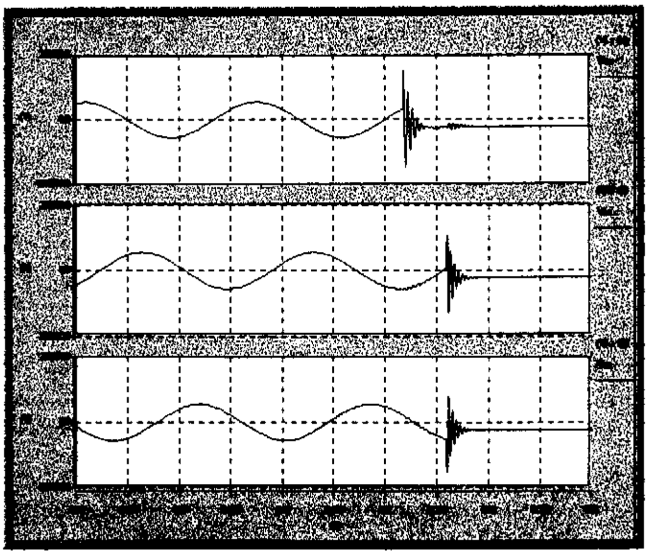

Fig. 5. Computational transient overvoltage generated by opening the circuit-breaker without including arresters.

The second case shows corresponding results by including the arresters. As it should be expected, the phenomenon is greatly reduced by their action. This is given in Fig. 6.

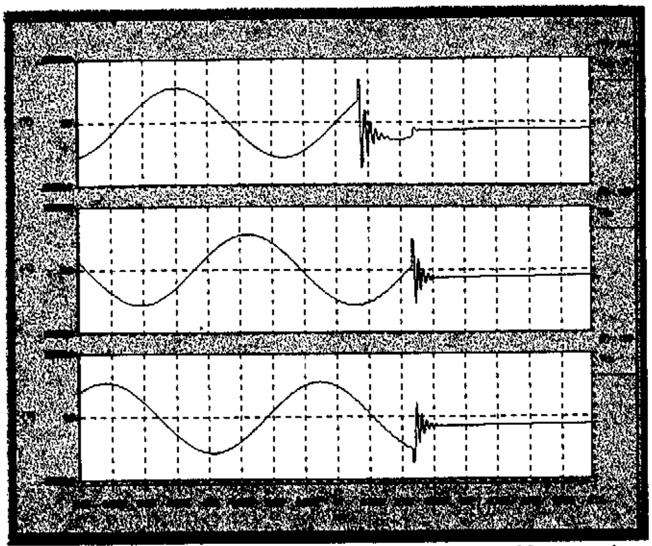

Fig. 6. Computational transient overvoltage generated by opening the circuit-breaker with arresters.

Finally, Fig. 7 is related to the switching operation described as the first case, but including three surge capacitors on the primary side of the transformer. These capacitors have been suggested as a possible solution for the insulation failure and the individual values are of 100 uF. This capacitance was specified by referring the secondary surge capacitor to the primary side and by performing a set of computational studies.

The results given by Fig. 7 are clear enough to emphasise the surge capacitor efficiency on eliminating the surges found in Fig. 5.

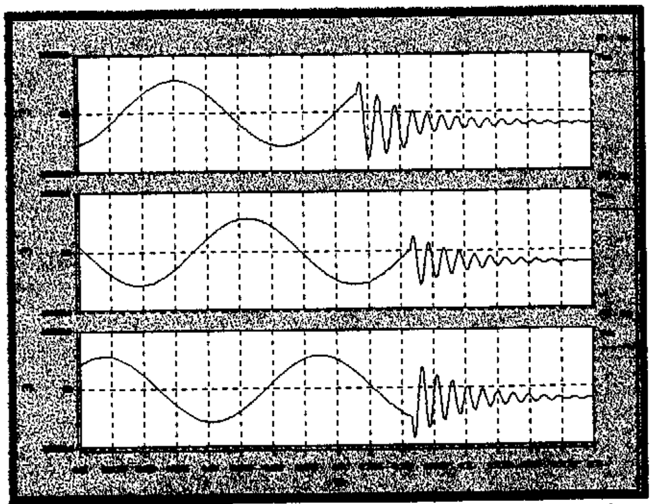

Fig. 7. Computational transient overvoltage generated by opening the circuit-breaker without arresters and including surge capacitors.

To illustrate even more the effect of the surge capacitor, Fig. 8 shows a comparative zoom for the transient with and without the inclusion of the capacitors. Again, the arresters were ignored during the simulation.

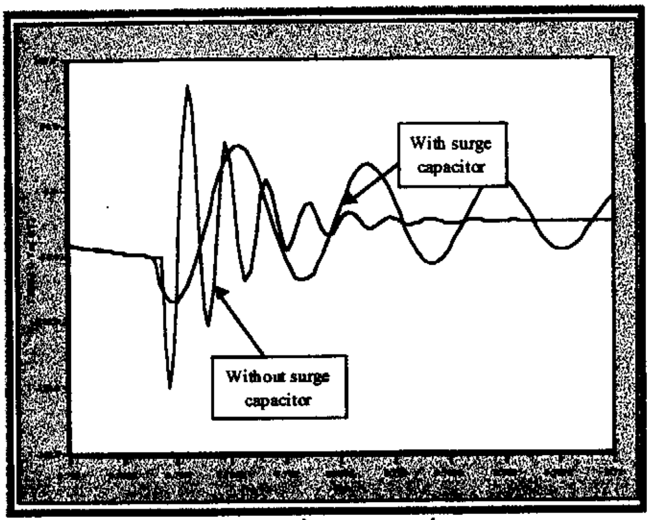

Fig. 8. Surge capacitor comparative zoom.

VII. CONCLUSIONS

This paper presented the results of investigations carried out to identify the reasons for a 69 kV/450-310 V, 60 Hz, 30/33.6 MVA transformer insulation failures. The search was initiated by measuring the most significant electrical quantities associated to the transformer steady state operating conditions. The results have demonstrated there were no further problems related to the RMS voltage profile, harmonics or loading. Then, the work focused the transient situations derived from typical and normal switching operations as required by the process itself. By following this strategy, substantial overvoltages were found during circuit-breaker manoeuvre under load conditions. The level achieved by these transients were high enough to justify the occurrences. This was specially noticed under circuit-breaker switch off operation with the arc furnace inserted into the system. The conclusion was that the arrester did not respond properly to the transients. This was probably a result of ground connections problems than arrester misoperation. Then, the paper went into the direction of computational investigations. The most important effect, i.e. the circuit breaker opening operation under load conditions was then simulated and similar results were obtained. In the end, a practical proposition was made to solve the problem. It consists in using phase-to-ground surge capacitors to be installed on the primary side of the transformer. Again, by utilising the same programme, the overall system was simulated and the results demonstrated the adequacy of the solution.

VIII. REFERENCES

[1] Greenwood, A., *Electrical Transients in Power Systems*, Wiley-Intersciense, 1971.

[2] Cigré Working Group 13.02, "Interruption of Small Inductive Current", *Electra*, 1980, pp.71-102.