INTERACTION BETWEEN POWER ELECTRONIC COMPONENTS AND DISTRIBUTION TRANSFORMERS – RISK EVALUATION AND MITIGATION TECHNIQUES

Gerd Voss[1], **Sidney Mattatia**[2], **Gerd Bajog**[3]
ABB Sécheron SA[1], Services Industriels de Genève SA[2], Bajog Elektronik GmbH[3]
Switzerland
gerd.Voss@ch.abb.com

INTRODUCTION

The Geneva city utility SIG operates a large medium / low voltage distribution network with a high number of distribution transformers in place. Within the last approx. 4 years an unusual high number of transformer failed due to a premature aging. These units were all delivered between beginning of 1996 until mid 1999. Only sizes of 630 kVA and 1000 kVA were affected. Within other MV networks as well 400 kVA and 1250 kVA units failed, however a smaller number.

Nondescript system failures, computer-/ control system-/ and process interruptions, apparatus and system destructions, explosions and fires were the reasons for 238 customer ordered measurements, network analyses and repairs in Germany, Austria, Switzerland, Italy and France throughout the years 2003 and 2004. Craftsmen's shops, doctor's cabinets, general stores, special repairshops, appartment houses in small and large cities, large offices, banking- and insurance buildings, large oil refineries, industries such as metal plastics manufacturing were affected internationally.*
At 157 cases systems and parts of them were destroyed. 7 cases resulted in building destructions following explosions and fire. Acc. to our knowledge the disturbances within the networks grew steadily from beginning of 1996 until the year 2000 and the increased exponentially. Within 229 cases the same cause could be determined.
Concerned apparatus are capacitor bank with and without chokes, active filters, transformers, capacitors, process controls, computers, light controls, telephone switchboards, safety units (alarm and fire detectors) inverters and electronically controlled systems.

1. TYPICAL DISTORTION SPECTRUM

Fig. 1 and 2 show two different ways of presenting distorsions acting on a transformer in a transformer station where several units were destroyed. Fig 1 is a representation in function of time and fig. 2 is the perturbation spectrum in function of the frequency.

At an automated stock in Austria, a thyristor controlled drive and other 6-pulses dc-drives created sporadic and repetitive voltage spikes and thus disturbances of the network with 5.32 kV/microsecs. Standard components being connected to the network tolerate normally a dU/dt of 50..150 V/microsecs.

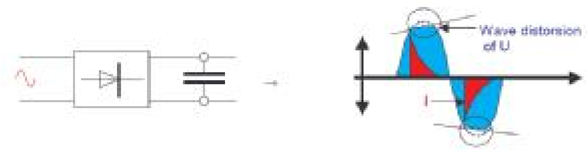
Similar network conditions can be found in Canada, USA, Malaysia and China.
Basically the load of the network of SIG is not different from similar networks within Switzerland or outside.

The waveform of the currents is well known by the power quality specialists and are seen as well in other networks in Switzerland and outside especially related to :

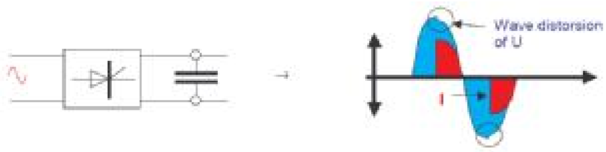
- Power electronics (diodes, thyristors, IGBT, IGCT, etc.)
- Consumer electronics (TV, video, PC, low energy lamps, etc.)

Network remote control does not pose a challenge and has been supported by older generation transformers.
Known and by measurements reconfirmed influences within the LV-network of SIG are:

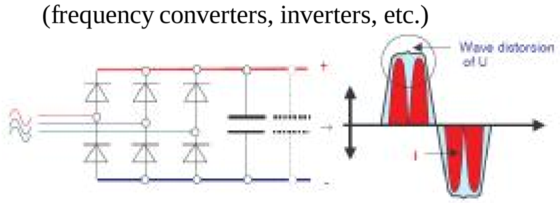
- Many single phase converters with non regulated rectifier followed by a capacitor



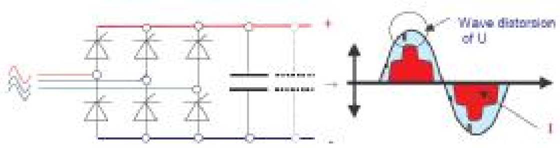
- Many single phase converters with regulated rectifier followed by a capacitor



- Three phases non regulated rectifiers of a certain size (> 10 kVA) with 6 pulses rectifier bridge (frequency converters, inverters, etc.)



- Three phases regulated rectifiers of a certain size (> 10 kVA) with 6 pulses rectifier bridge (induction furnaces)



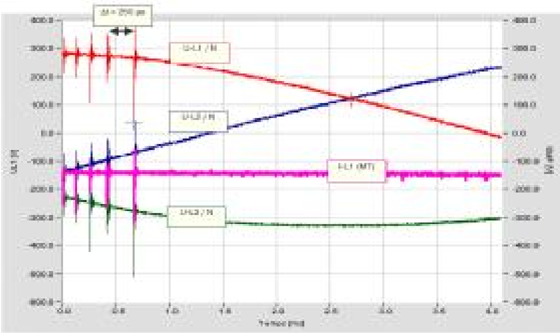


Fig.1 Typical distorsions in a shopping center (phase voltage vs. time)

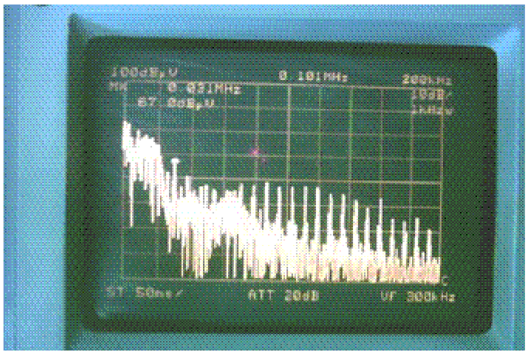


Fig.2 Perturbations spectrum in the range 10 – 200 kHz (dBmicroV)

2. POSSIBLE CAUSES

SMPS (switched mode power supplies),dimmers, thyristor bridges, IGBTs, and power transistors are all pulsed in the lower kHz range (2..10 kHz). Every single switching event represents a short circuit and thus emits the whole disturbance spectrum with max. energy content to the network. These high energy spikes with a high dU/dt are reaching the network and often have values of > 3 kV/microsecs. towards the network and > 10 kV/microsecs. towards the driven device (motor).
Mechanical contactors are much slower than power electronics, however the energy rich arc produced emits a similar disturbance to the network.

The sources of disturbances are damped only by the network impedances and resistances. In practice however even in distances > 500 m the energy content is large enough to destroy capacitors, network side electronics and even transformers > 1000 kVA
Standard components, such as small capacitors are designed to heal from a small break through of the isolating foils, but lower capacity and increased leackage currents show the pre-damage of the component resulting sooner or later in it's destruction. A similar stress can be observed as well at the enamel of copper conductors at inductivities and transformers.

Transformers dissipate these energy in their windings but throughout the years the stress will weaken the isolation up to a point where – depending of the actual load conditions – small arcs will appear and later on a short circuit will result.
Thus it is not astonishing that the lifetime of capacitors, transistors, and transformers under severe conditions is reduced to several weeks only.

Figure 3 shows that a lift drive without sufficient spike suppression in an appartment building destroying several machine controls and 5 PCs.

Failed transformers showed a fault in the isolation at the mid of the medium voltage coil (Fig. 4), at a zone where the electric stress from steep voltage fronts are normally not very high.

This leads to the assumption that resonance phenomena may be the cause. The inspection of the coil of damaged transformers and their isolation as well as an oil and gas analysis did not show any premature ageing. Other transformers of the same manufacturing lot , being in service since 6-7 years, have been retested under the same condition as the new ones (100 % applied voltage test).

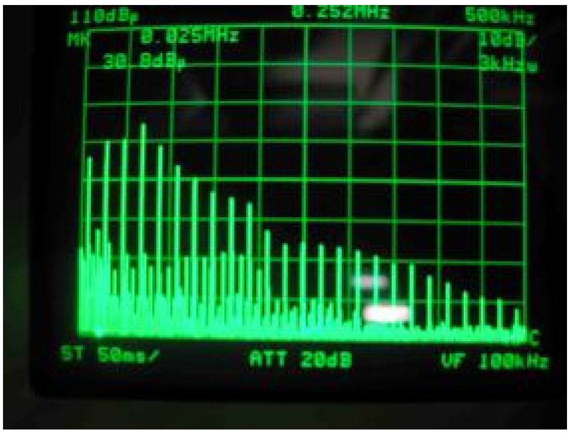


Fig.3 Network analysis in an Munich appartment building

Fig.4 Primary windings of distribution transformer after a failure.

3. IMPACT ON THE CUSTOMERS AND THE UTILITY

In the case of a distribution transformer failure the local utility receives numerous complaints from unsatisfied customers, has to immediately react on the supply interruptions causing additional workload and financial consequences for urgent repair works at nights and weekends. In addition new ways of redundant power supply has to be found and finally additional equipment has to be ready to be immediately despatched to sensitive customers.
The energy consumers suddenly face interruptions (1…7 hours long) at an avg. of 4 hours, it may be several hundreds not being supplied to and not having TV, video, PC.
Production loss, late deliveries, adulterated food, are some of the results. Claustrophobic reactions in lifts up to panicking, failed red lights at street crossings, waste water pumps, air condition or heating fails. Most important reserve units (UPS) have an autonomy of only 30 min. Additionally alarm systems do not operate anymore, the danger of fire increases, disabled persons being dependant of electronic devices are endangered.

4. APPLICABLE STANDARDS

Originally the transients in networks have been covered by the VDE 0871 (in Germany) defining max. levels in a range of 10 kHz up to 30 MHz. Since January 1996 the modified EN 55011…22/103 and /104 are applicable, covering only the range of 150 kHz up to 30 MHz. Additional standards, such as EN 50160 and EN 61000 ff. cover mainly flicker, harmonics and voltage changes.
Distribution transformers are designed in accordance to the IEC 600076. During the manufacturing period of 1996..1999 more than 1500 transformers at 630 kVA and 1600 kVA have been produced out of which approx. 80 have failed, 30 alone in the network of Geneva. All materials, paper, copper,oil, core, etc have been tested in accordance to the relevant standards.

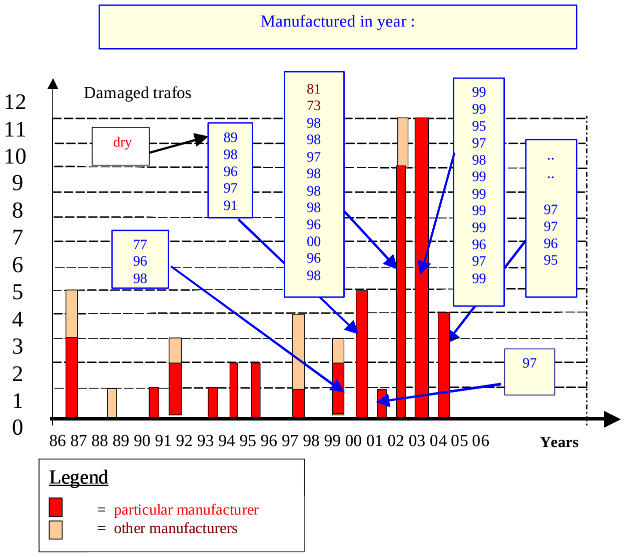


Fig.5 Damaged transformers in the said network since 1996 (no. vs. years)

5. FUTURE TRENDS

It cannot be expected that a reduction of the permissible transient levels, esp. covering the range of below 150 kHz will be integrated into the international standards. Thus an increasing number of failures of electronics and other equipment can be awaited.
The trend to cables in networks will reduce the network impedance further and as a consequence increase the short circuit power.

6. POSSIBLE SOLUTIONS

Systems and apparatus can be protected against high dU/dt by the right measures. Only installing varistors and the like will not be sufficient. A correct dimensioned filtering will be necessary. Whereas the correct earthing methods are well known in the area of distribution, the correct HF earthing must be taken into account in future.
With distribution transformers the classical methods of measuring the premature aging have been applied on a dozen of units, however failed to predict the point in time of a transformer failure. It can only be recommended to identify the network transients and determine the risk by a questionnaire.
Generally a reinforcement of the winding isolation is indispensible and may result in an isolation class one step higher (i.e. BIL 175) than required by the standards. In certain applications even shield windings may be necessary.

7. CONCLUSIONS

At 2004, 26 units have been exchanged as a preventive measure in the said network because of the non-delivery of electricity which had reached 44 MWh. Relying on statistics does not help at all: The interruption of 6800 customers due to transformer failures has reached 9 % in the reliability statistics, whereas the transformers manufactured prior to 1996 showed < 0.1%.
The failure rates can neither be explained just by an inferior production quality or by inadequate maintenance nor by typical known transients; it must be some atypical and complex interactions between the connected loads and transformers.
It seems that the actual design of the distribution transformers, even being in line with the existing standards do not suffice anymore today's stresses caused for example by modern power electronics. A new dimensioning, including more rigorous testing should be envisaged by adapting the relevant standards.

8. REFERENCES

[1] Fast Transients and their Effect on Transformer Insulation : Simulation and Measurements, H. De Herdt and co-authors, CIRED 2001
[2] Investigation on Failures of Oil Filled Distribution Transformers in Switzerland, Prof. Rufer and co-authors, June 2003, Internal report
*(*source of data: Bajog Elektronik GmbH)*