Transients due to Load Energizing in Low Voltage Systems

Anna Tjäder, Jaap Daalder

Chalmers University of Technology, Department of Electrical Engineering, Gothenburg, Sweden,

anna.tjader@elteknik.chalmers.se, jaap.daalder@elteknik.chalmers.se

***Introduction* — Measurements and simulations have been performed in low voltage networks to analyze switching transients from switched power supplies. The measurements have been taken in two different networks, one laboratory network with practically no other load present and one office network with many computers connected. The simulations have been performed in PSpice simulation program. The results show that large voltage and current transients are produced when the load is energized. The energizing of several computers simultaneously can result in very high amplitudes.**

I. Introduction

At one occasion when the power was returning after a black out at an office at Chalmers University of Technology, the low-voltage circuit breaker tripped due to the combined inrush currents of all computers. The reason for this was that almost all computers were in stand by mode before the blackout. The computers had to be switched off and then turned on in batches to avoid a new tripping. The frequency range detected in the measurements is about 100 kHz. This is the frequency range where the remote electricity meters will work. There is a probability that transients from energizing ordinary load in households will disturb the electricity meters, making them leave disrupted data or fail in the communication. This issue has to be further investigated. With this background and with other transient related problems in several industrial companies in Sweden [1] a reason for further investigating switching transients from ordinary low voltage loads was motivated

II. PERFORMANCE

The measurements have been performed using both a strong (laboratory) network and a weak (office) network. The loads in the measurement consisted of computers and computer screens. The main measurement system was a Dranetz 658 Power Quality Monitor with an impulse-sampling rate of 1.84 MHz. The focus was on the transients caused by energizing actions, as the de-energizing actions did not cause any transients. In the first measurement series one computer was energized, and in the second measurement two computers were switched on a few seconds after each other. In this case the transient behavior from the second switching was studied.

The simulations were performed using PSpice simulation program. The simulation circuit was a switched-mode power supply used in computers. The load behind the power supply is not present in the simulation circuit, as the time range studied is only some tenths of milliseconds. The values of the system components were taken from the transformer and cable data for the laboratory and office system respectively. After examining the power supply in the computers a simplified circuit was used in the simulations.

The differences in the transient behavior for the two networks were almost undetectable. The reason is that the transients are measured close to the load and the influence from the network characteristics was small. The net impedance behind the load have some but limited influence on the oscillatory frequency.

III. Voltage measurements and simulations

A. Measurements

In this system load is present during laboratory experiments; otherwise little load is present. As the propagation of switching transients is limited to a short distance [2], the energy-absorbing load has to be located very close to where the energizing action is taking place if damping of the transient will occur. The measurements have shown that load has to be present at the same feeder to influence on the transient behavior. Load present in the network affects the oscillating frequency. Fig. 1 shows the scheme of the power network and the first part of the power supply for the computer.

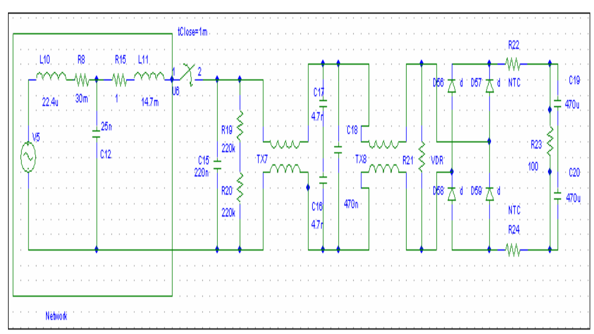

Fig. 1. Network and computer power supply

A simplified circuit is used in the simulations. Some of the small capacitors with values of some nanofarads are oscillating with the inductances in the circuit at a very high frequency. Fig. 2. shows a voltage transient by a computer energizing action.

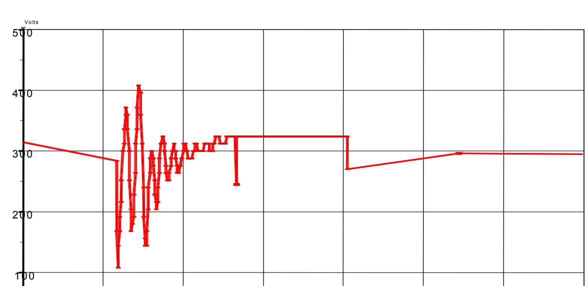

Fig. 2. Voltage transient due to computer switching, measurement, high resolution.

Analyzing the voltage transient in the figure results in the following values:

- Minimum value in the oscillation 110 V, maximum value 410 V
- Maximum oscillation amplitude p-p 300 V
- Main oscillation frequency approximately 110 kHz

The transient observed are typical for the tested equipment. Higher frequency components can be detected in the oscillation by frequency analysis.

B. Simulations

The first part of the circuit shown in Fig. 3is representing the transformer and the cables of the laboratory network. The second part, switched mode power, are the computer components.

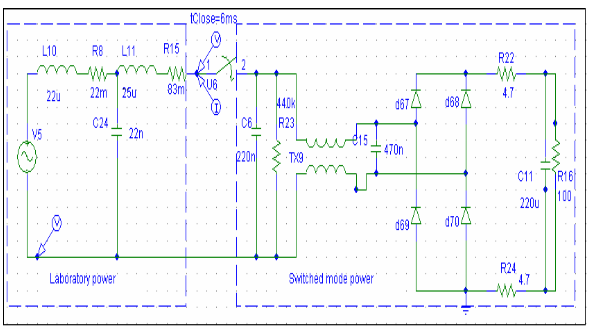

Fig. 3. The network and the power supply of a computer used in the simulations.

The simulation result is shown in Fig. 4. Simulating the circuit gives the following results:

- Minimum value in the oscillation is 10V, maximum value 430 V
- Maximum oscillation amplitude p-p 420 V
- Oscillation frequency 80 kHz

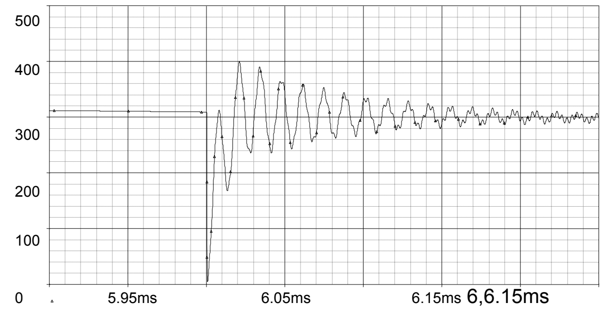

Fig. 4. Voltage transient due to computer switching, simulation, high resolution.

The oscillation frequency is the frequency between the network impedance and the network capacitor plus the source capacitor:

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

The calculated frequency from Eq. (1) for the laboratory supply network is 58.5 kHz compared to the simulated frequency derived form the plot, which is 80 kHz. The difference in the frequency between the calculated value from Eq. (1) and the estimated value from Fig. 4 indicated the influence from other components in the circuit. A simulation with a circuit shown in Fig. 5, where only the first capacitor in the switched mode power supply is present, results in a frequency of 50 kHz, which is well corresponding to the calculated results from Eq. (1).

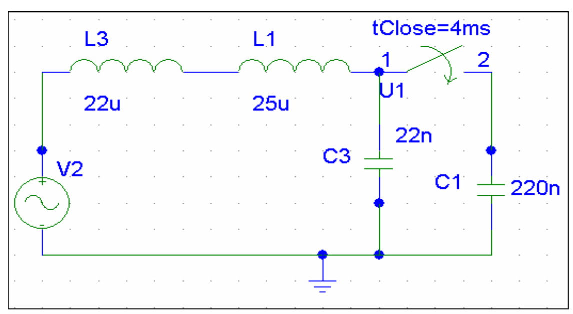

Fig. 5. Simulation test circuit

This indicates that Eq. (1) is not fully explaining the frequency behavior of the circuit. The other components in the switched mode power supply are also affecting the frequency behavior. The simulation indicates that the frequency is increasing when the whole circuit is present. A frequency analysis FFT, made on the simulation results in Fig. 4 indicates several frequencies in the resulting oscillation.

C. Comparison between measurements and simulations

The difference in frequency between the measurements and the simulations is a factor 1.4. The frequency derived from the simulations is 80 kHz compared to the frequency in the measurement which is 110 kHz. In the simulation it is assumed that the network is unloaded. If load is present in the network the inductance oscillating with the capacitance in the computer may be lower than the values in the simulated circuit. If a simulation is performed with load present before the computer as in Fig. 6 an oscillation frequency of approximately 100 kHz is detected. This indicates that a certain amount of load increases the oscillation frequency. The load characteristics have influence on the oscillation frequency and the transient characteristics. It also explains that the oscillating frequency is not always the same in different measurements.

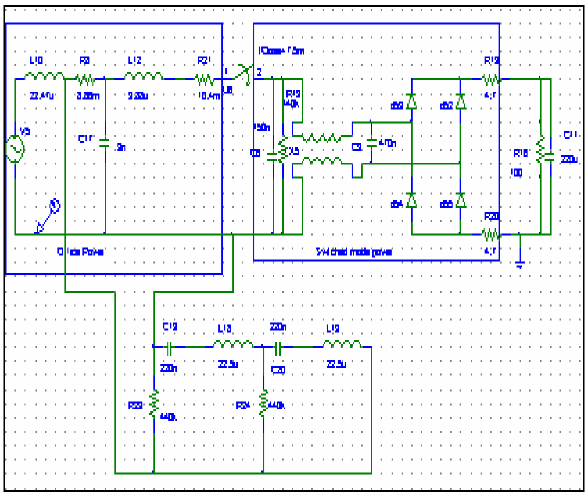

Fig. 6. Switched power supply with load present before computer

IV. CURRENT MEASUREMENTS AND SIMULATIONS

D. Measurements

The current measurements were performed with a 200 MHz oscilloscope. A current measurement is shown in Fig. 7.

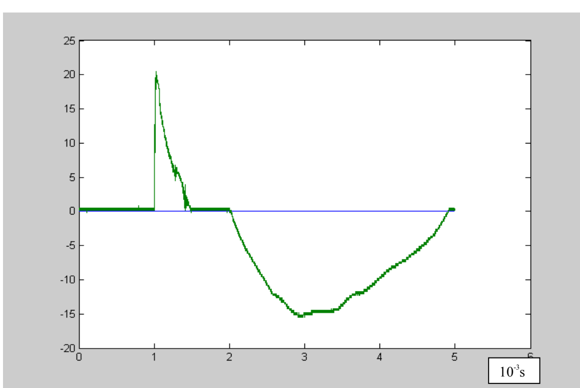

Fig. 7. Current transient due to computer switching, measurement

The initial current transient reaches a value of 20 A, and has a duration of 0.5 ms. this measurement show a current transient not far from the voltage zero crossing. An attempt was made to measure the maximum inrush current, with an energizing action at voltage maximum. Close to voltage maximum an initial current transient of almost 40 A was detected, see Fig. 8.

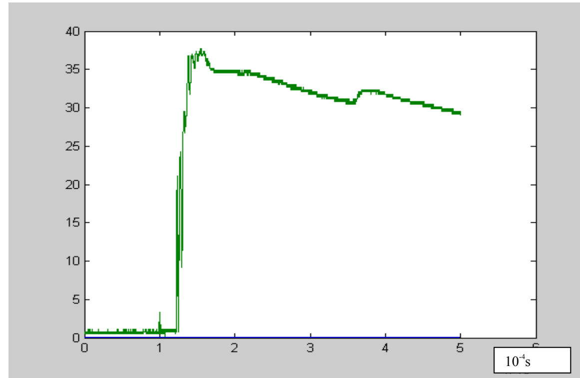

Fig. 8. Detection of maximum inrush current

E. Simulations

The simulation circuit is shown in Fig. 9. The initial current transient reaches a value of 16 A, and has a duration of 0.8 ms. See Fig. 9.

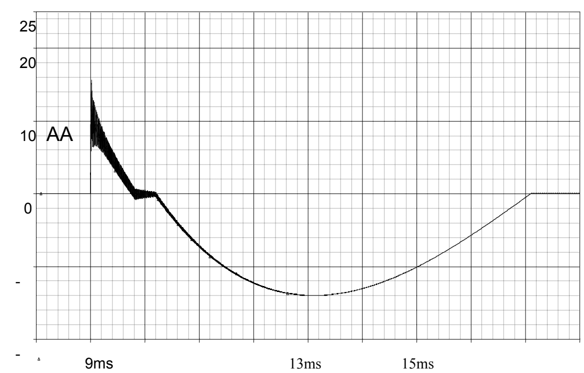

Fig. 9. Current transient due to computer switching, simulation

F. Comparison between measurements and simulations

The characteristics for the measurements and simulations correspond well. After some oscillations the current reaches its operating point which is approximately 0.4 A for one computer. The maximum inrush current is reached when the energizing of the computer takes place at voltage maximum. Simulations show that the maximum current transient can reach above 50 A.

V. VOLTAGE MEASUREMENTS AND SIMULATIONS TWO COMPUTERS

G. Measurements

In the measurements one computer was energized and after a short period a second computer was energized. The transient from the second computer energizing is shown in Fig. 10. The characteristics for the transient are depending on the load located on the same feeder. The existing load absorbs a part of the transient energy. The amplitude is smaller than the voltage transient for the case with one computer.

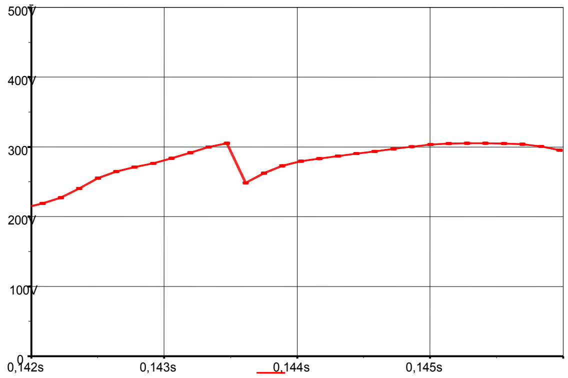

Fig. 10. Voltage transient for second computer energizing, measurement

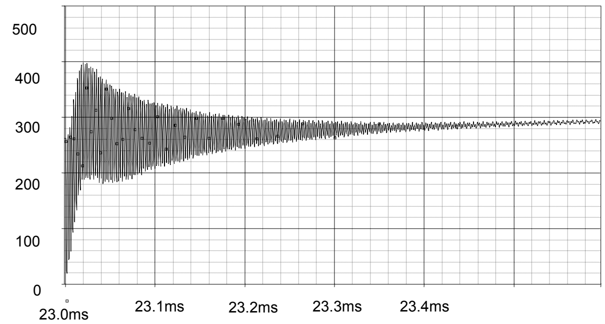

Fig. 12. Voltage transient for second computer energizing action, simulation.

H. Simulations

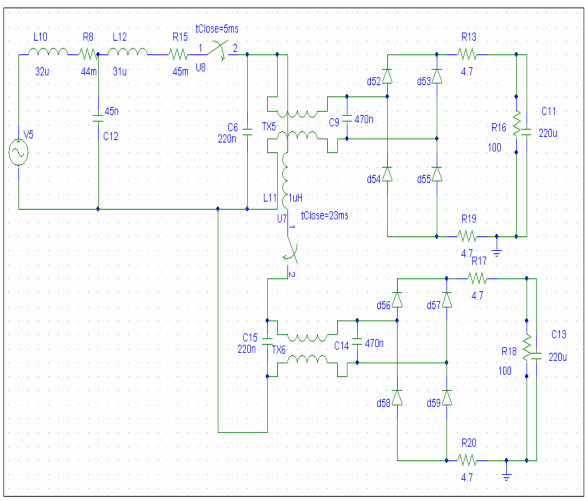

Fig. 11. Simulation circuit for two computers

The simulation circuit for two computers is shown in Fig. 11. The second computer is installed on the same feeder. An inductance is representing the distance between the two computers. The result from the second computer energizing is shown in Fig. 12.

The difference in the results can be explained by the fact that the complete load is not present in the simulation circuit and therefore the damping is not so distinct as in the measurements. The high frequency components are not visible in the measurements. It is obvious that the comparison between measurements and simulations becomes more complicated with additional load.

VI. Conclusions

For the voltage transients the measurements and simulations show a difference in frequency up to a factor of 1.4. The initial voltage transients reach high values. The measurements were taken in two different voltage systems but the difference in the results was very small. There are no indications that the existing load in the office supply network is absorbing energy from transients. The maximum inrush current for one computer reaches a high value, and there are reasons to believe that energizing of many computers at the same time is hazardous. The simulation circuit is a switched mode power supply used in normal electronic equipment such as TV receivers. This means that the simulation method can be used for transient behavior from other circuits besides computers. The most important conclusion is that ordinary computer load may generate severe voltage and current transients when energized.

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References

[1] A. Tjäder “High Frequency Conducted Disturbances”, Licenciate Thesis, Technical Report no.493 L, Chalmers University of Technology, Gothenburg, Sweden 2004

[2] R.J. Plowman. “EMC & Transients an Introduction,” IEE 1998