ANALYSIS OF HARMONIC CURRENT INTERACTION IN AN INDUSTIAL PLANT

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ABSTRACT

An analysis of current transients caused by the operation of a nearby device in an industrial plant is presented in the paper. The source of current transients in the factory lighting system was traced to the operation of the nearby six-pulse AC/DC converter. To determine the nature of the interaction, a measurement was done with a storage oscilloscope. Also, laboratory experiments on one lamp were conducted. It was possible to exclude the presence of a parallel resonance on this site. It was concluded that transients are caused by voltage notches in certain working regimes of the six-pulse converter. Possible solutions to the problem are separating the supplies of the converter and the lighting installation, filtering, or adding additional line reactance.

INTRODUCTION

The topic of this paper is a case of equipment interaction in an industrial plant. The phenomenon noticed was an increase in the currents of the factory lighting system at some moments while a DC drive connected to the same transformer is in operation. The first measurement at the site showed that the drive causes an increase in the voltage harmonics and voltage notches.

Voltage notches are a specific form of distortion, they can be described as voltage dips with steep edges, and they occur during commutations in rectifiers. The reason for voltage notch appearance is a short-term phase to phase short-circuit that takes place during the commutation process.

The mechanisms of voltage notch generation and their properties are described in [1]-[3]. These references show how a notch is formed, and how it is dependent on the systems short-circuit level, the line inductors connected in series with the converter, and the current in the DC bus of the converter. Reference [3] also describes the effects of the snubber circuit in certain conditions.

Having the DC current fixed, the system impedance and line inductor reactance determine the notch severity and propagation. A low system impedance value limits the voltage drop during every short-circuit, and by doing so, it limits the propagation of a notch on nearby buses. On the other hand, the value of the reactance has to be limited, because the voltage drop seen by the converter increases together with the reactance value.

IEEE standard 519-1992 [4] provides limits for voltage notch emission. Limits are separated in three characteristic cases, and the severity is limited by the notch area and depth. Notch area is the product of the notch depth (in volts) and duration (in µs). For dedicated systems (part of the system feeding the converter), such as the case analyzed here, the voltage notch limits are higher than for general systems (further from the converter). This makes the knowledge about the equipment reaction to voltage notches important when it is to be decided if some equipment can be connected to the busbar dedicated for a large converter.

Although the phenomenon is well known, there is not a lot of literature describing the effects of voltage notches on nearby equipment. Two cases of problems caused by voltage notches are described in [5], and solutions are suggested by altering the system impedance-frequency dependence using capacitor banks.

Measurement description

The industrial site topology is schematically presented in Fig. 1. One 1600 kVA transformer is connected to two low voltage feeders. In one of the feeders, a 453 kW DC motor is connected, through a six-pulse AC/DC converter and line inductors of 0.0225 mH per phase. The other feeder is supplying the lighting system in the factory hall, 54 kW in total, composed of discharge lamps with electromagnetic ballasts and parallel compensation.

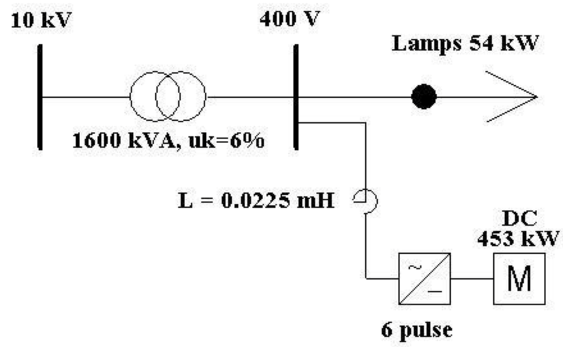

Fig. 1. Schematic diagram of the measurement site

Measurement was done with a storage oscilloscope, on six channels (three voltages and three currents), only at the terminals of the lighting installation. The sampling frequency of the measurement was 20 kHz, and two recordings were made with a duration of approximately two minutes each.

FIELD MEASUREMENT RESULTS

Results of long-term waveform recording are presented in this section. Fig. 2 shows the current of lamps in phase 1 during one 100 s time interval. Three specific regimes were aimed in the measurements: when the DC drive is lightly loaded (with RMS values of currents up to 200 A) – labeled with A, when the drive is highly loaded (currents of approximately 600 A) – labeled with B, and when the drive is suddenly changing its loading (short-term currents reaching 1000 A) – labeled with C. No lamp switching was occurring during the time interval shown in Fig. 2, the changes in the current are only caused by the changes in the current of the six-pulse converter.

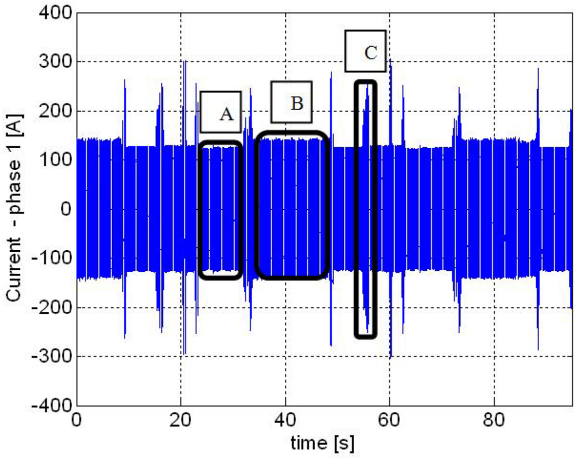

Fig. 2. Lighting current in phase 1 during one measurement

In the time interval A (steady state), peak values of the current are approximately 125 A. In the time interval B (also steady state), peak values are around 140 A. During high loadings (interval C), peak values are between 250 and 300 A (different load changes correspond to different peak current values). At different moments, regime C lasted 1 to 1.5 s.

Fig. 3 represents one zoomed period of the current for all three time intervals. The current in regime A has some harmonics superimposed, but relatively light distortion. The current in regime B has more distortion, with six distinctive oscillations per period – every time when a voltage notch happens. The current in regime C behaves in the same way, but this effect is largely augmented in this case.

Fig. 4 represents the voltage in the same phase in all three regimes, during one half period (to make the notches more visible). Regime A does not cause visible notches, only slight deviations of the waveform are visible at switching moments (since the drives current is relatively low). Regimes B and C cause visible notches. Sudden load changes cause very large notches, since the peak currents can be almost twice as large as during the constant high loading.

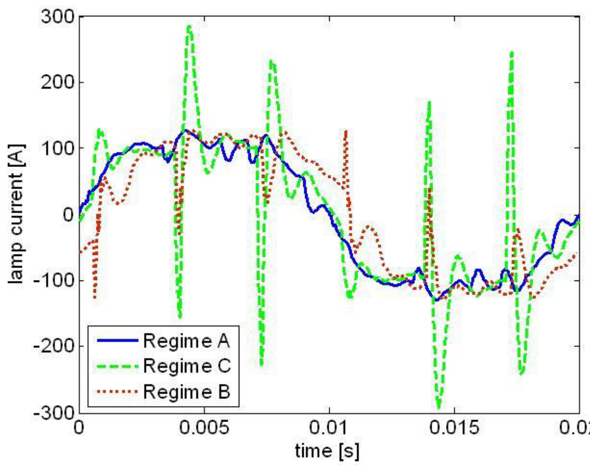

Fig. 3. Current of lamps in phase 1 with different regimes of the DC drive

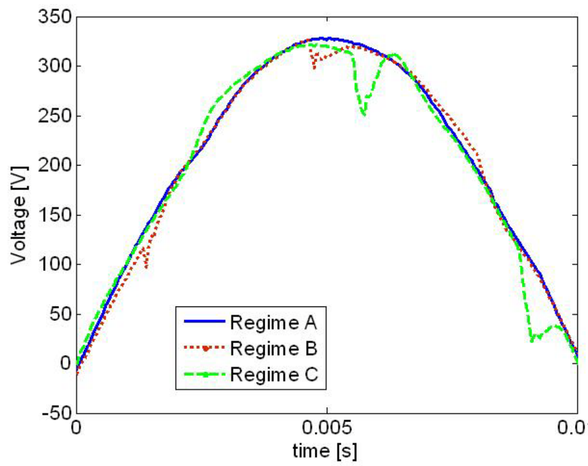

Fig. 4. Voltage in phase 1 with different regimes of the DC drive

ANALYSIS OF FIELD MEASUREMENTS

To illustrate the nature of these current transients, one 4 s period of time was chosen, containing short intervals of all three working regimes. Fig. 5 shows the time changes of the lamps voltage and current THD during this time period, calculated with a data window length of 20 ms. Working regimes are labeled on the figure, and it is noticeable that the shape of the current THD resembles the shape of the voltage THD, except for the greater values of the currents distortion.

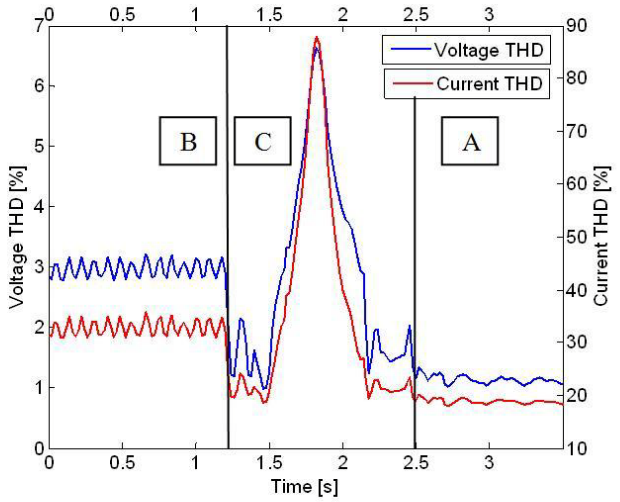

Fig. 5. Time changes of the voltage and current THD for all three regimes

The current spectrum of the lamps contains harmonics characteristic for a six-pulse converter ($6 \cdot k \pm 1$, k=1,2,3,…), but also the 3rd and 9th harmonic (triplen harmonics exist because of the characteristics of the lamps). Calculated spectrums of voltage and current are presented in Fig. 6 and Fig. 7, respectively. In regime A, the 3rd current harmonic is largely dominant. This regime is the closest to working with an undistorted voltage supply. In regime B voltage distortion is higher, with almost no changes in the 3rd voltage harmonic, but with a considerable increase of the characteristic six-pulse converter harmonic voltages. In this regime the level of the 11th current harmonic of lamps is almost the same as the 3rd. In regime C the 3rd voltage harmonic is again almost unaffected (there is even a small decrease during transients), while characteristic harmonics are increased even more. This is also affecting the currents of lamps, which become much larger than the 3rd harmonic on several orders.

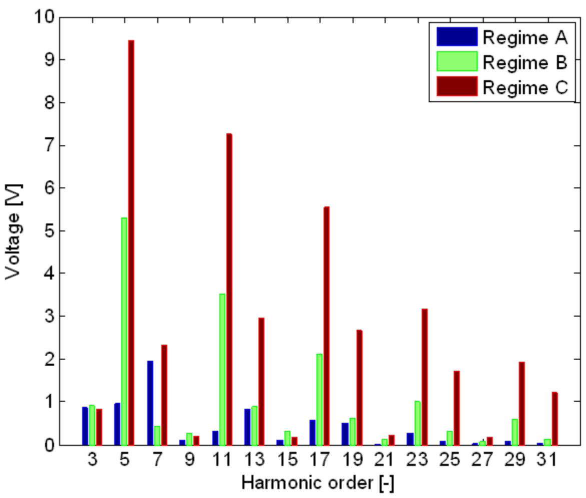

Fig. 6. Harmonic spectrum of the voltage in phase 1, for all regimes

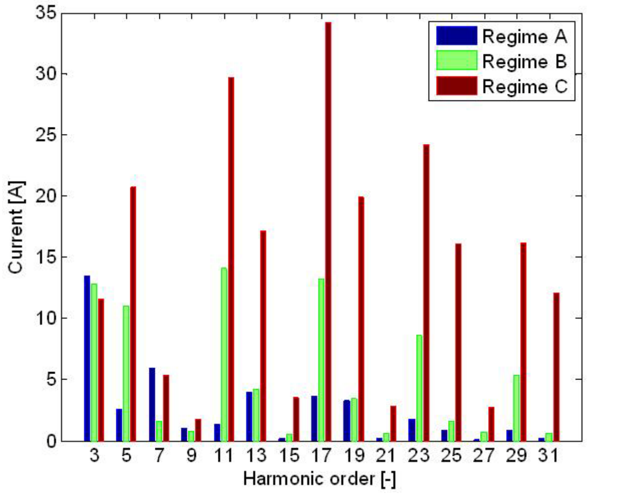

Fig. 7. Harmonic spectrum of the current in phase 1, for all regimes

Dramatic increases of the current imply that a parallel resonance might be excited during the transition periods. However, the voltage THD is roughly following the changes of the drives current, and a number of voltage harmonics are increased in the same way, instead of only a small bend of frequencies. This is suggesting that no parallel resonance is being excited, and that transients are a reaction of lamps to voltage notches with shortly increased depth. Also, all of the voltage harmonics and the THD comply with the voltage supply limits, given in [6]. The maximal value of the THD calculated over a data window of 20 ms is close to 7 % (by [6], 95 % of the measured values in one week averaged over 10 minute intervals, should be less than 8 %).

Higher order harmonics exhibit a higher increase than the lower order harmonics. The reason for this is the shape of the impedance-frequency characteristic of lamps, presented in Fig. 8. This characteristic was calculated from the measured harmonic voltages and currents (during the peak intervals – regime C).

LABORATORY MEASUREMENTS

To further explore the behavior of these lamps under voltage distortion, a set of experiments were done in the Power Quality laboratory of the TU/e. One lamp was supplied from a California Instruments MX45 programmable voltage source, and voltage and current were recorded and analyzed under different voltage conditions.

One set of experiments was done in order to obtain the harmonic fingerprint of the lamp, as described in [7] and [8].

When a clean sinusoidal voltage was applied, current THD was 17 %, with a dominant 3^{rd} harmonic component of 16 %, 5^{th} - 4.5 %, 7^{th} – 3 %, while other components had magnitudes smaller than 1 % of the fundamental. Peak value of the current was 3 A.

As harmonic voltages were added, harmonic currents were increasing in a linear way (on top of the starting harmonic currents). That makes it possible to make a model of this lamp consisting of only linear elements – a constant harmonic current source and linear impedances.

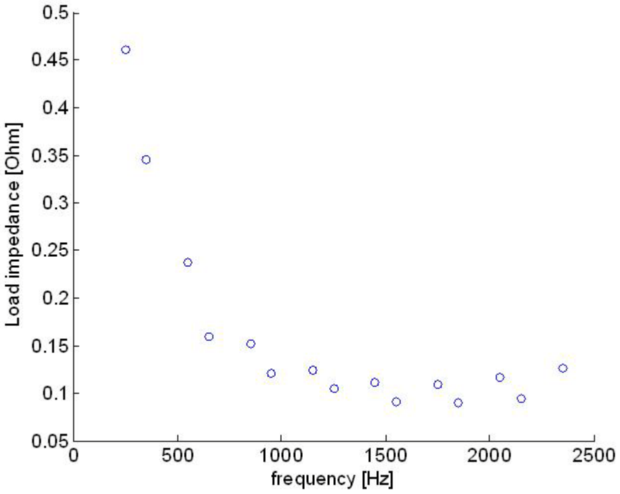

Fig. 8. Calculated impedance of lamps (per phase) as a function of frequency

Laboratory measurements showed that the harmonic content of the current depends only on the voltage distortion present, and is independent from the notch shape. On the other hand, the peak current values might be dependent on the voltage shape. This dependence can be further explored. Voltages measured in the field were also recreated in the laboratory. Voltages from regimes A and B were reproduced in a very accurate way, and current waveforms were matching results from the field measurement. Voltage notches from regime C could not be reproduced completely with the programmable source (oscillations were appearing during notches), so the measured current was even more distorted in the laboratory, and had higher peak values (up to 20 A).

CONCLUSIONS

An analysis of current transients caused by voltage notches is presented in the paper. The nature of the interaction is explained using field measurement data and laboratory experiments.

The analysis showed that a parallel resonance is not being excited, and that the transients are a reaction of the lamps to the voltage distortion in short-time intervals. A similar effect would be caused by another form of voltage distortion (without notches), especially of higher orders (as the impedance-frequency characteristic on Fig. 8 shows).

Laboratory experiments showed that although this type of lamps has a non-linear part and produces harmonic currents even with a sinusoidal voltage, it reacts to harmonic voltages in a linear way. Therefore, it can be modeled very accurately with its harmonic fingerprint, using a constant harmonic current source and impedances.

It can be concluded that the best solution to this problem is supply separation for the lighting installation (connecting it to another transformer if possible). The problem can also be solved with filtering on the mutual LV busbar. Another way to reduce the transients is inserting an extra inductor in series with the converter.

Acknowledgments

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