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INFLUENCE OF VOLTAGE SAGS ON PERSONAL COMPUTERS AND PWM DRIVES

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Abstract: *This paper discusses the sensitivity of personal computers and PWM drives to voltage sags and short interruptions on the basis of extensive test results. The results of the following tests are presented in the paper: testing against various types of single-phase, two-phase and three-phase voltage sags and short interruptions, as well as testing with the ideal and non-ideal supply characteristics. Presented test results show that behavior of both equipment types in the general case cannot be described with the only one voltage-tolerance curve. Instead, families of voltage-tolerance curves should be used for description of the PCs and PWM drives sensitivity to voltage sags and short interruptions. Special attention is given to similarities in responses between these two types of equipment. Those similarities are discussed in detail in the paper.*

Key Words: ***Short Interruptions, Voltage Sags, Power Quality, Equipment Sensitivity, Personal Computers, PWM Drives***

1. INTRODUCTION

Both personal computers (PCs) and pulse-width modulation controlled voltage source inverter drives (in further text: PWM drives) are typical examples of recently emerged, widely used, rather complex and sophisticated non-linear electronic equipment. They are already reported as very sensitive to voltage sags and short interruptions (e.g., [1]-[3]). All the consequences of such a high sensitivity are additionally exacerbated because the PCs and PWM drives are usually utilised in a variety of commercial and industrial continuous processes. The PCs and PWM drives are often a critical piece of process equipment, since other equipment involved in the process is usually either controlled by them, or attached to them as a peripheral, or an auxiliary device. Accordingly, if a PC or PWM drive trips, the whole process will be stopped.

Based on the results of laboratory testing this paper shows that PCs and PWM drives have similarities in responses to voltage sags and short interruptions. They both utilise rectifier at the front end: full-wave single-phase diode switch-mode power supply is usually used for the PCs, and full-wave three-phase bridge diode rectifier is used for the PWM drives. Their ride through capabilities are mainly determined by the same three factors: a) dc link capacitance (i.e., stored energy that is used during the sag or interruption), b) power/current consumption of the load (i.e., energy demand of the rectifier's load) and c) undervoltage/overcurrent protection settings (i.e., allowed deviations in voltage/currents values during the energy conversion and transfer).

2. SENSITIVITY OF PERSONAL COMPUTERS

The sensitivity of personal computers to voltage sags is usually expressed with the only one voltage-tolerance curve, indentifying sags that yield to restarting/rebooting of the computer. However, test results presented in full in [2] show that a voltage sag or short interruption might cause lockup of the actual operations performed by the computer and/or blockage of its operating system (OS) *without* restarting/rebooting of the computer. In other words, voltage-tolerance curves obtained only for restarting/rebooting malfunction criteria are not conservative. If only this voltage-tolerance curve is available, it may be misleading, especially in the case when a process controlled by the computer is of particular importance and interest (e.g., on-line processing, 24/7 Internet services, real-time data acquisition, the GUI, SCADA and other applications).

In the first part of testing, ideal supply characteristics were maintained before and after the application of rectangular voltage sags and short interruptions. It was found that voltage-tolerance curves of all tested PCs have the following three distinctive parts: a flat vertical part, a flat horizontal part, and a sharp “knee” between them. It was also found that different points on wave of voltage sag initiation and different phase shifts during the sag do not have any noticeable influence on the PCs behavior during the voltage sag. The detailed test results for one computer are shown in Fig. 1. There are significant differences between the three

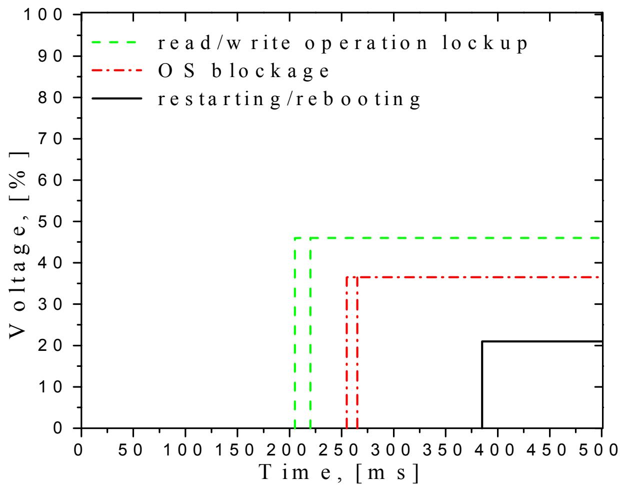

Fig. 1. *Voltage-tolerance curves for one tested PC.*

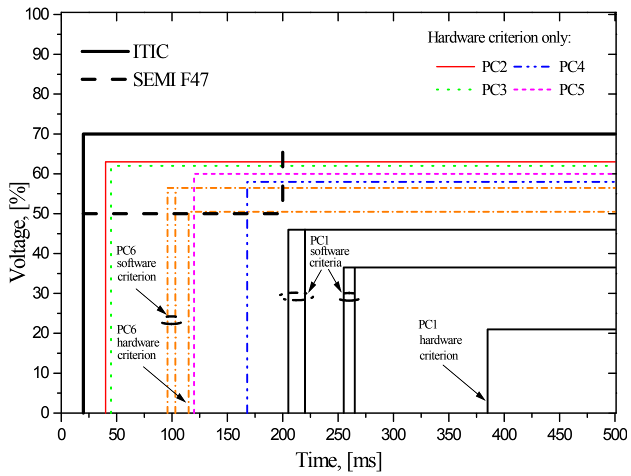

Fig. 2. *Voltage-tolerance curves for six tested PCs.*

different voltage-tolerance curves that correspond to three different malfunction criteria.

In Fig. 1, two software criteria (lockup of read/write operation and blockage of computer OS) result in a wider vertical part (a family of vertical lines whose boundaries are shown in Fig, 1) than the hardware (restart) criterion. This is a consequence of different power consumption conditions related to different stages of operation, or different OS execution states (i.e., different loading conditions). The hardware criterion results in a single vertical line because it is related to the (undervoltage) limit of the switch mode power supply. There are also significant differences in the horizontal parts of these voltage-tolerance curves. The difference in the sensitivity thresholds between the curves obtained using the first software criterion (lockup of read/write operation) and the hardware criterion (restarting/rebooting) is almost a 100% for the duration and more than a 100% for the voltage magnitude. These differences indicate the range of possible errors if ride-through capabilities of the computer were assessed only on the basis of the hardware malfunction criterion.

The rectifier dc voltage (5V dc output) was monitored during the tests. It was found that it starts to decay at about 200ms after the initiation of the voltage sag. The voltage sags and interruptions shorter than 200ms therefore, will not have influence on the behavior of computer. This happens because there is enough energy stored in a dc link capacitance to maintain correct operation of dc voltage regulator, i.e. correct operation and functioning of computer.

Results for all six tested computers are shown in Fig. 2. The voltage sag magnitude thresholds for tested computers vary between 20-65% of rated voltage, and duration thresholds vary between 40-400ms.

The ITIC [4] and SEMI F47 [5] power acceptability curves are also plotted in Fig. 2 (with thick solid and thick dashed line, respectively). It can be seen that all tested PCs satisfy the ITIC power acceptability curve, but all of them except one, violate the most recent SEMI F47 standard.

During the second stage of testing, the PCs were supplied from the non-ideal voltage source. Deviations from the ideal supply characteristics were within the following limits: voltage magnitude variations up to ±10% of the rated voltage, frequency variations up to ±2% of the rated frequency, and different harmonic content (3rd, 5th and 7th harmonic) superimposed to the fundamental frequency waveform with the THD not exceeding 20%. The above disturbances were applied both separately and simultaneously, in order to assess their individual and cumulative effect on the PC's operation during the sags and interruptions.

As an example, cumulative effects of both voltage magnitude variations and presence of the third harmonic is illustrated in Fig. 3. The third harmonic has the biggest influence and it is also the dominant harmonic in the "harmonic spectrum" emitted by the personal computers during the normal operation. It can be seen that the simultaneous variations of the pre-sag voltage magnitude and the harmonic content have a significant effects on the computer sensitivity to voltage sags.

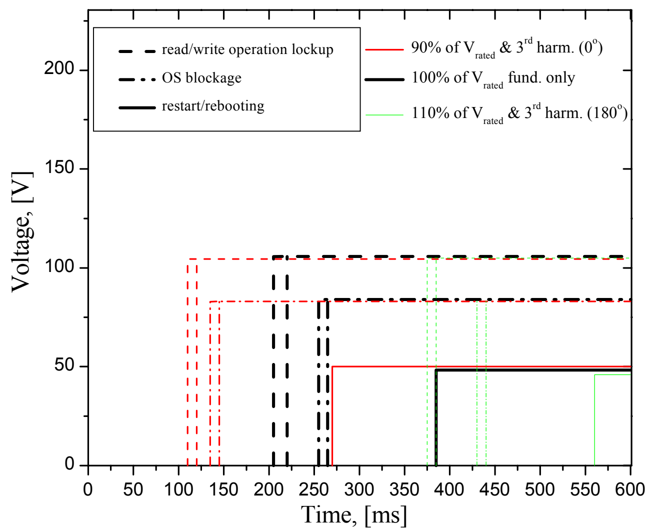

Fig. 3. *Cumulative influence of non-ideal supply (±10% voltage magnitude and 3rd harmonic with 20% THD).*

3. SENSITIVITY OF PWM DRIVES

The voltage-tolerance curves of the PWM drives identified in tests have several characteristics very similar to the voltage-tolerance curves of computers. The voltage-tolerance curves of the PWM drives also have three distinctive parts: a flat or slightly inclined vertical part, a slightly inclined horizontal part, and a smooth "knee" between them. As with the PCs, it was found that different points on wave of sag initiation and different phase shifts during the sag do not have influence on the drive behavior.

Three different load types were used in tests: a) constant power load, b) constant torque load, and c) quadratic torque load. Very small differences are identified between the voltage-tolerance curves for these three load types, and a constant torque load type was used in further tests.

The PWM drives are three-phase equipment and different combinations of the three phase voltages during the sags have different effects on their operation. However, not all combinations of phase voltages during the voltage sags and short interruptions are likely to occur in power systems. It was assumed in testing that sags and interruptions caused by different fault types (line to ground, double-line to ground, line-to-line and three-phase faults) propagate in a power systems in such a way that at least two phase voltages during the sag have equal (similar) magnitudes. Thus, testing of the PWM drives was conducted with the following three types of voltage sags:

1. Three-phase balanced voltage sags, i.e., during-sag voltage magnitudes in all three phases are equal.
2. Generalized two-phase voltage sags, i.e., during-sag voltage magnitudes of two sagged phases are equal; voltage in the third, “unsagged” phase is used as a parameter, and it can be either rated or below the rated.
3. Generalized single-phase voltage sags, i.e., during-sag voltage magnitude of one (sagged) phase is below the rated value; voltage magnitudes in two other phases are used as a parameter - they are always equal and rated, or equal and below the rated value.

Obtained test results show that the sensitivity of the PWM drives also cannot be described with only one voltage-tolerance curve [3]. In fact, the PWM drives have a more complex sensitivity pattern, resulting in a greater number of voltage-tolerance curves than in the case of personal computers. Each voltage-tolerance curve obtained in drive testing corresponds to one particular voltage sag type, one particular load type, one particular value of loading torque and one particular value of motor speed. Furthermore, in tests performed with generalized single-phase and two-phase sags, additional parameter was voltage magnitude in the unsagged phase(s), which resulted in additional sets of voltage-tolerance curves. Each voltage-tolerance curve from these additional sets corresponds to one particular value of voltage magnitude in the unsagged phase(s). Figures 4-6 show families of voltage-tolerance curves identified in tests with the three different sag types, constant torque load types, rated motor speed and rated loading torque.

For all three sag types, significant influence of actual loading torque value and adjusted motor speed on drive sensitivity was identified in tests. These two parameters (torque and speed) actually present different loading conditions of the drive. Voltage-tolerance curves for one PWM drive obtained in tests with balanced three-phase sags and different torques and speeds are shown in Figures 7 and 8, respectively. Similar behaviour (i.e.,

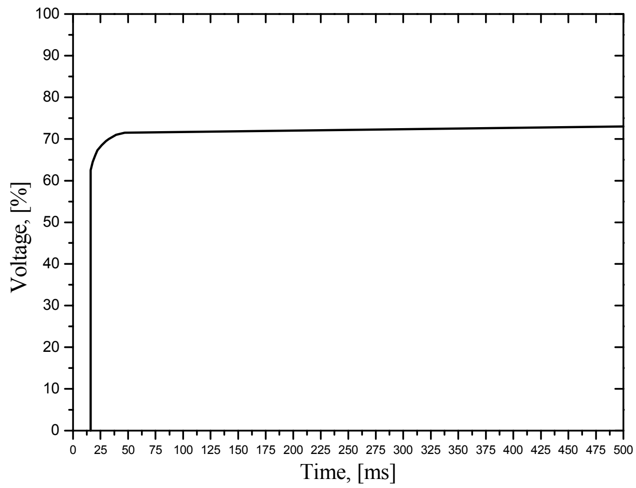

Fig. 4. *Voltage-tolerance curve of PWM drive for balanced three-phase sags and interruptions.*

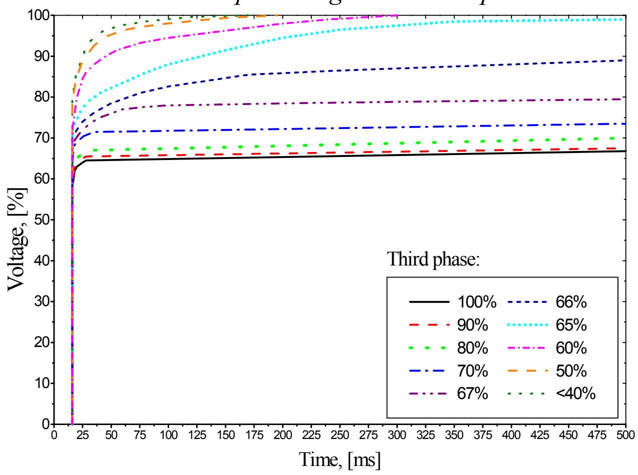

Fig. 5. *Voltage-tolerance curves of PWM drive for generalized two-phase sags and interruptions.*

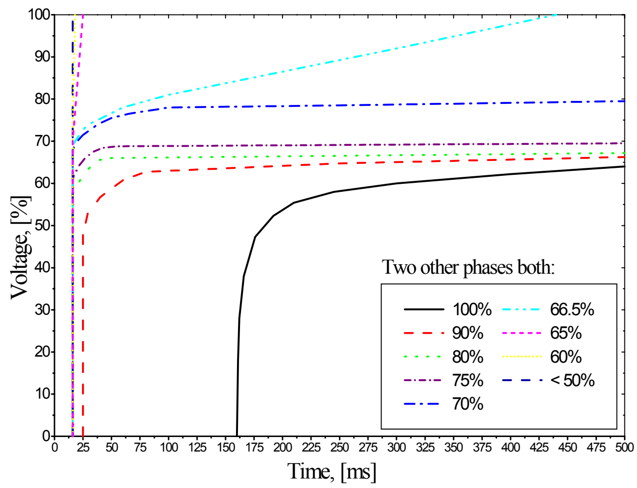

Fig. 6. *Voltage-tolerance curves of PWM drive for generalized single-phase sags and interruptions.*

better ride-through capabilities for lower torque and lower speed) were also identified in testing with generalized two-phase and single-phase sags and interruptions.

As in testing of the personal computers, drives were also tested for a non-ideal power supply conditions present before and after the initiation of balanced rectangular three-phase sags and interruptions. Applied

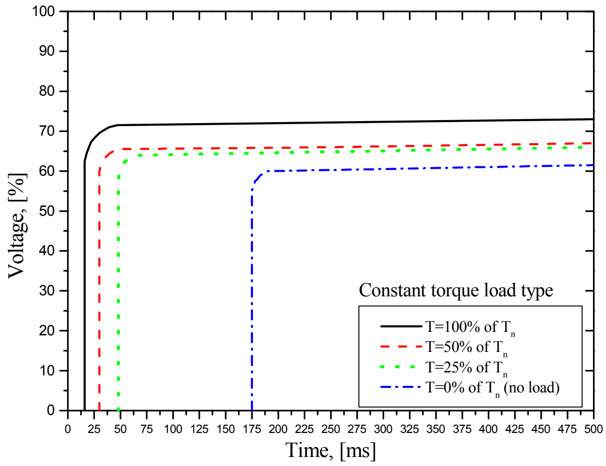

Fig. 7. *Influence of different torque values on PWM drive sensitivity to balanced three-phase sags and interruptions.*

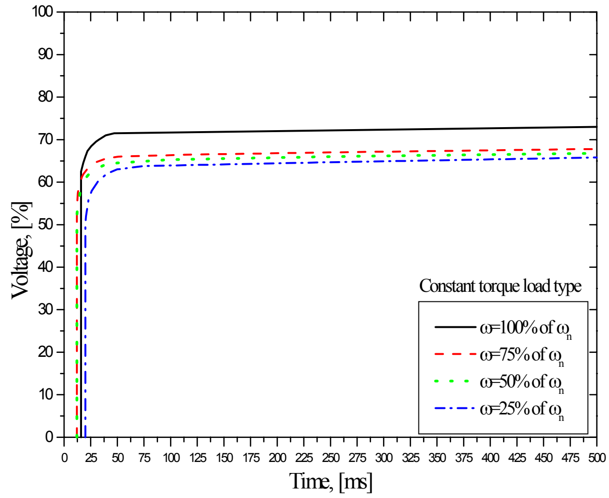

Fig. 8. *Influence of different motor speeds on PWM drive sensitivity to balanced three-phase sags and interruptions.*

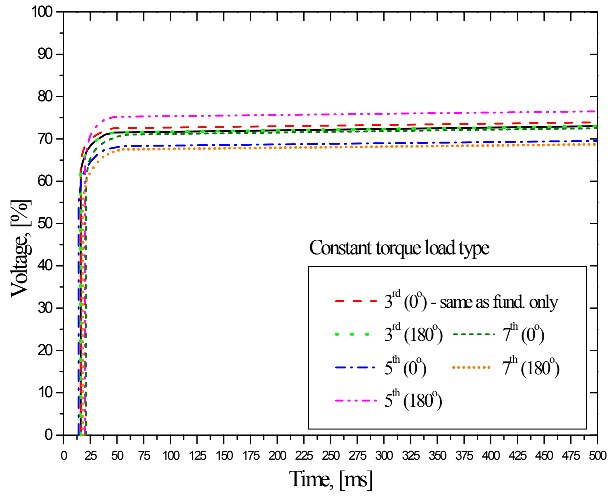

Fig. 9. *Sensitivity of PWM drive to balanced three-phase sags regarding the variations in harmonic contents of pre-sag and post-sag supply voltage.*

deviations in non-ideal supply characteristics were the same as in tests of computers. It was found that drives have similar responses to the non-ideal power supply conditions, even regarding the response to different harmonic contents.

The highest influence on drive sensitivity was identified for the fifth harmonic, again the dominant harmonic in "harmonic spectrum" emitted by the drive during the normal operation Figure 9.

4. CONCLUSIONS

The PCs and PWM drives are both recently emerged, widely used, very sophisticated (power) electronic devices, that utilise the rectifier at the front end. They are very sensitive and often a critical piece of equipment in continuous processes in which are involved. Besides these general similarities, results presented in this paper show that they also have similar responses to voltage sags and short interruptions.

The behaviour of both PCs and PWM drives cannot be described with only one voltage-tolerance curve. Instead, families of voltage-tolerance curves should be used for full description of their sensitivity to voltage sags and short interruptions. Both PCs and PWM drives have similar shapes of voltage-tolerance curves: this shape is rectangular for PCs, and almost rectangular for PWM drives. Only difference in voltage-tolerance curve shapes is presence of a smooth "knee" for PWM drives.

Point on wave of voltage sag initiation and phase shift during the sag, as the additional sag parameters, do not have influence on their sensitivity.

The sensitivities of both PCs and PWM drives vary significantly with the different loading conditions. With decreasing of the power/current consumption, their sensitivities decrease.

The non-ideal supply conditions also have similar effects on their behaviour during the sags and interruptions. Specifically, regarding the different harmonic contents, both PCs and PWM drives have the highest change in sensitivity for harmonics that are dominant in their spectra during the normal operation (the third harmonic for the PCs and the fifth harmonic for the PWM drives).

For both PCs and PWM drives, drop in ac voltage of the power supply during the sag is essentially seen as the drop in dc voltage at the output of the rectifier. Thus, maintenance of a continuous dc link voltage is crucial for normal operation of computers and PWM drives. The same three factors have the greatest influence on their dc link voltage and determine their overall sensitivity and ride-through capabilities: a) dc link capacitance, b) power/current consumption during the operation and c) undervoltage/overcurrent protection settings.

The same two protection systems are responsible for disconnection/tripping of both PCs and PWM drives during the sags and interruptions: the undervoltage and overcurrent protection systems.

After passing a particular magnitude and duration thresholds, the PCs and PWM drives both have the same characteristic in their responses to voltage sags and short interruptions (vertical part of their voltage-tolerance curves influence that there are no differences in tripping time between the sags and interruptions). The magnitude and duration thresholds are mainly determined by the settings of the undervoltage and overcurrent protection systems.

Due to the small power consumption, the ride-through capability of the PCs can be improved with a relatively small sag mitigation equipment (e.g., with a small uninterruptible power supply - UPS). For PWM drives however, their power consumption ranges influence the costs of adequatelly rated mitigation equipment which can be much higher.

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