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Immunity Level of Personal Computers to Voltage Sags in the 240 V/50 Hz Distribution Systems

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Abstract: This study focuses on investigating the vulnerability of personal computers (PCs) to voltage sags in the context of local power distribution system in Malaysia. Based on recent testing standards and utilizing a modern industrial power corrupter, extensive tests are conducted for a wide range of PCs. For predefined malfunction criteria, such as monitor image distortion and reboot/restart condition, sag depth and duration are varied to construct individual voltage immunity curves. To obtain a quick overview about voltage sensitivity of PCs and to compare with the standard ITIC and SEMI F47 design goals, a generic voltage tolerance curve is then developed. The experiment results show that the PCs used in the local system have relatively high tolerance level to voltage sags when compared to the design goals of ITIC and SEMI F47 standards. Furthermore, the developed voltage tolerance curve may be helpful to mitigate sensitivity of personal computers to voltage sags in the local environment.

Key words: Voltage tolerance curves, SEMI F47, ITIC, PC, power acceptability

INTRODUCTION

The importance of providing power with steady voltage and frequency has been recognized since the inception of the Electric Supply Industry (ESI). As ESI proliferates along with the introduction of power system deregulation, electronic and information technology equipment in a wide range of systems and unpredictable climate changes, it is almost impossible to avoid power system disturbances. Over the past few years, voltage sags have emerged as the most serious power quality problem, especially in the context of the Malaysian distribution systems. Voltage sag is a sudden decrease in voltage amplitude followed by a return to its initial level after a short time (Barros and Diego, 2002). Sags are caused by network faults, switching actions such as large motor starting, transformer energizing, capacitor bank connection etc. These incidents that initiate voltage sags can disrupt or damage sensitive equipments such as personal computers (PCs).

Personal computers first appeared in the late 1970s. The principal characteristics of PCs are that they are single-user systems and based on microprocessor technology. However, although PCs are designed as single-user systems, it is common to link them together to form a network. Through networking and interfacing it is used widely for on-line communication, continuous process control applications etc. The malfunction of PCs incorporated in on-line or even off-line systems can cost substantially, because there are losses associated to the computer controlled systems and process (Djokic *et al*., 2005).

Sensitivity of PCs to voltage sags can be defined as the conditions where the PCs start to malfunction and cause nuisance, loss of data or process interruption due to voltage sag appearing in the mains supply where it is connected. Studies for assessing sensitivity of voltage sags on customer loads are gradually increasing. These efforts are primarily divided into practical and theoretical approaches. The practical approaches investigate the effects of voltage sag by monitoring, conducting experiments on customers' sensitive loads and performing pertinent surveys (Bollen, 2000).

Current standards related to the testing of the equipment sensitivity to voltage sags and short interruptions suggest that the tests should be performed preferably at 0° point on wave of the voltage waveform (Djokic *et al*., 2005). Testing of the equipment for additional angles is necessary only if they are considered critical by product committees or individual product specifications. If so, a range from 0 to 360° in steps of 45° is optional for such additional testing (Bok *et al*., 2008; Djokic *et al*., 2005). Typically, sags include 80% remaining voltage for 1 sec; 70% remaining voltage for 0.5 sec and 40% (or 50%) remaining voltage of 0.2 sec.

Equipment sensitivity to voltage sag can also be considered and presented in the form of power acceptability curves which are also known as voltage

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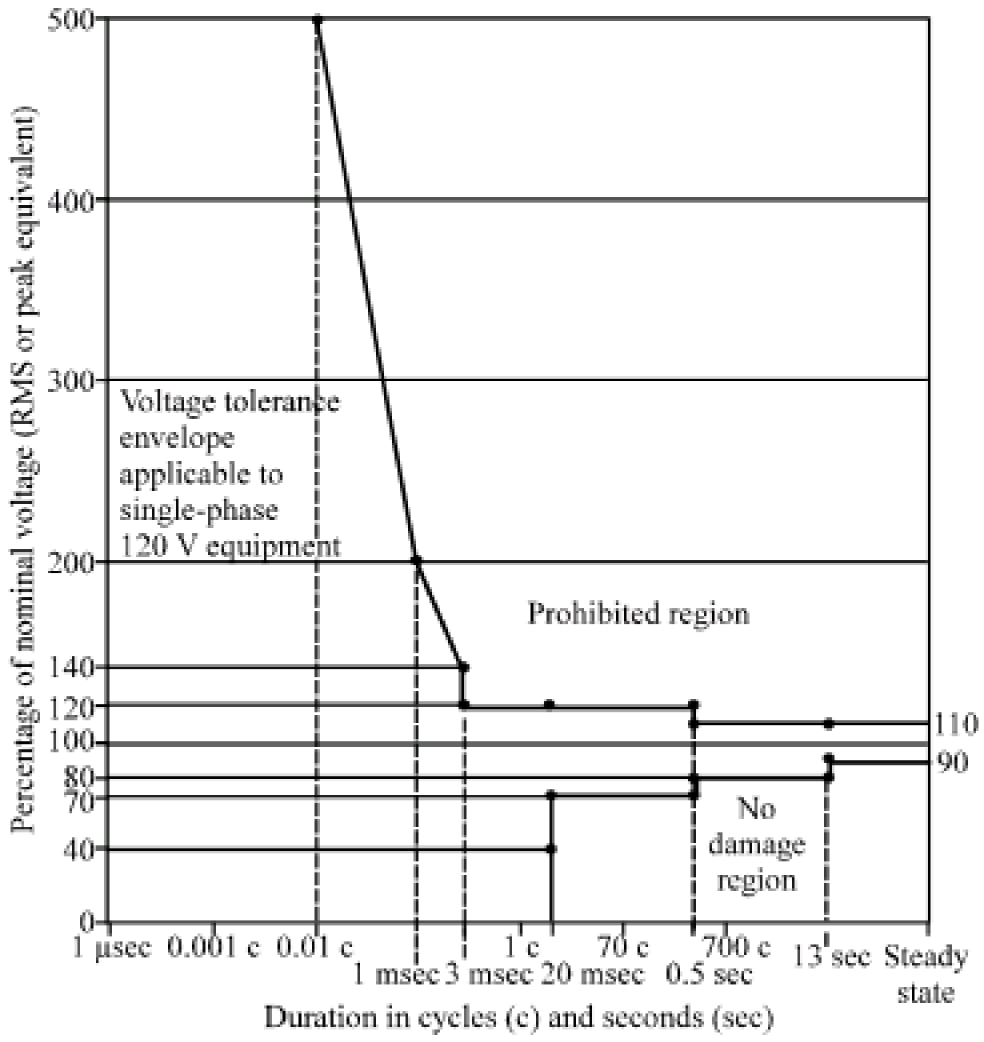

Fig. 1: ITIC (CBEMA) curve

vulnerability or sensitivity curves. One of these curves is the Computer Business Equipment Manufacturers Association (CBEMA) curve (Kyei *et al*., 2002). Since, CBEMA is now defunct, the Information Technology Industry Council (ITIC) has taken its place with major modification to its original curves as depicted in Fig. 1. Even with the new look, an ITIC (CBEMA)-type criteria has some important limitations. It is not in itself sufficient criteria for typical office systems (Institute of Electrical and Electronics Engineers Inc., 2005).

These curves are plots of bus voltage deviation versus time duration which separate the bus voltage deviation - time duration plane into two regions namely, acceptable and unacceptable regions. The lower limb of the power acceptability curve relates to voltage sags and momentary outages. The latest power acceptability standard, as shown in Fig. 2, is known as the SEMI F47 issued by the Semiconductor Equipment and Materials International (SEMI) in the year 2000 to satisfy minimum voltage sags ride through capability for equipments used in the semiconductor industry (Djokic *et al*., 2005). The specification simply states that semiconductor processing, metrology and automated test equipment must be designed and built to confirm to the voltage sag ride-through capability as per the defined curve. Equipment must continue to operate without interruption during conditions identified in the area above the defined acceptable region (Institute of Electrical and Electronics Engineers Inc., 2005).

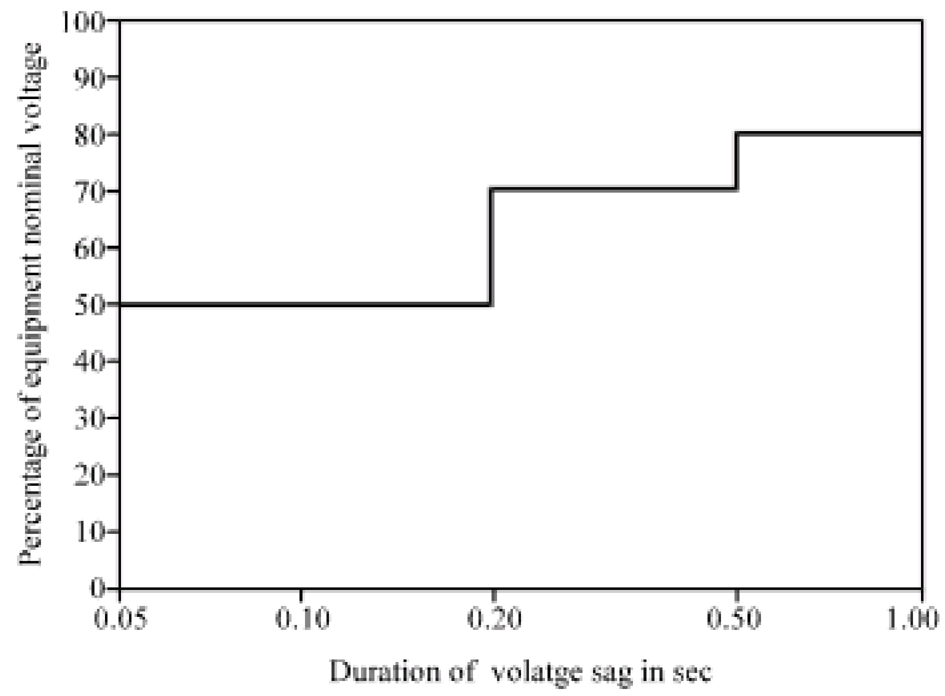

Fig. 2: SEMI F47 standard curve

The design of the above mentioned power acceptability curves clearly relates to whether the distributed power can be utilized or not. In other words, the distribution power should be considered acceptable if the industrial process served is operative. Thus, the ultimate criterion of power acceptability relates to the operating status of the industrial process and equipment. This criterion depends on the nature of the load. For example, simple incandescent lighting loads may have a very loose criterion for acceptability, while certain sensitive computer controls may have a much more restrictive criterion. The difficulty in the selection of a single suitable criterion is confounded by the many possible load types (Kyei *et al*., 2002). For this reason, Kyei *et al*. (2002) introduced the concept of the so called standard for different types of loads. For example, a voltage standard is a criterion for power acceptability based on a minimum acceptable DC voltage at the output of a rectifier below which proper operation of the load is disrupted (Lee *et al*., 2004). However, it is always better to conduct a characterization test to develop the voltage tolerance curves for different sensitive equipments to voltage sags such as PCs.

As an effort to understand the immunity level of PCs, many studies have been reported in the past. Test results on standard restart/reboot malfunction criterion for computers due to voltage sags can be found by Saksena *et al*. (2005). It is reported that if the depth of voltage sag is larger than 30% and lasts more than 8 cycles, the voltage sag may cause a computer to restart. These tests are only carried out for the 120 V/60 Hz systems. Furthermore, it is concluded that the performance of the switching power unit and the power consumption of a computer plays a vital role on the sag effect. Other than the standard restart malfunction criteria, the effects of voltage sags in other software criterions are not tested. A similar experimental test was conducted by Bok *et al*. (2008) to identify the effect of rectangular and non-rectangular voltage sags on the same restart/reboot malfunction criteria. Rectangular sags with loading condition are found to influence most on the susceptibility of PCs for the tested criteria.

Another comprehensive study on the behavior of PCs during voltage sags and short interruptions is presented by Djokic *et al*. (2005). Laboratory experiments are performed with rectangular voltage sags as well as with non-rectangular sags to simulate the starting of the large motors. Supply from the non-ideal voltage source is realized by incorporating harmonic and supply frequency variations. It was found that all the voltage tolerance curves for different computers have the same rectangular shape with two clearly distinctive vertical and horizontal parts, with a very sharp knee between them. Finally, for three different malfunction criteria, namely, read/write operations, blockage of the operating system and restart/reboot malfunction criteria, three different sensitivity curves for each tested PC is plotted. Malfunction of monitor image distortion and buzzing sound criterion is not investigated. Baran *et al*. (1998), considers several malfunction criteria in testing namely, lockup of the PC, slowdown of the network traffic, file corruption, etc. to investigate the effects of various power quality disturbances on PCs connected to a local-area network. However, it is assessed only with respect to short interruptions, but not with respect to voltage sags. The results are compared with the CBEMA curve and reported that in most of the cases it violates the immunity criteria of the standard curve.

Seven PCs of different age have been investigated for voltage sags by Pohjanheimo and Lehtonen (2002). The malfunction criterion for the PCs selected is automatic reboot. The voltage-tolerance curves obtained from the tests are found to be rectangular, having the flat vertical and horizontal part with a sharp knee between them. Researchers reported that the PCs tolerate the under voltage level up to 50-60% of remaining voltage for 100 m sec^{-1}. There is no clear correlation between the device age and sensitivity observed.

The onsite study carried out based on a voltage disturbance profile by Muhamad *et al*. (2007) in two local industrial areas for a period of one year is shown in Table 1. From the Table 1 it can be seen that the sag events having less than 60% nominal voltage is very rare. This information may be useful in understanding the number of voltage sag events appearing in the local distribution system.

Table 1: Sag event impact summary Senawang Tunku Jaafar and Ampang Harris industrial main substations

Reduction from nominal voltage during sag			
80-88%	70-80%	60-70%	<60%
16 events	10 events	7 events	3 events

This study focuses on investigating the vulnerability of personal computers to voltage sags in the local mains supply. So, far it has not been documented in the literature as to how PCs used in Malaysia behave in case of under voltage disturbances. Extensive laboratory tests are conducted for this purpose. These tests are carried out not only for standard restart/reboot malfunction criteria but also to examine the distortions on PC monitor and unacceptable audible noise generation. In order to evaluate the voltage tolerance levels of the PCs for the identified failure conditions, the test results are also compared with the design goals of ITIC and SEMI F47 standards. Finally, based on the performance of tested samples and superimposing individual immunity curves, a general voltage tolerance curve for PCs is developed.

MATERIALS AND METHODS

PC testing

Experimental setup: The methodology that is used in the testing is generally based on the guideline followed by Djokic *et al*. (2005) and Saksena *et al*. (2005). Five PCs with different specifications are tested to study the effect of voltage sags on the performance of the computers. The specifications of the tested PCs are shown in Table 2.

The experimental set up consists of four components namely, sag generator, Equipment Under Test (EUT), data acquisition system and a computer to analyze the signals. In this case, an Industrial Power Corruptor (IPC) from the Power Standards Lab is used. The IPC is a voltage sag generator combined with built-in data acquisition system which is capable of producing and interrupting voltages up to 480 V and current at 200 A in single or three phase systems. Figure 3 shows the real test environment where single phase local power supply at 240 V, 50 Hz is utilized.

Testing procedure: A series of test results on PCs is obtained by following the pre-defined procedure given below. The procedure is repeated for at least three times to avoid probable errors that may occur during the experiments:

Table 2: Specifications of tested PCs

PC No.	Specifications
PC1	CPU: Pentium III, 450 MHz Processor, 128 MB SDRAM
	OS: Windows Me
	Power Supply: 100-127 V/200-240 V, 5/2.5 A, 60/50 Hz, 145 W
PC2	CPU: Pentium 4, 2.40 GHz Processor, 261 MB RAM
	OS: Windows 2000 Professional
	Power Supply:100-120 V/200-240 V, 5/3 A, 60/50 Hz, 180 W
PC3	CPU: Core 2 Duo, 2.00 GHz Processor, 1 GB RAM
	OS: Windows XP Professional
	Power Supply: 100-127 V/200-240 V, 8/4 A, 60/50 Hz, 250 W
PC4	CPU: Pentium III, 933 MHz Processor, 256 MB RAM
	OS: Windows 2000 Professional
	Power Supply: 100-127 V/200-240 V, 9/4.5 A, 60/50 Hz, 300 W
PC5	CPU: Pentium 4, CPU 1.90 GHz, 504 MB RAM
	OS: Windows XP Home Edition
	Power Supply: 100-127 V/200-240 V, 6/3A, 60/50 Hz, 250 W

Fig. 3: Actual PC test environment

- Using the terminal blocks available at the back of IPC, the conductors from mains panel and conductors to the PC under test is connected and the IPC is powered on
- The PC with all input/output (I/O) and pointing devices connected is switched on and allowed to boot and load the operating system
- Staring from nominal voltage, voltage sags are initiated in steps of 2.5% down to zero volts. The sag initiation angle and the duration are kept constant. The initial sag duration and phase angle are set to 1 cycle and 0°, respectively. The critical sag depth for each of the pre-defined malfunction criteria is determined by repeated testing for at least 3 times for a particular sag magnitude and duration. If any malfunction condition is observed, a quick inspection for proper operation of EUT is conducted before initiating the next sag. For each triggered sag event, voltage and current waveforms supplying the EUT are recorded and an observation such as visible or audible influence on the PC is noted
- The duration of sag is adjusted in steps of 1 cycle and measurements outlined in Step 3 are repeated

A flowchart of the aforementioned procedure is shown in Fig. 4.

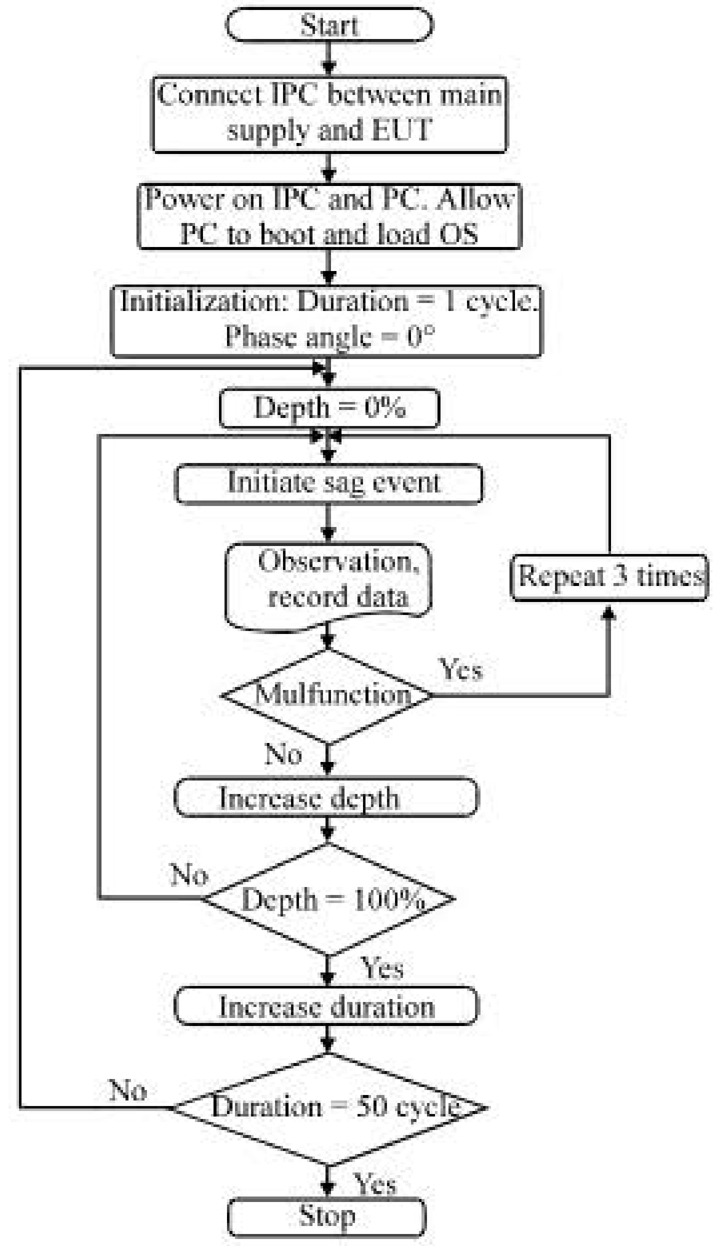

Fig. 4: Testing procedure

RESULTS AND DISCUSSION

Based on the findings, a generic voltage tolerance curve for PCs is then constructed and compared with the ITIC and SEMI F47 standards.

Analysis of individual PCs: The test findings from the experiments on sensitivity of PCs to voltage sags are presented as typical power acceptability curves. The upper region of these curves represents proper operation region while the lower regions indicates unacceptable voltage conditions for PCs' operation.

Effect of voltage sag on the first tested PC (PC1) is shown in Fig. 5. It can be seen that an unwanted buzzing sound started for a voltage reduction which last for 9 cycles. It is followed by image distortion at 22.5% of remaining voltage with duration of 11 cycles. Moreover, for sag duration between 9 to 13 cycles black screen conditions are observed for deeper sags. For sag duration beyond 14 cycles, PC1 starts to malfunction completely or is unable to perform the given task. At this point, it is automatically rebooted as shown in Fig. 5.

Figure 6 shows the effect of voltage sags on PC2. Similar to the case of PC1, personal computer PC2 also experienced image distortion, black screen and reboot

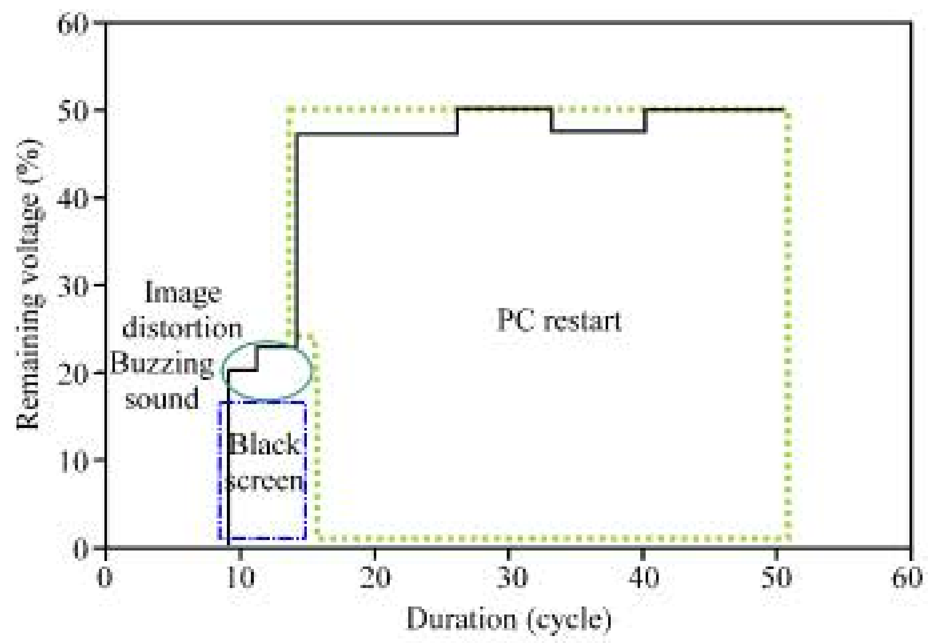

Fig. 5: Voltage tolerance curve for PC1

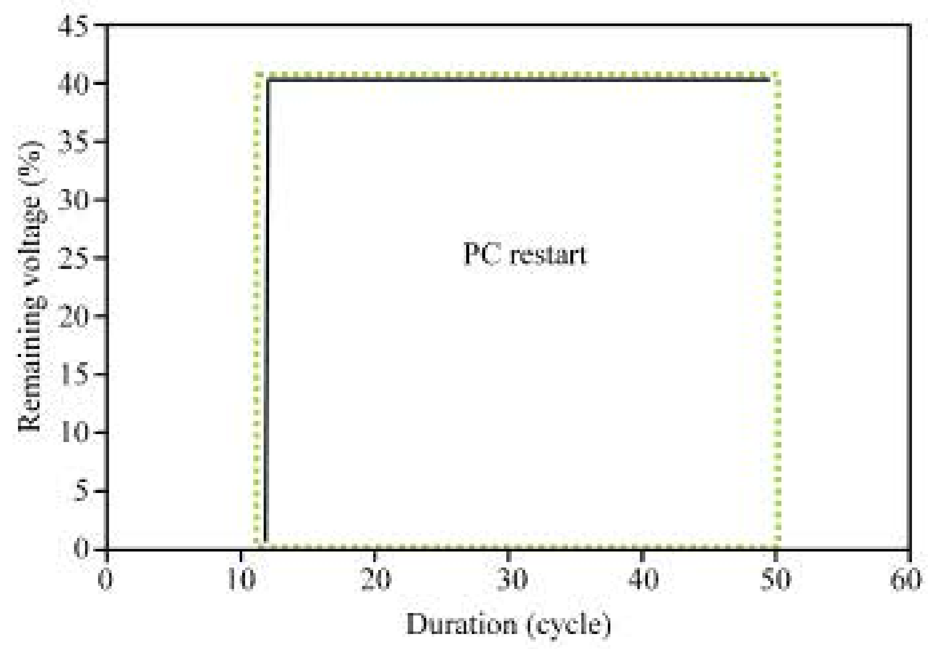

Fig. 7: Voltage tolerance curve for PC3

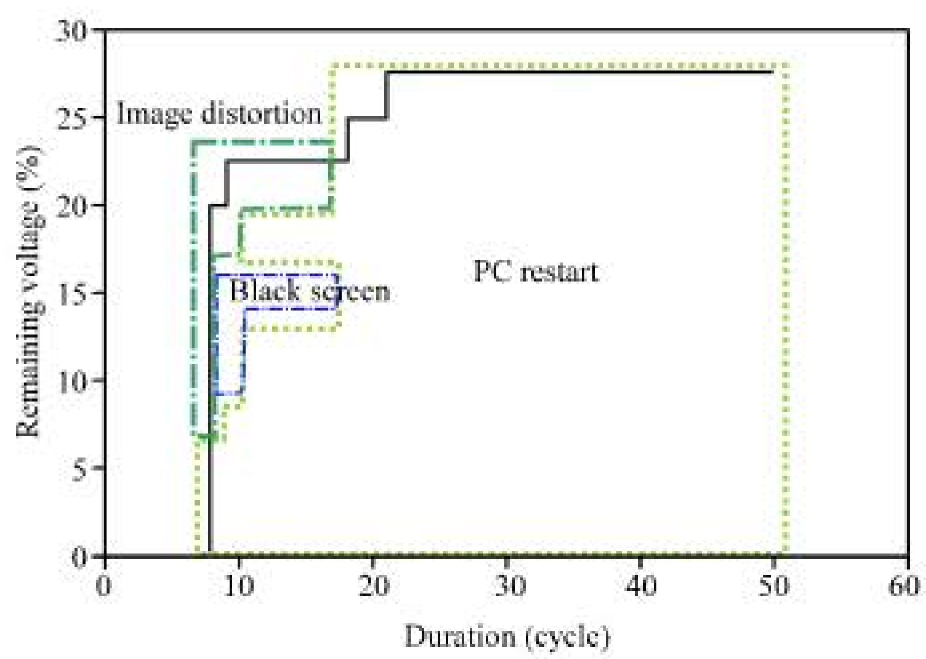

Fig. 6: Voltage tolerance curve for PC2

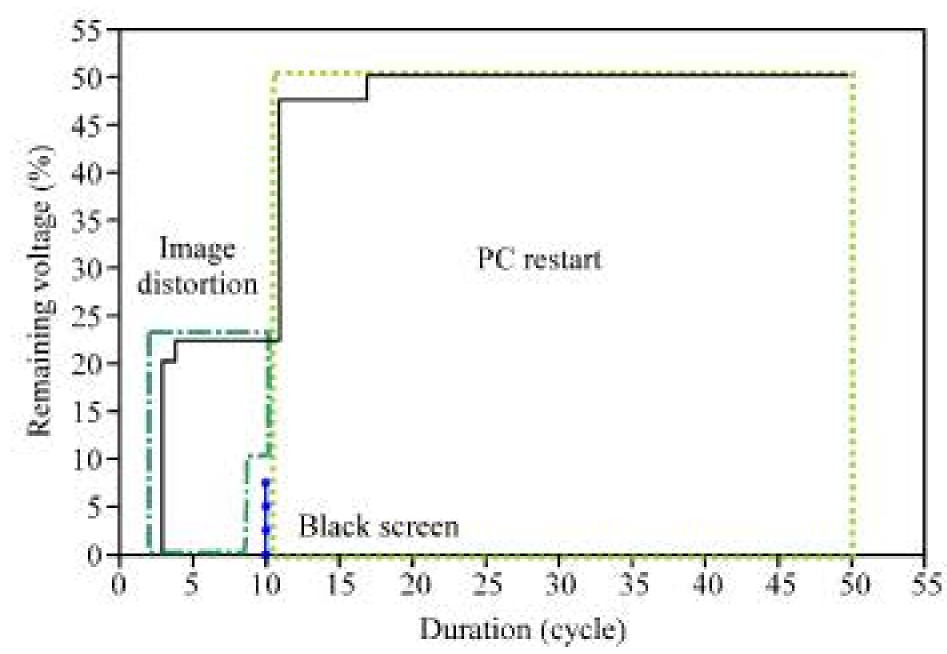

Fig. 8: Voltage tolerance curve for PC4

malfunction conditions due to voltage sag disturbances. As can be noted from Fig. 6, for short duration sags, the first improper operation observed is the monitor image distortion. This condition occurred initially for a sag with 80% depth and spanning for 8 cycles. Besides, for short duration events the image distortion is not the only limiting effect of voltage sag in this case, but deep sags seem to automatically restart the computer. The overall immunity level to voltage sags of PC2 is higher compared to that of PC1.

PC3 has the latest specification of processor and random access memory among all the tested PCs. The influence of voltage sags to PC3 is different compared with other PCs where the monitor malfunction criterion is usually first observed. In this case, the monitor and the CPU of the PC3 happened to restart simultaneously for any level of unacceptable voltage disturbance. This is found to occur for sag magnitude beginning from 60% and for all durations greater than 12 cycles as shown in Fig. 7.

PC4 is found to be the most sensitive personal computer selected for the testing. The monitor malfunction criterion is initiated for voltage sags as short as 3 cycles. For long duration sags, starting from 10 cycles, PC4 failed to perform its operations if the encountered sag depth is above 50%. At this point it is automatically restarted. Therefore, PC4 is also the most sensitive PC for long duration sags. The performance of PC4 is given in Fig. 8.

Figure 9 shows voltage sensitivity curve of PC5. It shows a very similar pattern to that of PC4. The main difference in this case is that it is a little more sensitive to short sags in the range between 7 to 11 cycles. During this period, bussing sound and image distortion is observed if the remaining voltage goes below 27.5%.

Development of a generic voltage immunity curve for PCs: As shown in above, each personal computer potentially has its own standard of power acceptability. An approach to define the overall acceptability region is the application of intersection to the individual voltage tolerance curves (Kyei *et al*., 2002) as shown in Fig. 10.

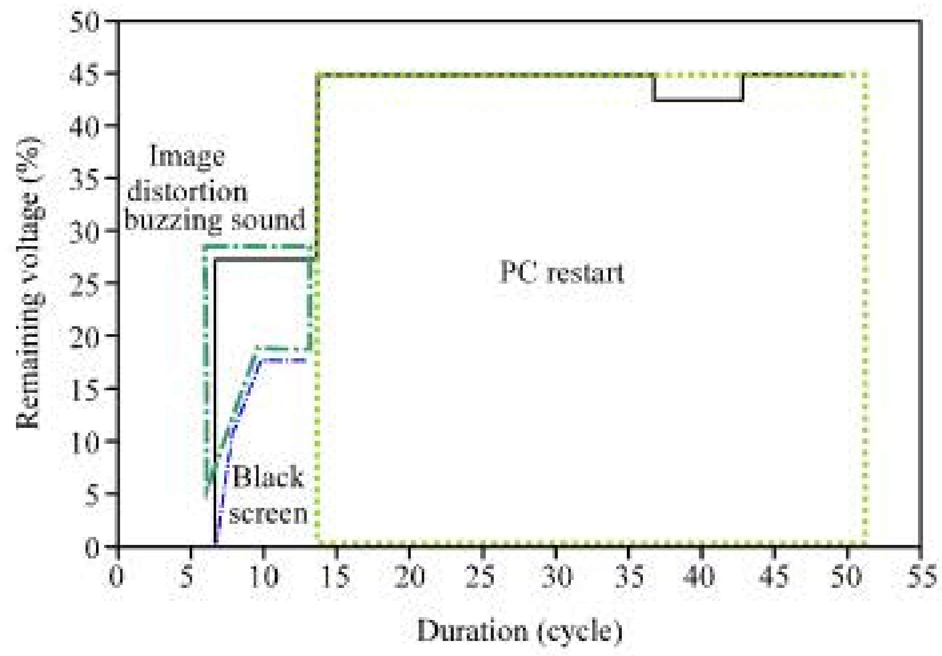

Fig. 9: Voltage tolerance curve for PC5

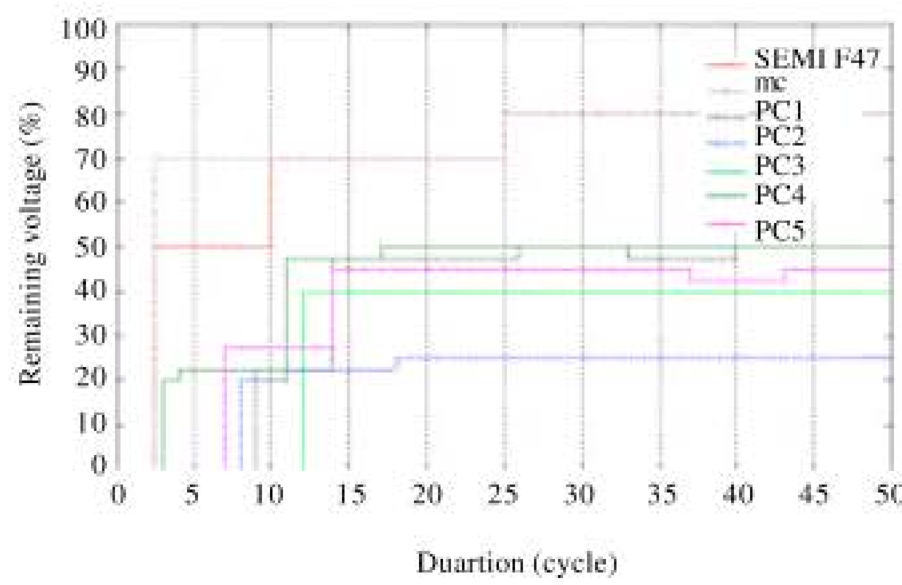

Fig. 10: Power acceptability of all PCs

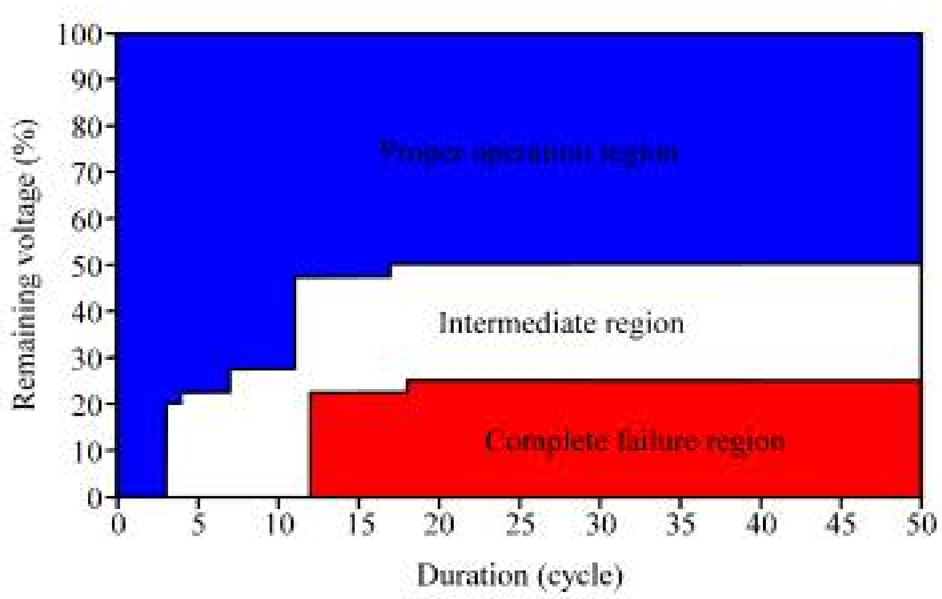

Fig. 11: Result of intersection of all individual voltage tolerance curves

The upper acceptable region is the region that all PC loads properly operate, the lower region indicates that all PCs fail and the intermediate region corresponds to some PC failures and some ride-throughs. The concept of intersection by overlaying many acceptable curves is shown in Fig. 11.

Finally a generic power acceptability curve for the PCs can be constructed by taking the upper

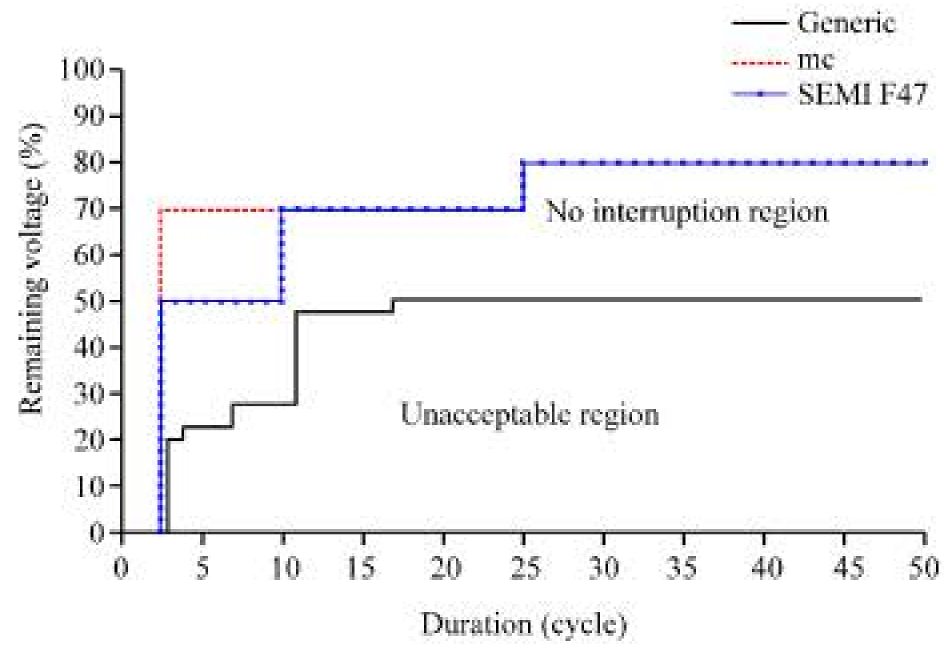

Fig. 12: Generic voltage immunity curve for PCs

tolerance region of the intersected curves as shown in Fig. 12.

From the constructed immunity curve for PCs depicted in Fig. 12, it can be noted that all PCs can tolerate short transient interruption which is less than 3 cycles. However, some sensitive PCs such as PC4 may start to fail if it is a little greater than 3 cycles caused by severe sag with depth greater than 80%.

If one takes the first section of the well known SEMI F47 standard which represents the immunity level of equipment for sag duration between 2.5 to 10 cycles and compare the developed power acceptability curve as shown in Fig. 12 for PCs, it can be observed that the latter curve has 3 distinctive steps in this period. The first step appears for the duration between 3 to 4 cycles and to magnitude of 80% nominal voltage. The second step represents immunity level of PCs to sag depths of 22.5% remaining voltage. This period lasts between 3 to 7 cycles of time axis in the developed curve. The final step that goes until 10 cycles corresponds to 27.5% of remaining voltage.

When the magnitude of these 3 steps of the proposed immunity curve are compared to ITIC and SEMI F47 standards sag depths, 70 and 50%, respectively, the obtained curve indicate much lower values for the duration between 2.5 to 10 cycles.

The remaining part of the developed immunity curve has two more steps unlike the SEMI F47 standard voltage tolerance curve. The next reduction of tolerance level occurs at 11th cycle with a large transition from 27.5 to 47.5% of the remaining voltage. Then a small increment in susceptibility level of PC loads is observed at the 17th cycle again. As it can be seen from Fig. 12, for longer duration sag which is greater than 17 cycles, some sensitive PCs may still fail to operate properly if the voltage drops below 50% of nominal voltage. One final observation that can be obtained from Fig. 12 is that all

PCs can tolerate a sag depth less than 50% voltage indefinitely according to the test results curve. However, the SEMI F47 accepts 50% reduction in voltage magnitude only for less than 10 cycles.

Finally from the test results and developed immunity curve for PCs it is possible to conclude that the SEMI F47 standard is not only designed for PCs working in single phase power supply of 230 V. It is noted that all the tested PCs satisfy the design goals of SEMI F47 and ITIC standard and exhibits a large margin between the actual malfunction conditions that may be observed due to any voltage sag arising on the supply system. Furthermore, by comparing the number of sag events that fall below 60% nominal voltage given in Table 1, it can be said that the sensitivity of PCs to voltage sags in local mains supply is low.

CONCLUSION

An experimental study has been performed to determine the effect of voltage sag on personal computers. From the results of the experimental study, voltage tolerance curves of PCs are constructed to describe the sensitivity of various PCs to voltage sags. It may be concluded that the voltage tolerance of the PCs used in the test varies over a wide range. All the immunity curves obtained appear to have similar shape with distinctive vertical and horizontal steps. Monitor image distortion, buzzing sound and black screen condition which is considered unacceptable in this study seem to emerge only for short duration sags lasting less than 18 cycles. Long duration sags mainly lead to a computer reboot. Although the computers tested covered a wide range of model, type and hardware configurations, there is no correlation between processor speed and operating system installed.

When the voltage immunity levels of the tested PCs are compared with the ITIC and SEMI F47 standards, all the tested equipment satisfy their design goals. Based on the experimental results it is possible to construct a generic voltage tolerance curve for PCs which can clearly show acceptable and unacceptable regions for different voltage sag disturbances. The curve provides a quick overview about the immunity level of personal computers in a particular power distribution network. In addition of having the knowledge about the PC sensitivities to voltage sags, there are few methods that can be investigated to immunize the PCs from voltage sags. These include the use of dc link capacitors at PCs' power supply unit and the use of power factor correction circuitry. The relationship between voltage sag and DC output variation of PCs' switch mode power supply is currently under investigation and the test results will be presented in the near future.

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