Virtual Instrumentation Applied to Electromagnetic Compatibility Testing

Francisco Domingo Pérez[1], José María Flores Arias[1], Antonio Moreno Muñoz[1], Víctor Pallares López[1], Aurora Gil de Castro[1], Isabel María Moreno García[1], and Juan José González de la Rosa[2]

[1] Universidad de Córdoba, Dpto. A.C., Electrónica y T.E., Escuela Politécnica Superior
Campus de Rabanales. E-14071 Córdoba, Spain
{p62dopef,jmflores,amoreno,vpallares,agil,p92mogai}@uco.es
[2] Universidad de Cádiz. Dpto. ISA, TE y Electrónica. Escuela Politécnica Superior
Avda. Ramón Puyol, S/N. E-11202 Algeciras, Spain
juanjose.delarosa@uca.es

Abstract. This paper focuses in the development of an electromagnetic compatibility test system for voltage dips immunity and supply current harmonic distortion. Voltage dips analysis is a complex stochastic issue, since it involves a large variety of random factors, such as: type of short circuits in the power system, location of faults, protective system performance and atmospheric discharges. On the other hand, harmonic distortion is a steady state disturbance which is caused by the rectifier employed in energy-efficient technology. This paper describes a system for voltage dips testing according to IEC 61000-4-11 norm and it also test the supply current harmonic distortion according to the limits given in IEC 61000-3-2. Results of the dips test are represented in a power acceptability curve obtained with the test levels of the norm; the harmonic distortion is represented in a bar chart compared with the IEC 61000-3-2 limits.

Keywords: Virtual instrumentation, electromagnetic compatibility, voltage dips, harmonic distortion, power quality.

1 Introduction

As more and more electronic equipment enter the residential and business environment, the subjects related to Power Quality (PQ) and its relationship to vulnerability of installations is becoming an increasing concern to the users. The two main aspects of PQ are [1]:

- Technical PQ, which includes: Continuity of supply or reliability (sustained interruptions) and Voltage Quality (VQ), that is, voltage level variations and voltage disturbances.
- Commercial services associated to the wires are regulated (such as the delay to get connected to the grid, etc.) as well as commercial services for energy retail to regulated customers.

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Sustained interruptions, which occur when voltage falls to zero more than a minute, are the reliability problem with which more electricity consumers have the greatest direct experience and are the key phenomena measured in traditional utility service quality and reliability statistics. Indices such as System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index respectively (CAIDI) do not capture PQ perturbations.

Power Quality is concerned with deviations of the voltage or current from the ideal single-frequency sine wave of constant amplitude and frequency. Poor PQ is a concern because it wastes energy, reduces electrical capacity, and can harm equipment and the electrical distribution system itself. Power quality deterioration is due to transient disturbances (voltage dips, voltage swells, impulses, etc.) and steady state disturbances (harmonic distortion, unbalance, flicker…) [2].

The quality of the power supply delivered by utilities varies considerably and depends on a number of external factors. Things like lightning, industrial premises which apply and remove large loads, non-lineal load stresses, inadequate or incorrect wiring and grounding or short circuits caused by animals, branches, vehicular impact and human accidents involving electric lines.

With the generalized use of PLCs, adjustable-speed drives (ASDs), computers and other susceptible devices, the subject related to power quality and its relationship to vulnerability of highly automated plants is becoming an increasing concern to the industry. Among all categories of electrical disturbances, voltage dips and momentary interruptions are the nemeses of the automated industrial processes. On the other hand, voltage swells (which are not so common) do not normally disrupt sensitive load, but can cause harm to equipment.

Voltage dip is commonly defined as any low voltage event between 10% and 90% of the nominal RMS voltage lasting between 0.5 and 60 cycles. Momentary voltage interruption is any low-voltage event of less than 10 percent of the nominal RMS voltage lasting between 0.5 cycles and 3 seconds. Voltage dips can be caused by natural events (e.g., trees falling on power lines or lightning striking lines or transformers), utility activities (e.g., routine switching operations or human error) or customer activities. Voltage dips at a customer bus are different depending on his location in the electrical network. Because of the short duration of these PQ events, residential customers are rarely aware that a VQ event has taken place. However, for many industrial customers, they pose a far more significant problem than outages because of their much greater frequency of occurrence and overall because of that their incidence can cause hours of manufacturing downtime.

In medium voltage distribution networks, voltage dips are mainly caused by power system faults. Even though the load current is small compared to the fault current, the changes in load current during and after the fault strongly influence the voltage at the equipment terminals. It has been discovered that the 85% of power supply malfunctions attributed to poor Power Quality are caused by voltage dips or interruptions of fewer than one second duration [3] [4].

Starting large motors can also generate voltage dips, although usually not so severe. Some major problems associated with unregulated line voltages (in particular, long-term voltage dips) include equipment tripping, stalling overheating and complete shutdowns of sensitive equipment if it is designed within narrow voltage limits, or it does not have adequate ride-through capabilities to filter out fluctuations in the electrical supply. These subsequently lead to lower efficiency, higher power demand, higher cost for power, electromagnetic interferences to control circuits, excessive heating of cables and equipment, and increased risk of equipment damage. The need for line voltage regulation still remains a necessity to meet demands for high industrial productivity.

There are several conditioning solutions to voltage regulation, which are currently available in the market place. Among the most common are Un-interruptible Power Supply systems, (UPS). Recently, new technologies like custom power devices based on power electronics concepts have been developed to provide protection against PQ problems.

Instrumentation and control operation require high quality and ultra-reliable power in the quantities and time frames that have not been experienced before. It was estimated that dips below 87% of voltage and greater than 8.3 ms in duration at the utility feed to the plant would likely disrupt production. However, nowadays the situation is worse, because more than 30% of the power currently being drawn from the utility companies if used for sensitive equipment, and this amount is growing up [4].

The IEC norm defines a voltage dip as “a sudden reduction of the voltage at a particular point of an electricity supply system below a specified dip threshold follow by its recovery after a brief interval”. The latest version of the IEC 61000-4-11 (second edition) dates from March 2004 and it is the only one which must be used since first of June 2007 [5].

This edition adds to the previous one a new dip level, whereas Edition 1 only used 0%, 40% and 70%, Edition 2 adds the dips level 80%. It also includes a definition of Equipment Under Test (EUT) classes, specifying test level and durations.

A power acceptability curve is a kind of graph that plots the change of the supply voltage (usually in percent) versus its duration (in seconds or cycles). The CBEMA curve divides the graph in two regions, the acceptable power zone and the unacceptable zone, which is divided into overvoltage and undervoltage. Lower durations (below 8.33 ms, a 60 Hz half-cycle) are considered acceptable for voltage dips. From about five seconds (steady state) is considered unacceptable a variation below 87%. The construction of the CBEMA curve is discussed in [6].

The CBEMA curve was replaced by the ITIC curve at the end of 20th century; this curve differs from the other one in having straight lines instead of curves. It also has a narrower steady state tolerance; whereas the CBEMA curve considered voltage variation less than 87% as unacceptable the ITIC curve set the steady state limit in 90%. Reference [7] explains every aspect of the ITIC curve.

A description about dips test procedures, power quality curves and existing standards is given in [8].

With regard to harmonics, harmonic analysis is a primary matter of PQ assessment. With the widespread use of power electronics equipment and nonlinear loads in industrial, residential and commercial office buildings, the modeling of harmonic sources has become an essential part of harmonic analysis [9].

Apart from that, harmonic attenuation refers to the interaction of the load voltage and current distortion [10]. Various research works have shown that a nonlinear load supplied with distorted voltage will inject less harmonic currents than those generated when the load is supplied by undistorted voltage.

The IEC 61000-3-2 norm deals with the limitation of harmonic currents injected into the public supply system, this norm is applicable to electrical and electronic equipment having an input current up to and including 16 A per phase. The standard divides the equipment into four groups; the devices tested in this paper are analyzed as class C (lighting equipment).

2 Methodology

The electromagnetic compatibility (EMC) testing facility described next has the main purpose of being used for voltage dips testing in electronic ballasts.

The test procedure for voltage dips testing is very similar to that given in [11], except from this is a test system for single-phase equipment and the use of the power acceptability curve at the end of every measurement.

2.1 Equipment

The following items were used during the system development.

- PC: to run the test software and store the measurement results.
- USB oscilloscope (min. 2 channels).
- Voltage dips generator controlled by USB serial adapter. The generator used by the authors incorporates predefined tests for de first edition of the voltage dips test norm, but it can be almost totally programmed by the serial port and run test with the durations of the second edition.
- Current probe.
- AC/DC voltage converters Evaluation Modules (EVM) with resistive loads.

2.2 Connection

The oscilloscope and the voltage dips generator are connected to the PC via USB. The generator input is plugged to the main line and the output is used to supply power to the EVM. Resistive loads are attached to the DC output of the EVMs.

One scope channel measure the generator signal that indicates the moment when the dip is running, the other channel measure the output voltage from the EVM.

In the harmonic test, the current probe is attached to the output of the dips generator.

2.3 Software

The control of the scope and the generator are separated in two virtual instruments. As this paper focuses in the monitorization of the tests it only shows the virtual instrument for the scope. The dips generator is run manual as it is not necessary to perform a test with other durations apart from the first edition of the norm, that is, 10 ms for a voltage of 0%, 200 ms for 40% and 1 s for 70% (referred to the nominal value).

The test software of the voltage dips test consists of one window, which integrates the graph of the measured waveform, the graph of the portion of waveform that contains the dip, the power acceptability curve (designed with the recommended tests of 61000-4-11 Edition 2, this curve is represented in [8]) and the instrument control.

The main window allows configuring the most representative parameters of the scope and selecting the voltage dips test. Selecting a test number is only applied to the frequency of the scope; the program selects a frequency to measure the dip with the maximum resolution.

During the test the RMS voltage is measured when the Evaluation Module (EVM) is working normally and at the end of the test, so the two parameters are taken to the curve plotting the RMS voltage variation.

The harmonic test software is simpler than the previous one. It only uses one channel instead of two; the controls are the same, the software processes the current waveform and obtains the harmonic spectrum, comparing with the limits in IEC 61000-3-2 and representing both in a bar graph.

2.4 Test Process

First, the dip level must be selected by hand with the generator dial.

The scope is configured for triggering when channel 1 detects a rising slope, this signal comes from the voltage dips generator and it is activated when the dip is running.

While the test is not running, the EVM is supplied by the main line, so it is working normally and the channel 2 is measuring the normal output voltage and storing it RMS and average value. Once the test starts the channel 1 is triggered and the clock scope is configured covering the dip test duration so the entire voltage during the dip is measured and stored for later revisions. The RMS voltage previous to the first test is used to reckon the voltage variation with the RMS value obtained at the end of the test. When a test fail, the number of the test and its result are saved, so the data can be reviewed to consider the fail importance. The result is also shown in the power acceptability curve immediately.

In the harmonic test, just plug the current clamp in the scope and measure the supply current, the harmonic orders are compared with 61000-3-2 limits.

3 Test Example and Results

In order to check the correct work of the system four EVMs have been tested. Both of them have been executed with the following equipment:

- PC: Intel Pentium IV 1.6 GHz, 512 MB RAM, 40 GB HDD, running Windows XP SP2.

- USB oscilloscope: Elan Digital Systems USBScope50, 50 megasamples per second, 8 bits resolution, full scale of 300 mV to 30 V with 1x probe.
- Voltage dips generator: Deneb Elettronica DNBGVD01, max current to load of 5 A and a dip rise time of 1 to 5 microseconds.
- The software has been developed using National Instrument LabVIEW 7.1.

The first test was developed under the following conditions:

- EVM: Texas Instruments UCC28514EVM, AC/DC voltage converter with Power Factor Correction (PFC), designed to operate over a universal input range of 85 V to 265 V_{AC} with a regulated 24 V, 100 W output. The used load is a parallel resistor combination of two 15 Ω//50 W.
- Test 1: 0% dip level, 0.5 ms (positive half-cycle).
- Test 2: 0% dip level, 0.5 ms (negative half-cycle).
- Test 3: 40% dip level, 200 ms.
- Test 4: 70% dip level, 1000 ms.

Every test has been repeated a minimum of three times with ten seconds between dips. As the EVM accepts a wide voltage range the output voltage almost did not change, as can be seen in Fig. 1.

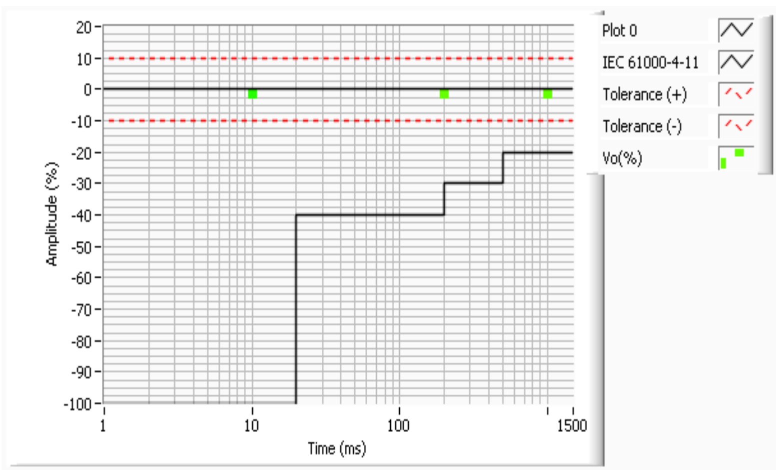

Fig. 1. Final results of the voltage dips test for UCC28514EVM

Fig. 1 shows the power acceptability curve with the results of the test, in the same curve it is represented the test results, in order to check if they are between the tolerances specified by the Equipment Under Test manufacturer.

The scope uses an 8 bits analog-digital converter, in order to measure 24 V we use the 30V scale, this way we have got an accuracy of 0.236 V.

Fig. 2 shows the harmonic test, the top graph represents the supply current, the bottom graph is the harmonic spectrum, and it is expressed as a percentage of the input current at the fundamental frequency.

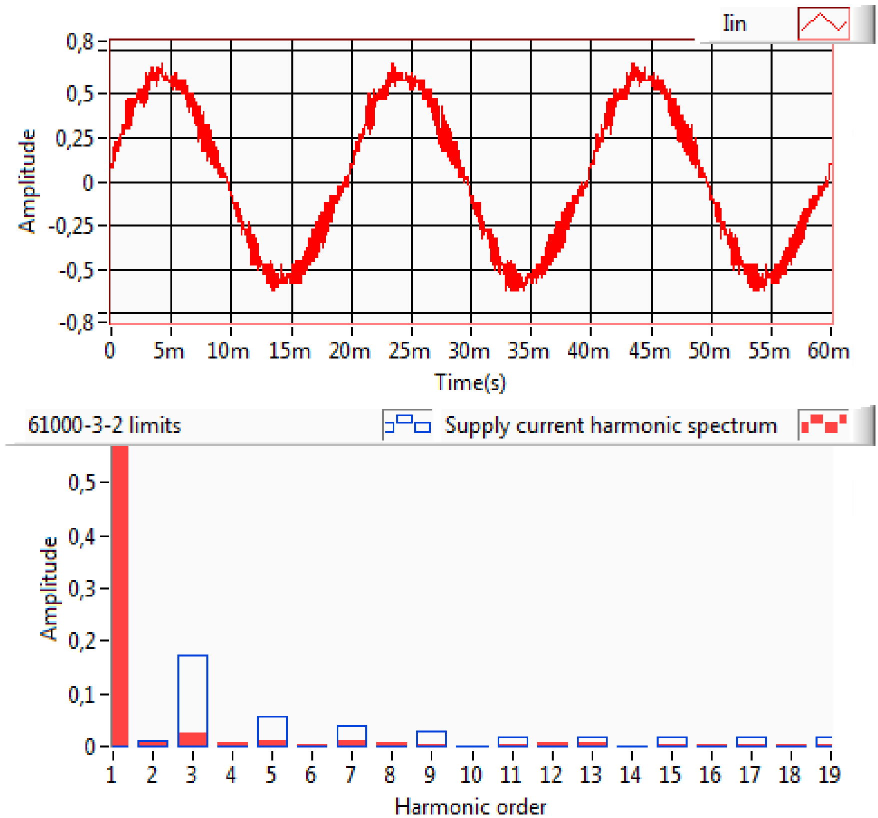

Fig. 2. Results of harmonics test for UCC28514EVM

The second test is similar to the first one, changing the EVM; all the parameters about durations, levels, etc. are still the same. The new EVM is following described:

- Texas Instruments UCC28019EVM, a PFC boost converter that accommodates an input voltage of 85 to 265 V_{AC} and provides a 390 regulated output at 0.9 A of load current. The resistive load is a combination of two serial resistors of 1 kΩ//50 W.

The measurement of voltages greater than 300 V requires an x100 probe, then we get a 3000 V full scale with a resolution of 8 bits, hence the accuracy is multiplied by ten, so the new accuracy is 23.6 V.

Previous test and the following two were also a success, so the graphs are nearly the same. The last two tests were:

- Texas Instruments UCC28061EVM and UCC28070EVM, two interleaved PFC pre-regulator with a 390 V, 300 W, DC output operating with an input voltage of 85-265 V_{AC}. The resistive load is a combination of two serial resistors of 1 kΩ//50 W.

4 Conclusions

The system can be used to test equipment according to IEC 61000-4-11 and IEC 6100-3-2. The voltage dips generator can be programmed by software to define any dip duration between 10 ms and more than 1 s. Because of this reason there is no problem in adapting the software to new norm revisions.

The next step to improve the voltage dips test system should be the possibility of changing the dip level by computer instead of turning the dial by hand (e. g. with a stepper motor); this will allow the user not to be present during the test execution for changing the dip level. As all the other parameters can be changed by software, the dip level makes the software almost useless, as it is necessary to turn the dial manually.

That way, the system is only limited due to the hardware specification. The low oscilloscope resolution makes very inaccurate any measurement above 300V. On the other hand, the voltage dip generator configuration is limited to changing the dip level and duration and the pause between dips, but the norm also advices about critical phase angles which should also be tested.

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