On the Immunity of Data Acquisition Systems Used in Power Systems

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Abstract - **The paper deals with some tests regarding the immunity for radiated emissions and compliance with international standards for electromagnetic compatibility (EMC) measurements for an industrial data acquisition system (DAS) used in power systems. The behavior of the DAS, when functioning near electromagnetic disturbance sources, is studied. The goal is to test its robustness in similar conditions as those encountered in its normal environment. It is known that multiple factors may affect the accuracy of data acquired by DAS. The Equipment Under Test (EUT), witch in this case is represented by DAS is tested for immunity in a specialized enclosure (GTEM Cell). The immunity based on the analysis of the influences of an electric field with constant magnitude and variable frequency in the range of 80 MHz...1 GHz is studied. After analyzing the initial tests results, partial and, afterwards, full shielding of the EUT's case is performed in order to remove the EM influence. The tests' results drive to the conclusion that it is necessary to design and build an enclosure from conductive material for the DAS. After the implementation of the measures, the EUT passed the tests concerning the immunity. The GTEM Cell construction, GTEM model, generation and distribution of electric and magnetic field inside the GTEM Cell, equipment under test (EUT), radiated emission measurement scheme, EMC standards for GTEM Cell, are exposed.**

Keywords: *Data Acquisition System, immunity tests, electromagnetic shield, electromagnetic interferences.*

I. INTRODUCTION

Immunity to radiation is the condition when the existence of radio-frequency waves into the atmosphere is likely to affect the normal operation of a device. In order to exemplify this phenomenon, we can mention the case of voltage fluctuations, harmonics etc.

Passing the immunity tests for a data acquisition system (DAS) means that the equipment has the capacity of functioning undisturbed in the environment where it is installed.

DAS purpose is to acquire the input analogical signals, to measure, analyze, process and display the measurement. The acquired data accuracy in our test isn't always high.

Because of some disturbance sources, significant errors can occur during measuring related operations.

By testing the immunity to EM radiations of DAS, one intends to analyze and remove the negative effects that appear in the measurement process.

Testing the equipment's immunity to radiations can be done with a specialized enclosure, such as the Gigahertz Transverse Electromagnetic Mode (GTEM) Cell [1].

GTEM cell is an improved version of TEM cell, with extended frequency range to GHz and increased working volume.

Unlike the anechoic chamber, the GTEM cell makes possible for easy testing using less power, when the size of the EUT allows this [2].

II. DATA ACQUISITION SYSTEM

Data acquisition systems are complex structures for processes monitoring in which usually a lot of physical quantities are occurring (Fig. 1).

The purpose of data processing differs with equipment destination. It can be the control of physical process, for protection, or it can be used informatively about the process evolution by data visualization.

DAS acquires analogical or digital signals, using transducers, in order to record, to display or process the information based on the transducer's nature.

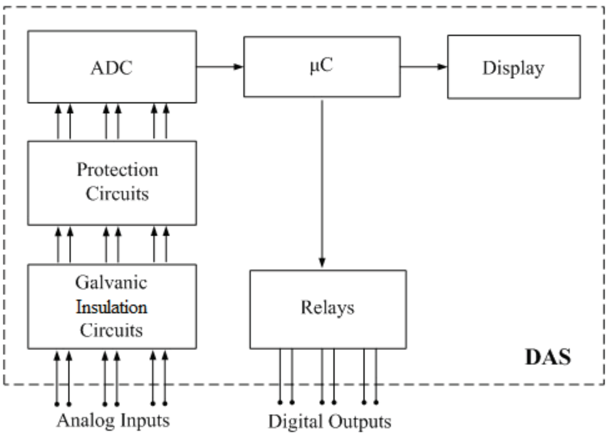

Fig. 1. The basic schematic of a data acquisition system.

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Fig. 2. The tested data acquisition system.

The specifications of the tested DAS (Fig. 2) are:

• Equipment used for measurements in the time domain, with eight analogical input channels of ±10 V and eight digital outputs;

• The Voltage inputs are completely differential, in order to connect it easily both to star (Y) and respectively delta (Δ) schemes;

• The analogical voltage input circuits provide the galvanic isolation of inputs signal to the analog to digital converters (ADC);

• The input circuits preserve the characteristic accuracy for more than 1.5 times the rated input quantities;

• The measuring equipment allows both synchronous acquisition of eight input signal, and over-sampling features.

In case of DAS, the electromagnetic disturbances can be generated by different equipment functioning nearby.

III. DAS Measurement Errors

The errors which appear in DAS measurement can have many causes, as detailed below. Among these, the EM pollution represents the most important sources which can radically influence the DAS operation, often altering the real input values. Removing this effect is the main goal of our research. In this case, the other causes can be neglected.

A. The analog to digital conversion of the signal, conversion errors

A first error is caused by the analog to digital (A/D) converter (ADC) which converts every value of the analogical signal to digital divisions.

In Fig. 3 one can observe that the real sinusoidal input signal recomposition is not precise. Because the resolution increases towards 16-bit, the number of steps increases to 216 = 65536, and one obtain a near perfect signal representation. Our data acquisition system uses 12-bit A/D converters for -10 V ÷ +10 V input voltage.

The 12-bit resolution A/D converter has the following minimum variation of voltage [3]:

$$U_d = \frac{U_{\max} - U_{\min}}{2^{12}}$$

$$U_d = \frac{10-(-10)}{4096} = 4.88\,mV \tag{1}$$

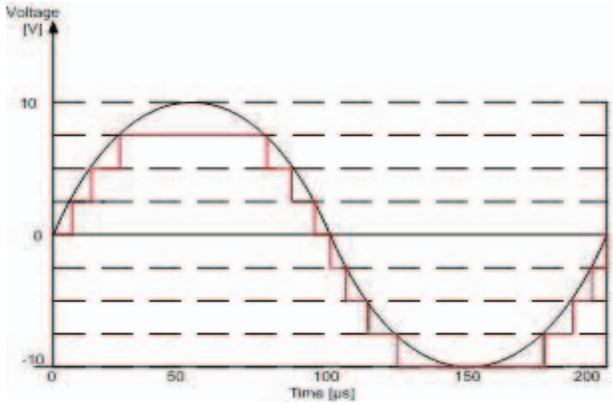


Fig. 3. Truncation errors at the 3-bit conversion of signal.

This minimum voltage variation represents one step. For signals between -10 and +10 V, the minimum detectable variations is 4.88 mV.

The continuous (DC) voltage is constant for a certain time interval:

$$U_{DC} = \frac{1}{(t_2 - t_1)} \cdot \int_{t_1}^{t_2} U(t)dt. \tag{2}$$

For a digitized signal the voltage becomes [14]:

$$U_{DC} = \frac{1}{N} \cdot \sum_{i=1}^{N} U_i \tag{3}$$

The root mean square (RMS) is computed with [14]:

$$U_{RMS} = \sqrt{\frac{1}{(t_2 - t_1)} \cdot \int_{t_1}^{t_2} U^2(t)dt}. \tag{4}$$

The quantization error (ε) can be determined with [14]:

$$\frac{0.5 \cdot U_{\min}}{U_{\max}} = \frac{1}{2^{N+1}} \le \varepsilon \tag{5}$$

where: N – number of bits of the ADC.

When one can estimate the limits of the signal values, it is recommended to choose a domain where the error is as small as possible.

B. Errors introduced by protection and isolation circuits

Another source of errors is represented by the ripple voltage (noise) introduced by the galvanic isolation and over-voltage protections circuits, or the supply. Typically, the ripple voltage value is 20 – 100 mV peak to peak.

Figs. 4 and 5 represent the waveform of a signal before and after filtering [3].

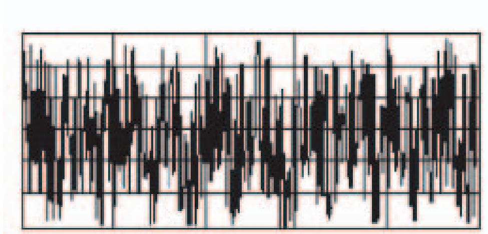


Fig. 4. The waveform of the original signal.

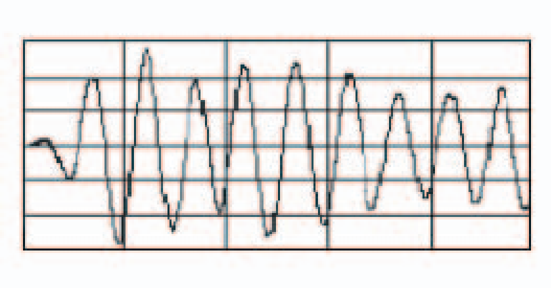


Fig.5. The waveform of the processed signal.

The noise removal can be realized by signal filtering. A data analysis is necessary (the acquired signal must be processed such as to get a reconstructed signal approximating as much as possible the original signal).

The signal filtering is performed using low-pass filters, which do not affect the low frequency components, but they mitigate the high frequency components. The frequency where the signal is attenuated (cutoff frequency) must be sufficiently high such as to preserve the useful components of the signal. Usually, it is chosen to be half the operating frequency of the circuits.

EM pollution represents an important source of perturbation. The removal of its effect is the primary purpose of our research. In the analyzed case, it has the greatest negative effect on the DAS operation.

C. Errors caused by EMC

The EM radiation affects directly the DAS behavior, having effects like: malfunctioning of the microcontroller, erroneous measurements and wrong digital outputs. They main sources of EM perturbations from the operating environment of the tested DAS are equipment built with controlled power semiconductors, which are functioning nearby DAS.

The detection of these problems is the starting point of this paper. One intended to test the DAS to immunity, using a GTEM 750 cell and eventually to take corrective measures if problems are detected.

IV. IMMUNITY TESTING OF DAS

Testing the DAS in the GTEM cell is realized in compliance with the generic standard IEC 61000-4-20, which refers to immunity testing in transverse electromagnetic (TEM) waveguides.

The GTEM Cell is a transmission line that simulates the electromagnetic energy transmission in the TEM mode (Transversal Electro-Magnetic) through which the electromagnetic wave propagates into the surrounding space. The GTEM cell, as a new measurement facility in electromagnetic compatibility (EMC), needs to be evaluated, especially considering its electric field distribution. It is important to determine the field strength and distribution in a GTEM cell for EMC and calibration measurements.

The field strength inside a GTEM Cell is a function depending on the input power as well as on the location along the longitudinal axis or septum height. Immunity measurements require field uniformity (75 dB according to IEC 61000-4-3 Standard) over certain test areas [4], [5].

Immunity tests assume that the equipment under test (EUT) must withstand a certain level of interference (level specified by the standard) such as to receive a positive opinion and pass the tests [6].

One used the software WIN 6000, compatible with GTEM 750 Cell and the related equipment.

The measurements have been done with a frequency step of 1%, the EUT being positioned in three different ways on the coordinate system's axes [1].

In this case, for testing, the EUT is placed in the cell and the amount of power is increased until the required value of the field is reached. For each measurement the EUT is monitored for the respective frequency (30 MHz – 1 GHz). The configuration of the test is depicted by Fig. 7 [7].

Test arrangement was performed in accordance with the standard IEC 61000-4-3, and the following equipment was included: amplifier; generator; bi-directional coupler; meter (power meter) depicted by Fig..6.

The electric field values within the cell and the measured forwarded and reversed powers during tests are depicted in Fig. 8. The "+" marker suggests the frequencies for which errors appeared.

The stationary step time for each analyzed frequency was 5 seconds. The testing was done for a value of 30 V/m for the reference input field, with an error tolerance of 1 %.

The DAS testing was performed with and without the signal's modulation in amplitude (AM). During tests, the DAS was operating with no inputs (the voltages and currents values were null). The measurements display (voltages and currents) on the DAS' screen is realized in a sequential mode.

No errors were recorded during tests with not AM.

During tests with AM one noticed that the DAS had an abnormal behavior, as explained in Table I.

As a consequence of the above, one proposed the shielding of the DAS.

Shielding is essential firstly for the limitation of the radiate emission of a system (EN55022 standard , for radiated emission between 30 MHz and 1 GHz), and on the other hand, for system protection against perturbations emitted by local equipment or more commonly against electromagnetic radiation in the environment.

Several standards define the method for testing the immunity to radiated perturbations, depending on the source of field and respectively on the frequency: incidental electromagnetic field – IEC 61000-4-3, 61000-4-10 and so on.

Shielding is generally acquired through a metal or metal plated casing, which surrounds the equipment (Fig. 11).

TABLE I.
ERRORS OCCURRED DURING TESTS.

Frequency [MHz]	Voltages [V]
0÷110	0
116	10
120	12
124	26
130	29
132	31
136	36
137÷438	0
451	restarted
471	Stopped working and restarted
495÷1000	0

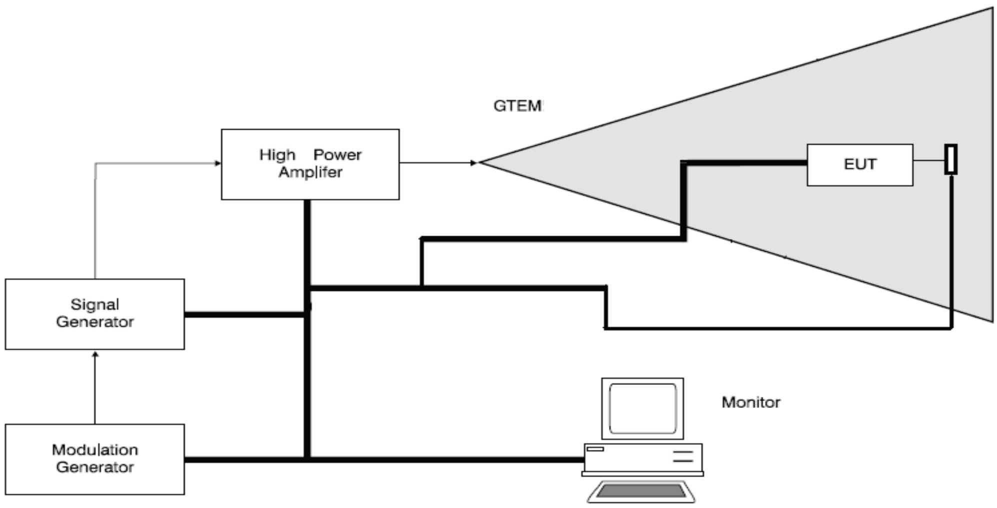


Fig. 6. Equipment disposal for the immunity test.

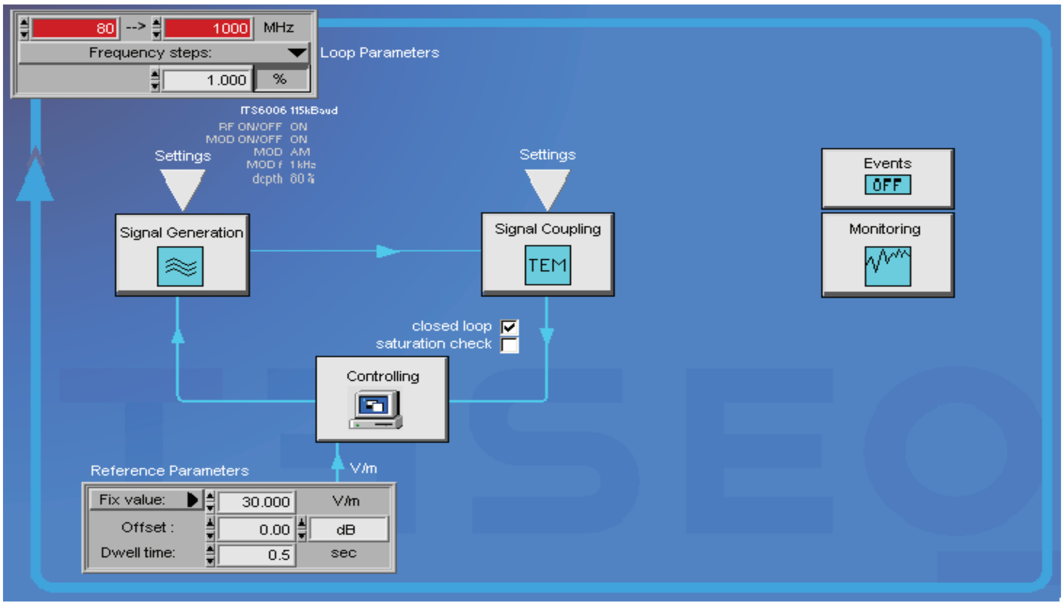


Fig. 7. Test equipment configuration.

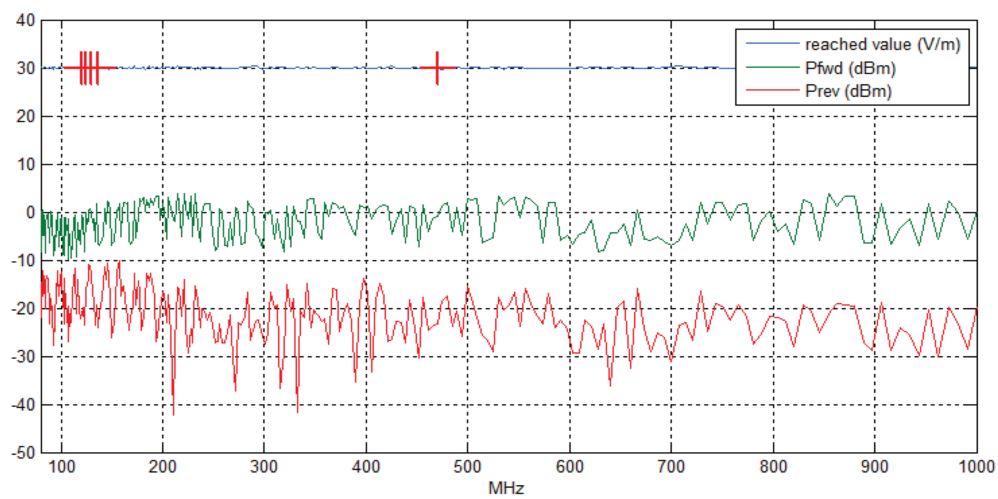
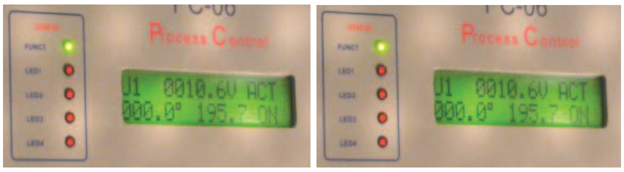
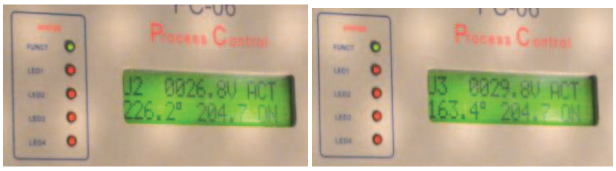


Fig. 8. Reached value of E-field, the forwarded and reversed power.



(a) (b)



(c) (d)

(e) (f)

Fig. 9. Voltages measured by DAS during testing within 110 MHz÷140 MHz range.

Fig. 10. DAS behavior at resetting for 451 MHz.

The shielding must protect the sensitive part of a device against exterior electromagnetic fields.

Because the tangential component of the electric field and the normal component of the magnetic field are null at the surface separating the shield from the environment, the conducting surfaces are absorbing electric field whilst rejecting the magnetic field. In the same time, the reflection (shielding) is improved along with the electric conductivity σ and therefore it is stronger for the Copper shields and weaker for the Iron ones.

Following the partial shielding, one noticed that for the 110 MHz ÷ 140 MHz range, parasite voltages were recorded, having values between 26 – 41 V (Fig. 12).

For the 430 MHz ÷ 480 MHz range one noticed a normal behavior of the DAS, the voltage remaining constant at 0 V (Fig. 13).

Further, a decision on DAS fully shielding DAS was made. The shielding was done with copper foil (which has high shielding properties), the shield being connected to ground (Fig. 14).

After the DAS's fully shielding, the voltages measured were at 0 V for the analyzed frequency range of 30 MHz ÷ 1 GHz.

In the first stage one partially shielded the DAS. The shielding was made with copper foil with a width of 0.08mm applied on the outer case of the DAS in the direction of the electric field's propagation.

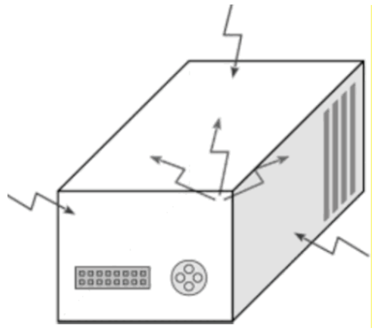
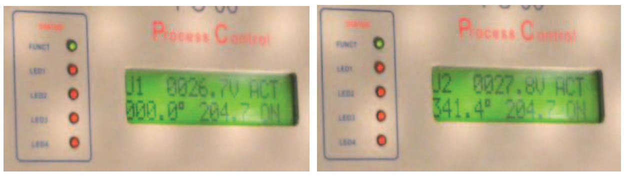
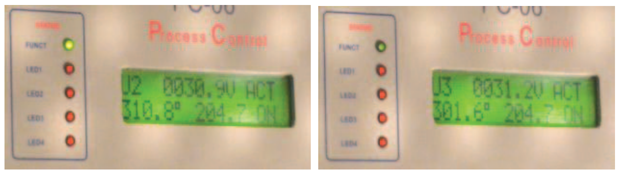


Fig. 11. Metallic case used to shield the equipment.



(a) (b)



(c) (d)

Fig. 12. Voltages measured by the partially shielded DAS during tests sin the 110 MHz ÷ 140 MHz range.

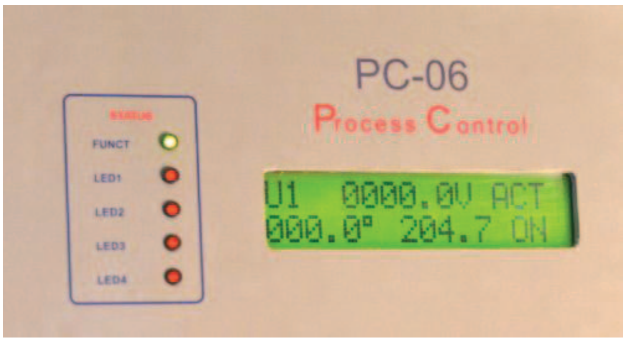


Fig. 13. Voltage measured by the partially shielded DAS during tests in the 430 MHz ÷ 480 MHz range.

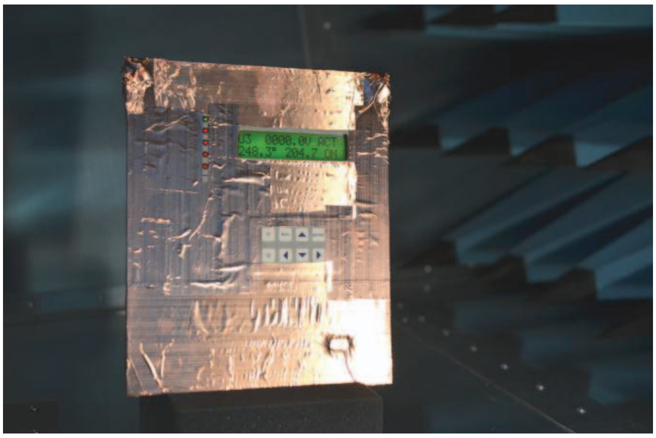


Fig. 14. DAS fully shielded with copper foil.

V. CONCLUSIONS

The tests concerned with the DAS revealed that the original case, made of Iron, did not provide immunity to electromagnetic radiation. Therefore a Copper foil was used to cover the DAS.

The advantage of the partially shielded DAS is that one managed to remove the unwanted effects that appeared within the 430 MHz ÷ 480 MHz frequency range, namely the DAS' resetting, blocking and shutting down.

The initial solution of a partially shielded DAS had limited effects, because one could not manage to remove all the negative aspects of EMC.

Further, one decided to fully shield the DAS with a shield connected to the DAS' ground.

In the end, the obtained results were satisfactory, the input sizes being null for the entire test period.

An important role, from the DAS' construction point of view, will be the DAS' case substituting by a metallic case made from a material with high EMC shielding properties (such as copper foil).

This solution should considerably reduce the negative effects of electromagnetic interference.

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