Measurement system for electrical variables in a high EMI environment

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Abstract: This paper introduces a system for measurement of electrical signals under very aggressive EMI conditions at a high power testing laboratory. Basically, the measuring process includes sensing voltage and current signals, in the order of tens of kV and kA, with the appropriate shunts or dividers, signal conditioning, analog modulation and transmission from the testing zone. The transmission media is optical fiber to ensure signal integrity, avoiding distortion due to EMI caused by the large currents and voltages during tests. At the other end, in the control room, the data acquisition system converts the optical signals back to electrical signals to be demodulated, amplified and digitized for further processing. The electronics take care of other potentially harmful influences such as temperature variation, which may cause DC-shifting and gain variations. The measurement system is currently under factory and on-site acceptance tests with excellent results so far. This system was conceived and developed in the Department of Instrumentation and Control of the Electrical Research Institute (IIE), under specific request from the National Electricity Company (CFE) in Mexico.

Key-Words: EMI, high power testing, measurement system, optical fiber, EMI distortion, DC-shifting, gain variation.

1 Introduction

In Mexico, the National Electricity Company (Comisión Federal de Electricidad – CFE) has a large equipment-testing facility formed by a group of laboratories, called LAPEM [1], to authenticate conformance to standards of all electrical devices or materials before buying and putting them into public service. Among the most important laboratories is the High-Power Mid-Tension (HPMT) laboratory [2], which is currently being upgraded. In this laboratory, devices such as circuit breakers, transformers, interrupters, fuses and others are tested to verify their response at specific currents and voltages, including destructive short-circuit conditions. The electromagnetic environment is very aggressive during the execution of tests, thus preventing the use of conventional hardware for measuring the electrical signals involved in the testing experiments.

Figure 1 depicts the one-line diagram of the HPMT laboratory. In the left side there are the two sources of energy that can be used for the testing experiments: a special purpose 2 GVA generator for up to 86 kA and 38 kV tests (GEN) for very high power tests and a 23 kV substation feeder (SE) for not so high power tests. Then, there are the short-circuit transformer zones (PTCC and STCC), with a series of switches to drive the test. The limiting reactance zone (RL) and the transitory tension circuit zone (TTR) for reestablishment. The PBAS zone includes the testing cell, where the device to be tested (DUT) is placed for experiments and observation. At the right end, there is the loads zone (RLC).

The HPMT laboratory requires the deployment of several systems to manage and to carry out the testing experiments, such as the Electric Variables Measurement System (EVMS), which is described in this paper.

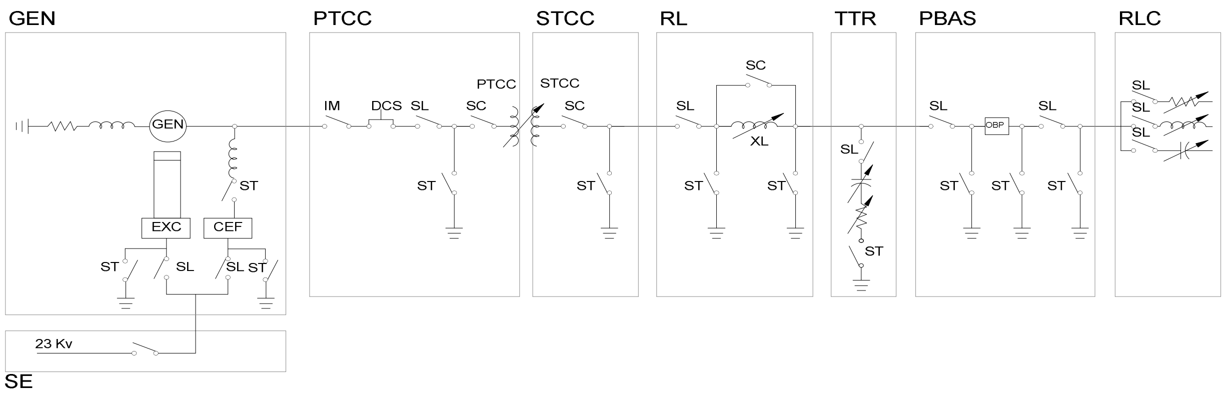

Fig. 1. One-line diagram of the HPMT laboratory.

2 Test Requirements

Measuring electrical variables inside the HPMT laboratory is a big challenge. The measurement and signal conditioning of large currents and voltages, in the order of tens of kA and kV, have to be considered, before transmitting this information to the control room for further analysis. However, the major problem is signal integrity, which has to be transmitted without any distortion. To solve this problem in the HPMT lab, a measurement system capable of measuring and carrying analog signals with minimum added error and with sufficient amplitude for post processing has to be developed [3]. Also, the signals to be measured depend on the type of test in process. Every time a test is configured, the amount and type of signals are selected.

2.1 Types of tests

Positively, the tests depend upon the type of DUT. However, main tests include closing capacity under short circuit, power arc, and electrodynamics stress resistance, as well as short-circuit interruption testing in terminals, and interruption of currents. Additionally, there are some specific types of test such as short circuit [5], short line failure, closing against failure, phase opposition currents, current in closed loop distribution circuits, magnetizing currents, internal arc, thermal current, dynamic current, and positioning among others, [6]. The DUT could be any of several types: power switches, transformers, reclosers, isolators, among others. In each test, selected parameters must be measured and analyzed.

3 EVMS

The measurement system was developed considering the HPMT laboratory operating requirements. Since the magnitude of voltages and currents to be measured are in the order of kV and kA, it is necessary to use dividers and shunts, respectively, in order to scale the magnitudes. The sort of measured variables are mostly analog and their ranges are between 50 mV and 120 V peak to peak. The next step is signal conditioning to prevent the overload of the modulator, and finally, the electrical to optical conversion. Figure 2 shows a diagram of the whole testing system, including the electric variables measurement system [4]. Figure 3 shows a more detailed diagram, where the tree main parts of EVMS are shown: transmitter, receiver and the optical fiber-based communication media.

The conceptual design of the system developed by the ERI was very concerned to obtain an efficient and effective solution. In order to solve the problem of susceptibility of metallic cables to high EMI, it was decided to use optical fiber as the communication channel [7]. However, the problem of having different temperature gradients for each remote transmitter during daily operation had to be solved by adding some compensation circuits and assembler language programs.

Figure 4 shows the integrated measurement system and its relationships with, the power signals and the digital systems for data acquisition and signal processing.

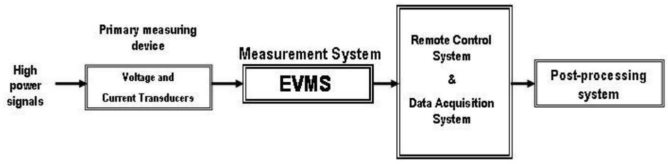

Fig. 2. Location of EVMS.

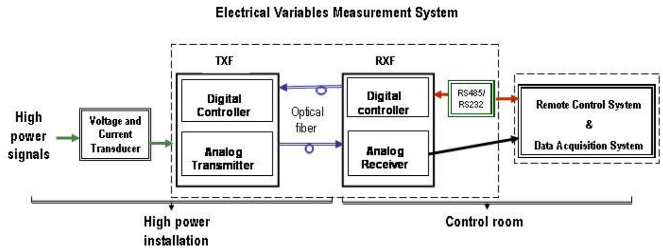

Fig. 3. Detail of EVMS.

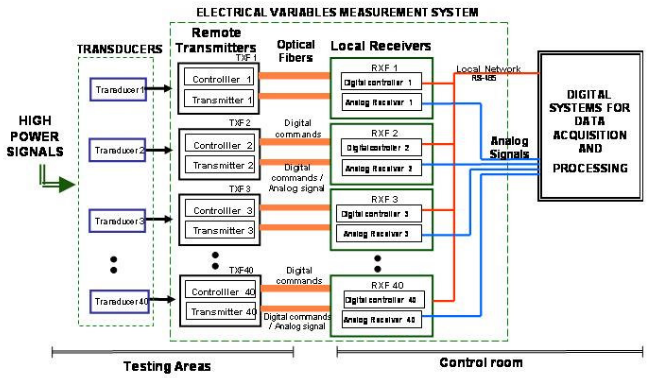

Fig. 4. 40-channel integrated EVMS.

The receivers are bundled in groups of four, with one digital control card for four channels [8]. Communications between receivers and the remote control system is accomplished by a serial port (EIA/TIA RS-485) [9] and a proprietary protocol. This interface has the added benefit of being multidrop and since the separation distance is very small there is no trouble in communicating the arrays of receivers.

3.1 Remote Transmitter

The transmitter equipment is located in the high EMI area; it is composed by digital and analog sections, separated but interacting one with the other [8]. The digital section is in charge of receiving and interpreting the serial commands coming from the digital section of the receiver which is located at the control room. Firstly, the analog section performs signal conditioning. Then, the signal is modulated and then converted into an infrared light signal in order to be transported through the optical fiber channel. Figure 5 shows a block diagram of the transmitter.

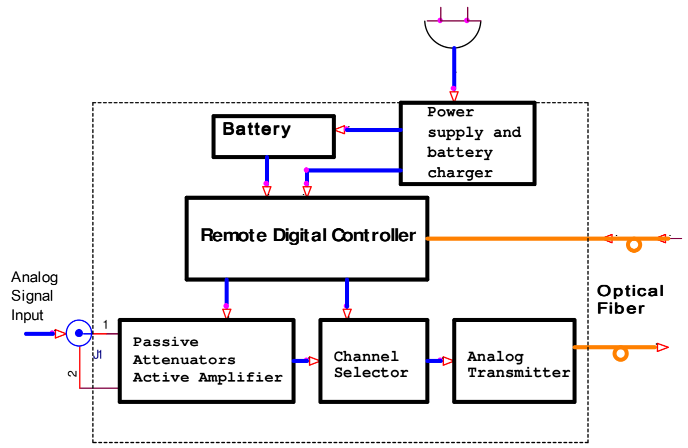

Fig. 5. Remote transmitter.

3.2 Receiver

The receiver equipment is grouped in arrays of four at the control room. However, each channel can be managed individually. Figure 6 shows a diagram of the array of four receivers.

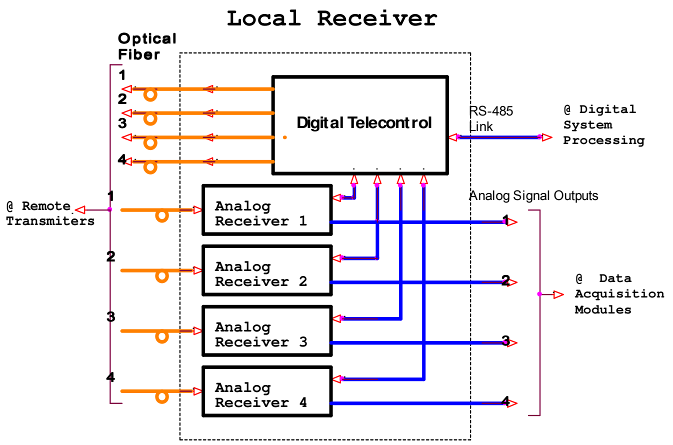

Fig. 6. Array of receivers.

The mother board has four sockets that accept one analog card each one. There is only one digital control card and it is responsible for controlling four measurement channels. There are two buses connected to the mother board, one for power supply at the rear and one for digital communications at the front side. The digital bus is an EIA/TIA RS-485; this bus communicates with the remote control system which is in charge of managing the whole measurement system.

Figure 7 shows a diagram of one receiver. As in the case of the transmitter, it has analog and digital sections.

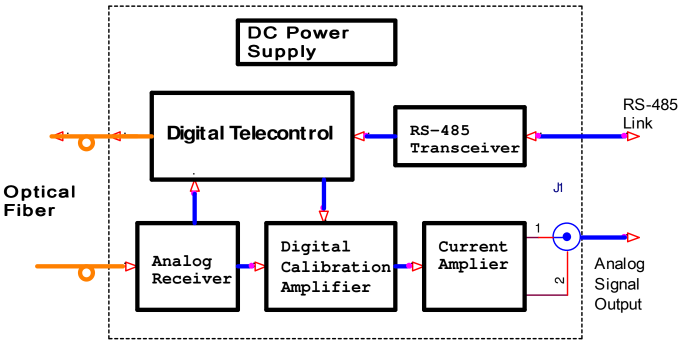

Fig. 7. Detail of one receiver.

The analog section is in charge of detecting, amplify and demodulate the incoming analog signal, after that it amplifies this signal to a level that is adequate to be digitized and post-processed. The digital section is the interface between the remote control system and the remote transmitter; it is responsible for sending and receiving commands trough an RS-485 interface.

4 System Tests and Results

The measurement system has been tested both at ERI facilities for Factory Acceptance Tests (FAT) and more recently On-site Acceptance Tests (SAT) at the HPMT laboratory. At the present time, the measurement system has shown excellent performance. Results have fulfilled the original specifications.

The test consisted of a direct phase to phase short-circuit, with no DUT, in the secondary side of the short-circuit transformer. Figure 8 shows the arrangement of the test zone at the HPMT laboratory.

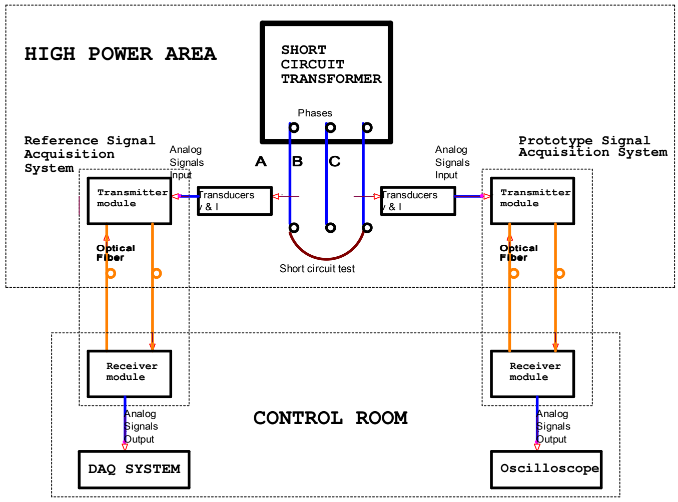

Fig. 8. Testing arrangement for EVMS.

The current measured was 10 kiloamperes with the resultant EMI influence over the remote transmitter prototype, as shown in Figure 9. As a reference, the signal provided by the old measurement system was compared. Results of both systems were almost identical.

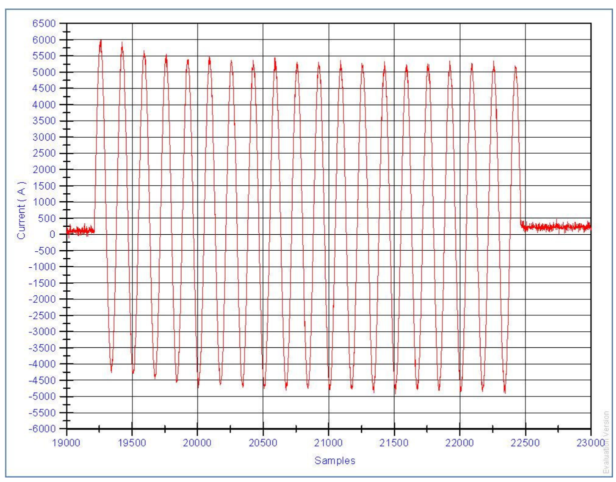

Fig. 9. Current measurement of short-circuit test.

Figure 10 shows the frequency response of the measurement system transmission media. The shape corresponds to a Butterworth low-pass filter. The frequency response of the original design is shown as the simulated plot, with a -3 dB cut-off frequency at 1 MHz. The actual response shows a cut-off frequency a bit below the desired 1 MHz bandwidth. Finally, the optimized response shows a large flat zone within 0.05 dB deviation up to 200 KHz, after that the cut-off frequency is at 800 KHz. For measurement purposes the 200 Khz flat zone is the most important requirement to be satisfied to keep measurement errors within ±0.5 %.

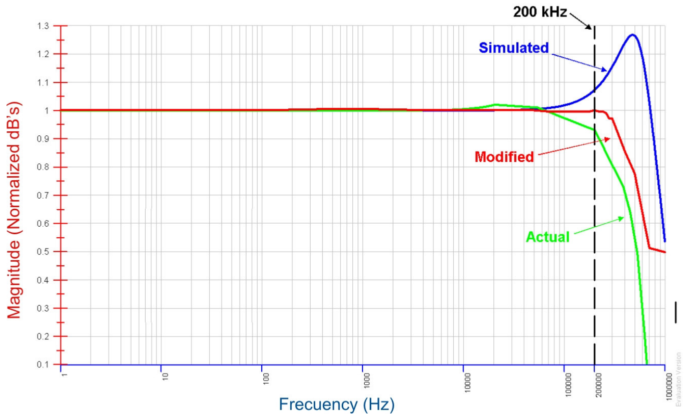

Fig. 10. Measurement system bandwidth.

5 Conclusions

The presented EVMS has fulfilled all requirements of CFE, and it satisfies Mexican standards. Results of FAT and SAT tests have proved that the EVMS is able to satisfy the strict requirements of the HPMT laboratory.

The technical behavior of the system has demonstrated very good robustness to external and internal disturbances. It has no affectation due to variations in temperature thanks to its compensation circuits and the double metal enclosure which helps to prevent the negative EMI influence too.

It was proven a great advantage to use the analog signal channel for sending digital signals and then closing the communication loop between the transmitter and the receiver. Other similar equipment has three fiber optic links to solve this problem.

The automated digital calibration process by means of an internal highly stable signal source inside the transmitter has proved not just to be efficient but to increase precision and reduce the amount of time used for this process.

Reducing the DC shifting to a tolerable level is not an easy issue to deal with. The best method found after several were investigated was to use a temperature transducer inside the transmitter and to have a control loop with a digital potentiometer which can be controlled by an on-board microprocessor.

The proprietary protocol used to communicate the arrays of receivers with the remote control system prevents any kind of misuse of the system and increase the security level avoiding the presence of informatics viruses.

The EVMS is a proprietary development. Research carried out by IIE about other measurement systems available in the market made it clear that there are just a few manufacturers of this kind of systems. Performance comparison gave very good results for the EVMS developed by IIE, especially in the functional features. There are still some matters lacking such as international certification and registration. Also, patent is pending.

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