1st International Conference on Sensing Technology
November 21-23, 2005 Palmerston North, New Zealand

Development of Condition Monitoring Instrumentation for Sensing Power Transformers

Perfecto Mariño, Francisco Poza, Santiago Otero, Fernando Machado
Electronic Technology Department, University of Vigo
Vigo, 36200, Spain
{pmarino,fpoza,jsotero,fmachado}@uvigo.es

Abstract

The objective of this work is the design and development of the Data Acquisition and Storage parts of a measurement system that will be used for the Condition Monitoring (CM) of Power Transformers. The data captured from the sensors and stored in a database will be used by an application that will predict the behavior of the Power Transformer. Data Store and Data Acquisition were developed using Data Warehouse techniques and Virtual Instruments. This paper focuses in the description of the Data Acquisition subsystem, although a brief introduction to the other subsystems will be made. The CM system is currently installed and working properly in four electric Power Transformers.

Keywords: condition monitoring, sensors, data acquisition, power transformers

1 Introduction

Currently there is an increasing interest in developing and applying Condition Monitoring (CM) techniques [1] for electrical equipment like transformers, generators and power induction motors. CM has the potential to reduce operating costs and maintenance, increasing the reliability. Power transformers' failures carry great costs to electric companies and its prevention is very interesting for them.

In the literature different CM systems applied to power transformers can be found. All this CM systems, independently that they be based in fuzzy logic, behavioral model, etc., have a thing in common: they always need a Data Acquisition System for the measurement of a set of physical variables that can indicate a transformer's anomalous behavior. Among said physical variables, temperature, moisture in oil, concentration of gases and vibration are found. To help in the maintenance of power transformers, the authors have developed the data acquisition and storage parts of a CM system based in behavior models [2].

During the development stages of the CM system, an experimental power transformer was used. This power transformer was custom made to function like a bigger real power transformer. In this experimental scenario the behavior models were designed and validated. They were fed with data coming from sensors installed both inside and outside the transformer.

In the current project, the models were modified so that they only use data from external sensors, or from internal ones that do not imply open the transformer when they are installed. This is necessary since the installation of internal sensors in real working transformers is very costly, could interrupt the service and could also break the transformer's guarantee conditions.

This paper focuses in hardware and software description of the Data Acquisition subsystem, from now Programmable Electronic Instrument (PEI), developed. Although, a brief description of the complete CM's architecture is also done. The PEI is responsible for acquisition, processing and storing of sensor's measurements.

The CM system is being tested in four 132KV/66KV 40MVA Power Transformers with satisfactory results and it is patent pending.

2 System Architecture

The architecture of the CM system is formed by three independent and interrelated subsystems: PEI, Data Store (DS) and Prediction Application (PA) (Fig. 1). All three subsystems run in the same industrial computer, but have been designed so that they are the most independent possible and their communication interfaces have been clearly defined. In this way the previously commented subsystems can be executed in a distributed environment and changes in one of them do not affect to the others.

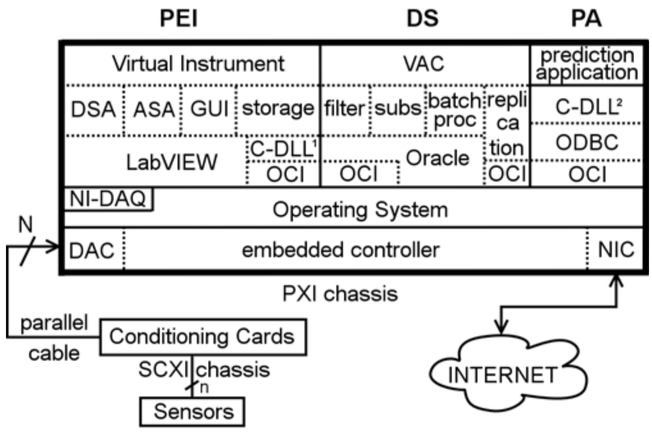

Fig. 1. Architecture of the CM system

A requirement that the system must fulfill is that it should operate properly inside a cabinet attached in one of the power transformer sides. For this reason and due the atmospheric, mechanical and electromagnetic hazard environment, the chosen architecture was an industrial computer based on the 3U PXI (PCI eXtensions for Instrumentation) standard [3][4]. The PXI architecture presents, among others, the following advantages with respect to other architectures (for example PCI or VXI [5]): small, compact and rugged industrial Eurocard packaging, high performance IEC connectors, specific cooling and extended environmental requirements (temperature, humidity, IP level), low cost, multiple vendors, etc.

As already was commented the three subsystems run in the same computer, and as a result they share the hardware and software elements commented next. The hardware core is based on a PXI-1002 chassis inside which the NI-8176 embedded controller is housed (both from National Instruments). The embedded controller is based on a Pentium III microprocessor running at 1.26GHz and with 512 MB RAM and 16 GB of hard disk storage. The operating system used is Microsoft's W2000 server.

A brief description of the PA and DS subsystems follows. The description of the PEI system will be made in Section 3.

2.1 Prediction Application

This subsystem was developed by another investigation team. Basically it is a software application made using the Visual C++ programming environment. Various equations are used for making different mathematical models of the power transformer. These models simulate power transformer's behavior under environmental agents like temperature, concentration of gases, moisture in oil and vibrations. This subsystem works with the measurements stored in the Data Store subsystem in two ways. In first place the measurements obtained from the power transformer are used to carry out the tuning of the different mathematical behavior models. This is done changing the different coefficients used in the mathematical equations. Of course, for the correctness of this step it is necessary a proper work from power transformer. Once this tuning has been done this subsystem is continuously comparing, in real time, the data measured and the values computed by the models. In the case of a significant variation between them an alarm is fired and sent.

2.2 Data Store

The mission of this subsystem is to carry out the store of the data captured by the PEI subsystem and to present them in a suitable form to the PA subsystem. It was developed using the Oracle 9i Data Base commercial application. The necessary data structures have been defined for the PEI and PA subsystems using metadata [6][7].

Also, it is necessary to point out that two Dynamic Link Libraries (DLL's) were developed using the C++ programming language. The PEI subsystem uses one of them to store sensor's measurements in Data Store subsystem (C-DLL[1] in Fig. 1). This library uses the OCI API from Oracle instead of the ODBC standard and makes possible for PEI subsystem to store measurements 25 times faster than using the ODBC standard.

The other developed library (C-DLL[2] in Fig. 1) uses the ODBC standard for communication between PA and DS subsystems. It presents to the PA subsystem a more suitable interface for data store and retrieval than ODBC does [8].

3 Programmable Electronic Instrument

This subsystem is in charge for the measurement, processing and storage of variables from the power transformer. The hardware used in this subsystem includes a set of sensors, for the measurement of the physical phenomena, preconditioning and conditioning equipment and a data acquisition card. The software is a custom made Virtual Instrument (VI). They are described below.

3.1 Sensors

As previously commented all the sensors were installed externally to the transformer. The system uses 26 sensors: 17 of it are analog sensors and the other 9 are digital sensors.

There are 4 PT100 sensors for the measurement of temperature. One is used for measuring the ambient temperature. Another two are used for measuring the temperature of the refrigeration oil in the lower and top most parts of the power transformer. The last one is encapsulated in the same probe with the capacitive hygrometer (see below). The type of all these PT100 is IEC60751 and they have a temperature coefficient α=0.00385055ºC^{-1}.

It is necessary also to measure the current that cross the power transformer. For doing that 4 current transducers are used. These current transducers are physically intensity transformers specially made for current measurement. Three of them are used to measure the currents in the R, S and T phases of the high voltage side of the power transformer. The nominal primary and secondary coil current ratio is 300A/5A. In the low voltage side of the transformer only the current across the S phase is measured. The current ratio for this measurement intensity transformer is 400A/5A.

On the same way 4 voltage transducers are used for measuring the voltage in the R, S and T phases of the high voltage side and in the S phase of the low voltage side of the power transformer. These voltage transducers are physically voltage transformers specially made for voltage measurement. The nominal primary and secondary coil voltage ratio is $132000*(\sqrt{3})^{-1}/110*(\sqrt{3})^{-1}$ and $66000*(\sqrt{3})^{-1}/110*(\sqrt{3})^{-1}$ for high and low voltage transformers, respectively.

For the measurement of the transformer's core vibrations, 3 piezoelectric accelerometers are used. These small accelerometers are located in the lower side of the transformer's oil deposit, just under each of its three phases. Its sensitivity range from 1.006 to 1.043 pC/ms^{-2}.

The moisture in oil is measured with one capacitive thin film sensor that acts like a hygrometer. The operation of the sensor is based on changes in its capacitance as the thin polymer film adsorbs water molecules. This sensor and one of the PT100 commented previously are encapsulated together in the same probe which is immersed in the oil.

The last analog sensor is used for measuring the concentration of the H_2 and CO gases dissolved in the transformer's oil.

Finally, with the 9 digital sensors the status of High Voltage switch, oil pumps and air fans of the power transformer can be monitored. These sensors are free voltage relay contacts that indicate the on or off status of the above mentioned elements.

3.2 Preconditioning equipment

Some of the previously commented analog sensors have specific commercial preconditioning equipment. Thus the NEXUS equipment (Brüel&Kjaer) is used to convert the charge measurement from the piezoelectric accelerometers in a voltage signal ranging up to 3.16Vp. The DOMINO equipment (Doble) supplies two analog 4-20mA current signals. One of them is proportional to the moisture measurement of the capacitive hygrometer in % relative saturation (RS), ranging from 0 to 100%. The other is proportional to the temperature of the oil that surrounds the capacitive hygrometer and ranges from -40 to 180ºC. Finally the HYDRAN equipment (GE Syprotec) supplies a 4-20mA current signal proportional to the concentration of gases measured by its built in sensor. The measurement ranges from 0 to 2000 ppm.

Several specific PCB HALL cards with Hall Effect sensors have been designed. These cards isolate and condition the voltage and current signals, from voltage and current measurement transformers, attached in High and Low Voltage sides of the transformer. As commented previously the current and voltage outputs from these sensors are 5A and 110/√3V, respectively. These values are out of conditioning cards input's range. Two types of Hall Effect sensors were used. The first supplies a nominal current of 20mA when a nominal current of 4A is applied to its input. The second supplies also a nominal current of 20mA when a nominal voltage of 110/√3V is applied to its input. These two current signals are 50Hz AC signals, with a similar shape and proportional to the instant value of the current and voltage original ones.

The power transformer location of some sensors and preconditioning equipment is depicted in Fig. 2.

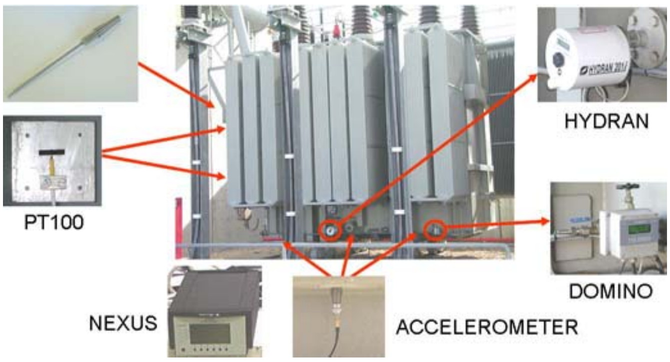

Fig. 2. Placement of sensors in the monitored power transformers

3.3 Conditioning equipment

For the final conditioning of the signals supplied by the different sensors and preconditioning equipment, one four slot SCXI-1000 (Signal Conditioning eXtensions for Instrumentation) chassis and the corresponding four specific conditioning cards have been used (all from National Instruments).

One of the conditioning cards (SCXI-1102C) arranges 32 voltage analog input channels ranging from -5 to +5V, and it is used to condition all the analog signals except for those of three PT100 sensors. Among these signals there are three AC voltage signals ranging from -3.16 to 3.16Vp (from NEXUS equipment), eight AC current signals ranging from -20 to +20mA (from HALL cards) and three DC current signals ranging from 4 to 20mA (two from DOMINO and one from HYDRAN equipment). Voltage signals are directly connected to inputs of the conditioning card, and current signals are previously translated to voltage using 249Ω precision resistors.

The 3 PT100 sensors are conditioned with a specific card (SCXI-1121), that feeds them with a constant current and amplifies the generated voltage. Another conditioning card (SCXI-1162HV) is used for isolating optically the digital signals. Finally, for conditioning the High Voltage switch, a specific circuit has been developed and mounted in a breadboard card (SCXI-1181). This circuit triggers the data acquisition hardware when the switch is changing (on to off or vice versa).

3.4 Acquisition

The data acquisition card used is the PXI-6025E model. It is inserted in one of the slots of the PXI-1002 chassis and has the following main characteristics: 16 common mode or 8 differential analog input channels, 12 bits resolution, 200KS/s, 2 analog outputs and 32 digital input/outputs. A picture of the PXI-1002 and SCXI-1000 chassis as they are arranged in the cabinet of the system, is shown in Fig. 3.

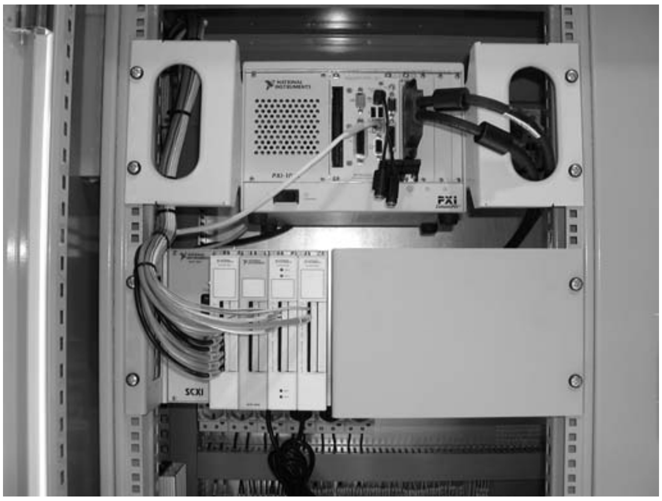

Fig. 3. Operating implementation of the PXI (topmost) and SCXI (just below) chassis.

3.5 Virtual Instrument

The PEI developed uses the hardware described previously and it is responsible for making the acquisition, processing and storage of measured data. It has been developed using the LabVIEW 6.1 [9] [10] [11] graphical application development environment from National Instruments. It is a multithreaded application where four processes are being executed concurrently.

One is the Graphical User Interface (GUI) that allows configuring all the parameters related to the data storage (Data Source Name, user and password), data acquisition (acquisition period, sampling rate, number of samples, sensors that must be acquired, etc.) and also displays the different measured signals (Fig. 4).

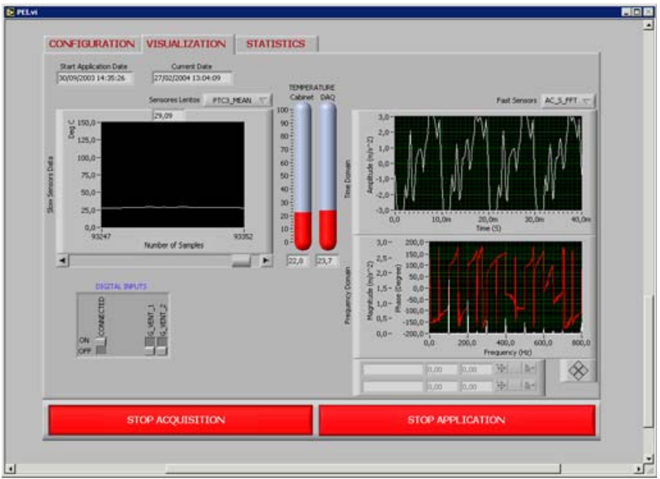

Fig. 4. Programmable Electronic Instrument GUI.

Another process is responsible for the acquisition of the analog signals. For all the analog sensors (at present 17) 4K samples are acquired with a sampling rate of 4KS/s. The interval between acquisitions can be configured by the user by means of the GUI and currently is preset to 5 minutes. From these 17 sensors a set of 25 measures are made due the requirements of the PA subsystem. These measures were divided in two groups: fast and slow. For the fast ones (vibrations, voltages and currents) it is necessary to calculate the frequency spectrum using FFT, and 50Hz harmonics from 100Hz to 800Hz must be stored. For the slow sensors RMS values (voltages and currents) and Mean values (temperatures, moisture in oil and concentration of gases) are calculated. All these operations are carried out using LabVIEW's mathematical Virtual Instruments (VI).

A third process is responsible for carrying out the acquisition of the 9 digital sensors. This sensors show the state on or off of the High Voltage switch, oil pumps and fans.

The last process is the responsible for storing all the measurements carried out in an Oracle Data Base. A temporary storage queue is used so that the PEI and DS subsystems are asynchronous.

Finally the reliability of the whole system is increased by using the watchdog timer included in the PXI industrial computer. If there is a software failure the system is restarted.

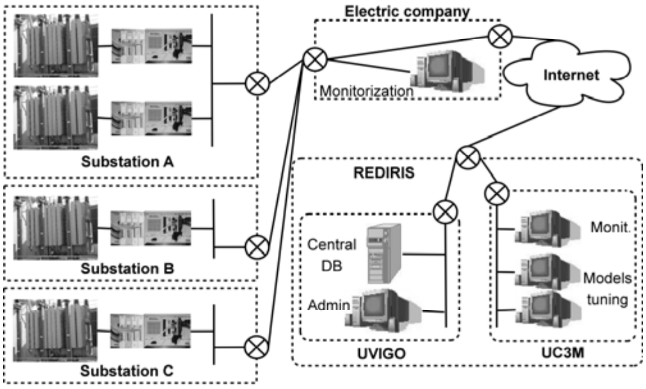

Fig. 5. Network infrastructure of the four clone systems installed

4 RESULTS

A PEI subsystem was developed using PXI and SCXI hardware standards and the LabVIEW 6.1 framework. It is open, modular and easily expandable. It is installed and working properly in four 40MVA power transformers (Fig. 5).

In this application it is used for the condition monitoring of power transformers, but it can be applied in whatever system that needs acquire and store measurements from sensors with little changes.

5 ACKNOWLEDGMENT

This work has been sponsored by two R&D projects from the following entities: R&D National Secretary-ship and CICYT, Ref. DPI2000-1702, Central Government (Spain);

and Presidency Department, Ref. PGIDT01TIC30301PR, Autonomous Government (Galicia, Spain).

6 References

[1] Y. Han and Y. H. Song, “Condition Monitoring Techniques for Electrical Equipment – A Literature Survey”, IEEE Transactions on Power Delivery, vol. 18, no. 1, pp. 4-13, January 2003

[2] H. T. Grimmelius et al., “Three State-of-the-Art Methods for Condition Monitoring”, IEEE Transactions on Industrial Electronics, vol. 46, no. 2, pp. 407-416, April 1999.

[3] The PXI Modular Instrumentation Architecture, PXI White Paper, National Instruments.

[4] PXI Specification. PCI eXtensions for Instrumentation. An Implementation of CompactPCI, PXI Systems Alliance, revision 2.0, July 2000.

[5] IEEE Standard for VMEbus Extensions for Instrumentation: VXIbus, IEEE Std 1155-1992.

[6] P. Mariño, C. Sigüenza, J. Nogueira, F. Poza, and M. Domínguez, “A reusable distributed software architecture driven by metadata”, in Proceedings 1999 Asia-Pacific Software Engineering Conference, Takamatsu, Japan, 1999, pp. 246-249.

[7] P. Mariño, C. Sigüenza, J. Nogueira, F. Poza, and M. Domínguez, “Metadata driven data paths: Improving data warehouse plumbing”, in Proceedings 2000 IASTED International Conference on Applied Informatics, Innsbruck, Austria, 2000, pp. 640-645.

[8] P. Mariño, C. Sigüenza, F. Poza, F. Vázquez and F. Machado, “Using Information Systems in Power Distribution Frameworks”, in Proceedings SCI2003 The 7th World Multiconference on Systemics, Cybernetics and Informatics, Volume I Information Systems, Technologies and Applications, Orlando, Florida (USA), 2003, pp. 254-259.

[9] LabVIEW Measurements Manual, July 2000 ed., National Instruments Corporation, 2001, part Number: 322661A-01.

[10] LabVIEW User Manual, July 2000 ed., National Instruments Corporation, 2001, part Number: 320999C-01.

[11] B. Mihura, LabVIEW for data acquisition, National Instruments virtual instrumentation series. Upper Saddle River, NJ 07458: Prentice Hall, 2001.