23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

PROPOSAL TO INTELLIGENT MONITORING EQUIPMENT IN POWER PLANTS USING IEC61850 SAMPLE VALUES, PARACONSISTENT ARTIFICIAL NEURAL NETWORKS AND CONDITION BASED MAINTENANCE

Antonio Bernardo de Vasconcellos Praxedes
Mechatronic Systems Graduate Studies - University of Brasília - UnB – Mechanical Engineering Department - Campus Darcy Ribeiro – Asa Norte – Brasília DF - Brasil
antoniobernardopraxedes@gmail.com

Alberto José Alvares
University of Brasília - UnB – Mechanical Engineering Department - Campus Darcy Ribeiro – Asa Norte – Brasília DF - Brasil
albertojalvares@alvarestech.com

Abstract. *The high availability requirements and reliability in power generation required by the National Electric System Operator (ONS) and the Regulatory Agency (ANEEL) require the use of innovative techniques to aid the maintenance and operation in power plants. This work proposes to demonstrate that it is possible to develop a methodology for diagnosis and fault prognosis in systems, subsystems, and equipment of the plant in real time using Paraconsistent Artificial Neural Networks and the concept of Condition Based Maintenance on along with a new communication protocol for monitoring and control based on ethernet network. To achieve this goal, the following assumptions are considered: 1. High speed of ethernet available along with use of the IEC61850 standard Sample Values communication service (SV), lets you send high-speed measurement information from the sensors to the pattern recognition software. This enables real-time analysis and also the monitoring of a large number of systems, subsystems and devices in a centralized manner, avoiding the use of separate systems for diagnosis and fault prognosis; 2.Use of Paraconsistent Artificial Neural Network (PANN) as the supervisory information analysis feature. This type of network has the characteristics of tolerance to noise, multiple patterns, conditioning, plasticity, memory, processing inconsistencies, fast and efficient software implementation, being a new Artificial Intelligence feature. Thus, the PANN is a resource, that besides making the recognition of failure patterns, can also treat properly supervisory information from two devices operating in redundant mode.*

Keywords: *IEC61850 Standard, Condition Based Maintenance, Pattern Recognition, Failure Detection*

1. INTRODUCTION

A power plant has various electrical and mechanical systems and sub-systems for implementing its main function: transform mechanical energy into electrical energy. The Brazilian Electric National Interconnected System form a complex network of power generation and transmission, in which the shutdown of a power plant in a high consumption time of day can cause overload in other plants, with the consequent cascade shutdown. Due to high levels of availability required by the ONS and ANEEL, became highly recommended the use of innovative features to minimize the downtime of generation. To increase availability, it is necessary to shorten the stopped time of the power generation system devices, either by the occurrence of failures, either by scheduled maintenance. Thus, the ways to achieve this are the following: 1. Detect and diagnose a fault in the shortest time possible to make the necessary arrangements. The steps are: a) avoid the possibility of damage to other devices due the fault; b) repair the defective component quickly with the aid of a report of diagnostic; 2. Estimate the operating condition of the devices to program the preventive maintenance procedures in the most economical way. Rather than make the preventive maintenance procedures at fixed intervals, schedule the procedures depending on the operating condition of the devices.

The purpose of this study aims to provide a low cost and efficient new tool for recognizing failure patterns and estimate equipment operation condition and standardize the format that information travels in power plants.

Currently looking up low cost and good efficiency solutions for condition monitoring using artificial intelligence features such as Fuzzy Logic along with SCADA Systems supervisory information (Cross, P. & Xiandong, M. 2015).

2. PROPOSAL

This work proposes to demonstrate the feasibility of application of a new method of acquisition, dispatch and analysis of mechanical and electrical supervisory information in a power plant, in order to make the detection and fault diagnostic and present equipment operating condition quickly and accurately. It is also intend to deal with information received from redundant equipment. This approach should be applied following an international standard, with the objective of providing interoperability and sharing the automation, supervision and control resources. To achieve the proposed objective consider the following assumptions:

1. Accomplish the acquisition and transmission of electrical and mechanical measurements of the entire plant in the form of samples in time to allow precise analysis of the fast variations in the signals;
2. The transport of samples of measures and state change events should be made for high-speed standardized network;
3. The analysis of supervisory information received via the communication network should be done centrally by a machine (computer) running a software application;
4. The computer used for analysis should have an operating system of free access and allow the installation of a free development environment for conventional programming language;
5. The application software must use a method of pattern recognition for analog signals with simple implementation in a conventional programming language to handle the maximum number of supervisory signals simultaneously;
6. The new system should be fully integrated into the architecture defined by the international standard.

3. BACKGROUND

3.1 The Concept of Condition-Based Maintenance

Condition Based Maintenance, also called "preventive maintenance", is based on the estimating of the operating conditions made by real-time monitoring through sensors and analysis equipment built into the system. This real-time monitoration is called Condition Monitoring (CM).

A maintenance procedure based on condition consists of three phases: Detection, Diagnosis and Prognosis. The detection and diagnosis of a failure by an automatic system allow for quick troubleshooting. In the case of prognosis, the system must have the ability to estimate the operating condition and thus also estimate the time of Remaining Useful Life (RUL) for scheduling purposes of preventive maintenance procedures (Kan et al., 2015).

The most efficient methods to make the detection and diagnosis of faults and the operating condition analysis to estimate the remaining useful life are based on Artificial Intelligence algorithms (AI). The AI algorithms in these applications typically use statistical resources or learning including pattern recognition (Kim, et al., 2012).

In this work, we propose the use of an AI feature that is capable of performing the detection task, diagnosis and failure prognosis that is useful in operation and maintenance of electric generation systems with rotating mechanical devices such as hydraulic and wind turbine-generator sets.

3.2 Introduction to the IEC61850 Standard

The IEC61850 Standard, published by the "International Eletrotechnical Comission", is intended to introduce a number of improvements in supervision, control and automation systems of substations and power plants. There is a tendency of the generation, transmission and distribution companies to follow this Standard in Europe and Brazil by the benefits it provides (Ribeiro et al., 2011) (Kimura, et al., 2008). The IEC 61850 standard defines the topologies and architectures used in communication devices in an automation system. The standard also defines the system requirements and the data model related to the functions of the plant or substation. The modeling of functions, including data communication interfaces provide interoperability of all plant devices. The unique features of IEC 61850 include intelligent electronic devices (IEDs) self-configurable and a standardized configuration language for all equipment (Brand & Wimmer, 2010).

3.3 The IEC61850 Communications Services

The Standard IEC 61850 defines five types of communication services (Baranov, et al, 2013) as follows:

1. Generic Object Oriented Substation Event (GOOSE): carries digital state change information on the link layer of the Ethernet network, usually from the Bay level to the Process Level and vice-versa;
2. Generic Substation Status Event (GSSE): carries digital status information;
3. Sampled Values (SV):carries measurement information in the form of samples in time on the link layer of the Ethernet Network, usually from the Process Level to the Bay level;
4. Time synchronization (Sync Time): carries time synchronization information in UDP type messages on the Ethernet network;
5. Manufacturing Messaging Specification (MMS): carries information-type event-report or other information-reporting format, usually send between Bay Level Devices for the Station Level Devices. The MMS type message uses the TCP/IP protocol over Ethernet network.

3.4 The IEC61850 Time-Critical Communication Services

The communication services SV and GOOSE replace the physical wiring signals of protection, state and measurement by messages sent over the Ethernet network. These messages have time-critical requirements, being carried by an Ethernet frame, i.e. do not use the higher levels of connection services such as UDP and TCP/IP. This reduces the protocol overhead and therefore significantly reduce the time traffic between the transmitter and the receiver (Sidhu et al., 2010). In addition, the transmission of these messages use the Priority Tag active, signaling traffic priority to the network devices. In addition, the connections made through Ethernet Network operating in redundant mode is safer than wired signal connections. It happens because wired connections can hide a hidden flaw, such as a broken cable or a faulty connection (Kimura, 2009).

3.5 The IEC61850 Sample Values (SV) Time-Critical Message

The messages "Sample Values" (SV) defined by the Standard IEC61850-9-2, contains samples in time of analog signals sent by Ethernet Network. These messages contains information of voltage and current from electrical measurement devices to the Intelligent Electronic Devices (IEDs) such as Digital Protection Relays and Measurement Units (Konka, et al., 2011).

The equipment Merging Unit (MU) operates at Process Level. It reads the analog measurement signals from the sensors, performs the analog-to-digital conversion, assembles and sends the SV messages over Ethernet network (Kanabar & Sidhu, 2011). Usually the MU reads the voltage and current analog measurement signals from the voltage transformers (VT) and current transformers (CT). The VT and the CT make the conversion between the voltage and current line levels to voltage and current measurement and protection levels. Currently, there are measuring devices that perform direct connection to the Ethernet Network and send the measures in SV messages. These devices includes optical CTs and VTs. (Li, et al., 2014).

The use of SV messages brings many benefits, providing the measurement information from the sensors for all equipment of protection and measurement in the plant without the need of analog signal cable installation. This also facilitates the installation and operation of redundant equipment (Pereira Junior, et al., 2011). The performance requirements define the maximum time for delivery of messages SV in three to four milliseconds (Kanabar & Sidhu, 2011). This low traffic time allows fast fault detection. In this work will be implemented the reception of the SendSVMessage following the IEC61850-9-2LE. The IEC61850-9-2LE Standard are designed to simplify the implementation procedure of the sending and receiving software SV messages (UCA International Users Group, 2004).

3.6 The IEC61850 Generic Object Oriented Substation Event (GOOSE) Time-Critical Message

The Generic Object Oriented Substation Event (GOOSE) message sends digital events information with high speed and high priority. It is done over the Ethernet network without the need for specific signal connection cables. The Standard IEC 61850-8-1 define the GOOSE message structure, where data is transported in a field called APDU (Application Protocol Data Unit) mounted on an Ethernet frame (Kriger, et al., 2013).

3.7 The Artificial Neural Networks for Pattern Recognition

An Artificial Neural Network (ANN) is a type of information processing system inspired by the way biological nervous systems, such as the brain, process information. The structure of the system consists of a large number of processing elements called Neurons, which have many interconnections with each other and operate together (Basu, et al., 2010). The ANNs have the following basic characteristics:

1. Have the ability to learn complex nonlinear input-output relations;
2. Use sequential training procedures;
3. Have the ability to adapt to the information.

The ANNs are not dependent on specific knowledge about the information being treated, and thus has been widely used for pattern recognition task of various types, from the character recognition to the recognition of measurement signal patterns like vibration signals of. For example, the application in anomaly detection of rotating machines by monitoring and analyzing vibration signals by ANNs (Ugechi, et al., 2009).

3.8 The Paraconsistent Artificial Neural Network (PANN)

The Paraconsistent Artificial Neural Network (PANN) is a new type of ANN with the ability to treat inaccurate, inconsistent and undefined signals, such as occurs in real systems mainly subject to noise, interference and failures. The latest application of PANNs is in pattern recognition in Electro Encephalogram signals (EEG) for diagnosis of some kinds of diseases like Alzheimer (Abe, et al., 2013).

The Paraconsistent Logic (PL) is a non-conventional type of logic that allows handling real situations in a simple and structured manner, avoiding inefficient procedures when using the Classic Logic. The PL deals with contradictory (inconsistent) or undefined information, caused by some kind of failure or interference, situations that often occur in supervisory systems, especially if they are complex and redundant.

The Paraconsistent Annotated Logic (PAL) is a type of PL. It deals with logical propositions as annotations values. (Da Silva Filho, 2014). In paraconsistent analysis, the most important is to determine the Degree of Certainty to define whether a proposition is true or false. The other parameter resulting from the analysis, the Contradiction Degree is a measure of inconsistency. A low Certainty Degree measure indicates a blurring, or lack of information. From the use of the basic concepts of PAL, is implemented the analyzer algorithm by the Paraconsistent Artificial Basic Cell (PABC).

The Paraconsistent Artificial Neural Cell (PANC) is the fundamental element of a PANN. There are several types of PANCs with several functions, combined to assembly a PANN. All PANCs derive from the PABC analyzer algorithm (Para-Analyzer Algorithm). Simple mathematical equations easy to implement in programming language describe each type of PANC. Using one learning algorithm, a set of PANCs can learn patterns with similar characteristics to Neurons commonly applied in classic artificial neural networks (Da Silva Filho, 2007).

The Paraconsistent Artificial Neuron so called Para-Perceptron is a Paraconsistent Artificial Neural Unit (PANU) constituted by a set of various types of PANCs. This set of connected PANCs have a behavior similar to the set of brain neurons. It takes five types of PANCs to compose a Para-Perceptron PANU. Through variations in connections between the PANCs can mount various types of PANUs with its own characteristics.

A Paraconsistent Artificial Neural Network (PANN) consists of a set of PANUs interconnected. A PANN can have various systems in different configurations running in parallel, which receive and treat the signals of measures applied in their entries. In this work, each configuration should treat a type of measurement signal from a sensor at the plant.

4. THE NEW ARCHITECTURE

The detection, fault diagnosis and estimating the operating condition of the plant equipment depend of various parameters of supervisory information came from electrical and mechanical devices. The IEC 61850 standard has two innovative communication features: Sample Values (SV) and Generic Object Oriented Substation Event (GOOSE).

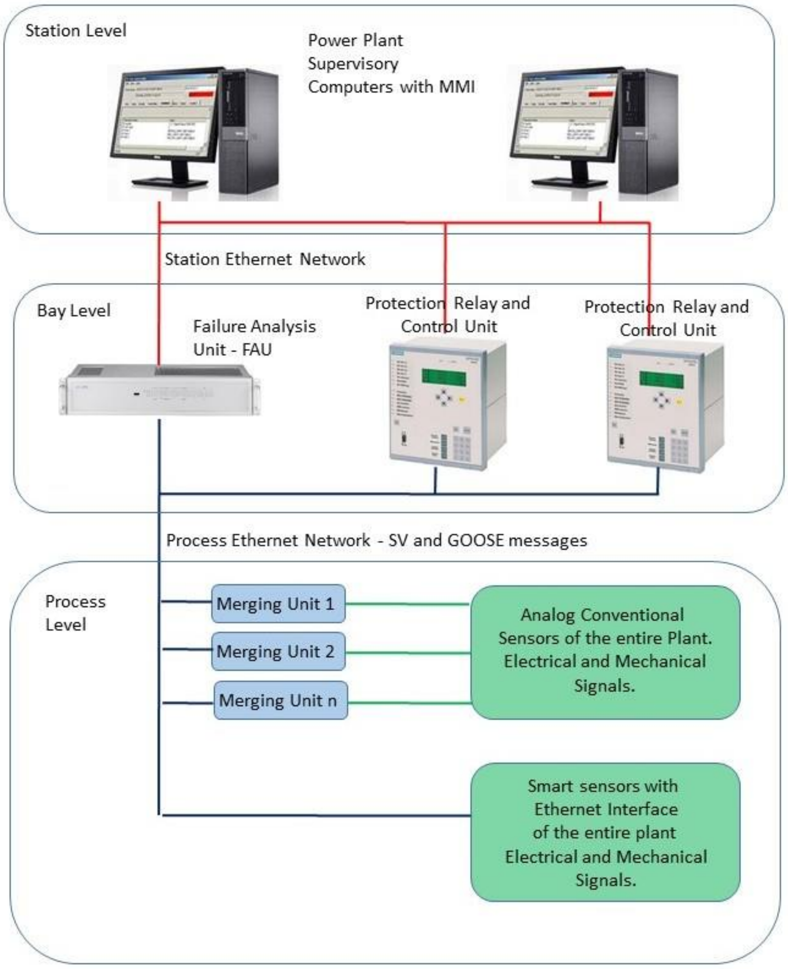

Figure 1. The New Architecture with Supervision of Mechanical Systems and the Fault Analysis Unit (FAU)

In this work, we propose a new approach and methodology within the architecture IEC61850, where the SV and GOOSE messages also send the information of analog and digital sensors of mechanical systems. Thus, in this new architecture, the information carried by SV and GOOSE messages goes too for a new equipment called Failure Analysis Unit (FAU). The information of the electrical systems are the voltage and current measurements, states of devices and protection actuation indication. The Mechanical System Information includes temperature, vibration, pressure, flow and position measurements, digital valve status information (open/closed), indications of the state of alarms, protection actuation indication, etc.

The FAU should be a computer fully integrated into the IEC61850 system of supervision and control and has the communication and data analysis functions. This equipment should run a software application for receiving analog and digital information of the plant through the SV and GOOSE type messages, recognize patterns in measurement signals, make decisions considering the result of the recognition pattern algorithms and digital signals, generate fault diagnosis and condition of equipment reports and send the reports to the Supervisory Software. In the IEC61850 architecture, the FAU should be located in the Bay level with the protection, control and measurement equipment.

5. THE NEW ARCHITECTURE IDEF0 FUNCTIONAL MODEL

The root functional block named “Intelligent Monitoring of Equipment’s and Systems” (A0) presented below, shows the new architecture, where the analog and digital sensors from electrical and mechanical systems are in the left as inputs. The fault alarms, anomalies alarms, diagnostic and prognostic reports are in the right as results of analysis. On the top are the controls like standards, logical rules, parameters and wave patterns. On the bottom are the mechanisms to perform the tasks like the Fault Analysis Unit, Ethernet Network, Merging Unit, Signal Conditioner and the SCADA MMI Station.

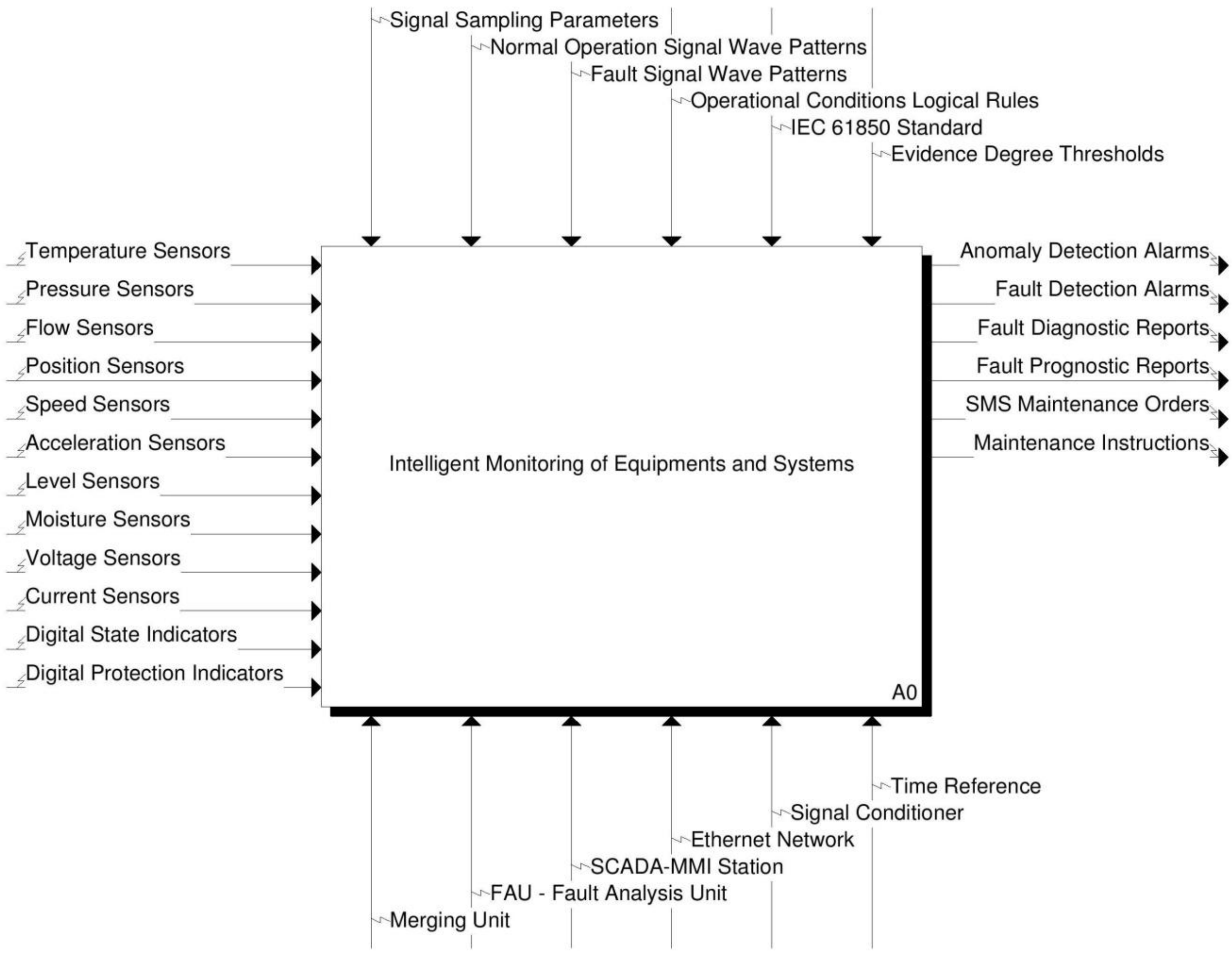

Figure 2. IDEF0: Functional Model of the New Architecture – Main Block A0

The functional diagram IDEF0 of Figure 3 is the result of root block A0 explosion. In this diagram, the analog and digital signals of the mechanical and electrical sensors enter in the module A1 at left. The functions of A1 are in the Signals Conditioner Module and the Merging Unit equipment. The Signals Conditioner Module is used to conditioning the non-electrical sensors signals (the electrical sensors are the voltage transformer and the current transformer). The supervisory information from the sensors is sent through the Ethernet Network by SV and GOOSE messages to the functional modules A2, A3 and A4 in the Failure Analysis Unit (FAU).

The analog sensors information is analyzed by PANN in the A2 module for pattern recognition and the result of PANN analysis along with the digital information received in the GOOSE messages are applied to the decision-making module (A3) in order to detect and diagnose faults and estimate the operating condition equipment.

The FAU makes up the reports and send by MMS to the supervisory software (SCADA) for presentation. The SCADA software is in the SCADA Station represented by the A5 module in the diagram.

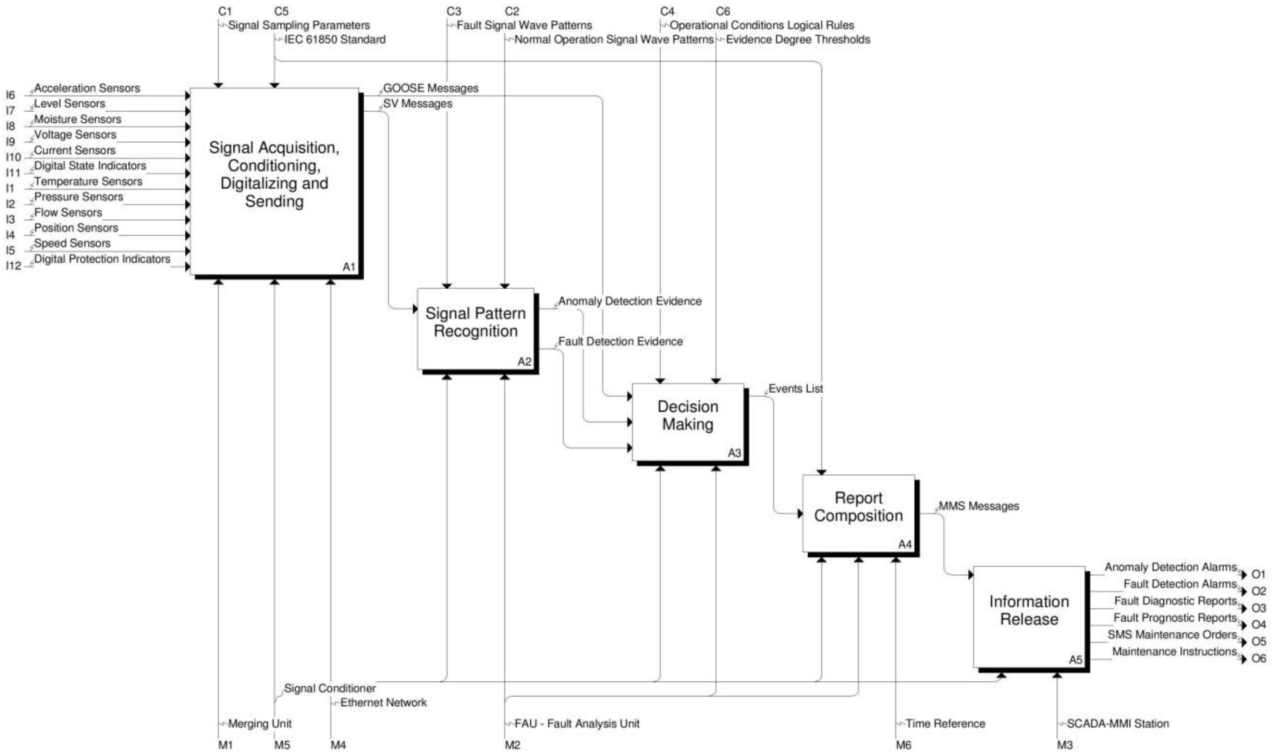

Figure 3. IDEF0: Functional Model of the New Architecture – Main Functional Blocks A1 – A5

6. METHODOLOGY AND EXPECTED RESULTS

The demonstration of the viability of the architecture presented should be done through the implementation in software and test of functional modules using a laboratory platform (Figure 4). The steps for the demonstration are presented below:

1. Activity 1: Implementation of the types of Paraconsistent Artificial Neural Cells (PANCs) necessary to compose a Paraconsistent Artificial Neural Network (PANN) able to recognize patterns in various analog signals;
2. Activity 2: Make the interconnection of PANCs to compose the Paraconsistent Artificial Neural Units (PANUs) necessary for the implementation of the PANN;
3. Activity 3: Implementation of the Paraconsistent Artificial Neural Network (PANN) able to recognize a set of signal patterns;
4. Activity 4: Training the PANN using a set of analog signals as samples. The PANN should recognize the patterns in the input signal even with the addition of noise;
5. Activity 5: Development and Testing of Decision Making Module;
6. Activity 6: Development and Testing of the Module for Message Composition the Event Report;
7. Activity 7: Implementation and routine test for SV messages reception. The test of this routine should be done using software simulator for generate the SV messages;
8. Activity 8: Implementation and routine test for GOOSE messages reception. The test of this routine should be done using software simulator for generate the GOOSE messages;
9. Activity 9: Implementation and routine testing for sending the MMS TCP/IP event reports messages. The test of this routine should be done using Supervisory Software for presenting the information;
10. Activity 10: Integration of Software Modules;

11. Activity 11: Functional Testing. During the functional tests will be applied various wave patterns and various digital signals for checking the PANN and decision-making module function;
12. Activity 12: Performance Tests. The performance testing aims to determine the time between sending a wave pattern and the presentation of the report by the supervisory software.

The Figure 1 shows the IEC61850 standard architecture modified to include the acquisition of the mechanical supervision signals and the Fault Analysis Unit (FAU).

Figure 4. Test Platform for Demonstrate the New Architecture Feasibility

7. CONCLUSIONS

This work is in progress to obtain the title of PhD in Mechatronic Systems at the Department of Mechanic Engineering of the University of Brasilia.

This idea fits into a standard IEC61850 architecture with minimal cost, providing a platform where can be developed many applications mainly for fault detection, fault diagnosis and estimating the operating condition of equipment for preventive maintenance.

8. ACKNOWLEDGEMENTS

Prof. Dr. Edson Paulo da Silva - Mechanical Engineering Department Graduate Studies Coordinator
CAPES (Financial Support - Brazilian Federal Government)

9. REFERENCES

Abe, J. M., Lopes, H. F. S. & Nakamatsu, K., 2013. Paraconsistent Artificial Neural Networks and EEG. s.l.:International Journal of Knowledge-based and Intelligent Systems 17, 99-111.

Baranov, P. F., Muravyov, S. V., Sulaymanov, A. O. & Khudonogova, L. I., 2013. Software for Emulating the Sampled Values Transmission in Accordance with IEC 61850 Standard. s.l., s.n.

Basu, J. K., Bhattacharyya, D. & Kim, T.-h., 2010. Use of Artificial Neural Network in Pattern Recognition. s.l.:International Journal of Software Engineering and Its Applications Vol. 4, No. 2, April 2010.

Brand, K. P. & Wimmer, W., 2010. The Concept of the IEC 61850 – A new approach for communication in substation automation and beyond. s.l.:ABB Review. Special Report IEC 61850.

Cross, P. & Xiandong, M., 2015. Model-based and Fuzzy Logic Approaches to Condition Monitoring of Operational Wind Turbines. International Journal of Automation and Computing, 12 February, pp. 25-34.

Da Silva Filho, J. I., 2007. Introdução às Células Neurais Artificiais Paraconsistentes. s.l.:Revista Seleção Documental No 8 Ano 2. Ed. Paralogike - Santos - SP Brasil.

Da Silva Filho, J. I. e. a., 2014. Electric Power System Operation Decision Support by Expert System Built with Paraconsistent Annotated Logic. s.l.:INTECH, Advances in Expert Systems, Chapter 2, 29-58.

Kanabar, M. G. & Sidhu, T. S., 2011. Performance of IEC 61850-9-2 Process Bus and Corrective Measure for Digital Relaying. s.l.:IEEE Transactions on Power Delivery, Vol. 26, No. 2, April 2011.

Kimura, S., 2009. Experiência da Elektro na Digitalização de Subestações Utilizando a Norma IEC 61850. s.l., s.n.

Kimura, S. et al., 2008. Aplicação do IEC 61850 no Mundo Real: Projeto de Modernização de 30 Subestações Elétricas. s.l.: Elektro Eletricidade e Serviços, S.A. e Schweitzer Engineering Laboratories, Inc.

Konka, J. W., Arthur, C. M., Garcia, F. J. & Atkinson, R. C., 2011. Traffic Generation of IEC 61850 Sampled Values. s.l.:s.n.

Kriger, C., Behardien, S. & Retonda-Modiya, J., 2013. A Detailed Analysis of the GOOSE Message Structure in an IEC 61850 Standard-Based Substation Automation System. s.l.:s.n.

Li, Z., H., L., Z., Z. & Luo, P., 2014. An Online Calibration Method for Electronic Voltage Transformers Based on IEC 61850-9-2. s.l.:s.n.

Mrad, N., Foote, P., Giurgiutiu, V. & Pinsonnault, J., 2013. Editorial - Condition-Based Maintenance. International Journal of Aerospace Engineering.

Pereira Junior, P. S. et al., 2011. IEC 61850-9-2 Avaliação e Testes de um Barramento de Processos. s.l.:Portal - O Setor Elétrico - Edição 63 Abril.

Ribeiro, R. S., Porto, J. A. S. B. & Silveira, C. F. M., 2011. Implementação do Protocolo IEC61850 no COSD da CEEE-D para Telecontrole Direto de IEDs. Florianópolis - SC, s.n.

Sidhu, T. S., Kanabar, M. G. & Zadeh, M. R. D., 2010. IEC 61850-9-2 Based Process Bus. pac World - Protection, Automation & Control World, Issue December 2010.

UCA International Users Group, 2004. Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850-9-2. s.l.:s.n.

Ugechi, C. I. et al., 2009. Condition-Based Diagnostic Approach for Predicting the Maintenance Requirements of Machinery. s.l.:Scientific Research. Engineering, 2009, 1, 177-187.

10. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.