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Decentralized Solution for Digitalization of Substations Using Protocol DNP3.0

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Summary

Due to large quantity of cabling needed for implanting a monitoring and control system using conventional equipment, Escelsa Energias do Brasil adopted a system with a communication bus, connecting various sensors to a remote unit, thus allowing complete monitoring of various parts of a substation, mainly power transformers.

The monitoring system aims, primarily, to eliminate the large amount of cables that turn out when a conventional centralized system is adopted, where the information of each sensor must be taken to the control room through independent cablings, at various meters from the substation yard.

In order to meet this requirements, a control system was developed with a modular and decentralized architecture, based on IEDs (*Intelligent Electronic Devices*) supplied by Treetech, installed at the operating unit of the power transformer, at the substation yard. These IEDs are developed specifically for the substation's yard conditions, like high temperatures and electromagnetic interferences. They receive information from various sensors, such as temperatures, voltages, currents, TAP position, alarms, etc., as well as to send control signals, such as increase and decrease TAP, turn on and off forced ventilation, block switch, etc., whereby all are interconnected to a remote terminal unit manufactured by Foxboro, installed at the control room and interconnected through optical fiber. The chosen communication protocol was DNP3.0, because its robustness ensures that the data from the sensors are sent to a remote unit in a complete and safe way, aside from being the protocol used in the existing remote unit.

This article will describe the adopted topology and the digital control system used for the monitoring system implemented on the substation "SE Ibes", located at Vila Velha - ES, in a 138/13.8 kV - 25/33/41.5 MVA transformer. The field experience with the implementation and operation of this system will be presented, by describing the obtained practical results.

1. Introduction

In 2007, increase of installed power of substation "SE Ibes" in Vitória - ES was carried out, with the replacement of one of its two 33 MVA power transformers by a new 138/13.8 kV - 25/33/41.5 MVA three phase transformer, called 7TR1, shown in the single-line diagram of figure 1.

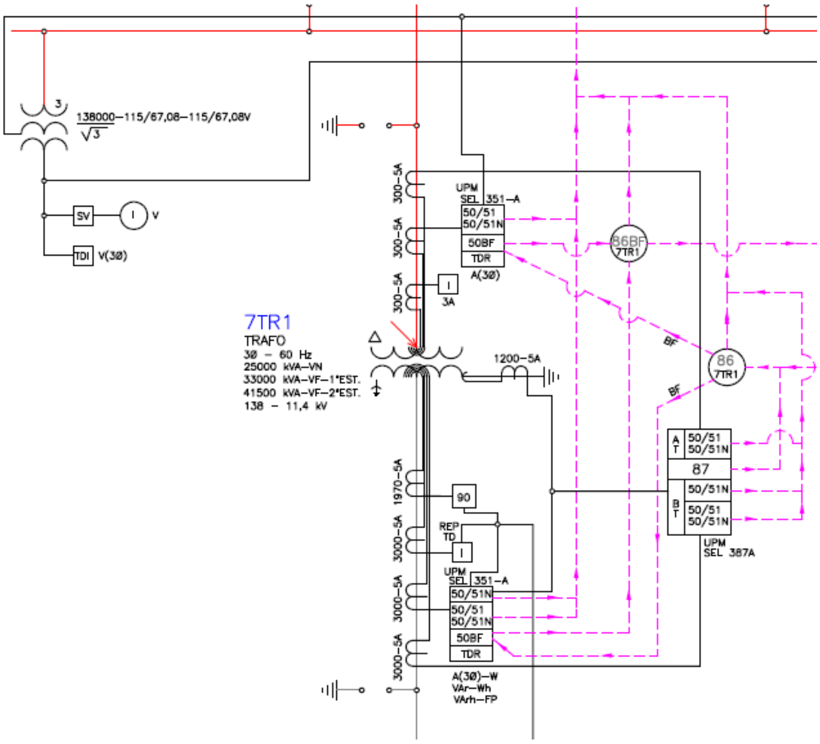

Figure 1 - Single-Line Diagram of Transformer 7TR1

With the change of transformer, modernization of the supervision and control system was also decided. However, due to the large amount of cabling needed for implementing a monitoring and control system by using conventional equipment, Escelsa Energias do Brasil opted for a decentralized architecture, using a system with a communication bus. It connects various sensors to a remote terminal unit, thus allowing complete monitoring of various parts of a substation, mainly power transformers, described as follows.

2. Digital Control System Architecture

The monitoring system aims, mainly, to eliminate the large amount of cables that turn out when a conventional centralized system is adopted, where the information from each sensor must be taken to the control room through independent cablings, at various meters from the substation's yard.

In order to meet this requirements, a control system was developed with a modular and decentralized architecture, based on IEDs (*Intelligent Electronic Devices*) supplied by Treetech, installed at the operating unit of the power transformer, at the substation yard. These IEDs are developed specifically for the substation's yard conditions, like high temperatures and electromagnetic interferences. They receive information from various sensors, such as temperatures, voltages, currents, TAP position, alarms, etc., as well as, to send control signals, such as increase and decrease TAP, turn on and off forced ventilation, block switch, etc., so as to create a system with local autonomy for decision making.

All IEDs are interconnected to a rmote terminal unit manufactured by Foxboro, model C50, installed at the control room and interconnected through optical fiber cables. The chosen communication protocol was DNP3.0, because its robustness ensures that the data from the sensors are sent to a remote unit in a complete and safe way, aside from being the protocol used in the existing remote unit.

The choice of architecture took in consideration the comparison of characteristics of the centralized and decentralized options, as table 1 shows, where the advantages of the decentralized architecture chosen for this application are listed.

Centralized Architecture	Decentralized Architecture
▪ Centralized system - a PLC or RTU concentrates information received from all sensors and sends them to the next block of the system.	➢ Decentralized system, where the sensors are IEDs (*Intelligent Electronic Devices*) which send the information directly yo the next block of the monitoring system.
▪ Input and output cards in the centralizing element (PLC or RTU) represent additional installation, programming and maintenance costs for the system.	➢ The number is reduced or even input and output cards are eliminated - reduction of costs.
▪ Input and output cards in the centralizing element (PLC or RTU) represent additional points of failure for the system.	➢ The number of points of failure of the system is reduced.
▪ Failures in PLC can lead to loss of all functions offered by the system.	➢ Failures in an IED lead to losses of only one part of the functions - the other IEDs continue in operation.
▪ The typical operating temperature of a PLC is 55ºC [1]. Installation in transformers is not recommended.	➢ Operating temperature between -40 to +85ºC, recommended for field installation (yard).
▪ Installation recommended in the control room - high number of connection cables between the devices and the yard.	➢ Typical installation in panels, yard - only serial communication (twisted pair or optical fiber) for connection to the control room.
▪ Typical insulation level of 500 V - not recommended for high voltage environments (ex.: substations).	➢ Typical insulation level of 2.5 kV - developed for high voltage environment.
▪ Serial communication ports do not tolerate typical surges, impulses and inductions of a substation, obligating the exclusive use of optical fiber for the communication network.	➢ Serial communication ports tolerant to the environment of a substation, allowing the use of twisted pair cables for sections or even the totality of the communication network - low configuration cost, without excluding the possibility of use of optical fiber.
▪ Centralized system, maintenances and expansions are more difficult.	➢ Naturally modular system, causing maintenances and expansions to be easier.
▪ For the application of SE Ibes, approximately 250 to 500 meters of 4 x 1.5 mm cables would be needed[2] – high installation cost.	➢ For application of SE Ibes, only one 50-meter optical fiber cable was used, reducing installation cost and simplifying system maintenance. Aside from this, the number of points of failure is reduced.

Table 1 - Comparison of Centralized and Decentralized Architectures

To ensure the robustness, reliability and local autonomy of the system, the IEDs used must be specifically designed and built for the extreme conditions found in substation yards, such as extreme temperatures, voltage impulses and electromagnetic interferences. For this case, they are submitted to type tests performed in official laboratories, such as IPT and by INPE, including.

→ Climatic Test: (IEC 60068-2-14): (-40 to +85°C);

→ Voltage Impulse (IEC 60255-5);

→ Applied Voltage (IEC 60255-5);

→ Surge Immunity (IEC 61000-4-5);

→ Radiated Electromagnetic Field Immunity (IEC 61000-4-3);

→ Immunity to Conducted Electromagnetic Disturbances (IEC 61000-4-6);

→ Electrostatic Discharges (IEC 60255-22-2);

→ Electrical Fast Transient Immunity (IEC61000-4-4);

→ Electrical Transient Immunity (IEC 60255-22-1);

→ Vibration response: (IEC 255-21-1);

→ Vibration resistance: (IEC 255-21-1);

3. The DNP Protocol

The DNP3.0 protocol *(Distributed Network Protocol* version *3.0)* was chosen for application because it is an open and non-proprietary communication protocol, based on IEC (*International Eletrotechnical Commission*) specifications, adapted to be used in highly safe applications, at moderate speed and amount of data. It is very flexible and can be used in any hardware platform.

The model specified by ISO-OSI *(International Standards Organization - Open System Interconnection)* establishes seven layers for a network protocol. Now the IEC specifies a simplified model, which consists in physical layers, data link and application only. Such model is called EPA (*Enhanced Performance Architecture*). Figure 2 below shows the EPA structure and its communication system.

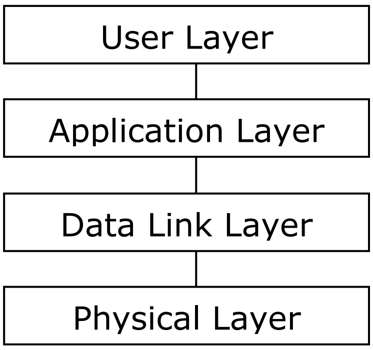

Figure 2 - Simplified ISO-OSI model

The *User Layer*can be defined as the place where the user will handle the data, after all communications. The user layer is used for sending / receiving complete messages from / to a device.

The *Application Layer*is responsible for specifying in details the requests from the user layer, and sending back to it the messages proceeding from the Data Link layer. In other words, it groups the messages from the user layer, calls from fragments, in a message from multiple fragments with the complete information to be processed and sent to a station through the Data Link layer.

The *Data Link Layer*is used for the transmission of messages between the primary (originator) and secondary (receptor) stations. It also packs the data, checks occasional transmission errors through CRC (Cyclic redundancy Check) checking and sends them to the network.

The DNP 3.0 protocol permits a large variety of commands that can be used according to the need of each application. In the application described here the subset of commands described in table 3 was used, which also corresponds to DNP functions that are available in the IEDs:

Code	Function	Description
1	Read	It requests the objects specified from the IED; it answers with the objects that are available.
2	Write	It stores the objects specified in the IED; it answers with the operation status.
3	Select	It selects or sets points of output but does not produce any action (controls, setpoints or analog outputs); it answers with the operation status. The Operate function must be used for activating these outputs.
4	Operate	It produces actions at previously selected outputs or points with the Select function.
5	Direct Operate	It selects and Operates the specified outputs; it answers with the status of the control points.
6	Direct Operate – No Ack	It selects and Operates the specified outputs but it does not send response.
13	Cold Restart	It reboots the IED.
23	Delay Measurement	It allows the application to calculate the delay (propagation time) for a particular IED.

Table 2 - DNP Functions used by Treetech IEDs

4. System Installation

The detailed architecture of this system can be seen in Figure 3 which follows. The remote C50 performs the entire reading logic of the IEDs, as well as their command and control sequences, such as turn on / turn off the groups of fans, increase / decrease the TAP position, etc.

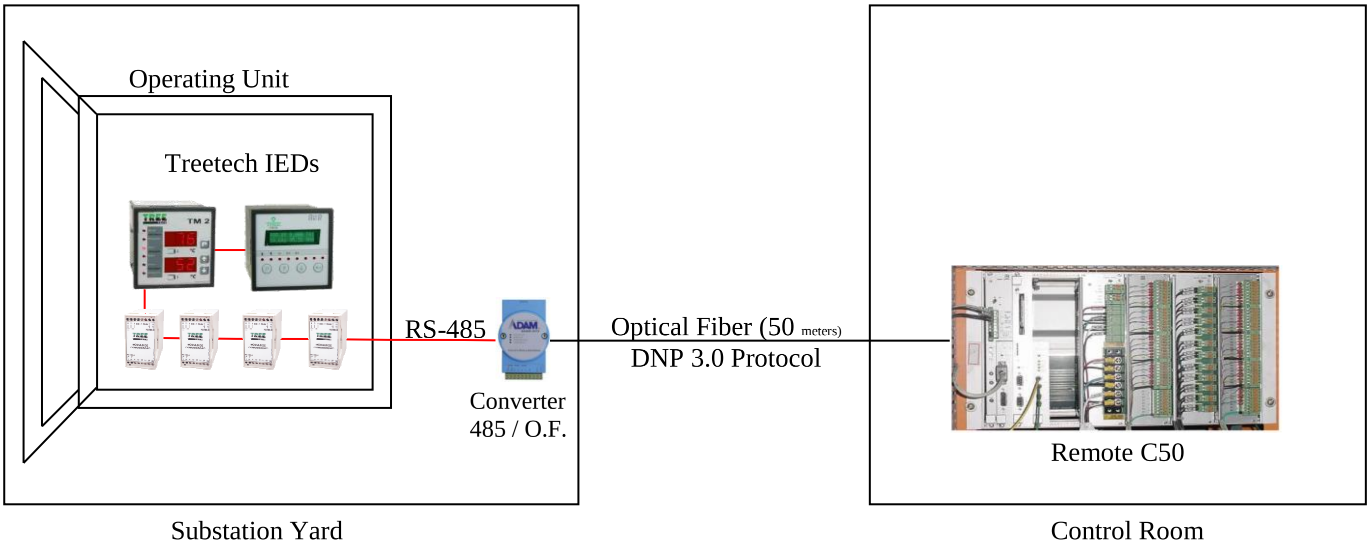

Figure 3 - Adopted Decentralized System Architecture

Table 3 describes the IEDs used at the transformer's operating unit, the acquired information and its functionalities performed locally. In Figures 4 and 5 the transformer 7TR1 and the installation details of the IEDs in its operating unit can be seen.

IEDs	Acquired Data	Control and Protection Functions
Temperature Monitor	- Oil temperature - Temperatures of the hottest point of the windings - Load currents	- Alarms and disconnections due to high temperatures - Automatic / Manual Control of the forced ventilation
Data acquisition Module	- Acquisition of input contacts - Acquisition of analog values - Actuation through output contacts	- Alarm contacts (buchholz relay, relief valve, oil levels, etc.) - Status of forced ventilation groups - Switch under operating load - Time of operation of the switch under load
Voltage Regulator Relay	- Phase voltages - Phase currents - Active / reactive / apparent powers	- Automatic control of the OLTC (raising / lowering TAP) - Alarms due to undervoltage, overvoltate and overcurrent
Parallelism Supervisor	- Switch tap position - Local / remote, master / commanded / individual and manual / automatic selections	- Alarms due to TAP reading error - Alarms due to synchronism error between banks and phases

Table 3 - IEDs associated to the monitoring system

Figure 4 - Transformer 7TR1

Figure 5 - Photograph of the Installed IEDs

5. Conclusions

The system described here is found in operation since November 2007. As reported by the field operation personnel, the communication with all IEDs was maintained stable and functional, both for acquisition and for command and control of all monitored variables.

The digital monitoring and control system has shown to be effective, because when adopting a decentralized architecture for this type of project, various benefits can be confirmed such as the reduction in the amount of cabling, reduction of costs and minimization of failures, that is, in case any module of the system fails, the system as a whole will not be compromised.

The system description, as well as the reported field experience with the use of this architecture, will allow an evolution of benefits and acquired experience with the presented monitoring system, which can generate applicabilities in highly important substations for the electrical network. Escelsa Energias do Brasil intends, at a near future, to adopt this solution to its other substations, thus standardizing this architecture so as to unify and simplify the entire monitoring and control process.

There is furthermore the possibility of future expansions, with the inclusion of new IEDs to aggregate new functions to the system, as for example the monitoring of moisture in oil and monitoring of capacitance graded bushings. Therefore, it is sufficient to connect the new parallel sensors in the existing communication network.

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