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Implementation of a SCADA System for the Control of an Intelligent Microgrid in a Rural Area

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Abstract

Objectives: To determine the criteria to follow for the implementation of a SCADA system in the design of an intelligent micro-grid. **Methods/Analysis:** Through this development some problems have been evidenced to maintain the control and communication in the interaction of each one of the elements that intervene in the network. For this reason it is intended to design a SCADA system for the control and communication of each one of the elements that intervene there in order to mitigate the problems evidenced. **Findings:** Obviously the issue concerning the optimization of energy resources to reduce the negative impact on the environment is an imperative parameter that every developed country should have and is a determining factor to ensure both the economic sustainability and the social and environmental well-being of a country. **Improvements:** This is how automation and control allows a network to be intelligent so that said network can optimize energy resources with quality.

Keywords: Communication, Control, HMI Interface, Intelligent Networks, SCADA

1. Introduction

Specifically, the implementation of the SCADA system will be discussed, proposing a guideline on how to carry out this process, since in the current network model there are clear problems in taking statistical data on their behavior, as well as problems in identifying and diagnosing real problems or problems potentials and impossibility of remote intervention if necessary.

According to the Inter-American Development Bank, Colombia has great potential for renewable energy. The great potential of hydroelectric power is estimated at 93 GW, with additional estimates of 25 GW for small hydroelectric plants. The wind regime in Colombia is among the best in South America, with a potential value of 21 GW. The solar energy resources are also remarkable.

Colombia's electricity capacity in 2009 was 13.5 GW, 67.1% was renewable energy and its national electrification rate was 95.6% for interconnected national systems and 65.2% for areas that were not interconnected. The generation of energy comes from 64% to 77% of hydraulic energy and from 23% to 33% of fossil fuels (ranges given due to seasonal effects). That is why when developing current networks it is necessary to implement a control and communication system aimed at automating and improving the efficiency of the behavior of the elements that intervene in the network[1].

2. Description of the Problem

At present, the economic and technological development of a country is determined by the degree of energy production that allows the potential boost of such growth. In the midst of competitiveness, globalization and industrial development; the production of energy with quality becomes a determining criterion in the economy of a nation (Figure 1).

Although economic sustainability at the energy level plays an important role in the technological production of a country, it is also necessary to consider

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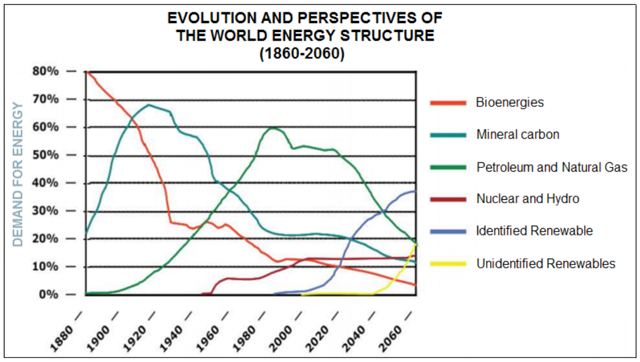

Figure 1. Evolution and Perspective of the global energy structure 1860 - 2060[12].

the environmental issue aimed at guaranteeing the quality of life and following the global pattern of sustainable development present in the regulations and norms global.

Obviously the issue concerning the generation of energy resources with quality and efficiency aimed at reducing the negative impact on the environment, is an imperative parameter that every developed country should have. It constitutes a determining factor to guarantee both the economic sustainability and the social and environmental well-being of a country. In an intelligent network, the improvement of power delivery and the collection of data in real time can increase the efficiency of network performance.

The generation of energy comes from 64% to 77% of hydraulic energy and from 23% to 33% of fossil fuels (ranges given due to seasonal effects). The use of fossil fuels has increased since the mid-1990s, after the 1992 droughts. Colombia is one of the main exporters of coal and a net exporter of oil. This reflects, on the one hand, the important need to develop energy production different from coal and oil, as well as to continue with the evolution of existing electricity networks.

In Colombia in November 2010, 125 participants from the private, public and academic sectors developed a national roadmap on smart power grids for Colombia[2] and introduced the smart grid initiative "Colombia Inteligente". Current projects and research on smart grids[3-4] in Colombia include an energy control system based on the phasor measurement unit (PMU), renewable energies (wind and solar energy) and electronic mobility (means of public and private electric transport). In this way the automation process was implemented in the substations, faster routing around the points of exit of the network, intelligent measurements and other improvements at low scale and in a conceptual manner, which has benefited consumers through a more robust network, flexible, reliable and safe.

These better ones have generated an intelligent network based on communication technologies, which work throughout said network sending information. The sensors developed were located in specific places through the network and in the homes of consumers to obtain information aimed at improving performance. This information captured by the sensors is sent to the applications so that they can act accordingly[5].

Thus, through automation and control it is possible to establish an intelligent electrical network that takes a specific input signal, based on the needs studied through data collection and consumption history analysis. This will allow this signal to be strictly accurate and distribute it to different sectors of the network in an exact manner. The automation will allow the autonomous operation of the network and the control will determine an accuracy system so that the variables change over time within the network, the necessary values are low and respond quickly to any disturbance or change. This process will then determine the efficient and autonomous operation of the electricity network.

However, in the process of communication and control problems have been evidenced to maintain a system that involves these concepts and that is able to integrate in a comfortable and versatile interface for the person who operates controls and monitors the network in question. For this reason, it is proposed as a possible solution the implementation of a guideline to follow for the design of a SCADA system capable of mitigating the inconveniences presented in said process.

3. Description of a Conceptual Methodology for the Design of an Intelligent Micro-grid in Rural Areas in Colombia

In order to design a SCADA system for the control of an intelligent microgrid[6], a proposed conceptual methodology for the design of an intelligent network will be described below. Based on the knowledge of the micro-grid design, it is coherent to perform the control design[7]. Figure 2 shows the design methodology of the microgrid.

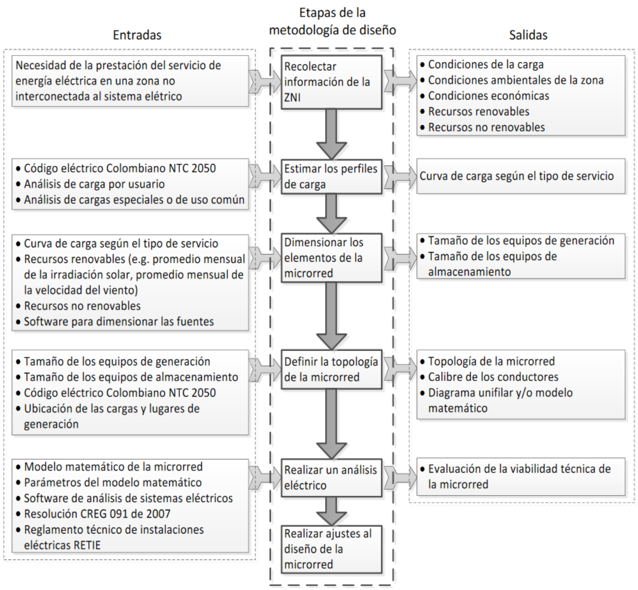

Figure 2. Flowchart of the methodology of micro grid design[13].

3.1 Collection of Information from the Rural Area

At this point it is necessary to gather as much information as possible in the rural area where the network is to be implemented. This can be done through a direct visit to the site in order to record the information, as well as a correct characterization of the instruments needed to measure the variables. It is also possible to use reliable statistical sources such as the National Administrative Department of Statistics (DANE), the Mining and Energy Planning Unit (UPME), the Energy and Gas Regulation Commission (CREG), IPSE, the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), National Aeronautics and Space Administration (NASA), National Renewable Energy Laboratory (NREL). The information that must be established and measured correctly on the site must be the following:

- Parameters and Characteristics of the load. Location and distance between users, load requirements in numbers of users. Dimensions of the house for the installation of generating elements, type of use of energy.
- Parameters and Characteristics of the area: average temperature, height above sea level, soil resistivity, humidity, average solar radiation and average wind speed.
- Socio-economic conditions of the sector: public and government funds aimed at the development of the region's infrastructure[8].
- Non-renewable resources: Diesel, gas, coal, gasoline.

3.2 Calculation of Load Profiles

According to the Colombian electrical code (NTC 2050)[9], the energy required per user and the specific energy for special uses or cases must be calculated. The defined load values are expressed as a maximum load fraction. According to the standard, the specific loads must be adjusted so that the energy consumption per user is approximately at least 92 KW/month.

3.3 Estimation and Topology of the Network

Based on the data obtained in the first stage, the capacity must be estimated and designed for each generation type that participates in the network. It must determine the power generation capacity (photovoltaic, wind, etc.) and contrast with the requirements for each user.

Depending on the terrain, the area and the requirements of the load, the desired type and form of electrical network must be defined. The location and distribution of generation equipment, configuration and layout of the distribution network, branch lengths, voltage levels, conductor gauge and other required information must be determined. According to NTC 2050[9], the caliber of the conductors must have a safety factor of 125%.

3.4 Analysis and Electrical Feasibility

The electrical analysis of the network before the variation of the load and the generation throughout the day will indicate the operative viability of the initial design. To do this, an analysis of steady state voltages is made, evaluating the power flow in each period or hour of service, on one or several days that represents the behavior of sources and demand throughout the year. The calibers of conductors must not be less than those calculated in the previous section. As established by CREG resolution 091 of 2007[10] in article 33 regarding the quality of service in rural areas, the magnitude of the voltage must be maintained within ± 10% of the nominal voltage at the generation terminals and the frequency within ± 1% of its nominal value. In accordance with the Technical Regulation of Electrical Installations (RETIE), it must be ensured that the voltage regulation at the end of each end user connection does not exceed 3%.

With the results obtained in the power flows, the operative viability of the microgrid is determined. If the voltage drops exceed the established limit, the caliber of the conductors must be increased. For the calculation of the power flow, the model of the slack generator is introduced in the simulation. The function of this element is to evaluate the generation capacity de-terminated initially. If the slack generator absorbs active power, it is assumed as a surplus of power that will go to the storage system. The amount of excess energy will determine if it is necessary to resize the storage capacity. If the slack generator delivers active power to the network, its contribution should be compared with the nominal capacity of the conventional generators that are part of the design.

Once a quantitative estimation of the behavior of the network is obtained, the operative viability of the microgrid is determined. If the voltage drops are greater than the established limit, the gauge of the conductors must be increased. To establish the power flow the slack generator model is used in the simulation. In this way, it will be possible to evaluate the generation capacity initially determined. If the generated slack absorbs active power, it is assumed as a surplus of power that will go to the storage system. The amount of remaining energy will indicate if it is necessary to rethink the storage capacity. If the slack generator delivers active power to the grid, its contribution should be compared with the nominal capacity of regular generators such as those using diesel, gasoline, coal, to know if additional energy can be assumed by the set of defined generators.

4. SCADA Systems

A SCADA system is software that is used as a machine-process-man interface to control and supervise industrial processes at a distance. Among other applications, the provision of a real-time feedback with all the elements and variables that intervene in the process is taken into account. The aim is to design a SCADA system that is able to control and monitor all the variables and measurements that are implemented in the electrical network and that were explained in the design model of the previous number. The SCADA system must be able to comply with the requirements to send information of the statistical data of each one of the measurements of the variables

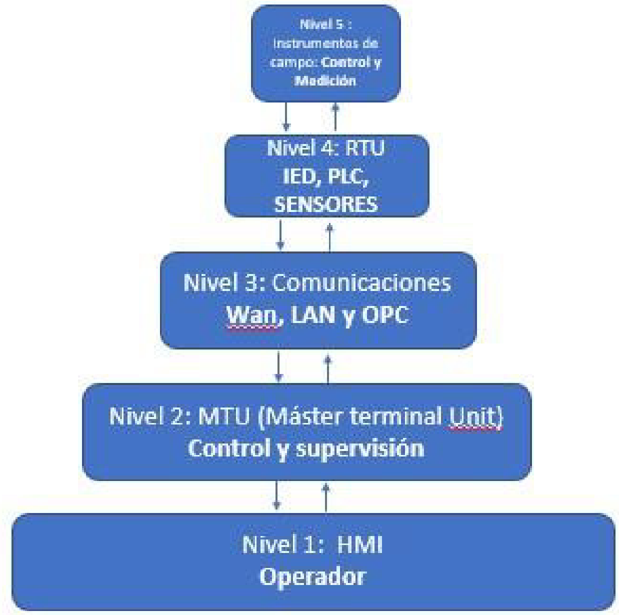

Figure 3. Typical architecture of a SCADA system[11].

of the network[11]. Below is the typical architecture of a SCADA system (Figure 3):

- In the first level of the SCADA architecture, the operator is the one who monitors and controls the variables of the network. The HMI interface must be clear and color-coded in a way that follows international warning and information standards.
- The MTU (Master Terminal Unit) station is located in the control room where operators can interact with the network through the first level. The MTU is responsible for monitoring remote devices and is responsible for data collection and data processing, displaying information and alarms in real time as scheduled.
- Level 3 involves connection and communication in industrial networks. It must take into account several traditional WAN LAN protocols, such as TCP-IP and protocols such as HART (High way-Addressable Remote Transducer) grouping the digital information on the typical analog signal from 4 to 20mA DC. PROFIBUS (Process Field Bus) International standard for high-speed fieldbus for control of standardized in Europe by EN 50170. There are three profiles: Profibus DP (Decentralized Periphery). Oriented to sensors/actuators linked to processors (PLCs) or terminals. Profibus PA (Process Automation). For process control, it meets special safety standards for the chemical industry (IEC 1 1 15 8-2, intrinsic safety). Profibus FMS (Fieldbus

Message Specification). For communication between process cells or automation equipment. FIELDBUS. Foundation Fieldbus (FF) is a digital communication protocol for industrial networks, specifically used in distributed control applications. It can communicate large volumes of information, ideal for applications with several complex process control and automation loops. It is mainly oriented to the interconnection of devices in continuous process industries.

The field devices are powered through the Fieldbus bus when the power required for operation allows it. MODBUS is a transmission protocol for process control and supervision systems (SCADA) with centralized control, it can communicate with one or several Remote Stations (RTU) in order to obtain field data for the supervision and control of a process. The Physical Layer Interfaces can be configured in: RS-232, RS-422 and RS-485. In Modbus the data can be exchanged in two transmission modes: RTU mode, ASCII mode. For the proposed case of this microgrid, the Modbus TCP-IP protocol is intended to be used since, due to its great commercial use and its versatility for remote communications, it makes it useful in the development of communication and control of the network. To communicate two different programming languages such as a PLC, microcontroller or data acquisition card with SCADA software, it is necessary to use a server that links and translates the two programming languages so that communication is possible server is called OPC.

An OPC server (OLE for Process Control) is a communication standard in the field of industrial process control and supervision, based on Microsoft technology, which offers a common communication interface that, allows individual software components to interact and share data (Figure 4).

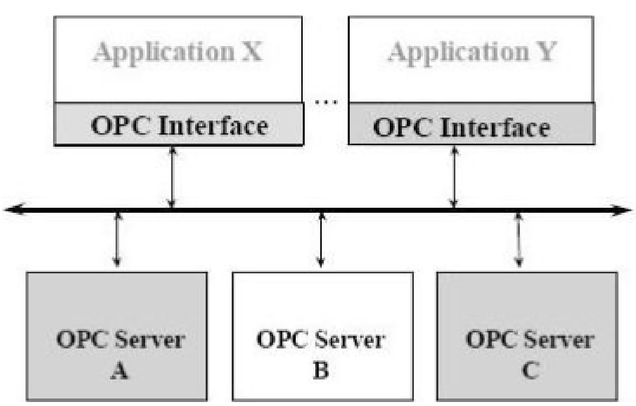

Figure 4. OPC server operation.

OPC communication is done through Client-server architecture. The OPC server is the data source (as a hardware device at the plant level) and any OPC-based application can access that server to read/write any variable offered by the server. It is an open and flexible solution to the classic problem of proprietary drivers. Virtually all major manufacturers of control, instrumentation and process systems have included OPC in their products.

- A Remote Terminal Unit (UTR or, better known by its acronym in English, RTU) is a device based on microprocessors, which allows obtaining independent signals from the processes and sending the information to a remote site where it is processed. Remote site is a control room where a SCADA central system is located which allows visualizing the variables sent by the UTR. In the RTUs it has been developed and expanded to other equipment (energy meters, protection relays and automatic regulators), the IEC or IEC 60870-4 communication protocol. For the internal communications of the equipment, or between them, the RTUs have adopted the Modbus protocol, in the form of Modbus RTU, which can be implemented on an RS-485 network or on a TCP/IP network.

For the design of the SCADA system of a micro-grid, a system of sensors must be implemented that meet the following requirements:

- Analog inputs (4-20mA) of devices that take physical measurements such as solar radiation, wind speed, flow and electric charge, and convert them into binary code to be represented in a decimal system. This is useful when controlling a variable in a specific range.
- Analog outputs: Normally used to manipulate and adjust the operating point of an actuator in a process, such as closing or passing through switches.
- Status inputs: Generally receives an analog or digital signal that indicates the position of an element, usually a voltage signal is sent to a contact that sends me a 1/0 signal depending on the state of the element, for example, ON / OFF.
- Output contacts: Also called control switches, are controlled by the RTU after processing a signal, generally functioning as an electromechanical relay opening and closing, in two ways: retained or instantaneous.
- Input pulses: These are contacts of special inputs that receive an instantaneous signal, normally these signals are used to record the number of times an event occurs, and can be continuous accounts or accounts in time intervals. o Pulse outputs, are contacts of instantaneous

outputs that carry these signals for accounts in a software in the MTU or another RTU.

The field instrumentation for this case is the teams that are around the process capturing the information and in some cases doing a local control; for the system of an intelligent microgrid, the different measurements of the variables such as radiation and wind speed are determined, which allows to have a statistical history of the parameters of the sector, it can be implemented over an RS-485 network or over a TCP/IP network.

5. Design of the Communication System between Devices and SCADA

5.1 Architecture and Conceptual Design SCADA for a Mini Smart Grid

The SCADA system for the intelligent network will be divided into three main subsystems, the power generation system and the control system (Figure 5). All systems will be connected bi-directionally through the OPC servers and the protocols that will be described in this section.

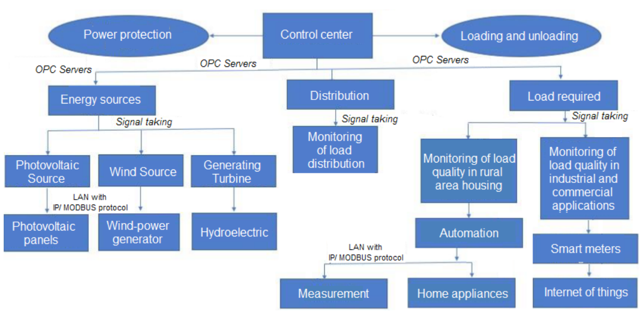

Figure 5. Architecture of the SCADA system for a microgrid.

5.2 Signals to be Monitored in the SCADA System

The following are the signals that will be monitored by the SCADA system:

- Generating Turbine
  Level (analog signal), Temperature inside the turbine (analog signal), Pressure at the output (analog signal). Flow at the entrance Flow at the exit, Turbine angular speed (RPM), Voltage and power generated.
- Photovoltaic Solar Energy System
  Voltage at the input and output of the inverter, Current at the input and output of the inverter, Energy generated by each panel, Total energy delivered to the network, Luminosity conditions of the environment, Temperature of the environment.
- Wind Generation
  Voltage at the input and output of the inverter, Current at the input and output of the inverter. Current at the input and output of the battery bank, Energy generated by each generator, Total energy delivered to the network, Wind speed. Temperature of the environment.
- Weather Station
  Room temperature, Atmospheric pressure, solar radiation, Wind speed and direction

5.3 System Communication

To design the communication system between the SCADA platform and the measurements and remote instruments, it is necessary to establish predominantly the software that will be used for the SCADA model. For this proposal, the Intouch Wonderware software will be used; whose number of analogue and digital variables of type I/O (remote input and output) is sufficiently adequate to support the design of the electric grid. The type of OPC server for this program is the Opclink, which establishes specific communication channels for the interconnection in the SCADA software and the platforms from which the measured data and information come. In this case, said platforms can be data collection cards. discrete or PLC's.

The OPC link allows to establish a channel of communication between the information obtained remotely and the SCADA system, so that the state of the variables is shown in the HMI of the SCADA and allow to interact with its components. To determine the link between the microgrid and the SCADA, a new connection must be created in the option called "OPC Servers". Within the module for the definition of the connection, entering the option NEW, there is the option to establish a name, the Node in case of using DCOM; The name of the OPC server to which it is required to communicate and it depends strictly on the card data acquisition or PLC manufacturer at remote stations.

For the collection of information, two RtuSimatic RTU3030C remote modules based on CC-Link Field will be used. These read the measured values of the connected sensors (production line and work station) and transmit them wirelessly to the control center control using a LAN connection with IP protocol. Likewise, a route to the OPC server is required, which specifies in a hierarchical way the input and / or output of the data to be displayed. In the same way it allows to establish the time interval for the reading of data and the way, in which the information is sent, for this case in which the communication is bidirectional, it is called "poke mode".

In the Browse option it allows to visualize all the variables in the form of input and output to which they are connected. In this case are the variables of energy sources (photovoltaic energy, solar energy, turbine generator). As well as the variables of the distribution and the variables of the required load.

5.4 Design of the HMI SCADA

5.4.1 Design Security Screen and Access

Initially, the security system of access to the control of the system must be designed so that only authorized personnel can control the microgrid from the SCADA system. In the Intouch Wonderware software, the security system for the microgrid was designed as follows: The graphical interface of the security of access to the control of the network is designed.

The program is configured to assign the variables and start of session, as well as the respective session closure, in this way you can determine what type of user can access the control and the privileges that may have. The system administrator may at any time add or remove users and change their authorizations to exercise the respective control of the microgrid.

Afterwards, the user administrator, password and InTouch security must be enabled. Once this function is enabled, it is now possible to access user control to add, delete or change their permissions. With the users already attached, you must then program the buttons on the home screen.

For user input, the operator entered system tag is used and password entry is selected to enter the password. For the button whose function is close to session, it must be programmed with the function b = Logoff ().

Finally, you must program an income button that will only be enabled if the user authentication and password are correct. For this button to be enabled correctly, it must be programmed as an action that shows the window and control only if the authentication is correct.

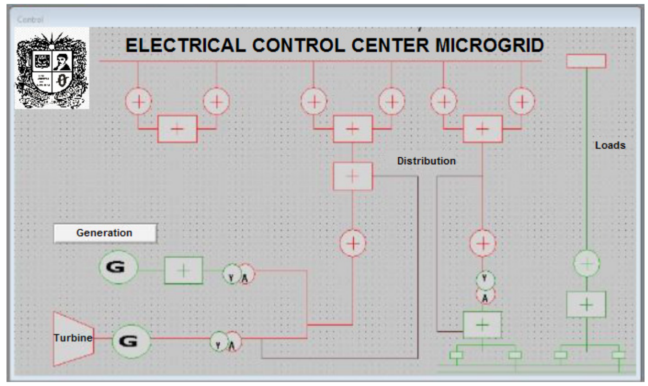

Figure 6. Graphic representation of microgrid in InTouch.

Once you have access to the system, the first window that must be displayed is the general representation of the electric micro-grid (Figure 6), where the 3 basic subsystems of the electric micro-grid are shown: Generation, Distribution and Charges. In the same way you can control the flow of current through the management and switches in specific points of the network.

5.4.2 Solar Generation Screen

The generation screen allows interacting with each of the generation types. It is possible to enter each of the types of energy source, as well as monitor the variables concerning that source. Similarly, it controls the activation of the flow or electrical power, as well as remote emergency stoppage if necessary. All this is shown in a real-time animated interface (Figure 7).

Figure 7. Graphic representation of photovoltaic generation.

The animation shows how the radiation enters the photovoltaic panels and how they generate energy. Likewise, the measurement of the variables in real time is shown with the instruments connected through OPC servers shown in the previous section.

5.4.3 Wind Generation Screen

Similarly, for the wind generation part, a graphical interface with animation is proposed that allows validating each one of the variables (Figure 8). As well as controlling the flow of energy delivered to the network. The animation represents the turn of the wind turbine, as well as the current flow.

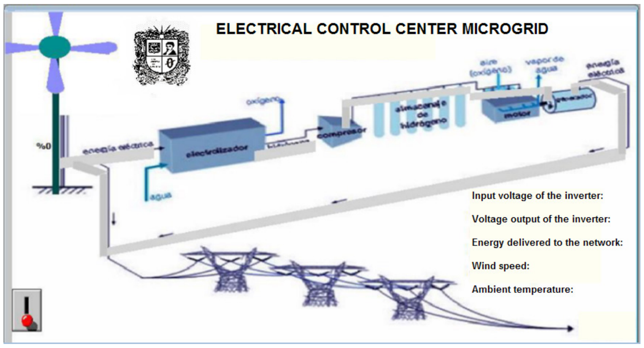

Figure 8. Graphical representation of wind generation.

5.4.4 Turbine Generator Screen

For the generating turbine the connection is made through the OPC server of the previously described variables and in the same way the animated graphic interface is performed where the operator can program the rotation of the turbines (Figure 9).

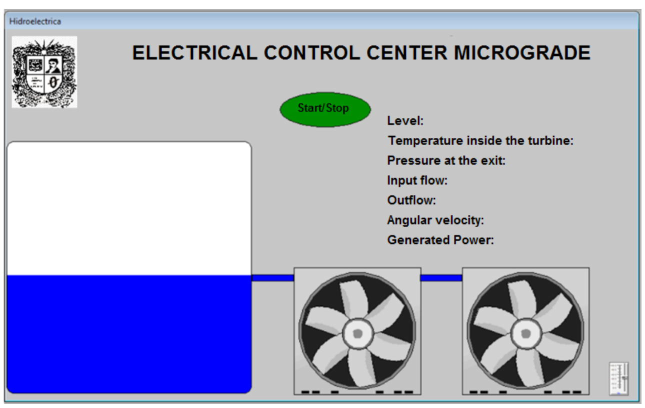

Figure 9. SCADA representation electric turbine.

The programming for turning the turbines at this point is done by the orientation function, after separation of the components of the image. That is, the image is separated and then the blade is selected to assign the rotation attribute.

5.4.5. Distribution Screen

In this screen you can see the basic connections of the microgrid and a representation of the distribution networks: this allows the operator to maintain the safety of the microgrid by easily identifying the area where the fault occurs to isolate it and to reduce the time of repairs. It shows in real time the electrical parameters of power and current in each of the previously programmed segments. In Figure 10 the proposal for this screen is displayed.

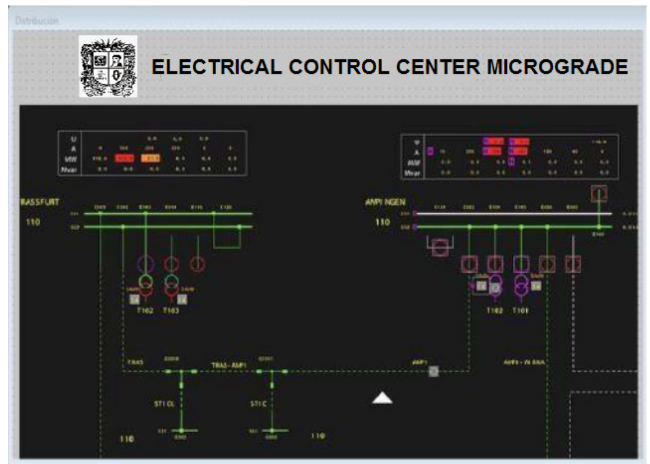

Figure 10. Interface for the distribution screen.

5.4.6 Load Screen

The load energy delivery screen is designed in a way that allows the operator to review the electrical magnitudes that are delivered to each of the users. It is a tool primarily for monitoring and aims to validate in real time each of the design parameters in the delivery of energy tending to comply with the Colombian electrical code. As a guideline for improvement, it is proposed to work to establish a control system, either classic PID or by representing state spaces so that the flow of energy delivery is stable and automatically feedback. The reference value (setpoint) is provided by the norm stipulated in the Colombian electric code.

6. Conclusions

It is possible to conclude that the implementation of the proposed SCADA system for an electric micro-grid in a rural area, allows implementing in a pragmatic way an improvement in the control and monitoring of said network up to 75%, improving the quality of the energy generated, quality of delivered energy and quality of electric service delivered. This as a consequence of the fact of controlling and remotely monitoring the parameters of the network, which increases the efficiency and reduces the operating cost significantly.

The monitoring of strategic points of the network, allows to significantly reducing the time and resolution of problems in the event of a failure, since through the SCADA system, it is possible to determine the specific sector where it is presented. This criterion is also evaluated through remote controlled switches, which allow increasing the security of the network and mitigating the risks of overloads in accordance with the provisions of the Colombian electrical code; by identifying the fault zone and allowing it to be isolated from the others.

It is necessary to take into account the constant maintenance and supervision of the elements used in the implementation of the SCADA system, since the OPC servers, the LAN connections and the hardware where the program chosen for programming and the SCADA interface, INTOUCH, are to be monitored for its correct operation.

The training time of the operator for the management of the SCADA system is relatively short considering that the graphic interface, the animation of the events that intervene in the network and the presentation of the variables and the control of the switches were designed in order to simplify understanding and management in control.

The development and implementation of a SCADA system for a microgrid, contributes to compliance with environmental standards worldwide, and constitutes a criterion of sustainable development, since it implements renewable energy sources and improves the generation and delivery of energy in a reliable.

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