Supervision of a Distributed Energy Resources Generation System Using IEC and ISA Standards

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Abstract—This paper develops a proposal for designing a SCADA system for the supervision of a photovoltaic generation system using IEC 61850 and ISA S101 international standards, and industrial communication protocols such as Modbus TCP and OPC. The complete description of the elements of the generating system and communication architecture for this, based on the standard IEC 61850-7-420 is performed. This standard contains the logical nodes (LN) for modeling systems of distributed energy resources (DER). An important contribution of this work is the design of the human-machine interface (HMI) of the SCADA, which follows the guidelines of the new standard ISA S101, which makes innovative proposals for graphical display of the processes to improve situational awareness in the supervision. The standard has been proposed for industrial processes, but is expected to be adopted in the power systems supervision. Additionally, the inclusion of a section that allows to select two new modes of operation (back up and optimization), as a contribution to the objective of integration of distributed generation in existing power system to promote the transition to a smart grid is highlighted. Finally, the continuous calculation of the amount of CO2 emissions that are avoided and the update on the carbon debt caused by the use of DER sources as a contribution to improving energy efficiency and a new variable to the relevant supervision system is presented. For this job is used mature technology in the electronic component of process control so the contribution is aimed at DER sources supervision and their integration into the power system.

Keywords—carbon debt; DER systems integration with power system; IEC 61850-7-420; ISA S101; logical nodes for DER; Modbus TCP; DER supervision.

I. INTRODUCTION

One of the most important challenges in terms of electric power systems is to design new energy sources that do not depend on fossil fuels. For this reason, it has developed new generation equipment that try to reduce environmental impacts, both in their manufacturing and operation, using resources that have greater availability and help to reduce the carbon footprint of such systems. Existing electric power systems are incorporating large-scale unconventional power sources in places where it does not have easy access to this resource or even as a replacement for conventional sources of electricity. These new sources have been called Distributed Energy Resources (DER) based generation systems, which include different forms of energy generation and storage and they have the ability to connect to power systems at different levels. Some advantages of the DER generation systems are [1], [2]:

- Promote the increasing of energy efficiency and reduced losses.
- Reduce the emissions of gases that cause the greenhouse effect.
- Help to reduce dependence on land use for the installation of large conventional power plants.
- May reduce the need for construction of new power lines.
- Improve the reliability and availability of the electricity service.

This scenario of massive implementations of DER systems brings other challenges such as transmission, integration and/or standardization of necessary information for the supervision and control of these systems. Usually it is possible to find solutions manufactured and installed by conventional suppliers, with devices running proprietary software solutions, which makes difficult the integration of information. This situation causes compatibility issues during operation and communication of such devices. Therefore, organizations such as the IEC have developed some communication standards in order to establish widespread and compatible way to perform a communication between devices that work with DER systems. One is the IEC 61850-7-420 standard, based on generic information models to simplify integration and monitoring of technologies based on DER [3]. This paper presents a proposal for a SCADA system design for monitoring a photovoltaic generation system using international standards such as IEC 61850, ISA S101, and industrial communication protocols such as Modbus TCP and OPC. The proposed supervision system is consistent with the conceptual model conceived in IEC 61850-7-420. This paper is divided as follows: Section 2 presents the current context of the relationship between the IEC 61850-7-420 and DER systems. Section 3 presents the proposed communication architecture for this work and the results of some tests on the component thereof. Section 4 explains the design of the HMI for the supervision system based on the ISA S101 standard. Section 5 defines the contribution of the supervision system by proposing the concept of monitoring carbon debt with the environment and by showing the ability to monitor the proposed system in two operation modes. Finally, section 6 presents the conclusions of the work done.
The DER system proposed for this work consists of six solar panels, a battery charger, four lead-acid batteries, a micro RTU (Remote Terminal Unit) and the SCADA. Regarding to the SCADA system, it is proposed implementing it based on the IEC 61850 communication standard and using DER LNs for supervision of the main variables of the system. Communication tests performed to the battery charger in conjunction with CODENSA S.A. ESP company personnel are presented, whom have been involved in the development of this project. The purpose of these tests is to integrate the variables taken from the battery charger into LNs for DER and validate such integration into the typical communication architecture of the distribution substations. The communications architecture used for testing (Fig. 2) consists of the solar photovoltaic system with -48 VDC voltage coupled to a Micro RTU Kalkitech Sync2101. This RTU has gateway functionality with ability to map the variables from the Modbus TCP protocol to IEC 61850 using the DER NL. The Modbus TCP protocol is installed previously from factory in the battery charger Tristar MPPT-60. The battery charger TriStar MPPT-60 uses maximum power point tracking technology (MPPT) TrakStarTM, for extract the maximum available power from the solar panels. The used Micro RTU has a specific list of LNs for DER systems. It is worth to mention that all this selected technology is already consolidated in the market and is not the main contribution of the work. For the execution of the tests, the LN used was ZBAT (for auxiliary battery systems), which can integrate all information relating to this devices. Such LN is completely defined in IEC 61850-7-420, along with the data object that contains the information about the battery status.

A. Modbus TCP Variable Reading

The initial reading of the variables of the battery charger is via Modbus TCP protocol by mean of the proprietary software of the device, which is the step prior to implementation. The objective of this step is to define the variables to be used in this test. The software used was MSView, and in Fig. 3 it is presented the value of these variables at the time they made the tests. The read variables were voltage, current, terminal voltage and temperature of the batteries. Then it was proceeded with the implementation of
each of the variables in client mode in the Micro RTU. This step was performed in order to obtain a Modbus TCP communication between the client-server Micro RTU and battery charger. After this, a communication test Modbus TCP client-server was performed to validate that the Micro RTU read correctly the information of the battery charger. The test was successful. Once it was found a successful connection with Modbus TCP client-server between Micro RTU and battery charger, it is read the rest of the selected variables.

B. Variable Mapping from Modbus TCP to IEC 61850s

In this process it was performed the variables mapping obtained from the battery charger in Modbus TCP protocol to the IEC 61850 protocol. It is worth to clear that at this point it is performed the mapping of variables associated with the specific ZBAT LN with their respective Data Objects. For the mapping task of the variables that are packed in the Modbus TCP protocol to IEC 61850 with logical nodes for DER, it was used a software for creation of SCL files, where the ZBAT LN was added with its data objects in order to create a IEC 61850 server in the Micro RTU (see Fig. 4). Next, it is related this information to this LN:

- **ZBAT DATA OBJECT**
  - Vol = Output voltage of the batteries.
  - InBatA = Input current to the batteries.
  - InBatTmp = Internal temperature of the battery.
  - InBatV = Input voltage batteries.

Finally, using the IEC 61850 client software Triangle Microworks it was verified that the LN would be properly implemented. Fig. 5 shows an image captured in the execution of the software, where it can be seen the highlighted section corresponding to the LN in question and in the lower section all information related to data objects of the LN.

IV. INTERFACE DESIGN FOR SUPERVISION

The proposed human-machine interface (HMI) was developed under the ISA S101 standard [11], which is a novelty in the design of interfaces for process automation systems with great advantages to be applied to DER systems too. The standard has been proposed for industrial processes, but is expected to be adopted its concepts in the power systems supervision. This work makes a novel proposal for HMI design based on ISA S101 to monitor a DER based electrical system. The use of this standard will generate greater ability to guide the design, construction, operation and maintenance of an HMI, which increases efficiency in the process control to normal and unexpected situations, thereby improving situational awareness in supervision. Among the most important principles for generating an HMI under this standard it can be find the next [12]:

- Simplicity in graphic design to avoid the lack of clarity in the interface.
- The interface design must be intended to support users in the knowledge of the current situation.
The user interaction techniques must be consistent and clear, and also the status and the system instrumentation.

The content of the interface must contain all types of tasks and activities required by the operator.

The symbols and the process status are represented in a simple, meaningful and consistent manner.

### Interface Components

The proposed HMI is divided into two pages. The first page (Fig. 6) shows the main components and variables to allow the operator to know the current state of the system. The electrical diagram (see section 1) has the representation of the different parts of the system (solar panels, batteries, power converters, final load). There, it is included the estimated charge percentage of the battery. At the top right of the interface are located the current and accumulated values of the main variables of the system elements (see section 2). There, it can be seen voltages, currents and powers. Manual controls are also included, and they are located below current values (see section 3). In this part, there is the option to operate the elements individually in case of any contingency. In addition, this interface contains an important contribution for the integration of distributed generation to the network. The contribution is to include three profiles of operation for the supervision system: manual profile, back up profile and optimization profile (see section 4). Activation of these profiles can be performed on the home page, and the values and reports of the variables monitoring are shown in the second page of the SCADA (see Fig. 7). On the other hand, the interface contains six alarm notifications (see section 5), which indicate the different states of abnormal operation that may occur in the system. These alarms are:

- Maximum current in the battery.
- Maximum voltage in the battery.
- Battery charge percentage under 30%.
- Lack of generation in the system.
- Maximum charge voltage.
- Maximum charge current.

It was also added a section containing energy information of the system (see section 6). There can be observed variables such as total CO2 reduction achieved with the use of solar panels, photovoltaic solar energy consumption, the total money saved and debt carbon value. The second page of the interface contains the reports for the variables of the three consumption profiles mentioned above: manual profile, back up profile and optimization profile (see Fig. 7). The manual profile shows the variables values of the system when the operator is performing the functions of the process. Backup profile operates as a support power source for loads with high availability requirements. This is activated when the battery has reached its maximum charge level. The optimization profile was configured to use the energy generated by the panels mainly and then the energy stored in the batteries, when the panels do not generate power. In each of the profiles, it is seen the generated current and power levels, which are represented in level bars. The up-to-date power generation is shown in the XY plane. Power consumption of the elements can be displayed by means of radial graphs. Finally, the number of connections of each element is presented in the level bars on the right side of the page.

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Fig. 6. First page of the HMI for DER supervision system. Here are the system variables, commands of the elements and the connection diagram of the devices that conform the system.
V. THE CARBON DEBT

Another contribution made in this work is the monitoring of the carbon debt value that has this type of implementations based on DER systems. Currently, different industries are looking to reduce the carbon footprint left by their manufacturing processes and operation, but sometimes it does not take into account that since its manufacturing, the devices arrive with a carbon debt [13]. Reducing carbon emissions is not only achieved by replacing conventional generation sources by alternative sources, it is necessary to consider such debt with which the devices come from its manufacturing. For this work, it is considered the carbon that generated the panels manufacturing and the amount of carbon that will be generated at the end of its useful life. Therefore, to keep a count of the carbon debt it is taken an initial value of these emissions calculated based on generic data found in the literature and as the panels generate energy, it is done the discounting from that value, which starts in negative units. The monitoring of this variable will help to be more aware of the real benefit obtained with the use of DER systems based on solar panels.

VI. CONCLUSION

Definitely, power systems are moving towards the adoption of international standards such as IEC 61850, IEC 60870-5-104, IEC 60870, IEC 60968 among others, due to its many qualities and especially due to incorporating the concept of interoperability, one of the basis features for a true smart grid. However, there are several restrictions to achieve a smooth transition in adopting these standards. One restriction that has been identified is that still there is not a consolidated technology offer for DER systems that have implemented the LNs. Therefore, it should expect manufacturers reconcile development costs and other market variables. Although there are already open source software and electronic platforms that allow creating functional solutions that show progress and feasibility in such solutions. Interoperability between devices is a latent concern in the industry. For this reason, it has been driven hard the creation and the implementation of standards such as IEC 61850-7-420, allowing the transfer of information from these elements in a more transparent way. Thus, it contributes to a significant reduction of protocol converters, and in turn reduce the complexity of deployments with equipment from different vendors. The description of the communication test was done with the purpose of demonstrating the possibility of an implementation based on the standard IEC 61850-7-420. The design of the HMI under the guidelines of the new standard ISA S101 is another important contribution of this work, because it contains extensive information about the states of the most important
elements, of the variables to following and displays information about generation and saving energy of the process. It also presents the operating modes (manual, back up and optimization), which define different policies of energy use and establish a strategy of integration of distributed generation to the current power system. Regarding the proposal for the design of the SCADA, although the ISA S101 standard provides new guidelines for designing interfaces with important benefits for operators of power systems, the migration to this point requires a cultural change that takes time and resources. However, it has identified a clear trend towards the adoption of design standards that could facilitate this required cultural change. Therefore, studies like this open the door in order to generate questions to the companies about these new trends.

REFERENCES