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Monitoring and controlling energy distribution: Implementation of a distribution management system based on Common Information Model

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ABSTRACT

The management of renewable and distributed energy resources is changing the way in which electric distribution systems are being operated. Many companies commonly create several custom system solutions to manage power distribution. The functions provided by these systems are network visualization, state estimation, system control and data acquisition, among others. Despite their relevance, many mid-size or small distribution companies have problems to install one of these solutions because they are either very expensive, incompatible, or limited by difficulties in data exchange. As a possible solution to this problem, this paper presents the development of a Distribution Management System (DMS) based on open source technology. This system combines four main components: OpenDSS-framework, ActiveMQ-broker, applications for visualizing and editing electrical network, and Common Information Model (CIM). The tool is part of Tenergia R&D project [1] and has a collection of applications designed to monitor and control the distribution networks located in Argentina.

1. Introduction

There is a significant interest for the electrical industry to develop systems supported by computer-aided engineering [1]. In order to attend decision making and maintenance activities, these systems should provide several functions: Network Connectivity Analysis (NCA), Distribution System State Estimation (DSSE), Load Flow Applications (LFA), Volt/Var Control (VVC), Fault Management & System Restoration (FMSR), Distribution Load Forecasting (DLF), among others [2–4].

A Distribution Management System (DMS) is a set of software components which monitor and control the network with the aim of optimizing the behavior of an electrical smart grid, and therefore enabling utility companies to provide power in a more reliable, efficient and safer way [5–7]. Moreover, it improves outage reduction, outage time minimization, maintenance of acceptable voltage levels and line loss reduction [8]. Many research and commercial tools such as DIgSILENT PowerFactory [9], ETAP [10], Schneider [11] are available.

Several works [12,13] present the benefits of installing a DMS, both for the end users and the distribution company. The process of instantiating a DMS requires specific software, communication infrastructure and hardware for the automation of different network components. In [14] it is shown that the software represents 20% of the total value for automating the network.

The implementation of such systems can be achieved developing solutions that could use existing open source components, and incorporating monitoring and communication network functions. In addition, the cost factor is interesting for the proposal. According to reference, for an investment of 28 million dollars in the first 3 years, the capital was recovered after 5 years, and the profit reached 51% of the invested capital after 10 years [14]. Although the values are interesting for any company, only a few distributors can afford such an investment. Considering that open source components allow cost reduction, the architecture is adapted to the needs of the region.

Moreover, this kind of systems have to be supplemented with appropriate message passing and synchronization capabilities in a prescribed format. For that reason, standards are being used to facilitate the data exchange between applications within a company, as well as with other companies. These two standards are the IEC 61970–301 and the IEC 61968–11, which correspond to

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the Common Information Model (CIM) and Distribution extensions [15]. Although CIM is primarily designed for node-breaker representation, with certain extensions it can be leveraged to achieve a standard interoperable bus-branch model representation and exchange format. The power system network can be modeled using CIM with as many abstraction levels as required. In [16] three models (physical, topological, and dynamic) to represent power network information on the developed DMS are described.

If more accessible analysis tools are needed, flexible and reliable open source software packages should be used [17]. In this context, OpenDSS is a comprehensive open source tool for electric power distribution systems developed by the Electric Power Research Institute (EPRI) [18] to model and simulate the electrical behavior of the distribution network. Another characteristic of OpenDSS is that it includes a COM interface to communicate with other applications, providing flexibility and modifiability [19,20].

Furthermore, being able to combine applications is important if a robust messaging scheme is required. Most messaging applications are implemented as a message broker which connects producers with consumers, where producers send messages and consumers process them [21]. There are many message systems that can be used to communicate information within different parts of the systems, such as RabbitMQ, ActiveMQ, OpenMQ [22]. The ActiveMQ broker is chosen because it is faster on message reception. This is an essential requirement in a system where several devices are constantly sending information [22].

The electrical companies have installed substantial monitoring equipment that regularly sends relevant information of the electrical network. In order to save this information, a variety of NoSQL and SQL databases [23] are studied. In this sense, the NoSQL databases show more benefits when the analysis of large volumes of data [24] is required, which is very important in the distribution sector. Thus, Apache Cassandra [25] is selected due to present a good performance in all the tests. Moreover, this is an open source database, which is one of the requirements defined by this development.

An EMS architecture is shown in [26]. Although it is useful in our proposal, it adopts only a static CIM to represent and update information. This feature degrades real-time data management performance. Besides, data acquisition and device control are not represented. Additionally, in [27] it is shown that software OpenDSS provides many useful algorithms for the distribution sector. However, it cannot support real-time execution.

Finally, current systems are very expensive and lack features such as oriented services, modularity, common standards and flexibility. Another drawback worth mentioning is the dependence on providers. Thus, the main purpose of this work is to design and implement a DMS architecture based on open source technology which provides the requirements mentioned above in contrast with existing monolithic structures. Moreover, the combination of OpenDSS, ActiveMQ, CIM and NoSQL databases on the proposed architecture allows the incorporation of new algorithms and tools dynamically in contrast with the closed and private existing systems.

The following section shows the motivation for using the mentioned applications and the requirements for their interconnection. The proposed architecture is demonstrated in Section 3 and described in Section 4 considering the most important implementation aspects. Section 5 depicts several tests which demonstrate the feasibility of using the system over a real distribution network. Finally, conclusions are presented in Section 7.

2. Motivation and requirements

The main purpose of this article is to contribute with solutions applied to the distribution grid. Therefore the design and implementation of the DMS is presented, with characteristics such as flexibility, extensibility and evolution, opposed to the monolithic architectures currently on the market. Instead of developing an independent solution, technologies that are well tested are combined and effectively used in the industry. Specifically, this DMS is developed by connecting several well-known technologies with a collection of applications designed to monitor and control distribution networks located in Argentina.

The analysis tools need to have a clear representation to synchronize real-world and simulation behavior. OpenDSS is a flexible and reliable open source tool to model and simulate the electrical behavior of the distribution network.

One important requirement of the current tools is the integration of power flow modeling and simulation environments. A mechanism to separate the application logic from the simulation execution is another important requirement. In order to combine different applications, it is essential to use a standard model with several levels of abstraction so as to export and import a variety of tools. The chosen data model should enable the generation of specific input models with a coherent transformation.

The main motivations for using CIM to model the network are the availability of tools and libraries to support this format and the high degree of compatibility with other industry standards. These facts facilitate the application integration of various distributed systems. Thus, CIM standards is used to facilitate the exchange of data between applications within a company and the exchange of data between different companies.

In turn, these developments are encouraged by research-funding entities to research on strategic issues in science, technology and innovation policy. Thus, they support new ideas and strategies to develop products and services. In this regard, there is an opportunity to implement a DMS that provides the specific functionality to the companies taking into account their local needs. The developed tool is being applied in Tenergia R&D project[1]. It is intended that the resulting tool will be generically applied to regional studies in certain selected regions of Argentina and, consequently, be available to a larger community.

3. Implementation

As mentioned above, most DMS are based on monolithic architectures. At present, the new challenges in the distribution sector need new integrated tools to help and improve the operation of the electrical system. Thus, it is necessary to incorporate quality attributes such as flexibility, adaptability and interoperability without losing performance and security. An important decision is to use ActiveMQ as a message broker to communicate information between different parts of the system. The broker pattern allows to decouple the operation of the subsystems, and it manages communication between the modules. In addition, to make a DMS safer, security tactics are implemented based on sessions and encryption. Besides, this architectural pattern allows the implementation of several availability mechanisms which make the system more fault tolerant. Moreover, new technologies in data bases are used to save all the obtained information. Mainly, the NoSQL databases are optimized to use data mining and machine learning algorithms which are very useful for the proposed system.

In this section, an analysis of open source components and information standards integrated into this project is presented.

3.1. Applications for visualizing and editing electrical networks

The proposed system has an operation diagram representation (schematic and geographic) which allows the user to create, modify and operate the power network. To implement the schematic