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Implementation of an educational real-time platform for relaying automation on smart grids

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ABSTRACT

The increasing research work on power networks has produced important challenges on distribution systems. These multiple advances bring an inevitable need to reshape and modernize teaching methodologies in order to understand the different issues of the smart grid complexity. This paper presents the design and implementation of an interactive platform to assess Advanced Distribution Automation (ADA) with applications and solutions focused on relaying solutions for educational purposes on smart grid. The proposed architecture integrates hardware/software tools to emulate the distribution system's behavior and recreate selected signals. Different features are presented and validated from a basic case study, where the students are able to comprehend the main concepts of relaying devices. The operational functionality of the platform offers the required flexibility to link theory with practice, which is suitable to enhance the learning process and encourage the class innovation. The user can incorporate protective algorithms and automation solutions under a real-time environment with hardware-in-the-loop techniques, such as adaptive protections and reconfiguration methods to optimize the grid. The impact of this platform in educational courses and the development of undergraduate thesis is assessed over the last 5 years in the faculty, and ABET guidelines are included in the evaluation of five Program Educational Objectives (PEOs) to measure the influence on students. Further potential applications are also discussed.

1. Introduction

The engineering efforts are highly focused on strategies to reach a more reliable and efficient distribution system [1]; as result of these efforts, the research on smart grids offers multiple working fields to integrate modern equipment into the current infrastructure [2]. This enhancing process is coherent with the goals of Advanced Distribution Automation (ADA) [3,4] and the continuous evolution of the research will enable to build the optimal grid of the future. Such challenges have been clearly defined in research and standardization as well: in grid equipment monitoring, fault location [5], isolation [6] and restoration [7], inclusion of renewable energy, electric vehicles, grid reconfiguration [8], adaptive protections, volt and var control, metering, event recording and communications infrastructure [9] are some of the examples of research priorities.

The attempt to improve reliability and power quality involve several applications on the smart grid, which require an important set of protection devices to monitor and control multiple relaying functions. This context has always been a priority in power engineering education [10,11] and many advances are widely recognized in the last years of modeling [12], simulation [13] and laboratory platforms [14–16]. In consequence, the teaching approaches of power engineering and protective relaying control has turned into a constant innovative evolution; certainly, the role of digital modeling and simulation is encouraging all the teaching efforts to form a new generation of students, well prepared for the smart grid challenges applications and research. The study reported in this paper, fits a customized platform for general-purpose on relaying automation, based on a hardware/software integration.

The proposed platform, incorporates needs aim to improve the learning curve of students in different areas. An important part of this project lies in the simulation software DSSim-PC [17], a free tool also developed at Universidad de los Andes, based on the powerful EPRI's OpenDSS [18]. As it will be introduced later, the program structure is designed to be scalable, flexible and feasible to be replicated in hardware architectures that follow the platform

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requirements. These first two features of the proposed test bench generate a low cost for development, which is an important need when applying customized platforms for research and educational solutions. The study presented in this paper is part of two master's thesis and the applications were developed by last semester undergraduate students. This novel integration has been used as a tool for undergraduate thesis, continued education projects, and graduate projects over the past 2 years. A more detailed statistical analysis of the platform's impact of the Electrical Engineering program is presented in Section 5, the results demonstrate the evolution and motivation that this test bench has consequently caused in undergraduate students, not only for academic purposes but also because it approaches them to real applications in their professional careers.

The paper is organized as follows, the proposed platform of hardware and software integration as a real-time hardware-in-the-loop architecture is explained in Section 2; the design, performance and validation strategy is presented as well with a basic case of study. This system evaluates different scenarios and a set of results demonstrates the real time simulation advantages. In Section 4, the platform is assessed under two different applications of adaptive protections and a reconfiguration algorithm to optimize losses. A statistical analysis is presented to evaluate the educational impact of the proposed platform in undergraduate students. Conclusions are given at the end.

2. Designing a RT-HIL environment

Electrical networks are rapidly evolving into a more complex and smart functionality, so the methodology to analyze them should be improved in the same direction. In the case of protective relaying control techniques as well as in many other areas, the use of modeling and simulation tools combined with an effective hardware/software integration results in a great alternative to understand the smart grid. This section introduces the early attempts to include more realism within teaching strategies, from software simulation solutions in the first decades until nowadays real-time approaches. After this background, the proposed platform is presented with the hardware and software integration, identifying the highlights to certain needs.

2.1. Background of educational RT platforms

Since the rapid evolution of computer relaying in 1980s, important educational efforts have been made. These studies were first focused on appropriate tools to emulate the dynamic behavior of power systems. They were concerned in different scenarios such as design issues, fault transient analysis that involves teaching aspects of the protective relaying field. DYNA-Test Simulator [19] (a dynamic testing based software as a protective relaying teaching tool) which integrates EMTP with a versatile user interface; furthermore, the inclusion of field recorded data in that study, brought closer students and protective issues from real systems. Other studies added TACs functions with EMTP to simulate a more accurate behavior of the relay functionality [20], relay algorithms, trip logic and switch dynamics. But most important, the development activity did not stop there. Academy and industry advances constantly encouraged to keep working on realism of simulations and testing methods. Students as future engineers need to understand fundamental concepts with practical and real tools, not only on the protective relaying field.

Reaching the 2000, full laboratory systems for educational purposes of protective relaying were reported. A PC-based testing station to monitor protection schemes of transmission lines was introduced by [21], in order to mitigate human error and the lack of student knowledge about the performance and limitations of different protective relay systems. While real-time hardware systems were developed, software tools with more realistic models with MATLAB [22] to enhance applications and design concepts, this toolbox was one of the first that allowed to create COMTRADE files from simulated relays modeled on MATLAB-Simulink. Curiously, some years later Simulink models could run in Real-time with OPAL-RT architectures [23,24].

The evolution of all these research efforts is visible in multiple examples. Successful real-time laboratories have been reported for different applications such as the study of EMS applications with IEC 61850 [25]. One of the best examples also integrates hardware/software tools and reaches valuable applications, for example closed-loop and open-loop impedance relay testing [14] which also includes hardware-in-the-loop. The proposed platform improves realism, flexibility, scalability and development time for another approach: protective relaying automation in smart grid's education. The platform continues with the the literature concept on educational platforms based in open source tools.

2.2. Simulation tools

At first, it is necessary to model and simulate the distribution system behavior including fault's programming. One of the most important actors in this work is DSSim-PC software [17], the non deterministic version of the DSSim-RT simulator, which is based on the powerful EPRI's OpenDSS [18] with a friendly graphical interface. Keeping this in mind, OpenDSS commands are going to be used in order to formulate the electrical model of the distribution systems and design a fault control simulation. This feature allows to assess different protection scenarios.

Some applications involving OpenDSS and LabVIEW with real-time analysis have been done with National Instruments hardware architectures [26]. Successful results show the great advantage of this software as a possible tool for Advanced Distribution Automation (ADA) research, such as fault location and isolation, feeder reconfiguration, service restoration and Volt–Var control [27]. According to these studies, electrical networks can be simulated and faults can be programmed with this software, but it is highly recommended to have a thorough background in OpenDSS codes.

The software integration uses DSSim-PC libraries to communicate current/voltage measurements and reclosers statuses with the user through TCP/IP protocol, which allows to transfer important data to the real-time hardware set. User's interface presents typical information about the electrical system (e.g., number of nodes, number of lines, simulation time). It is also possible to read current and voltage magnitudes during a fault in the network, because the front panel designed on LabVIEW lets the user to access a system monitoring screen. There is an indicator which shows the operating status, it would turn out red if a fault appears, or the green light remains in normal operation. Systems with 123 nodes have been tested in the platform, but DSSim-PC allows to simulate up to 8500 nodes.

2.3. Software programming

Before applying models on a real-time architecture, an intermediate program should be constructed. Two main actors are established for this design: the electrical system modeled in DSSim-PC, and the functional algorithm process to take protective control decisions depending on the application. It is not recommended to locate both modules in the same time loop, because the information processing will not be able to change until the first piece of data is done processing.

A producer/consumer design LabVIEW pattern [29] is used to integrate all the elements shown in Fig. 1. Based on the master/slave pattern, the first time loop (producer) generates the required data