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Real Time Distribution System Simulator-based on OpenDSS

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SUMMARY

Smart grid applications constitute the base to support the evolution of electricity grids. The inclusion of new computational technologies and transforming data into information by visualization tools will make possible to cover the new threads proposed by the power industry.
Advanced Distribution Automation (ADA) is a promising approach to power grid management activity because supports the evolution of Distribution Networks (DN) into Smart Grids. The activities covered by ADA include fault location, fault isolation, service restoration, Volt-VAr control and feeder reconfiguration, all of them supported by a reliable communications system. The testing stage of new control methodologies and equipment for ADA represents technical and economical efforts, and this stage delivers partial results to improve the product performance before it can be finally implemented. For this reason, it is necessary to develop new techniques and computational tools to support realistic simulation of DN. With Real Time Hardware in the Loop techniques (RT-HIL), it is possible to improve the quality of the simulation experience, including control, communications and power simulations and reducing the design and testing times at reasonable cost.
In this research, OpenDSS, which is a DN off line simulator developed by EPRI, is improved by including RT-HIL characteristics using parallel programing strategies available in Real Time (RT) hardware. The data delivered for the OpenDSS is represented using analog and digital signals, which can be sent to external equipment to do power HIL and control HIL. Additionally, the system variables are displayed using graphical interfaces, so the utility operators and managers can interact with the DN in a lifelike scenario. The system information is delivered by using the Dynamic Data Drawings (DyDa-Draw), which is a new tool for the transformation of data into information.
The development was made using National Instruments Real Time hardware architectures, OpenDSS software and the LabVIEW® RT software.
The IEEE 34 Nodes system is used for evaluating the RT simulation system where functionalities provided by the developed tool are presented. The results suggest that the proposed tool can be a powerful aid for ADA developments in the near future.
Finally, the future work is presented.

KEYWORDS

Advanced distribution automation, dynamic data drawings, hardware in the loop, LabVIEW, OpenDSS, real time.

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1. INTRODUCTION

On the last years, Distribution Networks (DN) have become more complex, the inclusion of new types of loads and equipment, demands the development of methodologies to guarantee the grid Security, Reliability, Power Quality and Availability (SQRA) [1], [2]. Smart grid applications constitute the base to support the evolution of electricity grids; including new computational technologies and transforming data into information by visualization tools for asset grid operators and managers, it will be possible to cover the new threads proposed by the power industry [3].
Technological advances in monitoring, data to information conversion and visualization technologies are necessary to cover the characteristics of the smart grid [3]; this way, the tools for smart grid development have to incorporate graphic environments, allowing the utility operators and managers interact with the DN simulated components in a realistic way.
Advanced Distribution Automation (ADA) is a promising approach to the power grid management activity, supporting the evolution of DNs to Smart Grids [4]. The activities covered by ADA include fault location, fault isolation, service restoration, Volt-VAr control and feeder reconfiguration. A reliable communication platform is included to ensure real time management of the grid [5]. The electrical Industry is showing great interest in computer aided tools to support the rapid development of methodologies, technologies and solutions to current challenges [6], [7]. Furthermore, new control methodologies, communication networks and equipment like reclosers, protection relays and meters units, must be tested in real scenarios to validate their operation before they can be offered and used by utilities in ADA [8]. Sometimes, tests have to be supported by additional security procedures to avoid accidents, which increase the cost of the test. For these reasons, it is necessary to develop realistic simulation tools to interact with external equipment and validate new control and communication strategies; in this way, the use of controlled and safe lifelike testing environments makes it possible to reduce the cost of the testing procedures [9].
OpenDSS is an open-source distribution system simulator developed by EPRI for distributed generation (DG) planning, harmonic studies, neutral-earth voltage studies, Volt-VAr control studies, and other special applications [10]; it has been used to conduct several smart grid research projects, including advanced automation, electric vehicle penetration, state estimation, and green circuits. In this work, the OpenDSS capabilities are improved incorporating RT-HIL characteristics to its operation. This is achieved employing parallel programing strategies available with RT hardware, and interfacing delivered data by analog and digital signals in RT. These signals could be applied to external equipment [11].
The difference between classic simulation software and RT-HIL simulation is the capacity of the simulator to generate and measure signals interacting with external equipment [12]-[17]. The employment of external equipment improves the quality of the simulation experience; the controlled signals generated and acquired by RT-HIL systems reduce considerably the testing times [18], [19]. This kind of simulation is mature and provides better computational efficiency, flexible and scalable programming, and preserves precision as good as conventional off-line simulation [20], [21]. This way it is possible to test controllers using control HIL (CHIL), or interact with power devices in a power HIL (PHIL) adding power amplifiers to the generated signals [22] as shown in fig. 1.

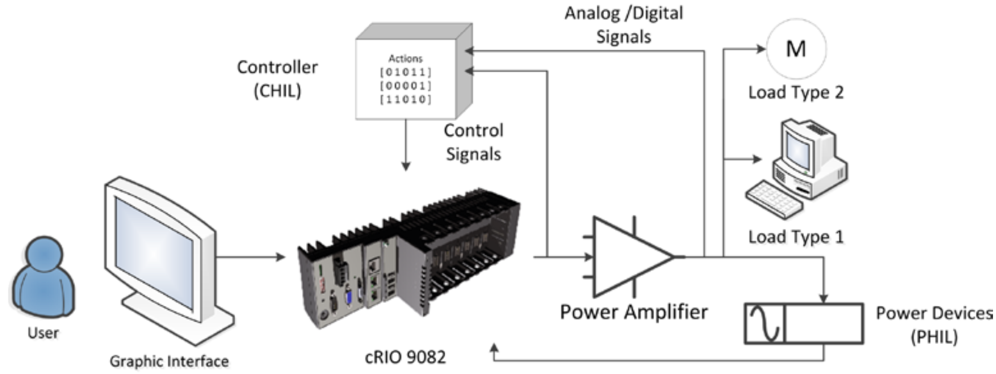


Fig. 1. Control HIL (CHIL) and power HIL (PHIL)

The graphic and simple human machine interfaces (HMI), delivering data to the Utility Operator (UO), are a key tool for the decision making process [23], [24]. For this reason, the development of the DyDa-Draw represents a novel and interesting alternative to deliver data to the user. These objects improve the user experience to evaluate the results obtained when something changes in the simulated grid, displaying requested data graphically and updating it in RT.
As result, a RT-HIL simulation system for DN called DSSim-RT is developed. In this system, it will be possible to concentrate the power system simulation theory supported by OpenDSS, to design supervisory control strategies to manage the DN exchanging information with simulated and real equipment through analog and digital signals, and verify communication methodologies by using communication ports like Giga Ethernet, RS 232 and RS 485. All these functionalities are supported by a RT hardware platform as shown in fig. 2.
In this paper every development was made using National Instruments Real Time hardware architectures, OpenDSS software and the LabVIEW® RT software.
This work is organized in three parts: The first one describes the DSSim-RT, which is the developed tool, and his current development status. The second part shows the RT simulation of the IEEE 34 nodes system using DyDa-Draws within the DSSim-RT. In the third part, the future work and the next releases for the DSSim-RT are described.

2. THE REAL TIME DISTRIBUTION SYSTEM SIMULATOR (DSSim-RT)

The DSSim-RT software is developed using National Instruments LabVIEW®; it is connected to the OpenDSS by the COM automated interface included in it. This interface is a set of methods and properties useful to interact with the OpenDSS engine in different modes [25]. The general procedure to interact with the COM interface can be seen on Fig 3. Method X refers to one of the different methods included in the COM interface of the OpenDSS; the same case applies to the property Y.
There are two versions of the DSSim-RT: the first one is the standard PC version and the second one is the RT-HIL version; this last is executed over a NI cRIO 9082. The main characteristic of this hardware is the concurrence of process; this is possible because the RT hardware is a multicore architecture which allows dedicating all the capabilities of a single core to execute a task in an exclusive way.
The cRIO 9082 incorporates an Intel Core i7 main processor (2 cores and 4 threads) at 1.33 GHz to attend the operative system (OS) and the programmed tasks using the NI LabVIEW® software. The OS employed in this application is Windows 7 embedded (WES7). In addition, an FPGA included in the hardware, allows defining hardware to attend processes in deterministic time cycles, so the parallelism between different tasks, like data acquisition or signal generation, can be attended by hardware. In this way, it is possible to dedicate one core to a complex process guaranteeing his completion in deterministic computing cycles. Moreover, it is possible to complete up to four complex processes in parallel (four threads) in deterministic computing cycles without affecting the data acquisition/generation stage that runs under the FPGA.
The simulation environment is composed by a workspace and a command bar. In the workspace the UO can place DyDa-Draws to visualize the values for different electrical variables on the system associated to an element. In the command bar, the UO can find different tools to create and edit the different elements disposed on the workspace.

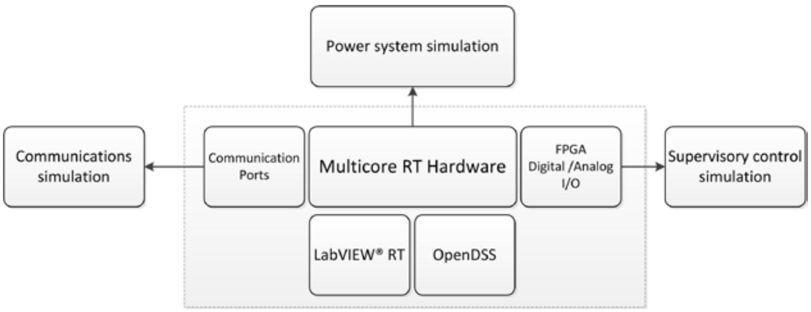


Fig. 2. Functionalities associated to the DSSim-RT System

All the system elements names and their parameters are delivered automatically by OpenDSS to LabVIEW; this way, it is possible to check topology changes, and update the interface and controls automatically. When the UO starts a simulation, the software loads the .DSS file that describes the system; which is required for OpenDSS. Then the user can interact with the system switches and place DyDa-Draws as needed. DyDa-Draws are figures to transform data into information; the data contains the values of the variables associated to an element.
There are two types of DyDa-Draws: the first one is the Polar Graph DyDa, which is a polar graph with the voltages of the phases associated to a node. The second one is the Table DyDa, which is a table that can contain information of Voltages (magnitudes and angles), Currents (magnitudes and angles), Power Flows and Power Losses of a certain element. Both types of elements are shown in fig. 4.
With DyDa-Draws the UO is able to visualize the values for different elements within the DN after changes on the network topology or when a fault happens. This visualization is graphical and in RT. This way, the UO can evaluate the behavior of the system when certain control strategy or methodology is applied to control the DN. The interface looks like a Control Board of a Control Center and the DyDa-Draws look like measurements taken in different parts of the grid. In Fig. 5a, the IEEE 34 nodes system with DyDa-Draws is shown.
The current state of the system switches can be updated by the user employing the "Available switches" window; it is a floating window that can be called from the command bar. The advantage of integrate OpenDSS and LabVIEW® is that new elements and strategies can be developed in LabVIEW®, and then be integrated with OpenDSS using the COM interface. This way, new developers can contribute to the evolution of the OpenDSS, from flexible programming languages like G Code (LabVIEW®) using RT programming strategies and hardware.

3. RT SIMULATION OF THE IEEE 34 NODE TEST DISTRIBUTION SYSTEM

The IEEE 34 node system has been modified including 4 switches to generate 4 different types of faults. Additionally, a wind generator is included as a DG unit and it can be connected to the grid using the switch sw1, which is connected to the node 816.

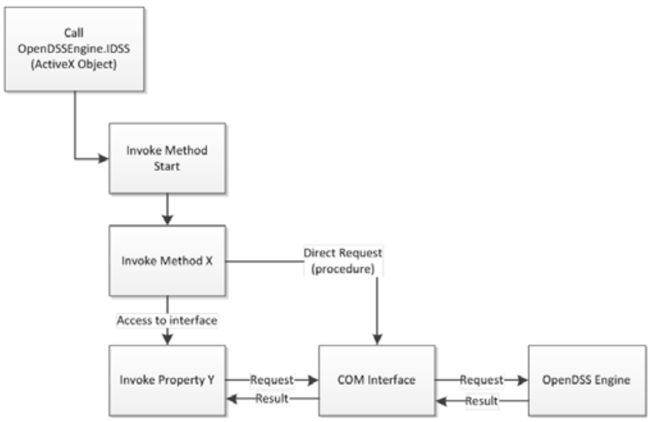


Fig. 3. General procedure to interact with the OpenDSS COM interface

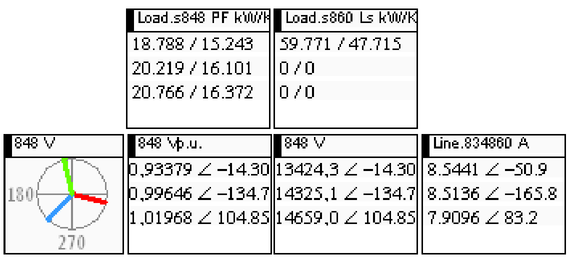


Fig. 4. DyDa-Draws for different types of data

The wind generator is configured in variable status and model 3 [25]. The generator behaves like a P-V node on the power flow. The OpenDSS is configured in snap mode to solve the unbalanced power flow with a base of 100MVA.
For testing the performance of the graphical interface of the DSSim-RT software, a three phase fault is connected to the node 840. The aim is to show the theoretical results and the simulated ones by measuring the Sag magnitude at node 816 and changing the distance from the fault to the measured node [26]- [28].
Then the DG is connected to the node 816 to improve the voltage profile when the fault happens [29], [30]. Both situations are compared; the nominal power delivered by the DG is set to 100 kW, 2 MVA and 5 MVA for three different analyses. The fault impedance is the OpenDSS default [25]. To analyze a theoretical approach, a voltage divider model is used [31]. This way, the equivalent system can be represented as it is shown on Fig. 5b [32].
The total distance between nodes 816 and 840 is 25.945 km. The fault is moved to different distances corresponding to the location of the nodes between 840 and 816 (except the branches). The voltage relative magnitudes versus the fault distance to the node 816 are drawn as shown in Fig. 6a. The same procedure is programmed on the DSSim-RT and the results are drawn as shown in Fig. 6b. The fault considered on every case is a three-phase fault, which corresponds to a type A sag [32].
Then, the DG is connected to the node 816 and its delivered power is changed to 100 kW, 2 MVA and 5MVA to obtain 3 different curves; the results are shown in Figs 6a and 6b for the theoretical and simulated cases respectively. It suggests that the inclusion of the DG improves the voltage profile, but the DG power capacity should be big enough to make an important improvement. In fact, the DG delivered power, and the DG location within DN has to be considered to guarantee an improvement on the voltage profile in case of a fault.
As shown in figs. 6a and 6b, the simulated results are closer to real measurements; this is because in the theoretical results there are many approximations and some segments of the network are neglected to simplify the calculations. Although the tendencies are similar in the theoretical and simulated results, the simulated results delivered by OpenDSS gives more realistic information related with the system status.

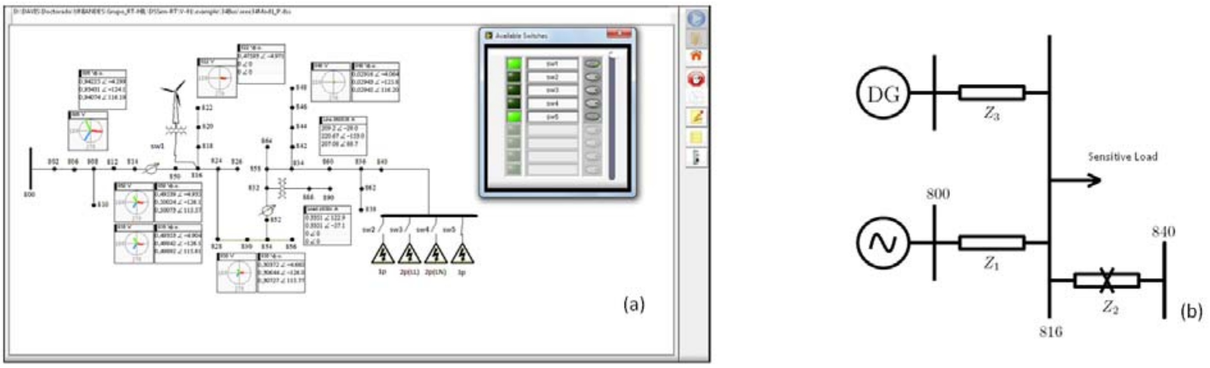
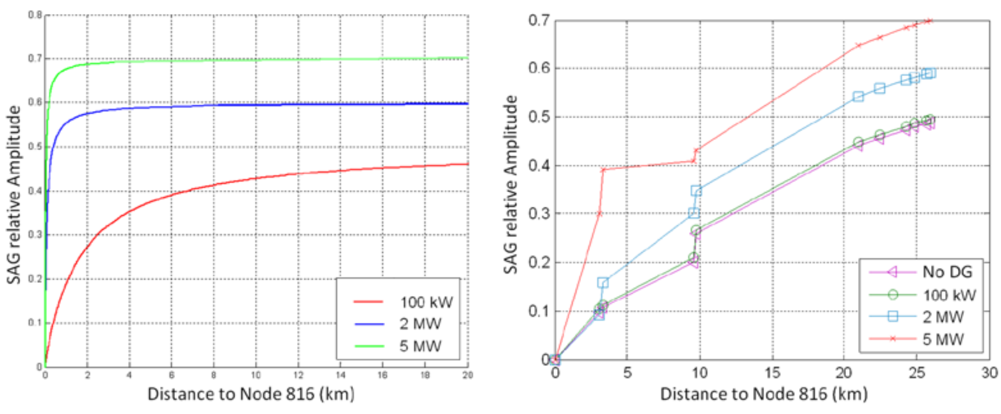


Fig. 5. (a) Graphic Interface for the DSSim – RT, (b) equivalent circuit.



(a) (b)

Fig. 6. SAG relative amplitude vs. distance. (a) Theoretical results. (b) Simulated results.

This kind of conclusions can be easily obtained by using DyDa-Draws. In Fig. 5a, it is shown how with DyDa-Draws placed in different parts of the DN, it is possible to evaluate the behavior of the voltage profile when a fault happens, in this case on the node 840. With the graphical interface of DSSim-RT it is possible to connect/remove the DG in the simulation at any time.
The advantage of the RT simulation performed with DSSim-RT is that the results are instantaneous. The classic off-line simulators deliver results evaluated only in a fixed time interval, restricting the interaction capability between the UO and the DN simulation; on the other hand, RT simulation delivers instantaneous results like in a control room. Distributed measurements and interactive controls, gives to the UO a lifelike experience within the simulation.

4. FUTURE WORK

As future work, it is expected a releasing of a "constructor" module. This module provides the user with the ability to build DNs graphically and generate the **.dss* (DSS file) to be processed by the OpenDSS Engine. The final version of the constructor will be able to translate DSS files into his graphical representation**.** In this way, DNs already modeled as DSS files could be modeled graphically within the DSSim-RT environment. Another important module to be released is the control module. With this module the user will be able to program his control algorithms using block diagrams and C++ routines. This way, the UO will be able to control the elements within the RT simulation, evaluating programmed control strategies in a graphical simulation environment. By using this module, the user does not have to be an expert programmer and it is possible to focus his attention on the problem to be solved.

CONCLUSION

In this paper, the development of a tool for RT graphic analysis of DNs based on OpenDSS was presented. The behavior of the tool is stable when the system parameters change by switching. The parallel programming characteristic allows interacting with digital and analog signals using programmable hardware in an exclusive way.
The result of the connection between LabVIEW® RT and OpenDSS is a powerful tool to analyze distribution systems in RT including unbalanced operation; the performance of the application suggests that in the near future can represent a reliable and efficient platform to develop ADA. Additionally, connecting LabVIEW and OpenDSS will bring more developers to contribute to the evolution of the OpenDSS, from flexible programming languages like G Code (LabVIEW®) using RT programming strategies and hardware.
The Dynamic Data Drawings (DyDa-Draw) is a new tool for the transformation of data into information. This way, utility operators and managers can simulate realistic scenarios with the flexibility of a graphical HMI. With DyDa-Draws it is possible to display information about the system status using graphical representations, which let the UO making decisions about the system in a fast and easy way.
The advantage of the RT simulation performed with DSSim-RT is that the results are instantaneous. The classic off-line simulators deliver results evaluated only in a time interval restricting the interaction capacity of with the UO; meanwhile, RT simulation delivers instantaneous results like in a control room. Distributed measurements and interactive controls, gives to the UO a lifelike experience within the simulation. This tool can be used in the near future for training future UO in a realistic and controlled simulation environment.
The cost associated to the construction of laboratories and their maintenance use to be high in the short, medium and long term. The RT-HIL systems represent an alternative to reach lifelike scenarios for the analysis of DN and training the professionals at reasonable cost in the medium and long term.

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