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Integration of the CYMDIST – RT-LAB Platforms for the Real Time Analyze of Distribution Networks

Ricardo Rodríguez Barrigas [a,*], Diego X. Morales [b]

[a] *Maestria en Energías Renovables, Universidad Católica de Cuenca, Cuenca, Ecuador.*
[b] *CIITT Laboratorio de Economía Circular, Universidad Católica de Cuenca, Cuenca, Ecuador*
Corresponding author: [*]edwin.rodriguez@psg.ucacue.edu.ec

Abstract— **Nowadays, one of the main challenges of electrical distribution companies is becoming part of the era of intelligent networks with computer systems developed in parallel with the electrical needs to obtain the entire distribution network simulations and models. The concept of automation must be implemented to carry out the planning, operation, and optimization processes of the behavior of the distribution networks. Thanks to this development, since 2004, the implementation of the simulation and the CYMDIST modeling system in Ecuador's electrical companies has been possible; nevertheless, with certain dynamic limitations in real-time. Therefore, this document presents the development of an interface that integrates the RT-LAB real-time simulation software to the CYMDIST environment, using the 34 node IEEE model. This proposed integration model will allow evaluating and validating the correct communication between the computer packages and examining the behavior of the proposed system under certain test scenarios that guarantee optimal performance by performing a load flow analysis that provides magnitude and angle values both in voltage and current. The results obtained were very close in levels of precision of the model, and it can be appreciated employing the proposed graphical interface. Furthermore, with this investigation, the possibility remains open for future investigations in which it is complemented with more detailed and complex analyzes.**

Keywords— **CYMDIST; RT-LAB; simulations; real-time; interface; communication.**

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I. INTRODUCTION

The electrical sector is in constant development. Its accelerated growth in demography, urbanism, industry, and commerce [1] has generated numerous technological changes because electrical networks are subject to an increase in demand, reliability levels, loss reduction, and policies that contribute to the reduction of Greenhouse Gases (GHG). Other characteristics that involve electrical systems are the interconnection and implementation of new small-scale sources of generation that demonstrate a constant growth in this type of system [2].

In general, the electricity sector allocates between 30 and 40% of its investment to distribution systems, but it has not had the expected technological impact of those obtained in generation and transmission systems. However, the importance of automating distribution systems to improve quality, efficiency, and continuity of service [3] has allowed electricity companies to enter the era of intelligent networks [4]. Technological advances in the world, specifically in the Ecuadorian sector, have made it possible to apply georeferenced information systems for electrical networks (GIS) and advanced demand management systems (ADMS). Also, customer information system (CIS), SCADA with real-time data and feeder demand, and a system for the management of outages (OMS) have been applied [5]–[7]. However, one of the distribution companies' challenges is developing computer programs with simulations and models of their entire distribution network, which provide the necessary information for decision making and the optimal operation of the systems.

In this regard, the distribution companies, in the particular case of the Empresa Eléctrica Regional Centro Sur (EERCS S. A.), have incorporated the primary analysis software CYMDIST available from CYME Inc, Canada [3]. Its great potential allows planning, operating, optimization, and simulation studies of the behavior of distribution networks under different operating conditions and various scenarios, through an efficient and user-friendly graphical interface. However, this software is limited due to the lack of considering of a real-time analysis component. Therefore, to develop simulations that run in synchronism with the studied electrical phenomena [8], both in new incorporations and changes in distribution networks.

However, the application of real-time simulators to the industry and academia has allowed the analysis of different components in electrical networks. In this context, the Catholic University of Cuenca (UCDC) has acquired the RT-LAB real-time simulator developed by the company OPAL-RT which allows executing Simulink [9] or System Build [10] models, creating parallel tasks from the original model and running them on several CPUs. The data exchange is done through a shared memory with extremely low latency in the order of the CPU system memory. This allows the simulation of electrical systems in parallel in less than 10 μs [10].

Due to the great potential offered by the two software and the lack of previous scientific evidence, the current research project addresses the integration between the CYMDIST and RT-LAB platforms for real-time analysis of the distribution networks. This will be based on a method based on network construction with the application of computer programs.

II. Materials and Method

Two stages were identified as the starting point for this research. The first one consists of describing the essential simulation tools. The second one describes the method of interest for the development of the research.

A. Simulation Tools.

1) Modeling of the distribution networks: The scope of the network model depends on different elements associated with the distribution networks. Those are transformers, loads, conductors, and non-conventional elements such as photovoltaic panels, wind turbines, and intelligent buildings [11]. In order to do so, some important and vital aspects must be taken into consideration. It is necessary to consider the distribution transformers since they are considered key elements in a distribution network [12]. The typical configuration in medium and low voltage, as well as power and the number of clients, are connected to the transformer [13]. Another important aspect is the configuration of the network and the model of the lines, which in particular require data such as the physical characteristics of the conductors, the distance, and lengths [14], the impedance values for both primary and secondary distribution networks, as well as the voltage levels with which they operate [12]. In addition, other aspects such as the load models that can be added or detailed should be considered while taking into account the classification of each of them as their behavior varies throughout the day [14]. A last and very important aspect that has been developed is the non-conventional charges, which can be modeled as a negative charge, electric vehicles, and intelligent buildings with equivalent blocks with specific charge profiles for each case [11], [12], [15].

2) Modeling and simulation of the CYMDIST platform: The CYMDIST simulation platform [16], is a primary distribution analysis software [3], which develops a series of processes and data to generate the network model [5]. The process to develop the complete system requires three different parts that can be generated or integrated independently. The first part is the equipment model, which identifies the different types and subtypes of devices used in the distribution system to model them in the CYMDIST library. The network models correspond to the physical model of the network; the parameters of each conductor are entered into the conductor library. The values of the distances can be entered, and the conductor can be chosen according to whether it is a phase or neutral. The last part is the load model, which should include the locations and data used for power flow studies [3], [13]. This input data required for the distribution system's modeling includes processed data in several programs before being imported into CYMDIST.

3) Real-time simulation RT-LAB platform: The RT-LAB simulator [17] allows parallel simulations of power units and electric circuits, using standard Simulink models [10]. In addition, this software can build computing and communication tasks that are necessary to generate the parallel simulation with standard PCs and communication links. RT-LAB allows the execution of control applications to test advanced distribution functions thanks to the characteristics of flexibility and scalability [17]. Among the main functions, we have reconfiguration, cut-reconnection. These simulations have the particularity that they can integrate Distributed Generation Systems (DG) and new services that connect real devices for evaluating their impact in the real environment [12]. This has allowed us to analyze the behavior and the operation of the network before the practical implementation. One of the main features to consider in the real-time simulators is the configuration of sampling time, which is constantly developed during the simulation process- Also, it has the possibility of including real devices in simulations [18].

4) Co-simulation interface: In general, an intelligent network is considered a complex network where the electrical energy systems and communication systems are independent; however, combining these systems, a co-simulation platform can be developed to establish realistic studies to understand its operation [19]. This co-simulation interface allows the construction of large-scale networks. The reproduction of recorded data allows obtaining instantaneous results of the behavior of the network, such as its physical state, which provides a deep understanding of the system [20]. This can be done using an available, cost-effective, and easily accessible communication medium such as the Internet or a VPN.

B. Development methodology.

The present study is based on the methodology presented in figure 1. It summarizes the steps to be followed during the development of the research in order to obtain the desired co-simulation model.

1. Description of the case study.
2. Simulation and modeling in CYMDIST.
3. Design and coupling in RT-LAB.
4. Configuration of the interface parameters.
5. Configuration of the input and output pins.
6. Compilation of the model.
7. Uploading the model.
8. Execution of the simulation.

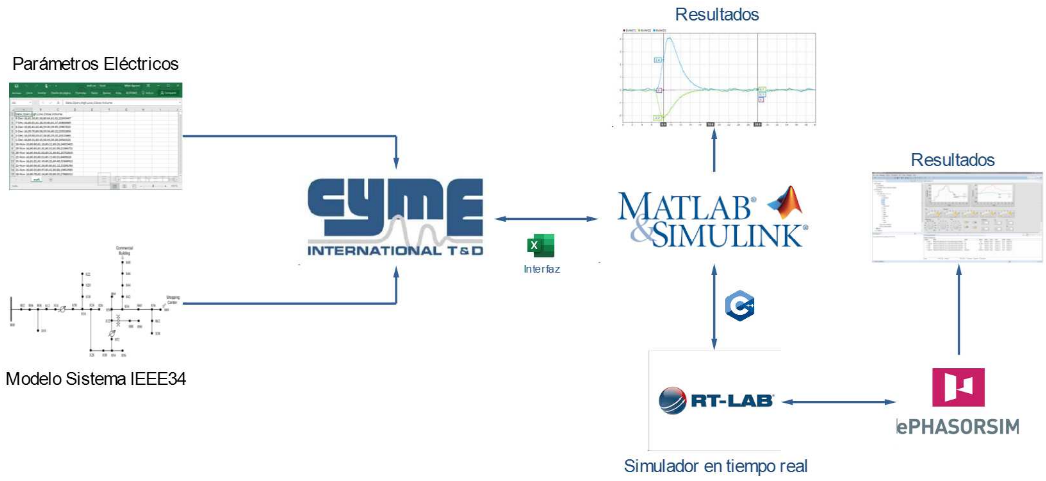

Fig. 1 Developed method for this research.

1) Case study: The methodology that will be applied is based on the models developed by the IEEE Sub-Committee on Distribution Analysis [21], [22]. This model has made available numerous test cases that can be used and analyzed by software developers. It also helps in the application and validation of new studies which engineers in the field have applied. The present study starts from the IEEE 34 radial type test system, presenting a real feeder in Arizona [23]. This original system has 60Hz, 24.9 kV, and 12 MV values, and it has a wide variety of components and diverse single and three-phase topological characteristics typical of a rural distribution network [24]. It also has several fixed and distributed loads connected to the main substation; the load is modeled with constant current, impedance, and power values [25]. The one-line diagram is shown in figure 2.

2) Simulation and modeling in CYMDIST. Due to its strong modeling and programming options, calculation, and versatility capabilities [11], the IEEE 34 test system simulation was done on the CYMDIST platform. The model is developed by using the electrical components of the CYME platform: power supplies, load bars, transformers, loads, distribution lines, capacitors, and voltage regulators [22] with the exposed values described in the IEEE34 base model [21], [22]. The composition of the diagram is adapted to the original. It can be observed in figure 3.

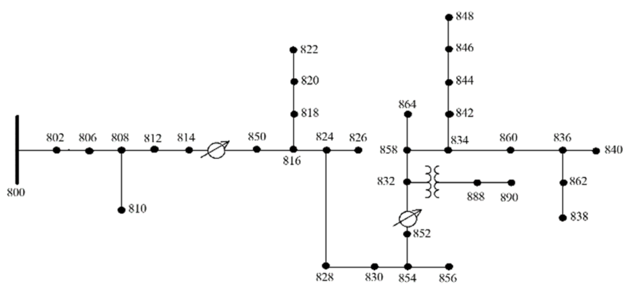

Fig. 2 IEEE34 radical system.

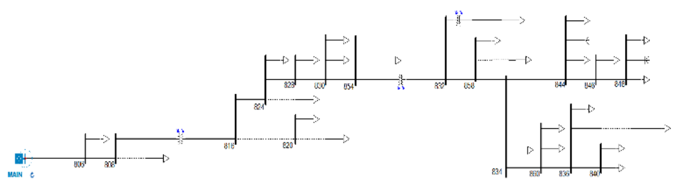

Fig. 3 IEEE34 radial system developed in CYMDIST.

3) Design and coupling in RT-LAB: As previously mentioned, the flexibility and scalability of RT-LAB allow performing multiple control functions under the MATLAB/SIMULINK programming. This allows the editing of the models in block diagrams which will be used later in the real-time simulator and to generate a C code needed for the execution in one or more processors [26]. Currently, there are few technically reliable simulators available. These allow the integration between software and hardware [27]. Therefore, the present research project is based on the development of the RT-LAB real-time simulator acquired by the Catholic University of Cuenca to develop a model that integrates the CYMDIST software package. In order to build the model, it is necessary to follow four (4) steps exactly as described in the user's manual to guarantee its correct functioning [17]. The first step is to design the precise model using MATLAB/SIMULINK, by implementing the necessary configurations and adjustments of the ePHASORsim tool for its correct performance, then RT-LAB is in charge of grouping them in two (2) subsystems and transforming them into a real-time model. This process is called compilation, and it is developed in multiple cores so that the user can interact with the acquired results.

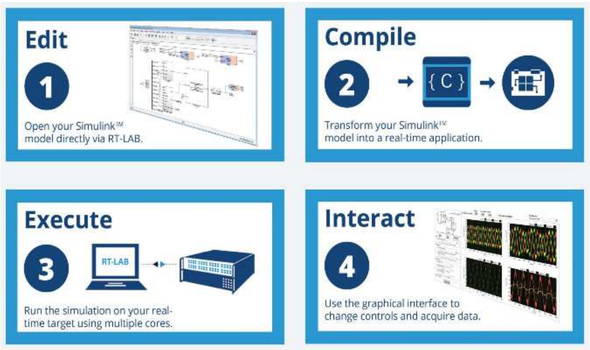

Fig. 4 Design and adaptation process in the RT-LAB [17].

For the construction of the two subsystems of the three existing ones [28], have been grouped; it is important to mention that each subsystem must contain its characteristic prefix for the RT-LAB to manage them; given that each subsystem is calculated in a different calculation mode in the OPAL-RT hardware.

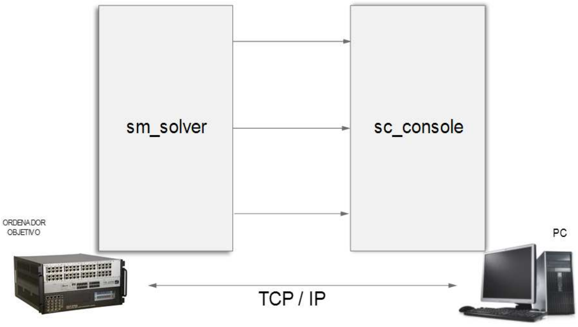

Fig. 5 Basic communication connection between the subsystems [28].

The "sm_master" or "sm_solver" block corresponds to the main subsystem, which includes all the model's computational elements and mathematical operations. It also includes the input and output (I/O) blocks and the generator signal; while the second subsystem belongs to the "sc_console," which includes the user interface among these screens, switches, and controls. Unlike the main subsystems (sm), it does not have signal generators or mathematical operations; however, these subsystems are the only ones that will be available during the execution of the simulation and will allow interaction with the system.

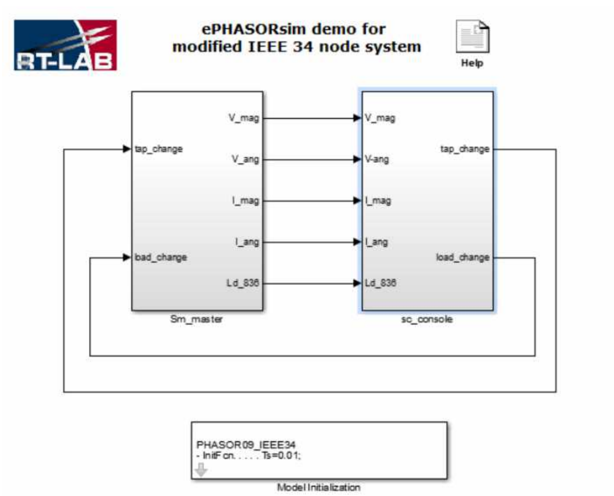

Fig. 6 General model developed in the RT-LAB.

The configuration of the communication interface parameters requires executing the ePHASORsim model of the IEEE34 radial network. It is necessary to select the input format and the configurations within the "solver" block. For reaching data linking and the model's functionality, the configuration of four fields or specific tabs is required. These tabs are: "Network data, Library, Simulation settings, and Scripting". This format requires an Excel input file with the configuration pin and a CYME file of the model. It is not necessary to import the files but to insert the names in the fields; if necessary, give a name to the load flow report box for the optional import of an Excel file with the calculations obtained from CYME for a dynamic initialization. The established configuration for the simulation is shown in figure 7.

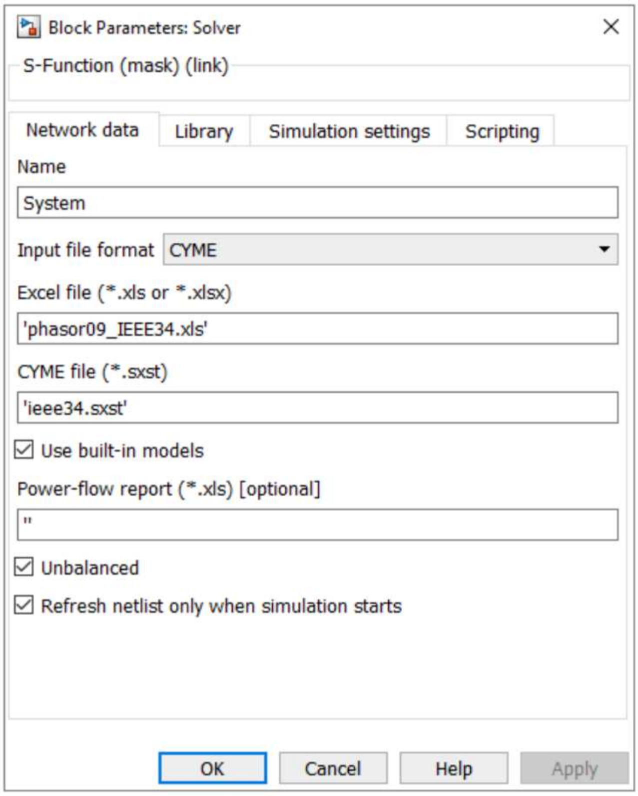

Fig. 7 Configuration of the parameters of the "Network data" tab.

Another important parameter regarding the settings is the tab "Simulation settings" used for the configuration of the dynamic simulation and power flow solvers. In the execution mode, there are three (3) options available. For this particular case, the power flow and dynamic simulation options are used. Their function is to initialize dynamic components based on voltage and power values calculated by the power flows. It is also necessary to establish the enabled parameters such as the number of interactions allowed for Newton Rapson with a constant value of 100 and the tolerance of the mismatch equations; the manual recommends 1E-8. It is also necessary to check the option to export the power flow report, just for Windows; the objective is to export different output files with extension .xls. These files have different information on the number of components existing in the network; reports on the types of busbars; power values, and reactive power limit of the machines; and a file that unifies all the previous files.

Finally, the number of partitions must be configured because the ePHASORsim model automatically divides the admittance matrix diagonally with a block edge for parallel simulation. This value depends on varies according to the topology power system.

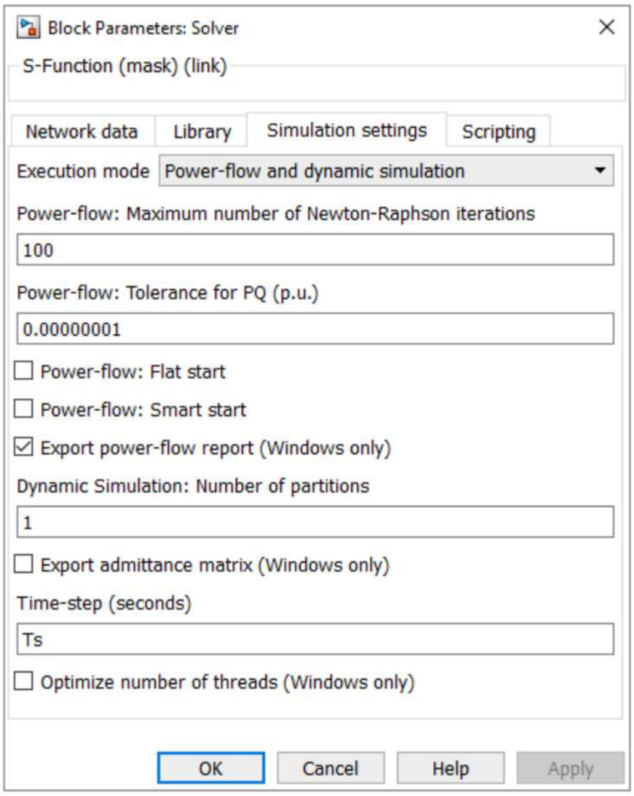

Fig. 8 Configuration of the parameters of the "Simulation settings" tab.

4) Input and output pin configuration: According to the user's manual; there are two types of pins available: incoming and outgoing. These pins are keywords configured by the user for the measurement of currents and voltages of a system. It should be noted that current measurements are positive except for voltage sources and synchronous machines where the current is in the opposite direction, although it is positive. The operating commands of the incoming pin are sent to the system, while with the outgoing pins, probes are specified to measure or monitor the state of the power system.

outgoing	V_abs	bus_810_b/Vmag	bus_822_a/Vmag
outgoing	V_ang	bus_810_b/Vang	bus_822_a/Vang
outgoing	I_abs	line_config_300_802_806/ImagFrom1	line_config_300_802_806/ImagFrom2
outgoing	I_ang	line_config_300_802_806/IangFrom1	line_config_300_802_806/IangFrom2
outgoing	Load_836	load_135/P1	load_135/Q1
incoming	Trans_tap	xf2w_832_888/tap_a	xf2w_832_888/tap_b
incoming	Load_836	load_135/P1	load_135/Q1

Fig. 9 Example of the configuration of the ePHASORsim pins.

III. Results and Discussion

The research is oriented towards studying the power flows of the IEEE34 model, which is simulated in real-time through a co-simulation interface between the CYMDIST and the RT-LAB platforms. This analysis validates and allows the observation of results by applying two test scenarios based on modifying input and output pins to the ePHASORsim model. The first one constitutes the Base Case 1 or test case used for the development of this research. This case involves modifying the initial load of the 836-bus for 6 seconds and verifying the output signals, while for the second scenario, named Base Case 2, changes in the input and output pins are applied. The variation of the initial load of the 858-bus extending the period to 3600 seconds is also changed. The goal is to evaluate different buses and lines that the model has to show the results of magnitude and angle both in voltages and in currents. Besides, the evaluation of the simulator is proposed. For this purpose, a simulation is to be executed during a 24-hour test period to compare the results and verify them. A comparison between the initial results and the final ones will be obtained. Finally, once the tests have been established, identifying the advantages of both the RT-LAB software and the CIMDIST software will be determined; the impact, feasibility, and profitability of each one will be established. There will be a brief description of the designed interface and its subsequent application in more complex electrical models.

A. Base Case 1

The methodology that was applied for the analysis of this case was focused on sending a command that modifies the active and reactive powers of the initial load of the 836-bus to the simulator after six (6) seconds. It aims to monitor the changes in the state in the different elements that constitute the radial IEEE34 system. The signals of active and reactive power can be observed in the following figures. These show the voltages and the powers of the different nodes or bars.

1) Instantaneous simulation signals:

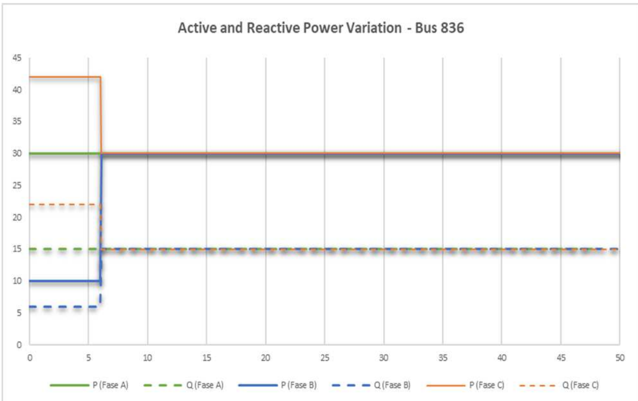

Fig. 10 Profile of the established charge for the 836 bus.

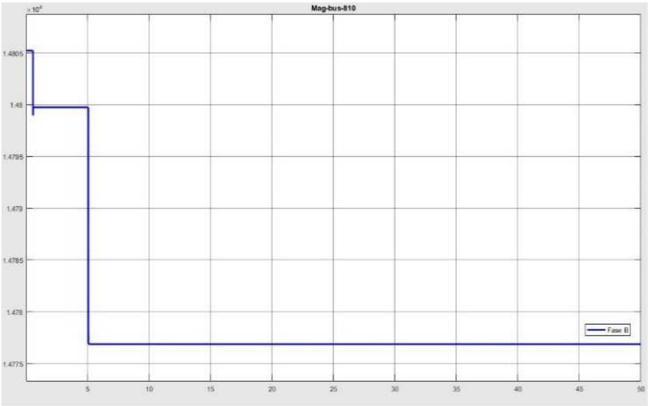

Fig. 11 Magnitude of the node-voltage 810.

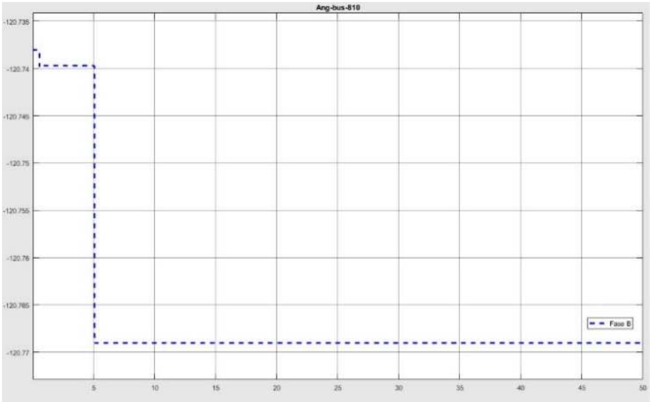

Fig. 12 Angle of the 810 node-voltage.

2) *Simulation signals 24 hours a day.*

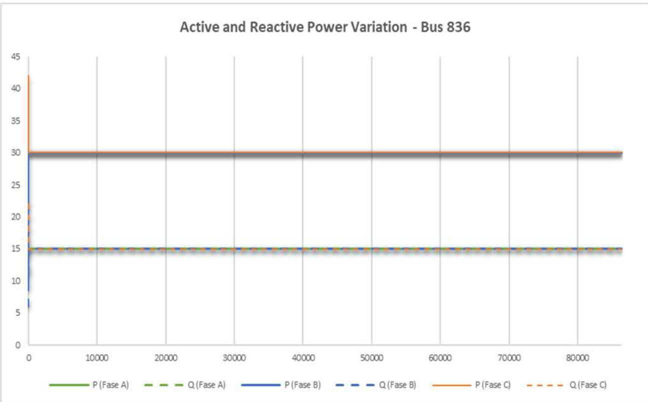

Fig. 13 Profile of the established charge for the 836 bus, 24-hour period.

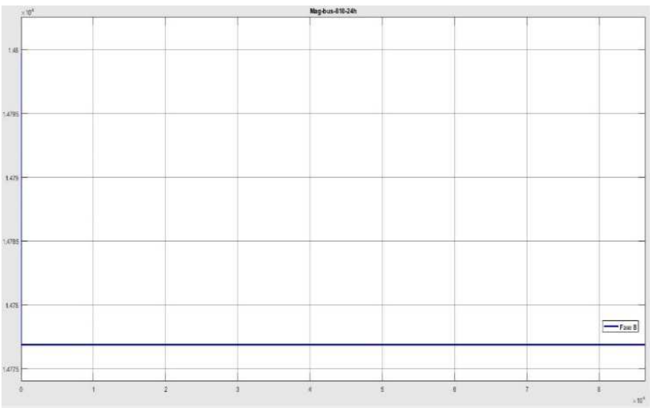

Fig. 14 Magnitude of the node-voltage 810, 24-hour period.

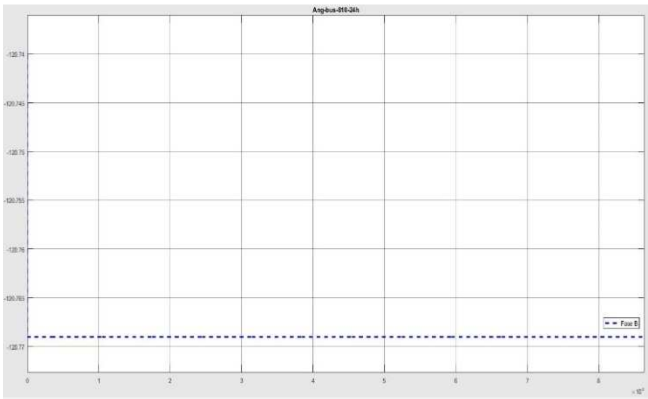

Fig. 15 Angle of the node-voltage 810, 24-hour period.

B. *Base case 2*

One of the objectives of this chapter is to include the modification of the base interface to incorporate new signals. These will be for both voltage and current, thus ensuring the interface's optimal functioning between the two simulators. In the following figures, the elements part of this simulation is shown. It should be noted that both the structure and parameters were established not drastically to modify the proposed model from the beginning. Unlike the previous case, the 858-bus was taken as a reference, and the time of the input signal was modified by a time of 3600 seconds.

1) *Instantaneous simulation signals:*

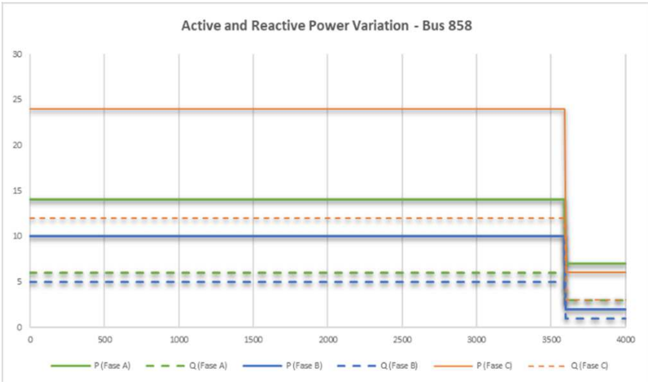

Fig. 16 Profile of the established charge for the 858 bus.

For this second analysis case, it was necessary to check the obtained results for the 832_858 line.

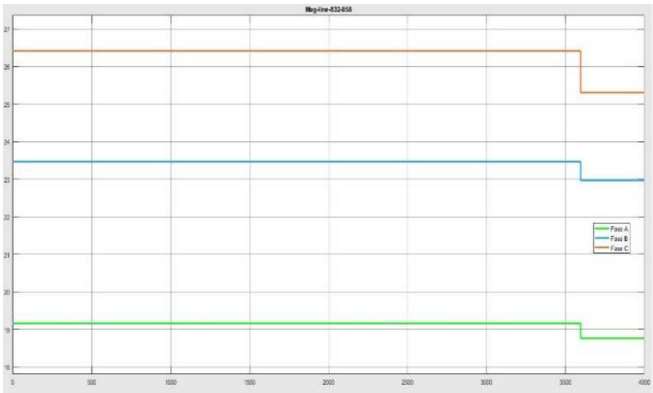

Fig. 17 Magnitude of the current 832_858 line.

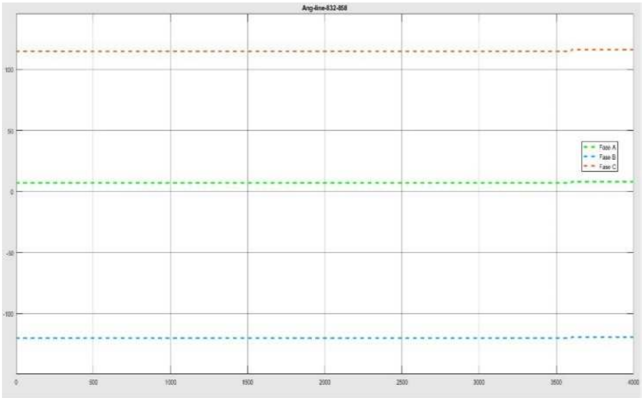

Fig. 18 Angle of the current 832_858 line.

2) Simulation signals 24 hours a day.

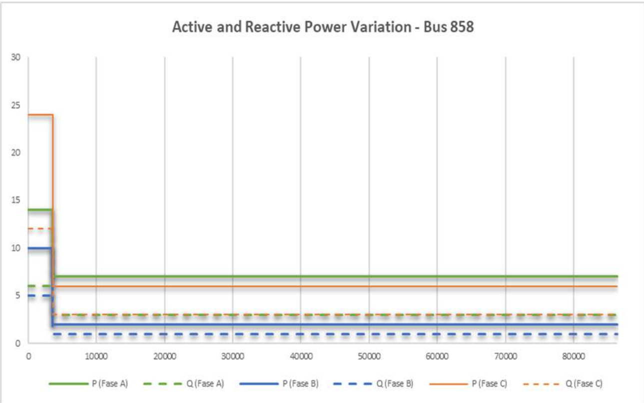

Fig. 19 Profile of the established charge for the 858 bus, 24-hour period.

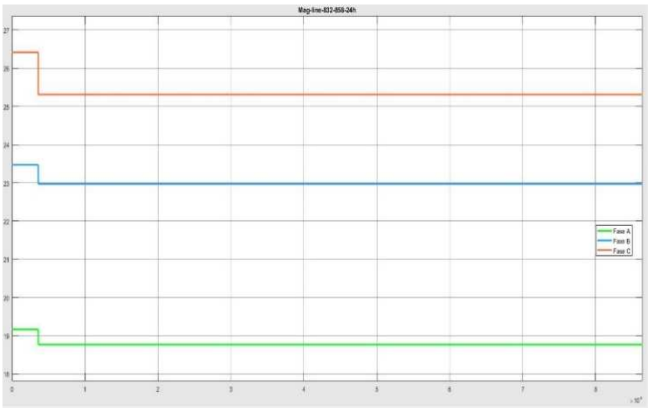

Fig. 20 Magnitude of the current 832_858 line, 24-hour period

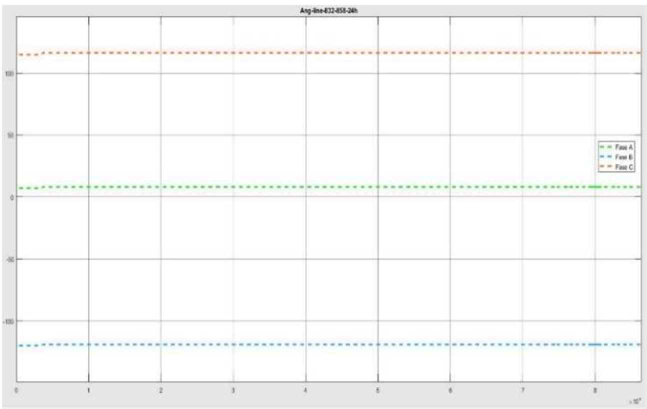

Fig. 21 Angle of the current 832_858 line, 24-hour period.

According to the configuration parameters established for the two analysis cases, a correct operation of the interface can be observed. This allows the observation of the resulting signals individually for the single-phase case and the three-phase cases. Also, the input power profiles for base case 1 and base case 2 are identified, directly affecting the magnitude and angle values for both voltage and current.

In the first case, there is a reduction in the magnitude values from 14.80 kV to 14.77 kV, while in the angles, the variation goes from -120.73° to -120. 77° for the single-phase node 810 connected in phase B. The analyzed values, in this case, are concerning a three-phase network section called 832_858. It was observed that phase C had the greatest change from 26.4 A to 25.2 A. On the other hand, the angles present a similar increase for its three phases. It also presents a similarity with the short-duration cases, which guarantees and validates the results obtained in this research.

IV. Conclusions

It was shown that the precision between the model executed in CYMDIST and the model executed in RT-LAB is 100%. The results are reliable when the real-time component is added to the model; the current, voltage, and power values are accurate in both cases, both in the instantaneous and daily simulations. The main advantage of the interface developed during this research is based mainly on the ability to use models previously built by the Utilities around the world in the CYMDIST platform. On these existing electrical networks with the potential of RT LAB, it is possible to add the simulation component in real-time. The next step to complement the study carried out consists of simulations involving load profiles, sources of generation, and the application of elements such as photovoltaic panels or wind turbines to observe the behavior and condition of these elements to the system.

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