Real-Time Hybrid Simulator of the Distribution Network for Smart Grid Applications

Simulador Híbrido en Tiempo Real de la Red de Distribución para Aplicaciones de Redes Inteligentes

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ABSTRACT

Free power markets and strong integration of distributed generation change the operation and control of distribution grids significantly. Traditional networks must evolve to the concept of "Smart Grid". These new grids can manage new services in a clever manner, keeping power quality, safety edges and optimal costs. In order to probe new smart grids concepts is necessary to model the system, its characteristics, stability and different topologies. This paper presents a methodology for the purpose of modeling low voltage networks in a Matlab-Simulink® environment, using a Real Time Simulator. Additionally, authors use real information to validate the showed methodology.

Keywords: Smart Grids, Real Time simulations, PHIL, LV modeling.

RESUMEN

Los mercados liberalizados y la fuerte integración de generación distribuida cambian significativamente la operación y control de las redes de distribución. Las Redes tradicionales deben evolucionar al concepto de "Smart Grid". Estas nuevas redes pueden gestionar nuevos servicios de forma inteligente, manteniendo la calidad de energía, los márgenes de seguridad y costos óptimos. Con el fin de investigar los nuevos conceptos de redes inteligentes es necesario modelar el sistema, sus características, la estabilidad y diferentes topologías. Este trabajo presenta una metodología con el propósito de modelar redes de baja tensión en un entorno Matlab-Simulink, utilizando un simulador de Tiempo Real. Además, los autores utilizan datos reales para validar la metodología.

Palabras clave: Redes Inteligentes, Simulaciones en Tiempo Real, PHIL, Modelado en Baja tensión

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1. Introduction

Transformation of traditional power grids in to smart grids, take place initially in distribution networks; since distributed generation, equipment with control and coordination ability is connected in low voltage networks.

In order to understand and manage these challenges Utilities Companies (UC) adopts two possible approaches: *i)* traditional one, which is to strengthen the power grid, build substations and increase generation and transport capacity, and, *ii)* implement a smart grid (SM).

Historically end users has been passive with patterns unpredictable and non-scheduled consumption, with the arrival of the SM, these users could manage their consumption based on hourly rates interacting with UC through smart metering and selling excess energy from electric vehicles, storage and distributed generation; users will now prosumer (producer + consumer)[1].

Denmark is pioneer in the development of smart grids; in its report "Smart Grids in Denmark" [2], it concludes that an Smart Grid is the most effective strategy to manage electric system evolution and prepare it to deal future challenges.

A smart grid can be defined as: "….an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both functions to efficiently deliver sustainable, economic and safe power supply" [3].

Smart grid includes users (most of them connected at low voltage) it is necessary to undertake the modeling of the low voltage network, in order to have a model in which to test the smart grid concepts.

2. Modeling of electric network

According [4] the first step involves modelling the different elements of the grid such as lines, wires, transformers, loads and unconventional elements like photovoltaic panels, smart buildings, electric vehicles and domestic wind turbines. Also, parameters and blocks used into Matlab-Simulink are described in [4]. Once the network is modelled, it is possible to analyse it in order to test new strategies and to assess the network impact considering new services.

2.1. Modelled network description

Proposed network modelling in medium and low voltage is contemplated in "Ecuador Smart Grids Project", driven by the Ecuadorian Ministry of Energy; which seeks to having the detailed electrical network in order to implement Smart Grid applications and evaluate the impact of new technologies; Table I shows details.

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VIII Simposio Internacional sobre Calidad de la Energía Eléctrica 2015 SICEL
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TABLE I
DESCRIPTION OF ONE SUBSTATION WITH ITS TRANSFORMER

Substation	Trafo	Power (KVA)	Customers
SE1	Tr1	100	90
SE2	Tr2	100	110
SE3	Tr3	75	55
SE4	Tr4	50	40

Low voltage network is on 220V phase-phase, 3F4C configuration, the whole project include three feeders in four cities. Substation were chosen due: *i)* its strong relation between them (there are possibility of reconfiguration), *ii)* large number of feeders in low voltage and, *iv)* high concentration of distributed generation and smart meters.

2.2. Scenarios

Main advantage of real time simulations is the possibility to perform scenarios reducing computation effort [5]. For testing the real time simulator, seven scenarios were defined:

Scenario S1

Unbalanced network topology, where the main load is concentrated on the phase C with no reactive power,

Scenario S2 y S3

These scenarios have the same chargeability that S1 but have the highest consumption in phases A and B respectively

Scenario S4

Chargeability is only 16% and load is located in phase A

Scenario S5

Chargeability is 32% and load is also located in phase A

Scenario S6

It has 100% use of the transformer; moreover, network is balanced

Scenario S7

It considers loads with reactive power in order to evaluate the model's accuracy.

S1, S2 and S3 cases allows to validate mutual line parameters, S6 and S7 could be useful to evaluate the best phase connection for DGs [6] and the other ones let to evaluate the model in real and different situations that could happen in a distribution network. With the intention to compare results, authors use an algorithm developed in General Algebraic Modeling System (GAMS) by [7], which is ideal for modeling linear, nonlinear and mixed integer optimization problems. It is useful with large and complex problems. Therefore, GAMS could be tailored easily to optimize load flow, where restrictions are the equations of power flow and the objective function is to maintain voltage levels within acceptable limits

3. Real time simulator

Several realistic online simulations are necessary to build a common understanding of functions of a SG [8]. These real-time simulations should include all participants playing reliability roles as coordinators, transmission and distribution network operators, power plants operators, aggregators and substations operators. These simulations seek to identify the impact on the grid of a high penetration level of distributed generation [9] and electric vehicles. In addition, they serve to test control strategies, which will be implemented in real life. A hybrid simulator has two parts[3]: a digital part, where the whole network in medium and low voltage is modelled, also the SCADA communication, and an analogic one with the interface to communicate field devices (charging stations for electric vehicles, inverters, and so on).

3.1 HIL and PHIL

Hybrid simulators usually are divided into 2 groups: *i)* Hardware in the Loop (HIL) and *ii)* Power Hardware in the Loop [4]. PHIL Simulator unlike HIL integrates a power amplifier between analogic and digital part, whereas HIL exchanged with digital part only control and monitoring signals. As presented in Fig. 1.

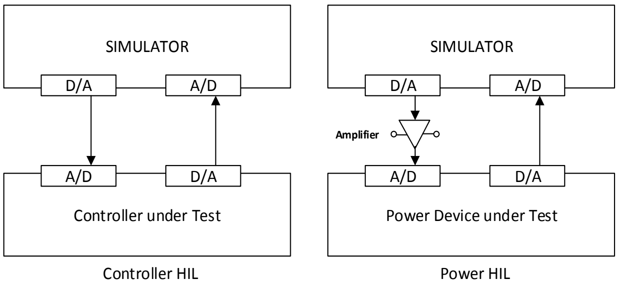


Figure 1. Hybrid HIL simulators and PHIL [10]

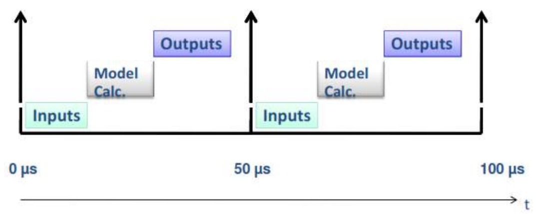
RT-LAB is a Simulink fully integrated software; it was selected inasmuch as allows incorporating real time measures into simulations using OPAL RT cards for analogic and digital inputs/outputs.

3.2 Real Time feature

Flexibility and scalability of RT-LAB allows us any simulation for control applications in order to test advanced distribution functions (reconfiguration, cut / off, peak shift, etc.) on the network. Those simulations can integrate distributed generators and new services connecting real devices in order to assess their impact on the real grid or even micro grids.[11]. Main advantages of RT-LAB are:

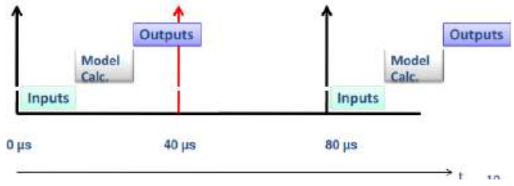
- ✓ Possibility to include real devices in simulations
- ✓ Real time simulations
- ✓ Low cost
- ✓ Increased functionality for testing parameters or impacts
- ✓ Automatic scripts to run 24h / 7d simulations

A key point in real time simulations is to sampling time setting "Ts", which is constant during simulation, real-time status is lost if: *i)* Ts is small enough, *ii)* input signals are not read, *iii)* model calculations are not computed, and, *iv)* model outputs are not updated. Fig. 2 presents an error on Ts assignment.



[3] OPAL RT (2013) Module 1: Real-Time System Fundamentals

a)



b)

Figure 2 Sampling time "Ts" a) properly selected 50us, b) selected wrongly 40us

4. Results

Figure 3 shows a section of low-voltage network modelled, "Three Phase Dynamic Load" blocks are fed with real demand curves following a random approach [12] for their selection from the available database.

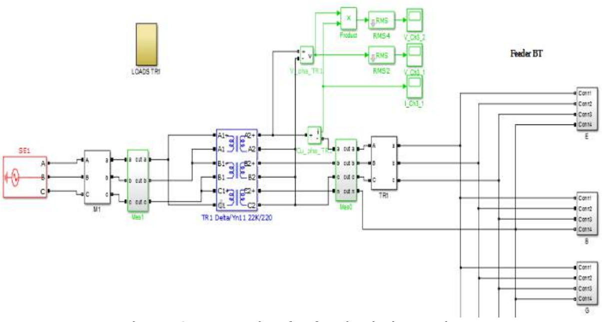


Figure 3. Example of a feeder in low voltage

A summary of the comparative analysis of results between the two models, Current and GAMS is presented in the table 2 and 3.

TABLE 2
IMBALANCE IN THE FARTHEST NODE (%)

	GAMS	Current Model
Scenario 1	0.4757	0.4793
Scenario 2	0.4725	0.4793
Scenario 3	0.4725	0.4793
Scenario 4	1.5041	1.5421
Scenario 5	3.2459	3.2881
Scenario 6	0.0000	0.0010
Scenario 7	0.0000	0.0000

Table 2 shows that imbalance percentage in farthest node is almost the same. While table 3 shows that active power values are very similar, there is little difference in reactive power results; this difference arises because Current model considers capacitance of the lines, but GAMS model does not. Voltages and currents were compared node-by-node with difference lower than 1%. Results of scenario 1, 4 and 7, wherein G is GAMS and C is Current model.

TABLE 3
RESULTS OF THE MAIN SCENARIOS

	Scenario 1		Scenario 2		Scenario 3	
	G	C	G	C	G	C
P (kW)	492.8	494.4	168	169.5	492.7	494.4
Q (kVAr)	15.7	16.5	6.3	6.5	113.3	114.4
S (KVA)	493.1	494.6	168.1	169.6	505.6	507.4

Once validated both models, real curves for active and reactive power with 144 points (sampling every 10 min) are assigned. Customers per phase and per node were allocated. A random curves assignment was use. Table 4 shows curves distribution.

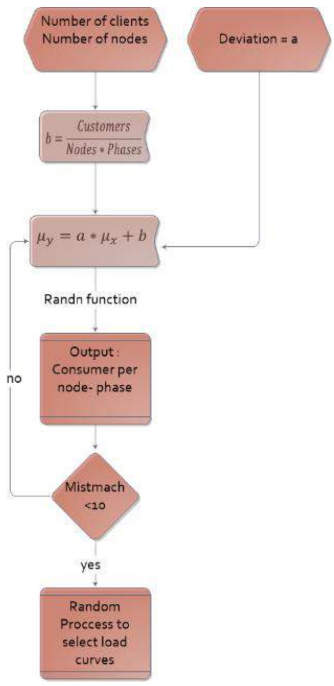


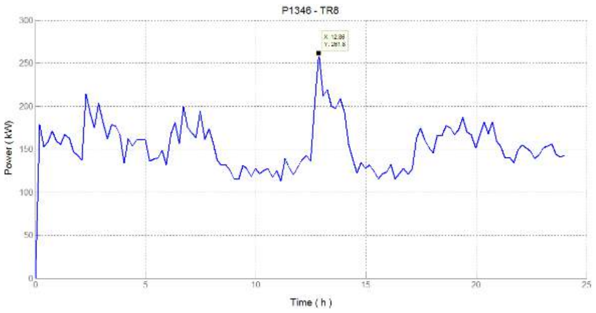
Figure 4. Random Approach Methodology [4]

Fig. 4 shows random load profile assignment methodology, it was proposed in [4]. As inputs, we need client and node number. Then the script performs calculations to select curves and client number in order to assign it automatically.

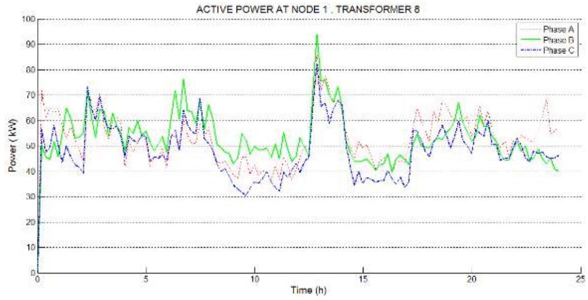
Multiple simulations were performed in order to evaluate: *i)* transformers load, *ii)* relative lines load, *iii)* voltage profiles in nodes. Figure 5a presents a daily load curve in the transformer; it is close to measured curves. Figure 5b shows a more detailed analysis of the same transformer where imbalance generated by variability of end users per node is considered

TABLE 4
RESULTS OF RANDOM APPROACH FOR CLIENT NUMBER AND DEMAND CURVES SELECTION.

Node	*Phase*	*Consumer Number*	*Curve Names*
10	*A*	*1*	*1,19,12,60*
	B	*3*	*18,11*
	C	*4*	*15,5*

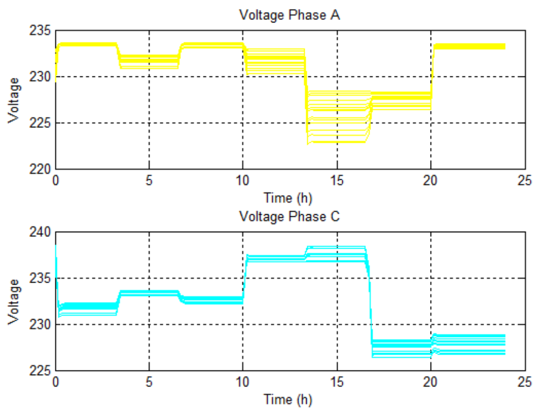


a)



b)

Figure 5. a) Power in the transformer b) imbalance between phases in the transformer [13]



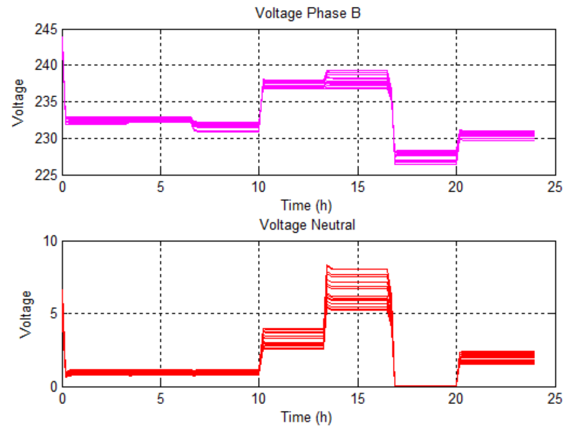


Figure 6. Voltage at all the nodes

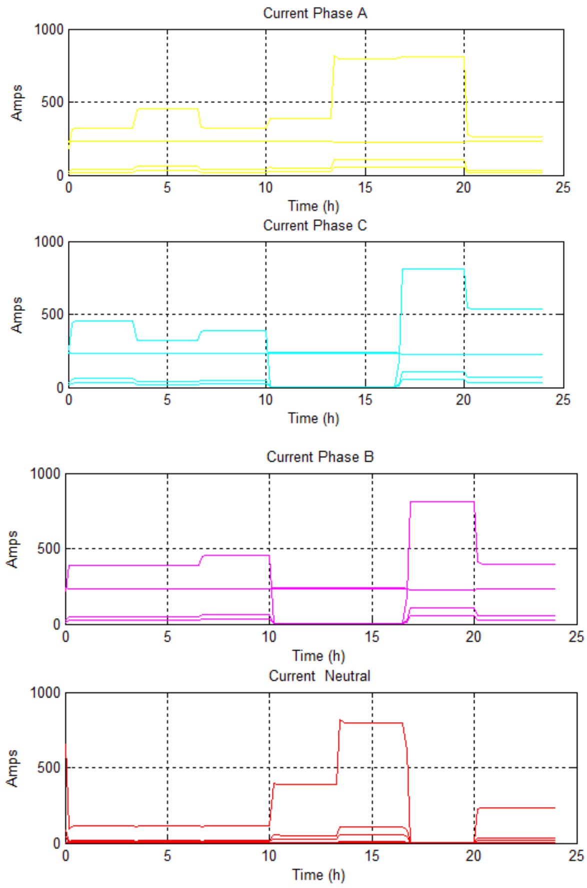


Figure 7. Current at all the nodes

Conclusions

Real-time simulations with PHIL simulators allow analyzing various scenarios with reduced optimizing costs time and effort; also offer the possibility of connecting real devices in the simulation. Different models in low voltage have been implemented in different environments like Simulink and GAMS and as results are similar, they show that this methodology is reliable. Random approach for selection of curve is adequate in order to recreate the particularity of electrical networks. Modelling methodology of low voltage networks modelling applies innovative concepts and provides procedures for obtaining reliable, contrasted and very useful results for a future application of advanced functions in distribution. When simulation results are compared with measured values, they show a difference of less than 2%.

Using real time simulation is possible to get accurate information such as voltage profiles, line current, and power in peak hours, phase imbalance, end user profile, and current in the power transformer and so on. All this information is necessary to understand the network state in both present and future scenarios.

Hence, the simulations help us to build a new vision based in smart grids which consider new services and effective strategies to face the challenges ahead for the distribution networks.

Once modelled and tested effectively the network, it possible to add communication to smart meters using IEC61850, as well as to implement a direct communication with a Virtual Power Plant in order to receive set point for DGs.

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VIII Simposio Internacional sobre Calidad de la Energía Eléctrica SICEL 2015