A COMBINED PLANNING AND SIMULATION APPROACH FOR SMART GRID RELIABILITY ANALYSIS

Diogo BALDISSIN
Sinapsis Inovação em Energia – Brazil
diogo.baldissin@sinapsisenergia.com

Gustavo HIMENO
Sinapsis Inovação em Energia – Brazil
gustavo.himeno@sinapsisenergia.com

Henrique KAGAN
Sinapsis Inovação em Energia – Brazil
henrique.kagan@sinapsisenergia.com

Gustavo TRAVASSOS
Neoenergia – Brazil
gtravassos@neoenergia.com

Ricardo PADILHA
Neoenergia – Brazil
rpadilha@neoenergia.com

Marcelo PELEGRINI
Sinapsis Inovação em Energia – Brazil
marcelo.pelegrini@sinapsisenergia.com

Daniel DUARTE
Sinapsis Inovação em Energia – Brazil
daniel.duarte@sinapsisenergia.com

ABSTRACT

Today, considering the raise of electricity companies seeking for a more reliable, economical and sustainable electricity grid, the transition to the Smart Grid model seems inevitable. The associated deployment challenges and costs drive the research community and electricity companies to search for methods to assess the performance of these innovative solutions. Simulation tools represent feasible candidates to assess this problem. However, Smart Grid multidisciplinary nature demands a more complex approach to integrate both electricity grid and communication networks characteristics in a co-simulation environment.

In this paper, we propose a new approach for combined planning of distribution automation solutions and telecommunications networks. The proposed methodology seeks a solution that optimizes communication project and the reliability of the grid.

INTRODUCTION

Planning Smart Grids is a multidisciplinary challenge faced by the next generation utilities. Companies seek to create approaches for optimizing cost-effective solutions with communication networks that meets Smart Grid features requirements [1], at the same time that the sector business model continually changes to accommodate new technologies.

Mobile telecommunications services are an option to address the communications needs of Smart Grid. Although, these services frequently lack performance and coverage in Brazil [2]. While Brazilian Government has not yet developed a national policy for Smart Grid adoption, local utilities started testing and developing their own telecommunications networks to meet its Smart Grids' requirements [3], resulting in additional strategies and resources for planning.

Traditionally, utilities have rigorous separation lines between functions. In general, departments work as isolated silos with specific responsibilities [4]. Therefore, addressing grid and telecommunications network planning alignment demands more than technical solutions, but changes in methodologies and utilities culture.

Most of the works related to combined simulations in electric networks are related to applications with high sensitivity to communication delay, such as the use of batteries to mitigate the impacts of distributed generation oscillations [5,6] and protection systems [7, 8] that have high sensitivity in terms of time performance. These problems require the calculation of latency. This way, most of the works treat a problem of synchronization between systems.

In 2013, Celli et al. [9] developed a new tool for the reliability assessment of distribution network based on a Pseudo-Sequential Monte Carlo simulation. This method considers renewable generation resources and communication infrastructure. This work was leaded by the concepts of Active Distribution Networks (ADNs), defined by CIGRE Working Group (WG) C6.11 as systems in place to control a combination of distributed energy resources (DERs), managed by Distribution Systems Operators (DSOs), in which DERs take some degree of responsibility [10].

In this paper, we propose a new approach for combined planning of distribution automation solutions and telecommunications networks. The proposed methodology seeks a solution that optimizes project costs and reliability of the grid.

In order to do that, we integrated a grid reliability simulator with a radiofrequency engineering tool to improve accuracy of Network Reliability Index calculation considering a grid with Distribution Automation features.

METHODOLOGY

The Methodology we propose in this paper exceeds the simulation approach, resulting in a combined planning process for distribution automation solutions and telecommunications networks. This process includes the use of a grid simulation tool and a radiofrequency engineering software, files exchange between computational tools, project design and interaction between utilities departments.

Combined Simulation Approach

Combined simulation or co-simulation describes an approach that combines existing specialized simulators

[11] to better comprehend an environment. In this project, the simulators consist of the commercial Radiofrequency Engineering Software CelPlanner and the commercial power system simulator SINAPgrid. These computational tools are specialized in planning activities. Therefore, the proposed combined simulation approach results in a combined planning methodology. Figure 1 summarizes the interactions between simulators.

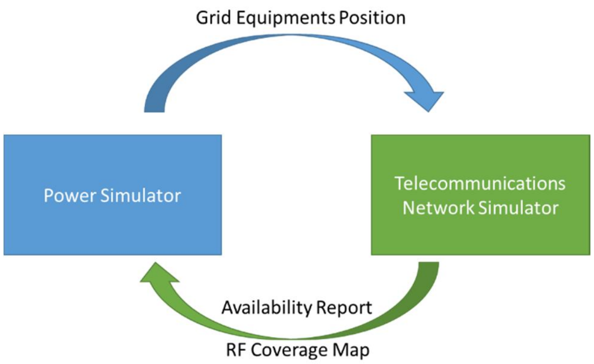

Figure 1 – Combined Simulation Interactions

The co-simulation occurs in a static manner, in which each simulator executes its functions and then allows exporting data to the other. Since, different departments develop each project. The tools are manually integrated.
We propose six interactions between the simulators:

a. SINAPgrid exports georeferenced reclosers positions to CelPlanner;
b. CelPlanner imports reclosers positions as telecommunications subscribers;
c. CelPlanner exports estimated RF coverage for the communications network;
d. CelPlanner exports estimated Availability for each recloser;
e. SINAPgrid imports RF coverage and displays it over electric grid;
f. SINAPgrid imports availability for each recloser.

Combined Planning and Simulation Approaches

We divided the combined planning and simulation approach into a process that includes the following steps:

Electric Grid Representation

We start by representing the georeferenced grid in SINAPgrid. This simulator is responsible for grid reliability analysis and reclosers allocation. Figure 2 presents a grid visualization on the simulator.

Calculate Minimum System Reliability Index

In order to establish the benefit range for this project, we simulate the best and worst cases scenarios. The worst-case scenario represents the grid configuration before automatic reclosers allocation. Therefore, considering no pre-existing automatic reclosers, the duration time to operate a switch in this grid is called t_{manual}.

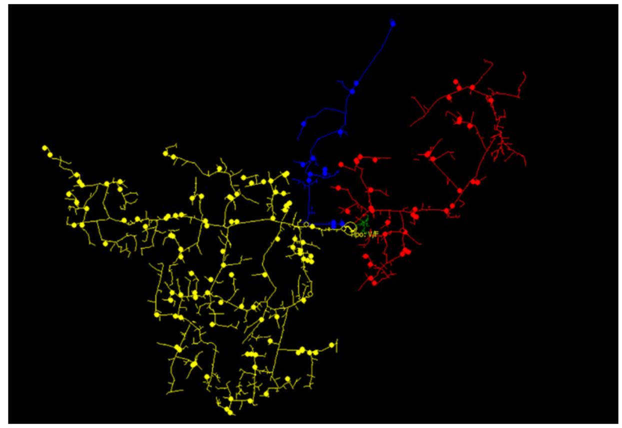

Figure 2 – Electric Grid Representation

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Allocate Automatic Reclosers and Calculate Maximum System Reliability Index

On the other hand, the maximum benefit is obtained after the automatic reclosers allocation, whose methodology is presented in this paper, considering a telecommunication network which is available 100% of time, resulting in an availability equal to one. The duration time to operate an automatic switch (t_{op}) in this grid is t_{auto}.

Export Recloser Positions

After estimating the minimum and maximum reliability benefits of the recloser allocation, we export these positions to the telecommunications simulator. We take advantage of this information to design the telecommunication network.. Figure 3 shows the software interface. The highlighted line represents an equipment information.

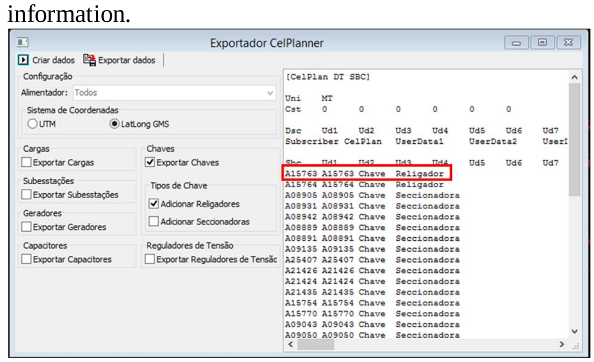

Figure 3 – Exporting Recloser Positions

Design and Simulate RF Communications Network

Using CelPlanner, we import the recloser position to use as a reference for design the wireless communication network. This is the strategy for creating the scenario where the utility intends to own the telecommunications infrastructure. Figure 4 shows grid equipments visualized over the topographic map on CelPlanner.

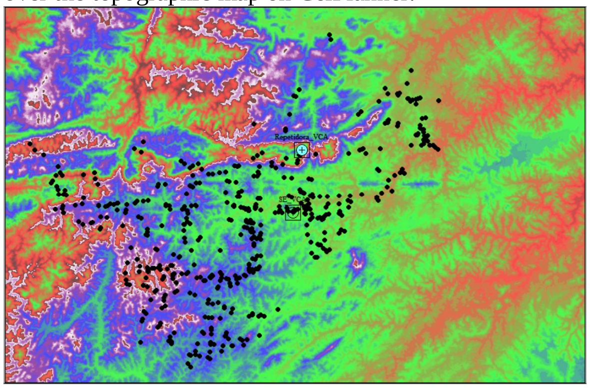

Figure 4 – CelPlanner Visualisation

With this information, a Network Engineering Department performs a RF Planning trying to meet most of the Smart Grid requirements.

The RF Planning results in an estimated coverage with sign levels for a pre-defined pixel size in the map. Based on coverage data, radio configuration for the reclosers, available tile margin for receivers, topographic map, morphology map and climate conditions for region, CelPlanner is able to estimated service availability for each equipment in the network. The software applies ITU-R P.530-15 recommendation methodology [12].

Export Availability and Coverage

We generate the coverage map and an availability report that we can import in SINAPgrid to assist in developing a better distribution automation configuration for the system. The availability report consists of the equipment list with its respective estimated telecommunication service availability. The availability of communication service measures how much time the service is available for users in a year and it is a probability. Figure 5 shows the availability report.

Define and Build Technology Scenarios

Although telecommunications network should work to meet requirements for users, it suffers from several external environmental impacts and equipment reliability. In practice, neither the minimum nor the maximum Network Reliability Index represents the final estimative to the project. We propose to create different technologies scenarios with its respective availability to allow project comparison. We can create scenarios either simulated with CelPlanner or inserted manually into the power simulator. Thus, allowing the evaluation of telecommunications owned project, thirty party services or any measured information about communication network availability.

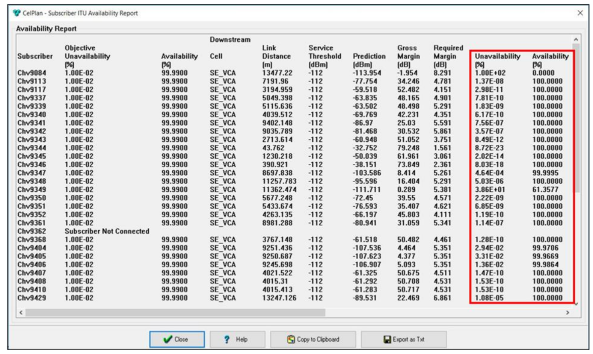

Figure 5 – Availability Report.

Figure 6 shows the interface for inputting availability scenario information for each automatic switch on the grid.

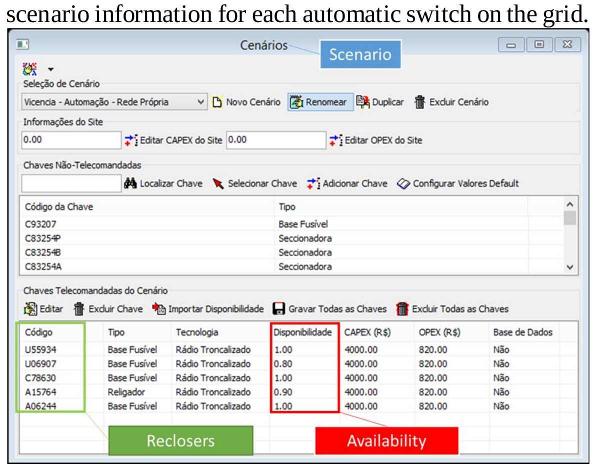

Figure 6 – Technology Scenarios

Allocate Automatic Reclosers and Calculate System Reliability Index for different Telecommunications Scenarios

In this work, we defined four different technologies scenarios to evaluate the proposed methodology by calculating each System Reliability Index. We applied the common equation for System Average Interruption Duration Index, known as SAIDI. Table 1 presents a summary of the scenarios.

Table 1 – Technology and Performance Scenarios

Scenario	Technology	Availability	Value Consideration
1	Cellular	60%	Same for all reclosers
2	Cellular	80%	Same for all reclosers
3	WiMax	90-100%	Individual for each recloser
4	Hybrid WiMax and Cellular	60-100%	Individual for each recloser

We chose these scenarios to meet practical examples measured in Brazil. First, a cellular network based approach for a country town with small population, results in an average of 60% availability for all reclosers. Second, a dual chip (two operators) cellular approach for country cities or individual operator in large cities, with the estimated average of 80% availability for all reclosers. The third approach refers to the CelPlanner WiMax simulation, which the availability reports demonstrate individual values for reclosers between 90 and 100%. Last scenario, we mixed both WiMax and cellular technologies to evaluate the impact of a hybrid network.

In order to obtain the best automatic reclosers configuration individually, the Optimal Allocation of Automatic Reclosers methodology, which is presented in the next section, is applied for each scenario.

Optimal Allocation of Automatic Reclosers

The methodology for Optimal Allocation of Automatic Reclosers used in this paper is presented in [13]. Although, this methodology was updated to consider the impacts of telecommunication availability on the allocation.

As a breakthrough in the 'A Priori' Reliability Calculation Approach, which is used to calculate the grades of each allocation solution, it was included the consideration of different duration times for transferring loads between manual and automatic switches. Thus, for a manual switch the duration time to change its status is called t_{manual}. In the same way, for an automatic switch, considering an ideal telecommunication network, which has 100% availability, the duration time to change its status is called t_{auto}. The telecommunication network availability affects the reliability indicators, as the automatic switches depends on it to succeed and transfer loads during a contingency.

Considering the feeder schematic presented in Figure 7 and a fault in Load Block #4, the operation crew can isolate the fault opening SW2 and closing AR1. This way, the duration of the outage will depend on the required time to operate both switches.

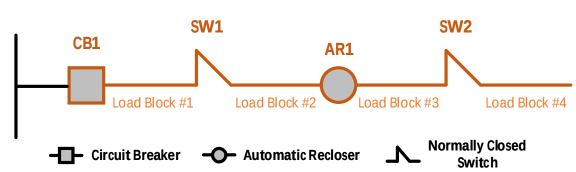

Figure 7 – Feeder schematic

However, if SW2 and/or AR1 are automatic, the successful operation of the switches depends on the telecommunication network availability. In order to consider the impact of this availability, the duration time to operate an automatic switch is calculated according to (I).

$$t_{op} = t_{auto} * availability + t_{manual} * (1 - availability) \quad (I)$$

Where,

t_{op} time to operate an automatic switch

$availability$ availability, where the switch is placed

CASE STUDY

Subject of Study – Electric Grid

The electric grid subject of study is a represention of a real grid from Neoenergia Celpe, a company from Iberdrola Group. The grid located in Vicencia, Pernambuco, has 1 substations with 5 feeders and 6 reclosers, 3 normally closed (NC) non-automatic reclosers and 3 normally open (NO) non-automatic reclosers. The NOs are connections between feeders. Figure 2 presented the Vicencia Substations grid on SINAPgrid before we realized new reclosers allocations.

Subject of Study – Communications Network

For the combined simulation, we configured CelPlanner with settings that represent the real communication networks that provide services for Vicencia Substation.. The communication project has 2 Radio Base Stations (RBS), one in the substation and another repeater unit. This is the network utilised in scenario 3.

The proposed combined simulation approach also provides the possibility of visualizing the communication coverage map over the electric grid on SINAPgrid, as seen in Figure 8.

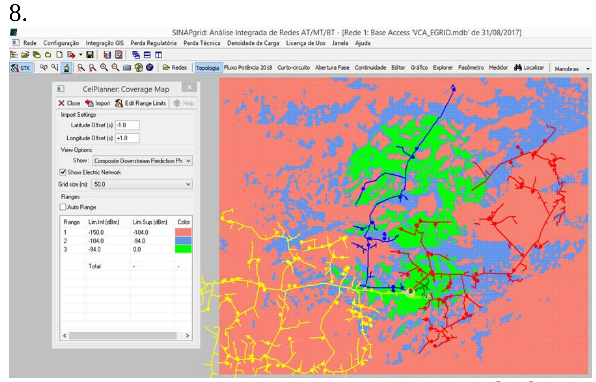

Figure 8 – Communication Coverage Map and Electric Grid Visualization

Results

Table 2 presents the results for each scenario.

Table 2 – Results obtained for each scenario after simulation

Scenario	SAIDI (hours/year)	ENS (MWh/year)	Allocated reclosers
Minimum System Reliability	31.94	92.87	-
Maximum System Reliability	18.01	49.12	11
Scenario 1	22.84	65.22	10
Scenario 2	20.87	58.62	10
Scenario 3	18.04	49.21	11
Scenario 4	20.96	58.76	10

Considering the minimum and maximum system reliability scenarios, an initial analysis shows that excluding the telecommunication network impacts, an optimal allocation of automatic reclosers brings a SAIDI and ENS reduction of approximately 14 hours and 43 MWh per year, respectively.
After that, when it is included the telecommunication impacts that reduce the benefit generated by reclosers allocation not only SAIDI and ENS got an increase, but also the number of reclosers reduced. A deeper analysis shows that this reduction occurs because this recloser cannot bring anymore a benefit that return its cost during its lifetime. The same result is obtained for both scenarios 1 and 2, indicating that even a minor change on telecommunication availability can lead to this.
Based on the analysis of scenario 3 it is possible to conclude that the real projected network in CelPlanner performs really close to an ideal communication network.
Finally, scenario 4 presents the tool capability to simulate scenarios that includes mixed technologies. This way, the network planner is able to compose a scenario in order to obtain a communication network that satisfies utility's requirements.

CONCLUSION

In this work, we proposed a combined planning and simulation approach for designing Smart Grid distribution automation solutions and telecommunications networks. The results demonstrates that considering telecommunications availability in System Reliability Index estimation has the potential to both change the planned reclosers allocation on the grid and reduce the estimated solution expected benefit for a project.
Further works could include expected costs for each solution, allowing project comparison through a cost-benefit relation. The approach could also be extended to other Smart Grid features such Smart Metering and Distributed Energy Resources planning.

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