An Integrated Program to Improve the Quality of Frequency Regulation in Colombia and the Andean Interconnected System

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Abstract – **This article will describe the integrated program to improve the quality of Frequency Regulation which was implemented in Colombia by XM, the Colombian Power System Operator. In this program, primary and secondary frequency control were first studied independently in order to determine the real generation unit control capability of each one. Then, several systematic tests were made to establish the regulation performance of the Power System and to obtain the final coordination of the two frequency control schemes.**

The Load Frequency Control (LFC) was extended to consider islanding system operation due to either a terrorist attack against the network infrastructure or to any other isolated system condition.

Additionally, a novel component-based application was developed using Visual Basic for Applications (VBA) and Excel. This software solution was designed to collect and integrate all data sources, such as ancillary services parameters, economic dispatch, SCADA/EMS, stand alone register, primary and secondary tuning parameters in one unique analysis and monitoring environment.

This paper also presents the results of the application of this approach in the Colombian, Ecuadorian and Venezuelan Interconnected Power System and its positive impact on making feasible the Andean Interconnected System.

I. Introduction

Frequency is the variable that measures the balance between load demand and generation in an interconnected power system. The rated frequency at which a power system normally operates is a standard reference value of either 50Hz or 60Hz. Balancing mechanisms are used to keep the System Frequency as close as possible to the reference value. Frequency Regulation is the ability of a balancing authority to help the interconnection maintain schedule frequency. This assistance can include both turbine governor response (primary control), and Automatic Generation Control (secondary control) [1].

Systems Operators (SO) or Independent Systems Operators (ISO) must guarantee a non-interrupted and reliable supply of electrical energy of high quality for modern industrial requirements. Frequency is an important parameter for defining supply quality. After the deregulation of the electricity industry, the quality of the frequency was integrated into a service package known as ancillary services [2]. The service has to be monitored via continued surveillance in order to guarantee the desired quality [3]. This package represents a set of tools designed to help ISOs to preserve the quality of energy supply in the context of an electricity market.

The Colombian System Operator designed an integrated program to evaluate and improve the quality of the frequency regulation in response to both domestic and regional necessities. The main objectives of this report are to:

- Present the phases executed in the program to adapt the control tasks to the new market requirements.
- Show the issues developed to adjust the tasks of the primary and secondary control to the specific operating conditions of the Colombian and the Andean Interconnected Systems.
- Describe the changes made, with the support of the technology provider, SIEMENS, on the Load Frequency Control (LFC). The extension was made to guarantee the Automatic Generation Control, even for severe cases of islanding operation.
- Present a novel software solution, designed for Frequency Regulation analysis and monitoring, which integrates all relevant data sources into a flexible, component-based application implemented using Visual Basic for Applications (VBA).
- Present the results obtained after the applications of the program.

The program was discussed and enriched in various national committees in which all power systems actors are represented.

II. Description of the Program

In 2000 the Colombian system operator XM started an integrated program to evaluate and improve the quality of System Frequency by means of better Frequency Regulation. XM's planning department, specifically the ancillary services group, was in charge of designing and implementing a methodology to cover the necessities of the Colombian and the nascent Andean Interconnected System.

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A. *Phase 1: National Survey to Analyze the current Status of the Primary Control and the Actual Response Capability*

Traditionally, the Colombian system was operated mainly using the secondary control. The reason was a combination between the historical way of operation and a lack of precise market rules to the frequency control. The first stage of program began with a survey designed to evaluate the current control status of all power generation units and their actual primary control capability [4].

The survey identified several problems: governor operation mode, availability of governor models, as well as Droop and Death Band adjustments. The latter were contrasted with Droop [4-6%] and Death Band [60 ±0.036 Hz] reference as defined by North America Reliability Council (NERC).

B. *Phase 2: Frequency Regulation Considering the Terrorist Attacks Against the Colombian System.*

The Frequency control faced two main problems: To improve an effective participation in primary control and to tune the secondary control in order to let the first one act properly and manage an islanding situation due to terrorist attacks.

The first task was done using the information collected in the survey phase and selecting the minimum set of controls on secondary control. The second task required the automatic resolution of an islanding situation and to give new information to each island so that a reasonably controlled schema could be attained.

The relevant aspects of this phase were:

1) Extension of the LFC: A Multi-Area ACG was implemented considering an Islanding System Operation [5]. In section III bellow, the functional specification of the LFC is provided.

C. *Phase 3: Monitoring and Coordination of the Primary and Secondary Responses.*

The relevant aspects of this phase were:

1) In-house software development for analyzing and monitoring the Frequency Regulation: The application is explained in detail in section IV.

2) Coordination of the Primary and Secondary Control: In this stage, the dynamic response of the frequency after a sudden loss of generation, without the activation of the Load Shedding Scheme, was studied. A set of parameters were analyzed, in order to increase the number of units in the AGC market and to take into account both domestic and international compromises.

III. Load Frequency Control (LFC) extention. Multi Area Automatic Generation Control (MAGC)

Terrorist attacks against the Colombian System, more than 200 per year, produce islanding conditions, which, in many cases, can be foreseen during the operation planning. However, the random nature of this kind of malicious event produces non-predictable areas which increase the complexity of the system's operation and its control.

Once the division of the system happens, the MAGC detects automatically the new topology condition and makes certain feasibility checks to determine if in fact one or more areas were created. The MAGC uses a default area as the initial condition and the information given by the Topology Evaluator (TOEV) program. The TOEV verifies circuit breakers and switches status, data communication validation and energy flow plausibility.

The following conditions are required for the formation and control of an isolated area: 1) Automatic topology reconfiguration allowing the definition of an electrical island and its components: Sub-stations, lines, transformers and other devices. 2) Automatic determination of which generators belong to each area. 3) Automatic determination of which frequency measurements are associated with each area. 4) Automatic Regulation Control of each area in all modes (Constant Frequency, Tie-Line and Tie-Line Bias). 5) A maximum of 10 control areas.

The functional specifications of the MAGC were designed considering both the Colombian and the Andean scenarios.

A. *Functional specifications of the MAGC in the Colombian Domestic Scenario.*

The Colombian Power System is divided into several electric areas which have a direct relationship with the principal energy consumption points (Fig. 1 left).

The MAGC in the domestic scenario considered two general conditions: Colombia as a single area or divided in more than two areas but less than 10. The control mode is Constant Frequency.

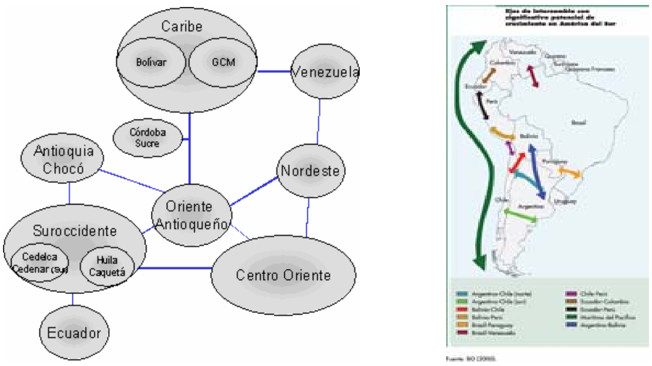

Figure 1. Electrical Areas of the Colombian Power System. Source XM-ISA (left). Axis of development in South America (right)

B. *Functional Specifications of the MAGC in the Andean Scenario.*

The integration of the energy market in Latin America (Central and South America), has received support from regional governments [6]. Institutions like the Inter-American Development Bank (IDB) consider the integration as a fundamental aspect of the development of Latin America. Investment in the integration is still continuously supported by IDB and the Corporación Andina de Fomento. The Andean Community approved the regulation frame that facilitates energy interconnection and exchange among member countries (Fig. 1 right).

The regional scenario for the MAGC considered the existing interconnections between Colombia and Venezuela, Colombia and Ecuador and future international connections with Central America. The MAGC conditions and their control modes for the Andean scenario are: 1) Colombia as an area which has one or more international connections. The mode of operation can be either Tie-Line or Tie-Line-Bias. 2) Colombia divided in two areas, each of which has international connections. For both areas, the control mode can also be Tie-Line or Tie-Line Bias. 3) Colombia divided in more than two areas. Different areas, whereby some areas have international connections and others do not. The control mode can be either Tie-Line or Tie-Line Bias for the areas with international connections and Constant Frequency for the isolated ones. An example of the actual islanding condition after an attack against the 500 kV system is shown in (Fig. 2 and 3).

In fact, since the beginning of the interconnection between Colombian and Ecuador in 2003, XM has provided the secondary frequency control to Ecuador when this country has problems with its own AGC. This support is made using the MAGC to control the Ecuador's biggest generation units, thereby allowing Ecuador to act as an island.

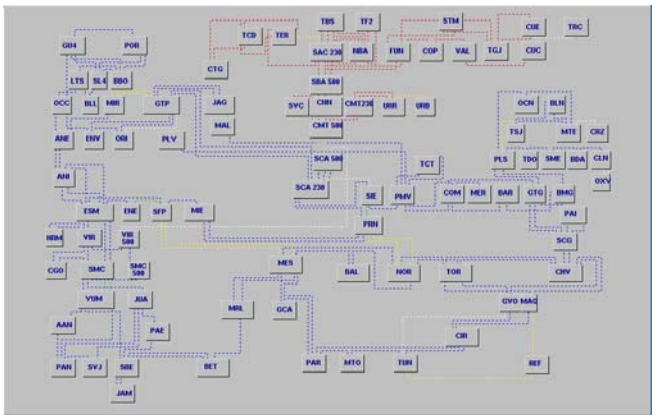

Figure 2. MAGC user interface. Colombia divided in two areas. These areas are red and blue colored. Source XM-ISA

Figure 3. MAGC user interface. Colombia divided in two areas. Valid areas are colored. Source XM-ISA

IV. Component-based Application for Analyzing and Monitoring Frequency Regulation (FRAM)

Independent System Operators need to analyze, track and supervise the Frequency Regulation as an integrated process. This implies that the information collected in the planning phase, such as unit parameters and unit-tuning test results, must be compared to the economic dispatch program and the real time power system operation.

The application makes it possible to analyze and monitor the Frequency Regulation as a unique and integrated process, closing the loop between planning, economic dispatch, and real-time operation.

A. *Application Overview*

The application is divided into several processes that are involved in the Frequency Regulation. Each one of them is described as a use-case using the Unified Modeling Language (UML) notation (Fig. 4). Both the Analyzing-Primary and the Analyzing-Secondary use-cases take information from the EMS/SCADA sinaut spectrum system, economic dispatch and planning servers. The Characterizing-Frequency use-case not only collects information from the real-time database but also receives information from stand alone registers.

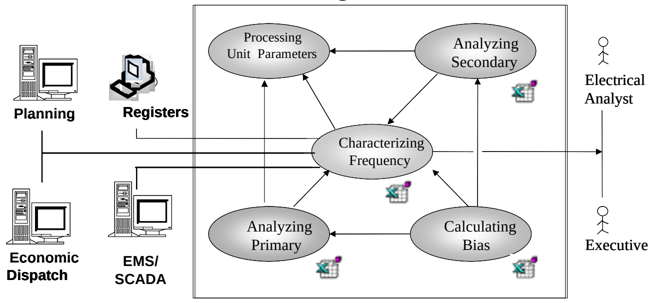

Figure 4. Use Case diagram of the software application. Source XM-ISA

1) *Analyzing-Primary*

This component is in charge of monitoring and evaluating the primary response of each telemetered power unit connected to the system. Unit parameters, Droop and Death Band, obtained during the first phase of the program as well as subsequent tests are here used. The delay time associated with the SCADA process also taken into account in (Fig. 5 and 6).

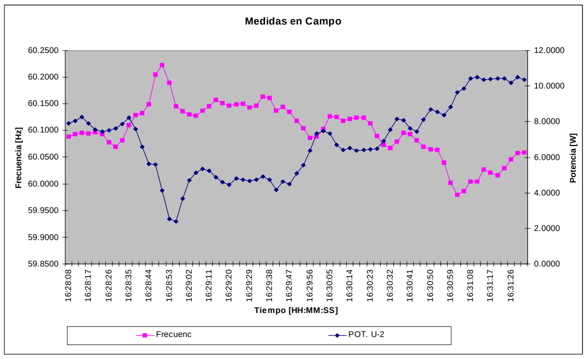

Figure 5. Monitoring of the primary response. Unit output power measured at the unit generator

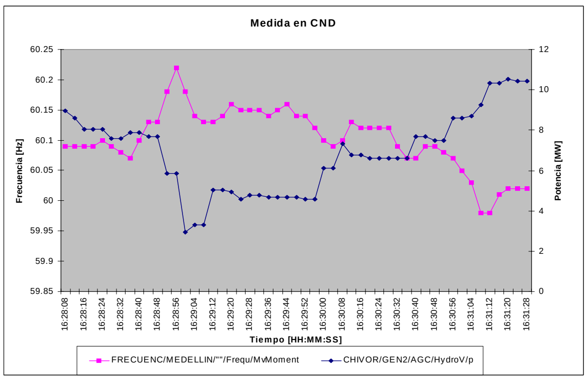

Figure 6. Monitoring of the primary response. Unit output power measured at the Control Center . Source XM-ISA

Additionally, a PT1model was modeled in the component in order to simulate the first order response of the primary control. Transient behavior is also evaluated after a sudden loss of generation, in order to contrast both real and expected primary responses (Fig. 7 and 8). The expected output power value is computed for each change of frequency of 0.1 Hz considering nominal power, nominal frequency and Droop, and Death Band of the unit.

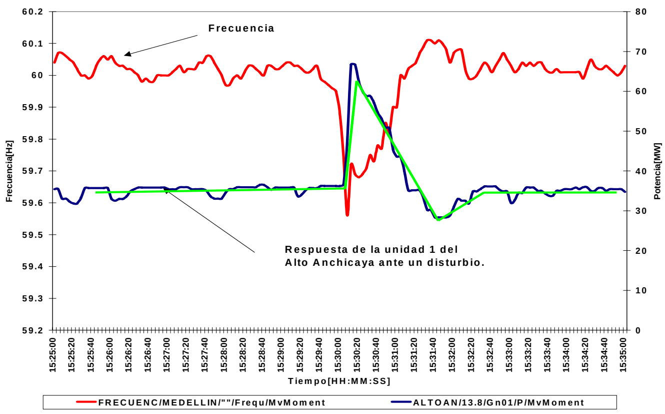

Figure 7. Real and expected primary responses in Colombia. Source XM-ISA

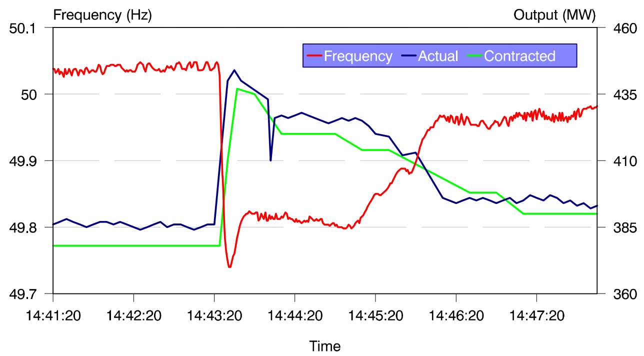

Figure 8. Real and expected primary responses in England. Copyright National Grid Company. With acknowledgement to National Grid

2) *Analyzing-Secondary*

This component determines if the real time response of the generation units, under AGC, is accurate and corresponds to the contracted one. An index of tuning quality is calculated by computing the output power error of the unit with respect to the AGC reference value. (Fig. 9 and 10), [Table 1].

The Economic Dispatch process considers parameters such as regulating ranges and power output rate as input parameters in the optimization process. The AGC component uses these parameters and compares them with the real time behavior [Table 1].

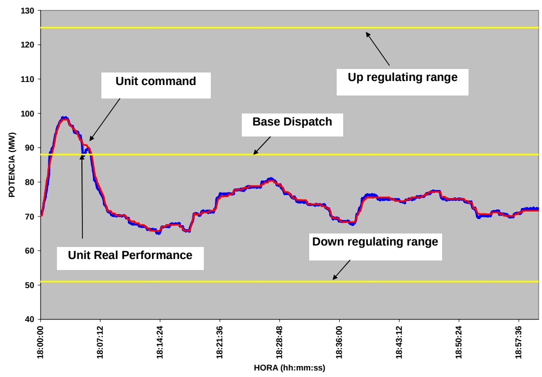

Figure 9. Unit with good tuning performance and its regulating ranges. Source XM-ISA

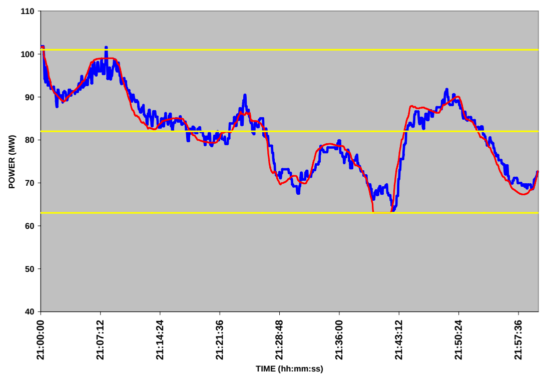

Figure 10. Unit that requires a re-tuning treatment

Table 1. AGG Units Summary. Excel result sheet

AGC Units Summary							
Unit	Dispatch [MW]	AGC_MAX [MW]	AGC_MIN [MW]	P_UP [Mw]	P_DOWN [MW]	P.Factor [%]	Error Pr_Ps [%]
CHIVOR1	72.5	125	20	52.5	52.5	13.13	0.861
CHIVOR2	88	125	51	37	37	9.25	0.855
CHIVOR4	72.5	125	20	52.5	52.5	13.13	0.763
CHIVOR5	72.5	125	20	52.5	52.5	13.13	1.397
CHIVOR8	72.5	125	20	52.5	52.5	13.13	
LATASAJ1	51	102	0	51	51	12.75	3.138
LATASAJ2	51	102	0	51	51	12.75	3.072
LATASAJ3	51	102	0	51	51	12.75	3.001
Total				400	400	100.02	

Additionally, both components of the Area Control Error (ACE), frequency and interchange, are shown and the values are used for computing the NERC CPS1 performance index. The usage of the regulating range of the system and each unit are also monitored and evaluated (Fig. 12).

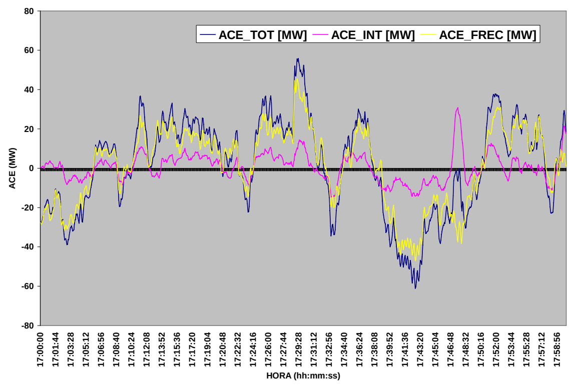

Figure 11. Area Control Error. ACE Total, ACE Frequency and Interchange components. Source XM-ISA

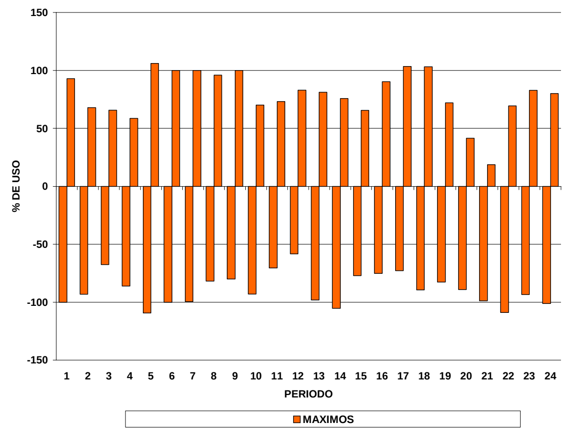

Figure 12.Usage of the System Regulating Range during one month. Source XM-ISA

3) Characterizing-Frequency and Calculating-Bias

These components were designed to analyze the quality of the Frequency Response of the power system. Here, while emphasis was on the steady state and on the dynamic behavior of the power system, but the main area of focus was on the primary and secondary control.

In the steady state, the quality of the Frequency Regulation is verified statistically by calculating parameters such as mean and standard deviation. The distribution of the Frequency is compared with an ideal normal distribution, in order to verify its deviation. A Kolmogorov-Smirnov test (KS-test) is also made. As an example, the results of one hour of operation are displayed (Fig. 13) with the following values: mean: 60 Hz, standard deviation: 0.02Hz, 68% of the data: between 59.98Hz and 60.02Hz and 95%of the data: between 59.96Hz and 60.04Hz.

Additionally, the steady state frequency is evaluated by means of quality parameters, such as nominal frequency: 60 Hz, power system death band: ±0.03 Hz and two regulating ranges: 60±0.1 Hz and 60±0.2 Hz. The first range: 60±0.1 Hz, represents the quality range according to the Andean Regulation Agreement. The second one: 60±0.2 Hz is used to calculate a quality frequency performance index in Colombia. Each value of the frequency outside of the second range due to an inappropriate Frequency Regulation is counted as a failure.

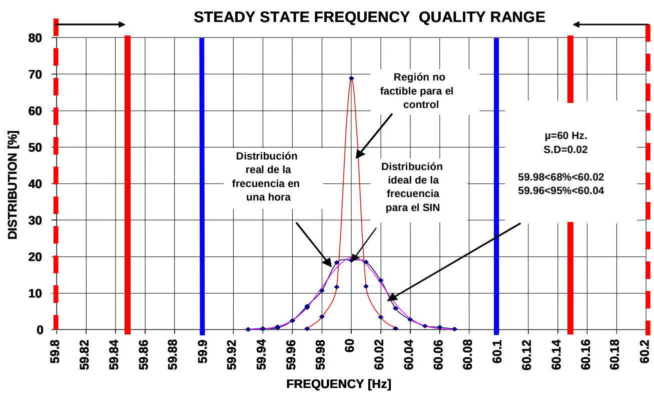

Figure 13. Steady State Analysis. Statistical distribution of frequency. Source XM-ISA

Considering the dynamic response of the Power System after a sudden loss of generation, the completed coordination and tuning of both Primary and Secondary Response is verified. The dynamic response is evaluated with respect to statistical values such as Frequency Response (F.R), Bias, primary response time, AGC recovery time, and primary and secondary regulating ranges (Fig 14).

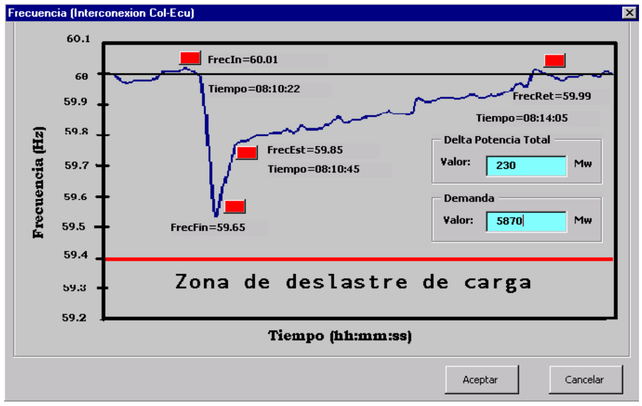

Figure 14. Dynamic Frequency Response user Interface. Source XM-ISA

V. Conclusion

During the application of the program, a period of more than three years, the Frequency Regulating has continually maintained high quality for both steady state and dynamic responses. The Colombian System Operator, XM, has developed a set of tools to evaluate and detect malfunctioning in the frequency process chain, which allows to the improvement the quality of the service. Even in critical security conditions, due to the number of terrorist attacks against the network infrastructure, the Colombian System Operator XM has preserved the reliable supply of electrical energy not only in Colombia but also in the Andean market.

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