Modelling of the response of the generators to the automatic generation control commands under communication protocols based on the international standard

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Abstract. The frequency of an electrical power system is controlled by generators doing primary frequency regulation, which stands for maintaining the stability and reliability in short times and secondary frequency regulation, also known as Automatic Generation Control, which its main goal is to maintain the frequency in a set-point. This last is done remotely from the control centre of an electric power system operator in most cases, and to carry it out supervisory control and data acquisition - automatic generation control - energy management system. These systems are used that make use of current international standards of the International Electrotechnical Commission that adapt in any case to many supervision and control mechanisms. Using those standards supposes the use of a range of available options; particularly, the commands used to control electric power generators fall into 2 possible options, and to evaluate responses under disturbances, a study of the modelling of generators under automatic generation control becomes necessary. A study of the response in closed loop control of automatic generation control is discussed to determine its models under different scenarios. Then, this is the input to determine responses to simulated deviations on the commands due to known failures or disturbances.

1. Introduction
The modern supervisory control and data acquisition - automatic generation control – energy management system (SCADA-AGC-EMS) systems used for centralized control use flexible communication protocols in terms of the interoperability of different control systems and different manufacturers. Over time these systems in the different control centres have evolved from proprietary protocols to standardized protocols by American or European associations. In Colombia, the current electric law indicates that the interoperability of electrical systems must meet the European standards of the International Electrotechnical Commission (IEC), IEC 60870 family [1]. On the other hand, the automatic generation control (AGC) looks after the balance between the load and the generation, so the system’s frequency of the interconnected electric power system remains stable and is performed using the existing standard protocols for control centres [2].

Studies are required to foresee the effects of some failures according to types of faults that could happen in real time operation. To look for their effects, there is a need to have a good model for the generator’s response under AGC, they are totally governed by SCADA-AGC-EMS and are fine-tuned once the generator is ready to work under AGC. There are scheduled tests for each generator operating
in an open loop to set the best parameters that respond to selected steps commands. Throughout this document, it is studied how this model could be identified even when the generator is in closed loop operation, having data-sets from selected operation scenarios. Conclusions are presented by using the models identified to simulate the response of some generators under some faults that should affect the AGC operation.

2. Supervisory for automatic generation control

The generators in a large-scale interconnected system have a daily schedule which is planned to cover the electric energy demand, however, it has deviations in time with respect to its expected profile with which the planning of the generation is carried out [2], that cause an undesired effect in the power system, better known as load-generation imbalance, in which the frequency of the entire interconnected system is affected. To correct it, control schemes are used for the generators connected and synchronized to the electrical network [3]. In a control centre, the AGC is performed by a SCADA-AGC-EMS, which are tools for operating electric power systems and its main feature is the remote control over long distances, so it brings the possibility of failures such as delays, momentary drops in the connection lines of commands, permanent drops due to natural causes, failures in the response of the control systems, and others [4].

The function of an AGC system is given by keeping the frequency of an area of the electrical system at a value close to its nominal value and maintaining a minimum error in the power interchanges between different areas of an electrical interconnected system. The area control error (ACE) computes the lack or excess of active power to generate and maintain the frequency and those power interchanges as in Equation (1).

\[ ACE = \sum_i\left(p_{\text{TIE}_i}^{\text{sch}} - p_{\text{TIE}_i}\right) - 10\beta\left(f_{\text{area}} - f_{\text{area}}^{\text{sch}}\right). \]  

Here, each neighbouring area i has a scheduled power interchange \( p_{\text{TIE}_i}^{\text{sch}} \) and a measured power exchange \( p_{\text{TIE}_i} \), and the area has a scheduled frequency \( f_{\text{area}}^{\text{sch}} \) as well as a measured frequency \( f_{\text{area}} \) [5]. In addition, there is a linear ratio between the load variations and the frequency variations of that area that is called the bias factor \( \beta \) usually expressed in MW/0.1 Hz but occasionally in MW/Hz. To keep the ACE close to zero every time leads to the implementation of a closed loop control system. In SCADA-AGC-EMS systems, this controller is a proportional, integral, derivative (PID) whose error input is the ACE and its output is the remaining power required at each moment of time. This remaining power is distributed into multiple generators through some participation factors \( \alpha_i \) and sent to the generators that are in regulating mode and therefore, if they obey the control signal correctly, the ACE will remain controlled and close to zero [6-8]. Figure 1 illustrates how the control loop looks with the above mentioned and how the disturbances \( N_i \) are possible to be present into the control loop.

In Colombia, the electrical system operator is called National Dispatch Centre (CND) as a part of the company XM S.A.E.S.P. It has a SCADA-AGC-EMS that uses standards of the IEC 60870 family to perform the supervision and control of the generation: AGC. It also has a historical data system that is called the bias factor \( \beta \) usually expressed in MW/0.1 Hz but occasionally in MW/Hz. To keep the ACE close to zero every time leads to the implementation of a closed loop control system. In SCADA-AGC-EMS systems, this controller is a proportional, integral, derivative (PID) whose error input is the ACE and its output is the remaining power required at each moment of time. This remaining power is distributed into multiple generators through some participation factors \( \alpha_i \) and sent to the generators that are in regulating mode and therefore, if they obey the control signal correctly, the ACE will remain controlled and close to zero [6-8]. Figure 1 illustrates how the control loop looks with the above mentioned and how the disturbances \( N_i \) are possible to be present into the control loop.

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- **C_SE_NA_1**: Set point command, normalised value, used to send a relative command.
- **C_SC_NC_1**: Set point command, short floating-point value, used to send an absolute command.
3. Modelling and simulation of generation systems under automatic generation control

The AGC in the SCADA-AGC-EMS of the CND simulates the expected response of each generator under every single command sent. However, the responses of any of them could be affected by disturbances discussed in the past section and therefore a difference from that expected behaviour can be observed. The goal of this work is to show how those behaviours can be obtained without affecting the real time system by using simulations based on the closed loop response of any generator and the historical system. It could be that the generator has a black box model into the SCADA-AGC-EMS, or it is too odd to get an easy result. We define variables to characterize the response of a generator under AGC as follows:

- \( P_c \): AGC control signal calculated by the AGC for a single generator.
- \( P_{\text{sim}} \): SCADA-AGC-EMS’ simulation of the generator’s response to the \( P_c \) command.
- \( P \): Real-time response of the generator under AGC (active power).

Real AGC operating scenarios were chosen to get the responses to AGC disturbances and to have the two types of commands described above as relative and absolute commands. The main difference between them is that the absolute commands are interpreted as the values the generator should reach in MW while the relative ones are interpreted as the amount in MW to change over the current delivered active power. The response to absolute commands shows a high linearity relation between the delivered power and the commands but the response to relative commands is highly nonlinear, then, for relative commands, a previous calculation is done to achieve a linear response: it is to calculate the command of power using a constant raise/lower factor \( ps \) previously adjusted by several tests, as follows Equation (2).

\[
P_{c[MW]} = P(t) + ps \cdot P_c(t).
\]  

\( P_c(t), P_{\text{sim}}(t) \) and \( P(t) \) time series are taken from the SCADA-AGC-EMS under the AGC closed loop. To model the generator’s response, the time series of \( P_{\text{sim}}(t) \) based on the response to the command \( P_c(t) \), without disturbances is identified by the discrete output-error model [12] since AGC in Colombia is a digital control algorithm with a known sampling time of 4 seconds. Then, to simulate the response of one generator to a disturbance, the series \( P_c(t) \) is altered according to some real issues and \( P_{\text{sim}}(t) \) is then recalculated to get the results to those simulated incidents like the following [13]:

![Figure 1. AGC closed loop with some disturbance.](image-url)
• The sending of the command failed.
• The command was sent, but its execution was not successful, or the measurement did not meet the requirement of the command.
• The commands are delayed.

4. Results
The samples of the Colombian AGC operation for this study were chosen considering that generators controlled by relative and absolute commands were under AGC simultaneously and are described in Table 1. The generators involved in those scenarios have the command configurations described in the specification of commands ASDU.

| Scenario | Start time | End time | Generators | Commands ASDU |
|----------|------------|----------|------------|---------------|
| 1        | 12/06/2019 | 13/06/2019 | G₁         | C_SC_NC_1     |
|          | 21:00      | 0:00     | G₂         | C_SE NA_1     |
| 2        | 12/06/2019 | 12/06/2019 | G₂         | C_SE NA_1     |
|          | 18:00      | 21:00     | G₄         | C_SC NC_1     |
| 3        | 12/06/2019 | 12/06/2019 | G₁, G₃     | C_SC_NC_1, C_SC_NC_1 |
|          | 9:00       | 18:00     | G₂         | C_SE NA_1     |
| 4        | 12/06/2019 | 12/06/2019 | G₁, G₆     | C_SC_NC_1, C_SE NA_1 |
|          | 7:00       | 9:00      | G₂         | C_SE NA_1     |
| 5        | 12/06/2019 | 12/06/2019 | G₁, G₇, G₉ | C_SC_NC_1, C_SC_NC_1, C_SC_NC_1 |
|          | 0:00       | 7:00      | G₂, G₆    | C_SE NA_1, C_SC_NC_1 |
| 6        | 11/06/2019 | 11/06/2019 | G₁, G₆     | C_SC_NC_1, C_SE NA_1 |
|          | 12:00      | 17:00     | G₅         | C_SE NA_1     |

Taking the first scenario, and from the time series \( P_c(t) \), and \( P_{sim}(t) \) a model is obtained for each of the two generators G₁ and G₂ using the output-error algorithm, resulting the following Equation (3) and Equation (4).

\[
P_{sim}(t) = \frac{0.1986}{1-0.005 z^{-1}} P_c(t) + e(t),
\]

\[
P_{sim}(t) = \frac{0.4737}{1-0.526 z^{-1}} P_{qMW}(t) + e(t),
\]

The above models fit the chosen data at 91.42% and 95.1% respectively. Figure 2 graphically shows the data of \( P_{sim} \) together with the data calculated passing \( P_c \) through the above models.

After getting and validating the models, a section of the commands data is altered to obtain a modified time series \( P'_c(t) \) as discussed before, and then a linear simulation is performed with these by each model, getting \( P'_{sim}(t) \), the time series modified for each generator, using Equation (5).

\[
P'_{sim}(t) = \frac{B(z)}{F(z)} P'_c(t).
\]

With the model in Equation (3), it is possible to observe many additional scenarios of disturbances and their effects on the AGC operation without the need to interrupt the participation of the generator in the AGC. All the models in Table 1 were adjusted using the output-error algorithm with successful results as in the first scenario with fit of estimations between 83.99% and 98.62%, where the worst estimations were for generator G₆ and the best for generator G₂. That is an indication of good or poor linearity in response to the AGC commands, which is an important characteristic in the AGC operation.
5. Conclusions

A study of a generation system under centralized automatic generation control was done to get to know how a modelling can be performed by data-sets obtained from real time operation in an AGC closed loop. IEC standards are practices that require particular studies for each system and could include a modelling scope to evaluate restrictions or risks. A study was conducted with real time data-sets from the Colombian AGC system for different scenarios, in which remote AGC commands have been implemented with ASDU C_SE_NA_1 and C_SC_NC_1 of the International Electrical Engineering standards of the IEC 60870-5 family.

Digital model identification for the responses to the commands in generators under AGC can be used to predict the response of AGC to some disturbances without affecting the real time systems. Relative commands include a non-linearity consideration in the models that can be solved by data transformation. The generators’ modelling work for studies that include real disturbances and can be used to compare different scenarios in which some failures can happen.

The linearity of the response of a generator under AGC commands, an important feature in AGC operation, can also be valued by identifying the discrete model in closed loop of AGC for long periods of time; then, corrections could be conducted to x some undesirable non-linearity. The laws of physics can be evidenced in the construction of the automatic control system as well as in the laws of the power system, all of them necessary to be able to properly formulate the problem and to be able to find an adequate solution.

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