AUTOMATIC GENERATION CONTROL IN COMPETITIVE ENVIRONMENTS: MODIFIED AGC FUNCTION

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Abstract – The fundamental tool for regulation purposes is the AGC (Automatic Generation Control) function. Following the orientation change in the energy dispatch in recent years at the Spanish market, the AGC function has had to undergo a necessary evolution for the adaptation to the new environment.

In the present paper, the main modifications carried out in Iberdrola's generation dispatch for the adaptation of the AGC function to the new environment are described. Specially, the definition of new dynamic filter for ACE signal is briefly described here.

The application of the described changes have allowed managers and operators of Iberdrola dispatch to reach an optimal process of supervisory control of interchanges between Iberdrola and other market agents.

Keywords: AGC, fuzzy, filter

1 INTRODUCTION

Since the introduction of a competition based electricity market in Spain at the beginning of 1998, it has been necessary to make many and important changes in the management of the electric power generation system. These changes have required the development of new tools and the improvement of the existing ones in order to ensure the best way of exploitation.

During main part of 1997, Iberdrola have undertaken an ambitious project for adapting its generation operating process, including staff reorganization, software updating and new work methodology.

In the following years (until 2000), additional effort was made for the tuning of the generation control software. The change of the regulatory framework, and therefore of the new competition and liberalization paradigm, has forced to the adaptation of the processes of Generation Scheduling and the Ancillary Services.

These services are automatically controlled by software which includes functions such as Economic Dispatch (ED), Production Costing, Hydro-thermal Coordination and others. However, the most important function is the Automatic Generation Control (AGC, or LFC by Load Frequency Control).

Changes on the market model necessarily force changes on the definition of this function. Moreover, depending on the legal rules, AGC could be implemented in different modes.

In the Spanish market the secondary regulation consists on a hierarchical system of areas (called RCP) that distributes and coordinates in a reasonable way the effort of controlling the deviation with France among the different areas. The Centro de Control Eléctrico (CECOEL) of Red Eléctrica de España, S.A. is the company in charge of the interchange deviation surveillance. To control this deviation, CECOEL sends to each participant area a signal of regulation requirement that, combining with the own deviation, defines the Area Control Error (ACE). This signal is calculated every 4 seconds and represents the power in MW that should be increased or reduced in the power station which constitute the regulation area of an electricity company.

The CECOEL interchanges data with each EMS available in the areas. The AGC software of each area is in charge of mediating between the requirements of the CECOEL and the real generation of the units.

A special characteristic to be taken into account in the Spanish case is the scarce interconnection of the Peninsular Electric System with the European synchronous system. This requires a careful supervision of the power flows with France, especially for not exceeding the acceptable power limits in any of the 4 lines (two lines of 220 kV and two lines of 400 kV). To be isolated of the rest of the European system would imply a notable decrease in the quality and security of the electricity supply.

In this paper, changes in the AGC function installed in the Central Office of Generation (DCG) of Iberdrola are described. These changes can be grouped in the following main points:

- Change in the definition of the interconnection concept. Considering the previous operation environment based on production costs, the AGC should control the interchange with the adjacent areas. In the actual environment, the interchange

that should be controlled is the fulfilment of the generation commitments besides the contribution to the peninsular regulation. Therefore, the new "interconnection" concept is closely related with generation point.

- Filter of ACE. A sine form of ACE signal deviation causes an excessive waste of the electromechanical control equipment of the generators. As a result of the filter that is described, it has been possible to stabilize the excessive ACE deviation signal, minimizing the waste of the generators and assuring in any case the security of the system (including interchange with France), even under important interference.
- ACE allocation logic. The error signal correction, once filtered, should be followed strictly, within the operation conditions of the generators and in coordination with the appropriate economical operation points, as established by the Economic Dispatch. A tracking logic has been included which allows AGC to identify the best way to distribute the error signal among all the remote generators.

The detail of these modifications, as well as the enumeration of others, is approached next.

2 CHANGE IN THE DEFINITION OF THE INTERCHANGE CONCEPT

As pointed, in the previous environment, the interchange value controlled by the AGC was the energy interconnection foreseen with other areas close to the regulation area. Now, this value is equal to the total generation over all the power station in the generation area. The AGC function has been modified to provide the particularities of the new meaning. Basically, an interconnection must share all the characteristics with a generator.

The new interconnection particularities that correspond to characteristic of the generators are:

- Lost generation for auxiliary services. This introduces the concepts of gross and net interchanges, before it was a unique concept.
- Limit verification in the interchange level with the generation limit of the generator.
- Negatives interchanges values are forbidden, except in generators with pumping abilities.
- Take into account the participation factor with other companies in some power stations (specially nuclear and thermal generation).

Another significant difference in the new interconnections is the play down of its values in the process control. AGC is a function that runs on a real time environment, connected to a SCADA system. In these systems, it is very usual that problems in communications or in measurement equipment causes lost of some values. In previous AGC, when an interchange value was lost, it was considered that AGC function could not be run in a correct way and, consequently, AGC was suspended.

Now, AGC function must be able to continue its calculations, although an interconnection data acquisition is lost. To achieve this functionality, AGC has been modified to include a specific logic for these situations. This logic follows the following guidelines:

- Last correct data acquisition is “frozen” for a specific (and adjustable) number of AGC cycles.
- If data acquisition error persist, extrapolation logic is activated, to determine the most possible value, as a generator will do. This logic is active for certain number of AGC cycles.
- If data acquisition error persist, AGC will be suspended.

AGC completes its tasks with supportive functions, such as ED (Economic Dispatch) or IS (Interchange Scheduling). In addition to these modifications in AGC basics, change in interconnection concept forces changes in two of the AGC support functions. Required adjustments to these functions are described next.

2.1 Energy Accounting

In order to facilitate the elaboration of the offers, in which the new operation environment is based, it is convenient to group the interchanges in different offer units, for both generation and pumping.

Energy Accounting (EA) function provides the managers, traders and operators with all information about the current and past energy transfer, generation and consumption. EA creates periodic summaries to display collected and calculated values.

To improve this functionality, it has been incorporated to EA options that allows the grouping, average and integration of all the variables of AGC function related with interchanges. Some characteristics of this system are:

- Default grouping of the offer units. The default option is always carried out by the integration of the offer unit energy of Iberdrola and of the parameters that allow the pursuit and retribution of the service.
- Real time calculation of the demand area. Total energy consumption calculation was lost with the concept change. Now, it has been reincorporated with new definition.
- Straight pass to History File of the raw, averaged, grouped and integrated values.
- Recurrence grouping definition of the offer units. This characteristic, combined with the multibelonging of each element to different grouping, allows obtain intermediate results in a simple and flexible way.

2.2 IS function

One of the important support functions of the AGC is the Interchange Schedule (or IS). Up to now, this function should keep in mind the different adjacent areas and the different kinds of energy that Iberdrola could exchange. Now, it should facilitate the introduction of

the generation area contracts in the DCG and transmit immediately to AGC any variations on initial schedule.

Between significant characteristics of the new IS function, following ones could be stand out:

- Remote reception of hourly future schedules for a week ahead. The received data is validated against logic values.
- Easy way to modify any schedule, with minute precision.
- Ramp definitions facilities.
- Alarming signal when schedule absences.
- Thread of historic data.

The new function, besides adapting the original definition from the schedule to the current environment, allows the system to connect the function AGC with the tools of planning and scheduling in the Generation Central Office of Iberdrola. At the same time, there is a new kind to carry out operations that make easier the usual work with IS function.

3 ACE FUZZY FILTER

It has been observed that the signal of the RCP error has an oscillatory nature of high frequency. This characteristic impacts strongly in the fulfilment costs of the service because of the electromechanical control kits of the generator demand an excessive waste. On the other hand, the RCP takes into account the penalties for a bad service of the operation that could be derived of an inadequate fulfilment of the error signal.

In order to optimize costs, taking into account the characteristics of the problem and using similar international experience [3], the use of fuzzy logic as technology that can be incorporate to the AGC in a more effective and simpler way has been proposed. Among the properties of the fuzzy logic it can be pointed out these ones:

- Use of logical sets instead of discreet values for the analogical variables.
- Definition of fuzzy rules and application on the input sets to generate new fuzzy output sets.
- Definition of belonging levels to the set.

3.1 Design of fuzzy control

In particular, the theory of fuzzy sets has been used with triangular definition of the sets, as t-norma and s-norma, the max-min functions of Zadeh [4] and inference of Sugeno style [5]. The particularization of the theory focusing in the concrete problem has been based on the following points:

- Control variable selection. They are the area control error (ACE) and its derivative (DACE). The inclusion of an integral component was ruled out because of his ineffectiveness.
- Fuzzy set definition. Each variable was divided in five fuzzy sets (NL, NS, ZE, PS and PL). Each set is overlapped a 50% with their adjacent set to assure the softness of the reply (figure 1).

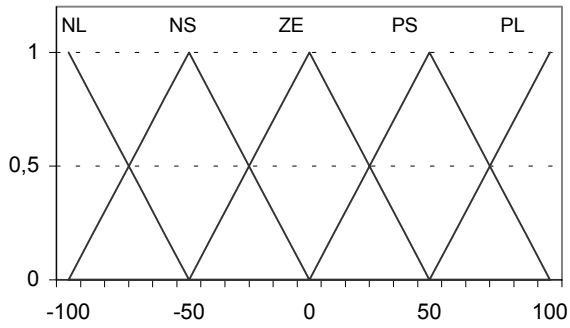

Figure 1: Membership function plots. X-axis represents raw ACE and Y-axis represents membership degree.

The meaning of fuzzy sets is:
NL: Negative Large
NS: Negative Short
ZE: Zero
PS: Positive Short
PL: Positive Large

- Filter rules. In a matrix of rules it is defined the operation type that is expected: in the cases that the DACE is of equal direction that the ACE, the efforts are not minimized. When they are small or of contrary direction, they decrease the efforts, except for very high values of ACE (figure 2).

ACE/ deltaACE	NL	NS	ZE	PS	PL
NL	NL	NL	NL	NS	ZE
NS	NS	NS	ZE	ZE	ZE
ZE	ZE	ZE	ZE	ZE	ZE
PS	ZE	ZE	ZE	PS	PS
PL	ZE	PS	PL	PL	PL

Figure 2: Rules fuzzy logic matrix.

- The matrix of rules that it is defined in this way has two areas: a central area where they are minimized efforts, and an external area where the correction of the error signal prevails.
- ZOOM Effect. It has been defined a gain on the ACE signal depending on the France interchange deviation so that, in case of high values of deviation, the signal shifts toward the external area of the matrix to correct quickly the deviation. It is a more effective alternative than to incorporate a new variable that increases the number of rules.

3.2 Results of fuzzy control

To study and evaluate the filter effect in the real-time system of Iberdrola the following variables have been used:

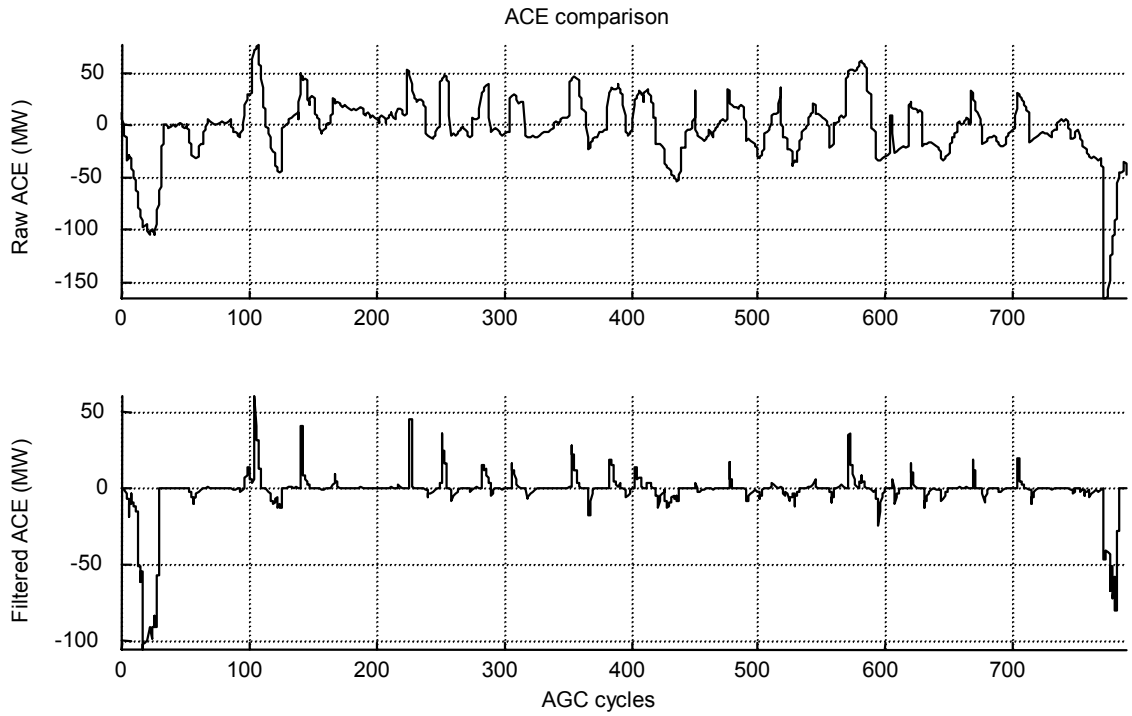

Figure 3: ACE comparison with and without the filter.

- Impact in the peninsular system, measured on the deviation interchange with France. It represents the effect of the filter as stabilizer.
- Number of solicitations to the generators. It indicates the effect of saving pulses.
- Cost of secondary regulation. Penalties can be expected in regulation costs in exchange for the beneficial effect of waste of the generators.

The described ACE filter is operative in the DCG of Iberdrola from June 1 2000. As a result of the filter the ACE signal becomes significantly smaller, an example of this is shown in figure 3 (on thirty consecutive minutes). The evolution of the previous variables in two similar months (with the same regulation requirements) has been followed, before and after the installation of the filter and they have been carried out observations that allow us to affirm:

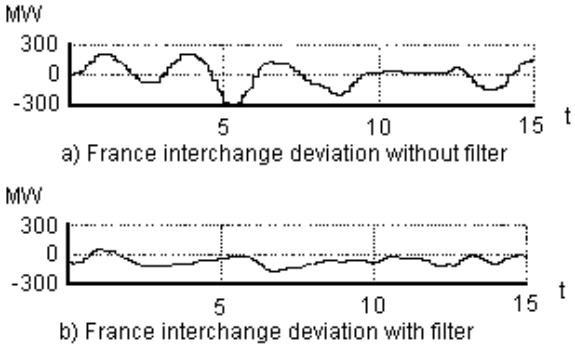

Figure 4: France deviation with and without filter.

- The standard deviation of the interchange signal with France was reduced in 20% what indicates a more stable signal. The maximum bandwidth values of the signal also decrease, although around 15%. In the figure 4 the different aspect is shown that has this signal without and with application of the filter, compared in days of similar characteristic and at the same hour.
- The requesting number to the generators goes down in approximately 40%, as it is shown in the table 1. The requesting average hourly values in two similar months and other statistics are shown. The decrease of the total of requesting is observed, as well as the standard deviation, in approximately 25%.

	Raw ACE	Filtered ACE
Raise pulses	5156	3354
Lower pulses	5333	2972
Total pulses	10490	6327
Emergency states	2502	1727

Table 1: Effect in secondary regulation.

- At first sight, it looks as if the saving generator pulses turn into deterioration in the signal error fulfilment that would increase the penalty cost. Nevertheless, the results have shown that, far from deterioration, the regulation improves due to the smallest requirements that it implies the global stabilization of the system. The results are summarized in the table 1, where it is observed that in spite of a bigger deviation between the schedules and the real demand, the requirements of secon

dary regulation and the penalties for bad regulations have decreased.

In resume, a tool designed for the saving waste of the machines, it has demonstrated to have some stabilizing characteristics that benefit to the whole system of peninsular regulation.

4 ACE ALLOCATION LOGIC

The generators among the regulation effort is distributed should be in remote mode. In this mode the generation control of the generators is responsibility of the AGC. The ACE must be distributed between these generators, but it could be made in different ways. There are some aspects to be taken into account in this distribution. The main ones are discussed next.

4.1 Regulation factors

In its previous implementation, the AGC distributed the ACE signal among the generators according to a static parameter assigned to each generator and calculated by its theoretical regulation capability. This parameter is called regulation factor.

This way of operation has been shown insufficient and it has been necessary the inclusion of a new dynamic logic to calculate the regulation factor, that adjusts its value to the fulfilment of each generator. This logic is in charge of decreasing the requirement regulations in the generators where its regulation tracking is bad, and moving this not supplied power to another generators with good fulfilment. It is possible in this way to obtain the best speed from the generators in used and, therefore, a better fulfilment of ACE signal.

The adjustment logic uses the tracking unit variable SUM2, calculated through a PI control of the error signal. A tuning parameter determines the rate of reduction of regulation factor for non-tracking.

When non-tracking condition disappear, regulation factor recovers its original value.

4.2 Limit adjustment

A frequent problem with AGC operation is the mismatch between real and expected limits. This causes a bad distribution of ACE, since unreal power regulation capabilities are assigned to generators.

For hydraulic power stations, a new cutting logic for the regulation limits has been implemented. This logic is based on the actual net head of each plant. With this change it is possible to eliminate penalties that habitually occurred when a generators arrived to a maximum of exploitation, but its regulation limits were bigger.

Hydraulic supervision logic calculates the maximum power generation capability taken into account the real reservoir elevation. This value is transmitted to AGC logic, which incorporates it like the new regulating limit.Furthermore, maximum water efficiency is calculated too, and could be used as regulation limit, if desired.

4.3 New regulation mode

So far, only one mode could be used as regulating mode. It was the automatic mode (or AUTO). However, this would be insufficient in certain situations.

It has been defined a new regulation mode, called BREG. Generators within this mode act as "reserves" for the AUTO generators. They are in charge of contribution to ACE regulation fulfilment when the AUTO generators are insufficient. These generators turn into its base value when the requirement decrease and the AUTO generators are able to manage the ACE regulation.

Regulating limits of this new kind of regulating mode are taken into account in reserve calculation, and regulation factors are adjusted as similar way as pointed, although in separate terms.

5 OTHERS

Besides these fundamental modifications developed in the AGC function, there are many of modifications that consist in small adjustments. They have improved in an evident way the AGC function. Among them they are:

- Optimization and reorganization code, by means of the elimination of obsolete functions in the new environment and the conceptual organization of the source code.
- To improve the fulfilment logic that allows to detect the generators that are not fulfilling the generation requirements appropriately and to act in consequence.
- Use of the local reference signal of each generator that plus to the desired generation value, it allows a better administration of the controls to send.
- It is added the concept of forbidden areas for the regulation in each generator.
- To adapt the treatment of the shared power stations.

Related to special control modes, the logic have been improved in this ways:

- Permissive ACE, blocking in a selective way the controls that would make move to the generators in opposite direction to the ACE signal.
- New type of operation, that allocates the entire regulation effort just to a generator when the ACE signal is small. The rest remains at the same power generation level.

6 CONCLUSIONS

The application of the new protocol of the Electric Sector of 1997 to the markets of Complementary Services in Spain has supposed a considerable increment of the relative importance of the improvements for this concept in the generation activity.

Iberdrola, aware of the necessity of improving the quality of their software of Automatic Generation Control, it has attacked during the years 98, 99 and 2000 an

ambitious project of improvement of the applications installed in their EMS.

By means of the incorporation of fuzzy logic and advanced systems of computing, a significant improvement of the economic and operative areas of the Complementary Service of secondary regulation has been achieved.

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