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# Operation of Rapid Start Units in an AGC Area

***Abstract**. Rapid Start units present high generation cost, so they are not usually online, but good dynamic response, so they are very suitable for AGC operation. The startup process of these units is very fast so they can be online and providing regulation within just a few minutes. In this paper a simple algorithm is presented to determine when to start up an offline rapid start unit to provide AGC service. The algorithm is tested using real operation data, with successful results. How to select the most appropriate values for the algorithm parameters is also analyzed in the paper.*

***Streszczenie.** Jednostki szybkiego startu są bardzo pożyteczne w systemach AGC (Automatic Generatiun Control). W artykule zaprezentowano algorytm umożliwiający kontrolę optymalnego startu jednostki ze stanu offline. Przeanalizowano działanie algorytmu oraz metodę doboru jego parametrów. (**Sterowanie jednostkami szybkiego startu w systemie AGC**).*

**Keywords:** Ancillary Services, Rapid Start Units, Load Frequency Control, AGC.
**Słowa kluczowe:** jednostki szybkiego startu, generacja energii, AGC.

## 1. Introduction

Load Frequency Control (LFC) is one of the ancillary services of a power system and its main objective is to maintain system frequency at its scheduled value. LFC is operated in three different levels [1]. Primary control is in charge of arresting frequency decay and a frequency deviation will remain in system frequency after its actuation. Automatic Generation Control (AGC), also known as secondary control, is intended to return frequency at its scheduled value. To operate AGC the power system is usually divided into several areas and an additional objective of AGC is to keep power interchange between areas at its scheduled value. Tertiary control objective is to restore AGC reserve when it has been used.

In order complain with AGC objectives each area needs to have an AGC regulator which adjusts the load setpoint of several online generators in the area to the required value [2,3]. However, offline units can be used to provide AGC regulation if they are assured to be online when they are needed. If this operation mode is used, the power setpoint of online units will be adjusted while the total regulation reserve available is considered enough. If the regulation reserve of the area is getting exhausted, then a rapid start (RS) unit can be started up so that it will contribute to AGC regulation with its own regulation band once it is online. This operation is only valid if the start up time of the unit is small enough for the unit to be online in a few minutes, i.e., before the area regulation band is completely exhausted.

Rapid start (RS) units are units that can be started up and made available in a few minutes (a typical value will be five minutes) [4]. RS units can be for example open cycle gas turbines (OCGT) or hydro units [5]. RS units have usually high operational costs, so that it is preferable to keep them offline. However, they usually also have high ramp rates, which makes them very suitable to AGC regulation. Thus it is advisable to keep rapid start units offline and to start them up only when they are needed, so reducing the operational costs but taking advantage of their high dynamic performance [6].

Rapid Start (RS) units usually have certain restrictions than must be taken into account when started up and switched off for AGC regulation. These restrictions depend on the actual technology of the unit. For example, as stated before, the start up process of the unit can last for several minutes. In some cases, the start up process can be stopped, especially at the beginning, without incurring in a great cost. This can be taken into account in the start up decision algorithm, and the process can be stopped, in case the situation changes just after a start up decision and advices that the start up of the unit is not needed. However, many unit technologies will not permit to stop the start up process once it has begun. Moreover, due to the unit internal processes, once a RS unit has been started up and it is online, probably it will have to keep online during a certain time before it can be switched off. Or, at least, switching it off just after it has been started up is much costly than keeping it online for a certain time, for example during one hour. For the same reasons, the switch off process will probably not be able to be stopped until it is finished, i.e., once the unit receives the switch off signal it will complete the switch off process and turn offline. And once the unit is offline, a certain offline time is needed before the start up process can be executed again.

The main risk when using Rapid Start (RS) unit in an AGC area is than if the RS unit is not correctly online when it is needed, the area will not be able to provide the necessary power to the system. This will mean a lack of a correct response of the area that can have important consequences. If the area is operating in an interconnected system, the power that one area can not provide will be generated by another area in the system, so that the system can still be correctly operated. However, the area with an incorrect response will be probably penalized somehow.

In order to successfully have rapid start units online when it is needed, an adequate algorithm has to be developed. This algorithm has to assure that RS units will always be online when they are needed but, on the other hand, it will have to try to minimize the time that RS units are online when they are not needed, so reducing the operating costs. Moreover, the process of start up will also have an impact in unit wear and tear and so in maintenance costs. Thus, the number of unit starts up needs also to be minimized. Several studies have been presented in the literature regarding the start up of RS units, but they are referred to starting up a unit when, due to a contingency, an online generating unit is lost [7,8], not to the start up of a RS unit for the normal operation of the AGC.

In this paper an algorithm to obtain the signal of start up and stop for a RS unit that will participate in AGC is presented. The unit will be started up when the regulation reserve of the area is getting exhausted and will be stopped when the regulation reserve without the RS unit becomes sufficient again. The algorithm will be tested by simulating the operation of an AGC area using real operation data as input.

The paper is organized as follows. The algorithm developed is described in section 2. The model used for the simulations is presented in section 3. Simulation results for the operation of the proposed algorithm using real data are shown in section 4, including an analysis of the best values to fix to the algorithm parameters. The main conclusions are presented in section 5.

## 2. Algorithm description

The algorithm developed is described. First, the main objectives for the algorithm are listed. Then, the algorithm is detailed, including the parameters established to adjust the algorithm behaviour. Finally, a discussion is presented regarding the appropriate values to be set to the algorithm parameters.

### 2.1 Algorithm objectives

An algorithm to obtain the signal of start up and switch off a RS unit has been developed. Then, the output of the algorithm is a true/false signal that will indicate if the unit is needed to be online or if it is better kept offline. Having in mind the requirements and restrictions stated in the introduction, the main objectives of the algorithm developed to start up and switch off a RS unit are:

– RS unit will have to be online whenever they are needed. This prevents the AGC area for a lack of response if the area has to increase its generation and it has not the necessary up reserve.

– the time that RS units are online when they are not needed is minimized. As RS units usually have high operational costs, the total AGC area costs are reduced if they are kept offline as much as possible.

– the number of RS unit start–ups are minimized. Every start up of a RS unit has an impact in unit wear and tear and thus supposes and extra cost. Reducing the number of start–ups reduces the AGC area costs.

### 2.2 Algorithm description

A very simple algorithm has been developed to comply with all this objectives. Although the algorithm is very simple the results obtained are very promising as will be shown in the simulation results carried out using real AGC signals. The algorithm proposed is described below. For the sake of simplicity, only one RS unit is supposed and thus only one start up logic signal is calculated. However, the algorithm presented can be easily generalized if more than one RS unit is available to be started up. The area is supposed to have *N* regulating units, *N*–1 always online units and the RS unit being the unit *N*. The algorithm is as follows.

First, the maximum area generation under AGC with the RS unit offline is computed (*PMaxNoRS*). This is the limit for the area generation without needing the RS unit. If the total generation needed in the area is less than this value, the area can provide it with the RS unit offline. On the other hand, if the area has to generate more than this power, the RS unit must be online, because otherwise the area will not have enough reserve to be able to generate the total power needed. *PMaxNoRS* is then computed using (1)

$$PMaxNoRS = \sum_{i=1}^{N-1} PMax_i \tag{1}$$

where $PMax_i$ is the maximum power of unit *i* for AGC regulation.

The unit has to be already online when the area generation is *PMaxNoRS*. As the start up process of the unit lasts for some minutes, the start up signal has to be sent to the unit some time before *PMaxNoRS* is reached. Thus, the start up signal is set to true (1) some time before the area generation is *PMaxNoRS*. In order to do so, a certain power margin is fixed for the RS unit start up (*DifStart*), i.e., the start up signal will be sent to the unit when the total generation of the area (*PGen*) reaches (*PMaxNoRS–DifStart*).

The algorithm has to decide also when the RS unit online must be switched off. A certain power margin is fixed again for the RS unit switch off decision (*DifStop*), probably different from *DifStart*. The switch off signal will be set to true (1) when the total generation of the area (*PGen*) goes below (*PMaxNoRS–DifStop*).

Only one signal (*UnitOnline*) is sent to the unit to indicate if it has to be online (*UnitOnline*=1) or offline (*UnitOnline*=0). Thus, *UnitOnline* signal is calculated using (2), where *PGen* is the total generation of the area for AGC.

$$UnitOnline = \begin{cases} 1, \; if\left(UnitOnline = 0\right) \& \\ \quad \left(PGen \geq \left(PMaxNoSR - DifStart\right)\right) \\ 0, \; if\left(UnitOnline = 1\right) \& \\ \quad \left(PGen \leq \left(PMaxNoSR - DifStop\right)\right) \\ UnitOnline, \quad otherwise \end{cases} \tag{2}$$

An example of the calculation of *UnitOnline* signal is presented in Fig.1. *PGen* is the area total generation for AGC operation. *PMaxNoSR* is represented together with parameters *DifStart* and *DifStop*. Signal *UnitOnline* is plotted at the bottom of the figure, low values is *UnitOnline*=0 and high value is *UnitOnline*=1. The instants of change of *UnitOnline* value have been explicitly indicated. In the figure it has been supposed than the RS unit is correctly online when it is needed (before *Pgen* reaches *PMaxNoSR*) and thus PGen can be increases over *PMaxNoSR*.

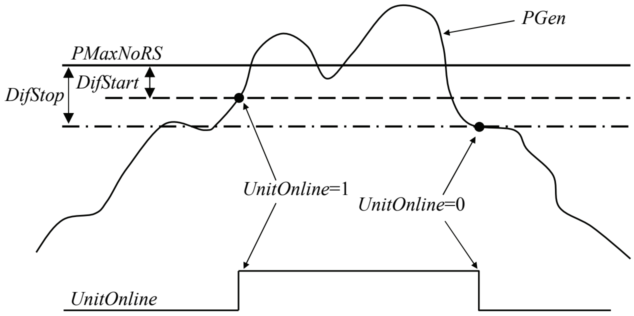

Fig.1. Example of calculation of variable UnitOnline

A certain hysteresis is needed to avoid continuous changes in *UnitOnline* when *PGen* is around the limit values (*PMaxNoSR–DifStart* and *PMaxNoSR–DifStop*). Thus, *DifStop* has to be set greater than *DifStart*. A more detailed discussion for the selection of *DifStart* and *DifStop* values is presented in the next subsection.

### 2.3 Parameter values discussion

The parameters *DifStart* and *DifStop* have to be carefully selected in order to obtain an adequate behaviour of the start up algorithm. Arguments to be taken into account when choosing the values to set to these parameters are discussed.

Parameter *DifStart* controls when start up process of the RS unit is initiated. If the value of *DifStart* is set to a too high value, the RS unit will be online before it is needed, and the area will be incurring in an extra cost. Moreover, as the evolution of the future total power needed in the area is not known, maybe the RS unit will be started up but *PMaxNoRS* will never be reached (the necessary generation can go down after the start up decision has been taken). In this case, the extra cost associated to the start up of the unit and the unit online operation for some time will be ineffective, as the contribution of the RS unit is not needed. On the other hand, if *DifStart* is set to a too low value, the area generation can reach *PMaxNoRS* before the unit is actually online (before the start up process finishes) and for some time the area will not be able to generate the needed power (until the moment the RS unit start up process finishes and the unit is actually online).

Parameter *DifStop* controls when the switch off process of the RS unit is initiated. If the value of *DifStart* is set to a too low value, the RS unit will switched off just near *PMaxNoRS*. But due to the unpredictable behaviour of the AGC generation needed in the area, this needed generation can increase again in the next minutes. As stated in the introduction, the switch off process of the unit can usually not be interrupted, and probably a certain time is needed once the unit is offline for the start up process to be carried out again. Then if the needed generation increases just after the switch off signal is sent, the RS unit will probably not be online fast enough for the area to be able to comply with that needed generation. Even if the subsequent start up process can finish in time, the cost of the new start up process will probably exceed the cost of keeping the unit online. On the other hand, if *DifStop* is set to a too high value, the RS unit could remain online much more time than it is needed, thus increasing generation costs.
The pros, contras and risks of a too high or too low value for parameters *DifStart* and *DifStop* are summarized in Table 1.

Table 1. Pros, contras and risks of parameters DifStart and DifStop

| Parameter | Too low | Too high |
|---|---|---|
| *DifStart* | Less operational costs but risk of not enough power when needed | Higher probability of enough power when needed but more operational costs and risk of a start up when not needed |
| *DifStop* | Less operational costs but risk of not enough power and maybe more operational costs | Higher probability of enough power when needed but more operational costs |

The relationship between *DifStart* and *DifStop* values is also important. If *DifStop* is set lower than *DifStart* (*DifStop<DifStart*), a change in *UnitOnline* from 1 to 0 (due to *PGen<PMaxNoSR–DifStop*) will be followed by a subsequent change from 0 to 1 in the next calculation, as *PGen* is still *PGen>PMaxNoSR–DifStart*. Moreover, as stated before, a certain hysteresis is needed to avoid continuous changes in *UnitOnline* signal when area total generation (*PGen*) is around the limit values. Thus, the values set to *DifStart* and *DifStop* should be *DifStop>DifStart*. The greater the difference between them, the less the probability of having continuous changes is *UnitOnline*, as once *PGen* has gone below (*PMaxNoSR–DifStart)*, it is still some time left till *PGen* goes below (*PMaxNoSR–DifStop).* On the other hand, a great difference between *DifStart* and *DifStop* will mean that DifStop will be high (even if *DifStart* is low), with the pros and contras stated before.

### 3. Simulation Model

Simulations have been carried out in order to evaluate the correct behaviour of the algorithm proposed and to set the most appropriate values for parameters *DifStart* and *DifStop*. A simple simulation model of an AGC area has been used. This simulation model is presented in Fig.2. All the regulating units have been included in an aggregated block except the RS units. This allows a simple modelling of the response of the area while focuses on the algorithm under test. The different blocks of the model are described below:

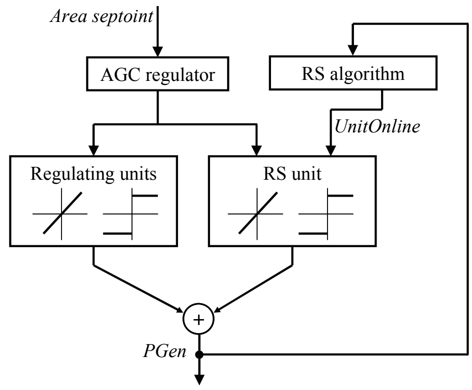


Fig.2. AGC area model used for the simulations

– AGC regulator: this block receives the area setpoint and distributes the area requirement among the regulating units. A very simple AGC regulator is used because it is not the main focus on the investigation carried out and to keep the results as general as possible. However, if the analysis is to be carried out for a certain AGC area, a detailed representation of the actual AGC regulator can be included in the model if needed to have more accurate results to the actual behaviour of that AGC area. The AGC regulator only distributes area requirement among the online units in the area. Thus, the RS unit is only taken into account in area requirement distribution when it is online after a start up process have finished.

– Regulating units: as stated before, an aggregated model of all the online regulating units except the RS unit is used. The aggregated model used has a ramp rate limiter, representing the aggregated maximum ramp rate of the units. This model also has an output limiter, representing the aggregated maximum and minimum power that the units under AGC can provide. The maximum limit has special importance here, as if the RS unit is not online when this limit is reached, the AGC area will not be able to provide the necessary generation (it will not be able to follow area setpoint beyond the maximum limit).

– RS unit: the RS unit is represented independently. Once the RS unit is online, its response model is similar to the regulating units aggregated model. The ramp rate of the RS unit and its maximum and minimum limits are included. The start up and switch off restrictions of the RS unit are also included in the model. Thus, the model receives the *UnitOnline* signal calculated by the proposed algorithm and calculates when the unit is correctly online and offline. Start up and switch off times are taken into account in this calculation.

– RS algorithm: this block implements the algorithm proposed to determine when to start up and switch off the RS unit. The input to the algorithm is the area power generation (*PGen*). The output is the *UnitOnline* signal that will be sent to the RS unit. Parameters *DifStart* and *DifStop* can be fixed to the desired values.

– *PGen* calculation: the total generation of the area is calculated adding the output of the Regulating units and the RS unit models.

### 4. Simulation results

In this section, simulation results of the behaviour of the proposed algorithm to determine the start up and switch off of a RS unit are presented. First, the results obtained for a certain values of DifStart and DifStop are presented. Then, an analysis is carried out based in simulation to select the best values for these parameters.

The simulations have been carried out using the model presented in Fig.2. The input to the model is the area setpoint, i.e., the total power generation than is needed in the area for AGC operation. In order to keep the simulation as real as possible, real data for area setpoint have been used. The actual generation of the area has been recorded during real operation in the Spanish Power System. This recorded generation has been used in the simulations as the power needed in the area (area setpoint). The total regulation band (up plus down reserve) of the area in the period of recording was 200MW. A unit with a 50MW regulation band in the area has been considered as the RS unit. Thus, the maximum AGC generation with this unit offline is *PMaxNoRS*=150MW. RS units usually have a small value for its minimum limit and then a value of 0MW for the minimum limit of the RS unit will be used in the simulations. Both the start up and switch off processes of the RS are set to last 5min (0.083h). The start up process can not be interrupted. However, if during the switch off process the unit needs to be started again, it can be online in just 1 minute (0.017h).

### 4.1 Algorithm behaviour example

An example of the operation of the algorithm proposed is analyzed. In order to present only the regulation band, the minimum generation of the units under AGC is set to zero. Thus, the AGC regulation band of the area is between 0MW and 200MW. As stated before, the RS unit will be considered to have a minimum limit of 0Mw and a regulation band equal to 50MW. The maximum AGC generation without this unit is *PMaxNoRS*=150MW. Parameter *DifStart* is set to 5MW and parameter *DifStop* is set to 20MW. Thus, the RS unit will be started when *PGen*=145MW and stopped when *PGen*=130MW. With these values a 15MW hysteresis is obtained, which is considered appropriate to prevent continuous start up and switch off of the RS unit. The results obtained are presented in Fig.  for three hours of the complete simulation time. Both area setpoint and area *PGen* are presented in the figure.

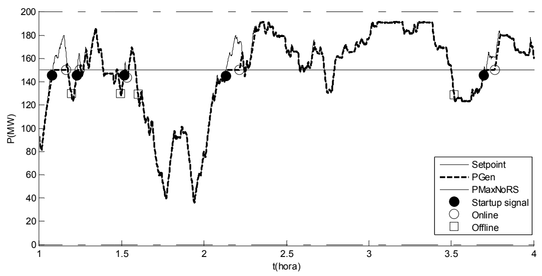


Fig. 3. Example of the operation of the algorithm proposed

The instant of *UnitOnline* changing to true (Startup signal), unit correctly online after its start up process (Online) and *UnitOnline* changing to false (Offline) have been highlighted in Fig.3. As can be seen in the figure, the Online instant is usually too late (see for example t=2.2h) and the area *PGen* can not correctly follow the area Setpoint. On the other hand, RS unit is switched of two times in the first half an hour (from t=1.1h to t=1.6h) and restarted again immediately after. Because this RS unit has been simulated to be able to be restarted during switch off process in just one minute, it gets online in time. However, if this where not possible, more time of area *PGen* not been able to follow area Setpoint will be obtained. Focusing only on this half an hour, it will be possible to avoid the two Offline instants if the value of *DifStop* were set a bit higher. Finally, in the three hours presented the area setpoint is most of the time above *PMaxNoRS*. Thus, the RS unit must be online most of the time and the possibility of reducing AGC operation costs seems to be low. However, it is important to notice that during other periods of the simulation the area setpoint remains lower and possibility of reducing AGC operation costs is higher.

### 4.2 Parameter values selection

As argued in section 2.3, the values of the algorithm parameters' have to be carefully chosen in order to obtain the desired objectives. The two main focuses in parameter values' selection are the cost reduction that is obtained and the time that the area generation (*PGen*) can not correctly follow the area needed generation (Setpoint). The first one is the main objective when using RS units and should be maximized. The second one is difficult to avoid completely but should be minimized or, at least, should be kept under a certain small value to avoid great problems in area response.

Examples where area generation (*PGen*) is not able to follow area setpoint have been shown in the previous subsection based on the results presented in Fig.3. It has been pointed there that changing algorithm parameters' values can minimize this situation. For example, it has been argued that setting a higher value of *DifStop* can prevent a RS unit switch off and a consecutive start up in a few moments. Moreover, setting a higher value of *DifStart* forces an earlier activation of *UnitOnline* signal and then makes it more feasible that the unit is correctly online in time. On the other hand this will have impact both in the number of start up processes and in the time the RS unit is online, i.e., in the AGC operation cost.

An analysis has been carried out to set the best parameters' values taken into account both setpoint not following and AGC operation costs. As an example, parameters *DiffStart* and *DifStop* have been increased in steps of 5MW from a small value (5MW) to a much higher value (30MW), related to the total regulation band of the RS unit (50MW). *DifStop* has been always set less than *DiffStart* (at least a 5MW difference is used) to have a certain hysteresis. The 15 different parameters' settings that have been tested are shown in Table 2.

Table 2. Different parameter's settings for the RS algorithm

| Case | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DifStart (MW) | 5 | 5 | 5 | 5 | 5 | 10 | 10 | 10 | 10 | 15 | 15 | 15 | 20 | 20 | 25 |
| DifStop (MW) | 10 | 15 | 20 | 25 | 30 | 15 | 20 | 25 | 30 | 20 | 25 | 30 | 25 | 30 | 30 |

For each simulation with a different set of parameter values', two different variables have been computed: (i) the percentage of the total simulation time that the area generation (*PGen*) has not been able to follow the area setpoint, and (ii) the AGC operation cost reduction of the area. The total AGC operation cost if the RS unit is kept online during all the simulation is used as the reference cost. A reasonable start up cost is used for each start up of the RS unit in the simulations when the RS algorithm proposed is used. The reduction in AGC operation cost is computed as a percentage to the reference cost. The results obtained for *PGen* not following area setpoint (% of total time) and AGC cost reduction (compared to full time online operation of RS unit) are presented in Fig.4.

As can be seen in Fig.4, increasing the value of parameters *DifStart* and *DifStop* reduces the time where *PGen* not following area setpoint but also lessens cost reduction. However, the slope of the variation in the time that area *PGen* is not able to follow area setpoint is greater than the slope of the variation in AGC cost reduction. Thus, it seems more reasonable to fix quite large values for parameters *DifStart* and *DifStop*. However, this conclusion is related to the data, RS unit characteristics and parameters' values studied. If this algorithm is to be used in a different AGC area, a similar analysis should be carried out to establish the best parameter values' using the actual

*PGen* profile of the area, the actual RS unit characteristics and costs and a sensible set of parameters' values.

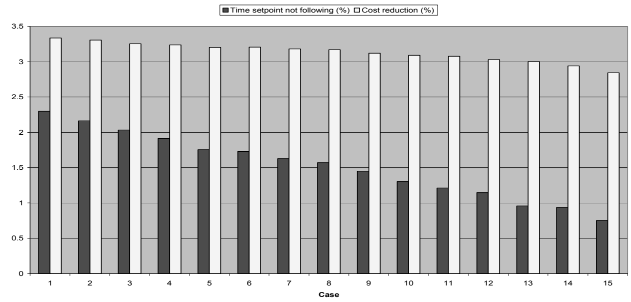


Fig.4. $P_{Gen}$ not following area setpoint (% of total time) and AGC cost reduction (% of total cost) for the cases in Table 2.

**5. Conclussions**

Rapid Start (RS) units are very suitable for AGC because they exhibit a good dynamic response. On the other hand, their generation cost is high and they are not usually dispatched. An algorithm is presented that permits starting up RS units only when they are really needed because AGC reserve is getting exhausted. This will allow taking profit of the good response characteristics of this units but reducing the AGC operation cost with respect to having the same units always online. On the other hand, the each start up of the RS unit will impose an extra cost and, moreover, if the RS unit is started too late, then during some time the area AGC power generation will not be able to follow the generation needed. The algorithm proposed is very simple but a correct setting of its parameters' values allows reducing generation cost with a small impact in area AGC setpoint following. The algorithm has been tested with real AGC operation data showing a good compliance of its objectives. Higher values for algorithm parameters seem to be more appropriate, but an analysis must be carried out for each actual AGC area as the results greatly depend on RS unit characteristics and costs, and in area generation profile.

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