Minimum Requirement for Frequency Regulation
And Control of Interchange in the Inter-Connectors

Introduction

Frequency of system is an indicator of real (active) power balance between generation and the summation of load demand and losses in the system. In the AC interconnection, the balance of real power is necessary for controlling system frequency and power exchange between interconnected systems. In order to achieve that, each country should have enough reserve capacity in order to maintain power exchange according to the schedule and control system frequency to meet the minimum standard in normal and emergency conditions.

Definition

AGC: Automatic Generation Control

SR: Spinning Reserve

ACE: Area Control Error

UTCE: Union for the Co-ordination of Electricity Transmission

P: Power in MW

LFC: Load Frequency Control

Purpose

The requirement has the following objectives,

1. To set up standard of frequency control of GMS interconnected power system
2. To set up minimum amount of spinning reserve each country shall have when they connected to the GMS system
3. To set up procedure and standard for maintaining generation reserve of each country.

Requirement

1. Every generator shall have the following systems.
    - A. Primary Control Reserve System
    - B. Secondary Control Reserve System
    - C. Tertiary Reserve System

A – Primary Control

A - R 1 Generation reserve and response will have primary reserve.

A-R 1.1 When incident is occurred such as sudden loss of generation or load, system will have enough primary reserve to main system frequency without interruption of load or generation.

A-R 1.2 Primary control shall have appropriate response according to the change of system frequency.

A-R 1.3 Primary control in each country will have appropriate response and it is coordinated accordingly with those of other countries. Amount of primary reserve depends upon the maximum load demand in that country plus MW import from neighboring countries. However, the amount of primary reserve has to be less than 30% of total generation reserve.

A - R 2 Characteristics of Primary Control Reserve

A-R 2.1 Ready to operate at all the times and have to be dependent from Secondary Control Reserve.

A-R 2.2 The exchange of Primary Reserves between countries is possible if it is agreed by those countries.

A-R 2.3 Each country shall announce Primary Control Reserve as well as the maximum power trades by December of each year.

A - R 3 Investigation

A-R 3.1 If the incident is occurred, details and impacts shall be recorded. The report shall be released if it is asked by member countries. In case of important incident, data and details of the incident shall be exchanged between interconnected and member countries

A-R 3.2 Frequency should be recorded every 1 minute but not longer than 10 minutes.

B - Secondary Control Reserve

B1 Generation Reserve and Response of Secondary Reserve

B - R 1 Secondary Control is used for compensating the power balance between generation and load demand. The response of secondary reserve is longer than that of primary reserve. Response of

Secondary reserve is between 30 second and 15 minutes in order to bring the frequency of the system back to nominal values.

B-R 2 Action of Secondary control is to reduce Area Control Error when the load is different from the planning or any power imbalance happened due to any reason. Agreement from other countries has to be given if the secondary reserve is used for other purpose.

B-R 3 Dispatching center of each country shall manage secondary reserve properly in order to handle power imbalance and emergency cases that might be happened.

B-R 4 Management of Secondary Reserve

B-R 4.1 All the country shall set up the time base on World standard time.

B-R 4.2 If AGC is not working due to any reason, the change of power generation shall be done by manual.

B-R 4.3 Dispatching center shall manage generation reserve in order to allow zero value of Area Control Error within a specific time.

B-R 4.4 Dispatching Center shall determine maximum generation when N-1 generation criteria is applied. Power system standard have to be maintained at all time when N-1 generation criterion is used.

B-R 4.5 Dispatching center shall announce the maximum generation reserve of their system in MW. This information shall be transfer once in a year to interconnected countries in order to maintain generation reserve.

B-R 5 Control and Inspection

B-R 5.1 Secondary Controller (AGC) shall operate on-line and Closed-loop. It should have black up system to increase reliability. The response of secondary controller at every power generator shall be monitored.

B-R 5.2 Dispatching center shall monitor the response of each power generation, tie line between countries during normal and N-1 case. The data shall be recorded for study purpose.

C – Tertiary Reserve

Tertiary reserve can be obtained from Off-Line power station. When emergency case is occurred, this type of generation shall be operate in order to substitute generation from Secondary Reserve and Primary Reserve within a specific time.

C-R 1 The amount of tertiary Reserve has to be enough to replace Secondary Reserve when emergency case is occurred. The total capacity of the system including this reserve has to be equal or higher than the maximum load demand.

C-R 2 When tertiary reserve is used, dispatching center shall consider: time of emergency condition, time to increase/decrease generation, fuel/water reserve and the risk of partial blackout.

C-R 3 Reserve can be called from interconnected country if tertiary reserve is not enough. However, power import has to be within the contract or capacity of the interconnector.

C-R 4 If the agreement of generation reserve through tie-line interconnection is changed, those countries shall notified ot6her member countries in order to change reserve between interconnectors.

2. Dispatching center has to have:

2.1 Automatic Generation Control System that can control frequency and interconnected tie line power trade.

2.2 Management of Spinning Reserve and Standby Reserve

2.3 Management of load demand in case of not enough generation

2.4 Special Scheme Protection in case of emergency condition

Standard

S.1 Primary Reserve

S 1.1 shall operate when frequency is over ± 0.05 HZ of nominal value. It will increase to the maximum value by 30 seconds or frequency deviation above 0.2 HZ.

S 1.2 shall have enough amounts in order to handle the outage of the highest generation of a generation in the system (700 MW) without power interruption.

S.2 Secondary Reserve

S 2.1 shall operate by adjusting MW set point at the power station. It will start by 30 second and reach the maximum by 15 minutes.

S 2.3 When the incident that causes the loss of generation is occurred, the frequency of the system will be decreased. The load may be decreased about 1% per 1 Hz. At the same time, primary response of the generators is automatically activated and depleted within 30 second. Secondary reserve shall increase to compensate the lack of primary reserve, thus makes frequency come back to nominal values (± 0.2 HZ) by 15 minutes.

S.3 Tertiary Reserve

S 3.1 shall replace secondary reserve by 4 hours.

S 3.2 shall have enough amounts to serve the load in case of outage.

Guideline

1. Availability declaration of power station in the next day will be released by 12:00 hrs of the present day. Status of Primary Control and Secondary Control shall be shown in the availability declaration. The information is then given to dispatching center or planning department in order to manage spinning reserve in the daily load planning.

2. Dispatching center shall test primary and secondary control system in the regular basis.

3. Dispatching center will have emergency plan when AGC does not operate. AGC should be brought back to normal operation as soon as possible.

4. Dispatching center will have a regular plan to make/revise the emergency procedure for Spinning/Standby Reserve management in case of generation deficiency. Special scheme protection shall be updated and activated appropriately at all times.

Compliance

1.Compliance monitoring system will be complied as follows:

1.1 Responsibility for monitoring and coordinating

- In power system of each country, dispatching center and power stations shall provide information according to generation control if it is required by investigator.
- Dispatching center of interconnected countries shall check the operation of AGC in order to achieve the desired operation.

1.2 Co-operation of investigation and times

Depend upon the requirement of investigator.

1.3 Data collection

Parameters related to frequency and system control will be recorded. These data may be used by investigator.

2. Level of Non–Compliance is as follows:

2.1 Level 1

2.2 Level 2

2.3 Level 3

2.4 Level 4

Appendix

1. Introduction

Frequency control is classified into 2 types based on time frame of response: Primary Control and Secondary Control. If the response is less than 10 second, it may be called Primary control. Primary control mainly depends on speed change of turbine. The second period is the secondary control, which is mainly depends upon the operation of Automatic Generation Control (AGC). AGC at the power station receives the MW set point from dispatching center to bring system frequency back to nominal value.

2. Primary Control

Primary control is the control of power balance in the single control area by using Governor Control System of generators to control the change of frequency or turbine speed after the incidents. The time frame of primary response is seconds. The final frequency of primary control is not equal 50 Hz as the response is the initial response. The system requires secondary control to compensate the power mismatch.

Primary Control is initialized when the frequency deviation is above 0.05 Hz. (Dead Band is 0.05 Hz) of nominal value. The amount of Primary Reserve is used when Primary Control is activated. The following are the requirement:

- Primary control reserve has to used up to 50% capacity within 15 seconds and
- It will be used up to 100% by 30 seconds.

3. Secondary Control

Secondary control system is the control of power balance between real power produced by generator and combination of load demand and losses in the single control area. Secondary control system is operated from Automatic Generation Control located at dispatching center by changing generation outputs of the generators. Secondary Control System will be started by 30 seconds after the incidents (after the primary control) in order to maintain the system frequency at the nominal value (50 Hz). The response of Secondary Control will be finished by 15 minutes after the incident. The change of generation output depends upon the secondary control reserve at that time.

4. Spinning Reserve Management

Spinning Reserve is amount of maximum generation of all generators less the actual MW output (Spinning Reserve = Daily Maximum Availability – Actual MW Output). This amount is used to determine the operation of Primary Control in 30 seconds and Secondary Control in 15 minutes. Standby Reserve is the amount of generation of standby units, which can be started up by 5 to 30 minutes depending on type of power stations, in order to compensate the losses of generation in a short time. Standby reserve may be used to manage spinning reserve in case of high load demand compared to daily forecasted value.

In normal case, dispatching center will have appropriate management of spinning reserve by considering actual MW output and reserve distribution of generators.

Secondary Control Reserve can be determined from the following equation.

$$SR = SR_{UCTE} + SR_{Dynl} \qquad [1]$$

where

SR_{UTCE} : Minimum Secondary Reserve

SR_{Dyml} : Secondary Reserve determined by the forecast of the increase of load demand, and

$$SR_{UTCE} = \sqrt{a.L_{\max} + b^2} - b \qquad [2]$$

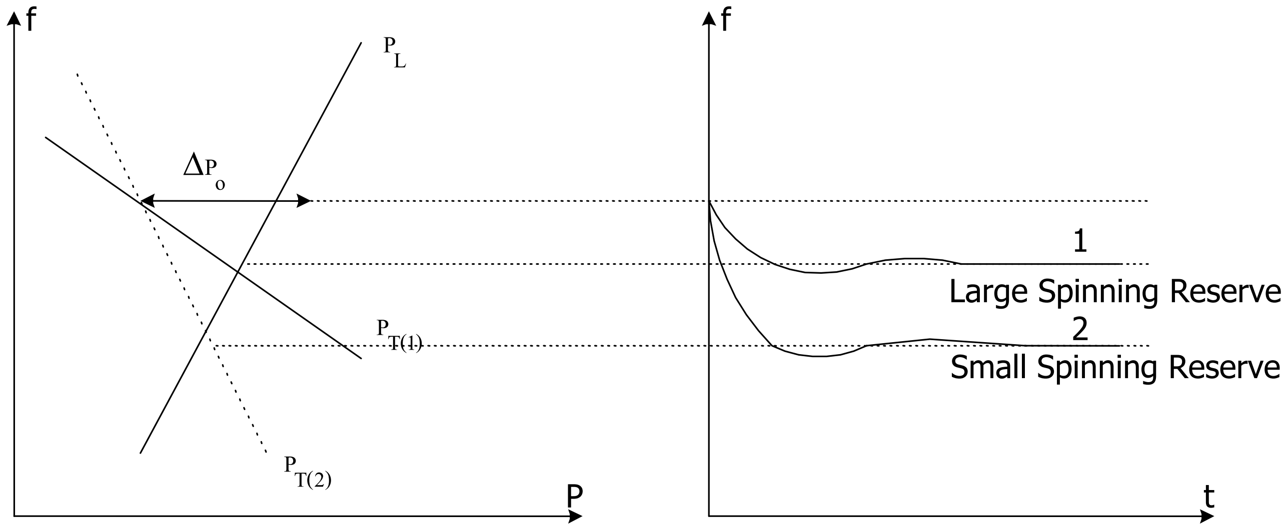
Where

$L_{\max}$: Anticipated Load of each country (UTCE use a = 10, b = 150)

Spinning Reserve can be computed from equations [1] and [2] and it can handle the trip of largest generation running in the system as well as the change of load demand. Equation [2] provides lowers cost of operation than equation [1] as the secondary control reserve is lower.

5. The importance of Spinning Reserve

This topic presents the importance of spinning reserve by considering the Fig. 1.



รูปที่ 1 Frequency Drop เนื่องจาก Power Imbalance

From Fig. 1, it can be seen that at the same power imbalance, frequency drop depends upon the amount of spinning reserve. The higher the spinning reserve, the lower frequency drop. Spinning reserve coefficient is determined from

$$r = \frac{\sum_{i=1}^{N_G} P_{ni} - P_L}{P_L}$$

$$p = \frac{\sum_{i=1}^{R} P_{ni}}{\sum_{i=1}^{N_G} P_{ni}}$$

where $\sum_{i=1}^{N_G} P_{ni}$ is the summation of power rating of all power station in the system and

$\sum_{i=1}^{R} P_{ni}$ is the summation of power output of all power station delivering the generation, considering only linear Characteristics

r is Spinning Reserve Coefficient, which depends on the MW left in the generators.

If every generator has the same droop constant and does not deliver at the maximum capacity, we would have $\rho_i = \rho$ and $K_i = 1/\rho$. Generators delivering the power at the maximum capacity would have $\rho_i = \infty$ and $K_i = 0$. Accordingly,

$$\Delta P_T = -\sum_{i=1}^{N_G} K_i P_{ni} \frac{\Delta f}{f_n} = -\sum_{i=1}^{R} K_i P_{ni} \frac{\Delta f}{f_n} \cong -K \sum_{i=1}^{R} P_{ni} \frac{\Delta f}{f_n}$$

$$= -Kp \sum_{i=1}^{N_G} P_{ni} \frac{\Delta f}{f_n} = -Kp(r+1) P_L \frac{\Delta f}{f_n}$$

If the above equation is divided by P_L both sides,

$$\frac{\Delta P_T}{P_L} = -K_T \frac{\Delta f}{f_n}$$

where

$$K_T = p(r+1)K$$

and

$$\rho_T = \frac{\rho}{\rho(r+1)}$$

When ρ_T is higher, Spinning Reserve will be decreased. If the P_L is equal to System Generating Availability, coefficients r and p will be equal to 0 and ρ_T will become ∞ (all generators delivers at the maximum capacity)

If linearization is used, Frequency Drop of the system can be calculated from

$$\frac{\Delta f}{f_n} = \frac{-1}{p(r+1)K + K_L} \frac{\Delta P_o}{P_L}$$

$$\Delta P_o = \Delta P_T - \Delta P_L = -P_L (K_T + K_L) \frac{\Delta f}{f_n}$$

Frequency drop depends upon the MW output that the generators can increase after power imbalance is happened. The large system will have high frequency bias as there are many generators that can share the load increase. However, electrical distance between generator and the location of power imbalance will have effect to the system frequency as generators at different locations see different frequency deviations. Thus, the proper distribution of spinning reserve is required to help the frequency recovery during the incident (In this report, the type of power plants based on frequency variation is not discussed. It emphasizes only on the impact of spinning reserve)

6. Automatic Generation Control (AGC)

AGC system is the control of power generation at the power stations during the secondary control in order to maintain the balance between real power at the supply and load demand including losses. AGC system is different from governor control system in that the governor system controls the output of individual generators. AGC, on the other hand, control the total generation of all power stations connected in the system to maintain the system frequency at 50 Hz or at specific value. The objectives of AGC are as follows:

1. To main frequency of the system at 50 Hz or at specific value
2. To control interchange power among control areas
3. To optimize total operating cost of the system.

AGC system can be classified into 2 systems: Load Frequency Control (LFC) and Economic Dispatch (ED). Details of LFC and ED are explained in the following sections.

7. Load Frequency Control Function (LFC)

LFC is classified into 2 systems: AGC control system and unit control system. AGC control System monitors the balance between generation and load. Unit control system changes the MW output of generators. Figure 2 shows the function of AGC and Unit Control Systems. Details of AGC control system and unit control system are explained in the following subsections.

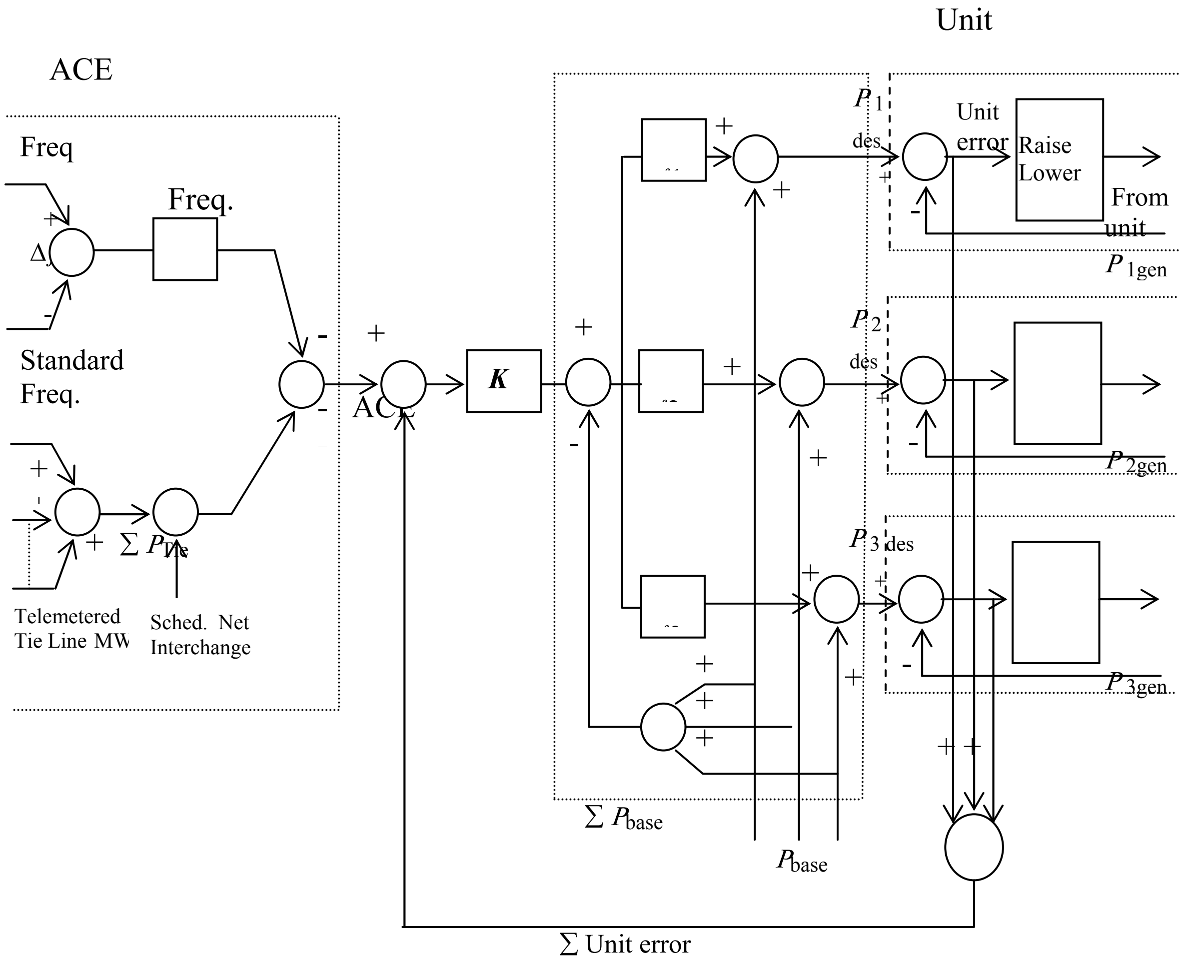


Fig. 2 Schematic Diagram of AGC

<u>AGC System Control</u>

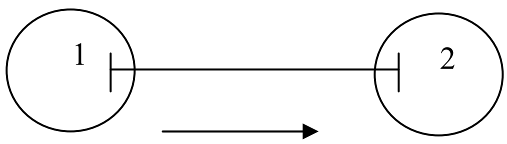
AGC use Area Control Error (ACE) as an indicator for power imbalance. From Fig. 2, AGC compares actual Frequency and normal Frequency (50 Hz) or Standard Frequency (specific value), and use the error to change MW set points of generators. The error is the power imbalance between generation supply and load demand. The positive error means over generation and the negative one means under generation. Monitoring system for AGC depend upon Area Control Error Mode, which monitor different variables. Area Control Modes are:

a) **Constant Net Interchange** In this mode, AGC system will check the tie line interchange and Inadvertent Energy Correction (If it is activated). If the tie line interchange is different from the targeted value, AGC will change the set point of generation at power stations, in order to bring the tie line interchange back to previous value.

b) **Constant Frequency** In this Mode, AGC will check the frequency deviation of system and time error correction (if it is activated). AGC change the MW output of generators to correct the frequency deviation. If this mode is used, the AGC will respond according to frequency deviation at another connected area as well. This may cause the problem to one area when the problem is occurred in the other area. The frequency deviation is dependent on the electrical distance between areas.

c) **Tie Line Bias** AGC will check both frequency and tie line interchange as mentioned in a) and b).

Example1: If the system is composed of Control Area 1 and Control Area 2. Tie Line Flow is from Control Area 1 to Control Area 2 as shown in Fig. 3



ΔP_{L1} = Power Change in Area 1

ΔP_{L2} = Power Change in Area 2

Fig. 3 Tie Line Bias Control of system with 2 Areas

The control action of generation in each area is determined from the following table.

Table 1 Control Action of AGC System in the Example 1

$\Delta\omega$	ΔP	Load Change	Resulting Control Action
-	-	ΔP_{L1} + ΔP_{L2} 0	Increase P_{gen} in System 1
+	+	ΔP_{L1} − ΔP_{L2} 0	Decrease P_{gen} in System 1
-	+	ΔP_{L1} 0 ΔP_{L2} +	Increase P_{gen} in System 2
+	-	ΔP_{L1} 0 ΔP_{L2} −	Decrease P_{gen} in System 2

Apart from the functions of frequency and tie line deviation, there are two additional functions, which use accumulated values of frequency and tie line interchange.

a) **Inadvertent Energy Correction Mode** AGC will use the difference of net actual and net interchange, which is collected as energy. The difference is used to adjust ACE gradually in order to reduce the inadvertent energy to zero in a long run. The compensation will not be used during emergency state.

b) **Time Error Correction Mode** AGC will use the difference of actual System Frequency and Desire Frequency and convert it to MW to compensate the over and under generation. The compensation is used to adjust ACE gradually in order to reduce time error to zero in a long run. The compensation will not be used during emergency state. This can be classified in the following example. If the power system has the positive time error, this means the system has over generation in the past. In order to have zero time error, AGC will adjust ACE more than normal operation in order to reduce the accumulated over generation thus the time error. On the other hand, if the system is under generation, AGC will adjust ACE less than the normal operation.

Unit Control

From Fig. 2, AGC sends signal to all power stations to adjust the generation considering unit limit and unit control mode. The change of generation is in the same way as the change of ACE Monitoring Level.

8. Economic Dispatch Function (ED)

ED system manages the generation of each power station to minimize total operating cost of the system. Fig. 4 shows Graphical Solution of Economic Dispatch. AGC will dispatch generation of participated generators in Unit Control Automatic Economic Mode and Automatic Mode by computing Economic Base Point and Participation Factors. The signal will be sent to adjust MW set point at power stations.

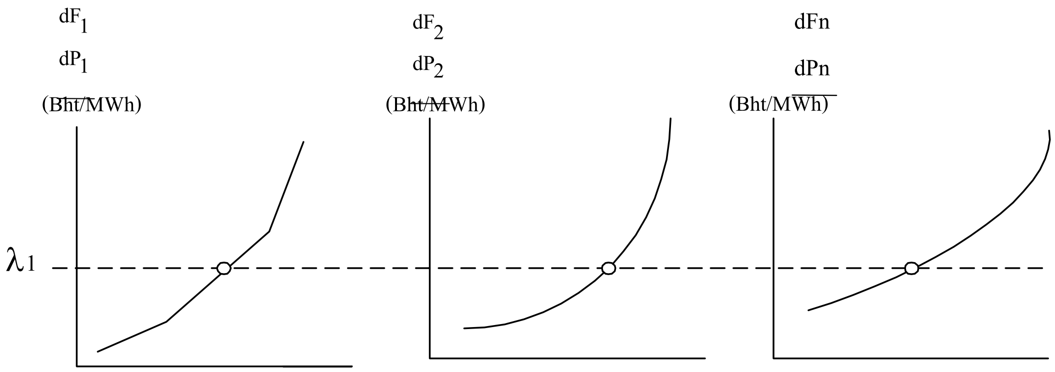


Fig 4 Graphical Solution of Economic Dispatch