太陽光発電の大量導入時の適応形負荷周波数制御
Adaptive Load Frequency Control of a High Penetration of PV Generation

AE19432 Nurul Izzatie Binti Zulkiflee　　Supervisor　Prof. Dr. Goro Fujita

1. Introduction

Along with the development of power system, the importance for automatic generation control (AGC) has been increasing in power system design and operation. The type of control that is responsible in controlling the real power output of generating units in response to changes in system frequency and tie-line power interchange within specified limits is known as load frequency control (LFC) [1].

Since Japan is an island country with power grid isolated from other countries, it is extremely important for Japan's power network to ensure the balance of supply and demand sides with a proper frequency. Various frequency regulation methods were considered to maintain the frequency balance and on 2016, IEEJ developed AGC30, which is a simulation model for frequency regulation [2].

In this paper, the LFC model in AGC30 uses proportional and integral controller or PI controller as feedback control to reduce the area requirement (AR). It is necessary to set the proportional gain and integral gain to an appropriate value that does not adversely affect the system. The purpose of this research is to determine the most suitable gain value for the Proportional Integral (PI) controller in the LFC.

2. Load Frequency Control

The function of frequency control is to control the output of a power plant in response to the ever-changing load fluctuations and to maintain the system frequency. This balance between load and power generation is maintained by frequency control, and different control systems are combined according to the load fluctuation cycle. In the AGC, appropriate frequency control is implemented by combining different control system. There are three main parts of control demonstrated as shown in Figure 1.

1. Governor Free (GF)
2. Load Frequency Control (LFC)
3. Economic Dispatch Control (EDC)

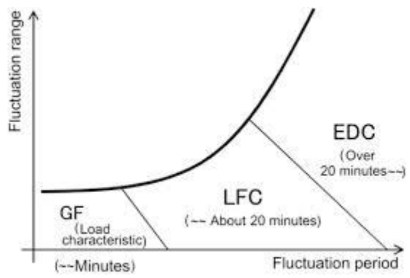

Figure 1. Control area for periodic demand fluctuations[2]

As for the division of each control, load fluctuations with a fluctuation cycle of up to several minutes are controlled by GF, and load fluctuations with a fluctuation cycle of several minutes to 20 minutes are controlled by GF and LFC. Then in the larger scale of operation, EDC will be utilized completely to minimize the total operating costs in an area by considering the most economical output distribution of the generator.

AGC30 model implemented two area interconnected power system which is two area with different settings are being connected by the tie line. In the supply and demand frequency simulation, it is necessary to simulate the generator and control system in detail not only in local area, but also in other areas to quantitatively evaluate the fluctuation of the system frequency.

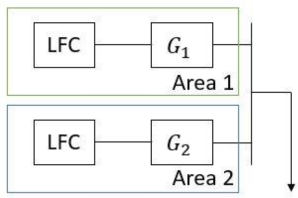

Figure 2. Two area model in AGC30

3. PI Controller

The type of controller that is related to this paper is PI controller, which is the combinational of proportional and integral control.

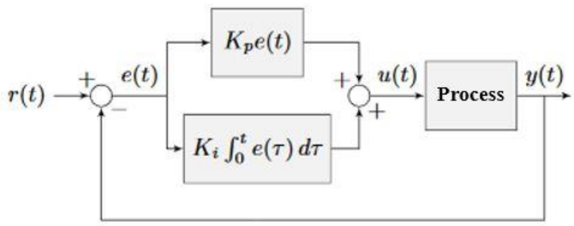

Figure 3. PI controller block diagram

PI Controller improves the steady-state performance of a control system. It is a feedback control loop that calculates an error signal by taking the difference between the output of a system and the set point. The mathematical equation for PI controller is written as below.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau \qquad (1)$$

From this mathematical equation, *u(t)* is the controller output while *e(t)* is the error signal representing as the controller input. K_p is the proportional gain while K_i is the integral gain of the controller. Proportional control uses a magnitude proportional to the deviation between the target value and the actual value as the control amount.

4. Simulation Results

The optimum values of proportional gain (K_p) and integral gain (K_i) when both local area and other area are interconnected are obtained by observing the power spectrum when the K_p and K_i are changed in Figure 4 and Figure 5.

For each analysis case, when compared with the power spectrum, the tie line differed depending on the value of the gain because the fluctuation period was about 10 minutes. It can be observed that when K_p=1.0 and K_i=0.003, it has the smallest power spectrum between $10^2 - 10^5$[s].

In Figure 6, at around 1.2 hour, the LFC output increases due to the rapid fluctuations of PV generation and causes the LFC to exceed the value of LFC capacity which is at 200[MW]. At around 1.5 hour, there is decreases in the PV generation and sharp increase in net demand, causing the AR output to drop below 200[MW] and causes a large LFC control balance because LFC was trying to compensate and follow the AR.

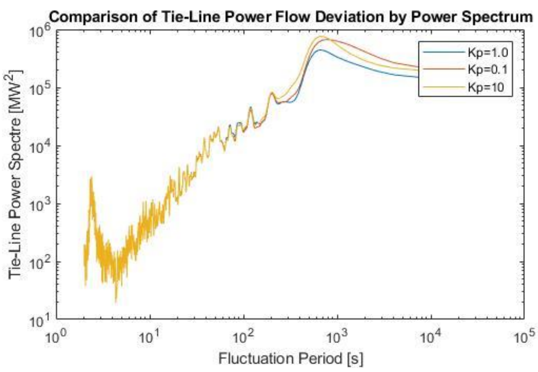

Figure 4. Comparison of power spectrum with different proportional gain

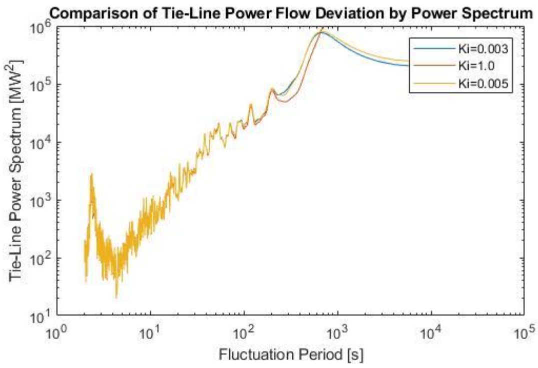

Figure 5. Comparison of power spectrum with different integral gain

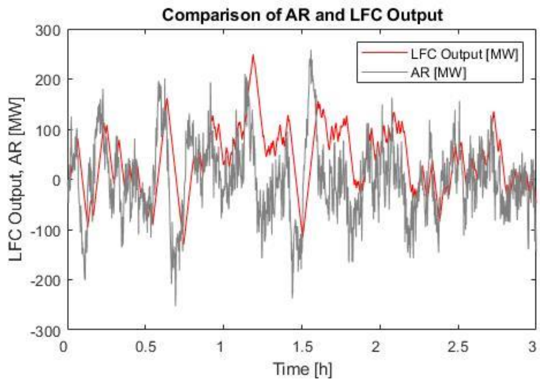

Figure 6. Comparison of AR and LFC Output when K_p=1.0 and K_i=0.003

5. Conclusion and Future Works

Tuning of PI controller used for adaptive load frequency control for two area interconnected power system has been presented. In this paper, power spectrum was used to determine the optimum values of the gain of the PI controller in LFC. The system performance was observed based on whether the value of AR and LFC output went over the LFC capacity and the stability of the systems. As a further study, this research can be applied to a longer simulation period, multi area power system and the optimum values for the PI controller gain value can also be obtained by applying Ziegler-Nichols method.

References

[1] W. Tan, "Unified Tuning of PID Load Frequency Controller for Power Systems via IMC," in IEEE Transactions on Power Systems, vol. 25, no. 1, pp. 341-350, Feb. 2010.

[2] Investigating R&D Committee on recommended practice for simulation models for automatic generation control: 'Recommended practice for simulation models for automatic generation control'. No. 1386, IEEJ Technical Report, 20 December 2016.