

# A Study on improve the Power System Stability by using the Load Following of the Nuclear Power Generator Control

<sup>1</sup>Hyun-Chul Lee, <sup>2</sup>Young-Gi Roh, <sup>\*3</sup>Byoung-Jo Jung

<sup>1</sup>Dept. of Electricity, Gimhae College, Gimhae-si, 50811, Republic of Korea

<sup>2</sup>Dept. of Electricity System Control, JHRDI, Gunsan-si, 54004, Republic of Korea

<sup>\*3</sup>Dept. of Lift Engineering, Korea Lift College, Geochang-gun, 50141, Republic of Korea

\*Corresponding author Email: [bjjung@klc.ac.kr](mailto:bjjung@klc.ac.kr)

## Abstract

**Background/Objectives:** This study is to improve the power system stability on the load following ability by using the governor control in the nuclear power generator.

**Methods/Statistical analysis:** The control method has been the speed droop of the governor which is changed at a certain rate within the allowable range of the standard. The evaluation was applied the N-2 generator contingency and simulated the frequency fluctuation limit. The simulation results, it is possible to reduce the frequency drop width and obtain more economical results than operating the amphibious power generation for the purposed of setting the conventional governor infinite droop.

**Findings:** The power capacity has increased due to the high growth of power demand in the power system. The power system was necessary that it has estimated the reasonable power reserve capacity for meeting the reliable supply power. The operating power reserve was calculated as difference between available power and operating power of the power supply generators. So, the power system is needed to secure the reserve power of generators control method. The generators weren't shown same influence in the power system. However, it was operated the constant output of the nuclear generator power on account of the stability in the nations of the operating nuclear power system. In this paper, the power system reserve capacity was calculated by analyzing the load capacity and power reserve rate.

**Improvements/Applications:** It is operating method that could be calculating the appropriate level of power reserve to apply economic feasibly and stability in the power system.

**Keywords:** Nuclear Power, Governor, Reserve Power, Speed Droop, Load Following, contingency

## 1. Introduction

A power demand is increasing by convenience and price stability in the Korea power system. The industrial structure was concentrated the power consumption due to the metropolitan area. It was shown the error about the power system supply prediction by rapid increment in the power scale. So, the domestic power system conditions are getting worse. This situation could be negatively influenced by the power system stability[1,2]. Nuclear power generator has no carbon dioxide (CO<sub>2</sub>) emission, and it is presented as a practical alternative to prepare for climate change conventions and to promote energy independence. The Nuclear power generator was operated by continuous operation that the output control is impossible.

However, the load following operation could be performed the output fluctuation operation in which the power generation capacity is adjusted in response to the demand fluctuation. Those operations could be reduced power grid operating costs and maximize energy efficiency[3]. In particular, the load following operation was under load follow up operation due to manage the nuclear power generator exceeds 70% of the total generation in France. So, only three nuclear power plants were driven under load following in Germany. In most other countries, the load following

operation was performed mainly by power other than nuclear power[3,4]. The output fluctuation method of the nuclear power generator for load follow up was as follows. It was operating with the slow fluctuation (12-3-6-3), moderate fluctuation (output drop rise speed is 2[%/min] of rated power), and fast fluctuation (output drop and rise speed is 5[%/min] of rated power). The domestic nuclear power generation has the maximum generation output at present[5-7]. As the proportion of domestic nuclear power generation increase, it is necessary to adjust the power of nuclear power generation in power supply regulation and frequency control.

In this paper, it is study to improve the stability of power system by using load following of the unclear power generator. The grid frequency change has been examined in case of the failure of nuclear power generator by the domestic power supply and demand plan of 2024 year.

## 2. Governor Model of the Nuclear Power

### 2.1. Governor Model

The governor model of nuclear power has been used the PSS/E program tool. The governor is controlled the frequency to be adjusted output power by modulating the supply valve of steam. The power is supplied by difference between steam power( $P_{st}$ ) and reference power( $P_0$ ) by using the speed( $\omega$ ) and gain( $K_1$ ) as shown

figure 1 and 2. The governor model of the domestic nuclear power uses IEEEG0 and IEEEG1. The IEEEG0 model was applied only 1 plant, and most of the nuclear generators were applied as the IEEEG1 model[8].

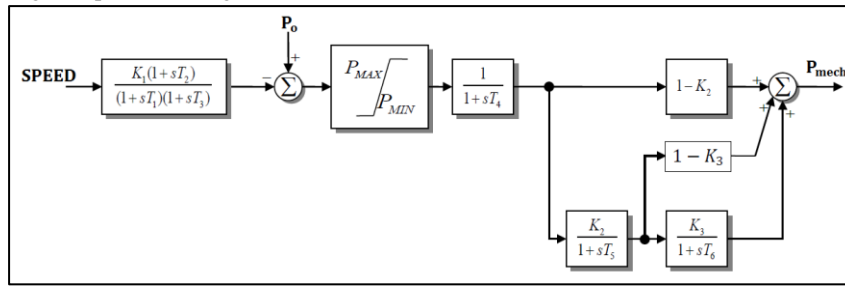


Figure 1: Governor Model 1 of the nuclear power (IEEEG0 type)

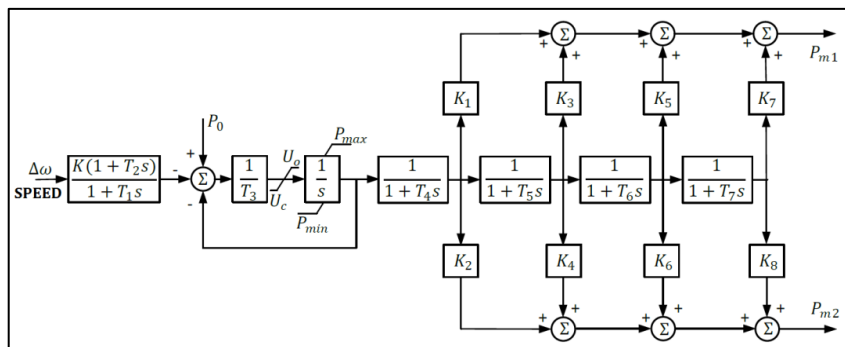


Figure 2: Governor Model 2 of the nuclear power (IEEEG1 type)

2.2. Operating Range

In the power system, it has been one of the biggest factors by the load following of the nuclear power that the system stability. The power system was thought the angle stability, frequency security

maintain condition, and declined stability for the load following of the nuclear power. It was shown the operating limit of the nuclear power and the stability by controlling reserve power of the power system as shown table 1[9].

Table 1: Operation limit by controlling speed of the nuclear power

Requirement		Mode A	Mode B	Mode Korea
Load Following	Range of power (% of the rated)	30~100	30~100	50~100 (within 2[hr])
	Fluctuation rate (%rated power/min)	0.3[%/min]	2[%/min]	3~5%
Monetary Reserve	Size and rate of increasing power	+15~20% Limit increasing power by 5[%/min]	5[%/min]	2[%/min] (maximum 10% in 5[min])
Frequency Control	Automation Frequency Control	±3%	±3%	-
	Load Control	±3%	±5%	-
	Range of fluctuation	1[%/min]	1[%/min]	-

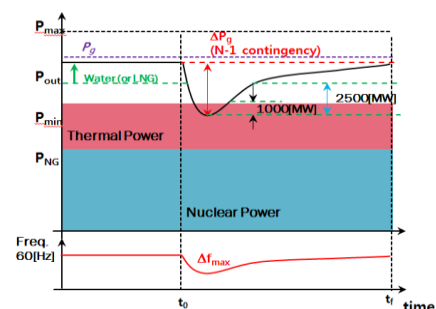
The fastest control characteristic of frequency control could be controlled up to ± 2.5% at the speed of 0.5[%/sec] of the generation capacity. It is possible within 5[sec] as maximum generation output. The momentary reserve power was controlled up to 10% at a rate of 2[%/min] of the generation capacity. So, it is possible within 5[min] as generation output. The slowest control characteristic is possible to fluctuate generation output 50% ~ 100% in maximum 2[hr] as the load following mode.

quick response characteristic in order to recover.

It was shown the power output and reserve power change due to the increase in Load in the power system as shown figure 3(b). In the case, it was need to the auxiliary generator. A power generation capacity exceeding the frequency adjustment capability has been required. It was to stabilize the power system by supplying operational reserve and alternative reserve.

2.3. Disturbance Type of the Power System

The disturbance type could be divided to the blackout of the generator, Transmission/distribution line, and the sharp increase of the load. The reserve power has been researched the power system effects as shown Figure 3. It was shown the power output and reserve power change due to the failure generator as shown figure 3(a). In the case, the power system frequency was dropped. It is necessary to stabilize the power system by performing the GFC(Governor Frequency Control) and AGC(Automation Generation Control) with the frequency adjustment capability as a



(a) Generator N-1 contingency

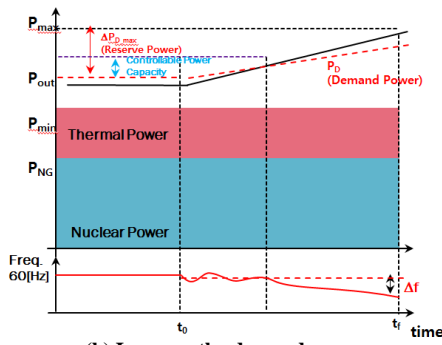


Figure 3: Forecast change of power system capacity by blackout

### 3. Power System Simulation

#### 3.1. Stability Evaluation

The estimation by reserve reference has been and assessment of the supply capacity serve required for the power system for GFC, AGC, and Load Following of the generator. Frequency Response Characteristic (FRC) was maintained the frequency of the power system stability in response to load fluctuation. It was a reserve power that could be automatically reacts instantly according to GFC and AGC operation.

The power system has been goal into two cases for the frequency maintenance [10-11]. First, in the normal operating of the power system, the frequency operation target was  $60 \pm 0.2$  [Hz] as prescribed by Electricity Business Act. Second, the frequency maintenance range from the viewpoint of the life of the turbine generator has been  $60 \pm 0.5$  [Hz]. It was a continuous operating range that did not affect the life of the turbine generator according to the ANSI/IEEE guidelines for abnormal frequency protection for power plants. The FRC of the power system were given in accordance with the governor response, load characteristics, etc. of the generator. The response characteristic of the power system was expressed as equation (1).

$$FRC = k \left( \frac{dP}{P_0} \right) \frac{1}{df} \text{ [%/Hz]} \tag{1}$$

Here, k is power system parameter ( $k_g + k_L$ ),  $dP$  [MW] is lack of generation power,  $df$  [Hz] is frequency error by lack of power, and  $P_0$  [MW] is load of the power system.

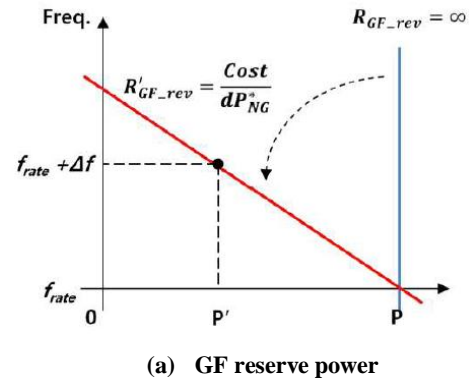
If the load fluctuation has been not followed by the supply serve of GFC and AGC of the power system. The frequency of the power system would be continued to decrease. To evaluate the disturbance of the power system, the fluctuation width of the frequency was detected. It was checked whether or not the range of the reference frequency exceed. And then the additional amount of GFC + AGC was calculated.

In this study, the existing R(droop) of the non-nuclear generator was not adjusted. The R has been adjusted the nuclear generator as shown in table 2. The stability range program has been used to determine the range of maximum frequency fluctuation though the change of the power system frequency.

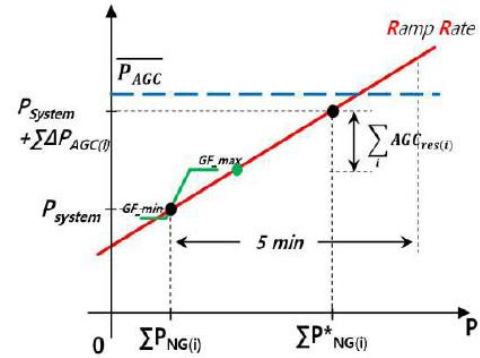
Table 2: Operating strategy for Load Following the Nuclear Power

Type of Gen.	R(droop) for GF reserve	
	Load Following (Not Operating)	Load Following (Operating)
Nuclear Gen.	$\infty$	$d_{cost} / dP_{NG}$
Thermal Gen.	5~8%	Constant
Water Gen.	10%	

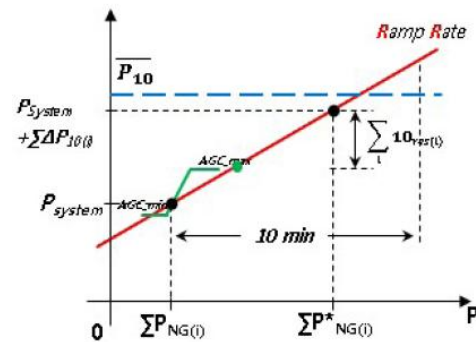
In order to load following of nuclear power generation, the power system should be confirmed in the reserve power required. It was the output characteristic of the generator according to the type of the reserve power as shown Figure 4.



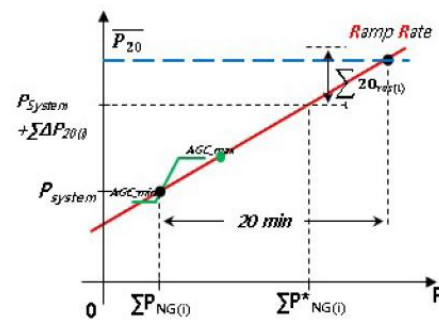
(a) GF reserve power



(b) AGC reserve power



(c) 10[min] reserve power



(d) 20[min] reserve power

Figure 4: Output characteristics of the generator according to reserve power

The GF reserve power was controlled by using the speed droop within the limits of the generator capacity. The AGC reserve power was controlled for reducing the value for the frequency cumulative deviation by the GF control. The 10[min] and 20[min] reserve power were calculated by waiting time to operate the pumped and the stoppage generator.

The formula has been server power for stabilizing the system as Table 3. The load following has been calculated by compering that

output cost due to reliable of the nuclear power generation and the power plant. system cost due to the generation operation of each non-nuclear

**Table 3:** Reserve power preparation for nuclear power plant safety and the power system stabilization

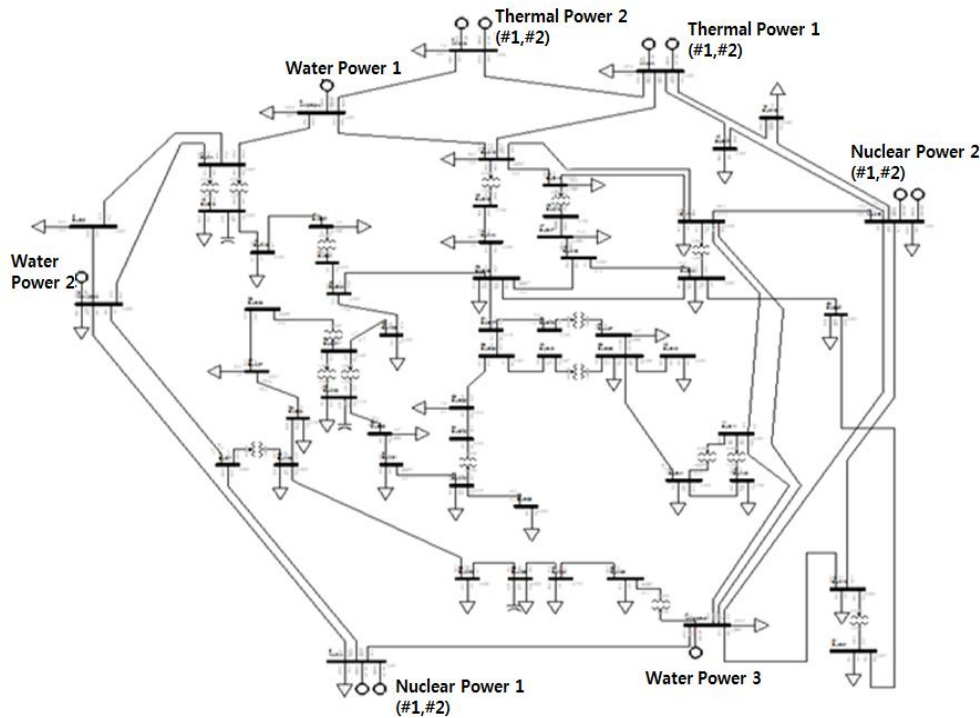
Reserve power type		Reserve capacity Equation	Reliability and Operation Cost
GF reserve		$\sum_i^n \max[\min(RA - MW, GF_q), 0]_i$	$\frac{dC_{power}}{dP_{GF_{rev}}} = \frac{dG_{NG_{security}}}{dP_{NG}} \Big _{GF_{ON}}$
AGC reserve		$\sum_i^n \max[\min(RA - (MW + GF_{rev}), RR \times 10, 0)]_i$	$\frac{dC_{power}}{dP_{AGC_{rev}}} = \frac{dG_{NG_{security}}}{dP_{NG}} \Big _{AGC_{ON}}$
Operation reserve	10[min]	$\sum_i^n \max[\min(RA - (MW + GF_{rev} + AGC_{rev}), RR \times 10, 0)]_i$	$\frac{dC_{power}}{dP_{10_{rev}}} = \frac{dG_{NG_{security}}}{dP_{NG}} \Big _{10_{rev_{ON}}}$
	20[min]	$\sum_i^n \max[\min(RA - (MW + GF_{rev} + AGC_{rev} + 10_{rev}), 0)]_i$	$\frac{dC_{power}}{dP_{20_{res}}} = \frac{dG_{NG_{security}}}{dP_{NG}} \Big _{20_{rev_{ON}}}$
Alternative reserve		$\sum_i^n RA_{120s_i}$	-

※where, RA is maximum generation capacity, MW is present output capacity, dC is reliable cost

**3.2. Simulation Scenario**

It was decided the load pattern that peak, mid-peak, off-peak load for simulation test. The test power system has been applied the IEEE 57 bus and simulated by the PSS/E program. It was shown

the test power system diagram as shown figure 5. It has been chosen the 4,000[MW] for the maximum facility capacity, and the reserve power has been calculated the 400[MW] as 10% of the maximum capacity.



**Figure 5:** Simulation test by using the power system diagram (IEEE 57 power system)

**Table 4:** Generation capacity and reserve by each load pattern

Unit[MW]		Off peak		Mid peak		Peak	
		Power	Reserve	Power	Reserve	Power	Reserve
Total Cap.		2,400	400	3,000	400	3,860	140
A	Nuclear	2,400	0	2,400	0	2,400	0
B	Thermal	200	50	300	300	1,060	140
C	Water	-200	350	300	100	400	0

**4. Conclusion**

The reserve power of the generator has been calculated by excluding the amount of power currently being output the generator at the reactive power limit of the whole generator in the power system. The reactive power has local characteristics unlike frequency. Therefore, it was not all generators have the same

effect on the voltage control of the system. It was necessary to calculate the new reactive power reserve which quantifies the reactive power value by applying the weight the generators having a large influence on the voltage maintenance of the main point of the power system. In additional, the economic feasibility of nuclear load following was expected to vary greatly from that of conventional generators due to the economics of the power generation curve (nuclear power generation (P<sub>NG</sub>) assumes

participates in load following). The real-time load charge for load fluctuation has been summed when the rate policy for the load response is given as  $P_{\text{limit}} < P_L$  and when the economics of the load following speed is high.

The power system has been increased the nuclear power rate by increasing the power demand. In this paper, the load following the nuclear power generator has been studied the power system stability that has been the effect. This is a basic study on the type of the power reserve need in the power system and the load following by the reliability of nuclear power generator. So, it should be expected on continuous research to the level of operation and optimal reliability of the nuclear power generation in the power system.

## References

- [1] Korea Power Exchange (2015), The 7th Basic Plan of the Power Supply and Demand, Retrieved from <https://www.kpx.or.kr/www/contents.do?key=92>
- [2] D.H. Ahn(2007), An examination report for reasonable supply reserve, Korea Power Exchange
- [3] Mycle Schneider, Antony Froggatt & Steve Thomas (2011), Nuclear Power in a Post-Fukushima World : The World Nuclear Industry Status Report 2010-2011, 1-85.
- [4] Hyun-Chul Lee, Young-Gi Roh & Byoung-Jo Jung(2018), A Study on the Nuclear Load Following and Supply Power Reserve Power for Stability of the Power System, International Conference on Next-Generation Convergence Technology.
- [5] S.G. Joo (2011), Evaluation of Supply Reserve and Operating Reserve Requirement Considering Enlargement of Power System Scale, Korea Power Exchange
- [6] H.C. Lee, Y.S. Beak & G.J. Lee (2012), A Study about the Power System Safety Requirements due to Load Following of Nuclear Power, The Korean Institute of Electrical Engineers, 61(11), 1566-1570.
- [7] Young-Chang Kim, Kwang-In Kim, Jong-Bae Park & Sae-Ii Oh, (1994), A Study On the Determination of Reliability Criteria in Generation Expansion Planning Through LOLP Sensitivity Analysis, Energy Engg. 7(1995), Vol. 4, No. 2 pp. 197—202  
Energy Engg. 7(1995), Vol. 4, No. 2 pp. 197—202  
Journal of Energy Engineering, 4(2), 197-202.
- [8] Siemens PTI (2009), PSSE32.0 Program Operation.
- [9] Laurent POURET & William J. NUTTALL (2014), Can Nuclear Power Be Flexible?, EPRG Draft Working Paper. Retrieved from <https://www.eprg.group.cam.ac.uk/wp-content/uploads/2014/01/eprg0710.pdf>.
- [10] Dae-Hoon Ahn, Seok-Kee Kwon, Haeng-Ro Joo & Eun-Jae Choi (2008), A Research of Optimum Supply Reserve Levels for Stability of Power system, The Korea Institute of Electrical Engineers, 22(9), 55-61.
- [11] Chang-Soo Oh & Kang-Wan Lee (2005), A Study on an Estimate of Frequency Regulating Reserve, The Korea Institute of Electrical Engineers, 264-266.