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An Examination on the Power Control by Load Following of Nuclear Generator

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Abstract

Background/Objectives: Nuclear power generator has supplied a large capacity power and operated to low CO2emission.

Methods/Statistical analysis: Nuclear power generation supplies a constant power for safety reasons in the power system. However, it could be operated an acceptable performance range for the control of generator considering nuclear safety. This study has been evaluated power frequency fluctuation limits by applying N-2 generator contingency, in consideration of the safety of the power plant.The load variation pattern was analyzed of nuclear power by using power system prediction data of 2024.

Findings: The frequency recovery of the power system reference for stable system operation reduces the frequency fluctuation by securing reserve power of the generation.This paper has been used the power control by using governor control of the generator.Simulation results has showed that using the governor load follow-up function of a nuclear power generator can reduce the frequency drop width by providing an immediate response reserve for the expected maximum emergencies. It was also more economical than hydro-dynamic operation for instantaneous response reserve.In this paper, analysis has been performed using commercial power system analysis program.

Improvements/Applications: It was possible to obtain cost-effective results than the hydro-generator operation of the momentary reactive reserve for conventional governor droop control. Nuclear power could be controlled by various operating methods, and could be used as friendly environment energy through reduction of CO2 in the environment side.It is proposed as a viable alternative to prepare for climate change and promote energy independence.

Keywords: *Nuclear Power, Load Fluctuation, Power Frequency, Reserve Power, N-2 Contingency*

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I. Introduction

A power system should be matched between supply and demand power. Generator has adjusting due to the demand for ever-changing capacity in the power system. Supply of power capacity is difficult by changed the domestic climate. So, a large-scale power generation facilities were under review by increased the electric power demand. It was presenting as a practical alternative to prepare for climate change convention and to promote energy independence. It is one of that low CO_2 emission was the nuclear power generation with large-scale power supply[1]. Nuclear power generation has been operating continuous operation, which isn't used output control the current operation mode. The nuclear power base-load mode has constant load or scheduled load operation.The scheduled load mode has been replaced by the flexible mode of frequency control of about 15~30% of rated power. Load fluctuation was normally less than 1~2[%/min] but a change of load of up to 5[%/min] or even 10[%/min] was sometimes required over a limited range. The load-following method has been controlled the output in response to the demand fluctuation in the power system. This method could be reduced the power system operating costs and maximize energy efficiency. In particular, nuclear power of Europe has been operated by controlled the load-following. The nuclear power of France has been operating to exceed 75% of the whole power generation capacity. Germany has been used to load-following method the 3 nuclear power generation along by using France's power generation[2-4]. In most other countries, it was used the load-following as the other type power than nuclear power.

This paper is study about the power system effect by using the load-following of the nuclear power. The frequency fluctuation has been evaluated by N order contingency in the power system. The load would be managed for stable system in the off-peak and peak load. The power frequency was operated on the basis of the power system in fault state. The power generator has been data by the domestic power supply and demand plan of 2024 year. It was simulated to changing the power system frequency by drop out the nuclear power generator by using the power supply and demand plan. It was investigated the frequency control characteristics of nuclear power generators and instigated the improvement of the power system stability with the recovery of the power system frequency through the governor control of the generator.

II. Nuclear Power GeneratorModel

GovernorModel

The regulator model of the nuclear power generator has been modified by PSS/E program[5-7]. The governor is controlled the frequency by adjusting the supply valve fo the steam in the generator. The governor controller model was the nuclear power generator as shown figure 1 and 2. Domestic nuclear power generator model has been using the IEEEGO and IEEEG1 model. Most nuclear power has been applied as the IEEEG1 model excet from the Kori generagtor.

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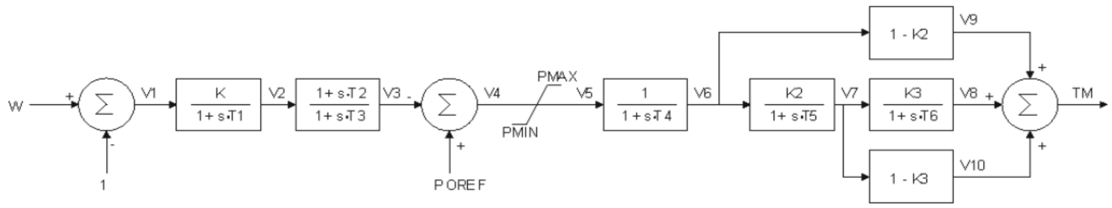

Figure 1. IEEE Standard Governor Model

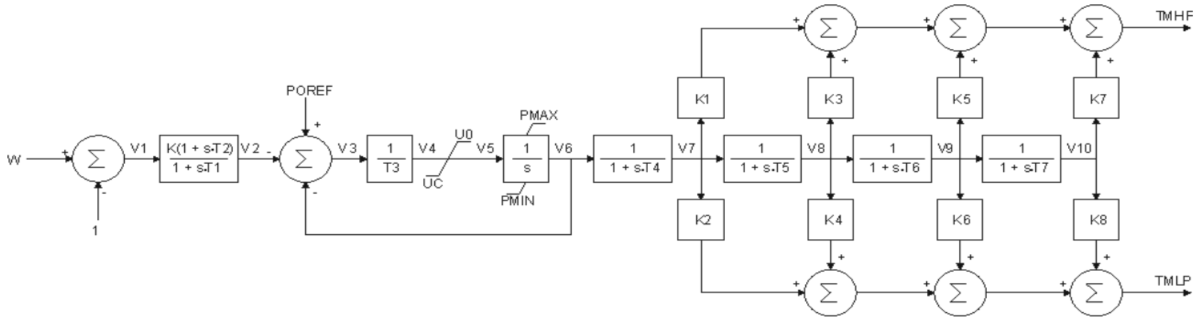

Figure 2. IEEE Type 1 Speed-Governor Model

Operating Range

It was the participation, response speed and allowable range of the load-following of the power system of nuclear power plant as shown table 1. Mode A and G was shown the control limits of nuclear power plants in Europe[8-10]. The Mode K(domestic nuclear control mode) could be controlled up to ±2.5% at the speed of 0.5[%/s] as Frequency control with the fastest control characteristic in nuclear power generation. The momentary reserve could be controlling up to 10% at a rate of 2[%/min]. Therefore, it is possible to output a net reserve within a maximum of 5[min]. The power output can be reduced to 50% from 100% at up to 2[hr] with load tracking with the slowest control characteristic.

Table 1: Operating limit by control speed of nuclear power

Need of the power system		Mode A	Mode G	Mode K
Load-following	Power range(% of rated power)	30~100%	30~100%	50~100% @ 2[hr]
	Variation(%rated power/min)	0.3[%/min]	2[%/min] @ 1day	3~5%
Momentary Reserve	Size and Rate of power incensement	+15~20% 5[%/min]	5[%/min]	2[%/min]
Frequency control	Auto(local)frequency control	±3%	±3%	10%
	Load control	±3%	±5%	±2.5%
	Variationrange	1[%/min]	1[%/min]	0.5[%/s]

III. Case Study

The reserve power for stability of the power system is GFC (Governor Free Control), AGC (Automatic Generator Control), and reserve capacity of the generator. In case of the power system failure, FRC (Frequency Response Characteristic) with frequency response is a characteristic for keeping the frequency of the system stable in response to load fluctuation. It is reserve power that could be automatically reacted instantly according to GFC and AGC operation. The power system could be operating normally as the frequency would be change by the load fluctuation. The frequency maintenance goal has been divided into two types. First, the frequency operation target for the normal operation of the power system is 60±0.2[Hz], and it is stipulated by the Electricity Business law. Second, steady frequency protection guidelines for power plants specified by ANSI/IEEE for frequency maintenance range from the point of view of life of turbine generator as 60±0.5[Hz] is continuous operation range without affecting turbine generator life. The system frequency has been varies depending on the load change in the power system. it has been the degree of imbalance between power generation and demand. The frequency response was depending on the governor response characteristics of the generator, load characteristics, etc. Therefore, the response characteristics of the power system are expressed as follows equation 1.

$$\mathrm{FRC}\ [\%/Hz] = \mathrm{k}\left(\frac{\mathrm{dP}}{P_o}\right)\frac{1}{dF} \qquad (1)$$

Here, k is power system parameter, dP is shortage power, dF is frequency error by shortage power, P_0 is power system load.

Simulation Scenario

The power system data was used to base on the 5^{th}power supply plan of Korea Power System in 2024 year[11]. The peak load and off-peak load were selected according to the operation power. The generation power amount was maximum value(93,617.2[MW]) and minimum value(57,806.1[MW]) by power system load as shown Table 1.

Table 2: The generatorcapacity in power system

Load	Number of Generator [MW]		Gen. Cap. [MW]	Max. Gen. [MW]	Min. Gen. [MW]
	Total Gen.	Operating Gen.			
100% (peak)	353	241	93,617.2	98,159.4	59,947.2
60% (off-peak)	353	84	57,806.1	59,569.0	41,647.2

The off-peak load of the power system has owned the low capacity value by the economy dispatch. This situation was decreased the load-following ability in case of failure the large-capacity generator (1,000[MVA] in each capacity). The system frequency variation by the simulation confirm in case of the two nuclear power plants fault at the off-peak and peak load. The system power scenarios for the simulation was set as follows.

1. Check frequency in basic power system.
2. Check frequency by controlling droop value of generators in basic power system.
3. Check the system frequency by controlling governor gain of nuclear power.

The power system frequency was adjusted by controlling the governor gain for improving the power stability. The power system stability was simulated by the variation of the system frequency and the frequency recovery rate by elimination the large capacity generator as shown Table 2. At this time, it has been controlled the governor gain (K = 1/R) of nuclear power generator.

Table 3. Set the governor droop rate (K=1/droop) on the nuclear power generator

Case Study	K value	Comment
Base Case	Base data	Power system planning data of 2024 year
Case 1	0	Locked the governor control of Nuclear power

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Case 2	5	Setting the 0.2(1/K) as the governor droop of nuclear power
Case 3	15	Setting the 0.067(1/K) as the governor droop of nuclear power
Case 4	20	Setting the 0.05(1/K) as the governor droop of nuclear power

Simulation Result

The power system simulation has confirmed the system frequency fluctuation by dropping the nuclear power in the large capacity generator. The simulation result was shown the fluctuation frequency by failure in nuclear power generators as shown Figure 3 and Figure 4. The system frequency has been shown fluctuation capacity in the peak load and off-peak load of the power system in case failure of two nuclear power (Uljin #1, #2) as shown Figure 1 and Figure 2. In case of the peak load, the drop-out of the generator has been showed that the frequency variation and the frequency recovery rate were fast due to the large amount of operation and reserve power of many generators.In case of the off-peak load, some generators have been used due to the stoppage and the maintenance of the generators. So, the system frequency was large fluctuated due to the drop of the large capacity generator.

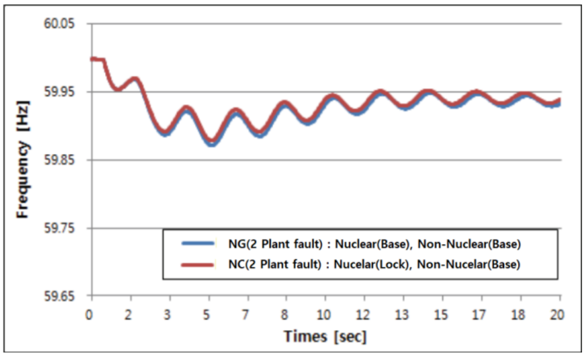

Figure 3. Change capacity of power system frequency by failure in two nuclear power generators in case of peak load

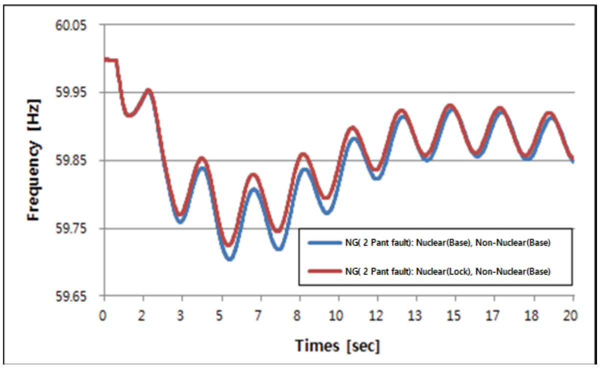

Figure 4. Change capacity of power system frequency by failure in two nuclear power generators in case of Off-peak load

IV. Review of the Power System state

The frequency fluctuation has been checked for case study by fault in nuclear power which was large scale capacity generation. It was K (droop) value of the governor of nuclear power due to the domestic power supply and demand plan as shown table 4.The governor gains (K) of nuclear power generation was adjusted from 0 to 20 as shown Figure 5. In case of the off-peak load (60% of load level), the governor gain of the nuclear power generator would be adjusted as shown in Table 4.

Table 4 :Governor Gain of the Nuclear Power (in case of base Power System)

K value	Nuclear Power (Count of Plant)	Number of total Pant
0	Kori(3), Wolseong(1), Youngkwang(5), Uljin(4)	13 Plant (38.2%)
5	SinKori(6), SinUljin(4)	10 Plant (29.4%)
12.5	Wolseong(3)	3 Plant (8.8%)
14.3	Kori(1)	1 Plant (2.9%)
20	SinKori(2), SinWolseong(2), Youngkwang(1), Uljin(2)	7 Plant (20.6%)

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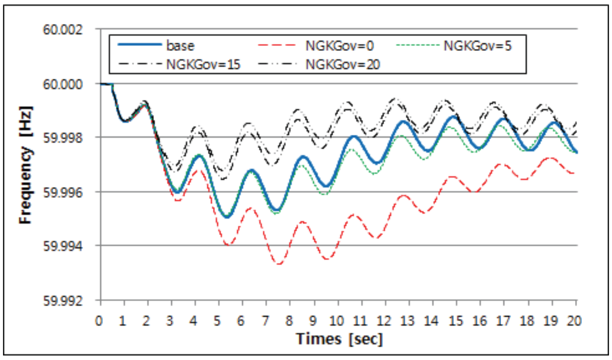

Figure 5. The system frequency by adjusting the nuclear power governor gain in case of the off-peak load

When the governor gain was zero (that is, governor lock), the system frequency was shown the largest fluctuation because it was not adjusted by the reserve power of the nuclear power plant. The fluctuation of the system frequency was shown changed small when the governor adjustment was large. It was appeared that the stability of the system was ensured by load-following in accordance with the frequency change.

V. Conclusion

The reserve power of the generator has been calculated by excluding the amount of power currently being output by the generator at the reactive power limit of the total generator in the power system. However, the reactive power has local characteristics unlike frequency, not all generators have the same effect on the voltage control of the system.It was necessary to calculate the new utility reactive power reserve which quantifies the reactive power value by applying the weight to the generators having a large influence on the voltage maintenance of the main points of the system. Nuclear power generators have frequency tracking ability, but due to safety problems, it wouldn't be controlled frequency by using speed droop.

In this paper, the simulation was proposed the stability of the system rather than the safety of the nuclear power plant. It has been reviewed about affection of the increase of power demand on the system due to the increase of the ratio of nuclear power in the power system. It has been confirmed that the recovery of the system frequency the generator by controlling the droop gain according to drop-out of the nuclear power. Simulation results, it was shown that the system frequency was restored by regulating the governor gain of the nuclear power generator. It would be improved the stability of the power system by monitoring the load of the nuclear power generation in the power system. In the future, it will be necessary to study the safety of the nuclear power generation due to the load-follow and to control the governor gain of each nuclear power generator.Itwas considered that the study on the operation of nuclear power generation and the level of optimal supply reliability in the power system. It should be continued as a basic study on the type of reserve required in the system and the dependency of load on the reliability of nuclear power generation.

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