Dynamic Analysis of Generation Control Performance Standards

Tetsuo Sasaki and Kazuhiro Enomoto

***Abstract*—This paper presents an evaluation of the North American Electric Reliability Council's (NERC) new control performance standards, as they might be applied to the Western Japanese 60-Hz system. Dynamic simulation of the system frequency response, including the effects of primary and secondary frequency control, power plant response, and load fluctuation characteristic were performed using a load flow program during normal system operation. Parameter sensitivities have been studied for some of the pertinent control parameters influencing the generation control performance, including power plant and automatic generation control (AGC) response parameters and amounts of generation under control for governor and AGC.**

***Index Terms*—Control area, control performance standards, generation control, power system.**

I. Introduction

DEREGULATION of the electric utility business has led to a renewed importance of understanding and quantifying the generation control performance of power systems. Many players enter the market, and frequency control is offered to the new players as an ancillary service. It is necessary to agree upon clear and fair methods to evaluate the contribution of the individual companies for frequency control. After an extensive analytical study, the North American Electric Reliability Council (NERC) introduced new control performance standards: CPS1 and CPS2. The new standards attempt to make the time average of an area control error (ACE) essentially unpredictable beyond some specified time period such that a control area uses the interconnection short-time assistance only on a random basis. The effectiveness, fairness, and benefits of the new standards have been field-tested and discussed [2].

It is very important to understand the quantitative performance of the frequency control system. For the Western Japanese 60-Hz system, it is also necessary to consider a clear set of standards to evaluate frequency control performance.

In this paper, we evaluated the effects of the primary and secondary frequency control system quantitatively and applied these standards to the Western Japanese 60-Hz system. Furthermore, we analyzed how these standards could be used to evaluate the primary and secondary frequency control system by dynamic simulation.

II. Simulation System

We created a plant model and a local frequency control (LFC) model to evaluate the effects of the frequency control system on the simulation. We had shown the simulator evaluating the frequency control system in [3].

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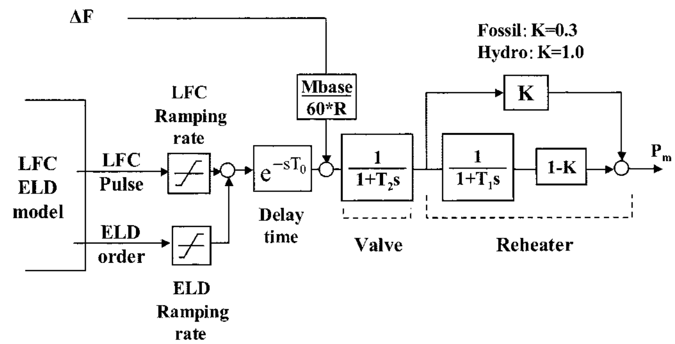

Fig. 1. Plant model.

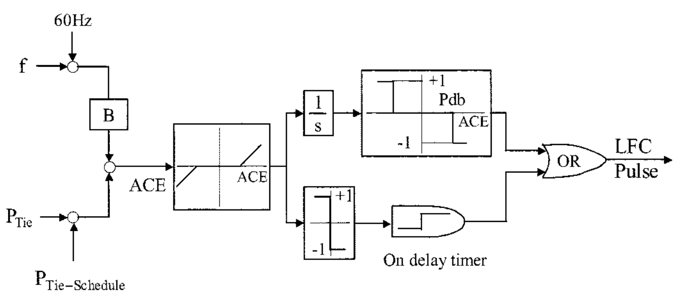

Fig. 2. LFC model.

TABLE I
CONFIGURATION OF LFC PARAMETERS

	Hydro	Fossil
LFC ramping rate (%MW/min)	20	4
LFC delay time (sec)	3	10

A. Plant Model

Fig. 1 shows the plant model. In this model, the plant output is determined by the governor, LFC pulse, and the setpoint of economic load dispatching control (EDC). We show the LFC logic in Fig. 2. If the integral of the ACE exceeds the threshold (Pdb) or the ACE exceeds the standard value continuously, higher or lower pulses are sent to the generating plants. We represented the characteristics of various plants (hydro, steam turbine, etc.) by changing the delay time and ramping rate.

We adjusted the LFC parameters for other plants, and we obtained the typical LFC parameters of fossil and hydro plants in Table I.

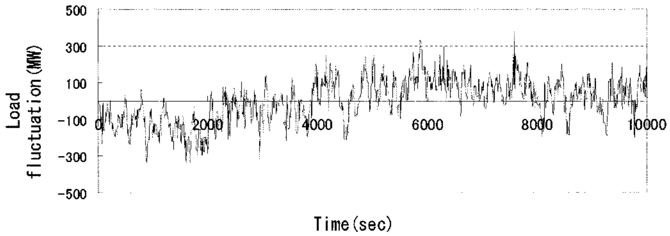

Fig. 3. Load fluctuation.

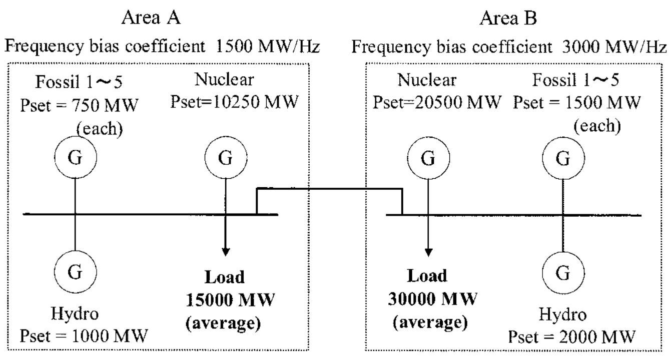

Fig. 4. Two-area system.

B. Load Model

To evaluate the efficiency of the primary and secondary control, it is important to understand the load fluctuation of our system. As one cannot directly obtain the load fluctuation data, we added the ACE to the total amount of power generated by the Kansai Electric Power Company (KEPCO) in one day and deducted the ordered power by EDC. Thus, we took out the short cycle load fluctuation. The time characteristics of load fluctuation are shown in Fig. 3.

C. System Model

We considered two interconnected areas as shown in Fig. 4, and the average value of the system capacity could be 15 GW (area A) and 30 GW (area B). The peak demand of KEPCO is about 32 GW, and Japanese 60-Hz system peak demand is about 100 GW. The amplitude of load fluctuation was multiplied by the constant so that the standard deviation of load fluctuation might be set to 82 MW (area A) and 116 MW (area B). By this operation, the standard deviation of load fluctuation of both areas might be proportional to the square root of the system capacity. The reason why we decided that the load fluctuation is based on the measurement of the Japanese 60-Hz system is because this characteristic is still almost the same by the present analysis. In that measurement, the standard deviation of load fluctuation is proportional to a square root of system capacity.

Moreover, we adjusted the read-out time so that the correlation of each area's load fluctuations might not arise. We simulated the effect of the frequency control system for about 3 h on each simulation case.

Table II shows the simulation parameters used to evaluate the primary and secondary control. We changed the governor capability and LFC parameters (delay time, ramping rate, and deadband), respectively.

TABLE II
CONFIGURATION OF GENERATION CONTROL SYSTEM

	Area A	Area B
LFC capacity (MW)	288	402
LFC ramping rate (%MW/min)	2.76	2.76
LFC deadband (MW)	70.7	100
LFC delay time	Hydro 3s, Fossil 10s	

TABLE III
SIMULATION CASES

	Case 1	Case 2	Case 3	Case 4
Frequency response characteristic (%MW/Hz)	No	10	10	20
Secondary control	No	No	Yes	No

We set ϵ_1 to 0.0131 Hz and ϵ_{10} to 0.0025 Hz in this paper. These values were obtained by the simulation parameters shown in Table II.

III. EVALUATION OF PRIMARY AND SECONDARY CONTROL CAPABILITY

We evaluated the control characteristics of primary and secondary control on the simulation. First, we varied the speed governor capability and changed the frequency response characteristics from 20 to 10% MW/Hz and compared the results that are produced in cases with and without secondary control. We show the simulation cases in Table III. The LFC parameters are shown in Table II. In this simulation, we set the frequency biases to agree with the frequency response characteristics for each case. As it takes too much simulation time to calculate CPS1 for one year, we used CF1 calculated by about 3 h of simulation. For the same reason, we calculated CPS2 by about 3 h of simulation. The standard deviation of frequency, that of interchange, CF1, and CPS2, are shown in Fig. 5.

Fig. 5 shows that primary control improves the standard deviation of the frequency from 0.15 to 0.03 Hz, and the control performance of the frequency response characteristics of 20% MW/Hz is superior to that of the frequency response characteristics of 10% MW/Hz + LFC for the frequency control. However, as for control performance of the interchange, it turns out that secondary control is effective, but primary control is not effective.

Since the standard deviation of frequency becomes smaller due to the increased capability of the speed governor, it can be said that the control performance of frequency is improved by increasing the governor capabilities, as we can see in the cases 1, 2, and 4. In addition, because CF1 agrees with the control performance of frequency, it can be said that CF1 can evaluate the result of the primary control correctly. Use of secondary control makes the deviation of frequency and interchange decrease, and CPS2 agrees with this fact. CPS2 can evaluate the secondary control and their contributions for frequency control and tie line control.

IV. EVALUATION OF PRIMARY CONTROL

We changed the capability of the speed governor and made a difference between the frequency response characteristics of

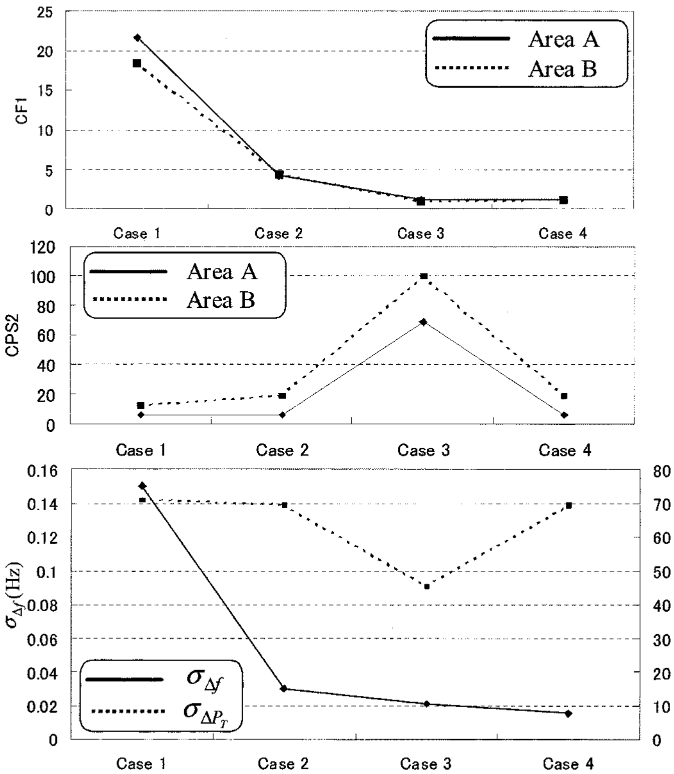

Fig. 5. Standard deviation of frequency, that of interchange, CF1, and CPS2 for primary/secondary control.

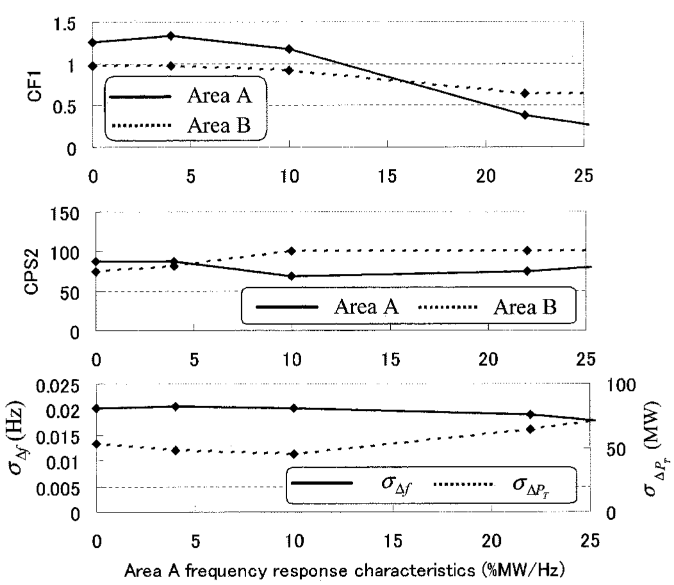

Fig. 6. Standard deviation of frequency, that of interchange, CF1, and CPS2 for governor capability.

each area to evaluate the efficiency of primary control using CF1 and CPS2.

We changed the capability of the speed governor for each control area on the condition that the frequency response characteristic of the whole area is equal to 10% MW/Hz, and we fixed the frequency biases of each area at 10% MW/Hz. The standard deviation of frequency, that of interchange, CF1, and CPS2, are shown in Fig. 6.

TABLE IV
CONFIGURATION OF LFC DELAY TIME

	Case 1	Case 2	Case 3	Case 4
Hydro	3s	5s	10s	No LFC
Fossil	10s	25s	40s	No LFC

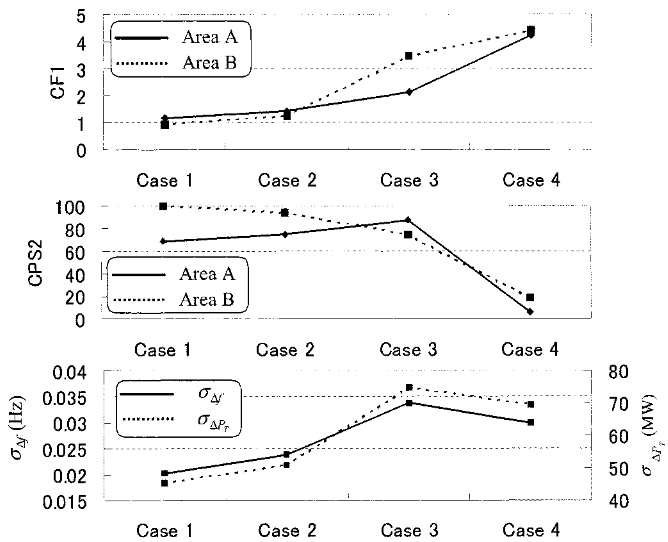

Fig. 7. Standard deviation of frequency and interchange CF1 and CPS2 for LFC delay time.

Fig. 6 shows that the standard deviation of frequency does not change as drastically as the interchange because the governor capability of the whole area is fixed. On the contrary, the standard deviation of the interchange is at a minimum when each area has the same governor capability, and it increases in proportion to the amount of mismatch between the actual frequency response characteristics and the frequency biases. It is because the area that has more governor response capability responds to the deviation of frequency caused by the other control area's mismatch. Especially when the area with the smaller demand capacity has more governor response capability, the deviation of the interchange becomes larger, and it is shown in Fig. 6.

CPS2 does not depend upon the frequency response characteristics of area A. CF1 of area A improves in proportion to the increase of area A frequency response characteristics. This fact corresponds with the statistical theory of CF1 [4]. As the sum of the governor capability of area A and area B is constant, the governor capability of area B decreases when that of area A increases, but CF1 of area B does not become worse when the governor capability of area A increases. This problem will be discussed in Section VI.

V. EVALUATION OF SECONDARY CONTROL

A. Evaluation of LFC Delay Time

When the LFC delay time is changed as shown in Table IV, the standard deviation of frequency, interchange, CF1, and CPS2 are shown in Fig. 7.

Fig. 7 shows the standard deviation of frequency and interchange increase when delay time increases. This suggests that the frequency control performance declines when the delay time increases. As CF1 becomes larger according to the increase of

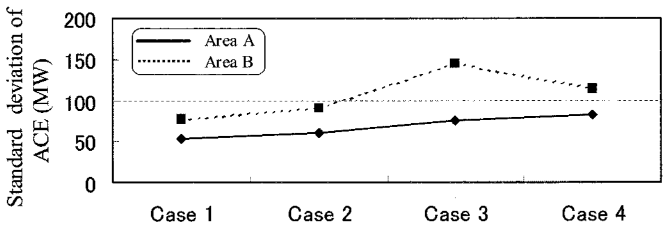

Fig. 8. Standard deviation of ACE for LFC delay time.

TABLE V
CONFIGURATION OF LFC DEADBAND

	Case 1	Case 2	Case 3	Case 4
Area A	50	100	150	No LFC
Area B	35.3	70.7	106	No LFC

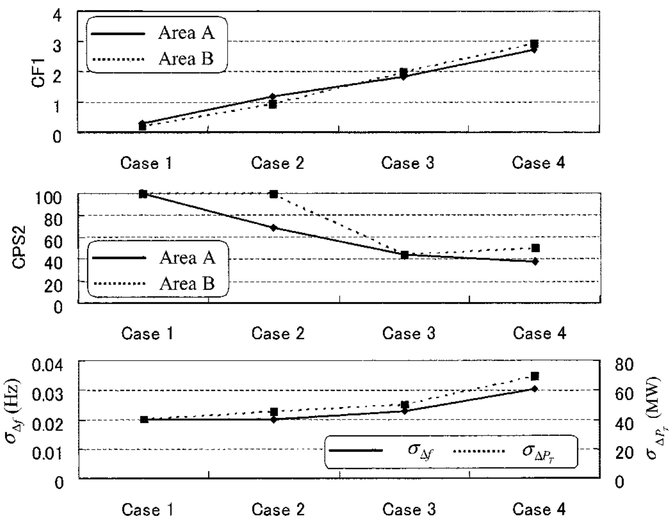

Fig. 9. Standard deviation of frequency, that of interchange, CF1, and CPS2 for LFC deadband.

delay time, CF1 can evaluate the effect of the delay time correctly. CPS2 of area A becomes larger in case 3, whereas CPS2 of area B becomes smaller. This fact shows that CPS2 cannot evaluate the effect of the delay time correctly. On the other hand, CPS2 is equivalent to the evaluation of standard deviation of ACE [4], and the standard deviation of ACE becomes larger in Fig. 8. Therefore, the reason why CPS2 cannot evaluate the effect could be that the duration of this simulation, which is about 3 hr, is too short to evaluate the effect of the delay time in detail by CPS2. CPS2 can also evaluate the delay time of automatic gain control (AGC) when data from a sufficiently long simulation data is available.

B. Evaluation of LFC Deadband

When the LFC deadband is varied, as shown in Table V, the standard deviation of frequency, that of interchange, CF1, and CPS2, are shown in Fig. 9.

Fig. 9 shows that the standard deviation of frequency and interchange are made smaller by making the deadband narrow. This suggests that frequency control performance becomes worse when the deadband is widened. Since CF1 becomes larger and CPS2 becomes smaller when the deadband is

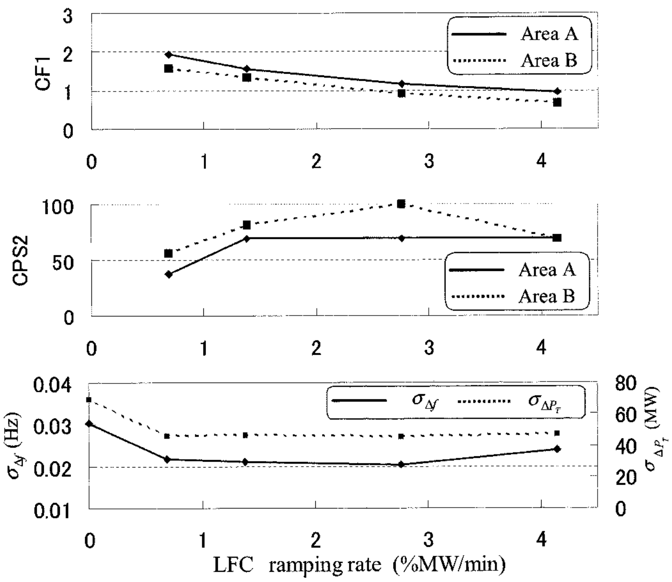

Fig. 10. Standard deviation of frequency, that of interchange, CF1, and CPS2 for LFC speed.

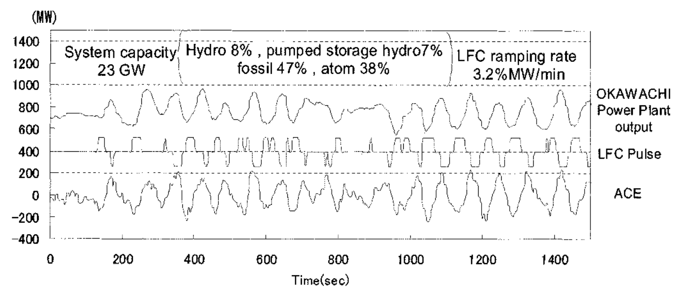

Fig. 11. Limit cycle oscillation (measured data).

widened, CF1 and CPS2 can be used to accurately evaluate the effect of the deadband.

C. Evaluation of LFC Ramping Rate

When the LFC ramping rate is changed, the standard deviation of frequency, that of interchange, CF1, and CPS2 are shown in Fig. 10.

Fig. 10 shows that there is an optimum ramping rate that minimizes the standard deviation of frequency and interchange. CF1 is decreased by the increase of the ramping rate at the beginning of Fig. 10. When the ramping rate exceeds 2.7% MW/min, the standard deviation of frequency begins to increase. The limit cycle oscillation occurs because the change of the output power resulting from one LFC pulse is too big. Actually, we experienced this oscillation in 1998. Fig. 11 shows the variable speed pumped storage (VSPS) output, LFC pulse, and ACE at the time. It is clear that the limit cycle oscillation occurred due to the LFC pulses. In addition, we can find that the ramping rate became too big due to the VSPS.

When the ramping rate is less than 2.7% MW/min, the standard deviation of frequency declines due to the increased ramping rate. Table VI shows the data measured in the KEPCO system during a certain one hour in 1998, and this data shows the same tendency as those of the simulation results. We set ϵ_1 to 0.036 Hz to calculate CF1 in Table VI.

TABLE VI
CONTROL PERFORMANCE FOR THE RAMPING RATE (MEASURED DATA)

	System capacity (GW)	Ramping rate ($\frac{\%MW}{min}$)	σ_{ACE} (MW)	$\sigma_{\Delta f_1}$ (Hz)	CF1
With VSPS	12.5	1.6	71	0.036	0.65
Without VSPS	11.6	0.4	102	0.042	2.32

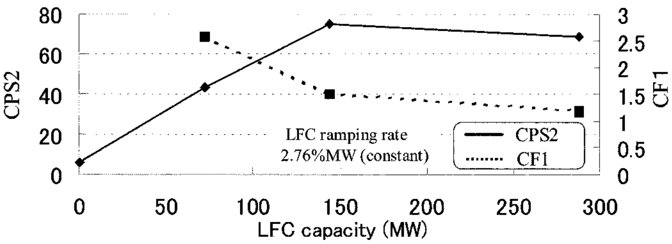

Fig. 12. Relationship between CF1, CPS2, and capacity of secondary control.

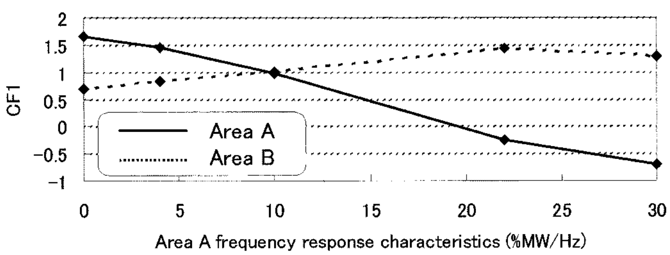

Fig. 13. CF1 calculated by 1-s sampling data.

D. Relationship Between LFC Capacity and Ramping Rate

At KEPCO, we reserve the LFC capacity to control the frequency and the interchange. Nowadays, as some of the plants, such as VSPS, have high ramping rates, not only the capacity, but also the ramping rate, has become an important factor to control the frequency and the interchange.

We analyzed the relationship among LFC capacity, ramping rate, and control results.

Fig. 10 shows that higher ramping rates contribute to improvements in CF1 and CPS2.

Around 1.2 $\sim$ 1.5% capacity of the total demand is required for LFC capacity in the Kansai power system. The required LFC capacity for the simulation case is 210 MW.

Fig. 12 shows the simulation results regarding the relationship among CF1, CPS2, and the capacity of secondary control. Compliance with CPS2 and CF1 does not become worse until the capacity of secondary control becomes around 140 MW.

Thus, we could reduce the LFC capacity under the condition that the appropriate ramping rate is held.

VI. INFLUENCE OF AVERAGE PERIOD FOR CONTROL PERFORMANCE EVALUATION

CF1 cannot effectively evaluate the effect of the governor capability as shown in Fig. 6. The reason for this is that the effect of the governor becomes smaller due to the use of the 1-min average value of ACE, system capacity, and frequency deviation. To confirm this, we calculated CF1 from the instant value of ACE, system capacity, deviation of frequency, and interchange. Fig. 14 shows CF1 calculated using 1-s sampling data.

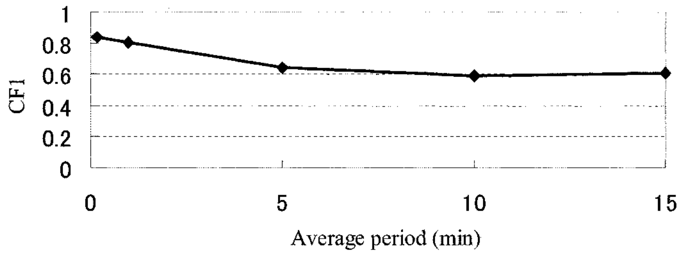

Fig. 14. CF1s by average period (KEPCO, October 2000).

CF1 of area B becomes worse when the governor capability of area A increases and that of area B decreases in Fig. 13. CF1 calculated using instant values can evaluate the governor capability correctly.

Fig. 14 shows that CF1s of KEPCO vary due to the length of average period, and this fact means that larger average periods deteriorate the discriminating power of CF1. The distribution of $\Delta P_T - \Delta f$ is tilted by the difference of frequency response characteristics of each area [4]. As the distribution of $\Delta P_T - \Delta f$ is concentrated to the average point gradually in proportion to the length of average period and the information of control characteristics included in ΔP_T, Δf is lost, as shown in Fig. 15.

Fig. 16 shows that the correlation coefficient decreases in proportion to the length of average period. The difference of frequency response characteristics and frequency bias also makes the correlation of ACEs of both areas, and CF1 using the ACEs calculated by the instantaneous measured data can evaluate its effects [4]. Fig. 16 shows that use of longer average period values deprives CF1 of its discriminating power.

VII. CONCLUSION

In this paper, we evaluated the quantitative performance of the primary and secondary frequency control system and applied these standards to the Western Japanese 60-Hz system. In addition, we analyzed how these standards could be used to evaluate the primary and secondary frequency control system by dynamic simulation.

When the capability of the primary control is different depending on the control area, CF1(CPS1) using the 1-min average of ACE and the frequency could not always evaluate the capability of the primary control.

We evaluated the capability of the governor with CF1(CPS1) calculated by 1-s sampling of the ACE and the frequency. This CF1 can evaluate the capability of the primary control even when the capability of primary control is different, depending on the control area. The length of average period influences the discriminating power of CF1.

On the other hand, CPS2 could not evaluate the capability of the primary control, but it could evaluate the capability of the secondary control of the overall system when the capability of the primary control was equivalent in all control areas.

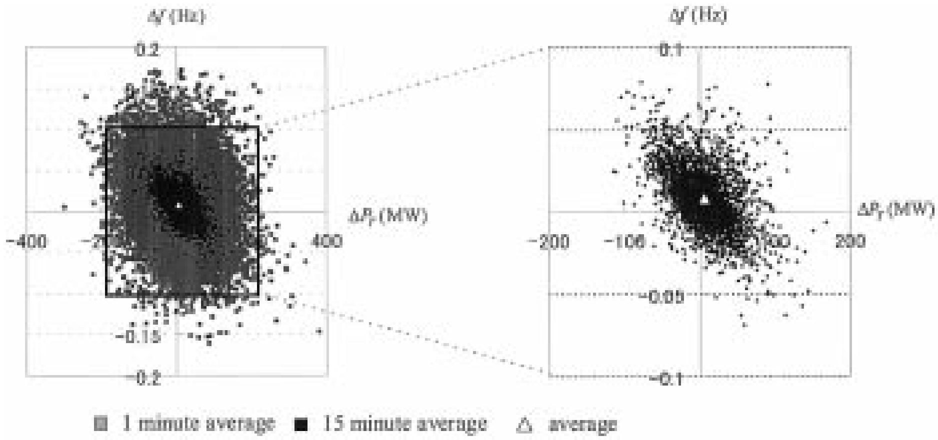

Fig. 15. Comparison of distribution of $\Delta P_T - \Delta f$ for average period.

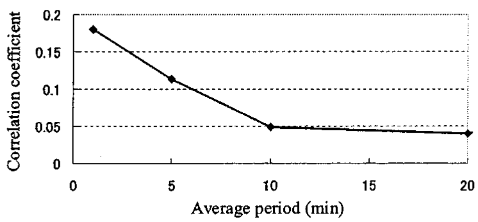

Fig. 16. Correlation coefficient of ACEs between KEPCO and Japanese 60-Hz system in October 2000 by average period.

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