Demonstration Test of Frequency Regulation by Autonomous Load Control

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***Abstract*-- If the share of variable generation will increase more, it will be difficult to maintain the supply and demand balance in the power system, which results in severe frequency deviation. Load control is one way for frequency regulation in a power system. In this study, a laboratory-scale independent power system has been composed by an engine generator and resistors with the control boards, and the validity of the autonomous frequency control has been demonstrated using the system.**

***Index Terms*-- Autonomous Load Control, electric power system, frequency regulation**

I. Introduction

Recently, in order to mitigate the emission of greenhouse gases, increase of renewable energy such as solar power generation and wind power generation has been important. In Japan, by feed-in tariff from 2012, the amount of solar power generation and wind power generation is rapidly increasing. However, output power of solar power generation fluctuates according to weather condition. So, if the share of variable generation will increase more, it will be difficult to maintain the supply and demand balance in the power system, which results in severe frequency deviation.

Load control is one way for frequency regulation in a power system. The authors have already developed autonomous load control boards, and demonstrated the autonomous control of water-heater loads and battery-charging loads according to frequency deviation while maintaining end users comfort [1,2]. In this study, a laboratory-scale independent power system has been composed by an engine generator and resistors with the control boards, and the validity of the autonomous frequency control has been demonstrated using the system.

II. EXPERIMENTAL METHOD

A. Control board

The authors created the control board by using the PIC16F886 that is a one-chip microcontroller of Microchip Technology. Overview of a control board that was used in this study is shown in Fig 1. A control board measures power system frequency with a 0.2 second interval and issues an on-off command in response to the frequency. Because the time constants of the actual power generating units are 2 to 10 s [3], the control board can react quickly to the frequency variation.

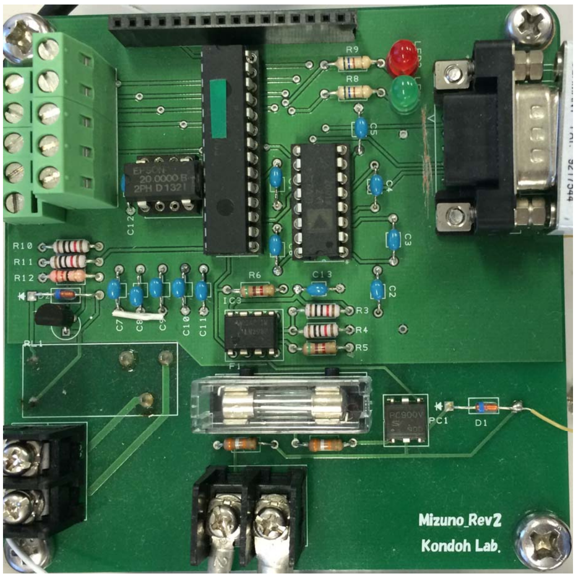

Fig. 1 A control board

B. Independent power system

In this study, a laboratory-scale independent power system has been composed by an engine generator and resistors with the control boards. The circuit diagram of the laboratory-scale independent power system is shown in Fig.2. The engine generator has a rated output of 5.0 kW and a rated voltage of 200 V with a nominal frequency of 50 Hz and a pole number of 2. By turning on/off the switched loads, unbalance between supply and demand occurs in the power system, which causes frequency variation. Each autonomous control load measures the frequency deviation and checks whether it is beyond lower/upper thresholds, which are allocated in advance [1] and then turns on/off the resistor. This experiment demonstrates whether autonomous control loads can mitigate frequency variation in a power system or not.

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[1] The control boards developed by the authors have the function to set the lower/upper thresholds automatically while considering the operational conditions of the loads in order to maintain end users comfort[1,2]. However, the function was invalidated this time.

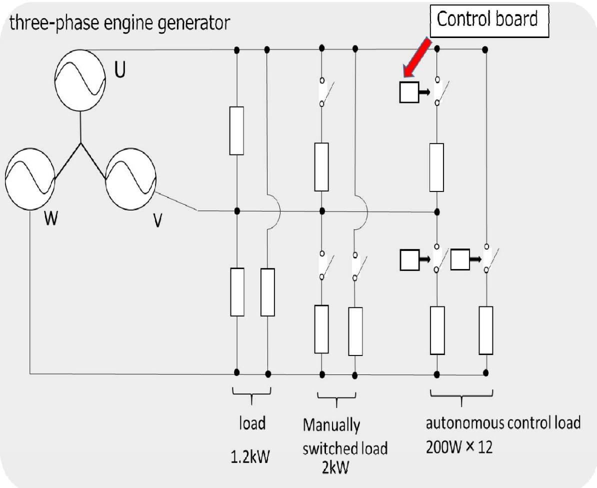

Fig. 2 Overview of laboratory-scale independent power system.

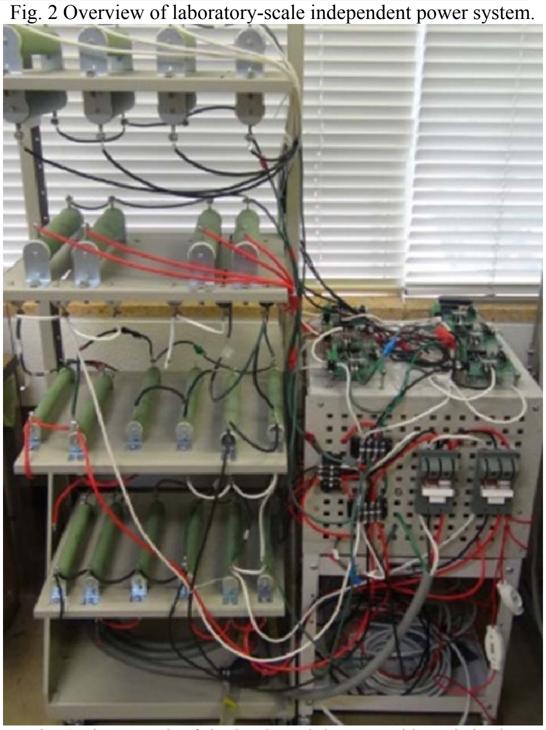
Fig. 3 Photograph of the loads and the control boards in the independent power system

C. Flywheel

When turning on/off the manually switched load in the independent power system, the frequency changed rapidly due to the limited inertia in the system. In order to smoothly vary the frequency by increasing the inertia, a flywheel was connected to the shaft of the generator. TABLE I shows the specifications of the installed flywheel. By mounting the flywheel, time constant is raised up to about 0.2 seconds. It is almost one tenth of practical power system, but the experiment was conducted using this system anyway.

TABLE I
THE SPECIFICATIONS OF THE FLYWHEEL.

Inertia	0.25 [kg·m^2]
Weight	22.22 [kg]
Radius	0.15 [m]
Thickness	0.04 [m]


(a) Flywheel

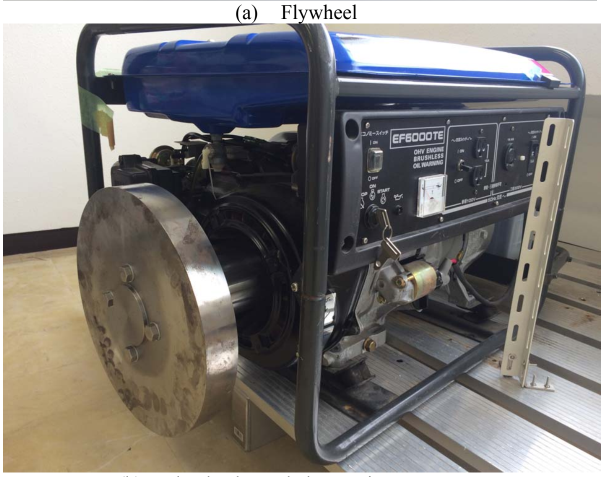
(b) Flywheel coupled to engine generator

Fig. 4 Flywheel used in research.

D. Threshold

Each control board are set specific lower/upper thresholds. The thresholds are distributed as shown in TABLE Ⅱ so as not to turn on or off at the same time.

TABLE Ⅱ
THE THRESHOLDS OF EACH CONTROL BOARD

	UV	UV	UV	UV
ON Threshold [Hz]	49.89	49.61	49.57	49.36
OFF Threshold [Hz]	49.26	48.81	48.73	48.43

	VW	VW	VW	VW
ON Threshold [Hz]	49.84	49.71	49.52	49.40
OFF Threshold [Hz]	49.18	48.96	48.66	48.46

	WU	WU	WU	WU
ON Threshold [Hz]	49.80	49.75	49.48	49.43
OFF Threshold [Hz]	49.11	49.03	48.58	48.51

III. FREQUENCY MEASUREMENT

A. *Commercial power system*

The frequency of the commercial power system (grid) was measured by using the control board and a precision power meter (Yokogawa WT3000). The results are shown in Fig. 5.

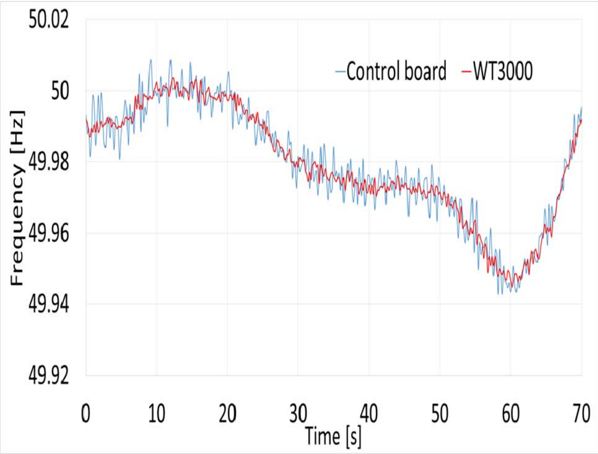

Fig. 5 Frequency comparison of the power system.

Average and maximum errors of frequency measurement were as shown in TABLE Ⅲ.

TABLE Ⅲ
AVERAGE AND MAXIMUM ERRORS

Average	Maximum
0.0002 [Hz]	0.0213 [Hz]

From TABLE Ⅲ, it was confirmed that the control board has an enough accuracy for frequency measurement.

B. *The laboratory-scale independent power system*

Fig. 6 shows the result of measuring the frequency of the laboratory-scale independent power system. A non-contact tachometer (Ono Sokki FV-1500 & LG-9200), was also used to obtain the frequency from the rotational speed of the shaft of the generator. Average and maximum errors of frequency measurement of the control board against a non-contact tachometer, are shown in TABLE Ⅳ.

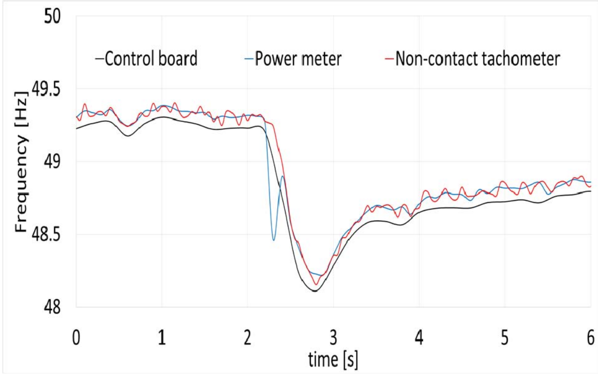

Fig. 6 Frequency measurement result

TABLE Ⅳ
AVERAGE AND MAXIMUM ERRORS

	Average	Maximum
FV-1500	0.117 [Hz]	0.470 [Hz]
WT-3000	0.121 [Hz]	0.609 [Hz]

Fig. 6 and TABLE Ⅳ indicates the frequency measured by the control board has a bias of 0.117Hz. A control board determines the period of voltage waveform by zero-crossing point and obtains the frequency by taking the inverse of the period [1]. Because frequency of FV-1500 and WT-3000 differ by control board about 0.1Hz, period is different about 0.04ms. The reason may be the high harmonics on the voltage waveform (Fig. 7) at zero-crossing point and a specific problem in this independent power system.

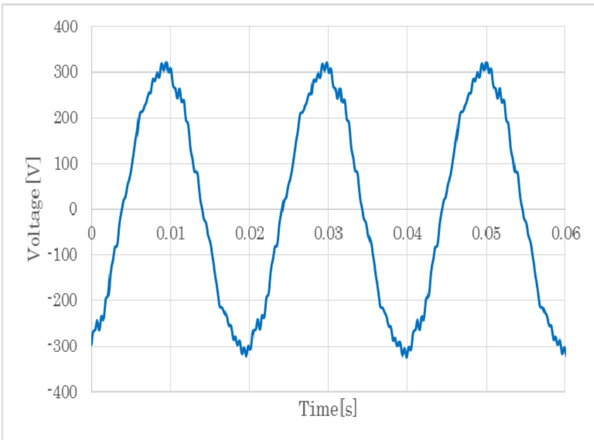

Fig. 7 Voltage of the generator

IV. Demonstration Experiment of Autonomous Load Control

Experiment to clarify the effect of autonomous load control was conducted. At the test, the manually switched load was turned on at t=0 and then the frequency started to decrease. A change in the power consumption and the frequency are shown in Figs. 8, 9 in the cases without or with autonomous load control. The numbers in the figures represent the number of autonomous control load with on-state.

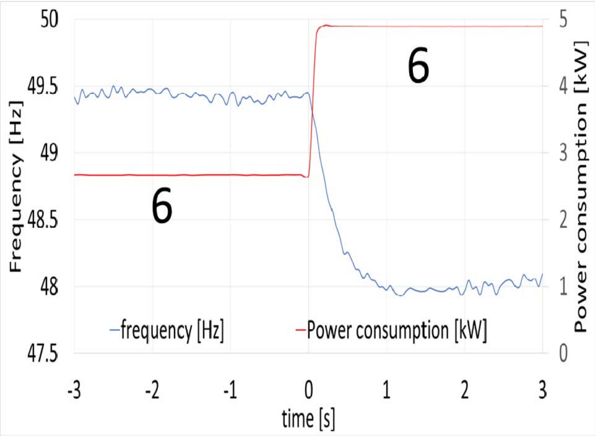

Fig. 8 Relationship between frequency and power consumption without autonomous load control

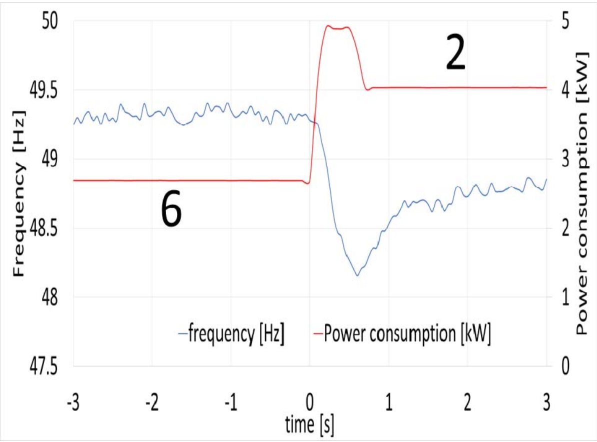

Fig. 9 Relationship between frequency and power consumption with autonomous load control.

The number of on-state autonomous control loads was set to six before turning on the manually switched-load. In the case without the autonomous control boards, the number of controlled resisters was kept to six, and large frequency deviation occurred after the manually switched load was turned on as shown in Fig. 8. On the other hand, when the autonomous control boards are active, the frequency deviation was mitigated as shown in Fig. 9. The average value of the stable frequency before turning on the manually switched load is defined as a reference value. Then, the average and maximum of frequency errors were calculated with respect to the reference value from 0 s to 1.75 s when autonomous load control had stabilized. The results are shown in TABLE V.

TABLE V
AVERAGE AND MAXIMUM OF FREQUENCY ERRORS WITH AND WITHOUT AUTONOMOUS LOAD CONTROL.

	Reference value [Hz]	Average of frequency deviation [Hz]	Maximum of frequency deviation [Hz]
Without autonomous load control	49.421	1.259	1.488
With autonomous load control	49.315	0.756	1.172

According to the comparison between without autonomous load control and with load control, autonomous load control was able to reduce 40% of average of frequency deviation and 21% of maximum of frequency deviation. In the case that the control boards were active, the fast frequency deviation cannot be mitigated. The reason is that the inertia of the independent power system is too small. That is, the time constant (~0.2s) of the power system is almost the same as the operational interval of the control board as described in section II. In practical power system, the time constant is longer in general. Thus, the control boards must be more effective in practical power systems.

V. Conclusions

In this study, a laboratory-scale independent power system has been composed by an engine generator and resistors with the control boards, and the validity of the autonomous frequency control has been demonstrated using the system. By this demonstration test using this system, it could be seen that autonomous load control was able to improve 40% of average of frequency deviation and 21% of maximum of frequency deviation.

References

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