Fuel Cell Co-generation and PCS Control for Suppressing Frequency and Voltage Fluctuation due to PV Power

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Abstract—**The purpose of this study is to control active power of fuel cell co-generation system and reactive power of power conditioning system to suppress frequency fluctuation in power system and voltage fluctuation in distribution system caused by variation of photovoltaic power. The governor-free control for fuel cell co-generation system is applied to reduce frequency fluctuation in power system. A method which controls power fluctuation in distribution system for power conditioning system is applied to reduce voltage fluctuation. The authors reveal the effectiveness of the method by a simulation model. The results suggest that fuel cell co-generation system and power conditioning system work to reduce each targeted fluctuation.**

Index Terms—**photovoltaic power, fuel cell co-generation system, power conditioning system, frequency control, voltage control**

I. Introduction

During the imbalance between demand and supply, frequency fluctuations occur in power system. The power from thermal and hydro power generators control frequency fluctuation and balance demand and supply. Nowadays, the number of Photovoltaic (PV) power has increased in power system. Due to changing of weather conditions PV power is uncontrollable. When the number of PV panels are connected to power system, controllable generators such as thermal power generators must be suspended to maintain the balance between demand and supply. Therefore, a frequency control mechanism in power system is lost which causes a power stability problem [1]-[3].

In distribution systems, variations of PV power cause voltage fluctuations because PV panels are directly connected to the distribution lines. This situation cannot keep the voltage within acceptable range (101±6 V) which is the rule in Japan power system [4].

On the other hands, on demand side, consumers have been attracted by Fuel Cell (FC) co-generation system which decreases CO_2 emission. About 5.3 million units are expected to be installed in 2030 in Japan [5]. The power of FC co-generation is controlled by Power Conditioning System (PCS) which has ability to control the power with high performances; high speed, high efficiency and so on [6].

This research focuses on active power of FC co-generation to reduce frequency fluctuations in power system, and focuses on reactive power of PCS to suppress voltage fluctuations in distribution systems. The final achievement of this paper is to control active power and reactive power independently to reduce each targeted fluctuation. Data to apply simulation is from one real house in Jono area, Kitakyushu city, Fukuoka, Japan to perform the simulation.

II. Fuel Cell Co-generation

FC co-generation is to make electrical energy and hot water simultaneously by gas. FC co-generation power is changed slowly because of reforming equipment.

Speed limit of FC co-generation is shown in Table I and the data in Table I is calculated from an experiment of a real equipment.

The data is applied to simulation models to analyze frequency fluctuations in the power system and voltage fluctuations in the distribution system.

TABLE I. Speed Limit of FC Co-generation

Operation	Speed limit
UP	5.2 W/sec
DOWN	−34 W/sec

III. Simulation Model

A. Power System Simulation Model

The power system simulation model is built by MATLAB/Simulink [2], [7], [8]. The model assumes Kyushu power grid in the spring. The capacity of PV power is estimated to cause frequency fluctuation by maximum 0.2Hz. The number of FC co-generation is estimated by a future situation in 2030 in Japan [5]. Condition of the simulation model is shown in Table II.

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TABLE II. CONDITION OF POWER SYSTEM FOR ANALYSIS

Type	Capacity
Power system	8,000 MVA
Photovoltaic power	450 MW
Fuel Cell co-generation system	350 MW

B. Distribution System Simulation Model

The distribution system simulation model is built by MATLAB/Simulink [1], [9], [10].

The distribution system simulation model has two kinds of transformer. One of them is changeable from 6600 V to 105 V and the other is changeable from 6750 V to 105 V. The model is defined by 35 nodes inside. The node is low voltage distribution model and it is composed of 14 or 15 houses. The tap controller controls Load Ratio control Transformer (LRT) by adjusting automatically voltage levels of the distribution system.

Data of consumption power, PV power and FC co-generation are inputted to the low voltage distribution model as current information. The condition of simulation is that there are 1,000 houses. 500 houses install PV panel and FC co-generation system. 500 houses install just FC co-generation system.

On the model, totally, there are 500 PV panels and 1,000 FC co-generation systems. The capacity of PCS of PV power is 5 kVA. The other PCS of FC co-generation is 0.75 kVA [8]. The PCS of PV generates just active power.

In this paper, the model uses each data from one real house at Jono area in Kitakyushu city Fukuoka.

IV. FREQUENCY FLUCTUATIONS

A. Proposed Method

FC co-generation generates electric power constantly and the governor-free control for FC co-generation is applied to reduce frequency fluctuations in (1). K_G is proportional gain and negative value. The gain K_G depends on the condition of power system. Frequency fluctuation (Δf) is input to the FC co-generation as a feedback signal and variation of FC co-generation power (ΔP_{FC}) cancels the frequency fluctuation.

$$\Delta \mathrm{P_{FC}} = \mathrm{K_G} \Delta \mathrm{f} \quad (1)$$

The target cycle of frequency fluctuation is from 20 to 1,200 seconds.

B. Applying Governor-Free Control to FC Co-generation

In Fig. 1 the blue line is the frequency fluctuation without control. The frequency fluctuation in this simulation is set higher than it actually is. The red line is with control by FC co-generation.

Compared blue and red lines, the red line is smaller than the blue line. The average fluctuation of the red line is 60.6 % of the blue one. This means that FC co-generation with the proposed method could reduce frequency fluctuation better than the condition where the governor-free control is not applied.

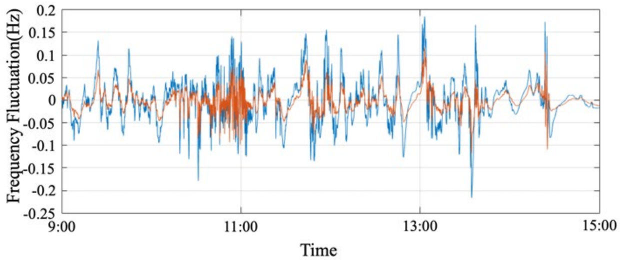

Figure 1. The comparison of frequency fluctuation.

C. Voltage Fluctuation Problem in Distribution System

In distribution system, variation of PV power causes voltage fluctuation. The governor-free control for FC co-generation generates variation of FC co-generation power. The power fluctuation also causes voltage fluctuation in distribution system, therefor voltage fluctuation could be higher than which without the governor-free control.

V. VOLTAGE FLUCTUATIONS

A. Proposed Method

With reference to the past research [6], reactive power in Jono area could be utilized for controlling voltage fluctuation in distribution system.

Fig. 2 is a sample of FC co-generation which could generate power in Jono area. In the graph the blue line is FC co-generation power.

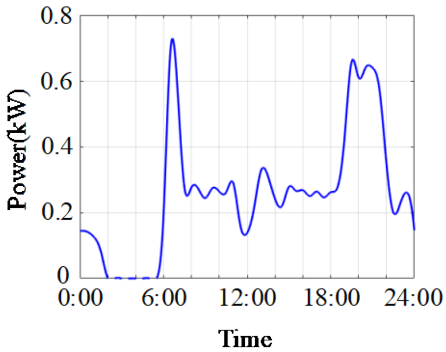

Figure 2. Sample of FC co-generation for the whole day in Jono area.

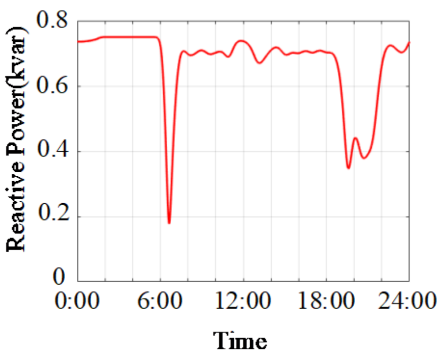

Figure 3. Sample of FC co-generation for the whole day in Jono area.

In Fig. 3, the red line is possibility of maximum output of reactive power which PCS with FC co-generation can generate. Fig. 3 shows that during daytime when variation of PV power occurs between 8 A.M. and 6 P.M., PCS has a lot of potential to output reactive power for suppressing voltage fluctuation. Since the PCS generates enough reactive power, this research focuses on the reactive power of PCS with FC co-generation to control voltage fluctuations in the distribution system.

The proposed method has a point that active power and reactive power of the PCS is generated independently. Equations of each power are represented as follows. In (2), the active power of PCS (P_{PCS}) is FC co-generation power (P_{FC}) to supply power and to reduce frequency fluctuation. In (3), the reactive power of PCS (Q_{PCS}) is to compensate the voltage fluctuation caused by active power of FC co-generation with governor-free control (P_{FC}) and variation of PV power (ΔP_{PV}) which is close to PCS.

$$P_{PCS} = P_{FC} \quad (2)$$

$$Q_{PCS} = KP_{FC} + K\Delta P_{PV} \quad (3)$$

$$\mathrm{K} = \tan\{\cos^{-1}(\beta)\} \quad (4)$$

The PCS generates reactive power in (3). Equation (3) has proportional gain which is K. In (4), β is the power factor. β also depends on the distribution system. Controlling β changes the output reactive power changed. This paper will reveal that PCS with FC co-generation can suppress voltage fluctuation in distribution system when it's under a condition where 1,000 houses, 1,000 FC co-generation and 500 PV panels.

B. Applying the Method to PCS

Equation (3) for PCS is applied to reduce voltage fluctuation in distribution system. To reveal the effectiveness of (3) for PCS, the voltage fluctuation is compared when variation of PV power and FC co-generation power occur.

Fig. 4 is voltage fluctuation without (3) for PCS and the voltage fluctuation is high. In Fig. 4, the upper voltage fluctuation is under the condition where the pole transformer is changeable from 6600 V to 105 V and the other condition is where the pole transformer is changeable from 6750 V to 105 V. In this research, the acceptable range is from 101 V to 107 V and the voltage fluctuation must be within the acceptable range [10]. This distribution system simulation model has the tap controller. When the voltage exceeds 106 V for 30 seconds, the tap controller controls LRT to decrease the level of voltage and when the voltage is less than 102 V for 30 seconds, the tap controller controls LRT to increase the level. In this simulation model, LRT controls voltage while the voltage fluctuation is uncontrollable.

When it's between 9 A.M. and 3 P.M. the voltage fluctuation is over the acceptable range.

Fig. 5 is voltage fluctuation with (3) for PCS under the same condition of Fig. 4. K in (3), depends on β in (4). When β is 0.85, voltage fluctuation is reduced significantly under the condition where there are 1,000 houses, 1,000 FC co-generation and 500 PV panels, and, in this section, 0.85 for β in (4) is applied.

PCS with reactive power control makes less voltage fluctuation in Fig. 5 than the voltage fluctuation in Fig. 4. In Fig. 4, the voltage fluctuation, when it's between 9 A.M. and 3 P.M., exceeds the acceptable range even when LRT controls voltage. In Fig. 5 combining PCS with reactive power control with the tap changer makes the voltage fluctuation within the acceptable range.

The result in Fig. 5 reveals the proposal method for PCS reduces voltage fluctuation.

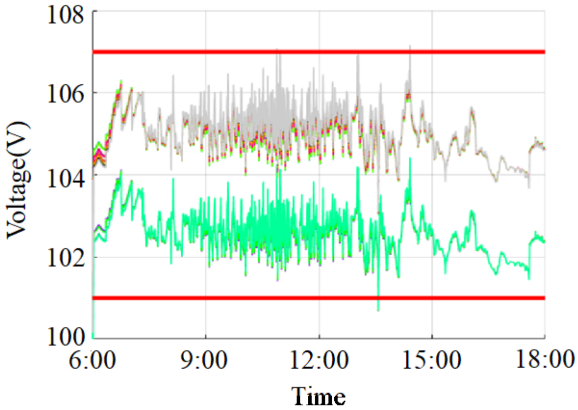

Figure 4. Voltage fluctuation due to PV/FC co-generation.

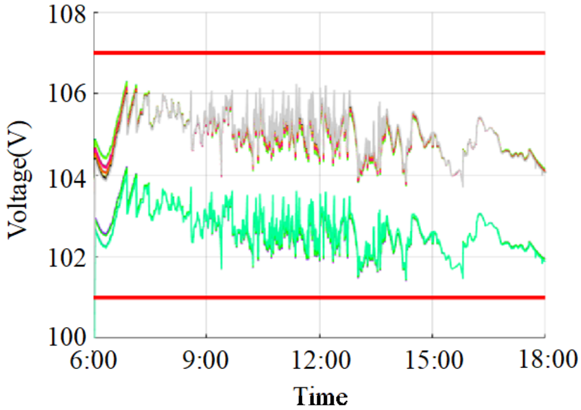

Figure 5. Same condition of Fig. 4 plus PCS with (3).

VI. SUMMARY

Controlling FC co-generation and PCS with the distributed equipment can solve stability problems, which are caused by variations of PV power. Active power of FC co-generation can reduce frequency fluctuation where governor-free control is applied to FC co-generation. In distribution system, PCS with FC cogeneration is utilized for suppressing the voltage fluctuation because the PCS has enough power to generate reactive power during daytime. By applying the proposed method, PCS generates active power and reactive power independently and the equipment can suppress the fluctuation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Shuhei Yamamoto conducted the research and wrote the paper. Yasunori Mitani guided and discussed the research. Masayuki Watanabe and Akihiro Satake discussed the research and reviewed the paper. Yoshiaki Ushifusa provided the resources and discussed the research. All authors had approved the final version.

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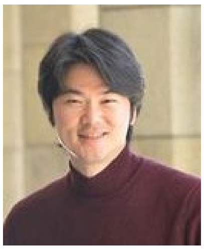

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