# Adaptive Droop Control for Frequency Regulation in Microgrid with Renewables and Electric Vehicles

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***Abstract*—It is of prime importance to keep system frequency within allowable range in microgrid with renewable energy sources because the moment of inertia is generally much smaller in the microgrid and the system frequency is easily oscillated by uncertain output change of the renewable energy sources. High speed output control of wind turbine based on kinetic energy stored in rotating mass can contribute to frequency regulation, so called inertial response control. In particular, in the case of the concept of synthetic inertia control, the wind power output is controlled to mimic the synchronous generator by using high speed inverter control. Here, the control signal can be generated by observing the rate of change of frequency, and this approach contributes to increase the moment of inertia equivalently. The same idea can be realized by charging and discharging control of electric vehicles. In general, it is expected that frequency fluctuation is mitigated by increasing equivalent moment of inertia. However, actual frequency fluctuation might not be improved so effectively only by simply increasing the moment of inertia because longer time has to be spent to restore the frequency deviation. Hence, in this paper, we developed a new control method in which the synthetic inertia control works only when it is possible to improve the frequency fluctuation by the synthetic inertia. The proposed control method is tested as "asymmetric synthetic inertia control" and its effectiveness is shown by using a microgrid model consisting of diesel and gas engine generators, wind turbine, photovoltaic, and load.**

***Keywords-microgrid, frequency control, wind turbine, inertial response***

## I. INTRODUCTION

There are a lot of remote islands in Japan where diesel engine generators are mainly used for power supply, namely, island microgrid. Since fuel cost is often higher than usual in these microgrids due to the transportation cost, it is highly expected that renewable energy integration into the island microgrid is realized to reduce the amount of fuel consumption. In the island microgrid with a large amount of renewable energy sources such as wind turbines or photovoltaics, more advanced control technique for frequency regulation is needed to keep the power system operation stable even under the uncertain output fluctuation [1], [2]. In particular, the frequency fluctuates more easily in the microgrid because the moment of inertia of the island microgrid is in general much smaller than that of the bulk power systems.

In order to mitigate the frequency fluctuation, there are various countermeasures. For example, rechargeable batteries have been installed into the microgrids for the purpose of frequency control. Although the frequency fluctuation can be improved by the battery, it is another issue to cope with the increased capital investment cost. On the other hand, it is expected that renewable energy sources can contribute to the frequency regulation with controlling their output based on converter control. In the case of wind turbine, it is well known that output curtailment is available based on pitch angle control or rotational speed control. In addition, it is possible to increase wind power output by slowing down the rotational speed to utilize stored kinetic energy [3]. This concept is defined as inertial response control which consists of temporal power surge and synthetic inertia. Wind power output can be largely increased only when the significant frequency drop occurred in the case of temporal power surge while the wind power output is controlled to mimic the dynamic behavior of synchronous generators in the case of synthetic inertia control. The authors have developed frequency control methods based on temporal power surge in [4], [5], and so on. Although the temporal power surge is effective approach to assist the frequency drop, its drawback is that the output has to be decreased to restore the rational speed after the contribution. There is a possibility that this recovery phase inversely causes further drop of the system frequency.

On the other hand, the synthetic inertia control method should work in both normal and contingency conditions to mimic synchronous generators by responding to the rate of change of frequency. However, the bigger inertia is not always better for frequency regulation. Hence, in this paper, we developed a new control method in which the equivalent moment of inertia is increased by wind power control only when the bigger inertia contributes to stabilize the system frequency. Specifically, synthetic inertia control works asymmetrically only when the system frequency is moving away from the normal value. It is possible to apply this control method by using not only wind turbine but also charging and discharging control of electric vehicles although only the wind power control was applied in the numerical simulation provided in section III and IV. The effectiveness of the proposed method is verified through numerical simulation based on an island microgrid model with both wind turbine and photovoltaic.

## II. Asymmetric Synthetic Inertia Control

### A. Synthetic Ineria

In general, system frequency fluctuates more easily in the power systems with small moment of inertia. These days, due to the penetration of renewable energy sources, the number of synchronous generators in operation often decreases to keep supply and demand balance. Then, the moment of inertia of the entire AC grid is decreased as well accordingly. It is effective to increase the moment of inertia equivalently by controlling active power from distributed generators or rechargeable battery based on the concept of synthetic inertia. It is possible to express the dynamic behavior of the synchronous generators by changing the generation output based on the product of rate of change of frequency and the moment of inertia. Therefore, the synthetic inertia control can be simply realized by using the control block diagram shown in Figure 1.

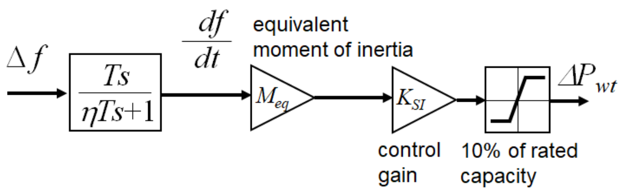



Figure 1. Synthetic inertia control.

### B. Asymmetric Control

Synthetic inertia is an effective concept to increase the moment of inertia to mitigate frequency fluctuation. However, in some papers, it was shown that synthetic inertia control was less effective than conventional droop control which was available by giving control margins at both upper and lower limits [6]. Because the system frequency changes more slowly by the synthetic inertia control, it is expected to contribute to reduce the frequency nadir when it works the moment frequency deviation is increasing. However, if the control works when the frequency deviation gets smaller, longer time is needed before the system frequency is completely restored. As above, the synthetic inertia control causes both advantage and disadvantage in frequency regulation.

Here, there is a possibility that better result can be obtained by applying the synthetic inertia control only when the system frequency is expected to be improved. Specifically, as shown in Figure 2, the synthetic inertia control should work when the sign of frequency deviation is positive (negative) and the system frequency is increasing (decreasing). Regarding the reverse case, it is not necessary to increase the moment of inertia because the frequency deviation is reduced naturally without applying any special control method, namely, small moment of inertia is more desired. As a result, it is possible to decrease the rate of change of frequency by increasing the equivalent moment of inertia only when the system frequency is moving away from normal value.

Figure 3 shows the proposed control block diagram to realize the above concept of asymmetric synthetic inertia control. Control signal is generated by multiplying equivalent inertia, $M_{eq}$, by the rate of change of frequency. This control signal is used as control input after multiplied by the control gain, $K_{SI}$, only when the synthetic inertia control is expected to mitigate the frequency deviation. This judgement can be given by the sign of product of frequency deviation and rate of change of frequency.

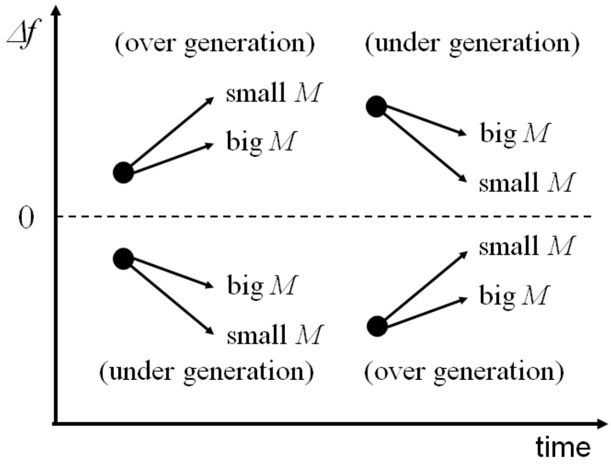



Figure 2. Concept of asymmetric synthetic inertia control.

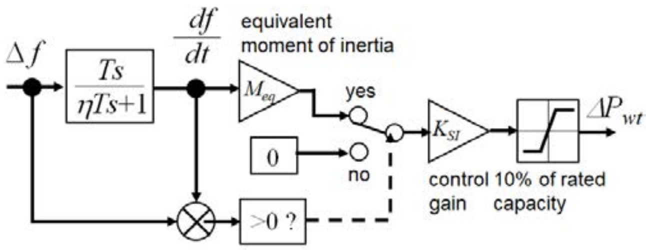


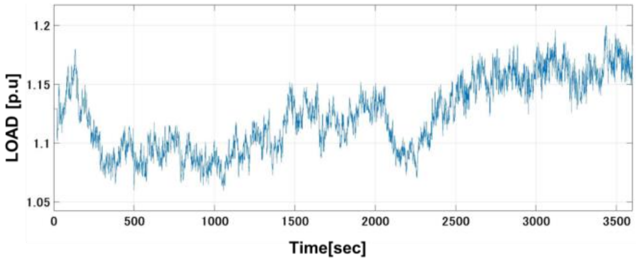

Figure 3. Asymmetric synthetic inertia control.

## III. Simulation Model

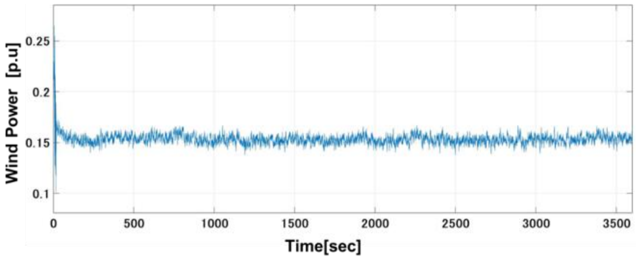
The effectiveness of the proposed method was tested based on a microgrid model which consists of diesel engine generator, gas engine generator, photovoltaic, wind turbine and load. The block diagrams of diesel and gas engine generators are based on [7] and [8]. Figure 4 shows the fluctuation data of load, wind, and photovoltaic output. Wind turbine model consists of rotational speed characteristic, maximization control of generation, and synthetic inertia. System parameters are shown in TABLE I.

TABLE I. System Parameters

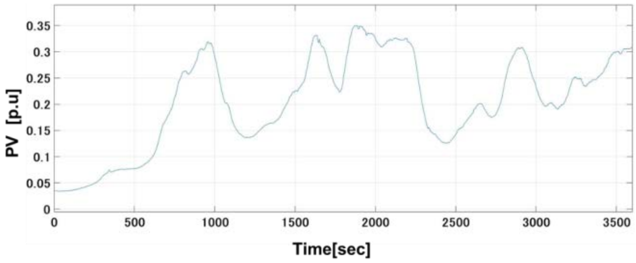
| | |
|---|---|
| Base MVA | 10 MW |
| upper and lower limits of generation output of DE | 0.1 – 0.7 p.u. |
| upper and lower limits of generation output of GE | 0.1 – 0.5 p.u. |
| moment of inertia of entire microgrid | 2 sec |
| damping coefficient of entire microgrid | 1 p.u. |
| equivalent inertia, $M_{eq}$ | 5 sec |
| control gain, $K_{SI}$ | -3 |
| rated capacity of wind turbine | 3.5 MW |




(a) Load




(b) wind power




(c) photovoltaic

Figure 4. Fluctuation data of disturbance.

## IV. SIMULATION RESULTS

Simulation was implemented in the following three cases.

Case 1: Base Case without synthetic inertia control
Case 2: Symmetric synthetic inertia control
Case 3: Proposed asymmetric synthetic inertia control

### A. Case 1

Figure 5 and 6 show frequency deviation from normal value and generation output from diesel and gas engine generators. Conventional generators were controlled to follow the apparent load change, however, the system frequency fluctuates due to the control delay. The biggest frequency deviation was around 0.18 Hz and by neglecting the non-essential bigger frequency deviation at the beginning of this simulation which was inevitable due to the stability of the numerical simulation.

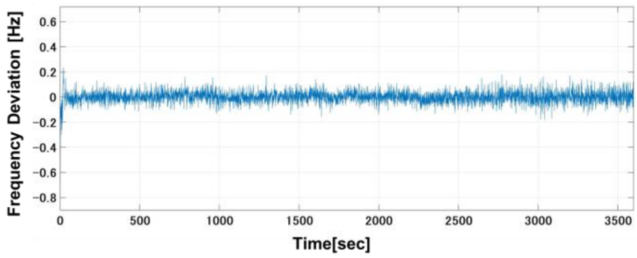



Figure 5. Frequency deviation in Case 1.

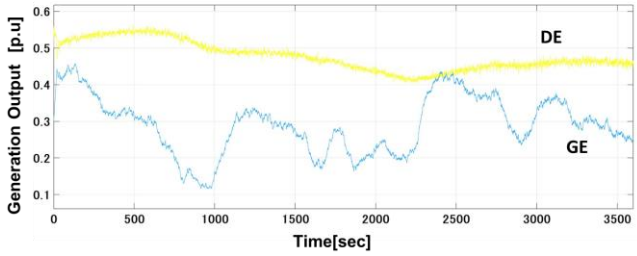



Figure 6. Output of diesel and gas engine generators in Case 1.

### B. Case 2

Figure 7 and 8 show frequency deviation and control signal to wind turbine for synthetic inertia control. As wind power output was controlled properly to cancel the frequency fluctuation throughout the simulation as shown in Figure 8, the frequency fluctuation was entirely mitigated. However, this control method does not always work effectively. In particular, the maximum frequency deviation got bigger than that in Case 1. It should be noted that rotational speed of the wind turbine was kept properly around the optimal value for maximizing the generation output although the inertial response control might affect the rotational speed of the wind turbine.

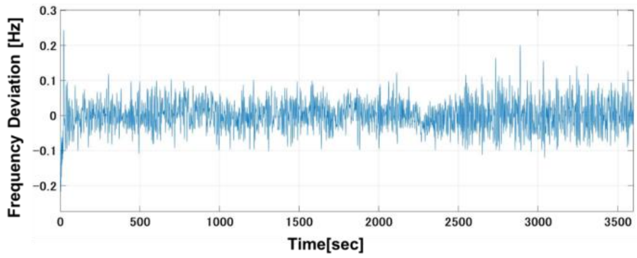



Figure 7. Frequency deviation in Case 2.

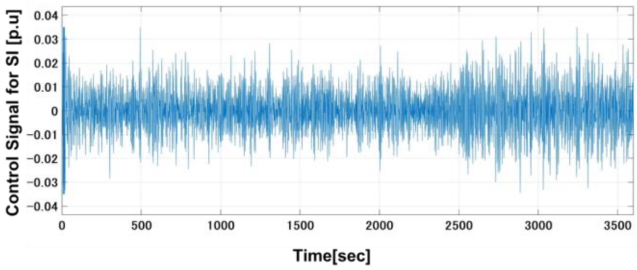



Figure 8. Control signal to wind turbine for synthetic inertia in Case 2.

### C. Case 3

The proposed asymmetric synthetic inertia control was applied in this case. The simulation results are shown in Figure 9 and 10. It is shown that frequency fluctuation was stabilized more effectively compared to Case 2 with symmetric synthetic inertia control. The maximum frequency deviation is around 0.15 Hz which is smaller than that in Case 1. Also, it is shown that the amount of synthetic inertia control becomes smaller compared to Case 2. Consequently, it was possible to keep the system frequency more efficiently by using smaller amount of synthetic inertia control.

The simulation results in all the cases are summarized in Table II based on two evaluation indices, the maximum frequency deviation in both positive and negative directions and percentage of sojourn time when the frequency was from -0.1 to 0.1. It is shown in the table that the evaluation indices in Case 3 with the proposed asymmetric synthetic inertia control was successfully improved than the symmetric control in Case 2.

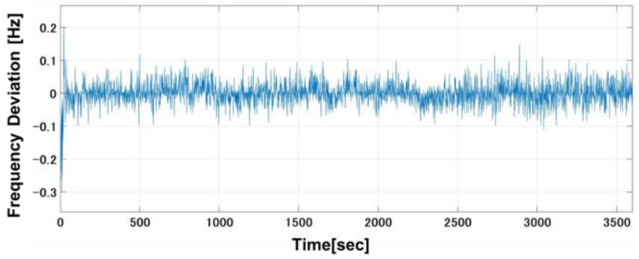



Figure 9. Frequency deviation in Case 3.

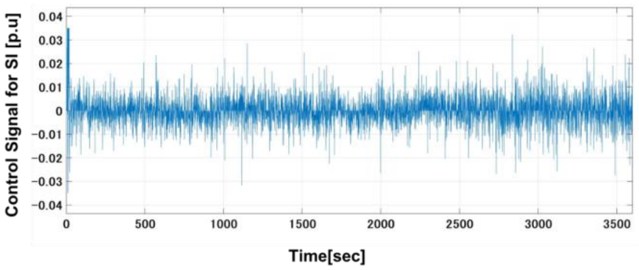



Figure 10. Control signal to wind turbine for synthetic inertia in Case 3.

TABLE II. EVALUATION INDICES

| | Maximum frequency deviation | Sojourn rate |
|---|---|---|
| Case 1 | +0.182 Hz<br>−0.183 Hz | 97.83 % |
| Case 2 | +0.20 Hz<br>−0.12 Hz | 98.85 % |
| Case 3 | +0.148 Hz<br>−0.109 Hz | 99.43 % |

## V. CONCLUSIONS

It is an important issue to mitigate frequency fluctuation in small scale island microgrid with a large amount of renewable energy sources due to both uncertain output fluctuation of renewables and small moment of inertia. To improve the stability in terms of frequency regulation, the application of synthetic inertia control is one of prospective approaches. Here, it should noted that the final goal is not to increase the moment of inertia but to mitigate the frequency fluctuation, in particular, the amount of frequency deviation should be reduced as much as possible. Hence, in this paper, a new control logic in which the synthetic inertia control is applied asymmetrically only when the system frequency is moving away from normal value. The effectiveness of the proposed method was shown in section IV, however, the further discussions will be needed mainly on the following points:

- It is not necessarily the best to apply the synthetic inertia control. For example, other inertial response control such as temporal power surge, or conventional droop control strategy can be used for stabilization as well. The effectiveness of the proposed method has to be examined through comparisons with the above methodologies.
- The equivalent moment of inertia of wind turbines and rechargeable batteries with electric vehicles are specified freely considering the control performance and its impact on the rotational speed of wind turbines or SOC. In this paper, the equivalent inertia and control gain were decided by trial and error approach, more theoretical method is needed to give the optimal parameter setting.
- The control effect also depends on system models. In particular, the system scale, penetration level of renewables, the number of electric vehicles that can contribute to frequency regulation, and fluctuation pattern of renewables. The proposed control method will be tested through the various simulation models.

## ACKNOWLEDGMENT

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