3rd International Hybrid Power Systems Workshop

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

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Outline

- Introduction
  - Background
  - Countermeasures
  - Objectives
- Asymmetric Synthetic Control
  - Synthetic Inertia
  - Asymmetric Control
- Simulation
  - Simulation Conditions
  - Disturbance
  - Simulation Results
- Conclusions and Future Challenges

Introduction

➢ Background

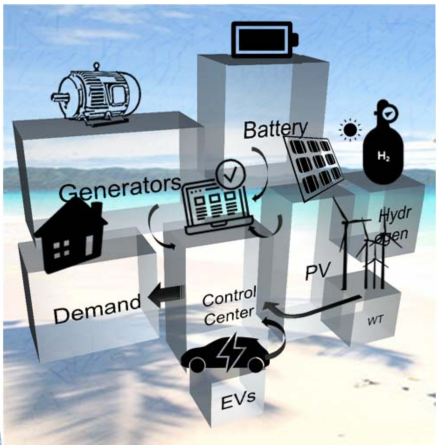


Fig.1 Microgrid

Background

- Sketch of an isolated island (Fig.1)
- ☐ **Japan has a lot of remote islands with independent small-scale power systems. These power systems can be regarded as "microgrid"**
- ☐ **The power system of a remote island is a typical microgrid which is independent of the bulk power system.**

• "Wind Energy Basics". American Wind Energy Association. Archived from the original on 2010-09-23. Retrieved 2009-09-24.

Frequency Fluctuations

Concern

- Supply and Demand Balance Management
- ☐ Sharp Frequency Fluctuations
- ☐ Cooperative frequency control among various resources

Introduction

➢ Miyako Island Microgrid

DEMAND

Item	Capacity
Peak Demand	52MW (Summer)
Bottom Demand	22MW (Winter)
Annual Consumption	262419 MWh

SUPPLY

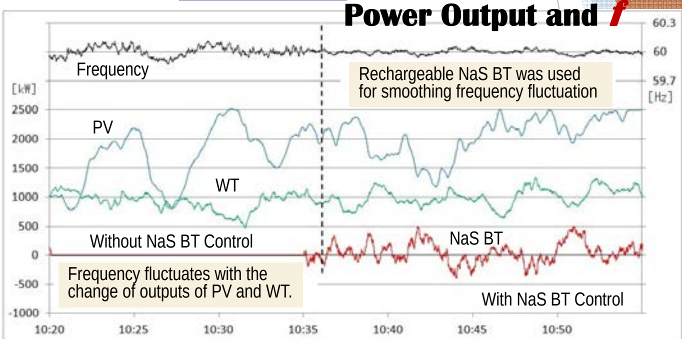
Item	Capacity
Diesel Generation	74MW
Wind Power	4.2MW
Photovoltaics	4MW
NAS Battery	0.5MW*8

LOCATION

Fig.2 Miyako Island

Area: 158.87 ㎢
Population: 55000

Power Output and *f*



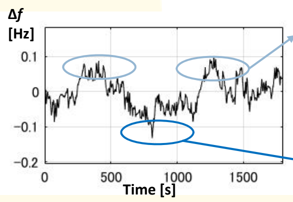
From Website of Okinawa Electric Power Company https://www.okiden.co.jp/active/r_and_d/miyako/

Introduction

➢ Countermeasures

- Supply > Demand
  - ➡ Frequency increases
- Supply < Demand
  - ➡ Frequency decreases

Previous work



System Frequency

■ ***Frequency Increase***

① EV Charge Control
② Delta Control

■ ***Frequency Decrease***

① EV Discharge Control
② Inertial Response (IR)
③ Delta Control

• Control of Renewable Energy

➢ Inertial Response (WT)
  - Synthetic Inertial
  - Temporary Power Surge

➢ Curtailment (PV)

• Control of Conventional Supply

➢ Output control of conventional power supply (GF, LFC, EDC)

• Rechargeable Battery

➢ Charge and Discharge Control

Introduction

➢ Objectives

I. Developed a new control method **based on the** synthetic inertia **in which the equivalent moment of inertia is increased by wind power control only when the bigger inertia contributes to stabilize the system frequency.**

II. **Specifically, synthetic inertia control works asymmetrically only when the** ***system frequency is moving away from the normal value*****.**

III. Testing the effectiveness of the proposed control **through numerical simulation based on an island microgrid model with both wind turbine and photovoltaic.**

The same control principle can be applicable for Charging and Discharging Control of Electric Vehicles, but only wind power is focused on this time.

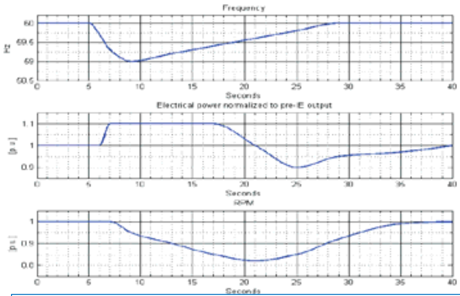
Asymmetric Synthetic Control

➢ Inertial Response

Frequency support in normal condition is available by changing the rotational speed

□ **Temporary Power Surge**

➢ WP output can be instantaneously increased to recover the sudden frequency drop only in short time.



Markus Fischer, Sonke Engelken, Nikolay Mihov, Angelo Mendonca: "Operational Experiences with Inertial Response Provided by Type 4 Wind Turbines",Proc. of the Wind Integration Workshop, 8B-2 (2014)

□ **Synthetic Inertial**

$$P_{WP} = -K_{WP}\frac{df}{dt}$$

➢ WP output changes depending on ROCOF to emulate actual synchronous generator.

Droop Control is better ?

□ **Droop Control**

➢ Proportional control with control margin secured by power curtailment.

✓ *Through comparing conventional SI control and Droop control, droop control is of obvious advantage, as the SI control increased the system inertial so that influenced ROCOF a lot.*

Jan Van de Vyver, Jeroen D. M. De Kooning, Bar Meersman, Lieven Vandevelde, and Tine L. Vandoorn: "Droop Control as an Alternative Inertial Response Strategy for the Synthetic Inertia on Wind Turbines", IEEE Trans. On Power Systems, Vol. 31, No. 2, pp.1129-1138, 2016

Asymmetric Synthetic Control

➢ Synthetic Inertia

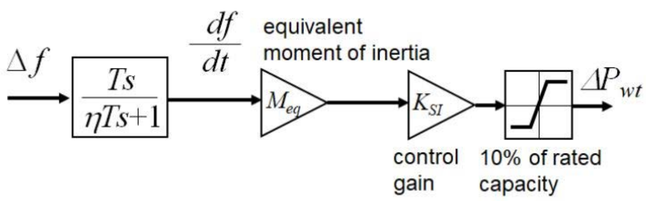


Figure.3 Synthetic inertia control

- **Synthetic inertia** is an effective concept **to increase the moment of inertia** to mitigate frequency fluctuation.
- It is possible to express the dynamic behavior of the synchronous generators by changing the generation output based on the product of **ROCOF** and the **moment of inertia**. Therefore, the synthetic inertia control can be simply realized by Figure 3. *Rate of Change of Frequency (ROCOF)

Asymmetric Synthetic Control

➢ Asymmetric Control

- However, it is shown in some papers that synthetic inertia is less effective than droop control because Big value of **M** makes frequency restoration slower.

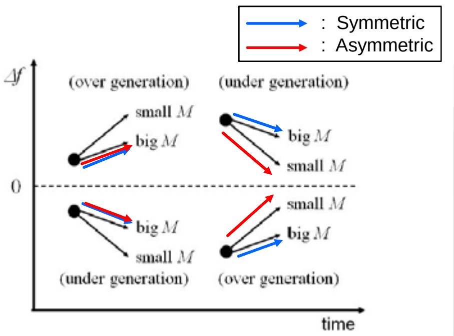


Figure.4 Concept of asymmetric synthetic inertia control

✓ 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 4, the synthetic inertia control should work when the sign of frequency deviation is positive (negative) and the system frequency is increasing (decreasing).

Asymmetric Synthetic Control

➢ Asymmetric Control

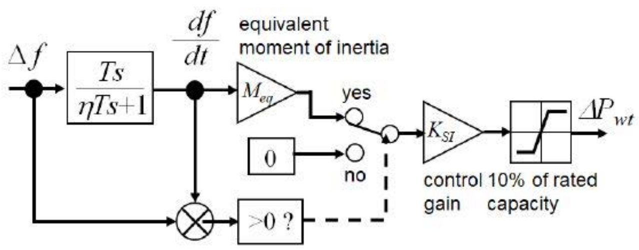


Figure.5 Asymmetric synthetic inertia control

- Figure 5 shows the proposed control block diagram to realize the above concept of asymmetric synthetic inertia control. Control signal is generated by multiplying equivalent inertia, Meq, by the rate of change of frequency.
- This control signal is used as control input after multiplied by the control gain, KSI, 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.

Simulation

➢ Simulation Conditions

Items	Setting Value
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

- 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.

Simulation

➢ Disturbance Model

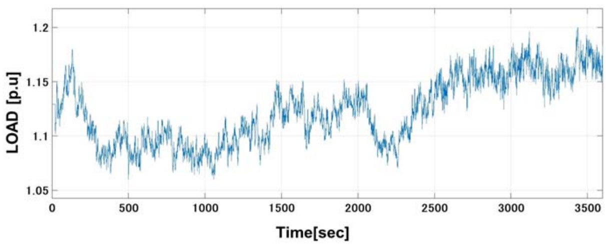


Figure.6 Load

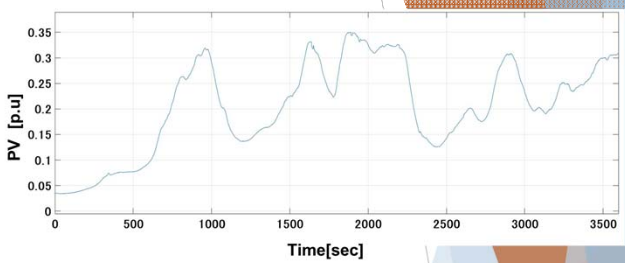


Figure.7 PV

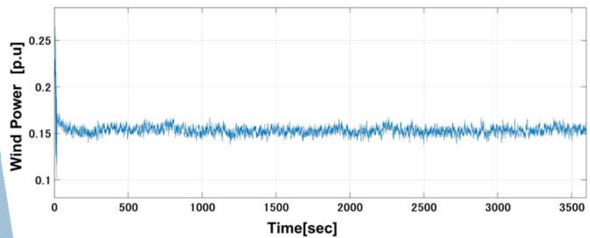


Figure.8 Wind Power

- Figure 4 to 6 show the fluctuation data of load, wind, and photovoltaic output.

Simulation

➢ Simulation Results : **Case 1**

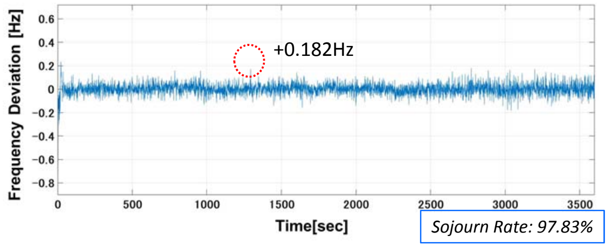


Figure.9 Frequency Deviation

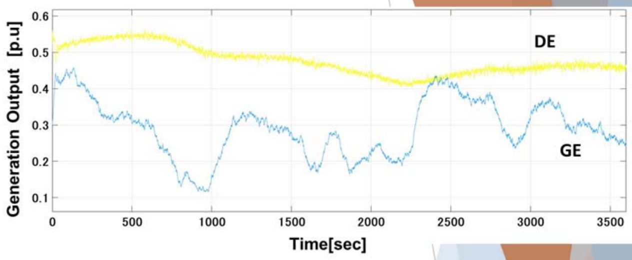


Figure.10 Generation Output of DE and GE

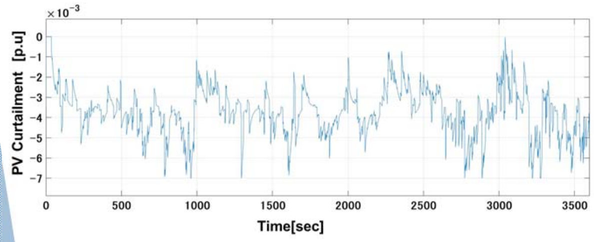


Figure.11 PV Curtailment

- **Case 1**: Base Case without SI Control
- **Case 2**: Symmetric SI Control
- **Case 3**: Proposed Asymmetric SI Control

Simulation

➢ Simulation Results : **Case 2 With Symmetric SI Control**

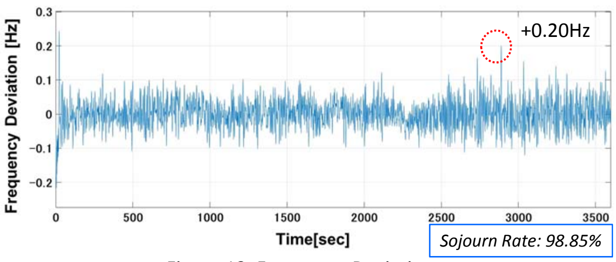


Figure.12 Frequency Deviation

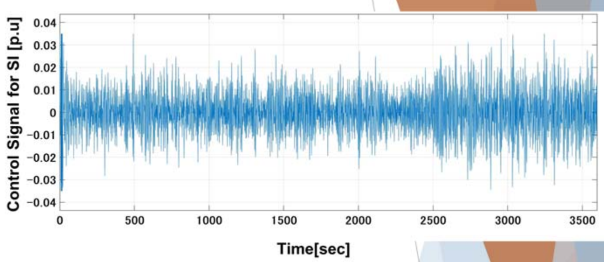


Figure.13 Control Signal for Synthetic Inertia

- **[Attention]**

**This control method was inferior even to 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.

Simulation

➢ Simulation Results : **Case 3 Proposed Asymmetric SI Control**

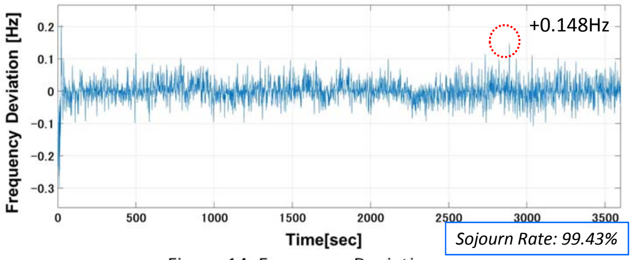


Figure.14 Frequency Deviation

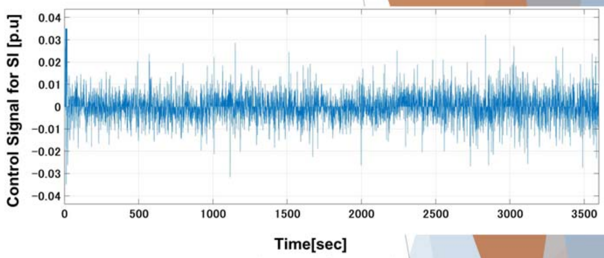


Figure.15 Control Signal for Synthetic Inertia

- ➢ 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 0.148 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.

Conclusions and Future Challenges

➢ Conclusions

- ✓ **Developed a new control method based on the synthetic inertia in which the equivalent moment of inertia is increased by wind power control only when the bigger inertia contributes to stabilize the system frequency.**
- ✓ **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 control was tested by simulations with 3 cases based on an island microgrid model.**

➢ Future Challenges

- ☐ It is not necessarily the best to apply the synthetic inertia control. The effectiveness of the proposed method ***has to be examined through comparisons with the above methodologies***.
- ☐ 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 proposed control method ***will be tested through the various simulation models*** not only in the microgrid model we used in this study.

Appendix- EV ADDED

➤ Simulation Results : **Case 1**

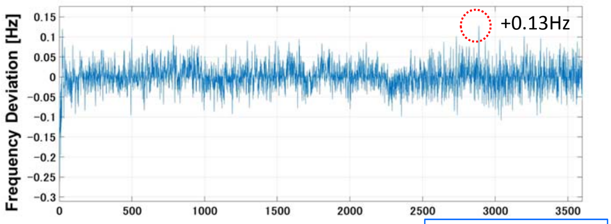


Figure.14 Frequency Deviation

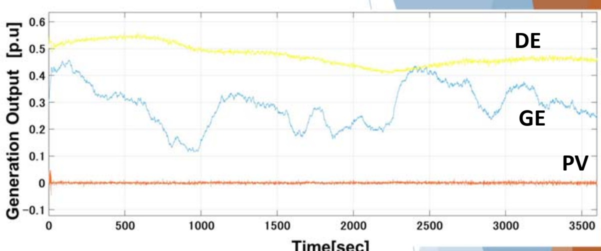


Figure.15 Generation Output of DE and GE

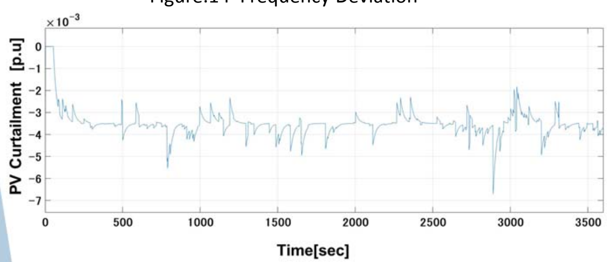


Figure.16 PV Curtailment

- ☐ **Case 1**: Base Case without SI Control
- ☐ **Case 2**: Symmetric SI Control
- ☐ **Case 3**: Proposed Asymmetric SI Control

Appendix- EV ADDED

➢ Simulation Results : **Case 2**

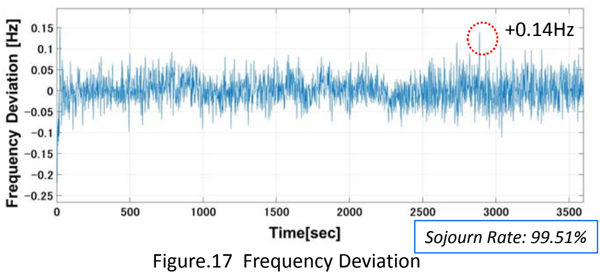


Figure.17 Frequency Deviation

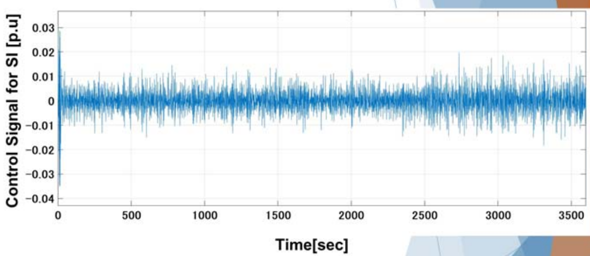


Figure.18 Control Signal for Synthetic Inertia

Appendix- EV ADDED

➢ Simulation Results : **Case 3**

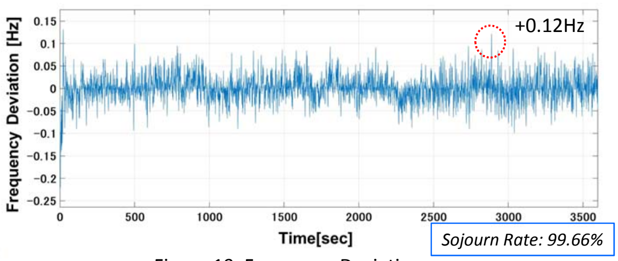


Figure.19 Frequency Deviation

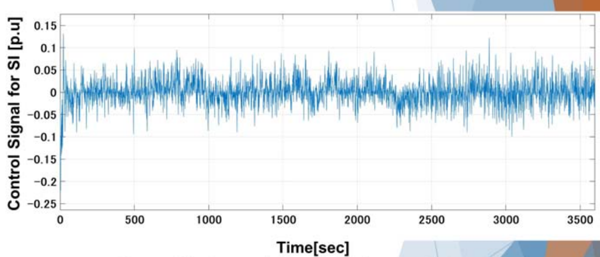


Figure.20 Control Signal for Synthetic Inertia