Mitigating Frequency Fluctuations in Power Grids with High Photovoltaic Penetration: AGC 30 Model Case Study

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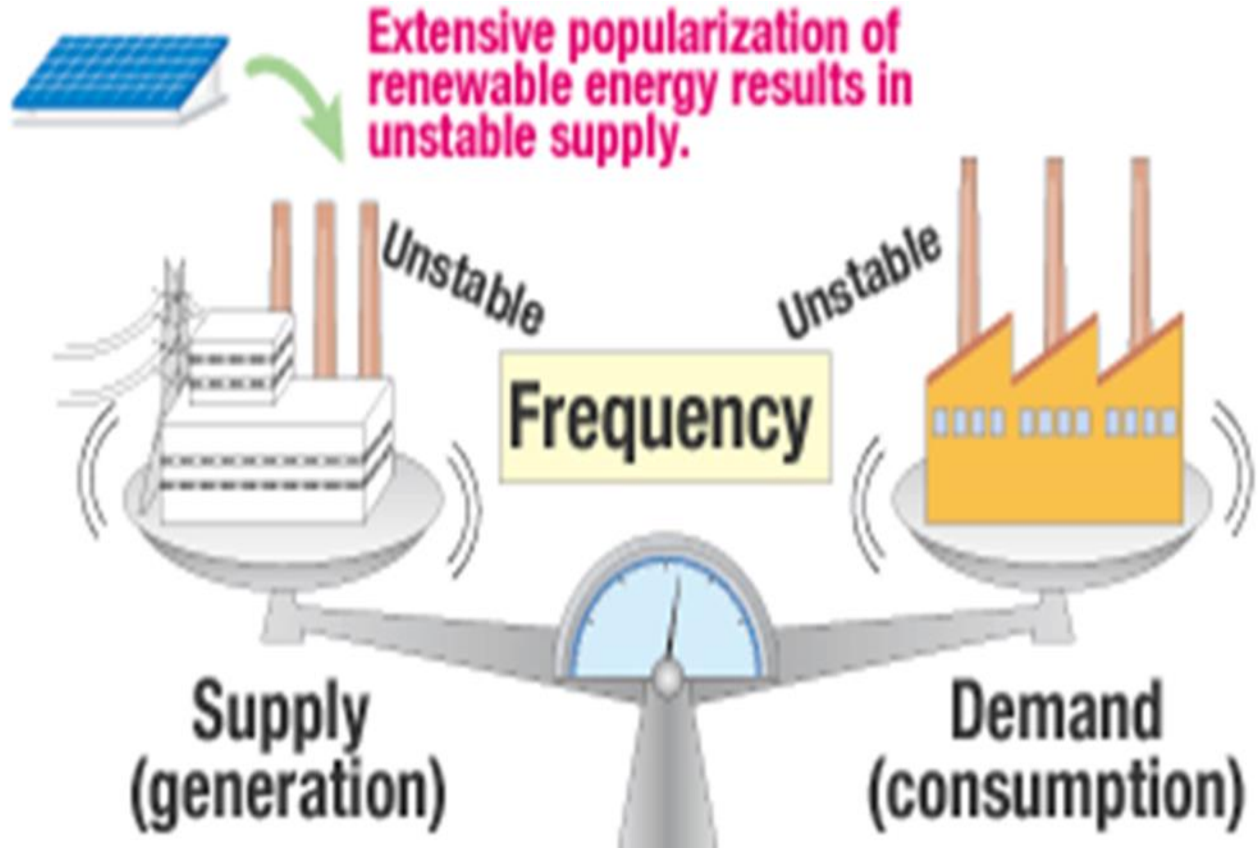
Outline

1. Introduction
2. Automatic Generation Control (AGC)
3. Delta Power Control (DPC)
4. Simulation Results
5. Conclusion

1. Introduction

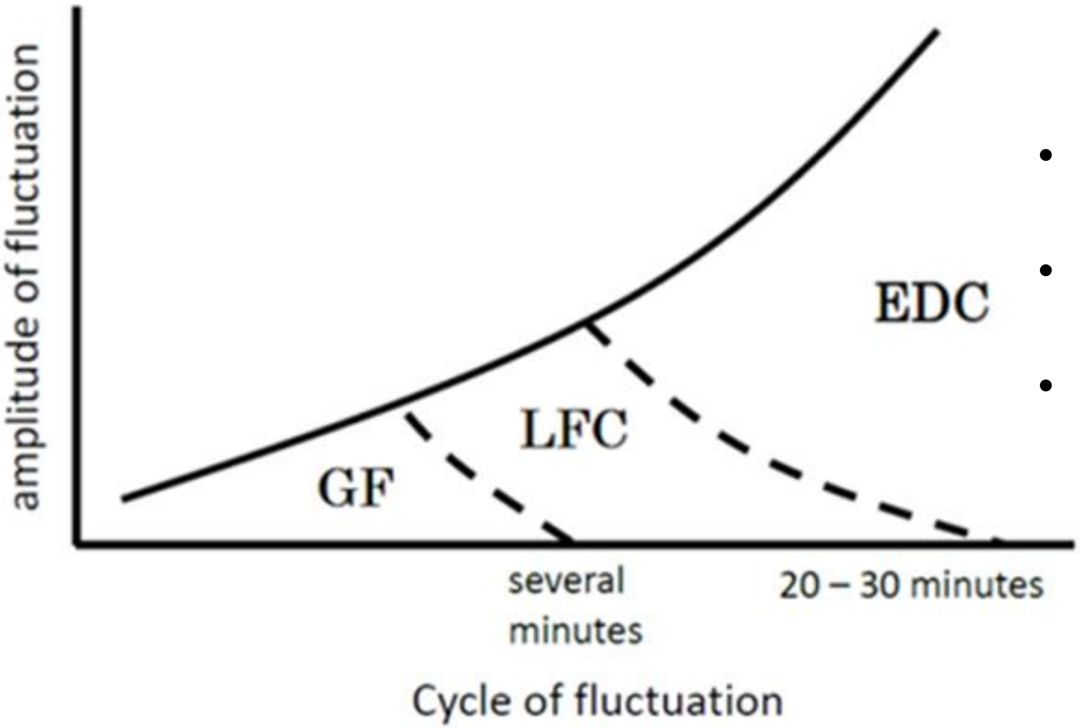
- Frequency is a function of power demand and supply balance
- Stable frequency is one of the features of good power quality
- Power output of renewable energy sources such as Photovoltaic systems (PV) are intermittent and they cause frequency fluctuations
- Consequently, there is the need to control the frequencies of a Power Grid that has high penetration of PV
- There are different strategies of achieving a stable or near stable frequency in a power system



This research is considering a strategy known as delta power control

2. Automatic Generation Control (AGC)

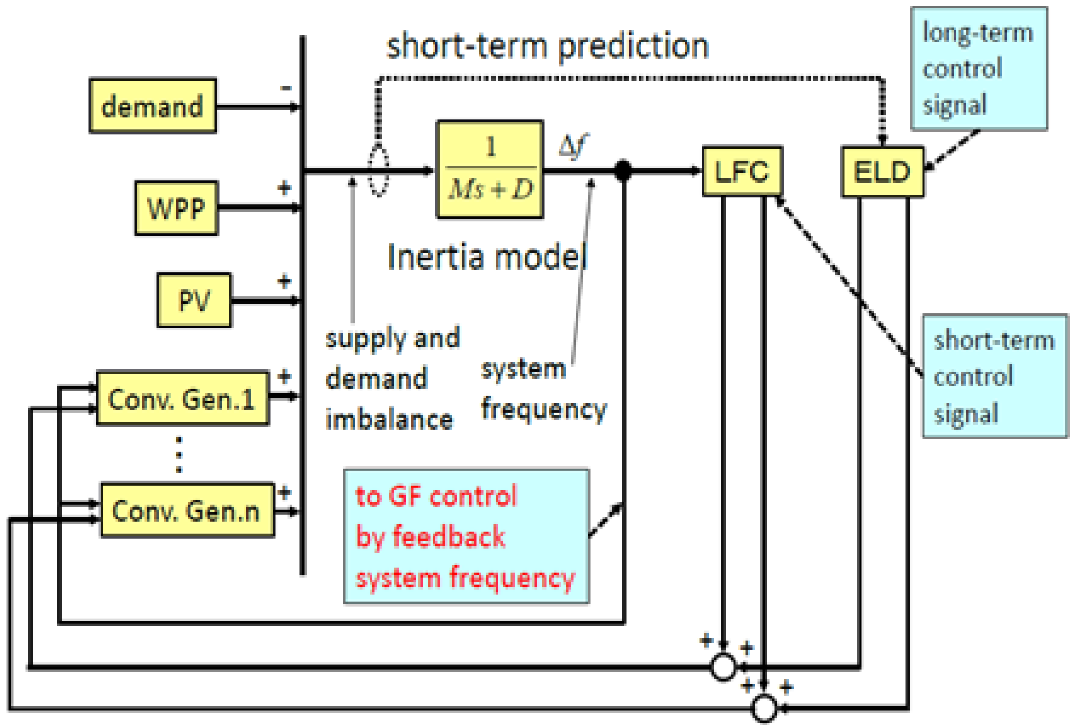
AGC in an electric power system refers to a control strategy wherein all generators contribute to regulate frequency by adjusting their respective power outputs in order to respond to changes in load thereby overcoming power imbalance.



Demand fluctuation and frequency Control

- GFC detects frequency deviation on site and controls within few cycles.
- LFC follows from seconds to about 20 minutes
- Larger scale of operation will utilize EDC in order to minimize total operating costs in an area

2. Automatic Generation Control (AGC)

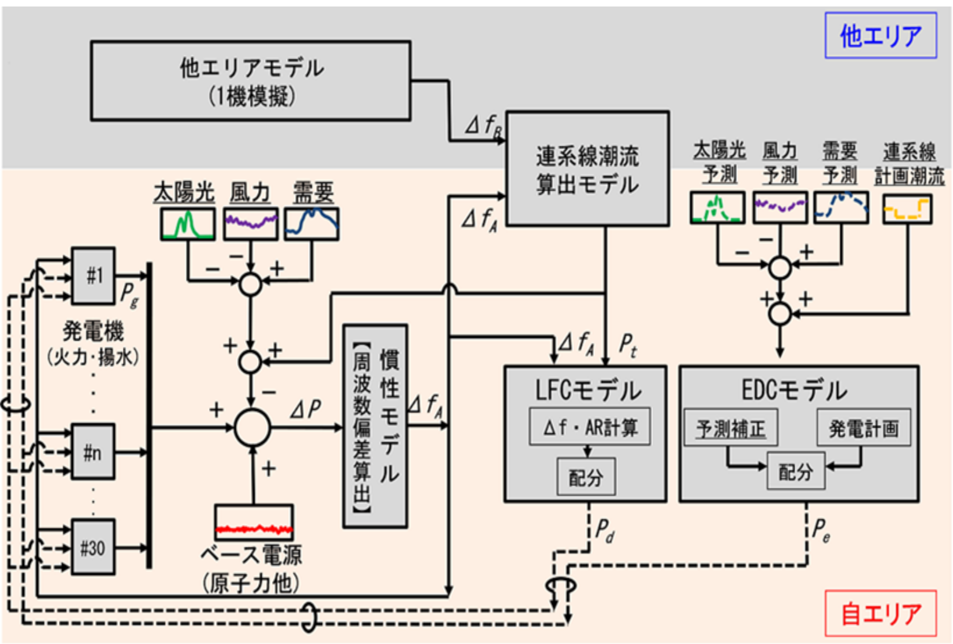


General frequency analysis model for an interconnected power system

2. Automatic Generation Control (AGC)

AGC 30

AGC 30 model is a standard analysis model of supply and demand frequency simulation proposed by the electricity supply and demand analysis model standardization investigation expert committee in Japan.



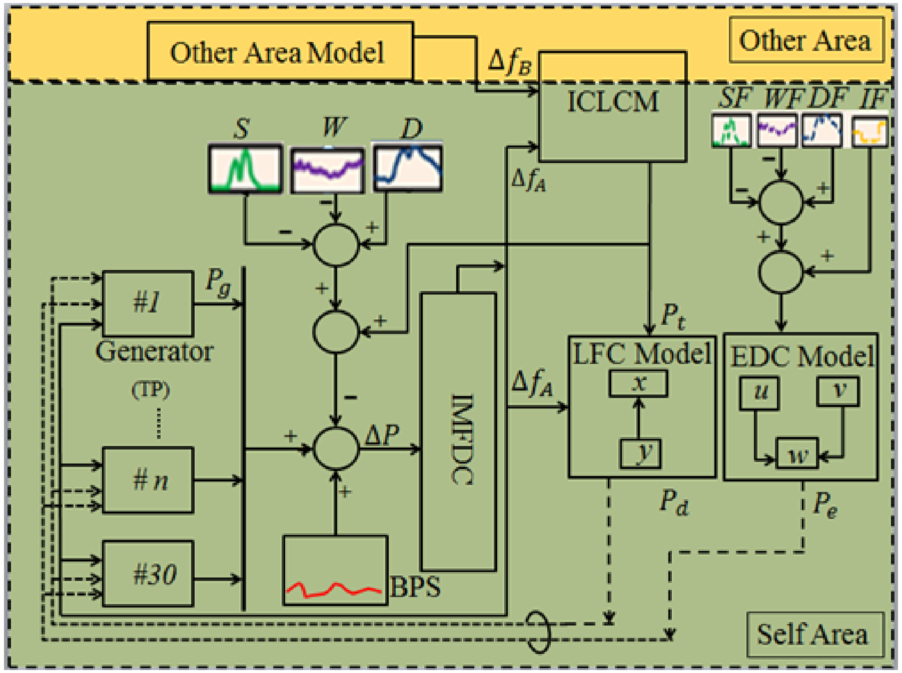


Diagram of AGC 30 model

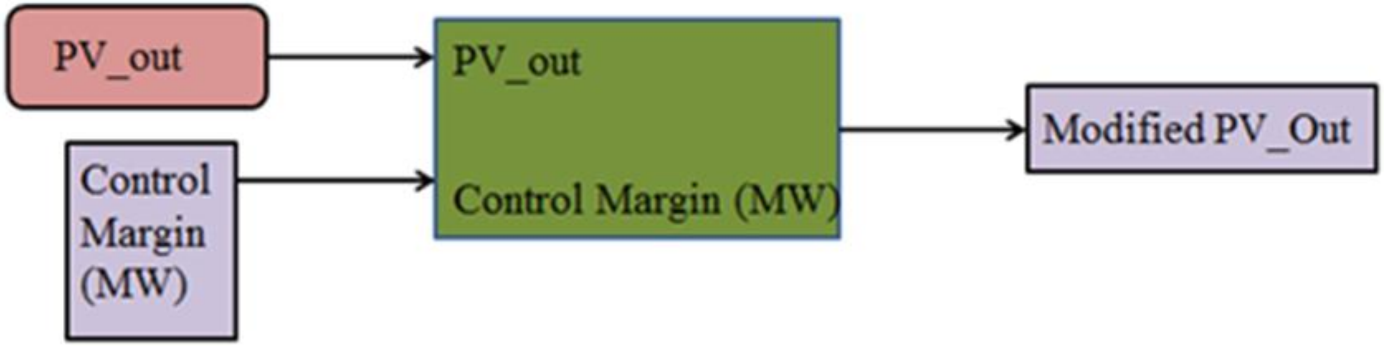
3. Delta Power Control (DPC)

DPC

Delta control curtails active power from PV. The concept of the DPC strategy is that the output active power from PV systems is reduced to a certain level in case of frequency deviations. This provides support for the grid and could also serve as power reserve. Delta power constraint can be summarized as:

$$P_{pv} = P_{avail} - \Delta P$$

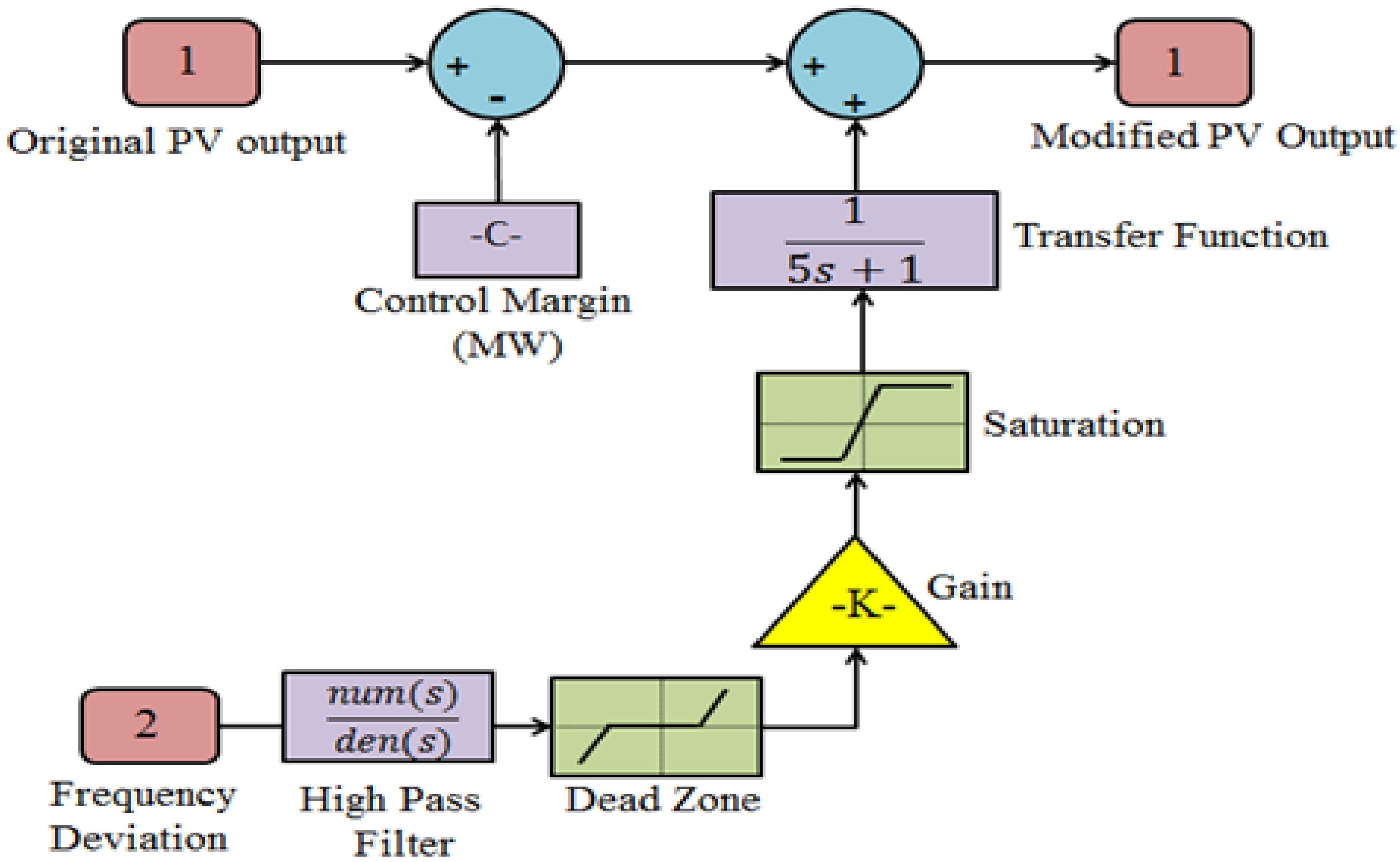
ΔP is the amount of active PV power curtailed during operation



PV Control Block

3. Delta Power Control (DPC)

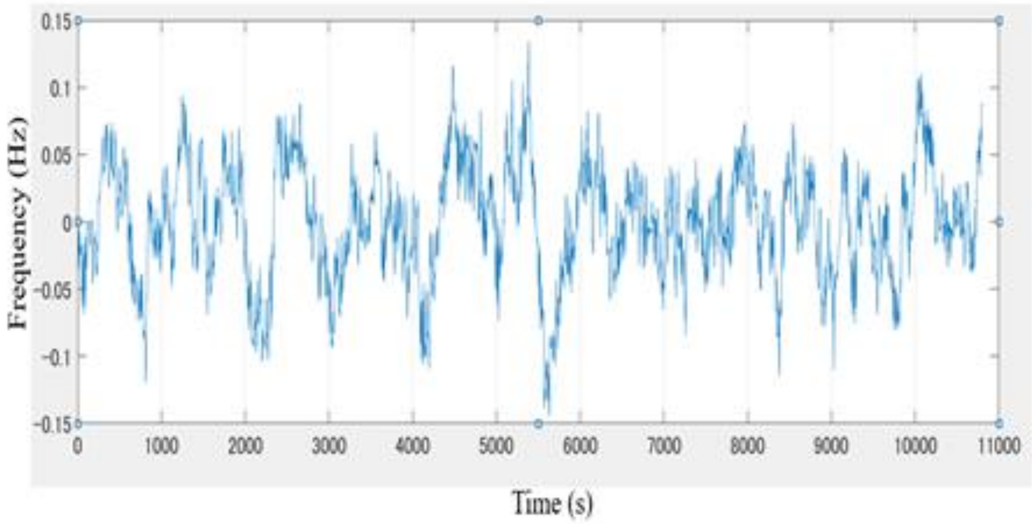
Control Structure



Delta Control Structure Diagram

Reference Power System

Without PV, purely conventional generating sources: four coal-driven generators; three Liquefied Natural Gas (LNG); and eight Combined Cycle generators.
The maximum frequency deviation of this system was **0.133 Hz** on the positive side and **0.1448Hz** on the negative, with an average deviation of 0.0834 Hz



Worst frequency:
Max. **0.1330**
Min. **-0.1448**
Ave. 0.0834

Reference power system frequency fluctuations

4. Simulation Results

Study Model

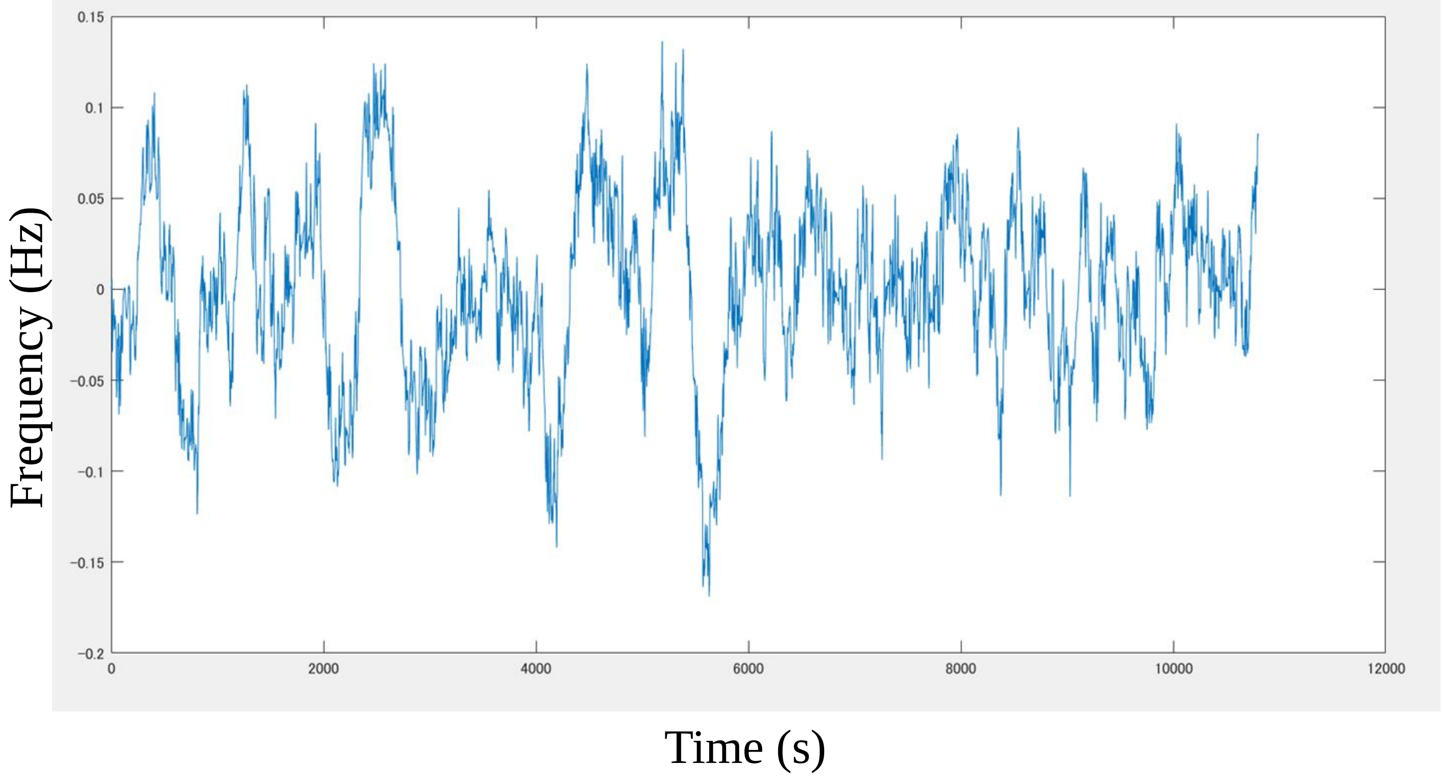
The system used for this study had it's conventional generators (LNG) capacity reduced to 2 and **3.3GW** PV was introduced to the system. The system consists of Coal generators (3.392GW), LNG generators (1.4 GW), Wind Turbines (2.3GW) and GTCC (2GW). Therefore, the total installed capacity of this power system is 12.392GW and PV represents **26.63%** of the capacity.

The simulation was done using a range of control parameters. The control margin (Delta) was varied from 25MW to 32MW with a combination of different gains and dead zone values.

4. Simulation Results

Study Model

Without Control



Worst frequency:
Max. **0.13627**
Min. **-0.16898**
Ave. 0.000489

Study power system frequency fluctuations (without control)

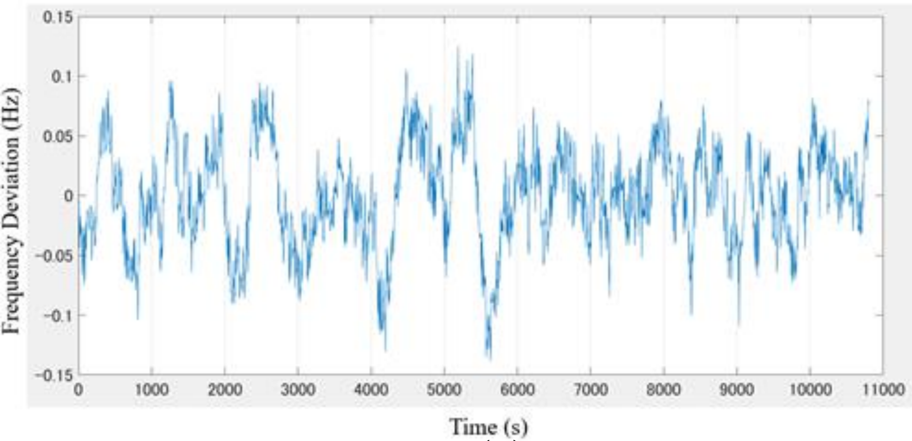
4. Simulation Results

Controlled System Results

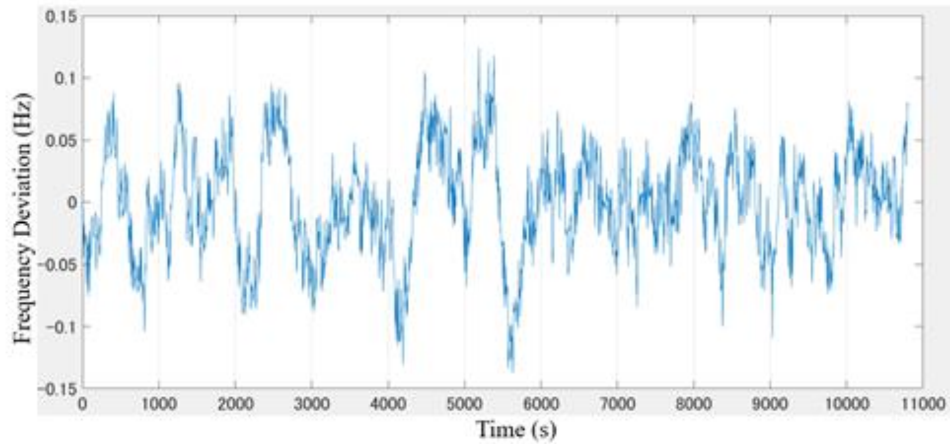
Delta (MW)	Δf_max (Hz)	Δf_min (Hz)	Δf_ave (Hz)	Discarded Energy (%)
25	0.124783	-0.13871	0.00294	2.64
26	0.124437	-0.13746	0.00295	2.78
27	0.124256	-0.13688	0.00297	2.86
28	0.124101	-0.13634	0.00300	2.95
29	0.124046	-0.13586	0.00302	3.08
30	0.124014	-0.13539	0.00303	3.19
31	0.123979	-0.13489	0.00305	3.40
32	0.123925	-0.13441	0.00308	3.40

4. Simulation Results

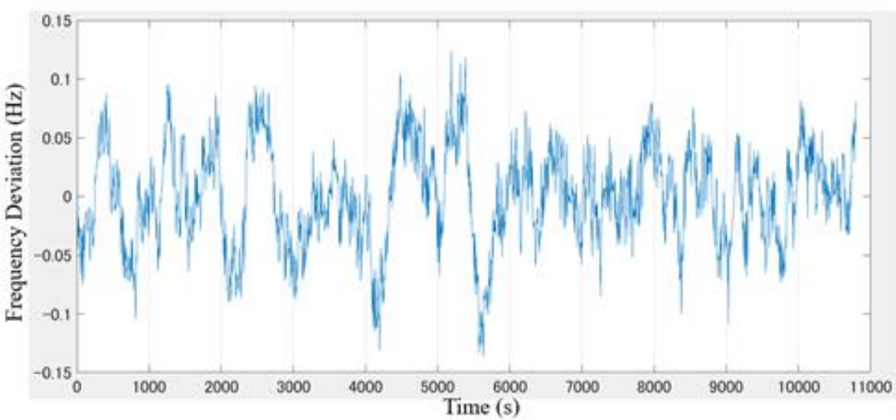
Controlled System Results



(a)



(b)



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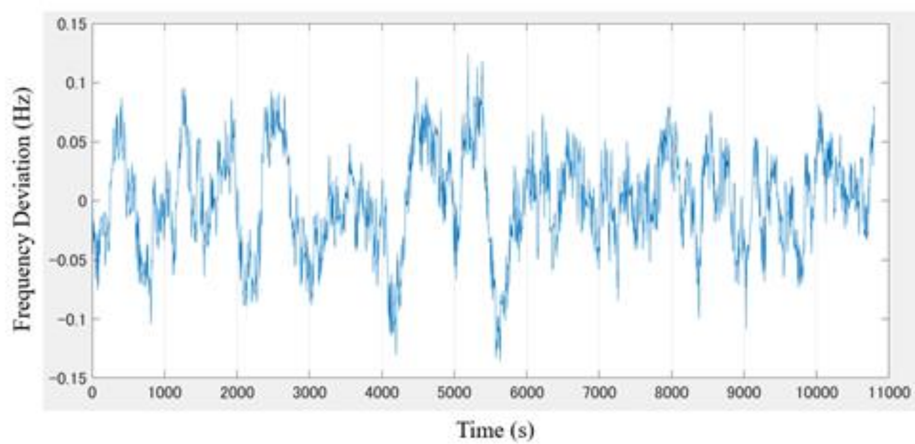
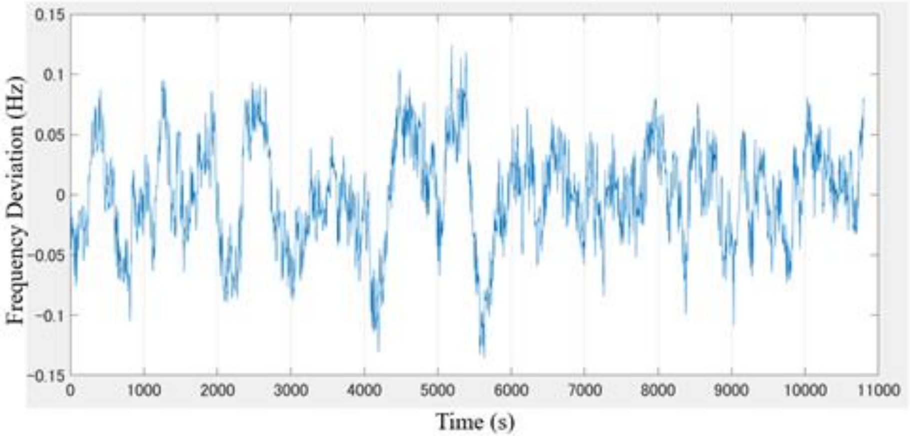


(d)

4. Simulation Results

Controlled System Results



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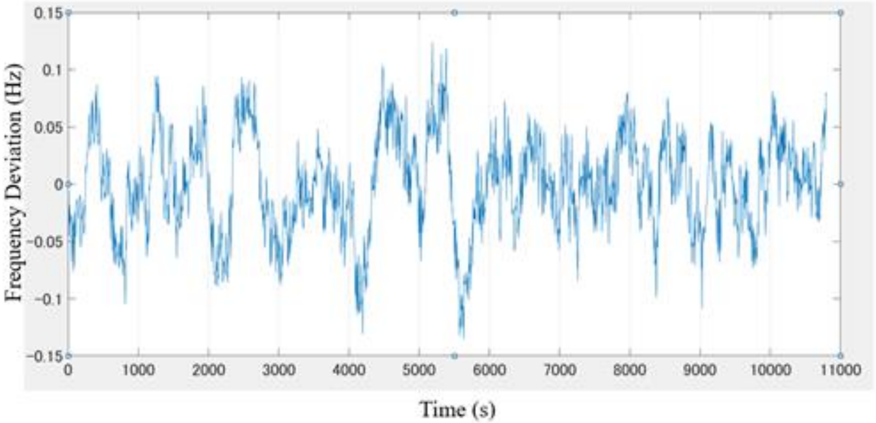

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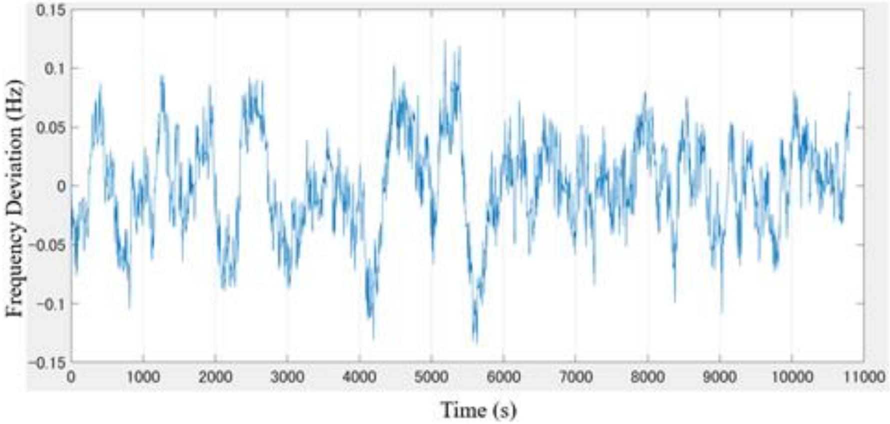
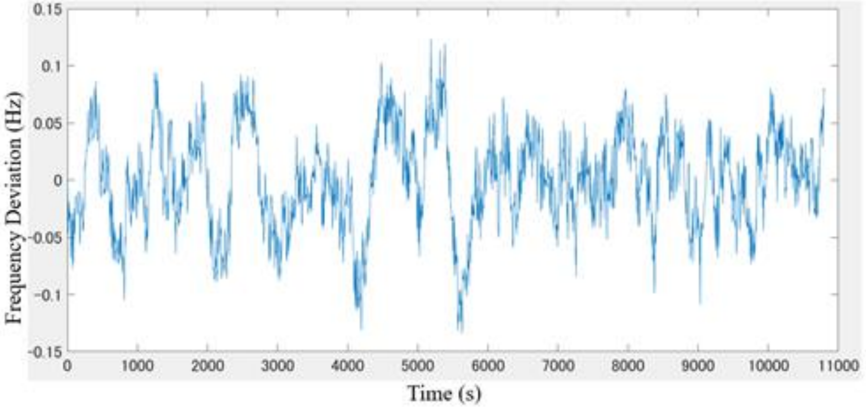


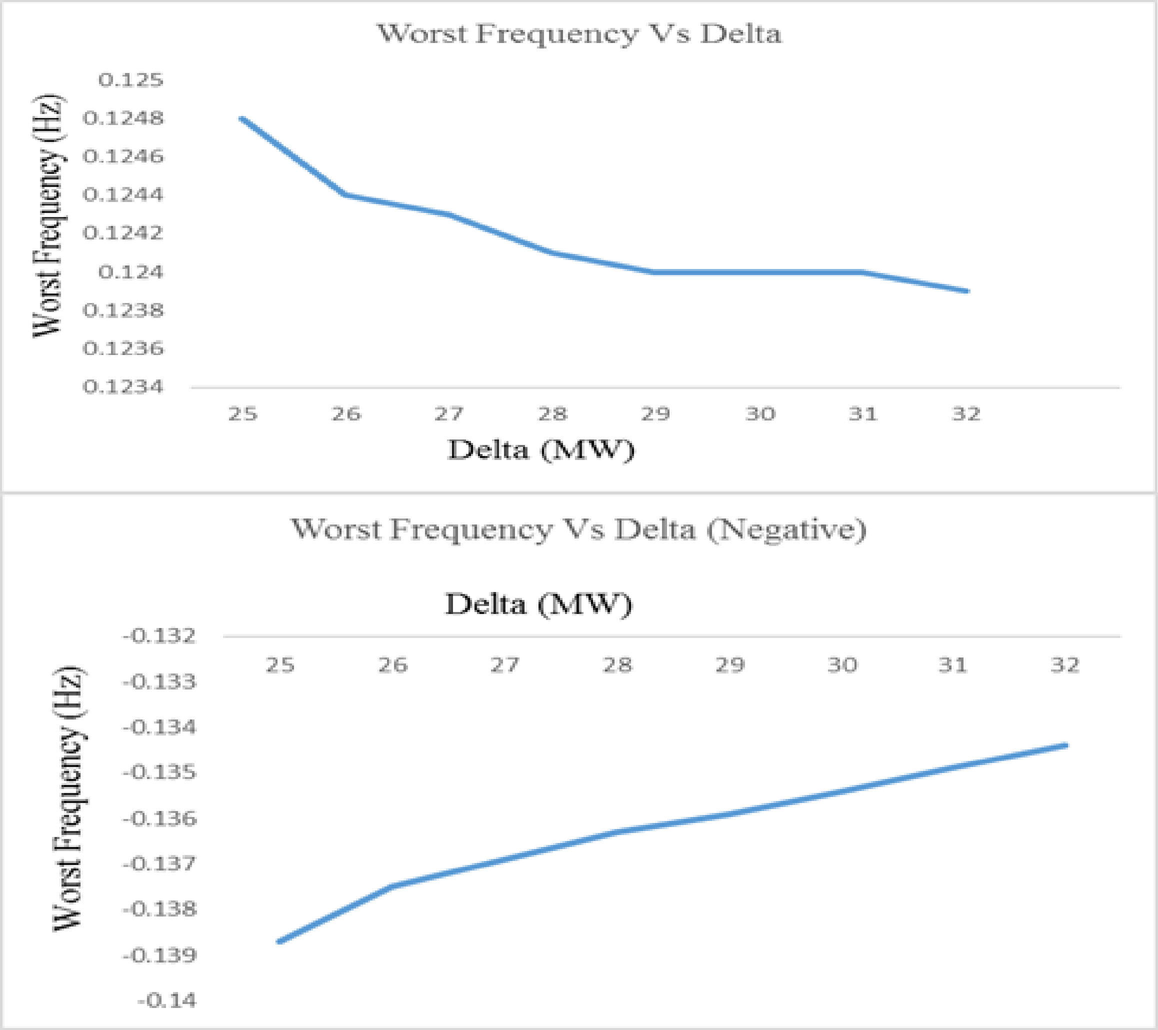
(g)



(h)

4. Simulation Results

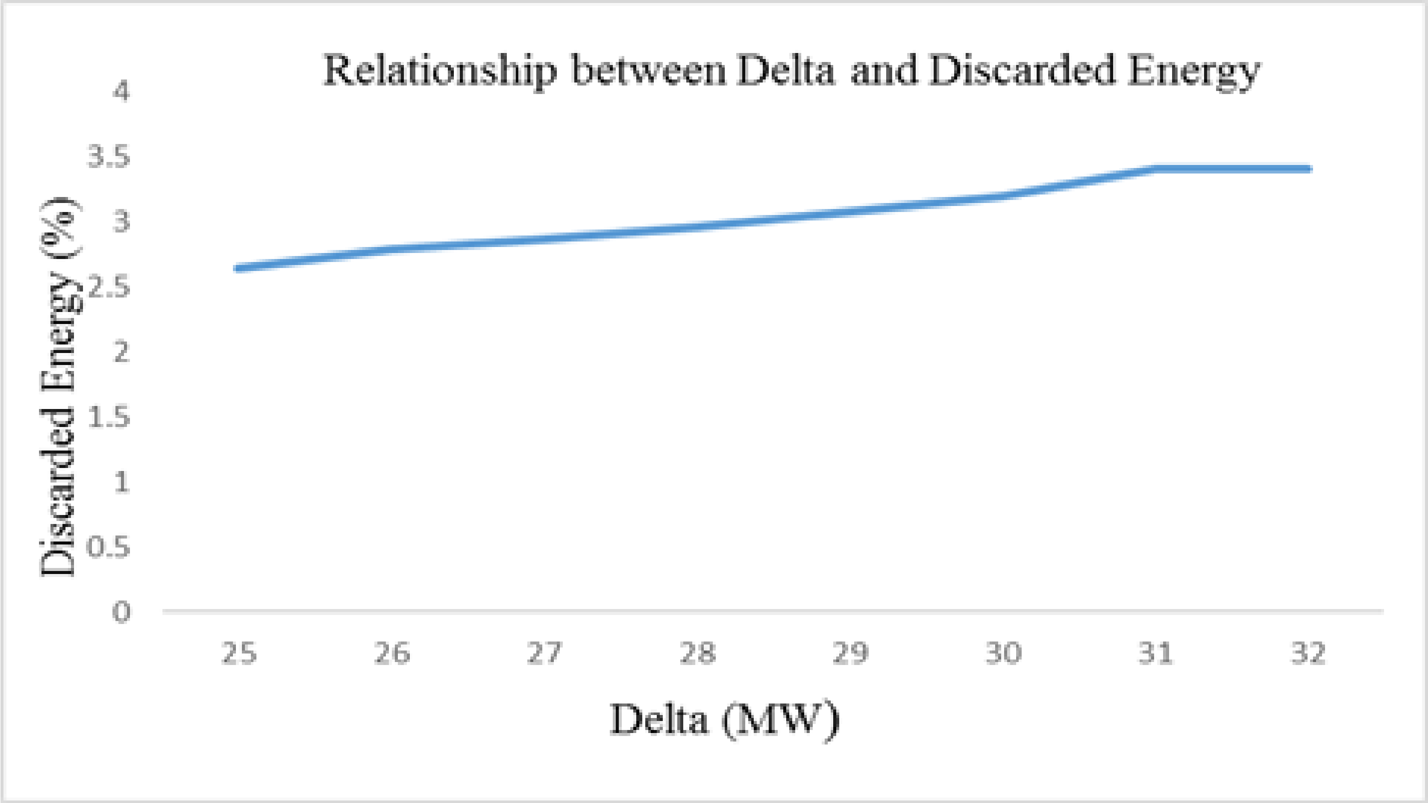
Controlled System Results



Relationship between delta and worst frequency

4. Simulation Results

Controlled System Results



Trade-off Relationship between delta and discarded energy

5. Conclusion

System	Δf_max (Hz)	Δf_min (Hz)
Reference	0.133	-0.145
Study Model Without Control	0.136	-0.145
Study Model with Control	0.124	-0.134

This paper shows a frequency control strategy utilizing delta power control which curtails active power output from PV source in order to achieve power balance in a grid that has high penetration of PV. AGC30 model was used for this analysis and from the results obtained, it was demonstrated that Delta Power Control margin ranging between 25MW and 32MW can be used to effectively mitigate the effects of frequency fluctuations in the power system that has 3.3GW PV capacity (26.63% of the installed capacity). It is still work in progress as we seek to obtain better values regarding frequency deviation minimization.

5. Conclusion

Thank you very much!

Danke!