Decentralized Secondary Frequency Control in an Optimized Diesel-PV Hybrid System

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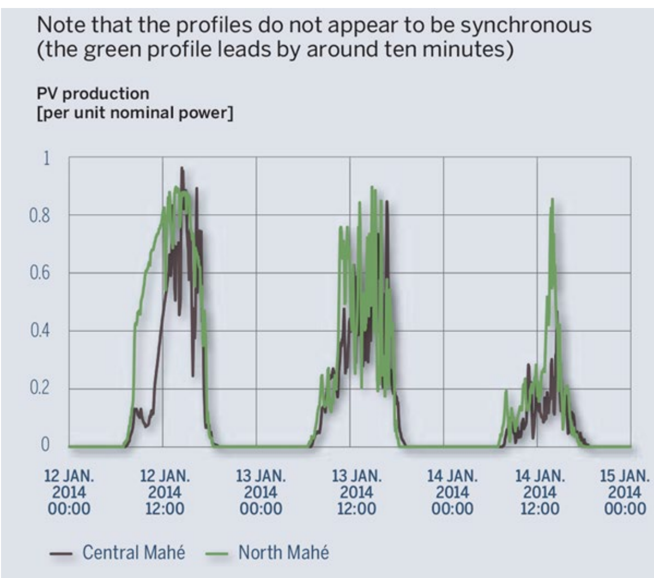
4th International Hybrid Power Systems Workshop

Crete, Greece, May 22nd/23rd 2019

BACKGROUND



High share of PV in island systems

- Multiple Energynautics projects in Indonesia, Seychelles, Bahamas, Barbados
- Strategy to reduce fluctuations: **Distribute PV** to utilize spatial distribution effects
- Reduces strain on diesel generators and requirements for battery size
- Downside: **PV needs to be controllable**, and controlling multiple PV units is more complex than managing a single large site
- Requires **real time communication** links to all sites
- Assignment for **student thesis**: <u>Investigate secondary frequency control involving PV without communication</u>

STUDY CASE

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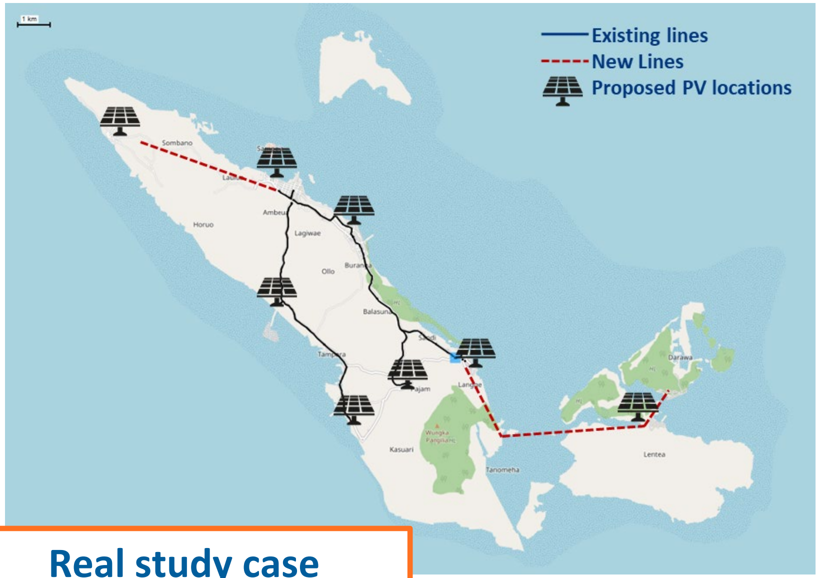
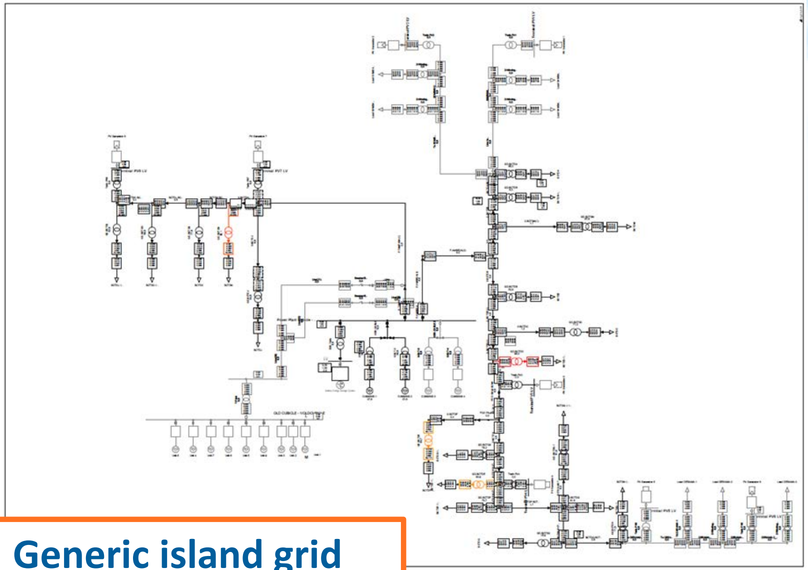


Real study case

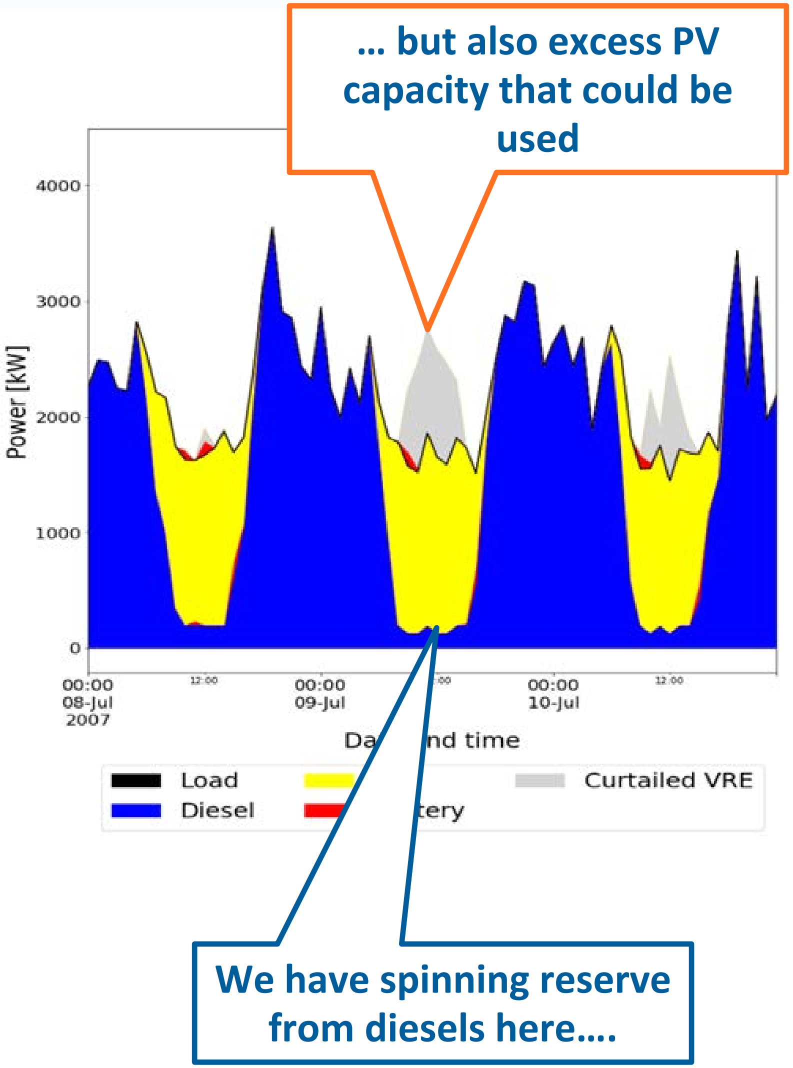


Generic island grid

Based on our experiences on Kaledupa, Indonesia, we set up a generic island grid model with similar properties to develop a decentralized secondary control strategy

- Multiple distributed PV sites connected to 20 kV grid
- High (>60 %) instantaneous PV penetration
- Single diesel powered generation site

PV AND FREQUENCY CONTROL



On sunny days, diesels run at minimum output, while the top end of PV is curtailed.

- PV power from one site could be used to balance fluctuations of other sites
- Reduces number of ramping operations from diesels
- Inverter based generation can react faster than diesel generators

FREQUENCY CONTROL

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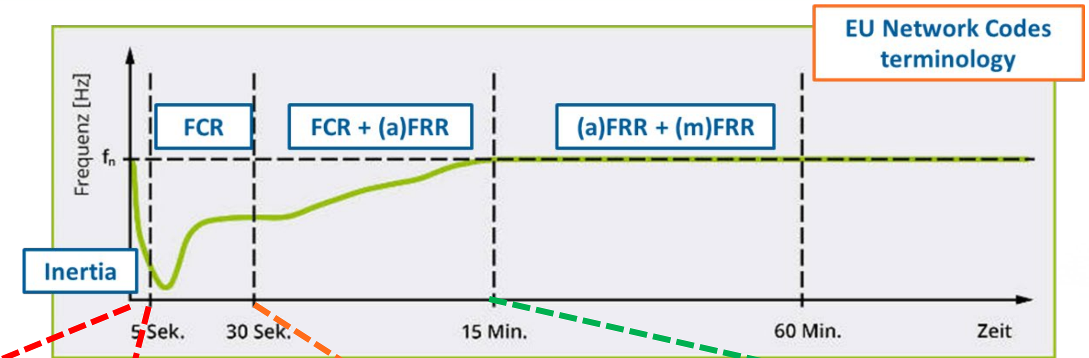

Focus area

Inertial response

- Determines RoCoF
- Determines FCR reaction requirement
- Depends on # of diesels dispatched

Primary control

- Stabilizes frequency
- Implemented by droop controllers
- No communication
- PV can easily be involved

Secondary control

- Leads frequency back to nominal values
- **Requires coordinated strategy between generators**

COMMUNICATION REQUIREMENTS

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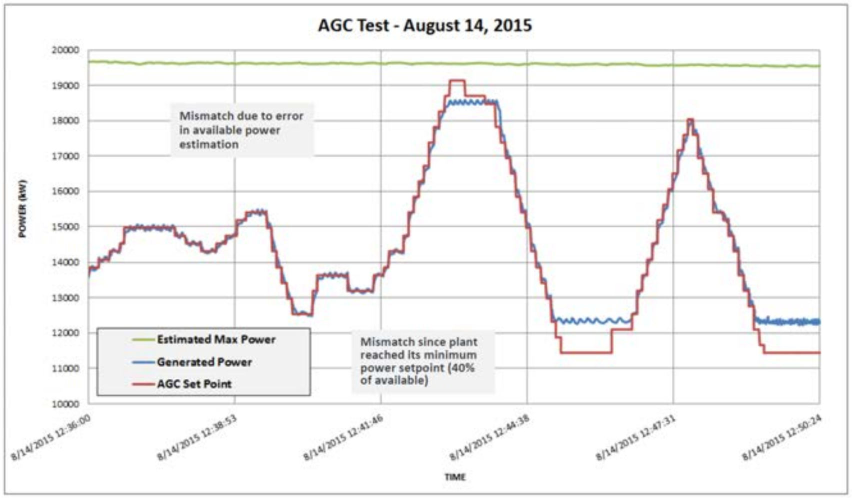
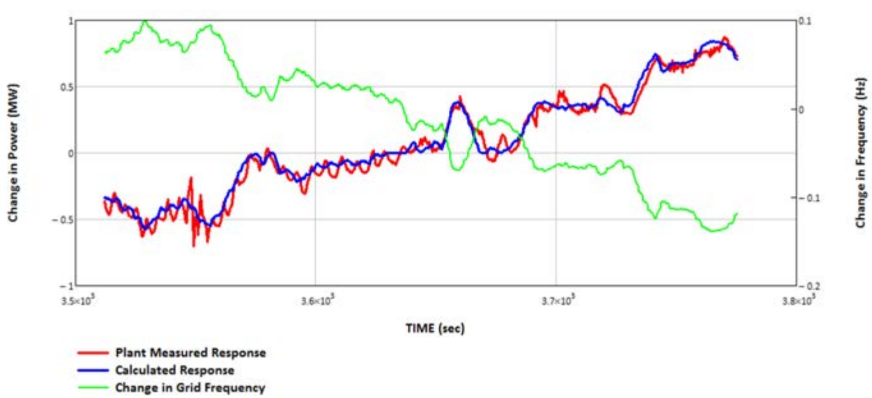
PV power plant in Puerto Rico following AGC signals





PV units quickly following setpoint signals to provide is nothing new.

However, this requires real time communication with all sites.

We are looking at very remote, barely developed islands here.

- Communication links cost money
- Links are prone to failure
- Is there any way we can make the system work without real time communication always available?

DECENTRALIZED SECONDARY CONTROL (1)

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Situation: Frequency is the only means of real time communication

Issues:

- PV and diesel gensets need to find their setpoints.
- PV is prioritized, so it is easy for the diesels – until they hit their minimum output
- PV needs to curtail autonomously
- All generators need to participate not only in primary, but also secondary control (frequency recovery to nominal value)
- Challenging with only the frequency as communication medium

DECENTRALIZED SECONDARY CONTROL (2)

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Situation: Frequency is the only means of real time communication

Objectives

- Return frequency to nominal value after events
- Maximize PV contribution at all times

➢ Frequency needs to be used as a communication medium also outside of events, which requires the introduction of artificial frequency events (state detection)

TIME-BASED DECENTRALIZED FREQUENCY CONTROL

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J. Rey, P. Marti, M. J. Velasco, M., and M. Castilla, “Secondary switched control with no communications for islanded microgrids,” IEEE Transactions on Industrial Electronics, vol. 64(11), pp. 8534–8545, November 2017.

$$P_{setpoint} = P_{meas} - \underbrace{\left(\frac{f_{meas} - f_{nominal}}{K_{droop}}\right)}_{\text{Droop contribution}} + \underbrace{\delta}_{\text{Secondary Control Contribution}}$$

Basic approach:

- Frequency event is detected and triggers control time span
- Droop control stabilizes frequency at offset value
- PI controller with relatively slow control time (stability!) activated in all units to lead frequency back
- If frequency is within deadband, process is stopped, setpoint stored and droop char shifted
- If frequency is still out of range by end of control time, control is triggered again

DECENTRALIZED SECONDARY CONTROL

Secondary control is normally implemented using real time communications for a good reason – there are some caveats to a decentralized approach.

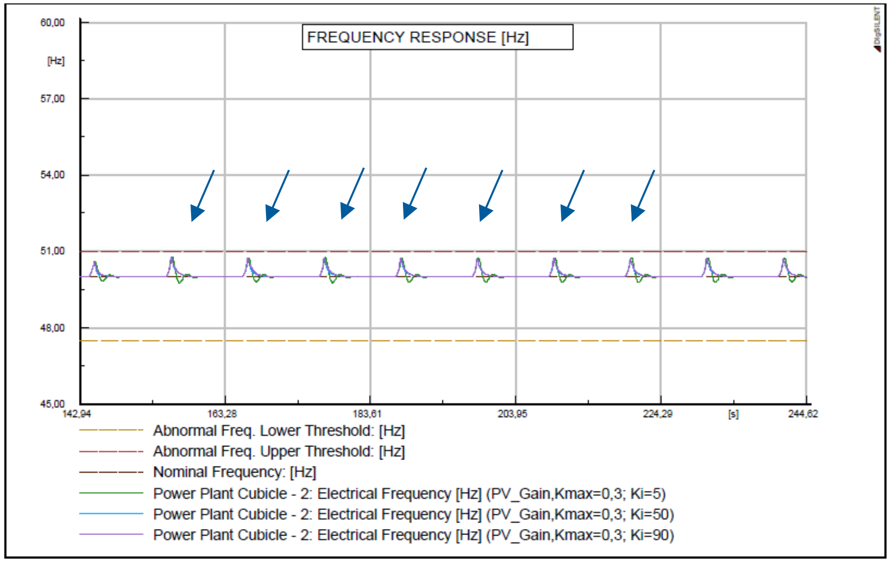
- Response speed: Controller speed must be relatively slow to avoid hunting effects
- Load sharing: Frequency is led back to nominal and system is stable, but the share of load covered by each generator can end up at random values
- Generators must be prioritized in their response, which is detrimental to response speed

- Solution: Diesel first (always available, small deadband, fast response), PV only at more severe events
- PV must find back to optimal setpoints afterwards

MAXIMIZING PV CONTRIBUTION

For an island with only two types of generation – diesel and PV – PV share should be optimized, while diesels must not run below their minimum output.

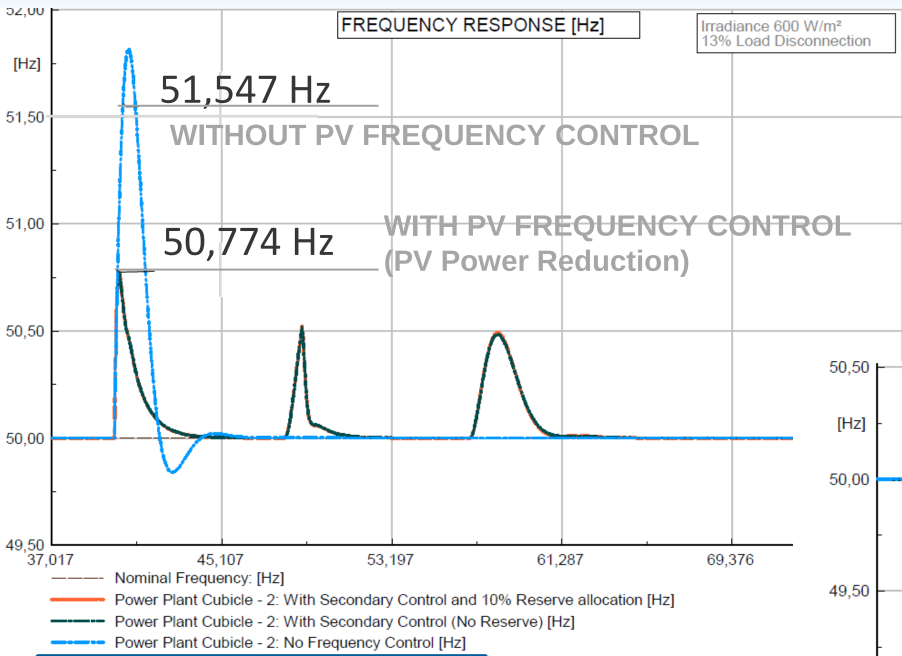
- After a frequency event, diesels may run at a higher setpoint while PV are curtailed too much
- PV must introduce frequency event to see whether they can still go „up“



- PV periodically increase output power
- If diesel can reduce output, it will do so before PV (smaller deadband)
- PV production is maximized
- Caveat: Frequent small frequency excursions
- Frequency is the only communication medium, so it cannot stay unchanged

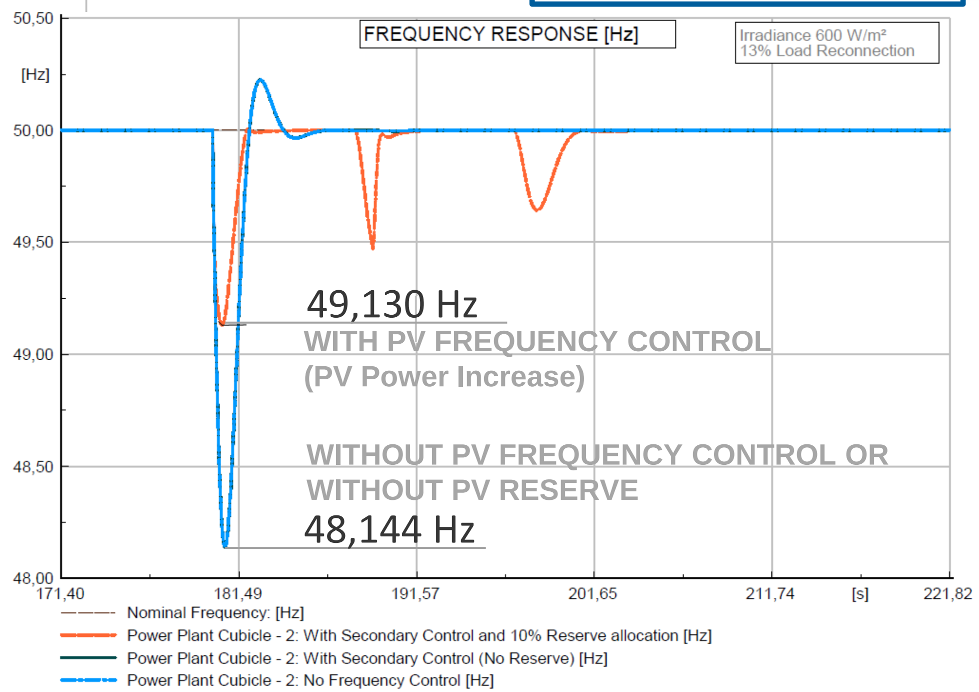
RESULTS OF FREQUENCY STABILITY ANALYSIS (1)

13% load trip and reconnection, Irradiance 600 W/m²



LOAD DISCONNECTION

LOAD RECONNECTION



RESULTS OF FREQUENCY STABILITY ANALYSIS (2)

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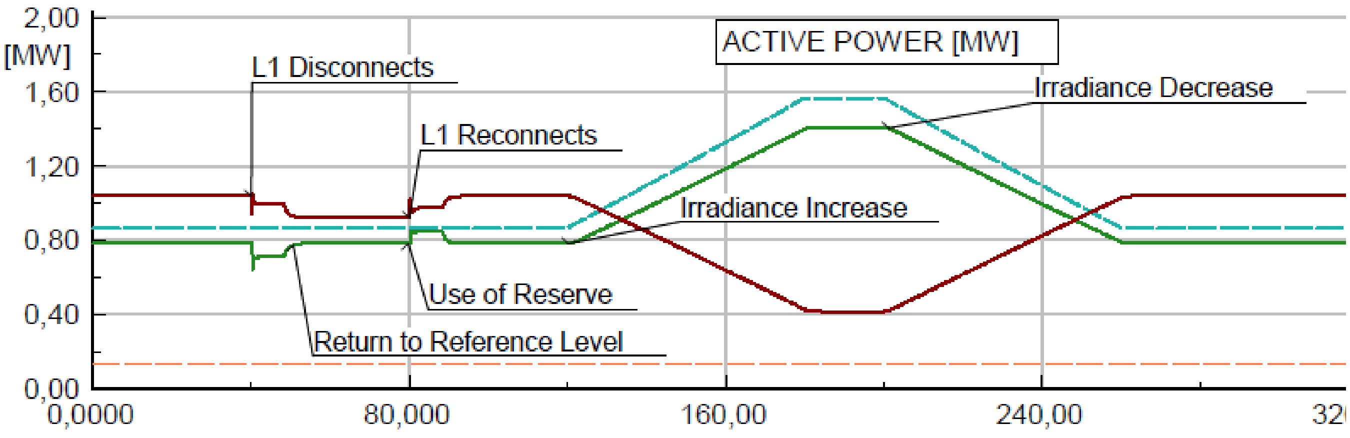
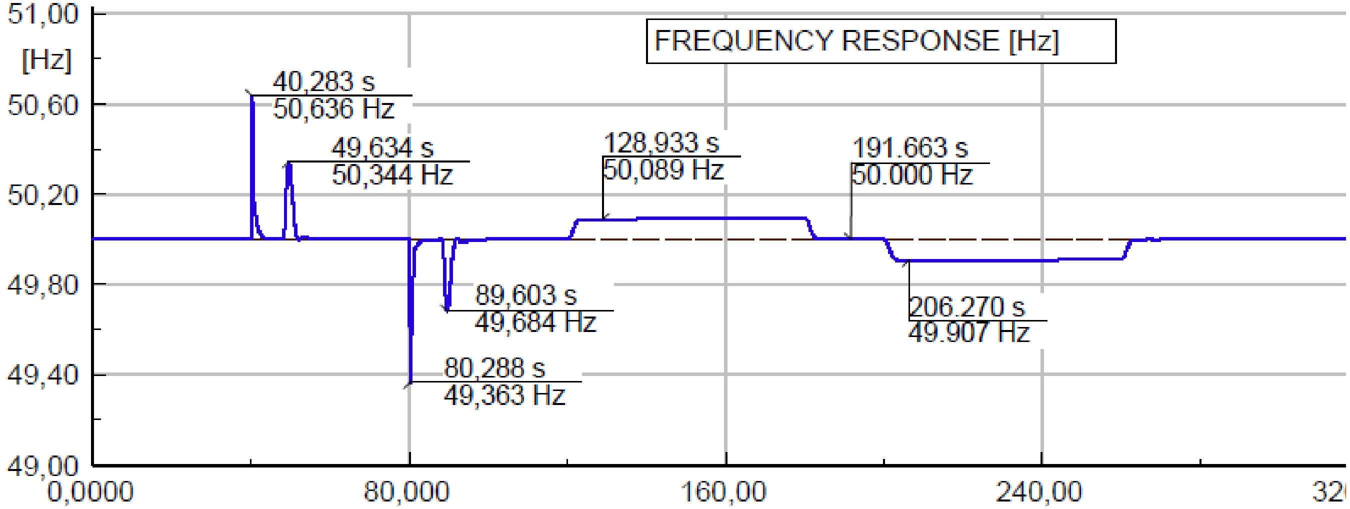
6,5% load trip/reconnection, **600 W/m²**



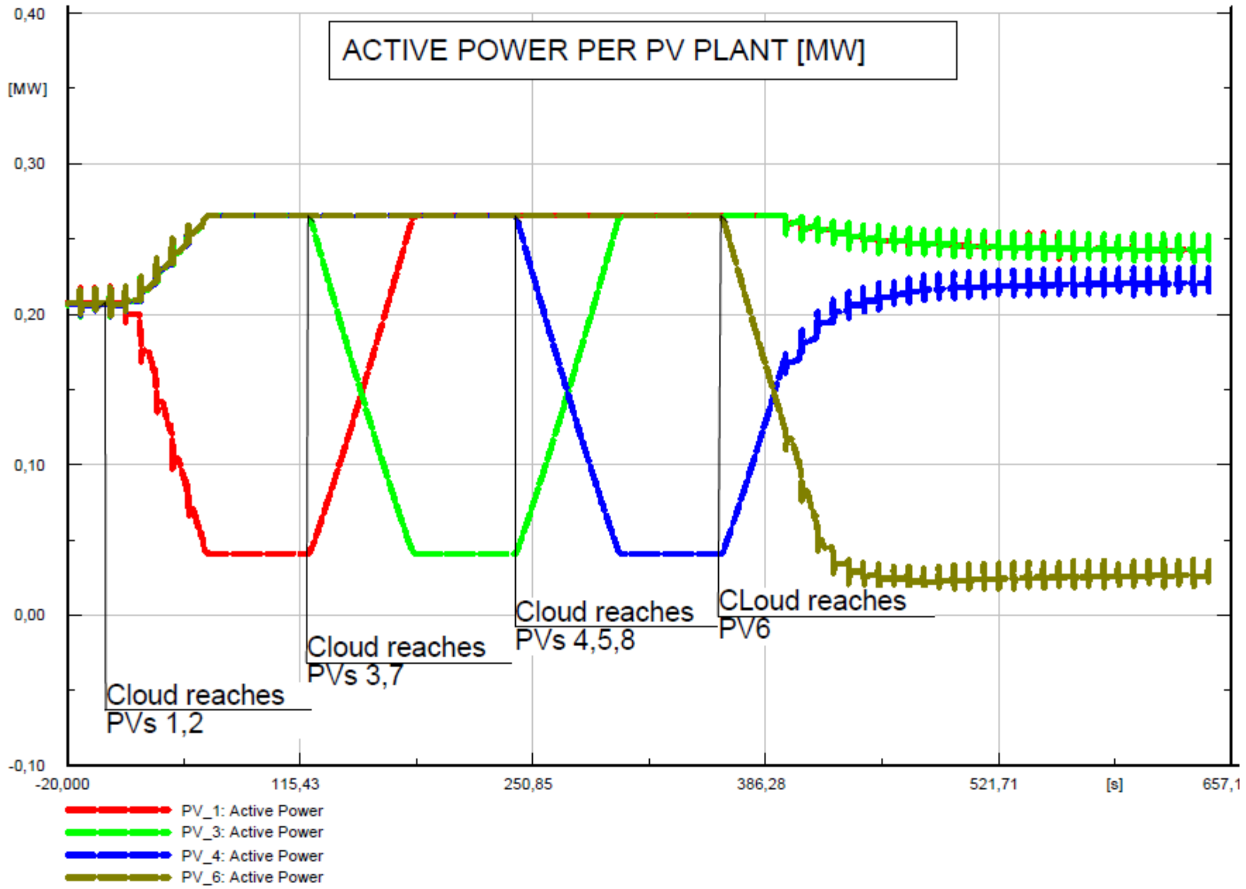
PV Total [MW]
PV MPP [MW]
Diesel Total [MW]
Diesel Minimum [MW]



Nominal Frequency [MW]
Frequency [MW]

PV LOAD SHARING

Overall PV share is maximized, but distribution between individual units is not



CONCLUSIONS

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- The time based reserve strategy proposed by Rey et al. allows stable operation
- Frequency is restored to nominal value without communications
- With Energynautics "probing" strategy for PV, PV contribution is optimized
- Downside 1: Frequency ripple due to PV "probing" the system
- Downside 2: Sharing of load and curtailment between PV is not optimized

➢ Strategy could see some use as a backup in case communication fails

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THANK YOU FOR YOUR ATTENTION!

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