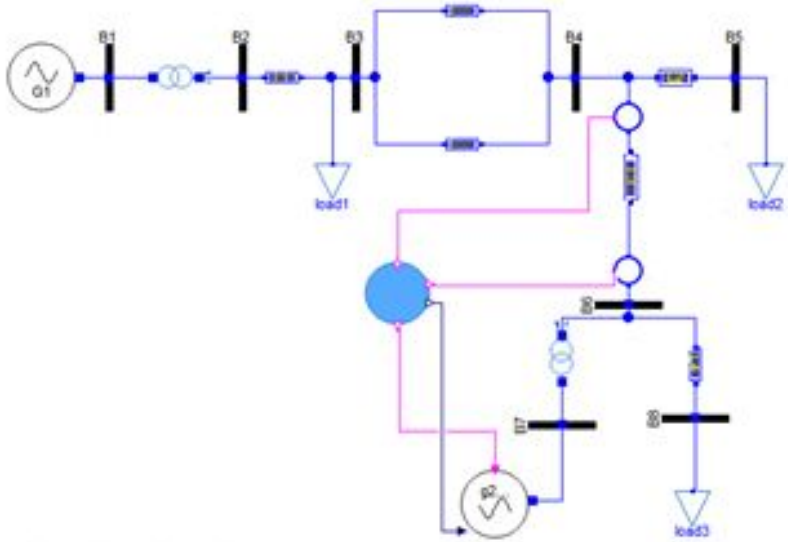


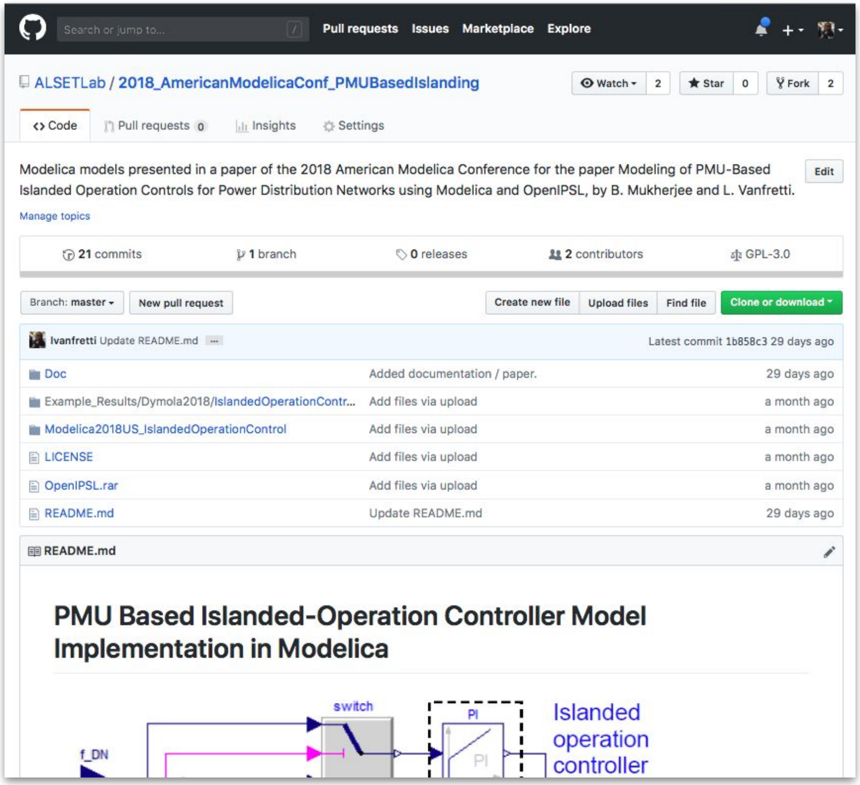
Modeling of PMU-Based Islanded Operation Controls for Power Distribution Networks using Modelica and OpenIPSL

B Mukherjee & L Vanfretti | 09/10/2018

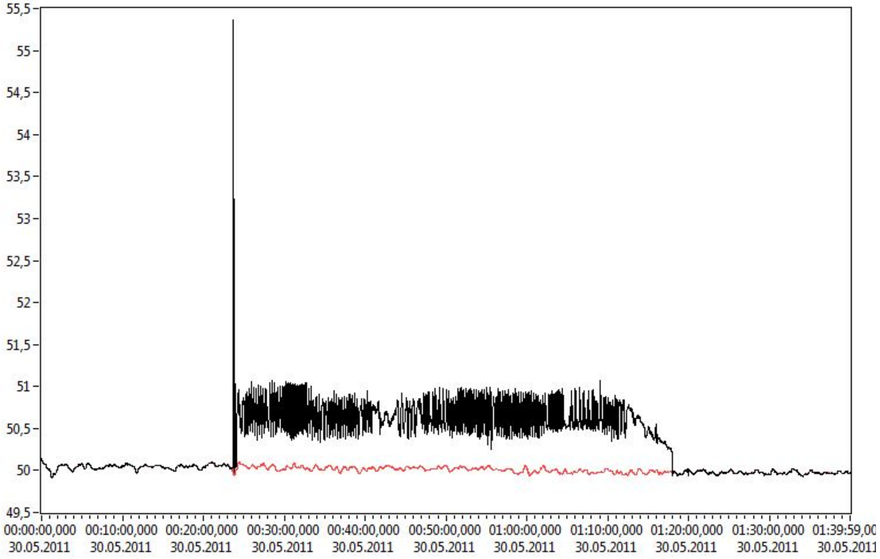
http://ALSETLab.com , luigi.vanfretti@gmail.com

Outline

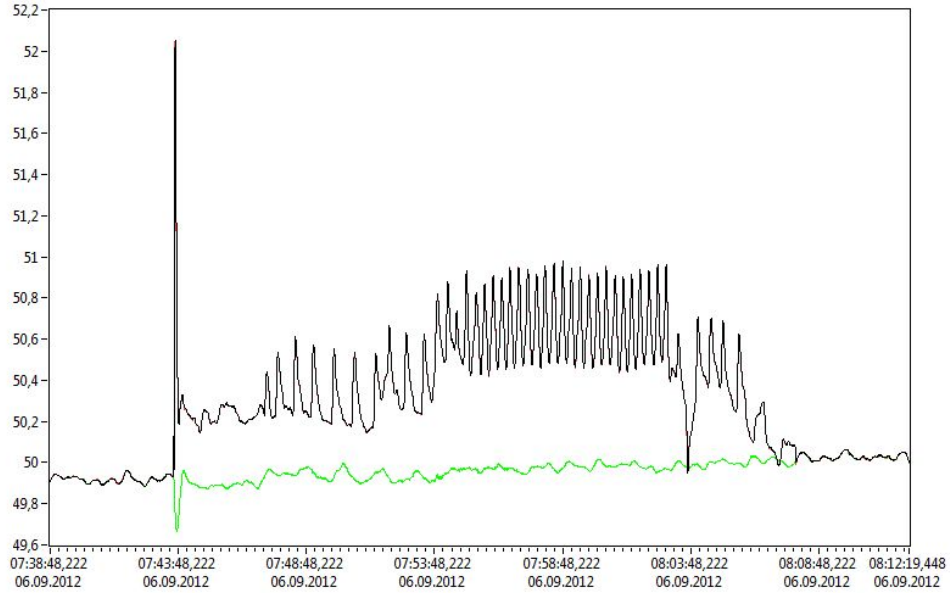
- Motivation
  - Islanding Events
  - PMU Technology for Controls
- Related Works
- Frequency Computation
- Islanded Control and Implementation
- Test Power System Model
  - Transmission Generator Model
  - The Simulation Set-up
- Case Studies
- Conclusions
- Research Reproducibility:
  - Models and results from this paper are available at: https://github.com/ALSETLab/2018_AmericanModelicaConf_PMUBasedIslanding



- Islanding events in northern Norway - separation from the main Nordic network.

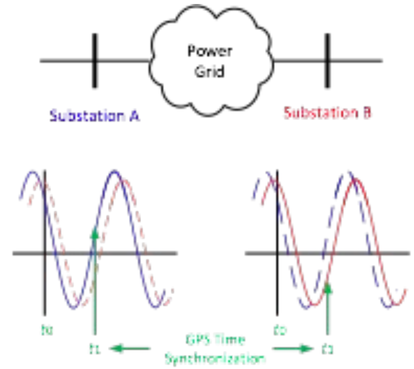


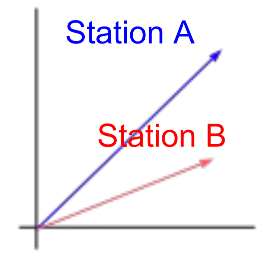
- Event 1 (2011), with approximately 1hr of duration.



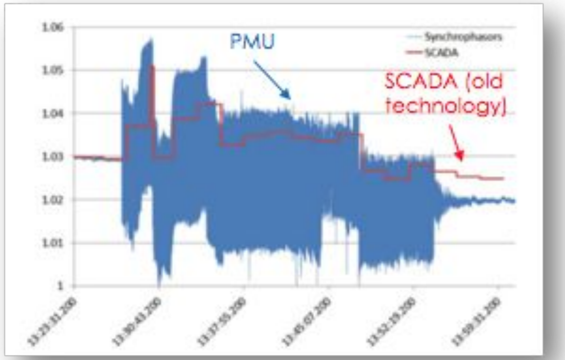
- Event 2 (2012), with approximately 25 min of duration.

- **What is a PMU?**
- PMUs provide time-synchronized measurements that can be networked into a synchrophasor system.
- Real-time measurement data exchange between different asset owners and grid operators, using a broadly adopted standard for communications.
- Higher resolution than traditional measurement systems used at SCADA/DMS/EMS: 30,50,60,120 Hz.





- **Why use PMU-based controller?**
- Time-synchronized data that is possible to exchange between different operational boundaries (i.e. gen., transmission, distribution, and DER)
- Frequency is a derived variable from computed phasors, readily available - no need for additional sensor/device.
- Some manufacturers (SEL, GE, …) provide PMU functionality within existing relays - simplifies tripping scheme.



Frequency computation

- In conventional power system simulation a **washout filter (WF) (Milano & Ortega, 2017)** is used for frequency estimation → phase angle of bus voltage is used to compute the bus “speed” deviation.

Frequency control in an islanded grid

- Challenging job is to restore the power/frequency balance.
  Solutions include:
  - Different **governor configurations**; **isochronous governor required.**
  - Use of additional controls with remote sensing (Taranto & Assis, 2012)

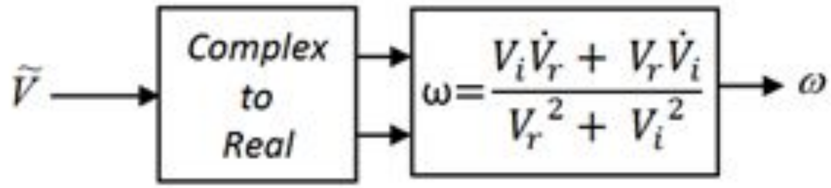
Proposed approach

- Use frequency estimation from **PMUs** for an **islanded operation controller**
- Advantages of such control scheme:
  - Provides **fast action**
  - Enhances **reliability**
  - No need for isochronous governor, no need for additional remote sensors.

Frequency computation model

Frequency computation block

Input: `u, u1`
Bus voltage phasor, in real and imaginary components



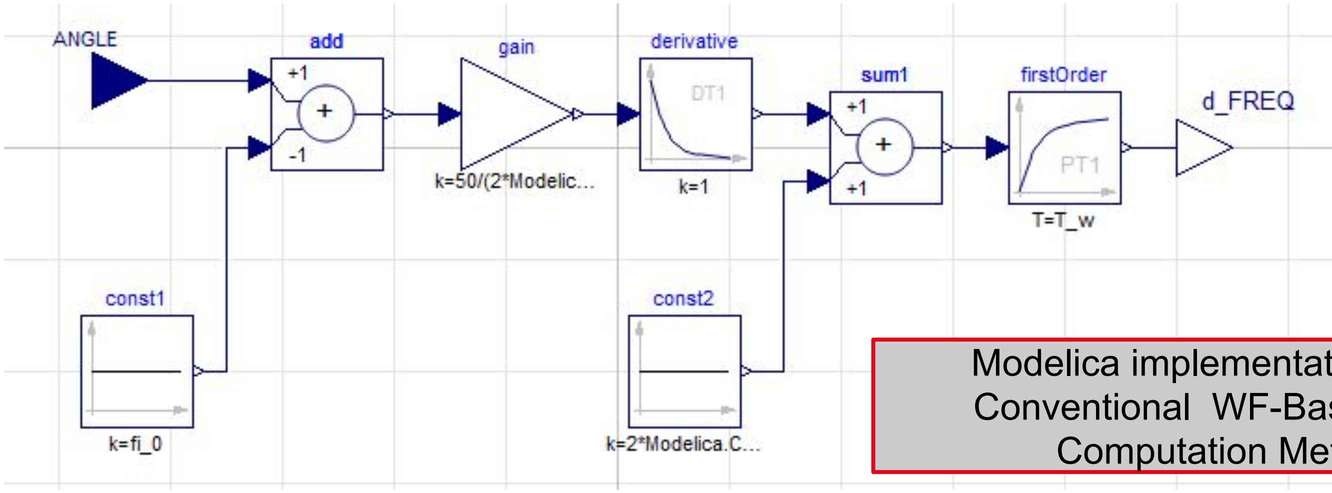
Output: `y`
Bus frequency deviation, in per until.

```
model frequencyCalculatiionBlock
  Modelica.Blocks.Interfaces.RealInput  u;
  Modelica.Blocks.Interfaces.RealInput  u1;
  Modelica.Blocks.Interfaces.RealOutput  y;
  Modelica.Blocks.Continuous.Derivative
 derivative;
  Modelica.Blocks.Continuous.Derivative
 derivative1;
equation
  y =  (u*(derivative1.y) + u1*(derivative.y))/ ((u^2) + (u1^2));
  connect(u1, derivative1.u);
  connect(u, derivative.u);
end frequencyCalculatiionBlock;
```

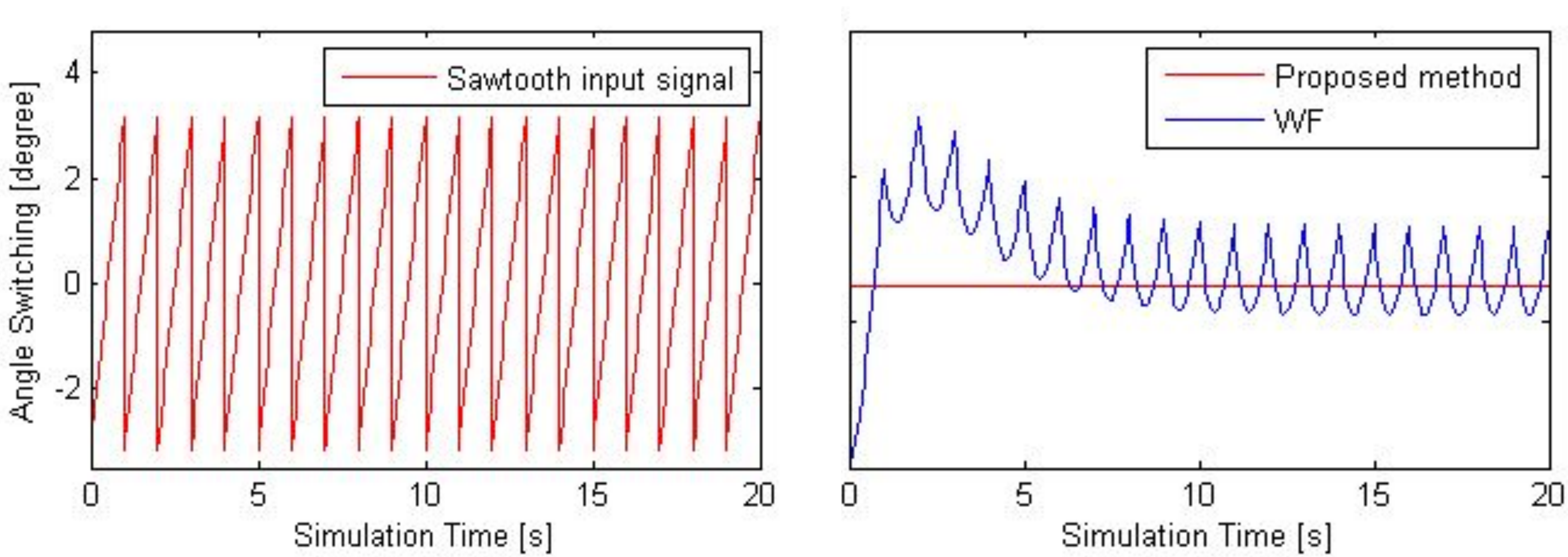
Textual representation of the **Frequency computation block**

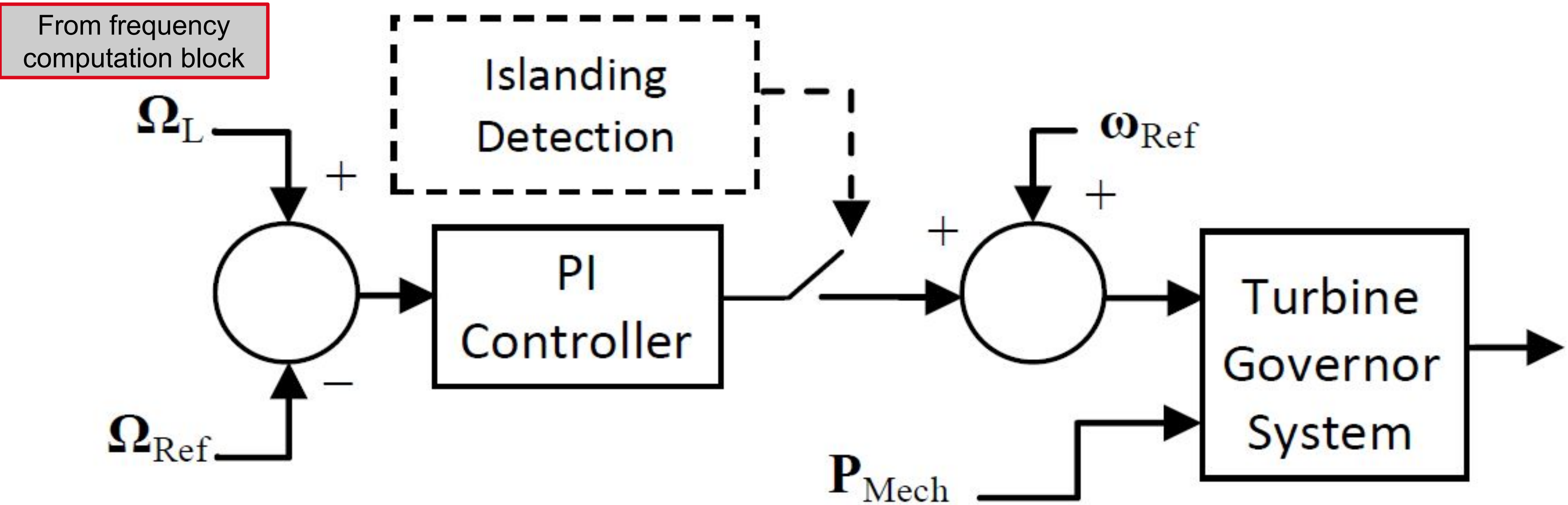
- If frequency is calculated from bus angle directly it may corrupt the frequency calculation (due to angle wrapping).
- To obtain the correct frequency for control purposes, this computation block is used.

ALSET lab



Modelica implementation of the Conventional WF-Based Freq. Computation Method



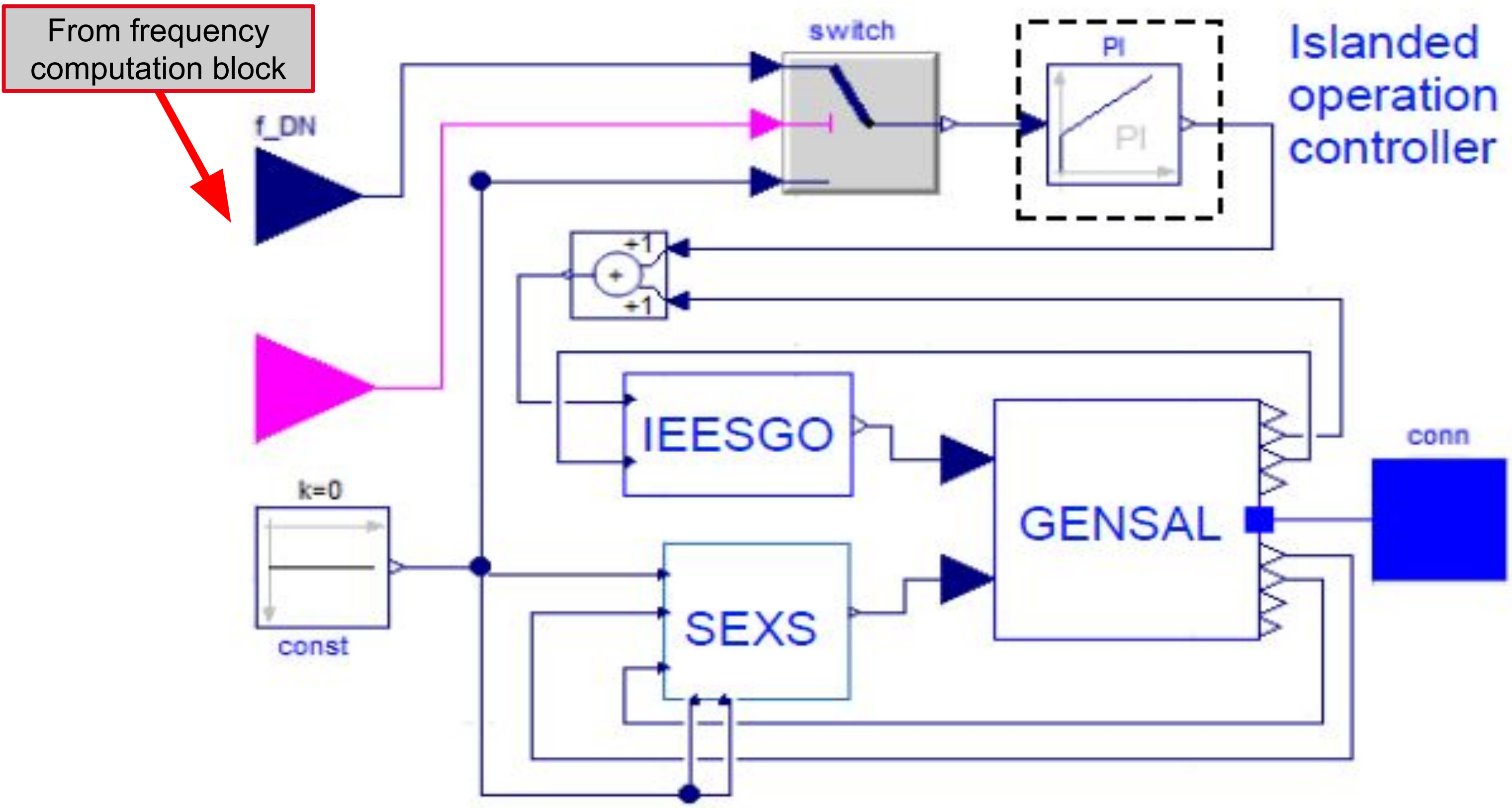


Ω_L = Load bus frequency

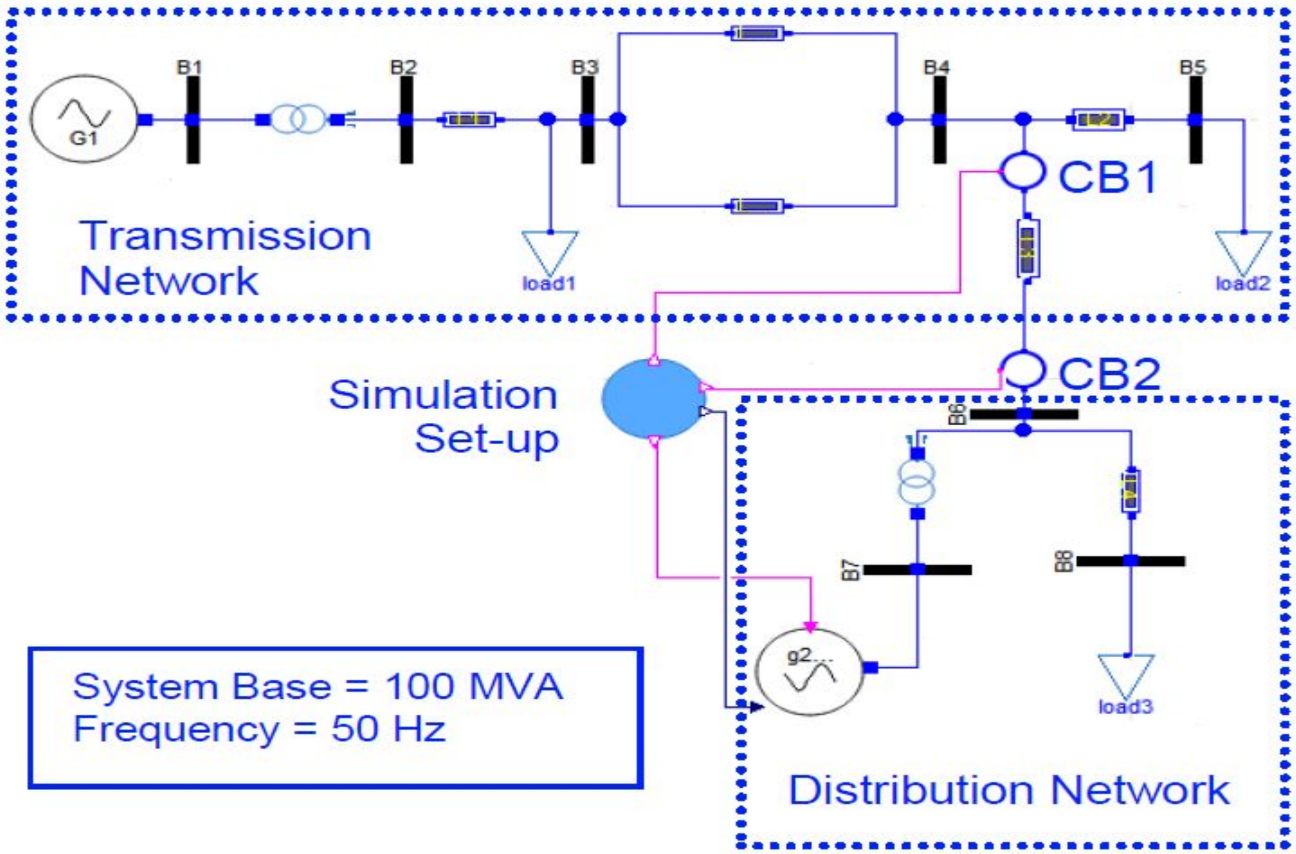
Ω_{Ref} = Reference frequency

ω_{Ref} = Reference speed

P_{Mech} = The mechanical power set-point corresponding to a prescribed power dispatch



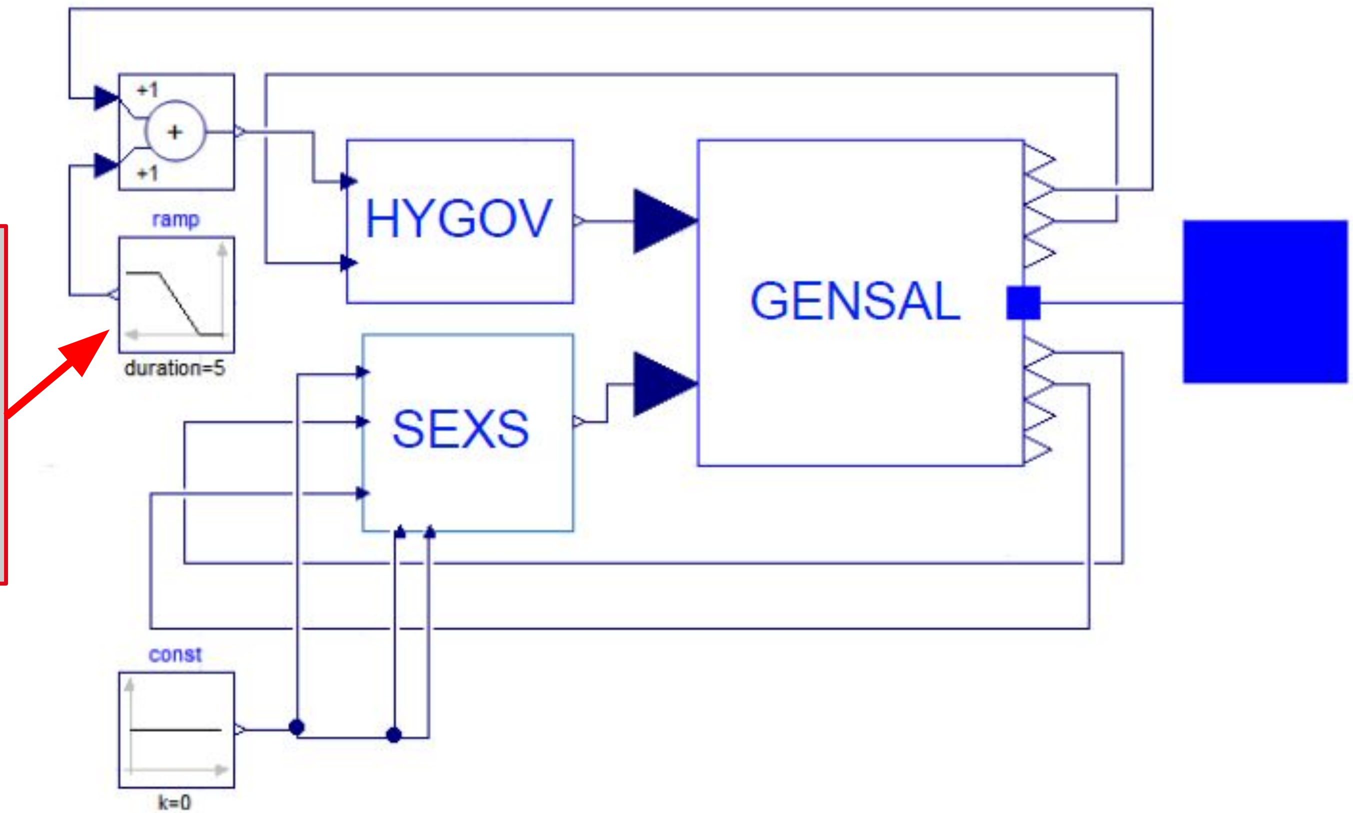
- **GENSAL** block corresponds to the synchronous generator
- **IEEESGO** corresponds to the gas turbine and governor model
- **SEXS** corresponds to the excitation control system of the generator



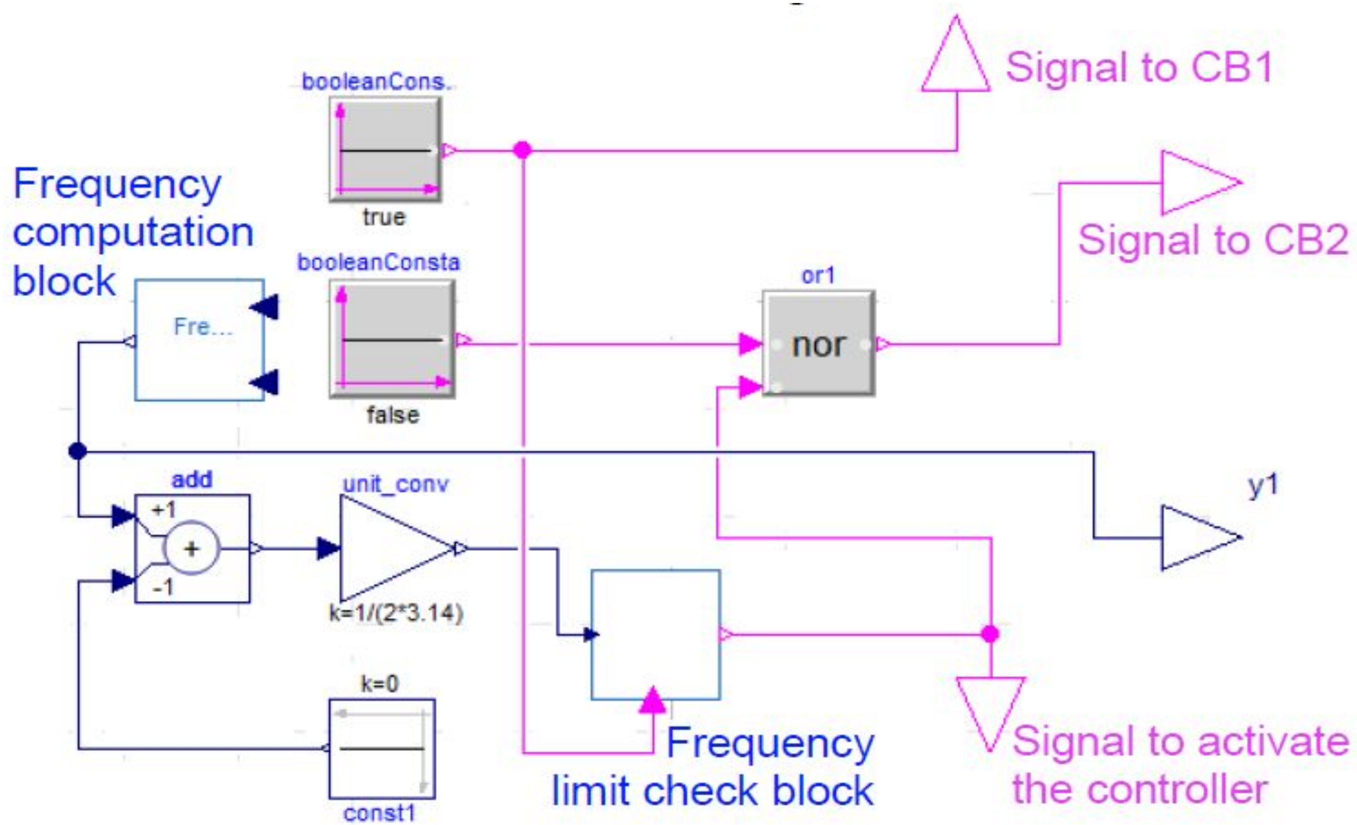
- The circuit breakers **CB1** and **CB2** are controlled using logic equations implemented in a **Simulation Set-up** block which is used to create the islanding event and to activate the islanded operation controller.

ALSET lab

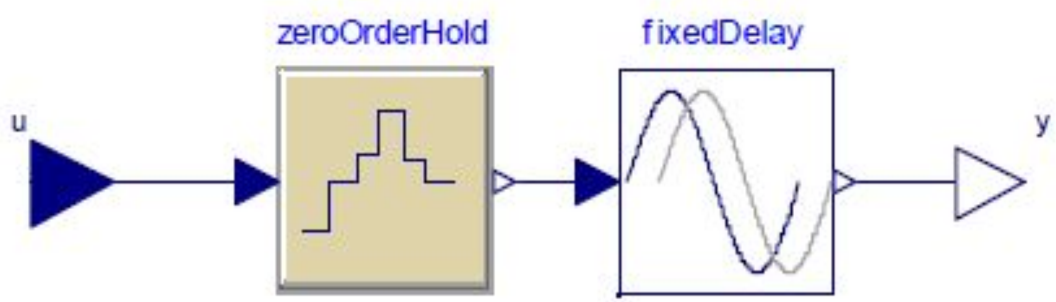
The overall system frequency is varied by introducing a **speech change** in the governor system



- **GENSAL** block corresponds to the synchronous generator
- **HYGOV** corresponds to the hydro turbine and governor model
- **SEXS** corresponds to the excitation control system of the generator



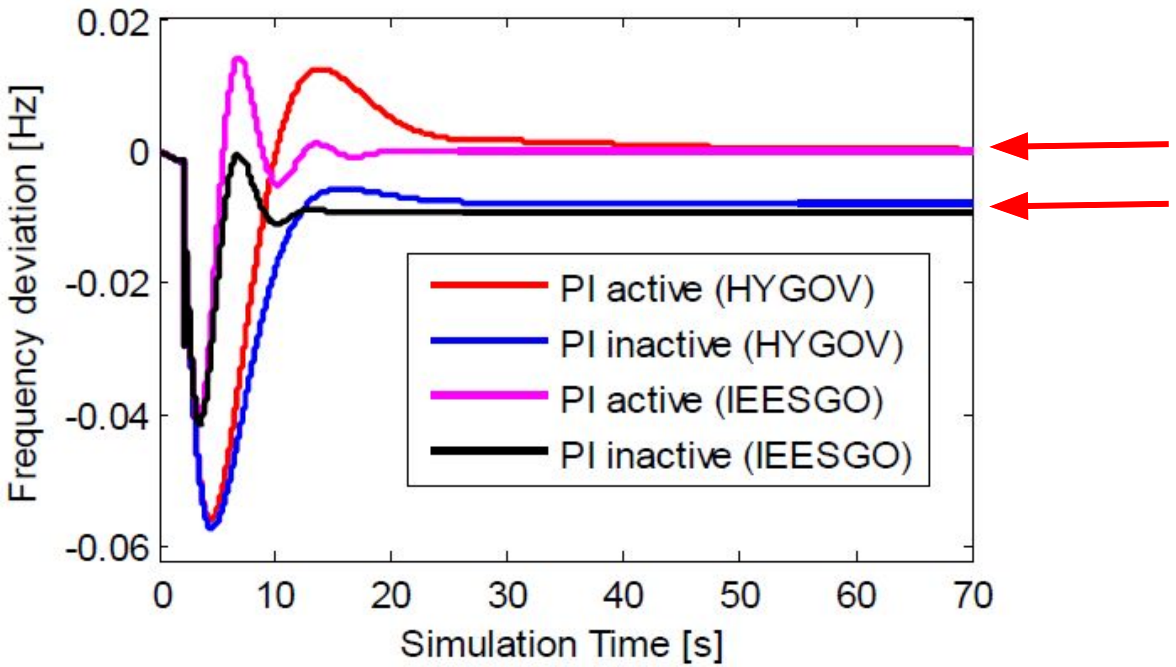
- This condition checks the frequency deviation to the set-point limit set in the **Frequency limit check** block.
- A Boolean true signal keeps the circuit breaker **CB1** closed in the transmission side network while maintaining the transmission line energized



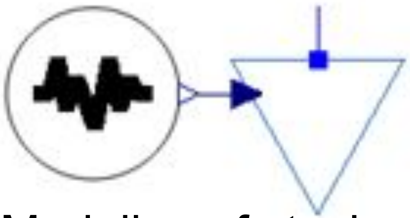
- A **Zero Order Hold (ZOH)** block from **Modelica Standard Library** is used to simulate different phasor **reporting rates**, streamed by a PMU device.
  - Note: reporting rate is the output of the PMU, the PMU internally samples at kHz level and computes phasors.

- The **time delay** due to data transmission from a PMU to Phasor Data Concentrator (PDC) and the controller is modeled using the **FixedDelay** block from the **Modelica Standard Library**.

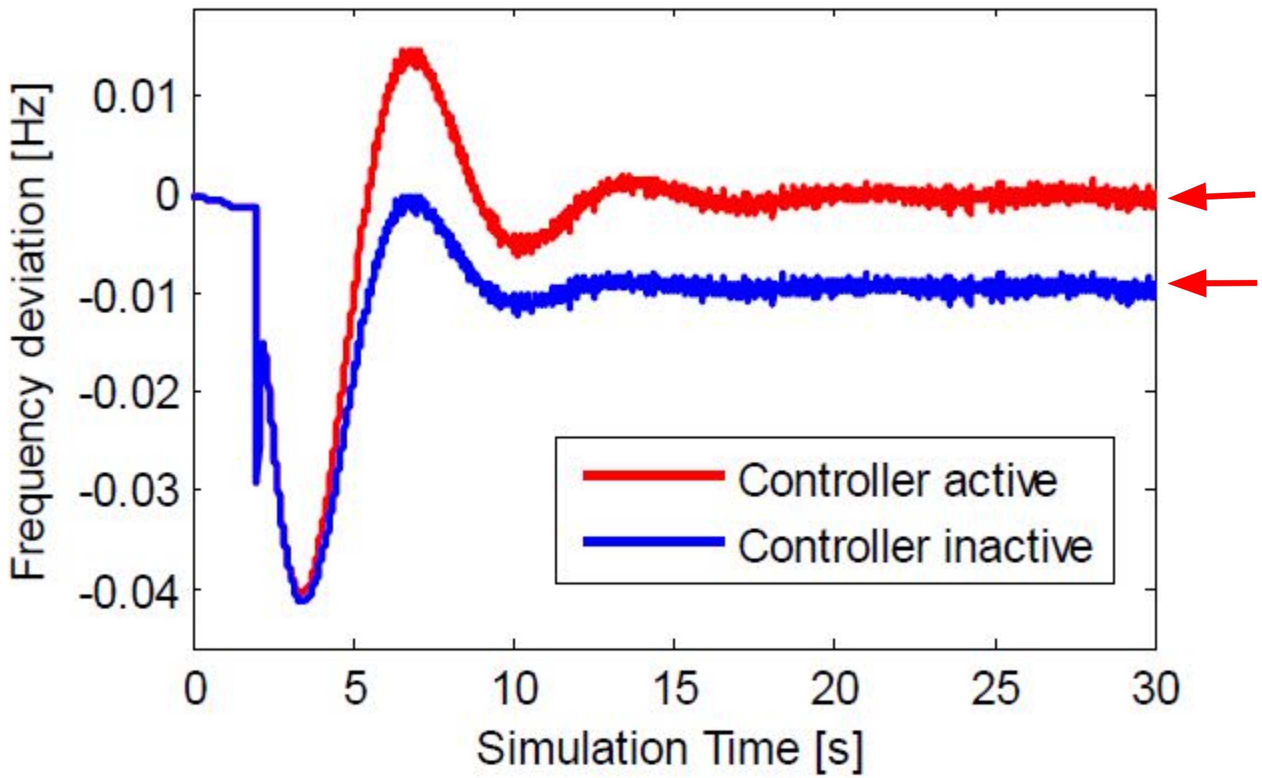
Case 1- Analysis of controller's action using both the HYGOV and the IEESGO turbine-governor systems



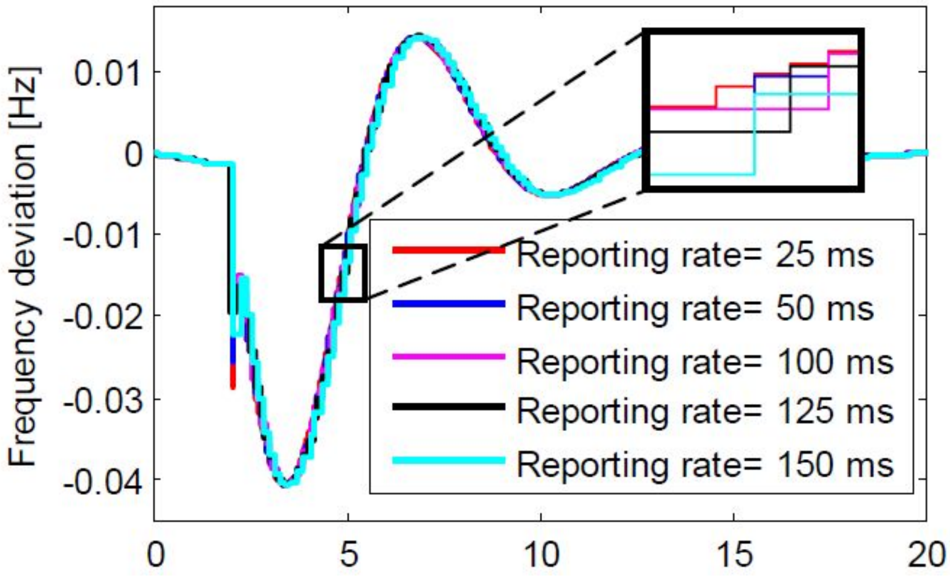
- Regardless of turbine-governor system type, the controller is capable of reset the island's frequency to the prescribed reference.
- IEESGO turbine-governor system:
  - Max. instantaneous values of frequency deviations are 0.0414 Hz and 0.0405 Hz respectively when the controller remains inactive and active.
- HYGOV turbine-governor system:
  - Max. instantaneous values are 0.057 Hz (when control action remains inactive) and 0.055 Hz (when control action remains active).



Modeling of stochastic load using **Modelica Noise** features

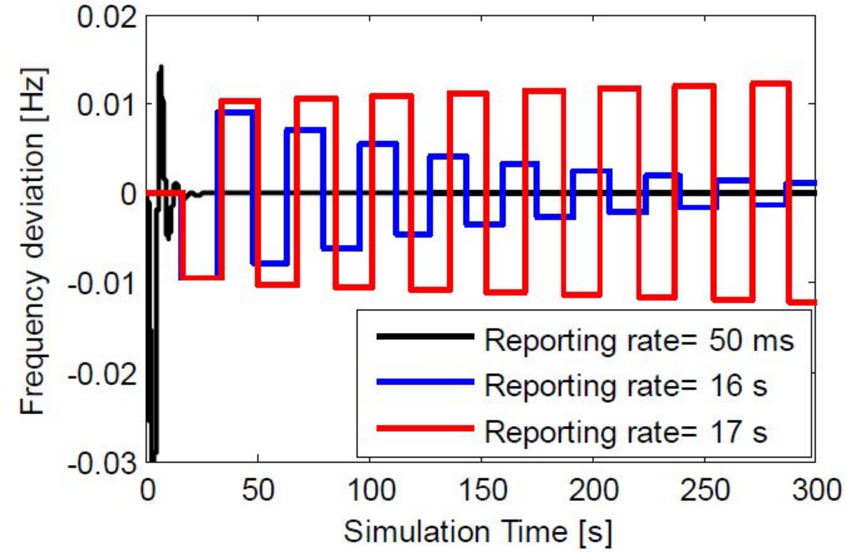


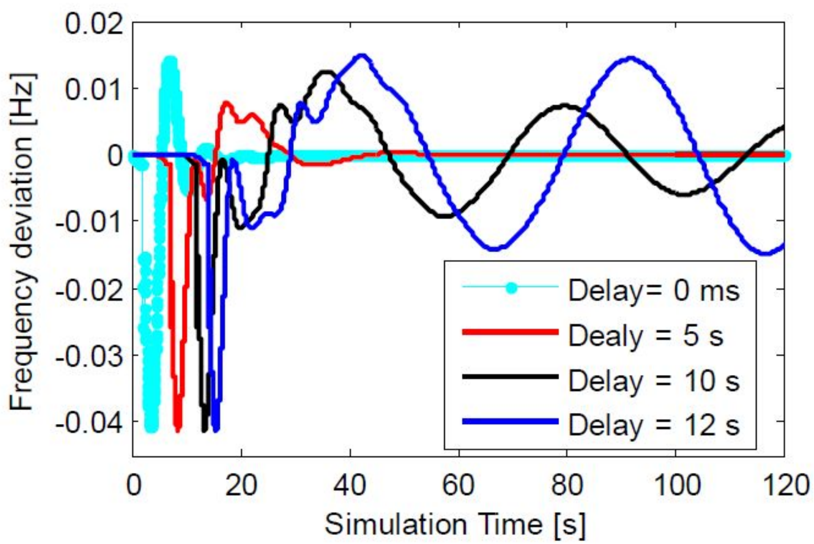
- The **stochastic load model** does not allow to accurately capture the frequency deviations due to time varying load changes. The controller is capable of reset the island’s frequency to the prescribed reference in case of stochastic load.

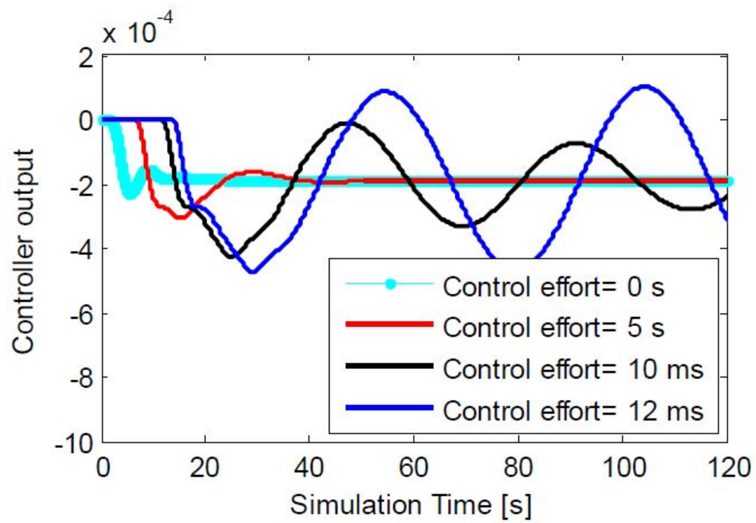


It is to observe that **delays** from **25 to 150 ms** have no major impact on the controller's performance, this is because the frequency dynamics being controlled are much larger than typical PMU reporting rates.

When the **reporting rate** is set to tens of seconds, the control loop becomes **unstable** i.e. **for the reporting rate > 16 s**. This is a positive result, as typical PMU reporting rates are ≤ 16_s, i.e. 10, 30, 50, 60 samples per seconds.

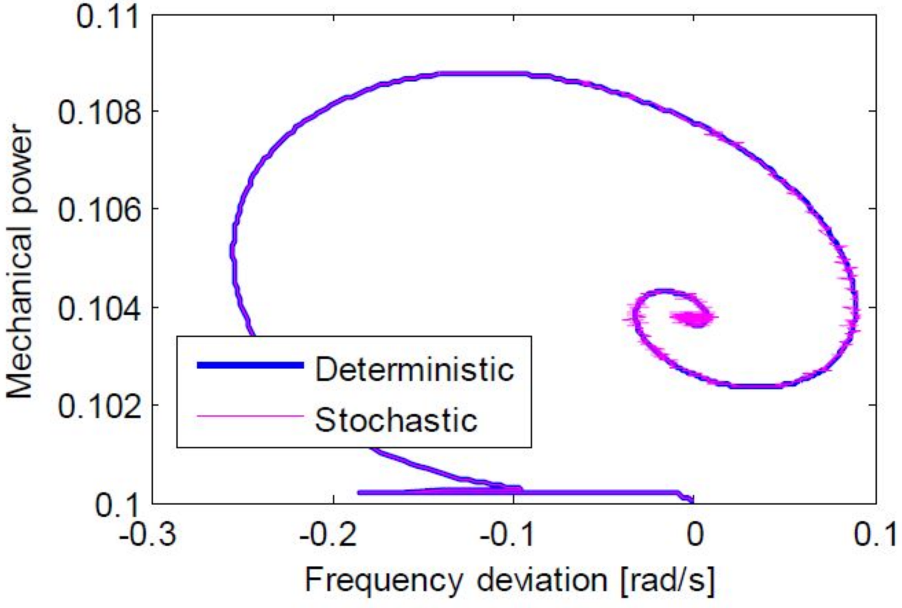


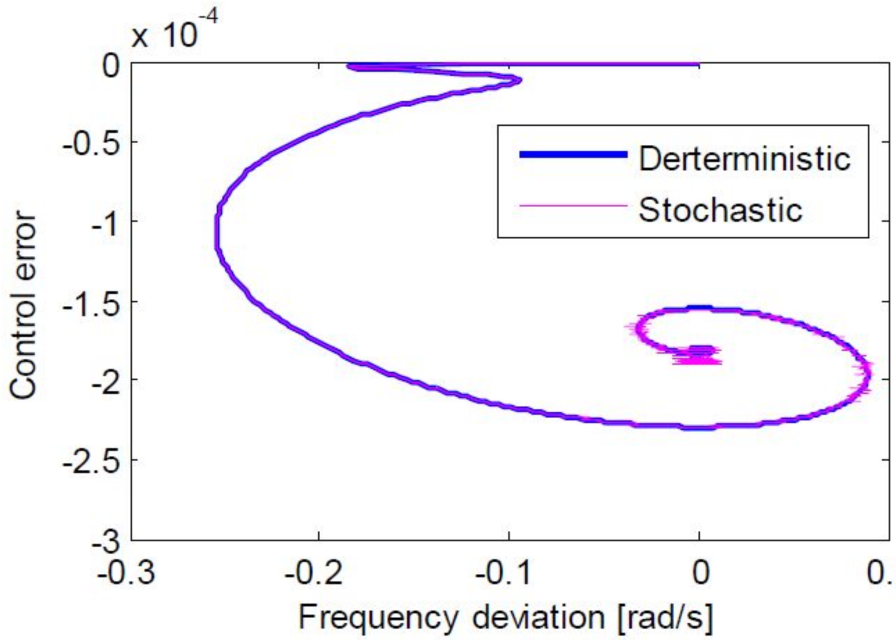




- A **FixedDelay** block is used to mimic the aggregate time-delay from a PMU device to the controller.
- As it can be observed in that the maximum delay bound is time delay ≈ 12s. These results are encouraging, as typical synchrophasor systems only incur in delays in the order of a 100s of milliseconds, up to a few seconds.

Case 5 - Impact of frequency deviation over both control error and mechanical power output





- The increase in the frequency deviation, increases the mechanical power up-to 10.88 %. However for both deterministic load and stochastic load model the control error decreases up-to 0.023 %.

- **This shows that stochastic load modeling is necessary when analyzing turbine-governor control systems.**

Conclusions

- A simple **new frequency computation technique** that uses bus voltage data and can be used during dynamic simulations has been proposed.
- A new supplementary **islanded operation controller was presented.**
  - The controller uses a PI function, when activated capable to retain **a frequency deviation of zero** when the distribution network is islanded from the main transmission grid.
- A technique to **simulate random load variations or stochastic load** using Modelica Noise library features was proposed.
- The performance of the proposed controller is studied considering different **PMU reporting rates and data transmission delays**.
- This controller could be attractive for new distributed energy resource (DER) integration in low-voltage distribution networks.

Research Reproducibility

- The models developed for this work are available on Github at:
  https://github.com/ALSETLab/2018_AmericanModelicaConf_PMUBasedIslanding

RENSSELAER POLYTECHNIC INSTITUTE
KNOWLEDGE AND THOROUGHNESS
• 1824 •

Rensselaer

why not change the world?®