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Electric Energy Systems Group

Electrical & Computer ENGINEERING

Enhanced Regulation and Stabilization to Ensure Frequency Quality During Normal Operations: The Case of Azores Islands

Qixing Liu, Marija Ilic, Milos Cvetkovic

e-mail: lqx@cmu.edu; milic@ece.cmu.edu; mcvetkov@andrew.cmu.edu

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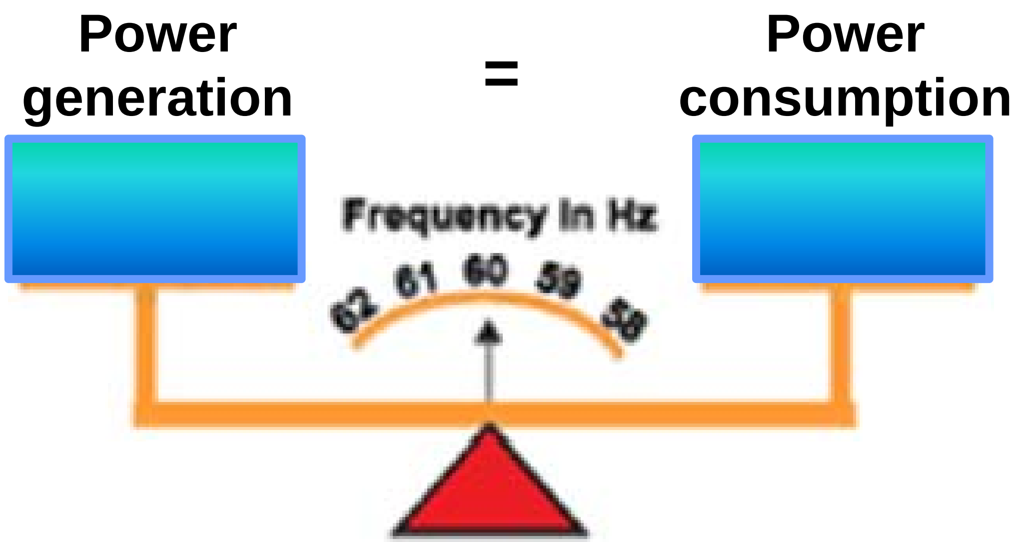
Background

❖ Frequency requirement in power system operation

- Nominal value (e.g 60 Hz in the US)
- Condition for frequency to stay at nominal value on real time



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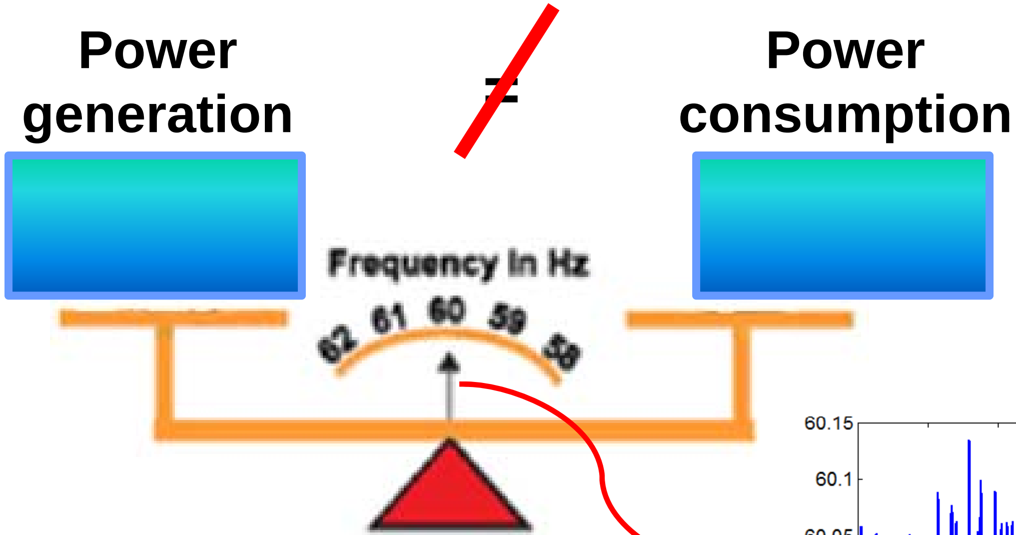
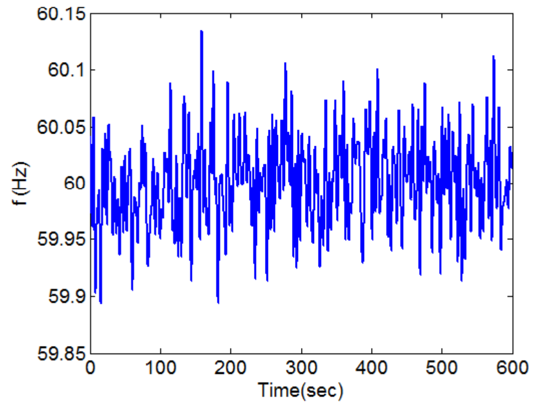
Problems with Green Energy Utilization

- Frequency variations





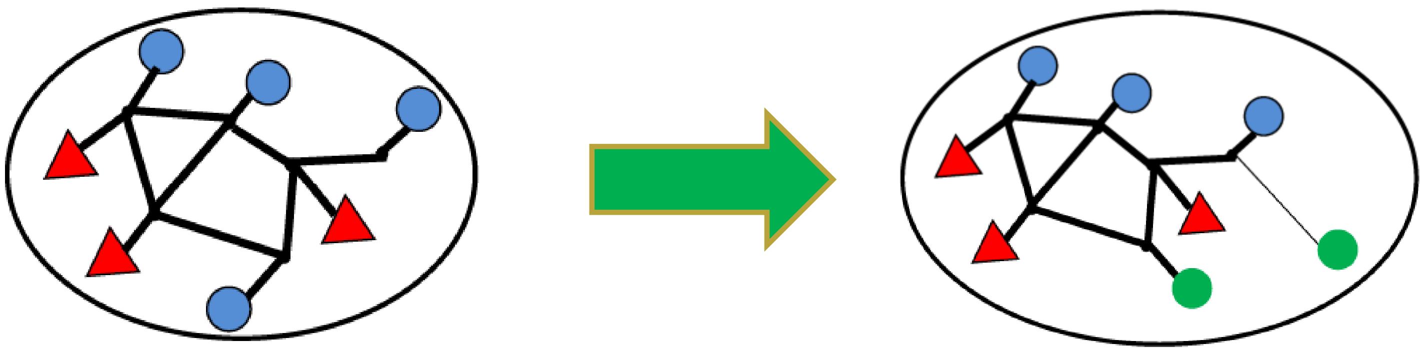
Impact: degrading performance of electrical equipment

Problems with Green Energy Utilization

❖ **Qualitative change interconnected system dynamics**

System with conventional sources

System with conventional and renewable sources



Synchronous generator

Load

Strong transmission line

Renewable power source

Weak transmission line

Impacts: weakly damped oscillations, instability, …

Research objectives in this monograph

- **Enhance frequency regulation by using active power control and energy storage devices (Chapter 15)**
- **Small-signal stability assessment and enhancement (Chapter 16)**

Chapter 15: Frequency Regulation in Future Electric Energy Systems by Using Active Power Control Equipments and Energy Storage Devices

❖ Control approaches investigated in this chapter

- Speed-governor control *(cons: wear-and-tear on mechanical part)*
- Flywheel energy storage control *(cons: high capital cost)*

❖ Objective of the designer

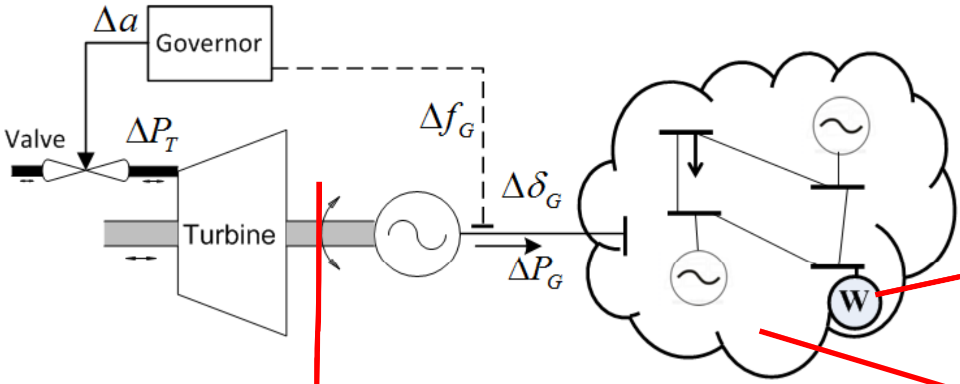
- Ensure frequency quality
- Reduce wear-and-tear on the speed-governor

[1] M. D. Ilic and Q. Liu, "A Framework for Enhancing Frequency Stabilization and Regulation in Future Electric Energy Systems, Part I: Considering Decoupled Active Power-Frequency Dynamics," Chapter 15 ofEngineering IT-Enabled Sustainable Electricity Services: The Case of Low-Cost-Green Azores Islands (To be published in the monograph).

System Modeling

- **Decoupled frequency-active power dynamics model (electromechanics)**
  - *Assumption: Stable Electromagnetics (Further discussed in Ch 16)*
- **Linearized model around the operating equilibrium**
- **Structure-preserving**
  - Help with understanding in details

Structure-preserved Model



$P_{Wind} = w(t)$

- Negative load

$\underline{\boldsymbol{P}}_G = \boldsymbol{C}_{cpG}\underline{\boldsymbol{x}}_G + \boldsymbol{C}_{cpL}\underline{\boldsymbol{w}}$

- **Network coupling constraints**
  - **Linearized power flow**
  - **w**: disturbances from renewable sources

$\dot{\boldsymbol{x}} = \boldsymbol{A}_G\boldsymbol{x}_G + \boldsymbol{B}_G\boldsymbol{u}_G + \boldsymbol{B}_f\boldsymbol{u}_f + \boldsymbol{D}\boldsymbol{P}_G$

- **States of generator**
  - **Electromechanics: [$\Delta\delta_G$, $\Delta\omega_G$]**
  - **Speed-governor: [ΔP_T, Δa]**
  - **Coupling variable: ΔP_G**
  - **u**$_G$: speed governor control
  - **u**$_f$: flywheel control

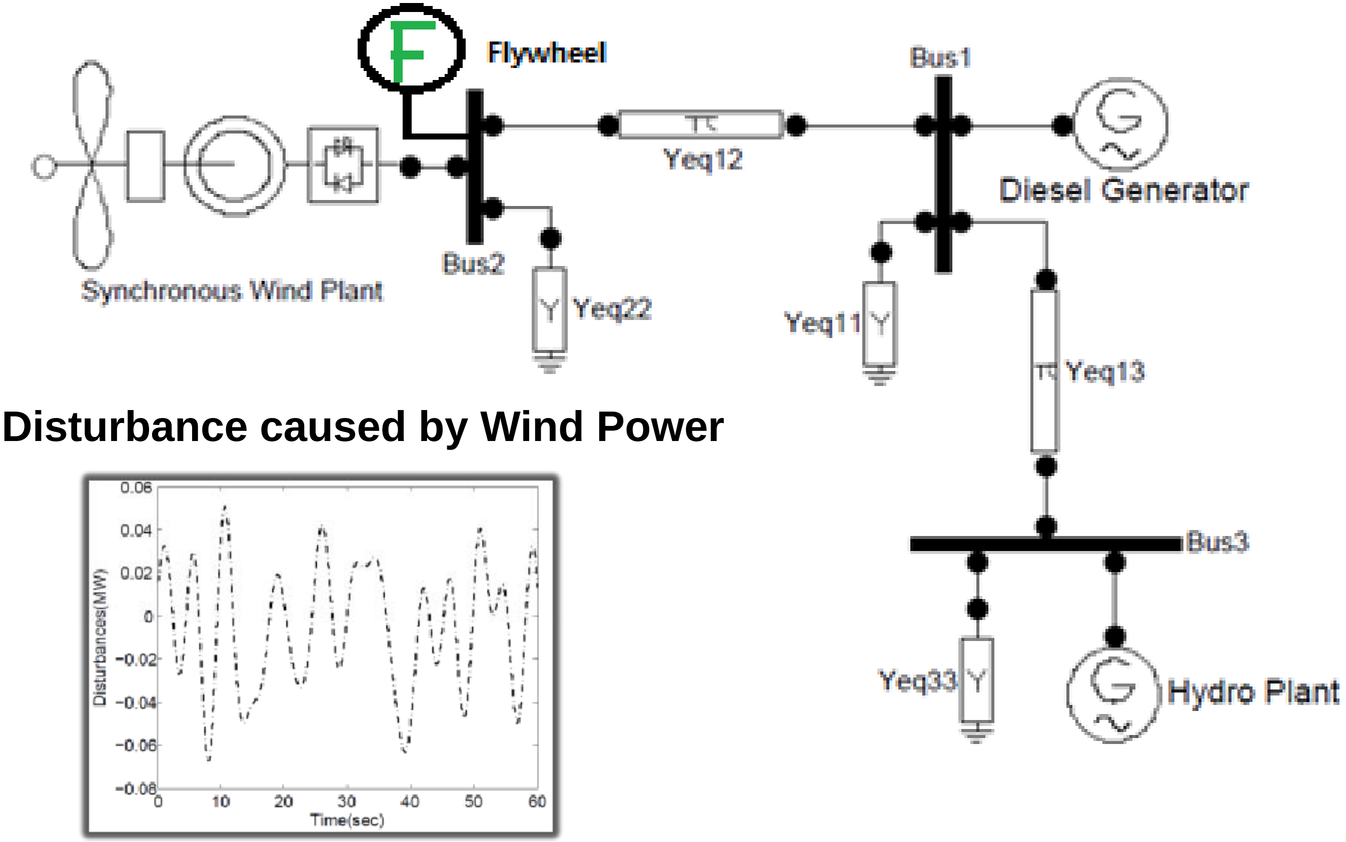
- **Standard state-space model**
  $\underline{\dot{\boldsymbol{x}}} = \boldsymbol{A}\underline{\boldsymbol{x}} + \boldsymbol{B}\underline{\boldsymbol{u}} + \boldsymbol{F}\underline{\boldsymbol{w}}$

Description of Control Approaches

- **Physical control equipment**
  - Speed-governors
  - Flywheel energy storage devices
- **Control Logics**
  - Decentralized control by using local measurement
  - Centralized output feedback optimal control
  - Centralized full-state feedback optimal control

Simulation Studies

❖ **Test system: Power System of the Flores Island**



Disturbance caused by Wind Power

Simulation Studies

❖ Simulation Cases

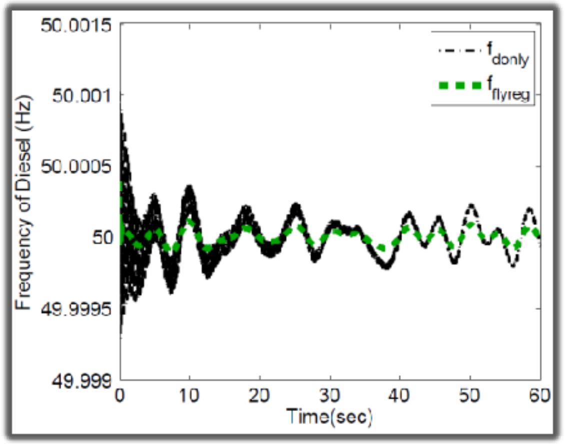
Case Number	Case Description
Case 1	No energy storage control, only decentralized speed-governor control
Case 2	Decentralized energy storage (flywheel) and speed-governor control
Case 3	Centralized output-feedback energy storage and speed-governor control
Case 4	Centralized fullstate-feedback energy storage and speed-governor control

More information;

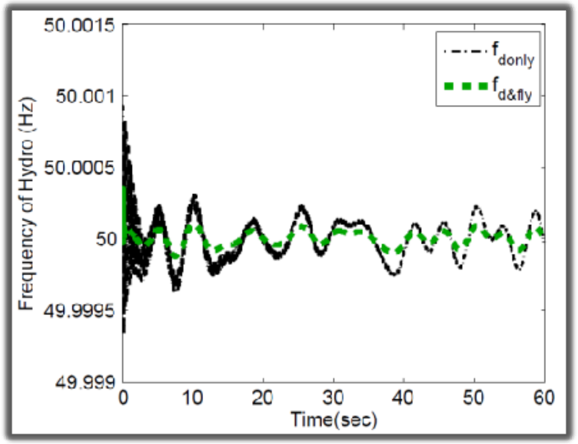
More control options

Results (case 1 and case 4)

Frequency: Diesel



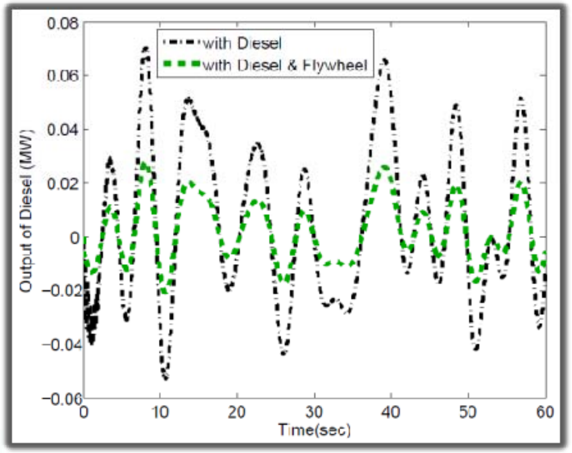
Frequency: Hydro



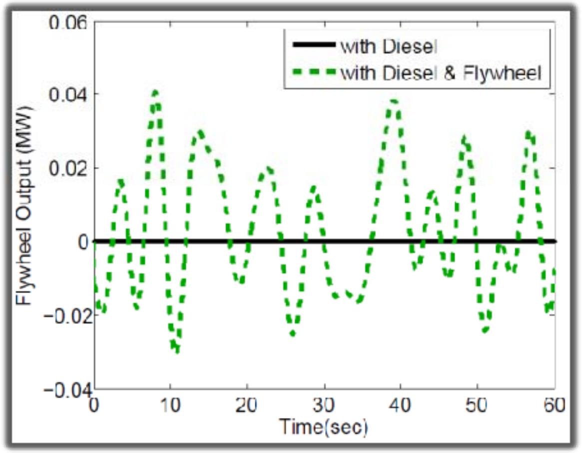
Case 1: without flywheel

Case 4: with flywheel

Output: Diesel



Output: Flywheel



Conclusions and Future Work

- Improved frequency quality obtained by using flywheels
- Reduced use on speed-governor and therefore less wear-and-tear
- Future work will concern the cost of installing flywheel v.s cost of wear-and-tear
- Future work will also consider using well-designed voltage control to balance and reduce wear-and-tear

Questions so far?

Chapter 16: Small Signal Stability Enhancement in Future Electric Energy Systems by Using Voltage Control

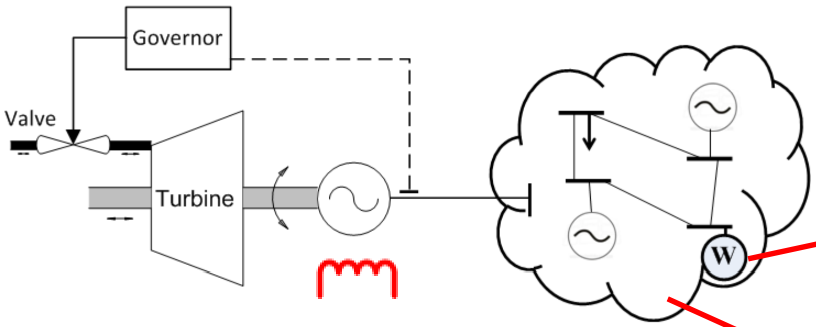
- **Assumption of *stable electromagnetics* may not hold, due to**
  - Qualitatively different dynamic characteristics of the renewable sources
  - The electrical distances between the renewable sources and the main power grid
- **Control approaches investigated in this chapter**
  - Voltage control (Field Excitation, PSS, DFIG, SVC, etc.)
- **Objective of the designer**
  - Enhance the small signal stability
  - Reduce wear-and-tear on the speed-governor

[2] M. D. Ilic, Q. Liu and M. Cvetkovic, "Toward Stabilizing Linearized System Dynamics in Future Electric Energy Systems by Means of Enhanced Voltage Control," Chapter 16 of Engineering IT-Enabled Sustainable Electricity Services: The Case of Low-Cost-Green Azores Islands (To be published in the monograph).

System Modeling

- **Coupled frequency-voltage dynamics model (electromechanics & electromagnetics)**
- **Linearized model around the operating equilibrium**
- **Structure-preserving**
  - Help with understanding in details

System Modeling



- **Wind generator**
  - Synchronous generator
  - Induction generator

- **States of generator**
  - Electromechanics: [$\Delta\delta_G$, $\Delta\omega_G$]
  - Electromagnetics: [E'_D, E'_Q]
  - Speed-governor: [ΔP_T, Δa]
  - Excitation control: [V_R , e_{fd}, V_F]

- **Network coupling constraints**

- **Standard state-space model**

  $$\dot{\underline{\boldsymbol{x}}} = \boldsymbol{A}\underline{\boldsymbol{x}} + \boldsymbol{B}\underline{\boldsymbol{u}}_G + \boldsymbol{F}\underline{\boldsymbol{w}}$$

Description of Control Approaches

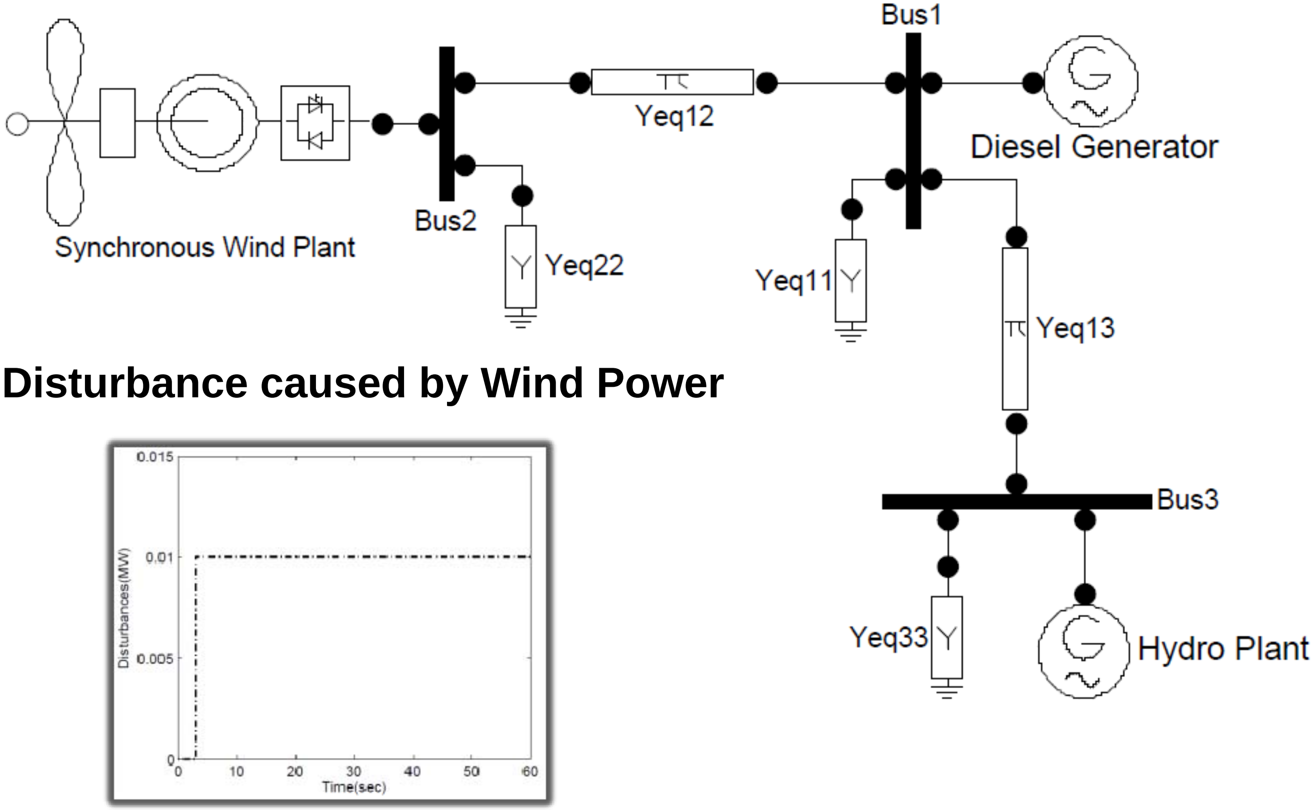
❖ **Physical control equipment**
  - Speed-governors
  - Field excitation control on synchronous generators
  - DFIG, SVC on induction generators

❖ **Control Logics**
  - Decentralized control by using local measurement

Simulation Studies

❖ **Test system: Power System of the Flores Island**

Disturbance caused by Wind Power



Simulation Studies

❖ Simulation Cases

- With respect to different wind generation technologies and electrical distances

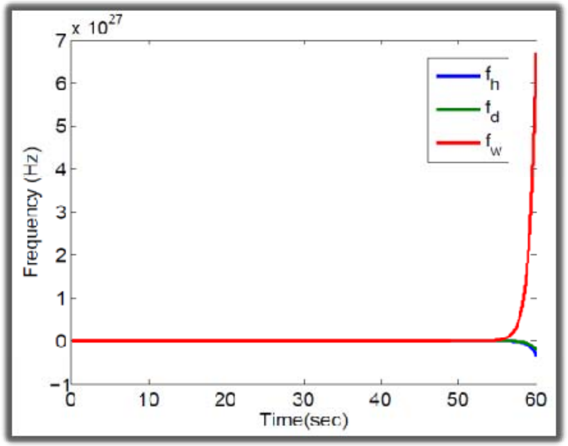
Case Number	Case Description
Case 1	Wind induction generator, small electrical distance with diesel generator
Case 2	Wind synchronous generator, small electrical distance with diesel generator
Case 3	Wind induction generator, large electrical distance with diesel generator
Case 4	Wind synchronous generator, large electrical distance with diesel generator

Results of Small-signal Stability

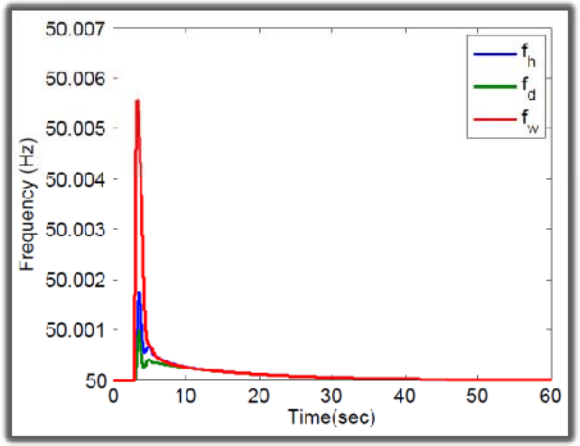
Case Number	Case Description	Small-Signal Stability
Case 1	Wind induction generator, small electrical distance with diesel generator	**Stable**
Case 2	Wind synchronous generator, small electrical distance with diesel generator	**Stable**
Case 3	Wind induction generator, large electrical distance with diesel generator	**Unstable**
Case 4	Wind synchronous generator, large electrical distance with diesel generator	**Stable**

Results of Case 4 (uncontrolled and controlled)

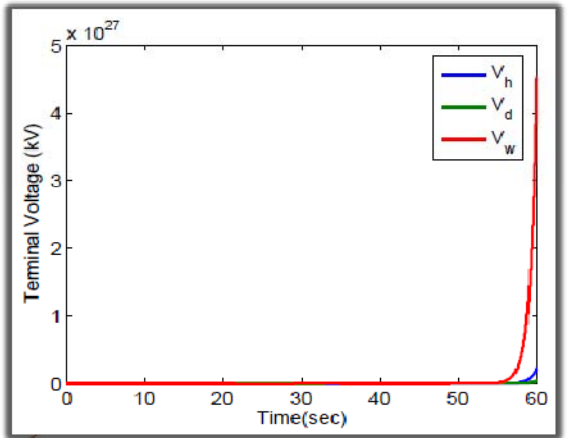
Frequency : no-ctrl on wind



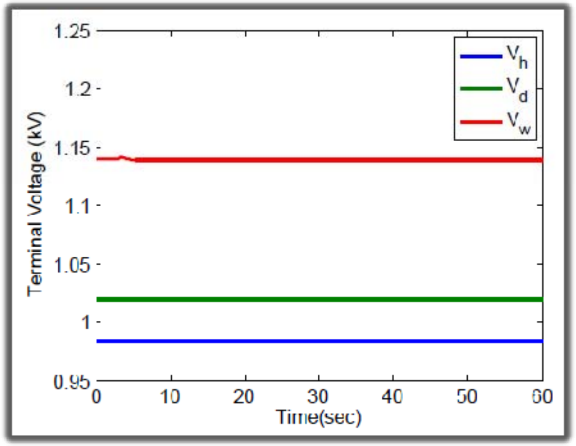
Frequency : SVC on wind



Voltage: no-ctrl on wind



Voltage: SVC on wind



Hydro

Diesel

Wind

Conclusions and Future work

- ❖ **Renewable energy generators may cause small-signal instability of the entire system**
- ❖ **Enhanced small signal stability by using controls on wind**
- ❖ **Reduced wear-and-tear on speed-governor shown in other simulation results**
- ❖ **Future work will concern applying more coordinated and robust control logics**
- ❖ **Standard of renewable energy integration from system dynamics point of view**

Acknowledgement

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