Dynamic Behavior of Distribution Systems with Distributed Generation

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Contents

1. Objectives
2. Distribution system modeled
3. Dynamic models of the network components
4. Study cases
5. Conclusions

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Objectives

- To demonstrate the effect of distributed resources on dynamic behavior of distribution systems.
- The study cases demonstrate the response of the system to disturbances and the effect of:
  - Type of embedded generation
  - Operating conditions
  - Degree of penetration of the DG resources

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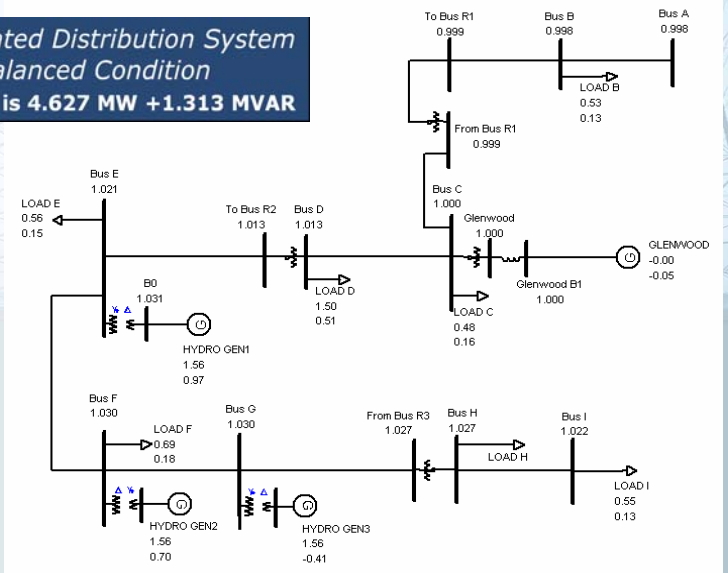
Distribution System Modeled

Investigated Distribution System
Balanced Condition
Total load is 4.627 MW +1.313 MVAR



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Dynamic Models of the Network Components

- The following components' models were used:
  - Load model including frequency and voltage dependence
  - Standard generator models
  - Excitation system models
  - Prime mover models
  - DG dynamic models
  - IEEE Anti-Islanding Protection

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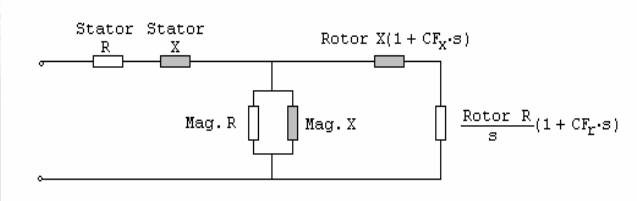
Generator Models (cont'd)

- **Induction generator model**
  - Used in conjunction with wind turbines. Modeled using equivalent electrical circuit



Induction Generator Equivalent Circuit

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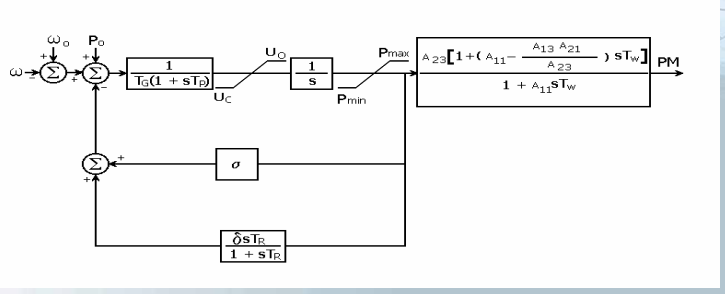
Prime Mover Models

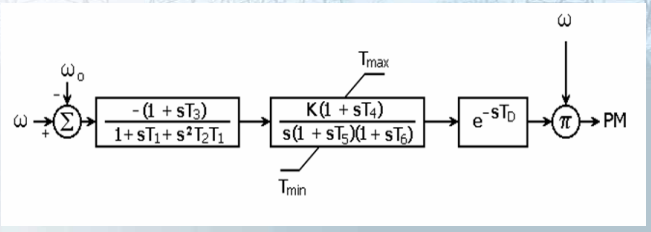
- **Hydraulic units**
  - Hydraulic turbine model reproduces water column dynamics and gate control.
  - Governor model includes permanent and transient droops.



Hydraulic Governor and Turbine Model

Prime Mover Models (cont'd)

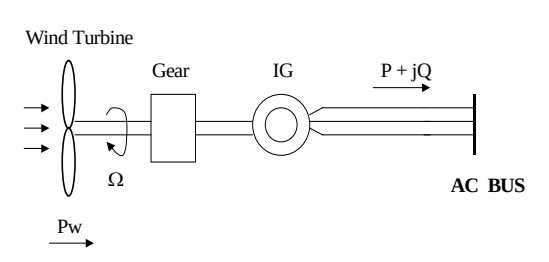
- **Diesel units**
  - Diesel unit governor - fast response and no permanent droop
  - Adjusts unit speed to its set point (60Hz) irrespective of load



Governor/Turbine Model of a Diesel Engine

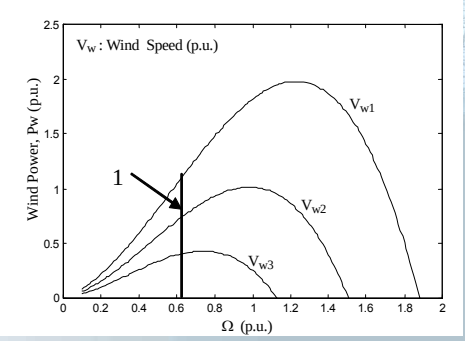
Prime Mover Models (cont'd)

- **Wind turbine model**
  - Directly coupled induction generators driven by wind turbine.

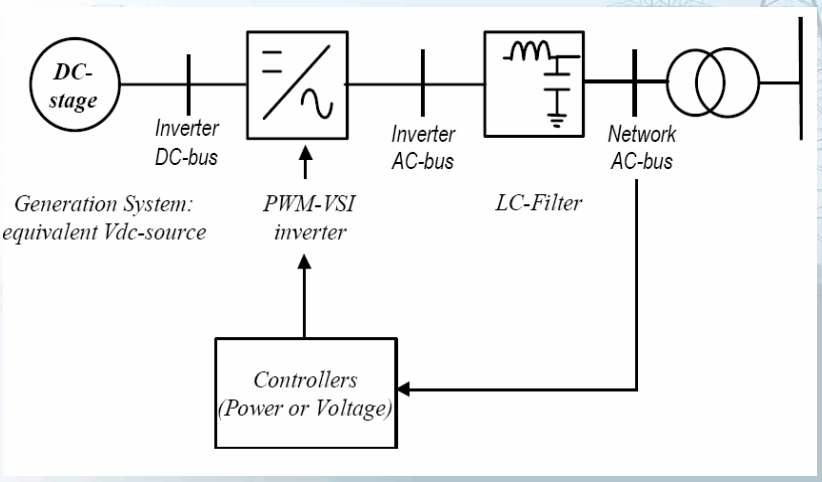


Prime Mover Models (cont'd)

- **Wind turbine model**
  - Operates at roughly constant speed.
  - Input wind power is determined entirely by wind speed.



Electronically-interfaced DG system



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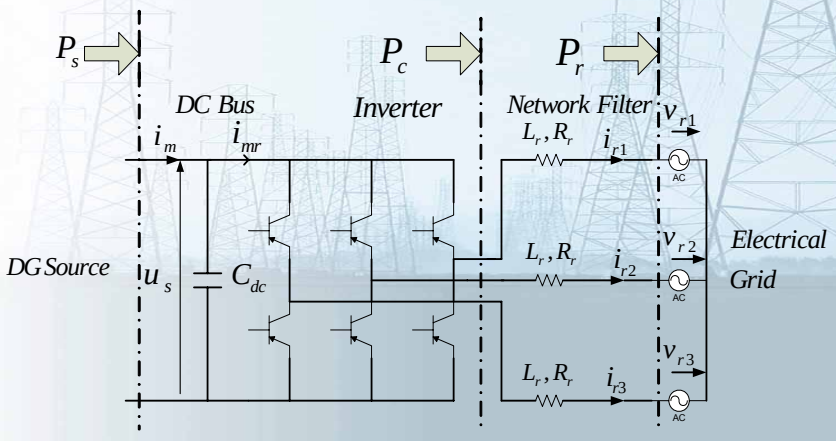
Simplified Model of Grid-side Converter



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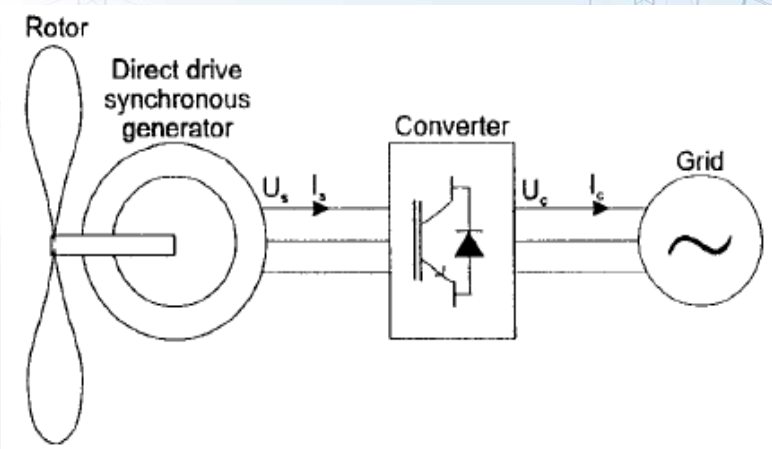
WECS - direct drive synchronous generator



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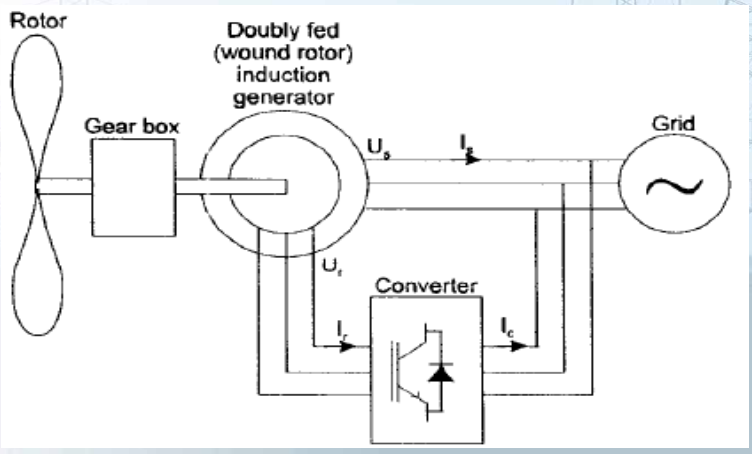
WECS – Doubly-Fed Induction Generator



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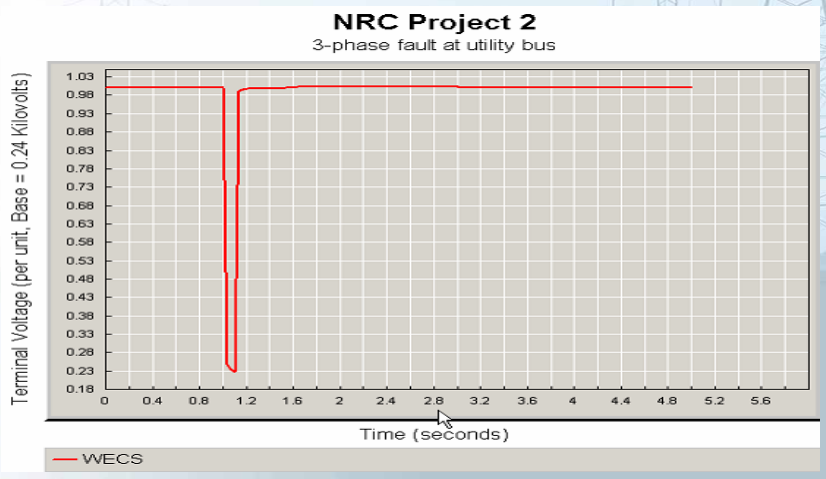
Three phase fault at Utility substation bus



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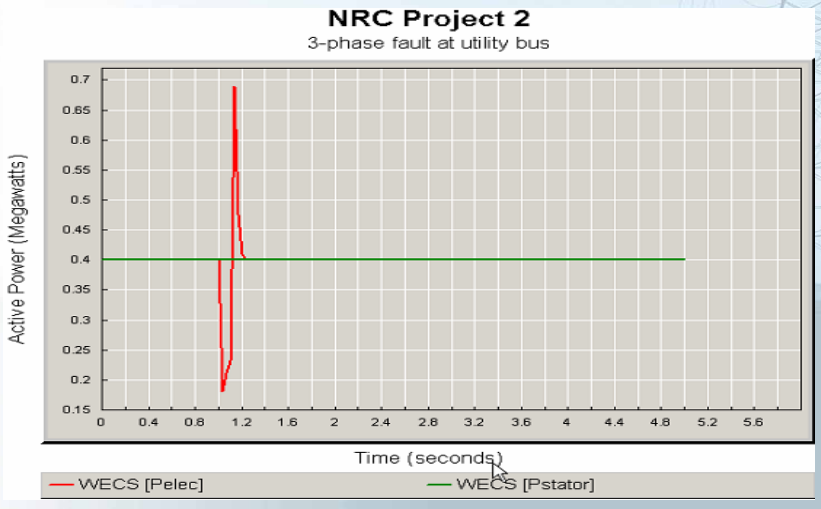
Three phase fault at Utility substation bus (cont'd)



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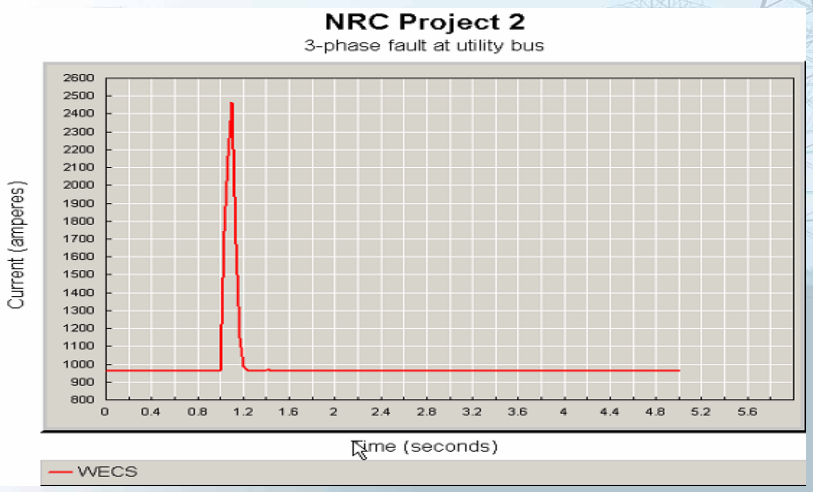
Three phase fault at Utility substation bus (cont'd)



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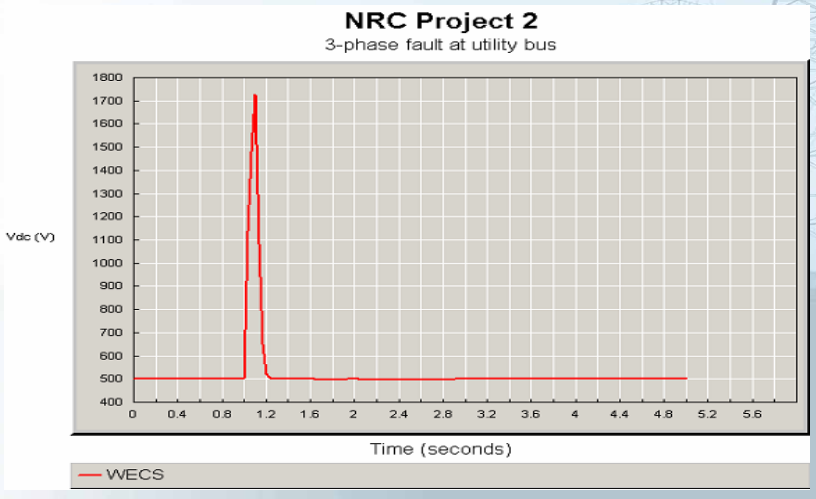
Three phase fault at Utility substation bus (cont'd)



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IEEE Anti Islanding Standards

Current IEEE Standards do not allow island operation of distribution systems

- **Voltage limits and clearing times**
  - When voltage is in specified range, DR disconnects within the clearing times indicated.

Voltage Range (% of base voltage[a])	Clearing Time[b] (s)
V< 50	0.16
50 ≤V<88	2
110<V<120	1
V ≥ 120	0.16

Notes.
(a) Base voltages are the nominal system voltages.
(b) DR ≤ 30kW, Maximum Clearing Times; DR > 30kW, Default Clearing Times

IEEE Anti Islanding Standards (cont'd)

- **Frequency limits and clearing times**
  - When frequency is in specified DR shall disconnect within the clearing times as indicated.

DR SIZE	Frequency Range (Hz)	Clearing Time[a] (s)
≤30 kW	> 60.5	0.16
<59.3		0.16
>30 kW	>60.5	0.16
< {59.8 - 57.0} (adjustable set-point)		Adjustable 0.16 to 300
<57.0		0.16

Note. (a) DR ≤ 30 kW, Maximum Clearing Times; DR > 30 kW, Default Clearing Times

Study Cases – Overview

- **System response to:**
  1. **Major disturbances such as load / generation loss or sever short circuits**
  2. **Detection of island formation**
  3. **System operation in island mode**
- **Study cases are conducted for different DG types, mixes and penetration levels**

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System Response to Major Disturbances

System response to disturbances not resulting in system separation such as:

1. **The loss of a large load**
2. **Loss of large generation**
3. **Severe short circuit condition**

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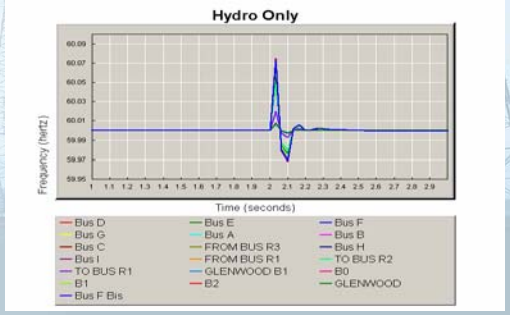
Distribution System with Embedded Hydraulic Generation

Loss of load condition

Frequency Response to Load Loss
Balanced Load/Generation
Hydro Units



- Frequency returns to its nominal value (60Hz).
- Maximum frequency excursion (60.07 Hz) within IEEE limits.

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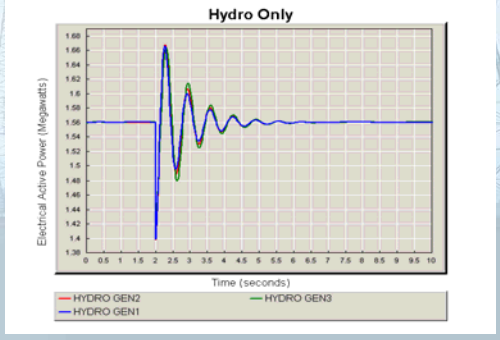
Distribution System with Embedded Hydraulic Generation (cont'd)

Loss of load condition

Unit Load Response to Load Loss
Balanced Load/Generation
Hydro Units



- Generator loads return to their original values.

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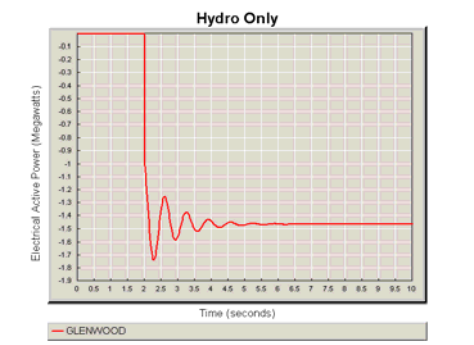
Distribution System with Embedded Hydraulic Generation (cont'd)

Loss of load condition

Transmission System Response to Load Loss
Balanced Load/Generation
Hydro Units

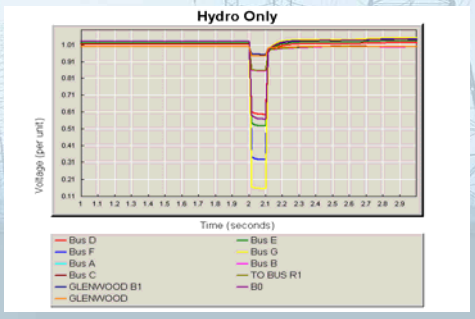


- Feeding system absorbs the excess power.

Distribution System with Embedded Hydraulic Generation (cont'd)

Short circuit conditions

Voltage Response to Three-phase S.C. at Bus H
Balanced Load/Generation
Hydro Units

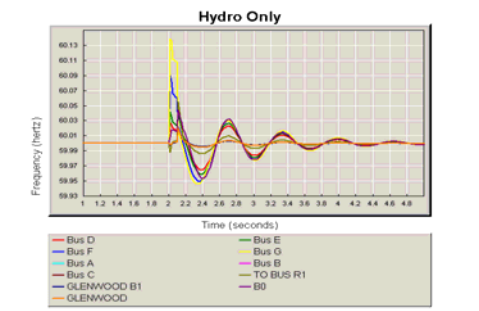


- **The voltage dips vary according to distance from the fault.**
- **The voltages at buses B0, F, and G drop to 0.56 pu, 0.32 pu, and 0.15 pu.**

Distribution System with Embedded Hydraulic Generation (cont'd)

Short circuit conditions

Frequency Response to Three-Phase S.C. at Bus H
Balanced Load/Generation
Hydro Units



- Frequency returns to its nominal value (60Hz).
- Maximum frequency excursion (60.14 Hz) within IEEE limits.

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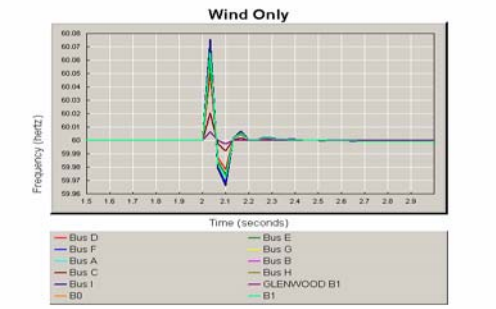
Distribution System with Embedded Wind Generation

Loss of load condition

Frequency Response to Load Loss
Balanced Load/Generation
Wind Units



- Frequency returns to its nominal value (60Hz).
- Maximum frequency excursion (60.08 Hz) within IEEE limits.

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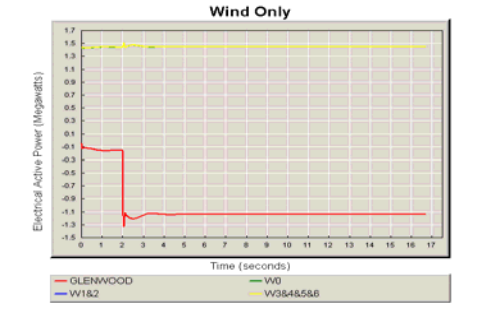
Distribution System with Embedded Wind Generation (cont'd)

Loss of load condition

Generation Response to Load Loss
Balanced Load/Generation
Wind Units



- Wind generation depends on remains constant.
- Main system absorbs the excess power.

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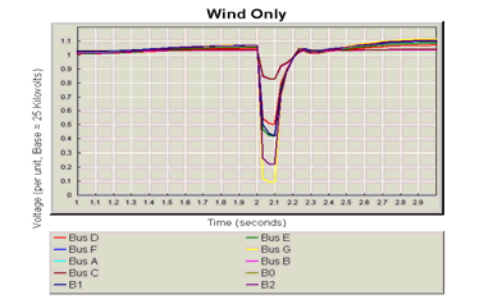
Distribution System with Embedded Wind Generation (cont'd)

Short-circuit condition

Voltage Response to Three-phase S.C. at Bus H
Generation to load ratio 2/1
Wind Generation Units



- **The voltage dips vary according to distance from the fault.**
- **The voltages at buses B0, F, and G drop to 0.42 pu, 0.42 pu, and 0.1 pu.**

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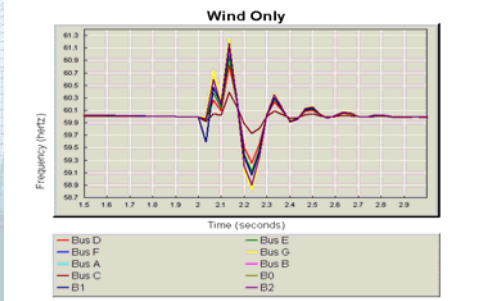
Distribution System with Embedded Wind Generation (cont'd)

Short-circuit condition

Frequency Response to Three-phase S.C. at Bus H
Generation to load ratio ½
Wind Generation Units



- Frequency returns to its nominal value (60Hz).
- Maximum frequency excursion (61.2 and 58.9 Hz) exceeds the IEEE limits.

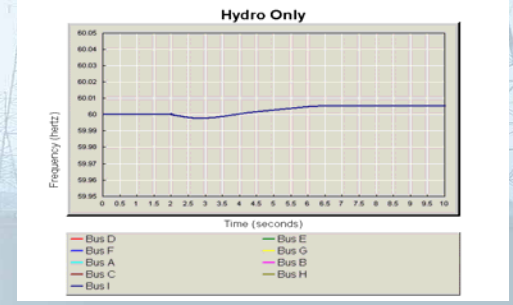
Detection of Island Formation

Detection of Island Formation after system separation

Distribution System with Embedded Hydraulic Generating Units

Balanced Load / Generation condition

Frequency Response to an Islanding Event
Balanced Condition
Hydro Units Only



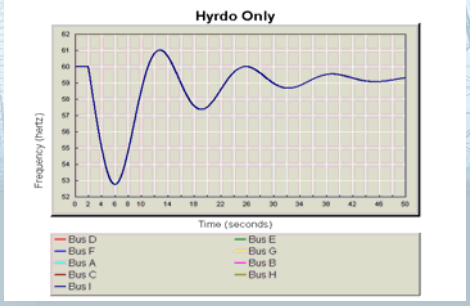
- Frequency variation is insignificant.
- Island formation cannot be detected based on the frequency value.

Distribution System with Embedded Hydraulic Generating Units

Under-generating condition

Two generators each producing 1.56 MW, 2/3 of total load.

Frequency Response to an Islanding Event Under-Generating
Condition with Generation/Load Ratio Equal to 2/3
Hydro Units Only

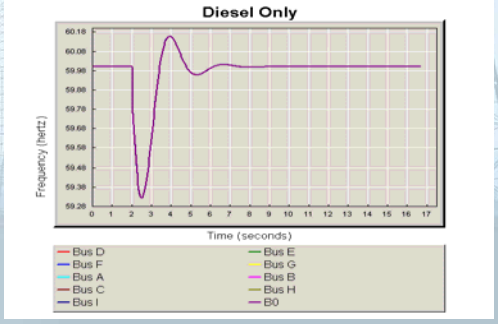


- **Large variation in the frequency of 55.6 Hz, Island can be detected.**

Distribution System with Embedded Diesel Generating Units

B.1 Under-generating condition

Frequency Response to an Islanding Event
Under-Generating Condition with Generation/Load Ratio Equal to ½
Diesel Units Only



- Small variation in the frequency (59.32 Hz). Island cannot be detected.
- Frequency returns to nominal value of 60 Hz.

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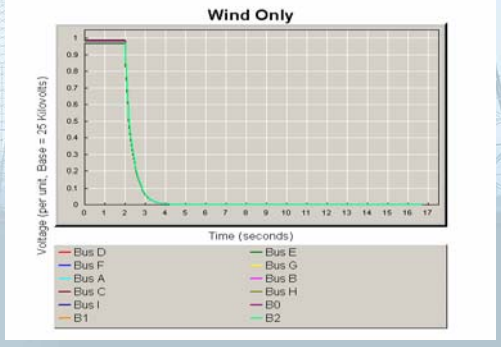
Distribution System with Embedded Wind Generating Units

Under-compensated condition

Voltage Response due to an Islanding Event
Under-Compensated Balanced Condition
Wind Units Only



- **Voltages decrease monotonically and drop to zero.**
- **The voltage values exceed the IEEE limits for island formation.**

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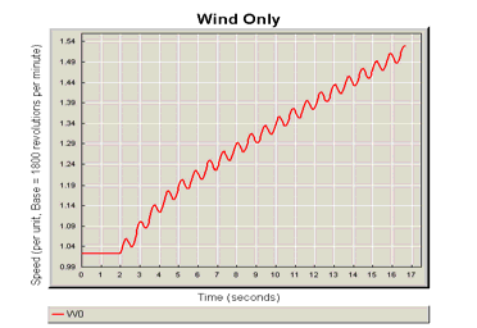
Distribution System with Embedded Wind Generating Units

Under-compensated condition

Frequency Response to an Islanding Event
Under-Compensated Balanced Condition
Wind Units Only



- Constant wind speed, mechanical power remains constant.
- System frequency increases monotonically.

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Island Mode Operation

Feasibility of island mode operation

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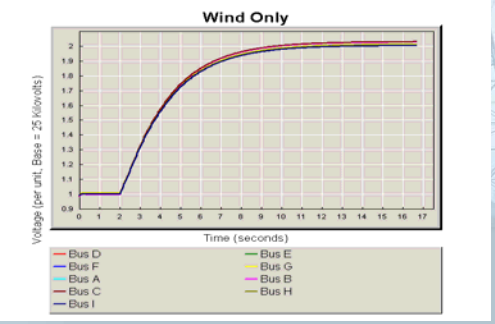
Distribution System with Embedded Wind Generating Units

Over-compensated condition

Voltage Response to an Islanding Event
Over-Compensated Condition – 0.43 MVAR
Wind Units Only

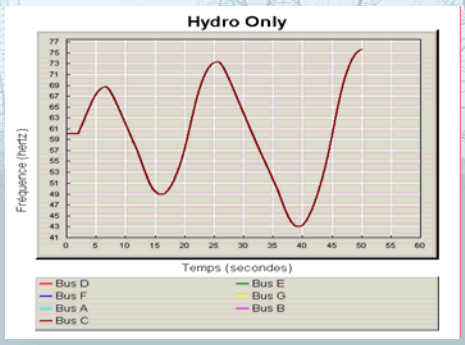


- Bus voltages increase monotonically.
- Voltages exceed the IEEE limits for island detection.

Distribution System with Embedded Hydraulic Generating Units

Over-generating condition with under damped governor

Frequency Response due to an Islanding Event
Over-Generating Condition with Generation/Load Ratio Equal to 2/1
Hydro Units Only

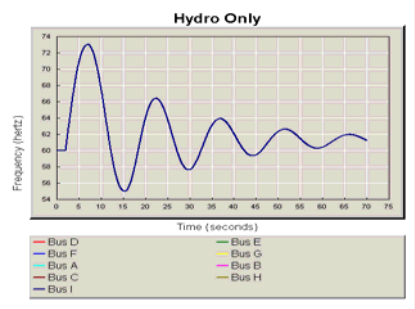


- Unstable island.

Distribution System with Embedded Hydraulic Generating Units

Over-generating condition with generation/load equal to 10 MW/4.6 MW

Frequency Response due to an Islanding Event
Over-Generating Condition with Generation/Load Equal to 10 MW/4.6 MW
Hydro Units Only

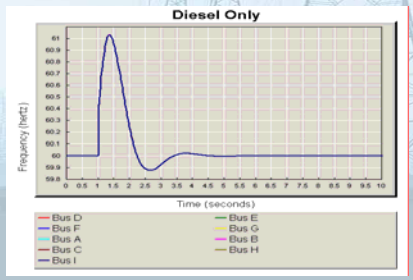


- The frequency excursion reaches 73 Hz.
- The generators trip on over-speed protection of the turbine set at 72 Hz.

Distribution System with Embedded Diesel Generating Units

Over-generating condition with generation/load equal to 10 MW/4.6 MW

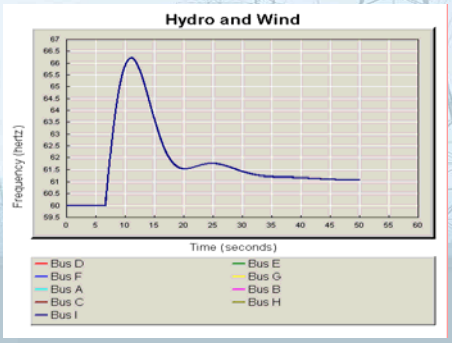
Frequency Response to an Islanding Event
Over-Generating Condition with Generation/Load Equal to 10 MW/4.6 MW
Diesel Units Only



- Maximum frequency 61.04 Hz.
- Not large enough to trigger over-speed protection
- System frequency returns to 60 Hz

Distribution System with Embedded Hydro and Wind Units

Frequency Response to an Islanding Event
Over-Generating Condition
Hydro Units 3 MW, Wind Units 2.9 MW



- Maximum 66.3 Hz
- Not high enough to trip the hydraulic unit
- Steady-state frequency 61 Hz

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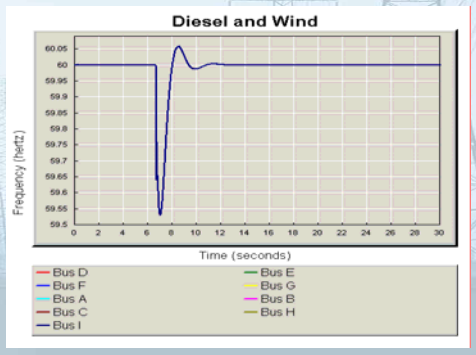
Distribution System with Embedded Diesel and Wind Generating Units

Frequency Response to an Islanding Event
Under-Generating Condition
Diesel Units 1 MW, Wind Units 2.9 MW



- Maximum frequency variation 59.53 Hz.
- Not low enough to trigger protection
- The system frequency returns to 60 Hz.

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Conclusions

- Study demonstrates the effect of distributed generation on the dynamic behavior of host distribution system
- Dynamic simulation of distribution systems with DG to predict their behavior to major disturbances is essential
- Dynamic simulation of distribution network with DG requires the use of detailed models of system and involved units
- Predicting system behavior based on current standards and/or rules of thumb can produce misleading results.

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