SAND2012-9950P

# Western Electricity Coordinating Council
# Renewable Energy Modeling Task Force

# WECC REMTF Wind/PV Generic Modeling Update

Abraham Ellis
aellis@sandia.gov

**REMTF and MVWG Meeting**
**Salt Lake City, UT / November, 2012**

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

# Activity Since June Meeting

- PV/Wind Model Specification Documents
  - Final WT1/WT2 model specs on pitch control **(REMTF/MVWG Approval Item – not on the list)**
  - Final WT3/WT4 model specs **(MVWG approval item)**
  - Large-scale PV model specification completed (PV1X, PVD1) **(MVWG Approval Item)**
  - Distribution-connected PV model completed (CMPLDWg) **(REMTF Working Document)**
- Other documents to which REMTF contributed
  - Generator Facility Data, Testing and Model Validation Requirements (Oct. 2012)
  - NERC IVGTF 3.1 – Interconnection Requirements (Aug. 2012)

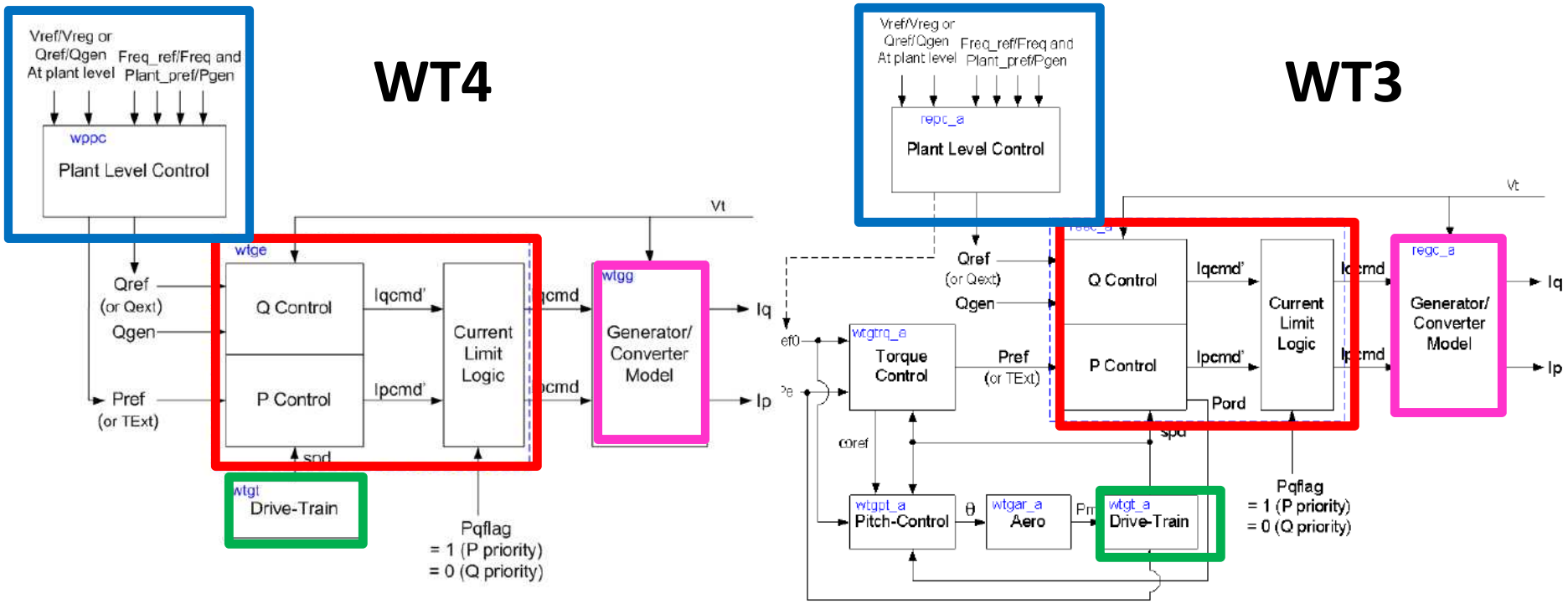
# Activity Since June Meeting

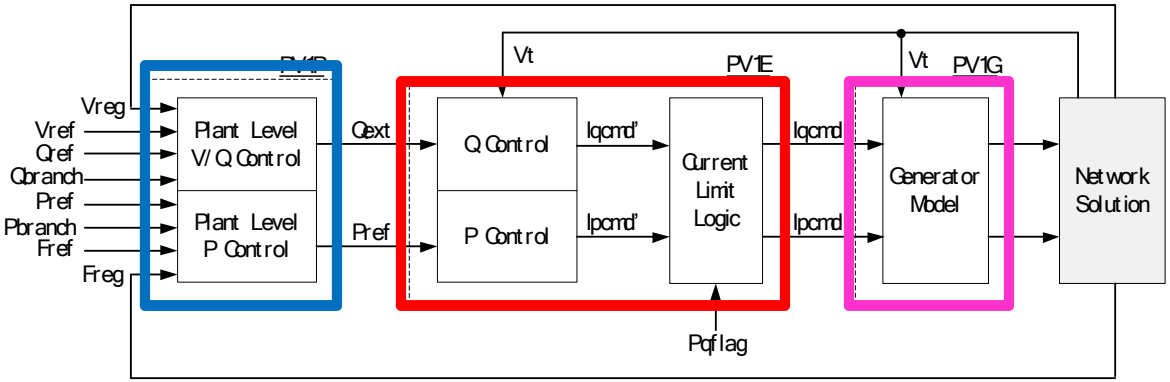
- Recent REMTF Meetings and Teleconferences
  - Review/approval of WT3/WT4 model specifications, July 30
  - Review and approval of large PV plant models Aug. 7
  - Review of IEC comments to WECC models, Oct. 8
  - REMTF Meeting November 5-6
- Other Related Meetings and Presentations
  - UVIG Variable Generation Workshop and Wind/solar Modeling Coordination, Sept. 18-21, Albuquerque, NM
  - IEC WG27 TF88 meeting, Sept. 24-25, Albuquerque, NM
  - NERC Modeling Workshop, Oct. 3, Bloomington, MN
  - UVIG Modeling & Interc. Users Group, Oct. 23, Omaha, NE

# Status of Phase 2 Wind Models

- Model specs done, 'frozen' for WT1, WT2, WT3 & WT4
- Model testing/validation at turbine (not plant) level
- Software implementation underway
- Near-term REMTF work
  - Inventory of wind models in WECC base cases
  - Model testing circuit/plan
  - Default data from manufacturers
  - System-wide studies with generic models
  - Model application guide
  - Guidelines/examples for model validation
  - Dissemination in collaboration with UVIG

# REMTF Renewable Energy Models



# REMTF Wind and PV Models

- Modular structure for wind and PV models
  - Easier to implement and maintain models

| Module | Use |
|---|---|
| **REPC_A** | Wind/PV plant controller |
| **REEC_A / REEC_B** | Wind /PV inverter electrical controls |
| **REGC_A** | Generator-Converter model |
| **WTGT_A** | Simplified Drive Train |
| **WTGAR_A** | Aerodynamic Model |
| **WTGPT_A** | Pitch Control Model |
| **WTGTQ_A** | Torque Control Model |
| **lhvrt** | Voltage/Frequency Protection Model (any generator model) |

PV1X

WT4

WT3

# Wind Models in WECC Base Cases

| | 2012 LS | 2012 HS | 2022 HW | 2022 LS | 2022 LSP |
|---|---|---|---|---|---|
| wt4g match | 17/24 | 17/26 | 26/28 | 27/29 | 367/369 |
| wt4g status = 1 | 1 | 1 | 6 | 27 | 344 |
| wt3g match | 29/38 | 27/41 | 39/41 | 37/41 | 51/57 |
| wt3g status = 1 | 5 | 5 | 16 | 35 | 44 |
| gewtg match | 30/37 | 25/32 | 28/33 | 31/41 | 50/64 |
| gewtg status = 1 | 24 | 24 | 26 | 25 | 39 |
| genwri match | 4/9 | 4/9 | 5/9 | 5/9 | 5/9 |
| genwri status = 1 | 1 | 3 | 3 | 4 | 3 |
| wt1g match | 10/10 | 10/10 | 10/10 | 10/10 | 10/10 |
| wt1g status = 1 | 1 | 1 | 1 | 10 | 9 |
| wt2g match | 16/16 | 16/16 | 16/16 | 16/16 | 21/21 |
| wt2g status = 1 | 1 | 1 | 3 | 16 | 21 |
| **Wind Gen MVA** | **973** | **1,338** | **2,290** | **10,032** | **18,899** |
| **Total Gen MVA** | **115,921** | **175,697** | **173,301** | **139,633** | **121,309** |

# Summary for 2022LSP

wtg4 data by area

| Area | MVA | PGEN |
|---|---|---|
| 10 | 1272.31 | 643.3 |
| 18 | 450.0 | 0.0 |
| 22 | 680.1 | 184.4 |
| 24 | 8347.8 | 4565.4 |
| 30 | 620.9 | 454.8 |
| 40 | 5400.8 | 2841.6 |
| 60 | 308.2 | 0.0 |
| 64 | 151.8 | 50.0 |
| 73 | 741.6 | 667.0 |

wtg3 data by area

| Area | MVA | PGEN |
|---|---|---|
| 14 | 56.0 | 50.4 |
| 24 | 916.4 | 0.0 |
| 40 | 4227.5 | 3746.8 |
| 54 | 90.8 | 50.0 |
| 60 | 359.3 | 258.5 |
| 65 | 165 | 40.0 |

gewtg data by area

| Area | MVA | PGEN |
|---|---|---|
| 10 | 351.9 | 302.9 |
| 22 | 806.6 | 610.0 |
| 24 | 167.0 | 0.0 |
| 26 | 477.3 | 150.0 |
| 30 | 514.0 | 156.3 |
| 40 | 438.3 | 17.3 |
| 60 | 112.0 | 95.0 |
| 70 | 2527.6 | 1907.0 |

genwri data by area

| Area | MVA | PGEN |
|---|---|---|
| 30 | 475.0 | 82.5 |
| 40 | 43.1 | 40.6 |
| 64 | 300.0 | 80.0 |

wt1g data by area

| Area | MVA | PGEN |
|---|---|---|
| 10 | 100.0 | 89.0 |
| 40 | 479.3 | 336.8 |

wt2g data by area

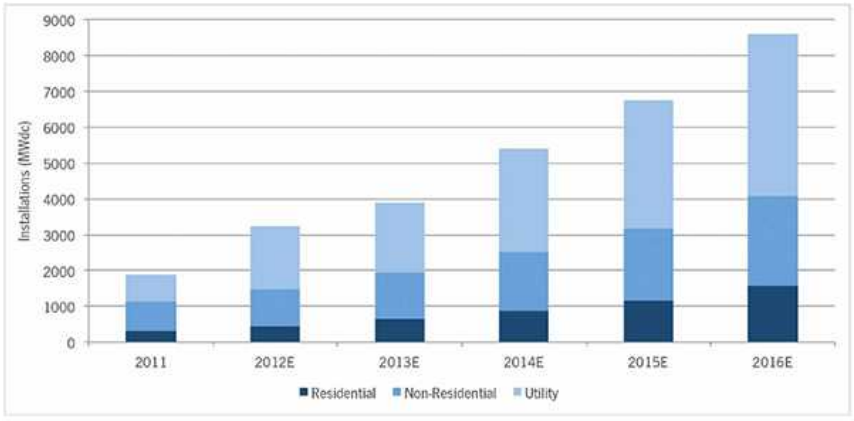
| Area | MVA | PGEN |
|---|---|---|
| 40 | 1527.9 | 1375.1 |
| 60 | 124.7 | 104.5 |

# Status of Solar Models

- Specification completed and “frozen” for PV1X & PVD1
- CMPLDWg model specification may need some adjustments (broader issue affecting CMPLDW)
- Software implementation underway
- Plant-level data collection for model validation
- REMTF to concentrate on
  - Collecting default data from manufacturers
  - System-wide studies
  - Development of model application guide
  - Guidelines/examples for model validation
  - Dissemination in collaboration with UVIG

# PV Plants Getting Larger and Larger

- Large, utility-scale PV plants represent an increasingly large portion of total PV installations
  - Large PV plants in the US as of 08/12
    - 4 plants >50MW$_{ac}$, several >50MW$_{ac}$ under construction, a few >200MW$_{ac}$
    - Agua Caliente, AZ: 290MW$_{ac}$ when complete
  - Large PV plants elsewhere:
    - 24 plants >50MW$_{ac}$, many >50MW$_{ac}$ under construction
  - http://www.pvresources.com/PVPowerPlants/Top50.aspx




Note: Full report contains market forecast through 2016 by state and market segment.

SEIA, Solar Market Insight Report 2012 Q2

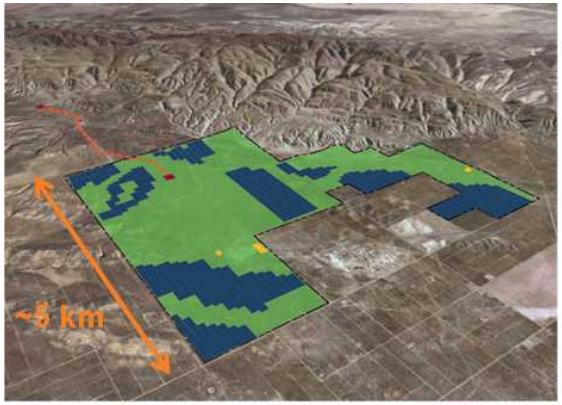
Agua Caliente Solar Project near Yuma, AZ. Photo Courtesy of FirstSolar.

# PV Plant Footprint

- Installed/Planned large-scale PV Plants
  - Some 500MW+ plants under construction


Agua Caliente 290 $MW_{ac}$ 410 $MW_{dc}$
Photo courtesy of FirstSolar

Charts courtesy of
SunPower Corporation




Solar Array Open Space

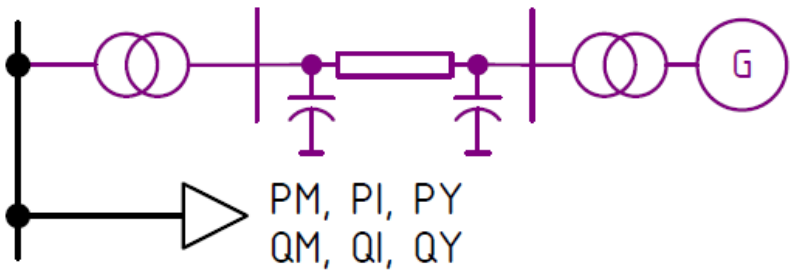
250 MW – CA Valley Solar Ranch


601 MW – Antelope Valley, CA
Overlaid on Washington, DC For Comparison

# REMTF Dynamic Models for PV

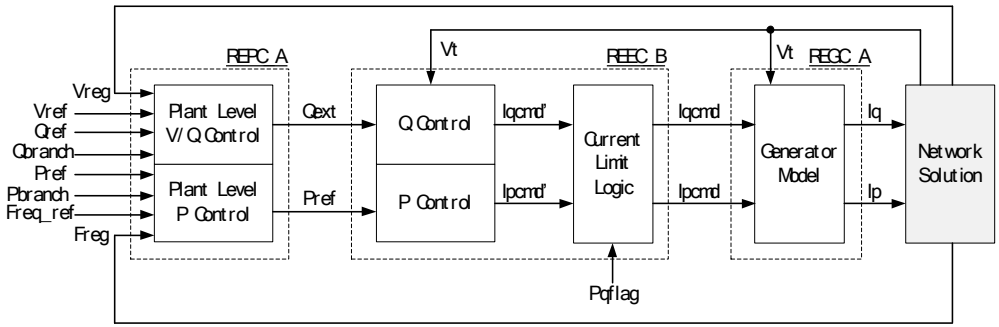
**In power flow, PV modeled explicitly as generator**

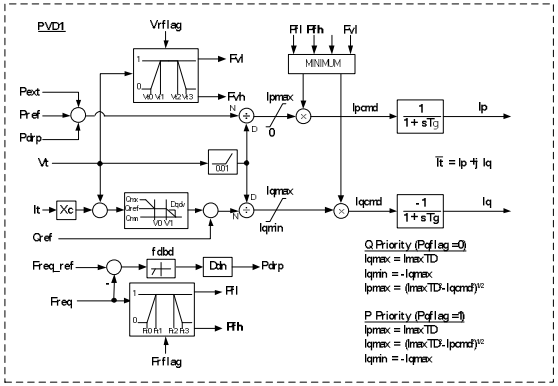
**Should include feeder or collector system equivalent per WECC guide**



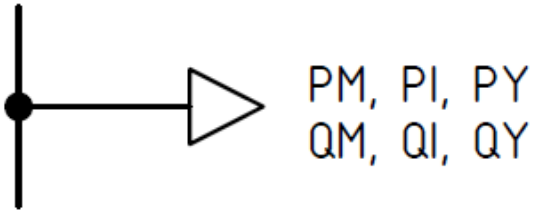

**In dynamics, use stand-alone full-featured or simplified model**

**Full-Featured Model (PV1X)** **OR** **Simplified (PVD1 )**

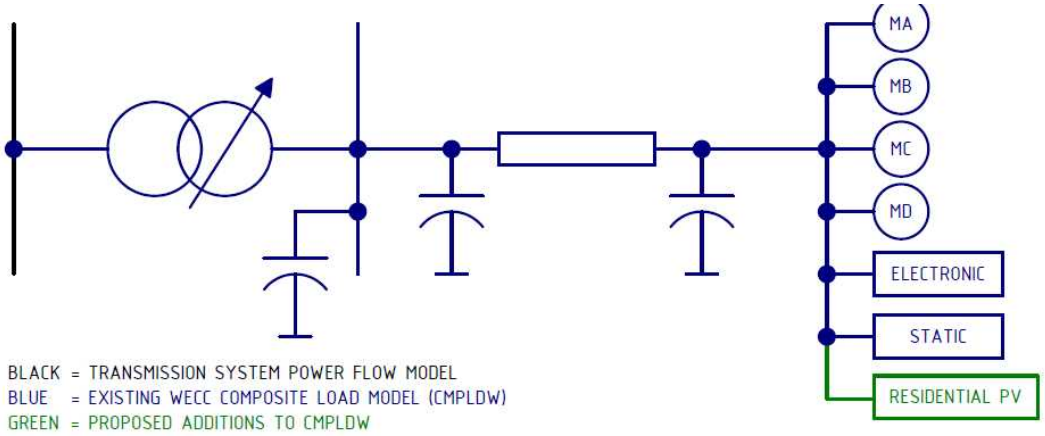


# Distributed PV Generation




**In power flow, residential/commercial PV would be load-netted or represented explicitly (several options possible)**



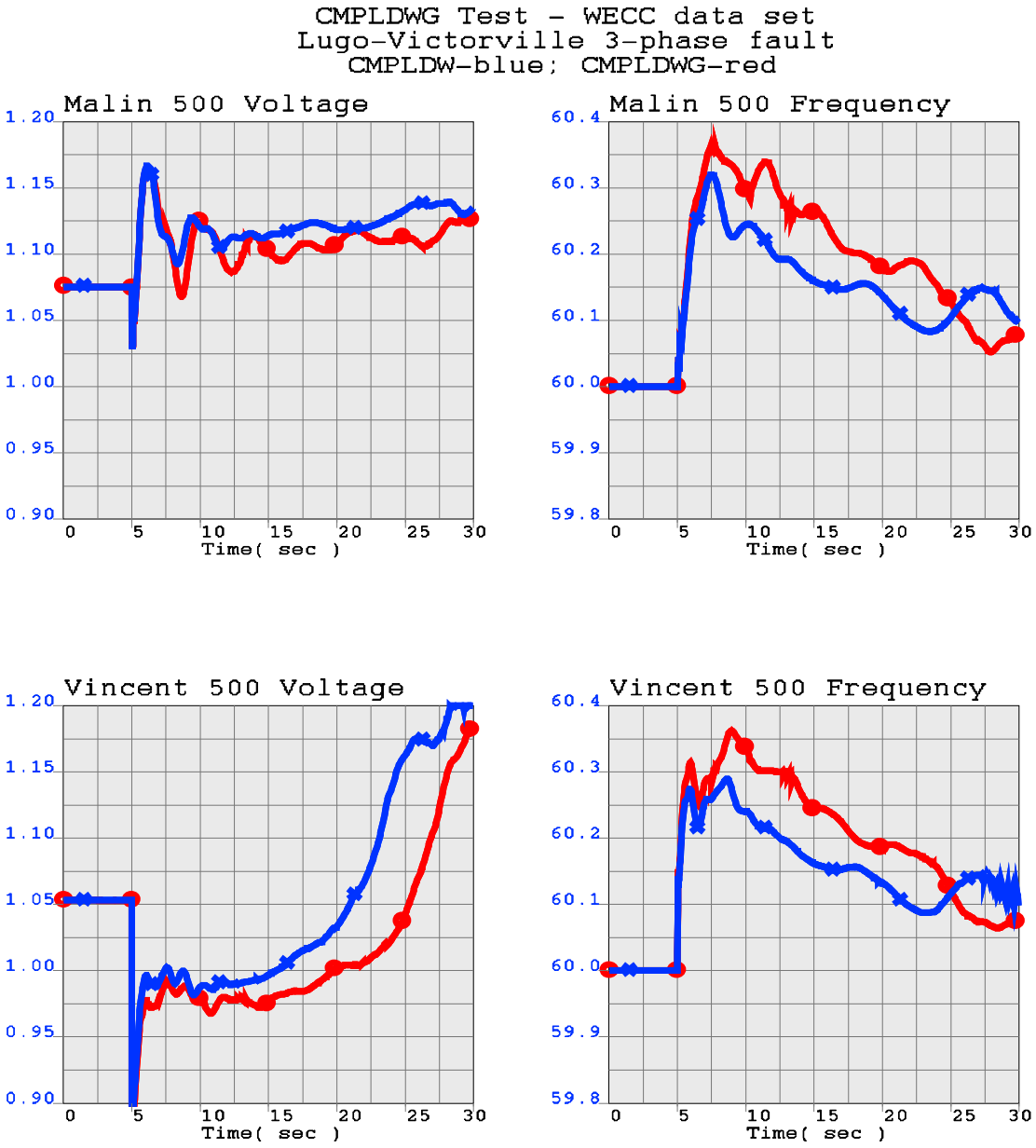

**In dynamics, represent with CMPLDWg model**

**CMPLDWg = CMPLDW + DG**

- **Simple version of PVD1**

# Does it matter?

Yes, if penetration levels are high enough…



# http://www.uwig.org:8080/index.php?title=Main_Page

Log in

Page | Discussion | Read | View source | View history | Go | Search

UVIG

## Main Page

Main page
Community portal
Current events
Recent changes
Random page
Help

Toolbox
What links here
Related changes
Special pages
Printable version
Permanent link

### Getting started
- What is VG Modeling Wiki?
- List of Turbines

### Documentation
- User's Guide
- Configuration settings list
- MediaWiki FAQ
- MediaWiki release mailing list

### News
- UVIG Fall Technical Workshop (October 23-25, 2012)
- AWEA Wind Energy Fall Symposium (November 13-15, 2012)
- UVIG Spring Technical Workshop and Annual Meeting (April 2-4, 2013)

### Wind Turbine Technologies
- Mechanical
- Electrical

### Wind Plants
- Design and Configuration
- Performance Characterization

### Technology Trends
- Turbines
- Wind Plants

### Current Fleet
- Characteristics
- Trends

### Generic Models
- Background
- Structure
- Known Issues
- Ongoing Developments

### Parameterization
- Test System
- Test Cases
- Turbines

Log in

iew source | View history | Go | Search

eries (disambiguation).

with a rated capacity of 1.5-megawatts. Three different models

to 20 revolutions per minute (rpm). Rotor speed is regulated by a
.5 MW series provides the option of a selectable power factor between
production to deliver more VARs during emergency under-voltage

General Electric – 1.5 MW Series

| | |
|---|---|
| **Power Regulation** | Active blade pitch control |
| **Operating Data** | |
| **Rated Power** | 1500 KW [1] |
| **Cut-in wind speed** | 3.5 to 4 m/s (8 to 9 mph) |
| **Cut-out wind speed** | 20 to 25 m/s (45 to 55 mph) |
| **Cut-back-int wind speed** | 17 to 22 m/s (38 to 49 mph) |
| **Wind Class** | IEC TC III+; IEC TC IIA; IEC TC IIB; IEC TC Ib |
| **Rotor** | |
| **Rotor diameter** | 70.5 m (231 ft) for the 1.5se, 77 m (253 ft) for the 1.5 sle, and 83 m (271 ft) for the 1.5xle model. |

Vendor Specific Model Characterization

**Model Performance: Case 1 – Fault Event**

In this case a remote fault is applied to bus 12 for a duration of 6 cycles (0.1 sec).

**GE-1.5 MW – Case 1 and SCR=5**

# WECC Generator Facility Data Testing and Model Validation Requirements

# NERC/WECC Model Validation

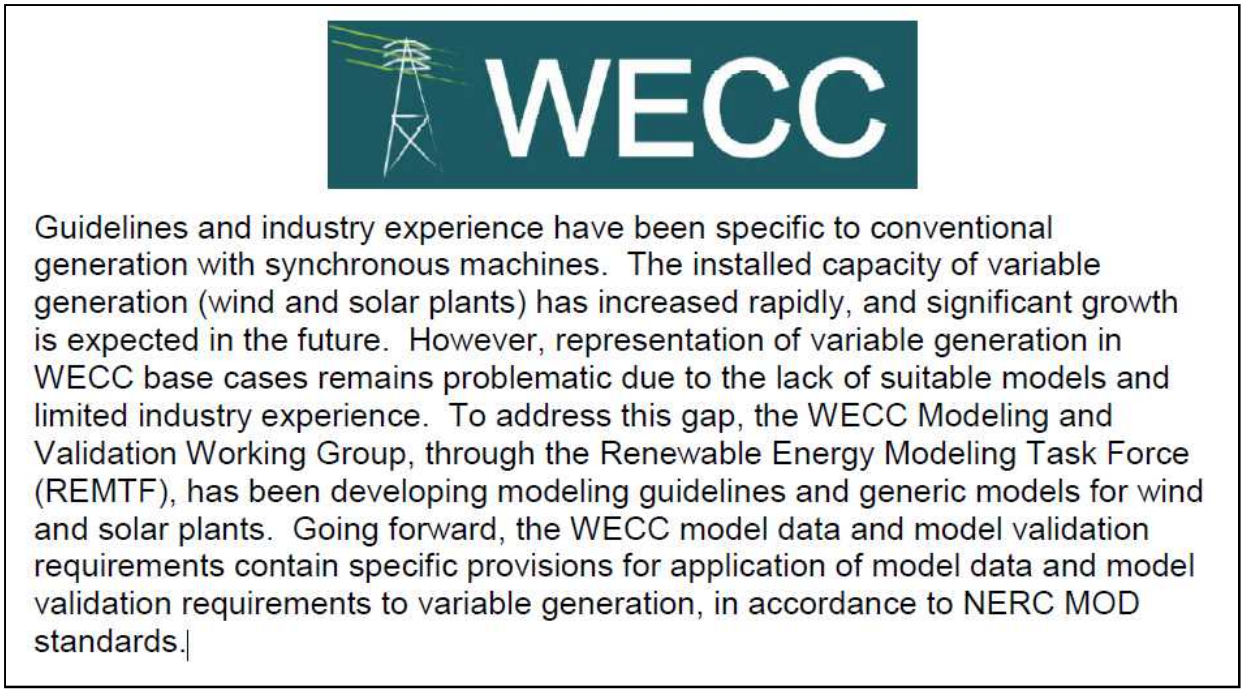
- NERC MOD standards related to generator models
  - MOD 10-15: Procedures, and requirements for power flow and dynamic models
  - MOD 25: Verification of P/Q capability
  - MOD 26/27: Verification of dynamic models

Ballot for MOD25 and MOD27 currently open through Oct. 29, 2012
**APPROVED!?**

- WECC recently adopted a Guideline that addresses NERC MOD requirements for generators
  - *Generator Facility Data, Testing and Model Validation Requirements* (Adopted in 2012)
  - Replaces/supplements several technical & procedural docs.
  - Makes specific references to wind/solar modeling (new!)

# Recent WECC Guidelines

- From the Background Section



WECC

Guidelines and industry experience have been specific to conventional generation with synchronous machines. The installed capacity of variable generation (wind and solar plants) has increased rapidly, and significant growth is expected in the future. However, representation of variable generation in WECC base cases remains problematic due to the lack of suitable models and limited industry experience. To address this gap, the WECC Modeling and Validation Working Group, through the Renewable Energy Modeling Task Force (REMTF), has been developing modeling guidelines and generic models for wind and solar plants. Going forward, the WECC model data and model validation requirements contain specific provisions for application of model data and model validation requirements to variable generation, in accordance to NERC MOD standards.

http://www.wecc.biz/committees/StandingCommittees/PCC/10102012/Approval Items/1/WECC Gen Fac Testing and Model Validation Rqmts v 7-13-2012.pdf (Type spaces)

# Recent WECC Guideline

- Appendix A: Periodic Model Validation
  - Every 5 years or after substantial change (NERC Project 2007-09 proposing a 10 year cycle for MOD 26/27)
  - Option 1: Validation using recordings taken at the Point of Interconnection of the generating facility
    - Staged tests or naturally-occurring disturbances
    - Approach could be suitable for wind & solar plants
  - Option 2: Validation using recordings taken at the generating unit
    - Full test to derive/measure generator and turbine model parameters, with unit out of service

# Recent WECC Guideline

- Appendix B: Baseline testing requirements for the purpose of model validation
- Upon plant commissioning or to establish validity of model for the first time
  - Items 1-5: Guidelines conventional generator, excitation system, PSS, OEL, turbine control
  - Item 6: Guideline for variable generation (VG) plants
    1. Baseline turbine/inverter type test (unit make/model)
    2. Baseline plant test (for plant-level controls)

# Recent WECC Guideline

- General guidelines for VG Baseline Type Testing
  - Baseline validation shall be against Reference Data
    - Reference Data can include factory test, field test, disturbance, simulated response from manufacturer-validated reference model
  - Voltage dip with residual voltage of 60% or lower
  - REMTF Comments Nov 2012
    - Clarify whether the “voltage” is positive sequence
    - Should balance detail versus over-specification. May be best to give an example of what we mean by “validation”
    - REMTF to collect comments for clarification

# Recent WECC Guideline

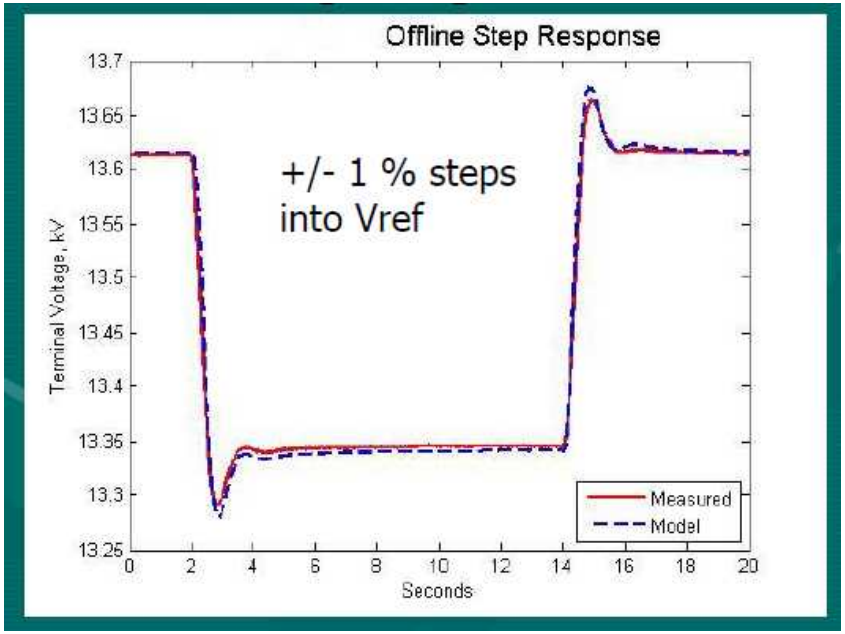
- General guidelines for VG Baseline Plant Testing
  - Plant volt/var response test can involve change in control set points, such as a change of volt/var reference, or staged capacitor/reactor switching
  - Include dynamic response (or lack thereof) to a frequency event
  - Include steady state active/reactive output range and control capability
  - Validation against measured data is also acceptable, provided that the disturbance is sufficiently large

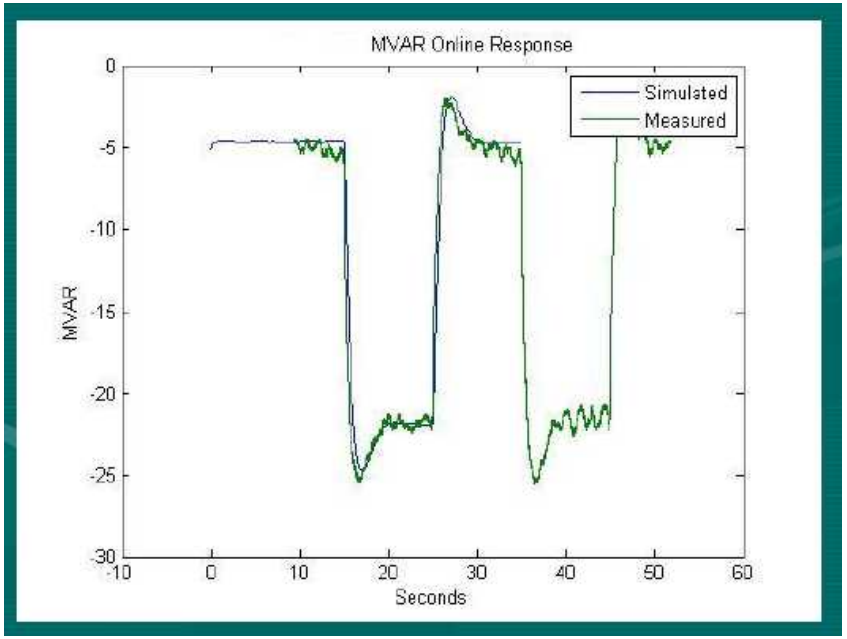
# Recent WECC Guideline

- Validation at partial output
  - *Evidence of validation should be provided for partial output (40% – 60% of MW rating) and near full output (>75% of MW rating).*
- Validation measure of success
  - *"The baseline validation should demonstrate a reasonable match between the WECC approved model and measured data with respect to reactive power response"*

# Recent WECC Guideline

- Successful model validation
  - Offline and controlled test typically produce good data and good isolation of specific controls

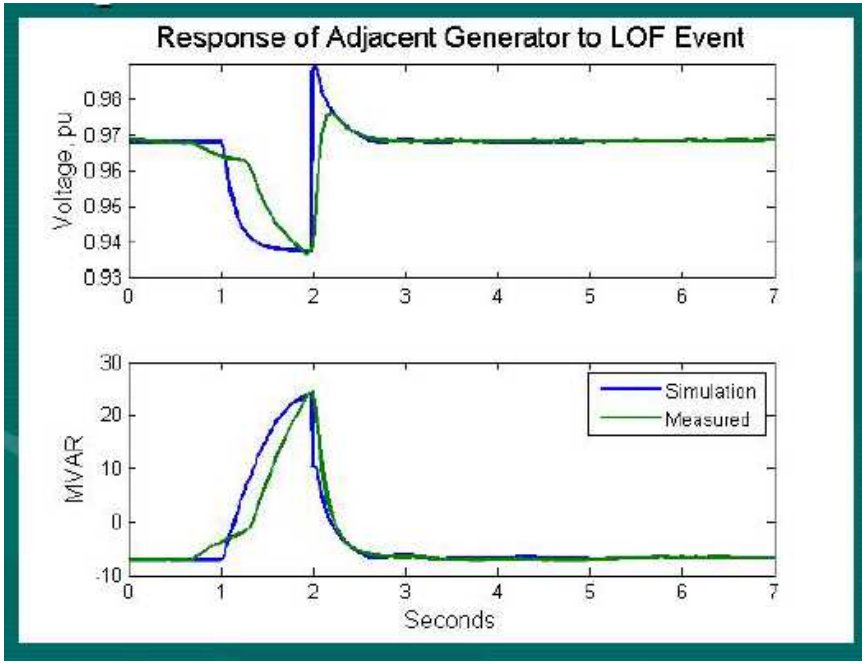


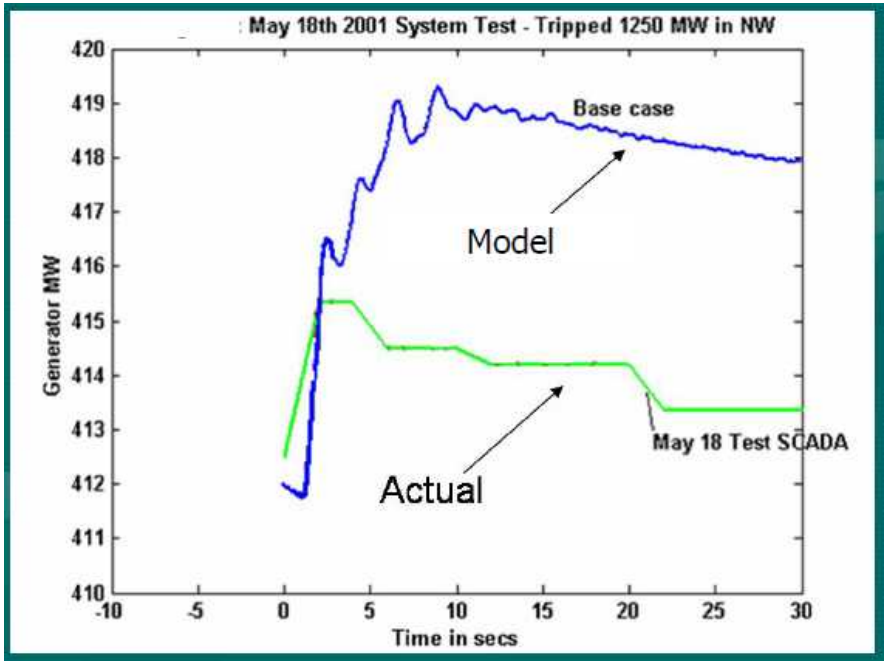




*S. Patterson, "WECC Model Validation Requirements, 2006*

# Recent WECC Guideline

- Successful model validation? Depends…
  - Harder to validate models against field disturbances
    - data quality issues, complex event, unbalanced conditions




*S. Patterson, "WECC Model Validation Requirements, 2006*

# Other Items

- Continuing coordination with IEC WG27 TF88 on wind modeling
- Short Circuit Modeling
- MVWG Modeling Workshop
- Demonstration of EPRI WT3/WT4 model validation tool

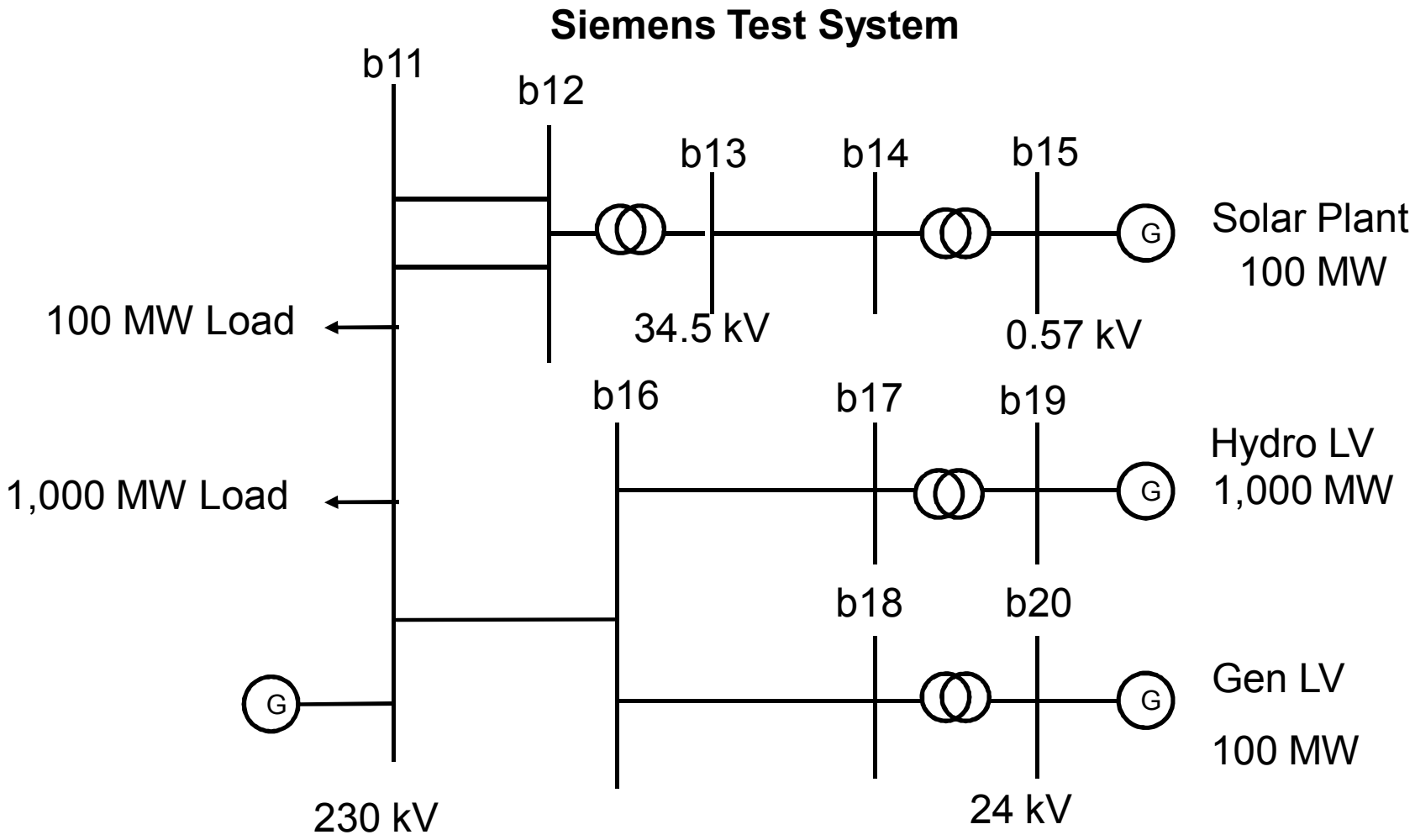
# Model Testing Slides

# TESTING ≠ VALIDATION

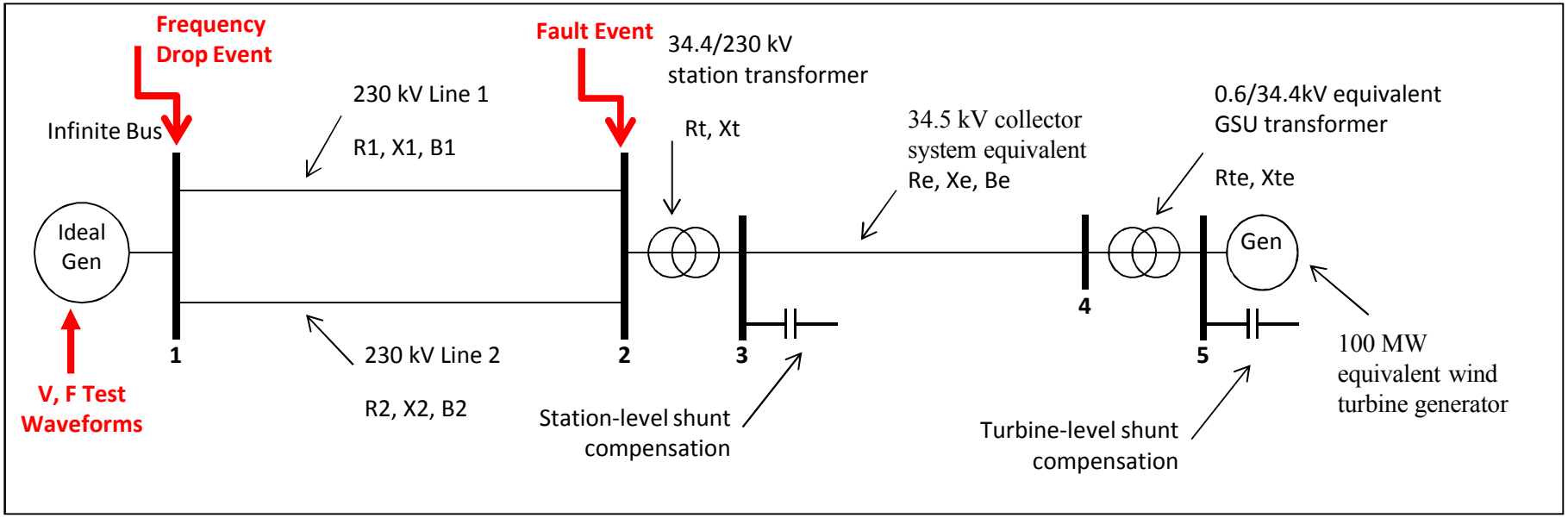
- Testing: Reconciliation of *model* response to *simulated* disturbance with expected *model* response to *simulated* disturbance according to model specifications

- Validation: Reconciliation of *model* response to *simulated* disturbance with actual *plant* response to *real-world* disturbance according to field and/or test data

# Generic Model Testing



# WGMG Model Test System




**Collector System Equivalent:**
Rt = 0.0, Xt = 0.1
Re = 0.015, Xe = 0.025, Be = 0.01
Rte = 0.0, Xte = 0.05

**Weak System (SCR = 10 at Bus 2):**
R1 = R2 = 0.020
X1 = X2 = 0.250
B1 = B2 = 0.05

**Strong System (SCR = 20 at Bus 2):**
R1 = R2 = 0.010
X1 = X2 = 0.100
B1 = B2 = 0.02

NOTE: All impedances in pu of 100 MVA base, kV as shown

# Dynamic Events for Model Testing

- Bolted 9-cycle, 3-phase fault at Bus 2 (POI.  Using weak system
  - With loss of one 230 kV line
  - Self-clearing
- Frequency Oscillation test applied at Bus 1
  - 0.3Hz, 0.5Hz, 1Hz, 2Hz, 3Hz at amplitude 0.1p.u.
- Frequency Ramp test applied at Bus 1
  - up 0.03Hz/sec or 0.05%/sec
- Voltage Ramp test applied at Bus 1
  - up 0.05p.u./sec or 5%/sec
- Frequency Step test applied at Bus 1
  - 0.3Hz per step or 0.05%/step
- Voltage Step test applied at Bus 1
  - 0.05p.u./step or 5%/step
- Pmech set (WT1)
  - 0.25p.u. per step
- Frequency drop test applied at Bus 1
  - 1% drop