Wind and Solar Power Plant Model Validation Using Test Data

Presented by:

Sam (Shengqiang) Li, M.Sc.,P. Eng.
Senior Engineer, Power System Studies

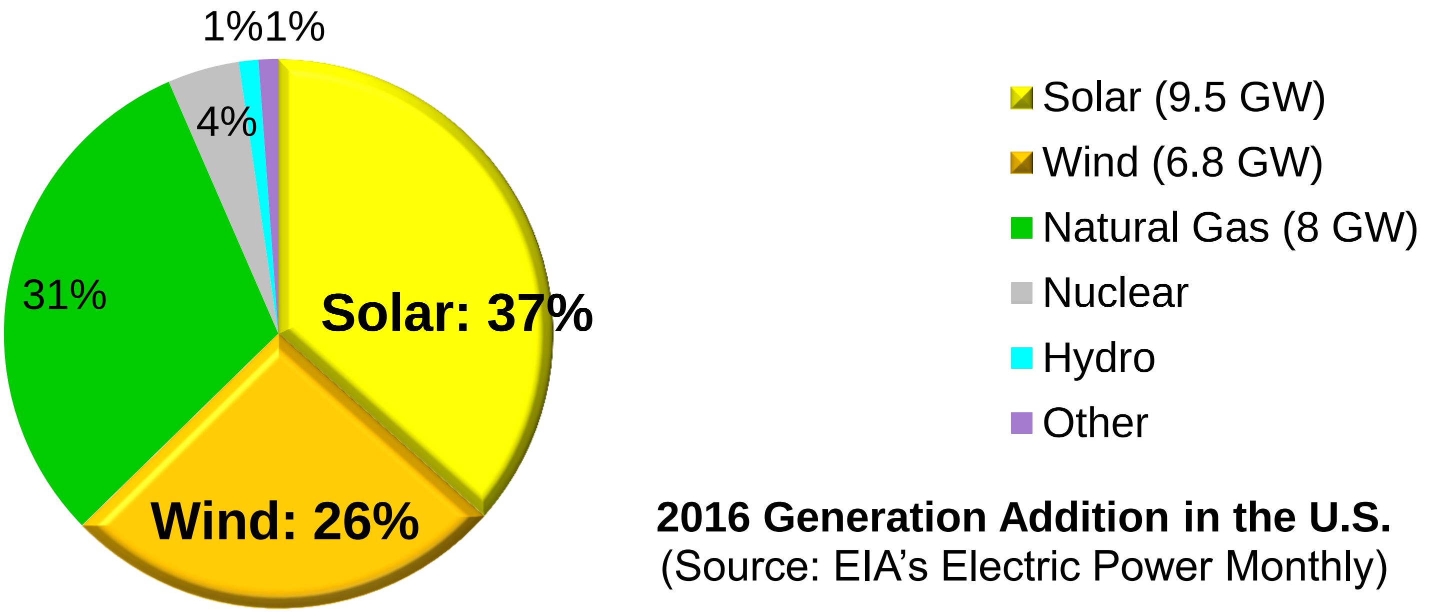
George Zheng, Ph.D., P.E., P. Eng.
Senior Engineer, Power System Software Technologies

Powertech Labs Inc.
12388-88th Avenue
Surrey, BC, Canada

Powertech

1. Background

- Wind and utility-scale PV represents a significant amount of generating capability in power systems, e.g. 10%~15%.
- Wind & solar are the fastest-growing generation source in the US.



2016 Generation Addition in the U.S.
(Source: EIA's Electric Power Monthly)

Why Does Wind/Solar Plant Model Need Verification?

- Having accurate models for wind/solar plants are therefore critical to simulation-based system planning and operation.

- NERC MOD-026/027 requires verifying voltage/VAr control and active power / frequency control model for applicable generating facilities including wind/solar farms**.**

- Using staged test data or disturbance recording is acceptable for NERC compliance model validation. Sources of data may include:
  - ✓ *PMU, DDR, PQM (Power Quality Meters)*
  - ✓ *built-in recorder in power plant controller*
  - ✓ *Portable data recorder*

Powertech Experience in NERC/WECC Compliance Model Valid.

Powertech Experience:

- ✓ *15+ years' experience in NERC/WECC-compliance generator testing and model validation.*
- ✓ *Tested 400+ generating units, with a total rating of 10+ GW.*
- ✓ *Tested 10+ renewable energy plants, including:*
  - *Wind farms (up to 200 MW)*
  - *PV solar farms (up to 500 MW)*
  - *Concentrating solar farms (up to 100 MW)*

Overview of Presentation

Objective:

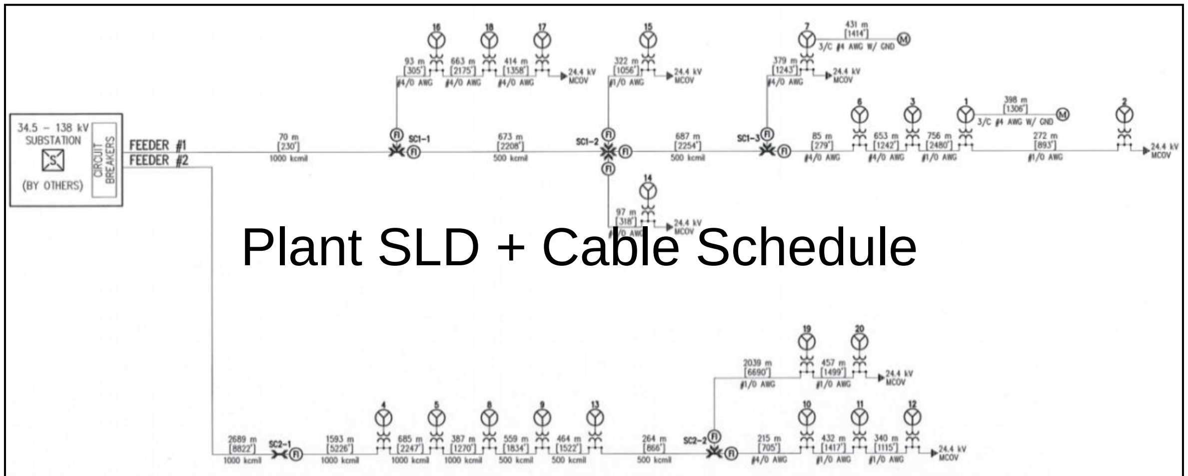
To share our experience using staged test data for wind/solar plant model validation demonstrated with examples.

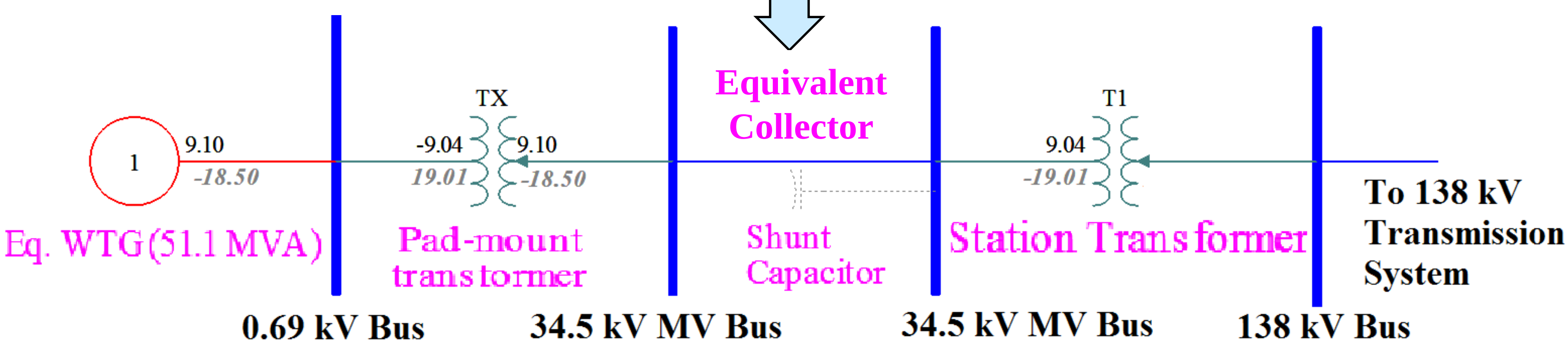
Outlines:

- ❑ Stability Models for Wind / Solar Farms
- ❑ Staged Tests and Model Validation
- ❑ Example Results
    - *Example A: a Type-4 Wind Farm*
    - *Example B: a PV Solar Farm*
- ❑ Summary and Lessons Learnt

2. Stability Model for Wind / Solar Farm

Powerflow Models:





Powertech

Dynamic Models for Wind/Solar Power Plants

Legacy Models

wt3g/wt3e/wt3t/wt3p
wt4g/wt4e

Proprietary Black-Box Model

GEWTG1/GEWTE1/GEWTT1…
GEWTG2/GEWTE2/GEWTT1…

Models still in use

2nd Generation Renewable Energy Model Package

Generator / Converter (REGCAU1)

Electrical Control (REECAU1/REECBU1)

Plant Controller (REPCAU1/REPCBU1)

Drive Train (WTDTAU1/WTARAU1 …)

Recommended By NERC / WECC

Sample Dynamic Data for Type-4 Wind Farm

############ **Generator / Converter Model**

regc_a 1001 "WTG Term" 0.69 "1 " : #9 mva=51.1 1   2.0   0.9   …..

############ **Electrical / Converter Control Model**

reec_a 1001 "WTG Term" 0.69 "1 " : #9   51.1 0.3 1.5 0 -0.05 0.05 0   1.05 ….

############ **Plant Controller Model (Normally not provided)**

repc_a 1001 "WTG Term" 0.69 "1 " 1007 "BusName" 34.50 ! ! 1008 " BusName" 34.50 20000 "BusName" 138.0 "T1 " 1 : #9 51.1 ……

############ **Turbine Drive Train Model**

wtgt_a 1001 "WTG Term" 0.69 "1 " : #9   51.1 4.876 0.424 1.00 0.2796   1…

############ **Over- and Under- Voltage Trip**

lhvrt 61543 "WTG Term" 0.69 "1 " : #9 1   -0.125 -0.15 ….

########### **Over- and Under- Frequency Trip**

lhfrt 61543 "WTG Term" 0.69 "1 " : #9 60   -3   2   0   …

Looking for preliminary parameters? – Ask the manufacturer, or Siemens PTI, or GE PSLF support group.

3. Staged Tests and Model Validation

Type Test
on a single WTG/ inverter
(Optional)

- **Against reference model**
- **Against Test Data**

Plant-level Testing

- **Using Event Recording**
  e.g. Voltage/frequency Excursion at POI
- **Using Staged Test Data**
  - Stepping plant volt/var set point,
  - Stepping plant freq set point,
  - Capacitor switching

Data requirement for model validation

Typical Data to be recorded:

- Voltage, active and reactive power at POI (PMU/DDR).
- Voltage, active and reactive power at Collector Bus (PMU/DDR).
- Number of WTGs/inverters online (SCADA).
- Shunt capacitor / GSU tap position status (SCADA).

Specifications:

- Ideally 30+ samples per seconds
- Trend for the entire transient period, i.e. up to a few minutes.

4. Example A: Type 4 wind farm

Basic Facts:

- 46 MW wind facility, 20 turbines (type-4), 2.3 MW each
- WTG output voltage 690 V, Collector Bus rated at 34.5 kV

Control System Settings:

- Volt / VAR Control Mode: Local Voltage Ctrl + **Plant Voltage Control**
- Line Drop Compensation: -4% on the plant MVA base
- Frequency Controller: 5% droop with 0.03 Hz dead band, responsive to over-frequency event only.

Additional VAR Support

- 6 MVA mechanically switched capacitor

Test A.1: Type Test on a Selected WTG

Test method:

Remove the selected WTG from the plant controller and apply a -4% step change in to the WTG's voltage command.

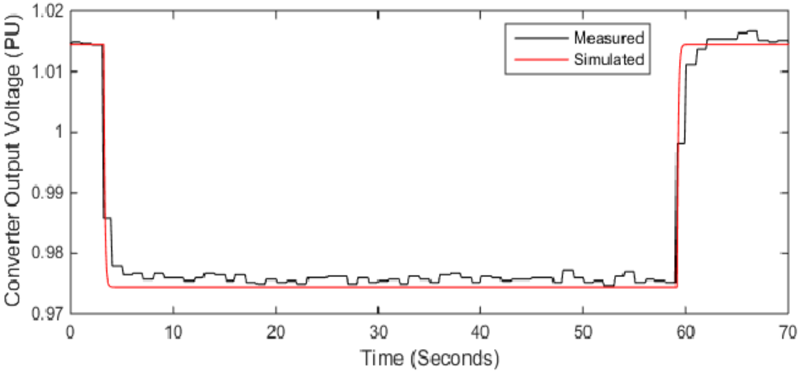
Parameters verified:

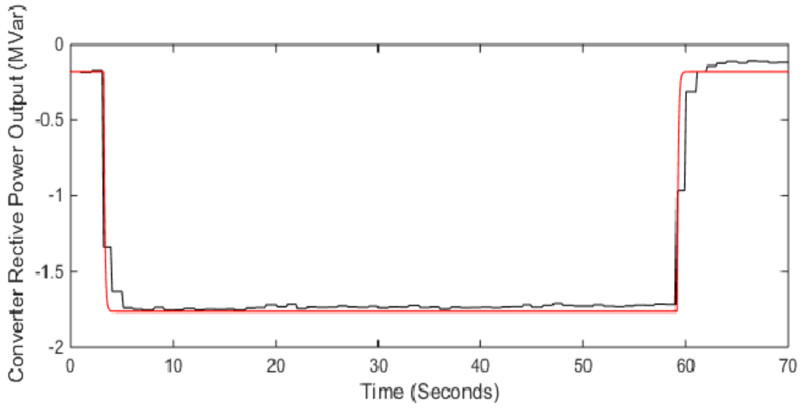
Electrical control model (reec_a):

Var/voltage control setting such as Kvp, Kvi,

Notes:

Voltage ramp limit must be temporarily disabled.





Powertech

Test A.2: Plant Controller Voltage Ref. Step Tests

Test Method:

Apply a 4% step change in to the plant voltage set point.

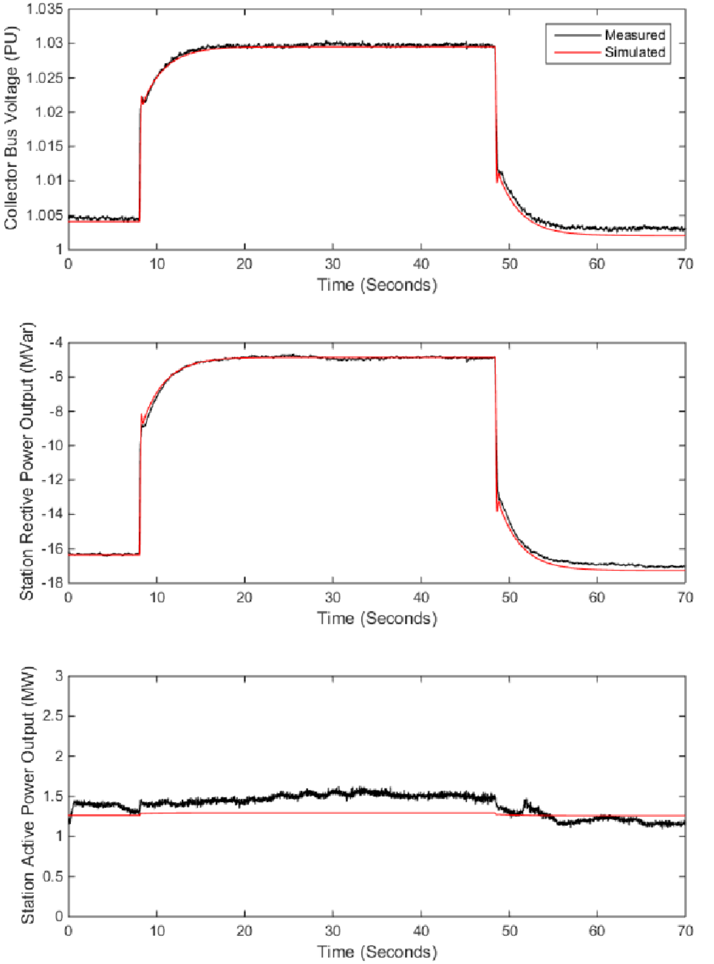
Parameters verified:

volt / var control settings in the electrical control and plant controller models.

- PI control setting: Kp, Ki
- Q / P.F. limit: Qmax/Qmin
- Reactive droop: Kc

Notes:

Voltage ramp limit must be temporarily disabled.



Powertech

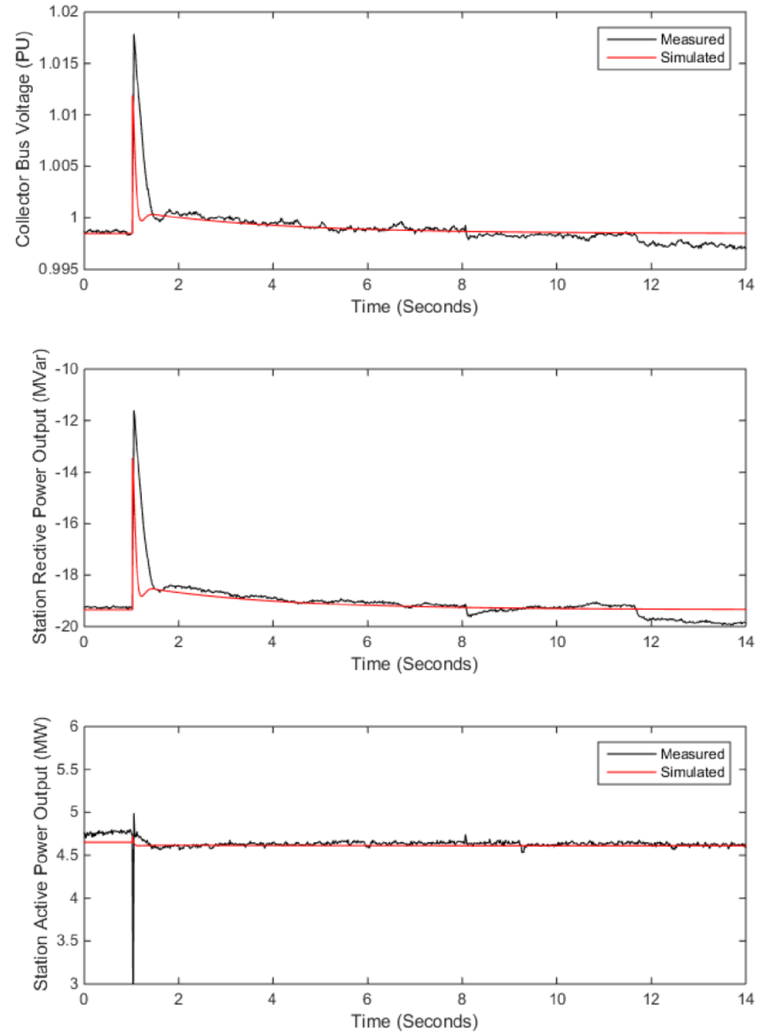
Test A.3: Capacitor Switching Test

Test Method:

Create a disturbance by switching on the 6-MVA capacitor, and record the dynamic response of the wind power plant.

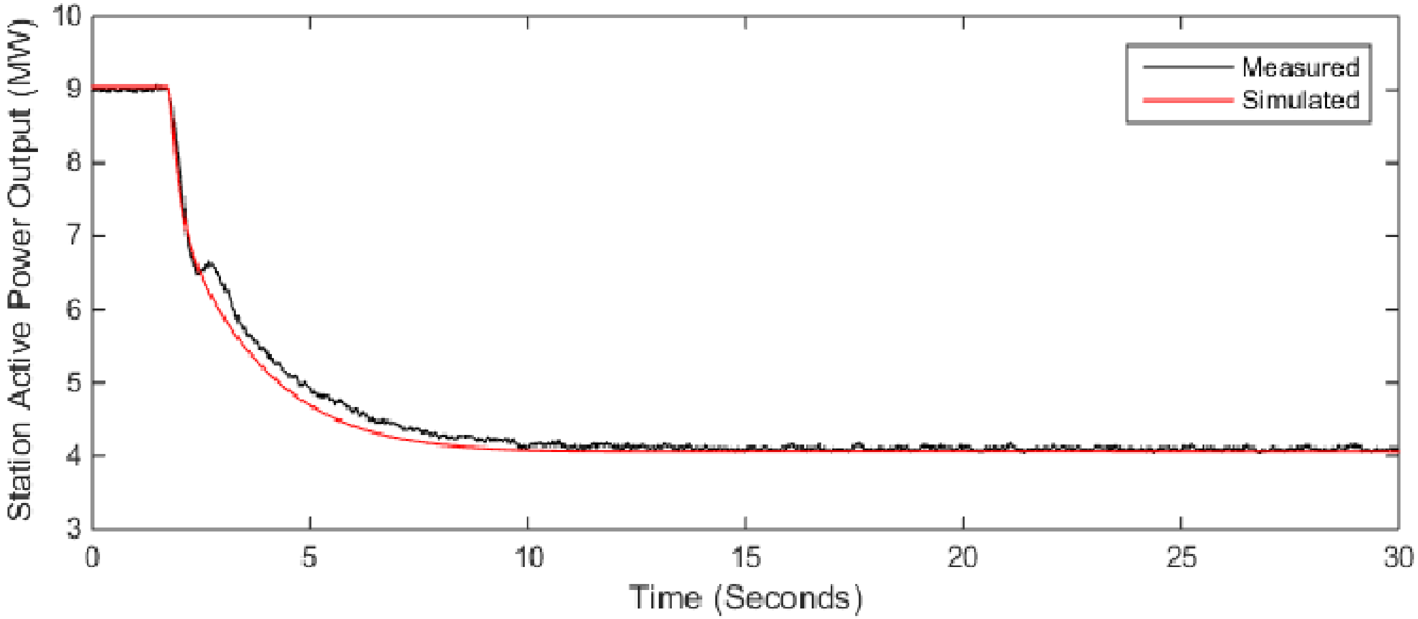
Parameters verified:

Verified overall volt / var controller settings with the entire model package.



Powertech

Test A.4: Frequency Step Response Test



Test Method:

Apply a bias of +0.3 Hz into the measured frequency, and record the subsequent active power change.

Parameters verified:

Droop and Active power controller setting (Kpg, Kig) in the plant controller.

Example B: PV Solar Farm (Quick Facts)

Basic Facts:

- 250 MW PV solar facility, 200+ photovoltaic inverters.
- Inverter output voltage 315 V, Collector Bus rated at 34.5 kV

Control System Settings:

- Volt / VAR Control Mode: **Local VAr Control** + **Plant P.F. Control**
- Line Drop Compensation: Not applicable
- Frequency Controller: 5% droop with 0.036 Hz dead band, responsive to over-frequency event only.

Additional VAR Support

- 2 x 18 MVA mechanically switched capacitor

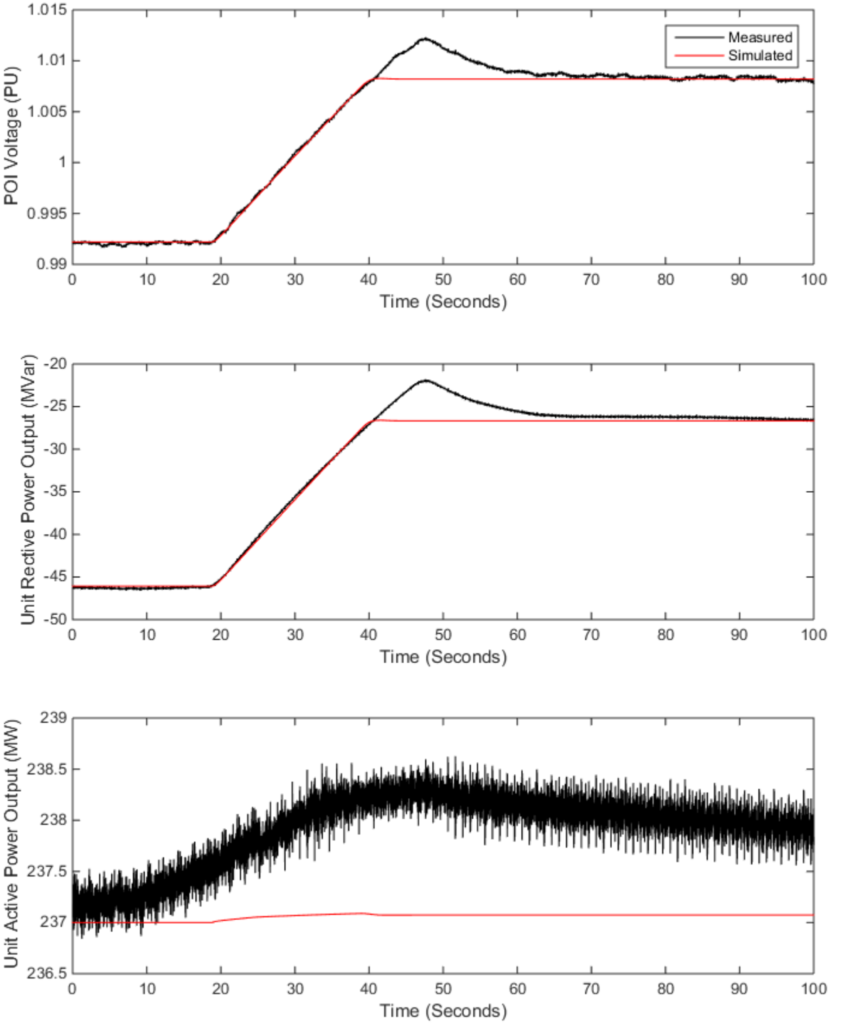
Test B.1: Plant Controller P.F. Step Tests

Test Method:

- Apply a 2% step change in to the plant P.F. set point.

Parameters verified:

Verified the P.F. / VAr control settings in the plant controller and electrical control model.



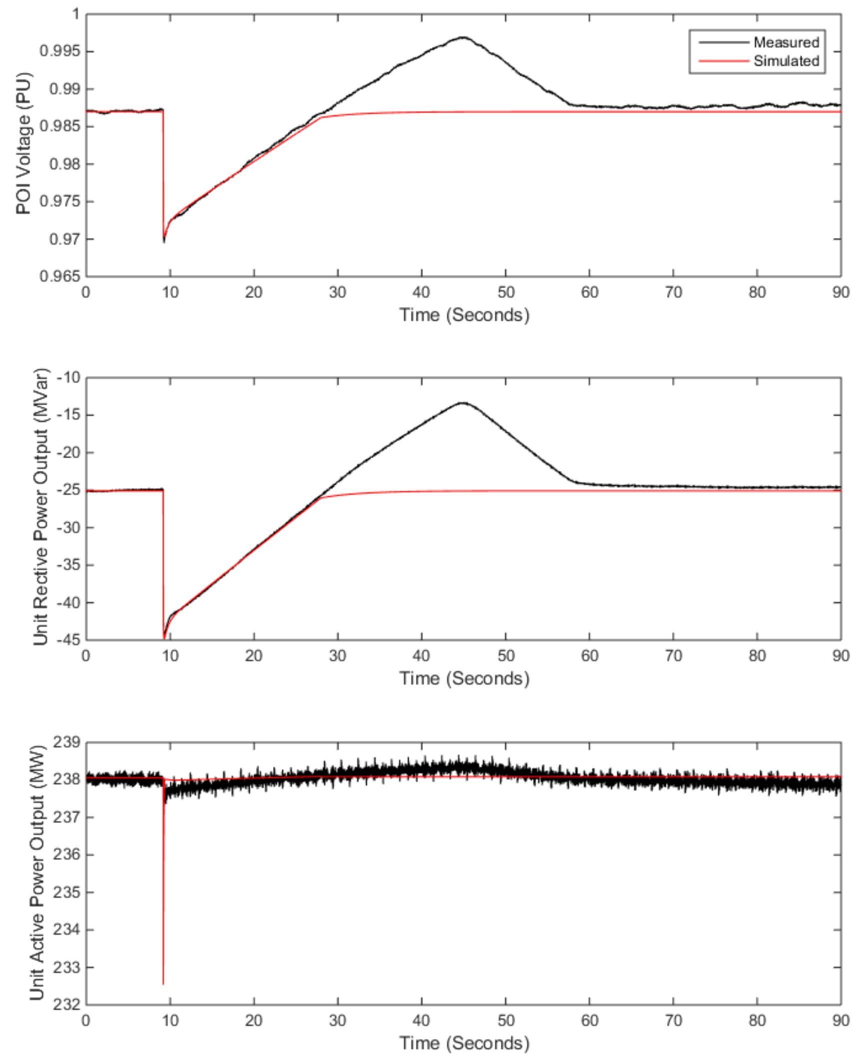
Test B.2: Capacitor Switching Test

Test Method:

Create a disturbance by switching off the 18-MVA capacitor, and record the dynamic response of the wind power plant.

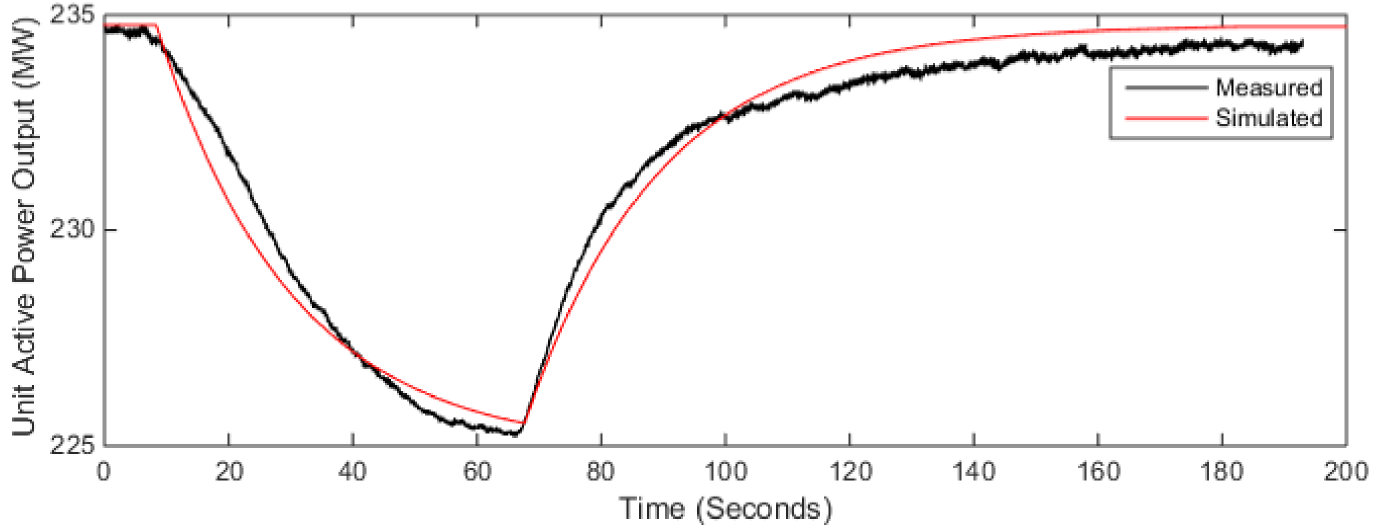
Parameters verified:

Verified the volt / var controller settings in the electrical control mode (reec_a) and plant controller.



Powertech

Test B.3: Frequency Step Response Test



Test Method:

Apply a bias of 0.15 Hz into the measured frequency, and record the subsequent active power change.

Parameters verified:

Freq. droop and plant MW control settings.

Powertech

5. Summary and Lessons Learnt

1. Staged test is a proven solution to validate model parameters for wind and solar power plants.
2. Model validation not only adds confidence to the dynamic model, but helps to improve / enhance the existing modeling practice.

   - *Example: Freq droop on P_{limit} v.s. P_{actual}*
3. Details in equipment and controllers are often unavailable; engineering judgement and reasonable assumption are required.
4. Some parameters in non-regular control loop, such as high/low voltage management parameters, are hard to verify unless large disturbances are available.
5. Wind/solar power is not dispatchable, so test data or system disturbances may not recorded at desired timing or load condition.