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
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 Validation

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)
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:

Plant SLD + Cable Schedule

Eq. WTG (51.1 MVA)

1 9.10 -18.50

Pad-mount transformer

0.69 kV Bus

34.5 kV MV Bus

Equivalent Collector

Shunt Capacitor

Station Transformer

34.5 kV MV Bus

138 kV Bus

To 138 kV Transmission System
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…

2nd Generation Renewable Energy Model Package
Generator / Converter (REGCAU1)
Electrical Control (REECAU1/REECBU1)
Plant Controller (REPCAU1/REPCBU1)
Drive Train (WTDTAU1/WTARAU1 …)

Models still in use

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" : #9 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.
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.
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.
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.
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.
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 $P_{\text{limit}}$ v.s. $P_{\text{actual}}$*

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.