Validation of Dynamic Model of Wind Power Plants

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Dynamic Model Verification

- Two basic types, based on the transient nature of the event
  - Fault event
  - Switching event

- Data
  - Monitored data at the wind power plant (event triggered)
    - High speed data (time, V, I, P, Q, F)
  - Network data
  - Preprocessed data

- Model Equivalencing

- Case Study: Taiban Mesa
Simplified single-line diagram of a wind power plant

- POI or connection to the grid
- Collector System Station
- Interconnection Transmission Line
- Feeders and Laterals (overhead and/or underground)
- Individual WTGs

National Renewable Energy Laboratory
The major components equivalent representations:

- The equivalent generator and associated power factor correction capacitors represents the total output of all the WTGs in the WPP.

- The equivalent generator step-up transformer (pad-mounted transformer) represents the aggregate effect of all WTG step-up transformers

- The equivalent collector system branch represents the aggregate effect of the WPP collector system.
Load Flow – Steady State Initialization

- Set the bus A voltage to match recorded prefault voltage at bus A.
- Adjust WTG’s $P_{gen}$ to match the initial $P_{measured} = P_{simulated} = 115$ MW at bus A.
- Adjust the regulated voltage $V_{reg}$ at bus C to match the initial $Q_{measured} = Q_{simulated} = 23$ MVAR at bus A.

Station Transformer

$A$

Transmission Station

Collector System Equivalent

$C$

Req = 0.0135

Xes = j0.0497

Beq = j0.1004

Pad-mounted Transformer Equivalent

$B$

WTG Terminals

$W$

Wind Turbine Generator Equivalent

$R = 0.014$

$X = j0.0828$

$R = 0.0027$

$X = j0.0245$
• Nature of the event: Fault event - single line to ground – 9 cycles

• 136 turbines – 204 MW rated

• V, I, recorded, P, Q, computed

• Method used: replay the voltage recorded and compare the PQ output

• Comparison of P, Q plots (recorded versus simulation data)

• Comparison: Measurement, Multiple Turbine Representation, Complete Model.

Real and reactive power measured at the POI.
Event Representation

(Type 3 Wind Turbine Generator)

91% WTGs stay "on" after the fault.

9% WTGs were dropped off line during the fault.

Complete Representation (136 turbines)

136 WTGs were represented

9% WTGs were dropped off line during the fault.
Reactive Power Control for Type 3 WTG

\[ \frac{1}{1 + sT_r} \]

\[ \frac{1}{1 + sT_c} \]

\[ \frac{1}{1 + sT_p} \]

\[ \tan \]

\[ K_{iq} / s \]

\[ K_{qv} / s \]

\[ Q_{gen} \]

\[ Q_{cmd} \]

\[ V_{max} \]

\[ V_{min} \]

\[ V_{ref} \]

\[ V_{term} + XI_{Q_{max}} \]

\[ V_{term} + XI_{Q_{min}} \]

\[ E_{q cmd} \]

\[ Q_{ref} \]

\[ Q_{ord} \]

\[ Q_{max} \]

\[ Q_{min} \]

\[ varflg = 1 \]

\[ vltflg = 1 \]

\[ P_{gen} \]

\[ varflg \]

\[ vltflg \]

Wind Plant Reactive Power Control Emulation

[Diagram of the reactive power control system for Type 3 WTG]
Sample of the Recorded Fault Data

(Instantaneous Voltage during fault event)

Instantaneous Voltage

Voltage and Phase Angle

FAULT
Data Conversion Process

\[
\begin{bmatrix}
f_{qs} \\
f_{ds} \\
f_{os}
\end{bmatrix} = \begin{bmatrix}
2 & -1 & 1 \\
3 & -3 & 3 \\
0 & -1 & 1
\end{bmatrix} \begin{bmatrix}
f_{as} \\
f_{bs} \\
f_{cs}
\end{bmatrix}
\]

\[V_{qde} = \sqrt{V_{qe}^2 + V_{de}^2} \angle \theta_{qde}\]

\[\theta_{qde} = \text{atan}^{-1}\left(\frac{V_{de}}{V_{qe}}\right)\]

\[
\begin{bmatrix}
f_{qe} \\
f_{de} \\
f_{os}
\end{bmatrix} = \begin{bmatrix}
\cos(\omega_c t + \theta_c) & -\sin(\omega_c t + \theta_c) & 1 \\
\sin(\omega_c t + \theta_c) & \cos(\omega_c t + \theta_c) & 1 \\
0 & 0 & 1
\end{bmatrix}\begin{bmatrix}
f_{qs} \\
f_{ds} \\
f_{os}
\end{bmatrix}
\]

\[|V|; f\]

\[\text{LPF}\]

\[\text{|V| input}\]

\[f\text{ input}\]
Voltage and frequency used as input to drive the simulation
Validation Technique

Compare P&Q measured to P&Q simulated
V and f

System Generator

A

Wind Turbine Generator Equivalent

B

Regulated Bus

C

Input

V and f
Voltages at different WTGs in per unit.
Conclusions

• This paper presents the methods to validate positive-sequence wind dynamic models. This technique was applied to the WECC generic model as an example.

• The validation method described in this paper is applicable for all the four types of wind turbine generators.

• The preliminary results of the simulations demonstrated that a generic model of DFIG generators provides an adequate representation of the actual wind turbines under fault conditions.

• It is also shown that modeling the wind power plant with an equivalent representation preserves the basic response of the wind power plant.