Current Contributions from Type 3 and Type 4 Wind Turbine Generators During Faults

Bruce English
Reigh Walling
Ekrem Gursoy
GE Energy
Background

• **Short-circuit analysis is important to:**
  – Protection coordination
  – Assessment of fault-current withstand requirements

• **Industry’s short-circuit analysis practices and tools based on synchronous generators**
  – Positive sequence represented by an ideal voltage source behind reactance
  – Negative sequence by a simple constant reactance

• **Modern wind turbines use variable-speed generators**
  – Doubly-fed asynch. generators (DFAG, aka DFIG) – **Type 3**
  – Full ac-dc-ac conversion – **Type 4**
  – Neither is adequately represented by conventional model
Full Conversion (Type 4) Wind Turbine

- All power output coupled via an ac-dc-ac frequency converter
- Generator frequency can vary as desired
- Generator can be:
  - Permanent magnet synchronous
  - Excited synchronous
  - Induction
Operational Behavior of Type 4 WTG

- Voltage-source converter (VSC) is controlled to regulate current
  - Current regulator has high bandwidth
  - Essential to protect sensitive IGBTs
  - Type 4 WTG is thus a virtual current source

- Real and reactive output current can be independently controlled

- Grid performance virtually independent from characteristics of physical generator
Type 3 (DFAG) Wind Turbine Generators

- Rotor connected to stator via an ac-dc-ac frequency converter
- Converter applies an “ac excitation” to three-phase wound rotor
DFAG Speed Variation Examples

Operation at 66.6% of synch. speed

- 800 rpm
- 20 Hz +Rotation

20Hz x 60 x 2 / 6 poles = 400 rpm eff. rotational speed of rotor field w.r.t. rotor

Operation at 100% of synch. speed

- 1200 rpm
- 0 Hz (DC)

Operation at 133.3% of synch. speed

- 1600 rpm
- 20 Hz -Rotation

20Hz x 60 x 2 / 6 poles = 400 rpm eff. rotational speed of rotor field w.r.t. rotor
What Really is a Doubly-Fed Generator?

• **Physically** – the machine resembles an induction generator

• **Conceptually** – it is like a variable speed, “synchronous” generator with bus-fed excitation

• **Functionally** – it tends to operate more like a current-regulated electronic converter
  – Laminated rotor allows high bandwidth regulation of real and reactive current output

*It is not just a type of “induction generator”; operationally, there is little in common with an induction generator*
Fault Behavior

Design objectives:
• Protect the WTG equipment
• Ride through the fault
• Provide grid support, as required

Comparison with synchronous generators:
• Synchronous generator fault performance established by fundamental physics
  – Little qualitative difference from one generator to another
  – One model structure applies to all
• Type 3 and 4 wind turbine fault performance governed by control design
  – Wide variations in control techniques
  – Voltage behind reactance does not work well as a model
Type 4 WTG Short Circuit Current

- Initial transient current – ~ 2 p.u. symmetrical
- Current regulator quickly takes control
- Current order increased for grid support in this design

3-ph. Fault to 20% Voltage
Type 3 WTG Short Circuit Current

- Initially, rotor circuit is “crowbarred” – acts like an induction generator – symmetrical current up to ~ 4 p.u.
- As fault current decreases, crowbar is removed
- Current regulator regains control
DFAG Crowbar Protection

• Severe fault induces high voltage on rotor
• Some form of “crowbar” needed to divert induced current
  – Chopper on dc bus
  – Shorting device on rotor circuit
  – Bypass through converter bridge
• Results in highly discontinuous fault behavior
  – Substantial complication of short-circuit modeling
• Crowbar initiation and removal thresholds vary with design
Unbalanced Faults

• Necessary to limit current magnitude of each IGBT in bridge
  – Positive and negative sequence behavior is not decoupled as in a synchronous generator
  – Simple sequence component-based analysis cannot be accurate

• Active limitation of negative sequence current commonly used in both Type 3 and Type 4
  – Negative sequence “bucking” may be nonlinear
  – Negative sequence does not appear like a passive impedance
Modeling WTGs in Short Circuit Studies

Alternative #1: approximate modeling

• Type 3
  – Model as a voltage source behind subtransient reactance
  – Provides upper limit to short-circuit current
• Type 4
  – Model as a current-limited source
  – Current magnitude 2 – 3 p.u. for first 1 – 2 cycles
  – Longer-term current could be from pre-fault value to ~1.5 p.u., depending on control

Approximate models are quite inexact, but may be good enough because WTG contribution to grid fault current is usually much smaller than total

Inadequate where wind plant current contribution is dominant, and accuracy is important
Modeling WTGs in Short Circuit Studies

Alternative #2: detailed time-domain simulations

- Performed in an EMT-type program (EMTP, ATP, PSCAD, etc.)
- Requires detailed hardware and control model
  - Such data are usually considered quite proprietary
  - “Generic” models are quite meaningless
- Not well suited for large system studies
- Requires an expertise different from that of most short-circuit program users
- Considerable computational effort for each case

*Technically superior alternative, but generally quite impractical.*
Modeling WTGs in Short Circuit Studies

Alternative #3: modified phasor approach

- Wind turbine manufacturer provides tables or graphs of current versus residual fault voltage for certain times
- Network short circuit analysis solved iteratively

Most feasible option at this time; short circuit software needs to be modified
Contrast to Using Standard Approach

Solid Line: Type 3 WTG upper/lower current limits
Dashed Line: Voltage source behind constant reactance
Contrast to Using Standard Approach

Solid Line: Type 3 WTG upper/lower current limits

Dashed Line: Voltage source behind constant reactance
Conclusions

• Type 3 and 4 wind turbine generators have complex short-circuit characteristics

• Approximate modeling using existing tools may often suffice due to low-level contribution

• More precise modeling is not supported by conventional short-circuit tools and practices

• Modified phasor approach described in this paper can provide reasonable accuracy with modest changes to software to support iterative analysis
Thank You!