ECE 529
Utility Applications of Power Electronics

Session 32
Grid Codes and Wind Turbines

- 1990s – Wind Turbines were required to disconnect from Grid during faults
  - Induction Generators consume VARs
  - Worsen voltage sags during faults
  - More time needed to recover
- 2010s – Wind turbines need to stay connected and support the Grid during faults
  - Better Power electronic control can supply VARs
  - Islanding is discouraged in current standards

Low Voltage Ride Through

Wind Turbine Types

Type 1

- SCIG (Squirrel Cage Induction Generator) tied to a Wind Turbine
- No variable speed control
- Capacitor banks required for reactive compensation
- Generates power only near rated wind speeds
Wind Turbine Types

Type 2

- SCIG tied to a Wind Turbine
- Narrow range of variable speed generation due to rotor resistance control
- Capacitor banks required for Reactive compensation

---

Wind Turbine Types

Type 3

- Doubly Fed Induction Generator (DFIG) tied to a Wind Turbine
- +/- 30% variable wind speed operation
- Back-to-back VSCs – rated at 30%
- Power extracted from Rotor and stator in Super-sync mode
Wind Turbine Types

Type 4

- Synchronous Generator tied to a Wind Turbine via back-to-back VSCs
- Can generate power for very low wind speeds

Controller Design

Grid side Controller

- Exports the power generated by Rotor at Super-synchronous speeds
- Imports power for the Rotor at Sub-synchronous speeds
- Tracking the System frequency very important
- Implemented using Phase locked loop
Controller Design
Grid side Controller

- Artificially excites Rotor at lower wind speeds by increasing the current to get the same flux linkage
- Extracts power from Rotor at super-synchronous wind speeds
- Needs to know rotor current frequency at all times
- Needs to regulate the Rotor current for maximum power point tracking

- How much detail on prime mover?
Assumptions

Type 3 Turbine

Controller Design
DC Voltage Regulator

- Many implementations – Here, it is a PI controller
- Regulates the DC voltage
- Regulates the power imported/exported by the Grid side controller based on requirements of the Rotor side.
Controller Design \textit{ECE529}

Phase Locked Loop (Stator) \textit{Lecture 32}

- \textit{slip} = \frac{N_2 - N_L}{N_s}

- Slip \rightarrow \text{Difference in Speed w.r.t. Synchronous Speed}

- Slip \propto \text{Rotor Current Frequency}

- Track Rotor speed \rightarrow \text{Calculate the slip and hence the frequency of the Rotor current}
Model Validation
Torque-Speed Characteristics

Characteristics are similar to a conventional Induction Machine
Library Machine Model is valid

Model Validation
Operational Characteristics

Operational Characteristics are similar to the Type 3 based Wind Turbines
Below rated Wind Speed: Prot < 0, Pstat > 0
Above rated Wind Speed: Prot > 0, Pstat > 0
Type 4 Wind Turbine

\[ \text{Pout} = V_{dc} I_{inj} \]

Ave. Conv Model - V_{dc} Bus Volt-reg
**AVERAGED NON-SWITCHING MODEL OF GRID CONVERTER**

- Based on sine-triangle PWM, describe converter dynamics as a function of the modulating signal.
- Reduces the complexity in dealing with switch models.

\[ n(t) = 2d(t) - 1 \]
\[ i_p = m(t) \cdot \frac{V_{ac}}{2} \]
\[ i_n = \frac{(1 + m(t))}{2} \cdot i \]
\[ i_n = \frac{(1 - m(t))}{2} \cdot i \]

- \( n(t) \) — Modulating signal
- \( d(t) \) — Duty ratio
- \( V_{ac} \) — Voltage across DC link
- \( i_p \) — Current in the positive leg of converter
- \( i_n \) — Current in the negative leg of converter

**DESIGN OF GRID CONVERTER CONTROLS**

*电网转换器控制设计*

**Gate Signals**

**PMU GENERATOR**

**Inner Current Controller**

**DC Bus Voltage Controller**

**DC Voltage Droop Controller**

**Grid-Side VSC**

**Reactive Power Reference Generator**

**Current Limiting Mode Controller**

**PCC**

**PCC**

**Spring 2021**
NORMAL CONDITION

CONVERTER RESPONSE TO UNBALANCED FAULT – AG FAULT