Power electronic topologies for wind turbines

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Source: ALSTOM WIND
Presentation of the wind systems: large numbers

☑ Annual offshore wind installation (2011)

![Diagram showing installed capacity by country at end of 2011.]

- **Size evolution of wind turbines over time**

![Diagram showing size evolution of wind turbines.]

Source: EWEA
General wind farm layout

Wind farm elements:
- Wind turbines (WT). WT connected in parallel to radials.
- Local wind turbine grid.
- Collecting point. To increase the voltage for transmission.
- Transmission system. HVAC or HVDC transmission.
- Wind farm interface. To adapt the voltage, frequency and the reactive power demand of the grid in the PCC.
- Point of common connection.
Fixed and variable speed wind turbines

Wind Turbine configurations

a) Wind turbine using an induction generation (IG).

b) Wind turbine using a doubly-fed induction generator (DFIG).

c) Wind turbine using a permanent magnet synchronous generator (PMSG).
Wind Turbine configurations

- The electrical generator is connected directly to the grid.
- An induction generator is normally used.
- Since the grid frequency is fixed, the speed of the wind turbine is settled by the ratio of the gearbox and by the number of poles in the generator.

\[ n = \frac{60 \cdot f}{\rho} \]
Fixed-speed wind turbines

Induction generator operating at fixed speed

Advantages:
- Robust design.
- No need for maintenance.
- Well enclosed.
- Produced in large series.
- Low price.
- Can withstand overloads.

Disadvantages:
- Uncontrollable reactive power consumption.
- Fixed speed means more mechanical stress.

Source: AEROSTAR
Capacitor banks

- Capacitors banks compensate for reactive power from the induction generator.
- Maxim use of the electrical grid is done operating at unity power factor.
If you connected (or disconnected) a large wind turbine generator to the grid with a normal switch, you would be quite likely to damage both the generator and the gearbox. Also large currents in the neighborhood grid would be produced.

To prevent this situation, wind turbines connect and disconnect gradually to the grid using thyristors.

To avoid thyristor losses under normal operation mode, a bypass switch is activated (main contactor).
Variable-speed wind turbines

- Doubly-fed induction generator

- A frequency converter control the currents in the rotor.
- The slip of the rotor can change within a wider range.
- Power converters have to stand only a fraction the nominal power (20% or 30%).
- It is the most common topology produced by large manufacturers nowadays.
- Less expensive compared to the full power converter.

Source: ALSTOM WIND
Multipole synchronous generators may not need a gearbox (these generators have a large diameter).

This is expected to be the most common wind turbine configuration in the future.
Variable-speed wind turbines

**Variable speed**

The frequency of the generator voltages can be different from the electrical grid (50-60 Hz) and therefore the turbine speed can change.

**Advantages:**
- More energy production.
- Less mechanical stress.
- Reduce power fluctuation.
- Capacity of noise reduction.
- May have more control on the grid currents.

**Drawbacks:**
- The system requires power electronic converters.
- More expensive.
Variable-speed wind turbines

- Wind turbine components
Permanent magnet synchronous generator

Variable-speed wind turbines
Wind Turbine Modeling

Variation of Power coefficient $C_p$ with Tip Speed Ratio

(for fixed values of $\beta$)

$$C_p = \frac{P_{\text{mechanical}}}{P_{\text{wind}}}$$

![Graph showing variation of $C_p$ with Tip Speed Ratio for different values of $\beta$.]

$C_{p\text{max}} = 0.48$

$\lambda_{\text{opt}} = 8.1$
Area of different control operation

Control regions for the WT

- **First interval**: variable speed and fixed pitch
- **Second interval**: variable speed and variable pitch
- **Third interval**: fixed speed and variable pitch
Power electronic Semiconductors

Power Electronic Converter topologies of a wind turbine

- Back-to-back-connected conventional two-level

**AC/DC/AC**

![Diagram of AC/DC/AC converter topology](image)

- The maximum voltage that the transistors have to withstand is the total dc-link voltage ($V_{dc}$).
- Low quality output voltage spectra. This implies large values of the reactive components to filter the output currents.
The modulation stage in a power electronic converter is responsible for defining the state of the switches from continuous (or sampled) control variables.
Modulation Strategies

Half-Bridge Inverter

To avoid shortcircuits, only one transistor is activated at any time.

The control functions define the state of the transistors. They can take two values \( s_a = \{0, 1\} \) meaning “0”=off and “1”=on.
Modulation Strategies

- If the upper switch is activated (ON state), the output voltage becomes $v_{a0} = \frac{V_{dc}}{2}$ independently of the current direction.

The upper transistor carries the output current

The upper diode carries the output current
If the lower switch is activated (ON state), the output voltage becomes $v_{a0} = -\frac{V_{dc}}{2}$ independently of the current direction.

The lower transistor carries the output current

The lower diode carries the output current
Remarks

- Only one transistor from the leg can be activated at any time (ON state).
- The transistor activated defines the output voltage level, independently of the output current direction.
- Only two voltage levels can be obtained at the output ($v_{a0} = \pm V_{dc}/2$).
- If sinusoidal waveforms are needed, the output variable (voltage and/or current) has to be filtered.
- The switching process is crucial (calculation of the ON and OFF times) to achieve a good output voltage spectrum which can be easily filtered. This process is determined by the modulation strategy.
Sinusoidal PWM (SPWM)

Modulation signal (sinusoidal):

\[ v_s(t) = V_{SM} \sin \omega_s t \]

Transistors control:

- If \( v_s \geq v_T \) \( \rightarrow T_a \) ON \( \rightarrow v = v_{a0} = + \frac{V_{dc}}{2} \)
- If \( v_s < v_T \) \( \rightarrow T_a' \) ON \( \rightarrow v = v_{a0} = - \frac{V_{dc}}{2} \)
- Back-to-back-connected conventional three-level

**AC/DC/AC**

- The transistors have to withstand only half of the total dc-link voltage ($V_{dc}/2$).
- The output voltage spectra have better quality.
- More switching frequency in the power devices
Three-level or neutral-point-clamped (NPC) converter

Two consecutive switches must be in on-state
Sinusoidal pulse-width modulation (SPWM)

- It is based on comparing sinusoidal modulation signals with a triangular carrier of significantly larger frequency.

Control applied to define the state of the output voltages:

- Reference above both carriers → High level output (1).
- Reference between both carriers → Medium level output (0).
- Reference below both carriers → Low level output (-1).
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Simulation Results

- Wye-connected load
  - $R = 1 \, \Omega$ and $L = 2 \, \text{mH}$.
  - $C = 2200 \, \mu\text{F}$
  - $V_{dc} = 1800 \, \text{V}$
  - $f = 50 \, \text{Hz}$