Mechanical torque is modelled using a sinusoidal variation
\[ T_{MECH} = T_a + T_0 \sin(2\theta) \] (2 bladed rotor)

Electrical torque control is parameterised by
\[ q = \frac{T_{ELEC}}{T_{MECH}} \]

Torque control strategies can vary between two extremes:
\[ q = 0 \] (fixed electrical torque) and \[ q = 1 \] (fixed rotor speed)

Depending on the strategy, there can be a torque imbalance between \( T_{MECH} \) and \( T_{ELEC} \) resulting in a changing rotor speed:
\[ T_{MECH} - T_{ELEC} = f\alpha \]

The variance in electrical torque and/or rotor speed will effect the copper and iron losses experienced by the generator

Copper Losses:
\[ P_{Cu} = R \left( I^2 + \frac{1}{2} (qI\Delta) \right)^2 \]
\[ P_{Fe} = \sum \left( A_{h}I_r^2 + A_{d}I_r^2 \right) B_{ref}^2 m_i \]
Both \( f_r \) & \( f_s^2 \) proportional to \((1 - q)\)

Iron Losses:
\[ \propto q^2 \]

Generator cost depends on peak electrical torque loading

Generator Case Study for Large Offshore VAWT
Generator is 5MW DD PMG for use in offshore H-rotor VAWT, see paper for specs

 knocks vary for different torque factor \( q \) settings.

Iron losses decrease linearly with \( q \)

At this speed losses are of similar magnitude

For 9m/s Losses minimised at \( q=0.4 \)

Generator Cost depends on peak electrical torque loading

Comparing how losses vary for different torque factor \( q \) settings.

Copper losses increase with \( q^2 \)

Iron losses decrease linearly with \( q \)

At this speed losses are of similar magnitude

For 9m/s Losses minimised at \( q=0.4 \)

Peak Electrical Torque Loading

Future research: aerodynamic efficiency from speed variation (potential loss at low \( q \), limited effect due to large rotor inertia); rescaling the generator (smaller generator with limit on \( q \) at rated)

PhD Overall Aim: optimise the VAWT powertrain design to minimise Cost of Energy & compare with commercial HAWTs

Vertical Axis Wind Turbine Case Study: Costs and Losses associated with Variable Torque and Speed Strategies

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