

Strathprints Institutional Repository

Argent, Michael and McDonald, Alasdair (2016) Vertical axis wind turbine case study : costs and losses associated with variable torque and speed strategies. In: IET Renewable Power Generation Conference 2016, 2016-09-21 - 2016-09-23, IET London: Savoy Place.

This version is available at http://strathprints.strath.ac.uk/59781/

Strathprints is designed to allow users to access the research output of the University of Strathclyde. Unless otherwise explicitly stated on the manuscript, Copyright © and Moral Rights for the papers on this site are retained by the individual authors and/or other copyright owners. Please check the manuscript for details of any other licences that may have been applied. You may not engage in further distribution of the material for any profitmaking activities or any commercial gain. You may freely distribute both the url (<u>http://strathprints.strath.ac.uk/</u>) and the content of this paper for research or private study, educational, or not-for-profit purposes without prior permission or charge.

Any correspondence concerning this service should be sent to Strathprints administrator: strathprints@strath.ac.uk



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

Michael Argent¹, Alasdair McDonald¹

¹ CDT Wind Energy Systems, Rm 3.36, Royal College Building University of Strathclyde, 204 George Street, Glasgow, G1 1XW

michael.argent@strath.ac.uk



1) OVERVIEW

Generator Case Study for Large Offshore VAWT

- Directly Driven Permanent Magnet Generator (DD PMG)
- Modelling effect on costs & losses of inherent cyclic torque loading caused by periodic variation in aerodynamic load from rotor blades

4) LOSSES FOR A FIXED WIND SPEED

Comparing how losses vary for different torque factor *q* settings.
Copper losses



Strategies to control magnitude of electrical torque variation q ratio
Equations for Copper and Iron Losses based on these strategies
Relationship between cost and electrical torque variation allowed
Work presented is part of 3 year PhD into VAWT Drivetrains

2) CYCLIC TORQUE

- Mechanical torque is modelled using a sinusoidal variation $T_{\text{MECH}} = \overline{T} + T_{\Delta} \sin(2\theta)$ [2 bladed rotor]
- Electrical torque control is parameterised by $q = \frac{T_{\Delta \text{ELEC}}}{T_{\Delta \text{MECH}}}$
- Torque control strategies can vary between two extremes: q = 0 (fixed T_{ELEC}) 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:

increase with q^2

- Iron losses
- decrease linearly with q
 At this speed losses are
- For 9m/s Losses are minimised at q=0.4



5) LOSS MINIMISATION STRATEGIES

 Calculate losses for each *q* strategy for whole range of wind speeds (% change vs fixed torque setting *q*=0)

- Losses minimised when:
 q = 1 at low wind speeds
 q near 0 at high speeds
- 0<q<1 medium speeds
- A loss minimisation strategy q_{OPT} can be setup which varies q with wind speed



T T $-L_{\alpha}$

 $T_{\rm MECH} - T_{\rm ELEC} = J\alpha$

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

| Varying T _{ELEC} (q>0) | Varying Rotor Speed (q<1) |
|---|---|
| Varying Current I | => Varying Electrical Frequency |
| Copper Losses : $\int I^2 R$ | Iron Losses depend on f_e |
| $P_{Cu} = R\left(\bar{I}^2 + \frac{1}{2}(qI_{\Delta})^2\right)$ | $P_{Fe} = \sum \left(A_h \overline{f_e} + A_e \overline{f_e^2} \right) \widehat{B}_{Fe_i}^2 m_i$ |
| | Both $\overline{f_e} \& \overline{f_e^2}$ proportional to $(1 - q)$ |
| Copper Losses $\propto q^2$ | Iron Losses $\propto (1-q)$ |
| Generator cost depends on peak electrical torque loading | |

3) GENERATOR MODELLING

• Single pole pair of generator modelled

- Electrical equivalent circuit in MATLAB
- Magnetic Circuit Model in Finite Element Analysis package FEMM
 Programming Procedure:



to minimise generator losses

q_{opt} 0.8% loss reduction vs best single *q* strategy (*q*=0.4) (1.5% vs *q*=0 fixed torque)

6) PEAK TORQUE AND COSTS

 Peak T_{ELEC} ∝ q (larger peak torque for fixed speed than fixed torque requires larger generator)

- *q*_{OPT} strategy: lower torque at rated => lower cost
- Restricting *q* at rated can lead to cost saving



7) CONCLUSIONS

Adjusting torque control strategy can lead to loss reductions
Biggest reductions allowing generator to adapt to wind speed
Loss reduction: fixed speed at low wind speeds

- MATLAB calculates generator sizings
- FEMM calculates airgap flux density
- MATLAB calculates equivalent circuit and resulting power output & losses
 Generator is 5MW DD PMG for use in offshore H-rotor VAWT, see paper for specs



Iow torque variation at higher speeds
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

EPSRC

Engineering and Physical Sciences Research Council This research was funded by the EPSRC through the Centre for Doctoral Training in Wind Energy Systems at the University of Strathclyde, award no. EP/G037728/1.

www.strath.ac.uk/windenergy

