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A Speed Control Strategy for Parallel Connected Tidal Turbines in an Array Using a Variable Ratio Drive

Simon Reynolds*[1], Aristides Kiprakis[1] and Mohammad Abusara[2]
[1] *School of Engineering, The University of Edinburgh, UK*
[2] *University of Exeter, Penryn, UK*

Summary: Shared export cables in conjunction with onshore converters has the potential to reduce the cost of energy generated by tidal turbine arrays. A key challenge to the implementation of this configuration is to successfully control multiple parallel connected generators whilst still optimising rotor performance over a range of varying flow speeds. A control strategy is proposed for use with a variable ratio drive to overcome this difficulty and validated using a Simulink model, with initial results suggesting it provides a viable solution.

Introduction

Export cables make up a significant proportion of the upfront material and installation costs for tidal turbine arrays. Reducing cable numbers would lower the cost of energy generated by an array, thereby improving commercial viability. This could be achieved by operating the generators of multiple turbines in parallel via shared export cables. In addition, the power conversion equipment required to convert the output from an induction generator into grid ready electricity is relatively failure prone [1]. Operating expenditure can be reduced by locating this equipment onshore, further lowering the cost of energy produced. Combining these two proposals poses a control challenge, since parallel generators must maintain their stator frequencies in phase for operation via a shared export cable and onshore converter. This is difficult to achieve when turbines are subjected to spatially and temporally varying flow speeds, without operating their rotors away from optimal Tip Speed Ratio (TSR). To maintain peak TSR and minimise slip differences between parallel generators, divergence in generator rotor frequencies can be reduced with a variable ratio drive, e.g. the Voith Vorecon /WinDrive [2]. A Simulink model was built to initially validate a proposed control strategy for this arrangement.

Methods

The Simulink model focussed on determining the necessary range of operation for the variable ratio drive and dynamically calculating the reference torque value required for the induction generator. The strategy used is explained visually in Fig. 1, with the limits of the Simulink model shown. A 12 hour flow regime was created (Fig. 2) using data obtained in Ramsey Sound from Acoustic Doppler Current Profiler (ADCP) measurement [3].

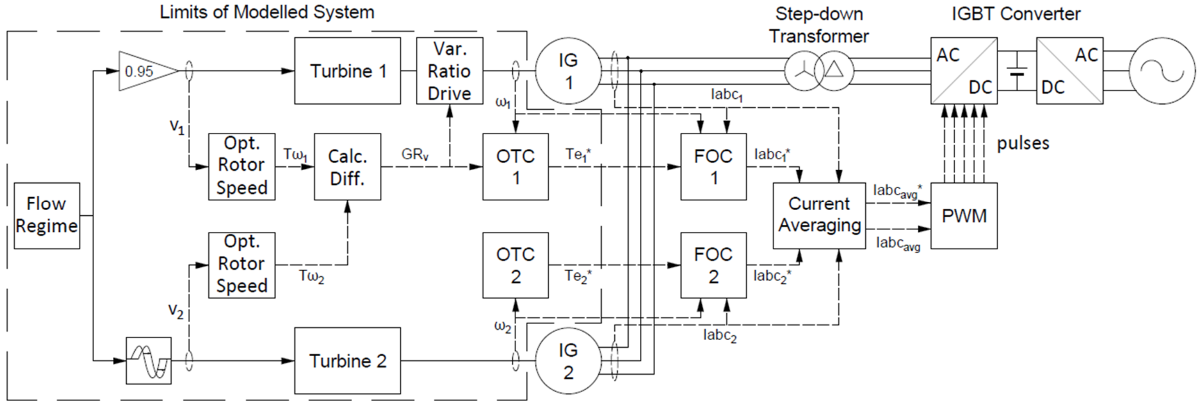

Fig. 1 Control Strategy Schematic with Simulink Model Limits Shown

The flow regime was sent to two turbine blocks, one seeing a 2 second delay and one having a 5% reduction. Optimum rotor speeds ($T\omega_x$) were calculated for each based on flow speeds (v_x) and the difference calculated to obtain the gear ratio (GR_v) required to maintain the same generator speed (ω_x) despite differing rotor speeds. Gear ratio and generator speeds were also used to calculate the reference generator torque (Te_x^*) needed for an electrical control strategy using a torque gain term (k_{TSR}) derived via Optimal Torque Control (OTC) [3]:

$$Te_x^* = \omega_x^2 \times k_{TSR}\ (Nm) \tag{1}$$

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[*] Corresponding author.
Email address: s.reynolds@ed.ac.uk

$$k_{TSR} = 0.5 \times \rho \times \pi \times R^5 \frac{C_p{}^{max}}{TSR^{max3} \times (GR_f / GR_v)^3} \qquad (2)$$

Where: ρ = fluid density = 1025 kg.m^{-3}; R = turbine radius = 6m; $C_p{}^{max}$ = maximum C_p = 0.40481; TSR^{max} = maximum TSR = 3; GR_f = fixed gearbox ratio = 72.

Results

Results generated from the Simulink model provided initial validation that the control strategy can match generator speeds using a sensible range of ratios (Fig. 4) for a variable ratio drive, whilst allowing the rotors to operate at their optimal speed for a given flow (Fig. 3). Generator reference torque was also calculated (Fig. 5); which would be sent to the Field Oriented Control (FOC) scheme before a current averaging calculation would generate control pulses for the parallel connected generators via Pulse Width Modulation (PWM).

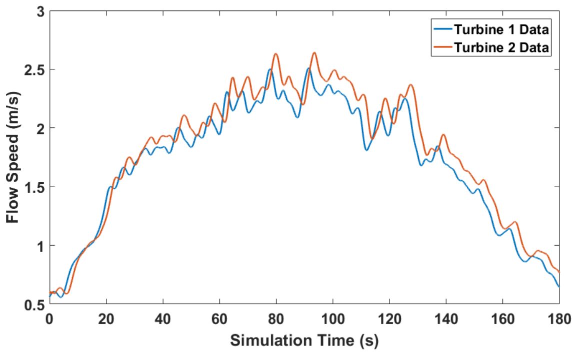

Fig. 2 Flow Speed vs. Simulation Time

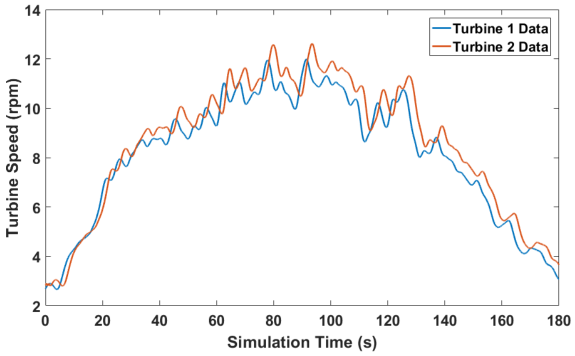

Fig. 3 Turbine Speed vs. Simulation Time

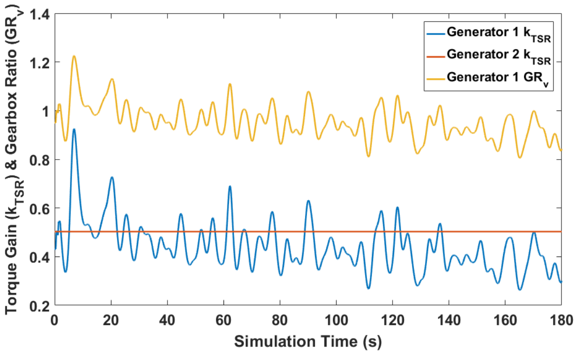

Fig. 4 k_{TSR} & GR_v vs Simulation Time (s)

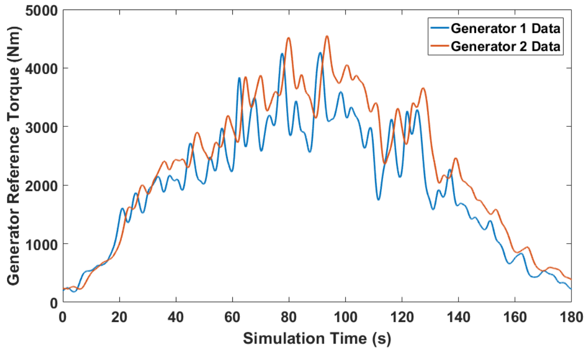

Fig. 5 Generator Ref. Torque vs. Simulation Time (s)

Conclusions

A control strategy proposed for speed matching of parallel connected generators using a variable ratio drive was validated using a Simulink model. The range of ratios used to match generator speed was found to be within sensible limits for existing technology. A torque gain term calculation method was derived and subsequently used to establish the required generator reference torque for an electrical control strategy. Crucially, both turbine rotors were able to operate at their optimum speed despite different tidal flows, thereby maximising efficiency.

Acknowledgements:

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References:

[1] Delorm, T. M., Zappala, D. & Tavner, P. J., 2012. Tidal stream device reliability comparison models. *Journal of Risk and Reliability*, Proceedings of the Institution of Mechanical Engineers, 226(6), pp. 6 - 17.

[2] Voith Turbo GmbH & Co. KG, 2018. Variable Speed Drives. [Online] Available at: https://voith.com/corp-en/drives-transmissions/variable-speed-drives.html

[3] Titan Environmental Surveys Ltd, 2012. CS0332 Ramsey Sound ADCP Final Report, Bridgend: Titan Environmental Surveys Ltd.

[4] Yaramasu, V. & Wu, B., 2017. Model Predictive Control of Wind Energy Conversion Systems. 1st ed. Hoboken: John Wiley & Sons Inc.