Renewable Energy 111 (2017) 849–860

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

An approach to the characterisation of the performance of a tidal stream turbine

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ARTICLE INFO

Article history:
Received 14 June 2016
Received in revised form
8 March 2017
Accepted 1 May 2017
Available online 2 May 2017

Keywords:
Tidal stream turbine
Time-frequency methods
Rotor fault diagnosis
Motor
Generator test bed

ABSTRACT

In order to better manage and maintain deployed Tidal Stream Turbine (TST) devices their response to complicated and severe loading mechanisms must be established. To aid this process the research presented details a methodology for mapping TST operational data, taken under a variety of operating conditions, to a set of model parameters. The parameter sets were developed based on a TST rotor torque model which, as well as providing means of characterising turbine behaviour, can be used to create TST simulations with minimal computation expense. The use of the model in facilitating parameter surface mapping is demonstrated via its application to a set of rotor torque measurements made of a 1/20th scale TST during flume testing. This model is then deployed to recreate the known rotor behaviour which is compared with the original flume based measurements. This is a flexible tool that can be applied to investigate turbine performance under conditions that cannot be readily replicated using tank-based experiments. Furthermore, Computational Fluid Dynamics simulations of such conditions could be time consuming and computationally expensive. To this end, the use of the model in creating drivetrain test bed based simulations is demonstrated. The model, which can be calculated in real-time, is used to develop representative turbine simulations at high turbulence intensity levels which were not achievable during flume experimentation. The intention is to provide a test-bed for future turbine performance monitoring under more realistic, site specific conditions. The work will also support the deployment of performance surfaces in real-life turbine applications.

1. Introduction

Tidal Stream Turbines (TST) renewable energy devices of commercial scale are currently being designed, deployed and tested. It is known that their operation within hostile marine environments will lead to significant and challenging dynamic loading regimes. The support they require to assure their long term operation in such environments is creating an increasing awareness of the required TST performance management and the associated maintenance activities. To date this work has been very well informed by intensive research and development activity based upon the utilisation of tools such as Computational Fluid Dynamics (CFD). Related research has considered the testing of model scale turbines in as near to realistic flow environments as can be achieved in flumes and tow tanks. This valuable body of work has been typically used to verify CFD models and as a staging point in the design of full scale TST. There remains a gap however in the replication of conditions to which these devices will be exposed in actual installations.

It is not the intention of this paper to fully review the extensive body of work reported in the above fields. In both cases research undertaken by the Cardiff Marine Energy Research Group (CMERG) is utilised here to support the developments considered here in. In doing so the work provides an additional tool in TST device development which takes the form of a parametric model and drive train simulator test bed. The parametric model and its associated parameter set allow for a standard characterisation of cyclic turbine rotor behaviours. This notion could possibly provide a useful extension to the non-dimensional performance curves commonly utilised to characterise TST operation [2]. The model format seeks to be flexible and to allow for characterisation from a variety of data sources. Furthermore, the model can be used to calculate developed turbine rotor torque in real-time allowing it to be used as input to

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http://dx.doi.org/10.1016/j.renene.2017.05.010
0960-1481/

drivetrain test bed simulations. This notion is demonstrated herein. The intention of this simulator is to recreate the results of realistic flow conditions on the TST rotor and apply these as inputs onto a drive train. These can then be used to operate a generator to produce outputs that will provide the basis of TST performance monitoring algorithms. The key concepts utilised in this paper uses outputs acquired from scale model TST tests to construct characteristic surfaces and operate a drive train simulator. Once verified the simulator can then be used to test more extreme and variable flow conditions and directly measure their effect on generator operation and output to enable the monitoring of turbine performance.

Section 2 of this paper briefly reviews previous research in order to underpin the approach adopted in this work. An overview of the turbine model and parameterisation approach is then presented in Section 3. The outputs of the turbine rotor model based on the developed parametric characterisation of flume based measurements are compared with original scale model datasets acquired. This approach is then adapted and deployed in Section 4 to control the operation of a physical drive train test bed. The intention is to enable more challenging turbine performance testing to be conducted quickly and at low cost within a laboratory environment. These simulations are integrated with the physical drive train emulator setup which operates optimal Tip-Speed Ratio (λ) control. The results of the simulations are then presented in Section 5. The implications of this approach are then discussed, in Section 6, in the context of its application to turbine monitoring. The paper concludes with an assessment of the further development of the approach and consideration of how monitoring approaches can be developed and implemented. This work is proposed to form the basis of on-going research that will consider and apply these techniques.

2. Previous research

Previous and current research within the CMERG has established a series of generic TST models [1]. These combine CFD and structural Finite Element Analysis (FEA) to provide Fluid-Structure-Interaction (FSI) based models. Within a structured framework of simulations these have provided non-dimensional power and thrust curves for a variety of TST configurations and flow conditions [2,3]. This work was confirmed experimentally in tests mainly conducted in recirculating flume tanks [4]. This work can be aligned with findings reported by other investigators [5,6] to provide a good basis for future investigations of turbine operational performance. To this end, this and other research has linked CFD directly with full scale turbine operation [6,7,8]. It is worth noting however, that in all cases the modelling effort and time and computing load associated with the CFD approaches outlined are always stated to be considerable.

Taken as a body of work the modelling and simulation of marine and wind turbines can be considered to be broadly based in five areas: resource simulation, simulation of the turbine rotor, drive train simulation, generator control and grid integration simulation. The simulations have been conducted with varying degrees of complexity and coupling depending on the study requirements. In this research the focus is on a data driven simulation approach. This approach allows for both characterisation and subsequently real-time simulation of TST drive train behaviours. There have been a number of previously published approaches to deploying electrical motor and generator performance of marine turbines to support drive train simulations [10–12]. There is also a body of work relating to the application of electrical power output and characterisation in the similar field of wind turbine drive train simulation from which important features can be drawn [13–15]. The approach, adopted in this paper, is to produce a drive train emulator based on a motor coupled to a generator. This may consider drive characterisation through a gearbox when simulating indirect-drive turbine setups or without a gearbox when simulating direct-drive turbine setups. Similar methodologies and approaches have been previously demonstrated [9,15,16]. This approach affords great flexibility in terms of rotor or drive train input modelling, allowing the simulation of the rotor only or the simulation of other drive shaft components to be fed into the generator [17]. Furthermore the generator control can be simulated with grid integration emulated via hardware or in software.

The key extension afforded by the parametric modelling approach is to facilitate the simulation and evaluation of non-steady-state conditions thereby allowing the development and testing of both steady state and non-steady state turbine operation. This follows from the recognition that in-situ turbine operation will inevitably be non-steady-state as defined by the turbine design, the characteristics of the tidal resource and the effects of wave-current interaction [18,19]. The approach will ultimately support the monitoring of tidal turbines based primarily upon the response of the generator and/or the associated control actions. The actual implementation of the developed approach will of course depend upon the design and configuration of specific devices deployed. However previous research has considered such systems at a generic level with some good effect [11,15,20] and has identified a number of effective approaches [21,22].

3. TST rotor model development and parameterisation based on flume tests

The development of a rotor torque model for a specific turbine rotor based on the results of a transient CFD modelling exercise has been previously reported [9]. The model viewed the torque on the turbine drive shaft developed by the rotor as a composite of three blade contributions each deconstructed into a mean component and a fluctuating component. Each of the blade contributions were then summed for a given tip-speed ratio (TSR) "λ" and rotor position to give the torque developed by the rotor, at the given position. Such a formulation, whilst incorporating many simplifications, was convenient for two reasons. Firstly, the turbine rotor torque could be appraised simply with knowledge of the turbine characteristic curves, the model parameters and the position of the turbine. Secondly, the process of constructing the model in itself gave insight into the frequency content of the drive shaft torque observed within the CFD models utilised.

In this paper a similar approach was used to produce a more complete rotor model based on parameterisations created utilising acquired flume data. Details of the flume testing campaign undertaken to support this work can be found in Ref. [29]. The model was formed from a mean component based on the turbine characteristic curves, a fluctuation component based on the frequency content of the rotor torque fluctuations measured during flume testing and a stochastic component simulating experimental, measurement and chaotic effects associated with the flume-based experimental setup. The model format was considered to be useful in providing both a means of characterising turbine rotor behaviour under a range of on-coming fluid velocities and λ-values. This information is presented in the form of parametric surfaces. The model format and parameter mapping process undertaken are presented in this section.

Having considered the strength of the previous formation [9]