UNIVERSITI PUTRA MALAYSIA

COMPUTATIONAL STUDY ON TURBULENT FLOW AROUND A MODEL OF WIND TURBINE ROTOR

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirement for the Degree of Master of Science

October 2010

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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October 2010

Chairman: NOR MARIAH BT ADAM, PhD

Faculty: Engineering

There are different methods to study flow characteristics around a wind turbine; common methods are the Blade Element Momentum theory (BEM), wind tunnel tests and Computational Fluid Dynamics (CFD). The BEM approach has limitations on predicting velocity profiles around rotor disk and also it needs some initial data about the 2D airfoil section. Wind tunnel test also has its own problems and limitations and also it is so expensive. This study is concerned with simulating 3D flow around the rotor of a horizontal axis wind turbine using a commercial CFD package code FLUENT 6.3 and comparing experimental data from Sant (2007).

Axial velocity was calculated on two measurement planes at downstream ($Y_{a=}$3.5cm & 6cm) for different radial positions. Coefficient of lift force on the blades is also considered. All the simulations have been done by CFD software, code Fluent 6.3, for three different yaw angles ($\Psi = 0^0, 30^0 \& 45^0$). A Gambit pre-processor tool is used for

mesh generation. A Moving Reference Frame (MRF) model in Fluent is used for modeling rotation of the wind turbine blades. Four turbulence models including Reynolds Stress, k-ε-Realizable, k-ε-standard and k-ω-sst are used and evaluated. The experimental data from (Sant, 2007) is used to compare the simulation results with the wind tunnel test.

The k-ω-sst was the least expensive in terms of computational effort. K-ε-standard and k-ε-realizable were similar to each other in case of computational effort and both took slightly more time in comparison with k-ω-sst. Reynolds Stress Model (RSM) needed about 40% time more than the other turbulence models to get the convergence.

Almost in all of the positions for $\Psi = 0^0$, k-ε-Standard did the best prediction in comparison with the other turbulence models for calculating the axial velocities. A very good agreement was reached at $\Psi=30^0$, all turbulence models performed a reasonable job for prediction of axial velocity at this position, except the k-ω-SST. None of the turbulence models did an acceptable prediction at $\Psi=45^0$. K-ε-realizable and Reynolds Stress did a better job for prediction of C_l on a blade in comparison with k-ε-Standard and k-ω-SST.

Pressure and velocity contours are presented to show the flow behaviour around the rotor disk. According to the extracted results from the simulations all the turbulence models have predicted that on the upstream side at the vicinity of the blade surface by increasing the pressure along the blade from the hub to the tip blade velocity drops. Drastic changes in pressure at tip of the blade cause in significant changes for the velocity.

Abstrak tesis yang dikemukakan kepada senat Universiti Putra Malaysia sebangai memenhi kepeluan untuk Master Sains

PENGAJIAN PENGKOMPUTERAN ALIRAN TURBULEN KELILING MODEL ROTOR TURBIN ANGIN

Oleh

AMIR PAKRAVAN

November 2010

Pengerusi: Profesor Madya Ir. NOR MARIAH BT ADAM, PhD

Fakulti: Kejuruteraan

Terdapat beberapa kaedah untuk mengkaji ciri-ciri aliran kelajuan bendalir sekitar turbin angin. Kaedah lazim yang digunakan adalah Teori Momentum Elemen Bilah (Blade Element Momentum theory (BEM)), ujian terowong angin dan pengkomputeran Dinamik Bendalir (Computational Fluid Dynamics (CFD)). Terdapat kekangan dalam kaedah BEM bagi menganggarkan profil kelajuan di sekitar cakera rotor dan ia juga memerlukan data awal mengenai bahagian aerofoil 2D. Ujian terowong angin turut mempunyai masalah serta kekangan yang tersendiri dan ujian ini memerlukan kos yang tinggi. Kajian ini tertumpu kepada simulasi arus 3D di sekitar rotor pada turbin angin pada paksi melintang dengan menggunakan pakej komersial CFD kod FLUENT 6.3 dan membandingkannya dengan data eksperimental diperolehi Sant (2007).

Usaha telah dipergiatkan di dalam kajian untuk mensimulasi aliran bendalir 3-Dimensi di sekeliling cakera rotor, dengan halaju paksi dikira pada pengukuran dua satah (Ya=3.5cm & 6 cm) untuk posisi jejari yang berbeza mengikut eksperimen yang telah dijalankan oleh Sant

(2007). Terdapat juga kajian lain yang berkaitan pekali daya angkat pada bilah (C_l). Kesemua simulasi telah dijalankan menggunakan perisian pengkomputeran bendalir dinamik (CFD) Fluent 6.3 untuk tiga sudut ($\Psi = 0^0, 30^0 \& 45^0$). Penghasilan *mesh* telah dilakukan dengan menggunakan perisian Gambit. Model pergerakan bingkai rujukan (MRF) di dalam perisian Fluent telah digunakan untuk pemodelan bilah-bilah turbin angin yang berputar. Empat model pergolakan gelora iaitu Reynolds Stress, k-ε-Realizable, Standard k-ε dan k-ω-SST telah diguna dan dinilai. Perbandingan telah dilakukan di antara keputusan simulasi dan data ujian terowong angin daripada ujikaji oleh Sant (2007).

Model pergolakan gelora k-ω-SST memerlukan kos yang kurang mahal didalam masa pengkomputeran. Penggunaan model Standard k-ε memerlukan masa yang lebih cepat daripada k-ω-SST. Manakala penggunaan model k-ε-Realizable memerlukan masa yang lebih panjang berbanding model Standard k-ε. Model Reynolds Stress pula mengambil masa 40% lebih panjang berbanding model-model yang lain. Hampir kesemua posisi untuk $\Psi = 0^o$, model Standard k-ε telah memberikan nilai bacaan yang terbaik berbanding model-model pergolakan gelora yang lain bagi pengiraan halaju paksi. Keputusan yang paling bagus diperoleh pada posisi $\Psi = 30^o$ oleh semua model-model pergolakan gelora kecuali model k-ω-SST. Pada $\Psi = 45°$ tiada model pergolakan gelora yang memberikan hasil yang memberangsangkan. Model k-ε-realizable dan Reynolds Stress memberikan ramalan terbaik bagi C_l pada bilah berbanding model Standard k-ε dan k-ω-SST.

Berdasarkan dengan keputusan semua model pergolakan gelora, tekanan dan kontur kelajuan dapat dipaparkan untuk menunjukkan perilaku aliran di sekitar cakera rotor. Kesemua model meramalkan pergerakan berhampiran permukaan bilah akan meningkat apabila nilai tekanan ditingkatkan, manakala disepanjang bilah dari bahagian tengah ke bahagian hujungnya halajunya akan menurun. Perubahan tekanan secara drastik dibahagian hujung bilah menyebabkan halaju berubah dengan nyata.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude and appreciation to Dr. Nor Mariah Bt Adam as a project supervisor for her helpful advice, guidance, suggestion, support and valuable opinion throughout the presentation and upon completion of this thesis. Thanks are also express to Dr. Megat Mohamad Hamdan B Megat Ahmad and Dr. Mohd Khairol Anuar Bin Mohd Ariffin as the Co-supervisors for their kindness, information and suggestion during the project research.

The author would like to thanks, Institute Technology Maju (ITMA) AREL lab staffs for their help and support during the working on the simulations at Fluent work stations.

Thanks are also given to the author's mother for her supports and encouragement in his study life.

I certify that an Examination Committee has met on data of viva voce to conduct the final examination of Amir Pakravan on his Master of Science thesis entitled "**COMPUTATIONAL STUDY ON TURBULENT FLOW AROUND A MODEL OF WIND TURBINE ROTOR**" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the relevant degree.

Member of the Examination Committee were as follows:

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the supervisory committee were as follow:

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DECLARATION

I declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that if has not been previously and is not concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

Amir Pakravan

Date: 29 October 2010

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