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Studies of some high solidity symmetrical and unsymmetrical blade H-Darrieus rotors with respect to starting characteristics, dynamic performances and flow physics in low wind streams

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ABSTRACT

Vertical axis wind turbines can be successfully installed in low wind speed conditions but its detailed starting characteristics in terms of starting torque, starting time and dynamic performances have not been investigated thoroughly which is important for increasing the energy yield of such turbines. Amongst their designs, H-Darrieus rotor, in spite of having good power coefficient, possesses poor self-starting features as symmetrical blade profiles are used most of the times. Instead of using symmetrical blades if unsymmetrical or cambered blades are used with high solidity, then starting performance of H-Darrieus rotor along with its power coefficients can be improved. Though this performance improvement measures are correlated with improvement in the starting characteristics, a detailed work in this direction would be useful and for this reason the present work has been carried out. Three types of blade designs have been considered; two unsymmetrical blades namely S815 and EN0005 and one conventional symmetrical NACA 0018 blade, and experiments are conducted using a centrifugal blower test rig for three-bladed H-Darrieus rotors using these three considered blades at low wind streams (4 m/s, 6 m/s and 8 m/s). Considering reality, the effects of flow non-uniformity and turbulence intensity on the rotor performance at optimum condition as well as flow physics have also been studied. It has been found that unsymmetrical S815 blade rotor has higher dynamic torque and higher power coefficient than unsymmetrical EN0005 and symmetrical NACA 0018 blade H-Darrieus rotors.

1. Introduction

Global warming trends, declining fossil fuel sources, hike in oil prices etc. have renewed the interest of many researchers to generate energy from renewable energy sources as they are inexhaustible and pollution free. Among various renewable energy sources, wind energy has got increasing attention as a large scale power production technology in urban and rural areas to meet the energy demand of people. At present, vertical axis wind turbine (VAWT) systems are getting prime attention for power generation in low wind regime among all wind turbine systems because of their structural simplicity, independency of wind direction, cost effectiveness, easier maintenance, lower noise emission, inessentiality of yaw mechanism etc. Generally, VAWTs can be classified into two types: Savonius and Darrieus turbines or rotors. Darrieus rotors are lift type machines which have higher power efficient than the Savonius rotors. H-Darrieus rotor, a variant of the curve bladed Darrieus rotor is becoming very popular recently. These rotors have straight vertical blades which are of simpler construction and design, and these blades can be connected directly to the rotor shaft by means of struts [1]. H-Darrieus rotor shows higher power coefficient than curve bladed Darrieus rotor [2] and hence this rotor can be useful for generating significant power, crop grinding, and water pumping etc. in remote areas. But the main disadvantage of this rotor is its poor self-starting features because of symmetrical blade designs [3,4]. So more research work is required for finding suitable blade designs so that the VAWT can be self-starting at all rotor angles and its performance can also be improved. Various solutions were presented by a number of researchers to overcome the poor self-starting ability of Darrieus rotor: a combination of Savonius and Darrieus rotor for making the

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Darrieus fully self-starting and its efficiency improvement compared to Savonius rotor [5], application of guide-vane [6], employment of mechanical system for optimizing blade pitch [7], use of specially designed blades that transform their shape almost like an airfoil during rotation [8,9]. All these designs had more or less problems; either these models were too complex to manufacture and needed good support for blades or they showed decrease in operating range and peak efficiencies though they resulted increment of starting torque. However, unsymmetrical or cambered airfoil shaped blades can be a better design prospect for obtaining good starting features [10]. Dominy et al. [11] investigated the effect of number of blades on the self-starting behaviour of H-Darrieus rotor having symmetrical NACA 0012 airfoil at 10 m/s wind speed. They observed that though two-bladed rotor has self-starting potential, but it is not possible for all starting position of the rotor which is a problem for commercial viability. However, they confirmed by model testing that irrespective of its starting position, three-bladed H-Darrieus rotor has the capability to self-start under steady wind conditions. Barker [12] made a theoretical comparison between the performances of an unsymmetrical NACA 0012 airfoil and a symmetrical NACA 0012 airfoil blade and noticed that the unsymmetrical profile exhibited more tangential thrust over a wide angle of attack range and ensured that this blade design can be consistently self-started. Despande and Li [13] performed a numerical study of a three bladed fixed pitch H-Darrieus rotor based on three different airfoils which were symmetrical NACA 0015, NACA 0018 and unsymmetrical S1210. Considering two different solidities like 0.2 and 0.4 for symmetrical and cambered airfoils respectively, various advantages of cambered S1210 blades were shown. Islam et al. [14] analysed an unsymmetrical special purpose airfoil named MI-VAWT1 for smaller capacity three bladed H-Darrieus rotor based on different parameters varying the solidity range from 0.1 to 1. It was reported that this particular blade shows better aerodynamic performance than NACA 0015 airfoil. Beri and Yao [15] investigated a two-dimensional unsteady CFD analysis on cambered NACA 2415 shape three bladed fixed pitch H-Darrieus rotor. The 2D simulation showed that significant average torque is generated which could be sufficiently self-starts this H-Darrieus rotor for this particular cambered airfoil. Sayed et al. [16] performed a CFD simulation of different low-speed flow past 2D S-series blade profiles of wind rotor developed by The National Renewable Energy Laboratory (NREL). It was observed that at low angle of attack the lift coefficient increases and drag decreases by using an unsymmetrical airfoil, and an airfoil having high lift/drag ratio would have higher efficiency than the one with lower lift/drag ratio. Gupta and Biswas [17] analysed the performance of a twisted unsymmetrical three bladed H-Darrieus rotor by a steady-state 2D CFD analysis. It was noticed that when blade angle is greater than 90° having blade twist of 30°, then the self-starting of this rotor could be expected. Recently various high solidity (in the range of 0.4–1.0) three-bladed H-Darrieus rotors are being investigated. Saeidi et al. [18] designed and optimized a three bladed cambered NACA 4415 shape H-Darrieus rotor to check its economic feasibility. It was found that at solidity 0.4 and rotor aspect ratio 1 with tip speed ratio (TSR) 4, the rotor shows maximum power coefficient 0.472 and this power coefficient decreases when solidity is decreased and increases when TSR is increased. Bhuyan and Biswas [4] studied experimentally the self-starting and performance features of a cambered S818 shape three bladed simple H-Darrieus rotor and a hybrid system with Savonius rotor connected at its centre. It was found that for aspect ratio and solidity 1, simple H-Darrieus rotor is not fully self-starting at all rotor positions and shows maximum power coefficient of 0.28, whereas hybrid rotor fully self-starts at all rotor angle and its maximum power coefficient is 0.34. Mohamed [19] investigated some techniques to improve the poor self-starting ability of two-bladed H-Darrieus rotor for S-1046 symmetrical airfoil blade shape. It was concluded that solidity increment (as high as 0.43) improves the self-starting ability of H-Darrieus rotor as it increases the static torque coefficient with solidities higher than 0.25. Singh et al. [3] performed an experimental analysis for high solidity three-bladed H-Darrieus rotor having S1210 unsymmetrical blades to evaluate its self-starting characteristics and performance with various rotor aspect ratios (from 0.8 to 1.2) at various rotor angular positions and wind speeds. This rotor exhibited self-starting for all aspect ratios considered at all rotor positions while the highest power coefficient of 0.32 was found for aspect ratio 1. It was noticed that this unsymmetrical blade with high solidity has got better prospect in terms of starting torque and power coefficient though its operating range is smaller. Nguyen et al. [20] performed a numerical study on the blade thickness effect and starting time at different azimuthal angles for three bladed H-Darrieus rotor at wind speeds 3–7 m/s using four symmetrical blades namely NACA 0012, NACA 0015, NACA 0018 and NACA 0021. They concluded that for larger thickness of the airfoil, self-starting ability is also higher. However a detail performance study of unsymmetrical three bladed H-Darrieus rotor for different high solidities with regards to static characteristics, starting time, dynamic performances and various unsymmetrical blade profiles at low tip speed ratios are less. So some research work is needed in this area to show that these types of vertical axis rotors can work in low wind speed conditions effectively.

2. Objective of the present work

From the earlier section, it has been understood that for solving poor self-starting problem of H-Darrieus wind rotor, optimal blade number should be three with cambered or unsymmetrical airfoil shape. It has also been seen that high solidity three-bladed H-Darrieus rotor has much better prospect in terms of starting torque and performance. Most of the existing studies have been done with low solidity and high TSR for rotor power generation, for which the high solidity rotors might not be appropriate as suggested by various researchers in the past [1,13,15,19]. But high solidity and low TSR unsymmetrical H-Darrieus rotors give some promising things like: it gives higher static and dynamic torque [3,4] than the symmetrical blade rotors. In low TSR power coefficient of such rotors are less, but in terms of dynamic torque these designs are very significant for small scale applications like pumping, grinding, sailing boat etc. So in such environment H-Darrieus rotor performance data is needed. In this paper, along with rotor solidity and aspect ratio like the past researches, starting time has been considered an important parameter for improving the performances of cambered blade H-Darrieus rotor, which could increase the energy yield in low wind regimes. Moreover, there is still very less work on the self-starting evaluation, static and dynamic torque coefficient measurement etc. of high solidity H-Darrieus rotor having cambered blades at different rotor aspect ratios, so that some clear perception can be gained for this type of VAWT rotor in low wind regime. It has also been observed that unsymmetrical airfoils can exhibit higher tangential thrust which helps them to offer better self-starting features than symmetrical airfoils, and thicker cambered blades are also better for good self-starting of a rotor [3,4,21,22]. Therefore, unsymmetrical S815 airfoil profile has been selected here as its thickness is higher than other popular NREL S-series airfoils like S818, S809, S1210 etc. [23], and its detailed performance of H-Darrieus rotor with S815 blades has not been investigated comprehensively in the past. Another unsymmetrical EN0005 blade is chosen as its performance is better than NACA 0018 and NACA 4418 airfoil in case of self-starting [24]. So, in this paper experimental analysis has been done on symmetrical