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Vertical axis wind turbine project report pdf free printable form template

When a direct driven permanent magnet synchronous generator is used, a much more direct (and, consequently, safer) choice is at hand: simply short-circuit the generator. More surprisingly, perhaps, the case of two blades shows a revolution time of about 50 seconds, owing to the fact that has less deep minima than for three-bladed case. Radius () 13 m Blade area () 58 m² Shaft torsional stiffness () 3·10⁶ Nm Turbine moment of inertia () 3·10⁵ kg m² Generator moment of inertia () 2.4·10³ kg m² Inner resistance of generator () 0.065 Ω No-load voltage per angular velocity () 140 Vs³. An elegant way to avoid oscillations for a direct-driven turbine with a permanent magnet synchronous generator is to short-circuit the generator. It is noted that nondamped braking will, for the two-bladed turbine, imply oscillations in the thrust force with a frequency depending on both the wind speed and the turbine azimuth, especially near the thrust force minimum. The solution to (3) is then where is the amplitude and the frequency is Since (and consequently) is proportional to the wind speed squared, the frequency of the oscillation is both wind speed and wind angle dependent. A turbine of this type is considered with respect to strategies for safe parking during extreme wind loads. Modern HAWTs rely on a quite impressive list of moveable parts for its function, for example, individually pitchable blades and usually a gearbox-expensive and maintenance demanding matters [1], which in part explains the incentives dependence. If we neglect the contribution from and consider as an external driving source, the damping ratio becomes For the numbers given above, we note that the damping ratio is , that is, not far from critical damping. Depending on the amount of variation of along the revolution, this time will be stretched. Solving the system of (5) numerically, we get a revolution time for the three-bladed turbine of about 90 seconds and an average power absorption of 12 kW, which is only slightly higher than the losses at nominal load, losses which the cooling system of the generator has to be designed to handle. The generator torque per angular speed, , could in principle be lowered by increasing the resistance in the circuit. The moment of inertia of the turbine is also a quantity that is not desirable to increase. There will be no torsional vibrations, and unfavourable positions where blade flutter could possibly occur are quickly left. 3.4. Pitch Angle Dependence So far the pitch angle has been set to zero. However, as the wind direction is never perfectly constant, the turbine is in reality not expected to come to rest. Also, changing the pitch angle has little effect on the average torque. The considered turbine is essentially at rest (or very slowly revolving) at high wind speeds, suggesting that static airfoil data can be used, where the angle of attack is just the azimuth (possibly plus some offset). The direction is not maintained, but the damping is simple and efficient. The power absorbed in the generator is then , where is the torque directly on the generator, the no-load voltage and the inner resistance. The challenge is, therefore, to reach a point where manufacturing and maintenance costs of VAWTs, as compared to HAWTs, are at least 20% lower per swept area, in order to render the concept viable. In this study, a straight-bladed VAWT, also called H-rotor, is considered. Consider now a turbine with two blades. Strategies for parking a vertical axis wind turbine at storm load are considered. To calculate a simplified circuit model for the synchronous generator may be used, where the contribution from the inner reactance to the circuit impedance is neglected due to the slow revolution. This implies a Reynolds number of about for the three bladed turbine where the chord length is close to 1 m. In addition to the reference turbine having three blades, the cases of two and four blades are also shown. This is reasonable from the point of view that the power absorbed by the turbine is small compared to the power contained in the incident wind; on the other hand, not realistic for some specific positions where a blade is directly behind another. It is therefore not possible to save on tower dimensions for two blades, as compared to three and more blades. However, for the rough estimates made here, this simple model is expected to suffice. In what follows we use the data in Table 1 for the calculations. However, this would at the same time decrease the revolution time and consequently raise the need for cooling due to higher power absorption. We see from Figure 2 that a change of only from the minimum gives rise to a thrust force comparable to the ones for three and four blades. The thrust force and torque as functions of the azimuth are calculated according to the simplifying assumptions discussed above where is the air density, the wind speed, labels the blades, is the drag coefficient, is a possible offset pitch of the blades, is the radius, is the number of blades, and is the tangential component of the lift and drag coefficient. Given the data in Table 1, which corresponds to the turbine described in [8, 9] (Figure 1), the thrust force and torque are shown in Figure 2. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. Ottermo et al. Nondamped braking is found to be especially problematic for the case of two blades where torsional oscillations may imply thrust force oscillations within a range of frequencies. 1. Introduction It has become increasingly important to broaden the search for potential technologies for renewable energy conversion, as part of the joint effort to cut greenhouse gas emissions. However, the shaft is already quite robustly dimensioned with respect to expected ultimate torque on the turbine, and it is not desirable to further increase the cost and weight of this component. Possible coupling to the tower frequencies has to be taken into account when dimensioning the tower. Storm load is of increasing concern at growing scale since the wind speed increases with the height and faults may have more hazardous implications for large turbines than for small turbines closer to the ground. 2. The H-Rotor at Storm Load For the estimates performed in this study, blade loads are calculated from measured lift and drag data for the NACA0018 profile [11]. More exactly, the system is described by the equations where is the turbine angle, is the generator angle, is the torque per angular speed due to the short-circuited generator, and is the moment of inertia of the generator. From an aerodynamic point of view, a well-chosen nonzero pitch angle is typically advantageous for turbine performance [12]. It is therefore reasonable to keep the current trade-off between damping and power absorption. 4. Conclusion A straight-bladed VAWT (H-rotor) with a direct-driven generator has been considered, with respect to parking strategies at storm load. The turbine then becomes heavily loaded with a torque proportional to the rotational speed, and any torsional vibrations are efficiently damped. One alternative might be to place the brake closer to the turbine, thereby shifting significantly upwards. When parking the turbine near we note that an oscillating angle will imply oscillations in the tower force. We see from Figure 2 that the force on the tower is angle dependent, especially near the . In addition, no correction for finite aspect ratio is included. The solidity of the turbine is here defined as of the total blade area to the total swept area. On the other hand, 33 seconds is a reasonable lower limit, since we know that is likely to be somewhat overestimated (no correction for aspect ratio, for example). As we will see, orienting the two-bladed turbine at the thrust force minimum might actually be a position that should be avoided. 3.2. Nondamped Braking Consider initially a design where a nondamped brake is situated at ground level. As expected, for four blades the revolution time is lower, about 40 seconds, due to a more stable , and the power absorption is consequently doubled. The effect is then roughly to switch the term for a term. Besides that, the slow revolution is probably only beneficial. It might, therefore, be tempting to orient the turbine at the thrust force minimum, to minimize the load on the tower. As , the angular frequency dependence indeed cancels out and hence, for the low a.c. frequency range that we are considering here, may be treated as a constant. Then the frequency will be more stable, and the amplitudes will decrease. As a consequence, no special or preferred orientation emerges with respect to the wind direction when parking the turbine. Hence, cooling of the generator need only be slightly improved to render this concept for parking at storm possible for all turbine configurations. Acknowledgments This work was conducted within the StandUP for Energy strategic research framework. However, it is not obvious that these oscillations will be less dangerous since the angular acceleration will still be of the same magnitude, owing to the fact that the exciting forces are unchanged. 3.3. Damping by Short-Circuiting the Generator The natural solution is to introduce damping. It is probably wise to try to avoid any type of oscillations during storm load. This means that all torsional vibrations are very effectively damped. An even better damping could be achieved by, for example, making the shaft stiffer, which means increasing . The wind speed used here is m/s, which is a realistic rated survival wind speed of this turbine. As a bottom line, then, with only small improvements on the generator cooling, this concept for parking the turbine at storm should be viable for any turbine configuration. 3.5. Damping of Torsional Vibrations In the solutions to (5), it is seen that all kinds of excited initial conditions are effectively damped. The generator of VAWTs may conveniently be placed on ground level, facilitating use of bulky direct drive generators which may be optimized for low cost rather than low weight. The Swedish Energy Agency and VINNOVA are acknowledged for supporting the Swedish Centre for Renewable Electric Energy Conversion. Copyright © 2012 F. Patented already in the 30's by Darrieus [3], the VAWT concept was studied quite intently during the 70's and 80's [4, 5], but since then the major resources have been directed towards HAWTs. VAWT activities in the mean time have mostly been concentrated to small-scale turbines where the technology has indeed been successfully commercialized [6, 7]. Hence, when dimensioning the tower for the two-bladed turbine, one has to take into account the risk of resonance between the tower frequencies and the oscillations, where the frequency is both wind speed and wind angle dependent. It is also assumed that the incident wind flow on each blade is unaffected by the presence of the other blades. For the two-bladed turbine, we note that the tower force will be almost twice that for the three-bladed one for a wide range of angular positions. Prescribing a model where the wind direction is constantly changing would consequently lower the revolution time (for all pitches), especially for the three bladed turbine. Due to the coarse model used, and the strong dependence on regions in the Figure 2 where the separate blade torques add up to a small total torque, the revolution time results may not be very accurate. This means that for a perfectly constant wind direction this would make the turbine come to rest (which is good at least from a power absorption perspective). The no-load voltage, is proportional to the angular speed. Renewed interest in larger-scale turbines has arisen lately, especially in the context of offshore applications where the low center of gravity may be advantageous [4]. For the current generator we get Nms. The average value of the torque for one revolution is about kNm (for two blades, slightly lower for three and four blades due the difference in Reynolds number), so if were constant the turbine would have made one revolution in 33 seconds. An H-rotor with a generator at ground level is considered, the generator being connected to the turbine through a shaft. 3.1. Orientation and Tower Dimensions It is evident from Figure 2 that the thrust force is close to constant for three and four blades. Deciding the solidity for large VAWTs is generally a trade-off between aerodynamic efficiency and large forces on the blades and the tower (during operation and storm). Another concept for harnessing wind power, the vertical axis wind turbine (VAWT), has the inherent potential to reduce the number of moving parts as pitch and yaw mechanisms are not needed [2]. A 200 kW prototype H-rotor with direct drive has recently been manufactured based on research from Uppsala University [8–10]; this turbine is currently one of the largest operating VAWTs in the world, see Figure 1. Within wind power, the established and through incentives now commercially viable technology of horizontal axis wind turbines (HAWTs) has attracted most of the attention during the last decades. The wind direction may, however, change quickly at storm. It is, therefore, reasonable to keep the solidity constant when varying the blade count. The tower might as a consequence need to be dimensioned more robustly. It is found that the maximum rotational frequency leads to a power absorption that is of the same order of magnitude as the losses under nominal operation. The generator is then heavily loaded, producing a torque that is proportional to the rotational speed. As for the generator data, these correspond to the generator described in [8]. For two blades, on the other hand, the thrust force is highly angle dependent. With shaft torsional stiffness and turbine moment of inertia, the dynamic equation for the azimuth is For small oscillations around an equilibrium position, we may write the torque as , where . It is probably possible to construct a damped brake that maintains the direction, one that merely adds a term to the left-hand side of (3). By comparison, the European standard IEC 61400-1 states that the turbine, during extreme wind conditions, shall withstand wind direction changes of in 5 seconds. For power absorption in the range 20–25 kW, which seems to be the case for two and four blades, cooling of the generator might have to be dimensioned more robustly. Is it a problem that the turbine position is not maintained? For the parked turbine at storm, it is clear from (2) that the torque curves will change by the introduction of a pitch angle. For the three- and four-bladed turbine, on the other hand, the tower force is nearly constant for all angles, so tower frequency coupling is not an issue in this case. Let alone these additional problems for the two-bladed turbine, we see that any turbine will suffer from angle oscillations with the nondamped brake design proposed above. Parking Strategies We will now discuss different scenarios for parking the turbine during storm load and also indicate implications of different blade counts in this context. It is proposed that if a directly driven permanent magnet synchronous generator is used, an elegant choice is to short-circuit the generator at storm, since this makes the turbine efficiently damped. In particular, the torque can become partly negative for some pitch angles of the three bladed turbine. For the large-scale VAWT prototypes that have been demonstrated so far (i.e., those constructed in the 70's and 80's), the aerodynamic efficiency is of the order of 35–40%, which is somewhat lower than for HAWT.

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