Improved Pitch Angle Control for 1.5MW Variable-Speed Wind Turbine System

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Abstract

Wind energy is the most promising renewable energy sources. In the past several years, 1.5 Megawatt wind turbine system has been distributed in China widely.At the same time, variable-pitch method was recognized as an attractive solution to performance improvement, thus majority efforts had been devoted into blade pitch angle effect on aerodynamic performance. The research work presented in this paper is aimed to provide a variable speed stall regulated controller of variable speed wind turbine system which could improve wind power output efficiency. This controller model is appropriate to variable speed turbines which employ a frequency converter to decouple the generator speed from the fixed frequency of the grid, and which do not use pitch control to limit the power above rated wind speed.At last, the controller model is applied to the 1.5 Megawatt variable-speed wind turbine system of the Shijingao Wind Plant in Liaoning province of China. Comparative analyses of the two different controller model were conducted, a relative increase of the power coefficient by more than 3.7%.

Keywords

Wind turbine, Pitch angle, 1.5 Megawatt wind turbine system, Variable speed stall regulated controller.

1. Introduction

The variable pitch and variable speed wind turbine has widely used in the wind farm in the past ten years. And the 1.5MW variable-Speed wind turbine become mainstream models. Liaoning Datang International Shijingao wind farm is located in Fuxin city of Liaoning province Fumeng County, the northeast of China. The altitude is about 500m, the site for the hilly terrain. Annual mean wind speed is 7.2m/s, and the annual average wind power density is 439.4.64W/m2. Shijingao wind farm engineering installation of 33 stand-alone capacity 1.5MW Ming Yang 1.5Se wind turbine, impeller diameter 82.6m, tower height 80m.

2. Methodology

2.1 The variable speed stall regulated controller

The controller model is appropriate to variable speed turbines which employ a frequency converter to decouple the generator speed from the fixed frequency of the grid, and which do not use pitch control to limit the power above rated wind speed. Instead, the generator reaction torque is controlled so as to slow the rotor down into stall in high wind speeds. The control loop is shown schematically in Figure 1.

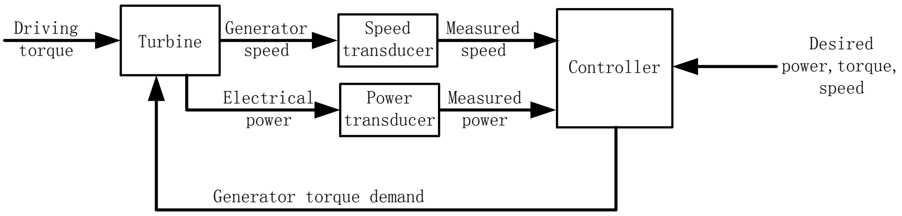

Figure 1: The variable speed stall regulated control loop

2.2 Steady state parameters

The steady-state operating curve can be described with reference to a torque-speed graph as in Figure 2. The allowable speed range in the steady state is from S1 to S2. In low winds it is possible to maximise energy capture by following a constant tip speed ratio load line which corresponds to operation at the maximum power coefficient. This load line is a quadratic curve on the torque-speed plane, shown by the line BG in Figure 2. Alternatively a look-up table may be specified. If there is a minimum allowed operating speed S1, then it is no longer possible to follow this curve in very low winds, and the turbine is then operated at nominally constant speed along the line AB shown in the figure. Similarly in high wind speeds, once the maximum operating speed S4 is reached, then once again it is necessary to depart from the optimum load line by operating at nominally constant speed along the line GH.

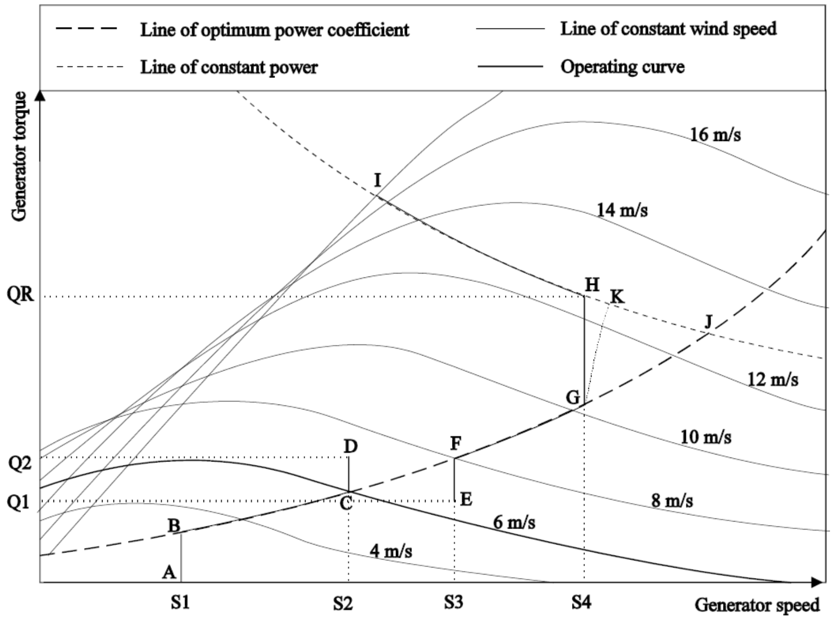

Figure 2 Variable speed stall regulated operating curve

Once maximum power is reached at point H, it is necessary to slow the rotor speed down into stall, along the constant power line HI. If high rotational speeds are allowed, it is of course possible for the line GH to collapse so that the constant power line and the constant tip speed ratio line meet at point J.

Clearly the parameters needed to specify the steady state operating curve are:

The minimum speed, S1

The maximum speed in constant tip speed ratio mode, S4

The maximum steady-state operating speed. This is usually S4, but could conceivably be higher in the case of a turbine whose characteristics are such that as the wind speed increases, the above rated operating point moves from H to I, then drops back to H, and then carries on (towards J) in very high winds. This situation is somewhat unlikely however, because if rotational speeds beyond S4 are permitted in very high winds, there is little reason not to increase S4 and allow the same high rotor speeds in lower winds.)

The above rated power set-point, corresponding to the line HI. This is defined in terms of shaft power. Electrical power will of course be lower if electrical losses are modelled.

The parameter K_λ which defines the constant tip speed ratio line BG. This is given by:

$$K_\lambda = \pi\rho R^5 C_p(\lambda) / 2\lambda^3 G^3$$

where

ρ = air density

R = rotor radius

λ = desired tip speed ratio

$C_p(\lambda)$ = Power coefficient at tip speed ratio λ

G = gearbox ratio

Then when the generator torque demand is set to $K_\lambda \omega^2$ where ω is the measured generator speed, this ensures that in the steady state the turbine will maintain tip speed ratio λ and the corresponding power coefficient $C_p(\lambda)$. Note that power train losses may vary with rotational speed, in which case the optimum rotor speed is not necessarily that which results in the maximum aerodynamic power coefficient.

As an alternative to the parameter K_λ, a look-up table may be specified giving generator torque as a function of speed.

2.3 Dynamic parameters

To calculate the dynamic behaviour of the control loop, it is necessary to specify the dynamic response of both power and speed transducers, as well as the actual algorithm used by the controller to calculate a generator torque demand in response to the measured power and speed signals. Two closed loop control loops are used for the generator torque control, as shown in Figure 3. An inner control loop calculates a generator torque demand as a function of generator speed error, while an outer loop calculates a generator speed demand as a function of power error. Both control loops use PI controllers.

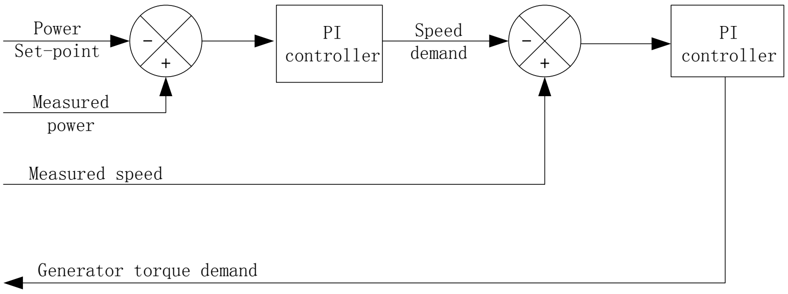

Figure 3: Stall regulated variable speed control loops

Below rated, the speed set-point switches between S1 and S4. In low winds it is at S1, and the torque demand output is limited to a maximum value given by the optimal tip speed ratio curve BG. This causes the operating point to track the trajectory ABG. In higher winds, the set-point changes to S4, and the torque demand output is limited to a minimum value given by the optimal tip speed ratio curve, causing the operating point to track the trajectory BGH. Once the torque reaches QR, the outer control loop causes the speed set-point to reduce along HI, and the inner loop tracks this varying speed demand.

3. Simulation Results

1# wind turbine updated the pitch angle control system in Shijingao wind farm. And the 1# wind turbine worded steady from May 1st to May 31th. We got the data of average wind speed per 30s and everage power per 30s from April 1st , 2ed, 4th(before improved), May 12th, 13th, 14th, 15th (after improved) to generate the power-wind speed curve(Figure 4). The blue line in Figure 4 depicts the established generator torque for improved controller. In below rated wind speed, optimal power is attained by regulating (optimal performance coefficient), therefore, the pitch angle is kept at a mechanical minimum and rotor speed is controlled in such a way that (optimal tip speed ratio) is always acquired. By analyzing the simulation results, it can be concluded that the present models allow an accurate approximation of the dynamic response of the wind turbine operating with different winds, although the wind turbines generate the maximum reactive power.

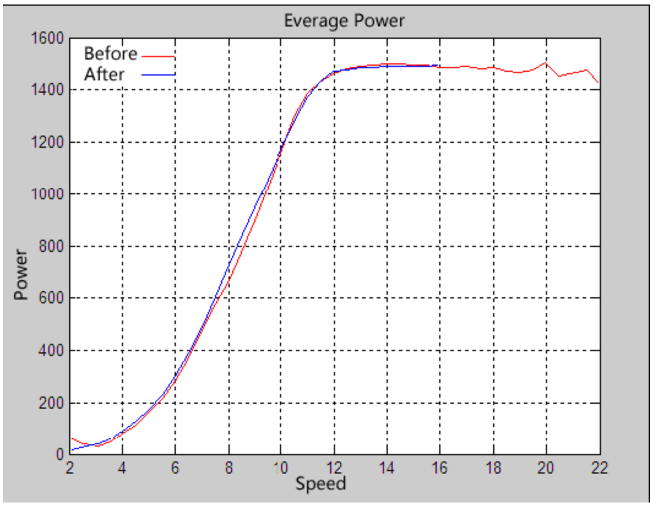

Figure 4: Everage power-wind speed curve per 30s

4. Results

The power output of the pitch controlled wind turbine generator, as a function of the wind. Power and energy production values between improvement at different wind speed levels are shown in Form 1. The improvement rate of energy production is about 0.3%. Energy production between improvement depicted in Figure 5. The output power variation is large (12%). The performance of the pitch angle control is highly effective.

Form 1: Improvement rate at different wind speed levels

Speed (m/s)	Utilization hours of generation(hours)	Before Improvement		After Improvement		Improvement rate (%)
		Power (kw)	Energy production(kwh)	Power (kw)	Energy production(kwh)	
3.0	336.6568303	28.71860722	9668.315276	39.34231509	13244.85909	0.3699242
3.5	379.1815212	50.58429079	19180.62833	59.09065246	22406.08349	0.1681621
4.0	414.3752612	79.78229154	33059.8079	91.24263108	37808.68909	0.1436452
4.5	441.6447878	114.7148376	50663.21013	127.6643305	56382.28616	0.1128842
5.0	460.6923013	166.2135115	76573.2851	176.968254	81527.91219	0.0647044
5.5	471.5086053	219.0358422	103277.2845	231.4925487	109150.7288	0.0568706
6.0	474.3546126	283.0927303	134286.3424	303.7499782	144085.2032	0.0729699
6.5	469.7319972	373.4442909	175418.7326	392.6216963	184426.9735	0.0513528
7.0	458.3448381	477.3689676	218799.6022	487.9829427	223664.4629	0.0222343
7.5	441.0547655	578.7444889	255258.0148	607.9332394	268131.8523	0.0504346
8.0	418.832466	667.1724283	279433.4734	726.4922677	304278.548	0.0889123
8.5	392.7084761	772.9215818	303532.8565	845.6361919	332088.5002	0.0940776
9.0	363.7260165	894.5014704	325353.4566	948.6668643	345054.8195	0.0605537
9.5	332.8982551	1028.227576	342295.1659	1057.167673	351929.2736	0.0281456
10.0	301.1718702	1157.214903	348520.5765	1172.535705	353134.7712	0.0132394
10.5	269.3981897	1297.904552	349653.1366	1277.441057	344140.3082	-0.015767
11.0	238.3125559	1385.455395	330171.4163	1374.151449	327477.5439	-0.008159
11.5	208.5219684	1430.802848	298353.8261	1433.778388	298974.2916	0.0020796
12.0	180.500531	1459.787493	263492.4176	1469.899317	265317.6072	0.0069269
12.5	154.5918074	1482.510838	229184.03	1476.198958	228208.265	-0.004258
13.0	131.0168916	1491.496821	195411.2772	1484.193882	194454.4689	-0.004896
13.5	109.8868298	1493.076222	164069.4127	1487.015878	163403.4607	-0.004059
14.0	91.21798479	1499.744571	136803.6775	1488.828619	135807.9464	-0.007279

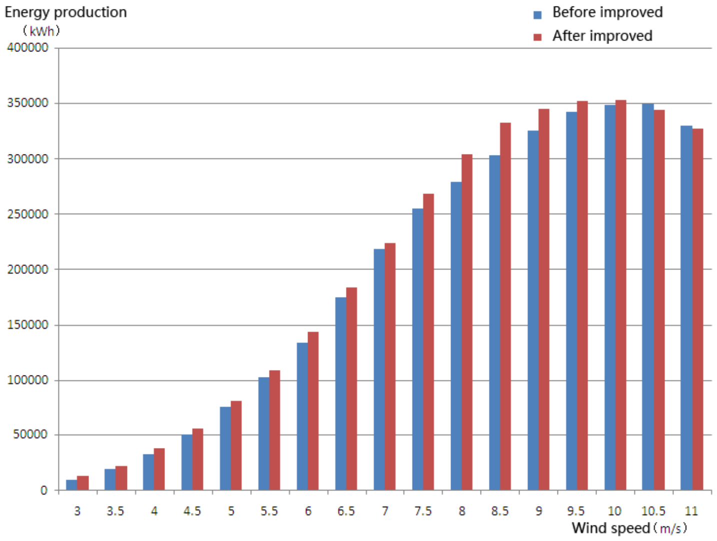

Figure 5: Energy production at different wind speed levels

Form 2: Annual electricity energy production (AEP) and capacity factor improvement

1.5MW (82m blade)	Before improved	After improved
Rated power(kW)	1500	1500
AEP(kWh)	3916991.55	4063224.71
Capacity factor (%)	29.8	30.9
Capacity factor(hours)	2611	2709

Conclusion

This paper has presented a simplified improved modeling and simulation of a variable speed variable pitch wind turbine. The proposed control system has applied in Shijingao wind farm which improved annual electricity energy production (AEP). The capacity factor is from 29.8% to 30.9%, and the hours of wind turbine capacity increased by 98 hours. An improved pitch angle control for 1.5MW variable-speed wind turbine system is compared with the proposed schemes.

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