Kulaib, A. M. & Khalafallah, M. G., Journal of the Association of Arab Universities for Basic and Applied Sciences, Vol. 5, 2008, 37-46

Effect of Blade Surface R4oughness on the Wind Turbine Performance

[1]Kuliab, Aboelyazied M. & [2]Khalfallah, M. G.

[1]Mechanical Power & Refrigeration Dept.,
College of Technological Studies, PAAET, Kuwait
Koluib@hotmail.com
[2]Mechanical Power Dept., Faculty of Engineering,
Cairo University, Egypt.

ABSTRACT

Suggestions for improving the efficiency and power production of a horizontal axis, stall-regulated wind turbine is proposed in this paper. Changing the local roughness on the blade surface to improve the wind turbine performance is discussed. The study included the effect of roughness grade, size and location of roughened area. Two different roughness values (P150 and P100) were utilized and their data were compared to those of a smooth surface. The investigation was performed on the Nordtank 300 kW horizontal axis, stall-regulated wind turbine that exists in Wind Energy Technology Center (WETC) at Hurghada, Egypt. The experimental work covers eight rectangular rough area cases having a width ratio of 2.5%, 5%, 7.5% & 10% of chord length and a length of 10% & 20% of blade length from tip side. Experimental results indicated that the power output of the wind turbine is improved at condition of low annual wind speeds as a result of increasing local surface roughness at blades tip.

KEYWORDS: Wind turbine, Blade surface roughness, Performance.

INTRODUCTION

The performance of the wind turbine is an important measure as the economy of wind turbines, to a large extent, is affected by the ability of the turbine to produce power over a wide range of wind speeds. The present study of wind turbine performance was carried out for the case of steady state of wind flow on a real wind turbine. Under unsteady conditions flow, particular difficulties are encountered in characterizing the amplitudes and frequencies of the aerodynamic forces whenever the flow is not well defined, such as in stall regime. Also, it is necessary to decide how much power a unit should be capable for generating electrical energy. This is because the main factor, which affects the wind turbine sales, is its power production rate as function of wind speed. On the other hand, the increasing importance of wind power encourages the development of new methods for increasing wind turbine efficiency especially at low wind speeds. This is because reduction of wind speed away from design value greatly reduces output as power produced is proportional to the cube of wind speed.

Experimental studies on airfoil performance (Long Ze-quiang et al, 1995) (Abdel-Rahman et al, 1997) show that locally enhanced surface roughness can in certain circumstances increase the lift-drag ratio of an airfoil. To investigate the effect of increasing roughness in some areas of airfoil surface, the incompressible viscous flow equations are solved using conformal transformation with the stream function-vorticity-function method, and a roughness band is simulated by locally modifying the viscosity. The resulting lift and drag are evaluated for different wind velocities and angles of attack (Long Ze-quiang et al, 1995).

In an another research work (Zhong et al, 1998), three different wind turbine profiles were subjected to simulated velocities of 30 and 60 m/s at angles of attack of 5, 10, 15 and 25°. A roughness band of 20% of chord was placed in three different positions in each case, and values of lift and drag coefficients and lift-drag ratio were computed for all combinations. When the roughness band is placed on the lower surface near to the trailing edge, the lift force increases more rapidly than the drag, causing the lift -drag ratio to increase. Also the mentioned study recommends that, for moderate angles of attack the optimum position for a roughness band intended to increase the lift-drag ratio should be adjacent to the trailing edge on the lower, i.e. pressure surface.

The wind turbine units located in the wind farm belonging to The Wind Energy Technology Center (WETC) have their nominal power at wind speed of about 13 m/s. The Center is located 12.5 km north to Hurgada city, Egypt. The farm area is about 2.5 km x 1 km with the length parallel to the coastline. The annual mean wind speeds at this site deteriorated greatly in last years due to changes of site surface roughness as a result of Hurghada city growth. The average mean wind speed is about 6 m/s. The power outputs of the installed wind turbine units do not reach now their nominal values and hence the capacity factor of the wind farm was affected very much by the annual wind speed reduction. So, the objective of the present work is to investigate the possibility of improving the power output of a stall-regulated, horizontal axis, 300 kW wind turbine by increasing blade surface roughness at some locations.

EXPERIMENTAL SET-UP AND PROCEDURE

The wind turbine has three-bladed upwind turbine rotor with fixed cantilevered blades NACA 63200 having a length of 14.2m and the total rotor diameter is 31m.The rotor is held by two bearings, the rated speed is 34 rpm and rated power is 30 kW. The wind turbine is manufactured by Nordtank Company, Denmark. The gearbox is mounted on the main shaft behind the bearing and a torque stay is led to the machine foundation. The gearbox and the generator are connected with a flexible clutch. The generator is induction type and mounted on the end of the nacelle and its speed is 1500rpm. Yawing of the machine is carried out by an electric motor controlled by a wind vane mounted on the top of the nacelle. The electric control system is mounted in a box at the ground. The tower is tubular and its height is 30.5m and it is mounted as two sections. The Nordtank 300kW wind turbine has been equipped for testing by many of measuring systems. Continuous measurements, recording and analysis of wind speed, power output, torque and other parameters are carried out. When the power for the generator is passing a lower level, the generator of the turbine is disconnected. The stop wind speed value is at 25m/s.

The measuring sensors were mounted at different locations on the nacelle of turbine. The measurement of the electrical power output by the turbine was carried out by three-current transformers, one for each phase, and using a power converter that converts the signal to a voltage signal. The current is measured with a separate current converter, which is positioned on each phases. The electrical power sensor measures the true RMS value of the active power. This sensor was mounted on the electric grid side of the wind turbine, so that it is only the net power of the wind turbine that is measured. Power consumption by the turbine own equipment in that connection was estimated. The wind speed was measured with a cup anemometer with three cups. The wind speed sensor was mounted at 1m above hub height of the wind turbine. Also the wind direction was measured with a wind vane system. The wind vane sensor was used to sort out the data within the measurement sector. All measuring sensors were connected to a data acquisition system, which is capable of collecting data for all channels of sensors. Data was collected continuously during the whole measurement period in the operational range of the wind turbine. All of the stored data were averaged over 10 consecutive minutes.

EXPERIMENTAL RESULTS & DISCUSSION

Figure (1) shows a demonstration of the geometry and position of the roughened blade area which was carried out in the study. Figure (2) shows the experimental results of investigating the effect of blade local surface roughness on the power output of Nordtank 300 kW wind turbine.

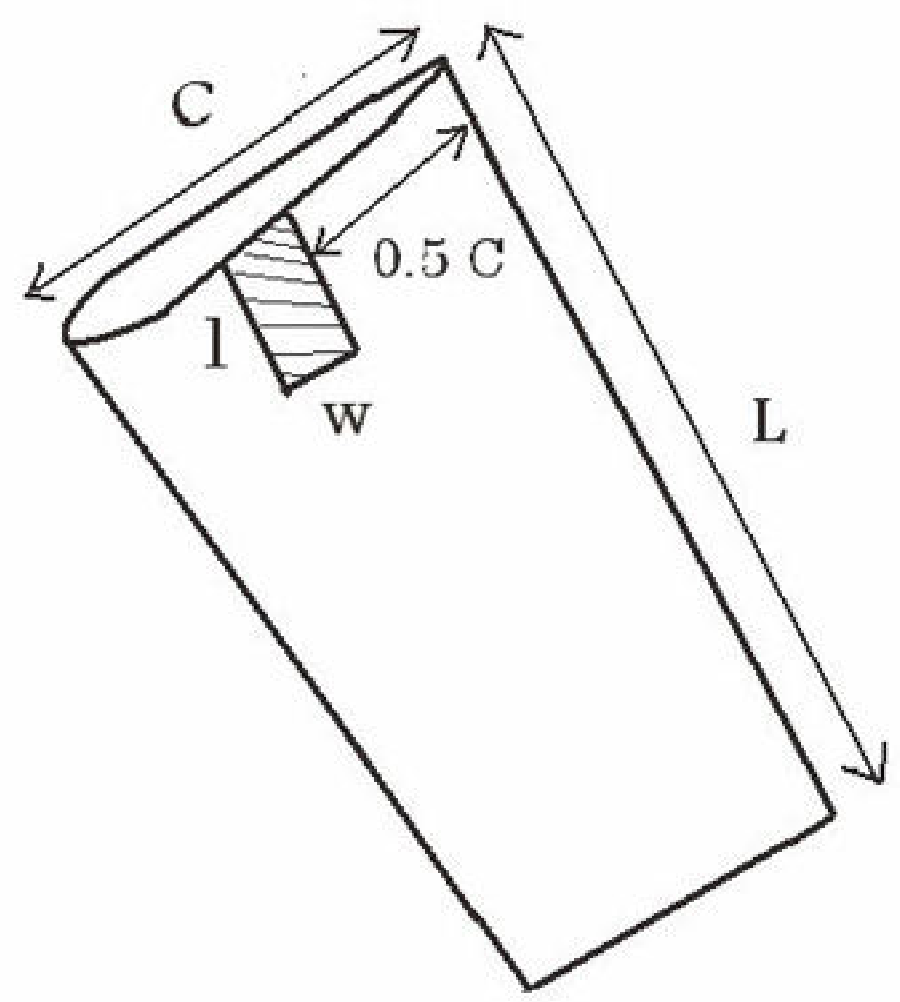

Figure 1. Geometry of the blade roughened area
(Width ratio WR = w/C %, Length ratio LR = l/L %)

The results cover four cases for blade roughened area width ratio 2.5%, 5%, 7.5% and 10% of chord and for a roughness grade size (Roughness Index) P100. The blade roughened area length ratio is 10% of blade length. In all cases of study the change of roughness was realized, on the lower surface of the blades, by gluing a specified roughness tapes (P100 or P150). Figure (1) shows the geometry of the blade investigated roughened area of the wind turbine.

As shown in Figure (2), for the case of (2.5%) roughened area width and 10% length and using P100 roughness index, it is shown that power curve of turbine was slightly improved especially at low wind speeds. The power output continues to improve up to 15m/s wind speed, after that it decreases compared with that for the normal (clean) one. But in case of (5%) roughened area width, the power improvement is higher than pervious case due to increase of the blade roughened area and also the improvement in power output is noticed up to 17 m/s wind speed, but the decrease in power output of turbine is higher than case 2.5% after 17 m/s. This is very clear in case of 7.5% roughened area width, whereas the improvement is higher than 2.5% and 5% cases, but it exists up to 14m/s only, after that the power output decreased greatly.

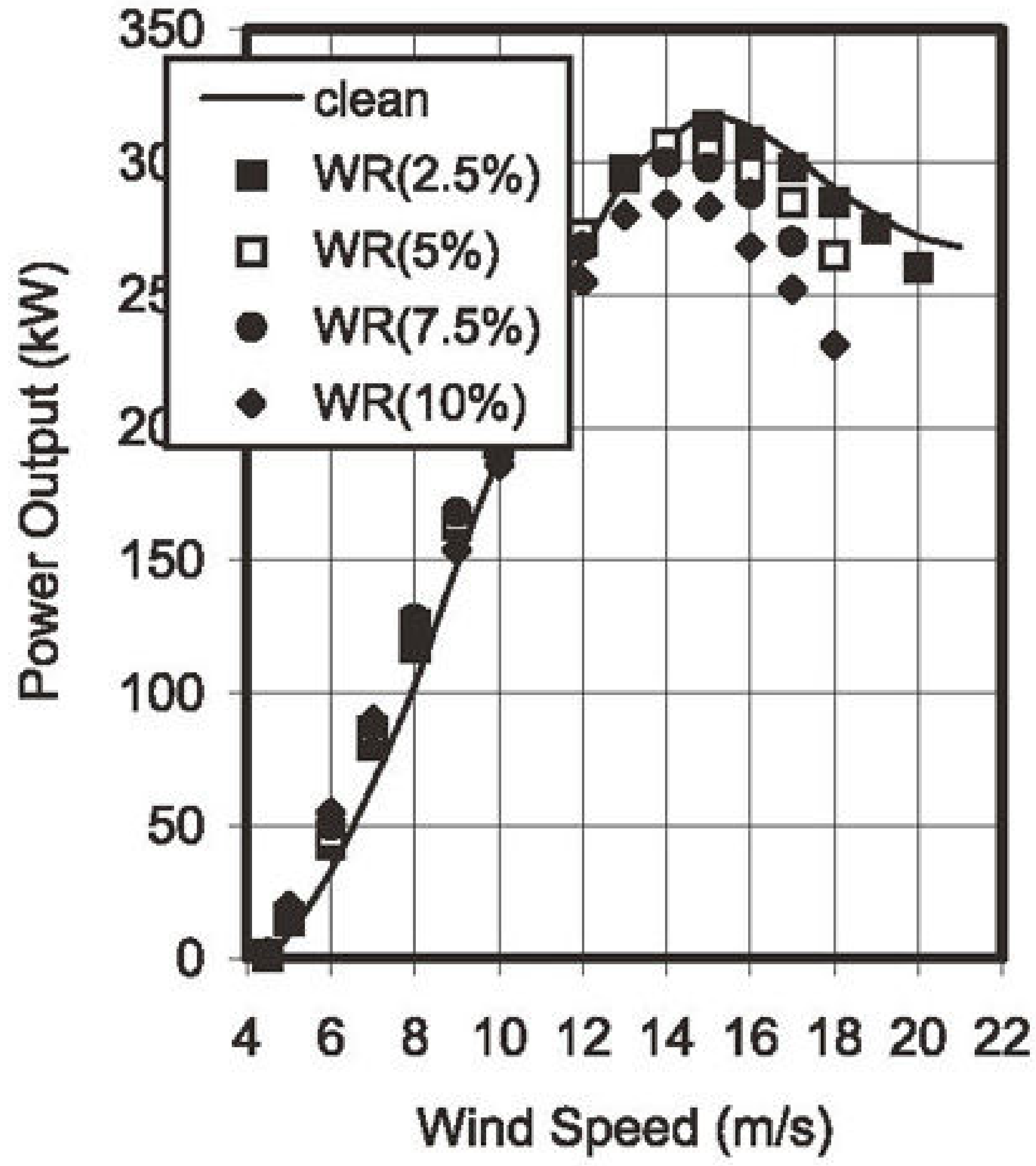

Figure 2. Wind turbine power for various rough-area width ratios.
(Roughness Index P100 - Rough-area length ratio 10%)

The results for the case of 10% roughened area width shows that the rate of improvement is less than the 7.5% case width. The reason of decreasing power output of turbine in case of 10% especially starting from 11m/s wind speed could be due to increase of friction on blade surface as a result of change of flow regime. Whereas, laminar flow is smooth and uniform and resembles the friction-free flow away from the body. Turbulent flow is rough and disorganized. Laminar flow destabilizes and changes to the turbulent flow when certain physical limiting conditions with in the boundary layer flow are exceeded. The process of this change is called transition. So, the increase of blade surface roughened area is limited, because increase blade surface roughness leads to increase of stall (separation) on a longer part of the blade and hence the power produced is decreased.

Figure (3) shows the results of testing Nordtank 300kW wind turbine for the same values of roughened area width as in Figure (2) and for the same value of roughness index but with a roughened area length of 20%. Generally, the power curve improvement in these cases is better than previous cases of 10% roughened area length, and the best case is 7.5% width like that for case of 10% blade length but the maximum wind speed was decreased from previous conditions. Also, it is noted that there is a sensible decrease in power at that value of maximum wind speed. It is concluded that the local blade roughness affects by its length and width on the blade performance of the wind turbine. As blade surface roughness increases the improvements of power increases at low wind speeds only, but power decreases greatly for high wind speeds due to increase of separation on blade surface and consequent decrease of lift and increase of drag. Also, due to increase of wind speed, the Reynolds number increases and it is known that, Reynolds number affects airfoil lift - drag behavior.

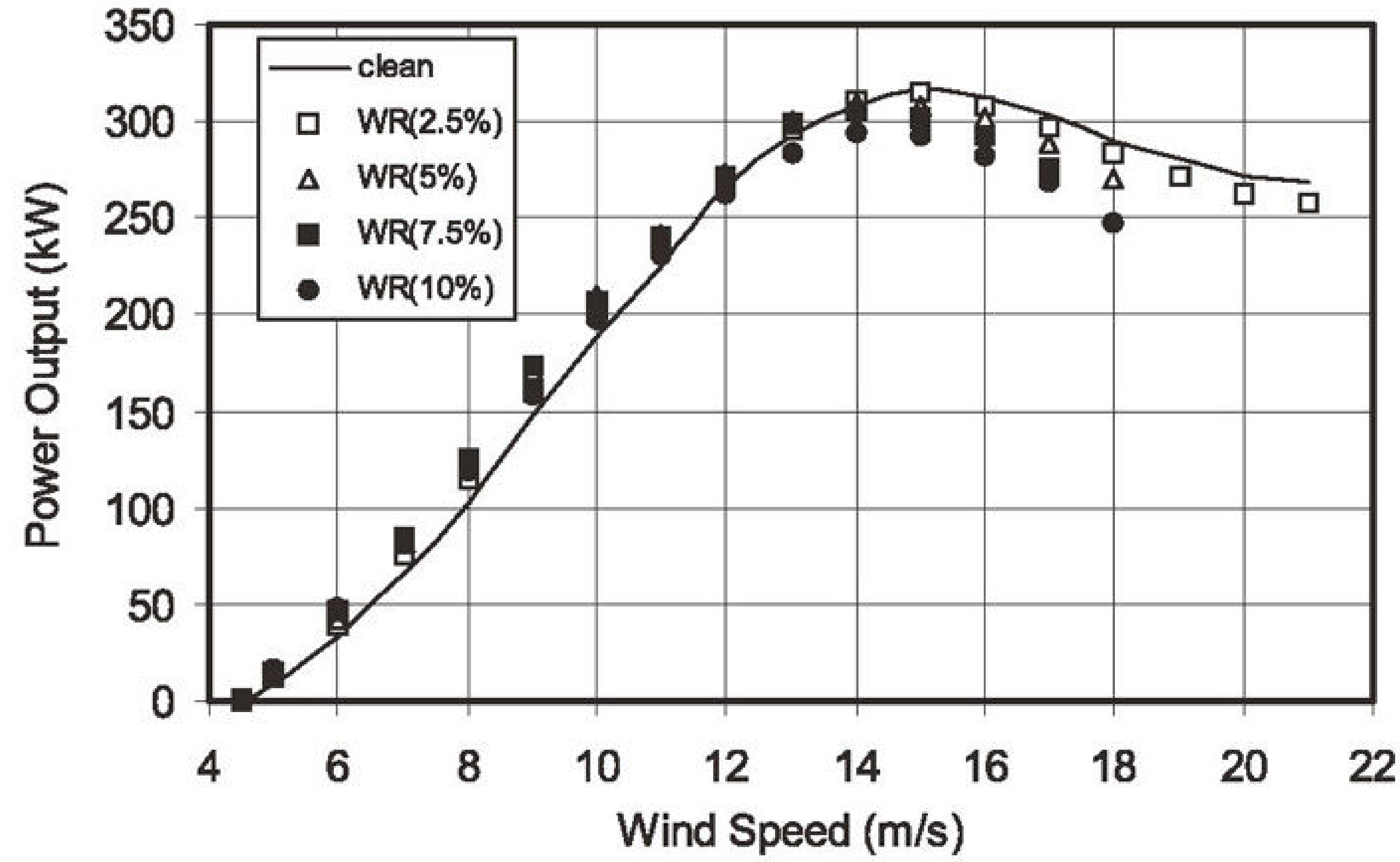

Figure 3. Wind turbine power for various rough-area width ratios.
(Roughness Index P100 - Rough-area length ratio 20%)

The comparison of results in case 10% and 20% roughened area length with same roughness index (P100), shows generally that for all values of blade roughened area width, the 20% length cases have higher power improvement compared with the 10% length cases at low values of wind speed. Also, the wind turbine realizes its capacity value (300kW) at lower values of wind speed relatively. It is shown also that power deteriorates for high wind speeds especially in case of 20% roughened area length.

The effect of second roughness index (P150) for different combinations of blade roughened area width of 2.5%, 5%, 7.5% & 10% and length of 10% &20% is shown in Figures (4) and (5). By increasing the roughness index (roughness grade size) the efficiency of aerofoil increased, and so the power output increased at low wind speeds, but the stalled part of blade increases with increasing wind speed and correspondingly the power output of turbine decreases compared with the other roughness grade size (P100).

The results show that, the best case for local roughness on blade was (5%) width for the two length cases (10%) and (20%).

Figures (6) to (7) show the results of comparison for the two-roughness index cases (P100) and (P150) and for the same locations and dimensions of roughened area. The new improved power curves in various cases are compared with the normal (clean) one. As shown in the figures, the effect of P150 roughness index is very clear at low wind speeds only, but at medium values of wind speeds and especially with high roughened area width, the improvement in the turbine power output is very low. At higher values of wind speed the wind turbine power output decreased very much due to increase of separation and skin friction losses corresponding to turbulent flow

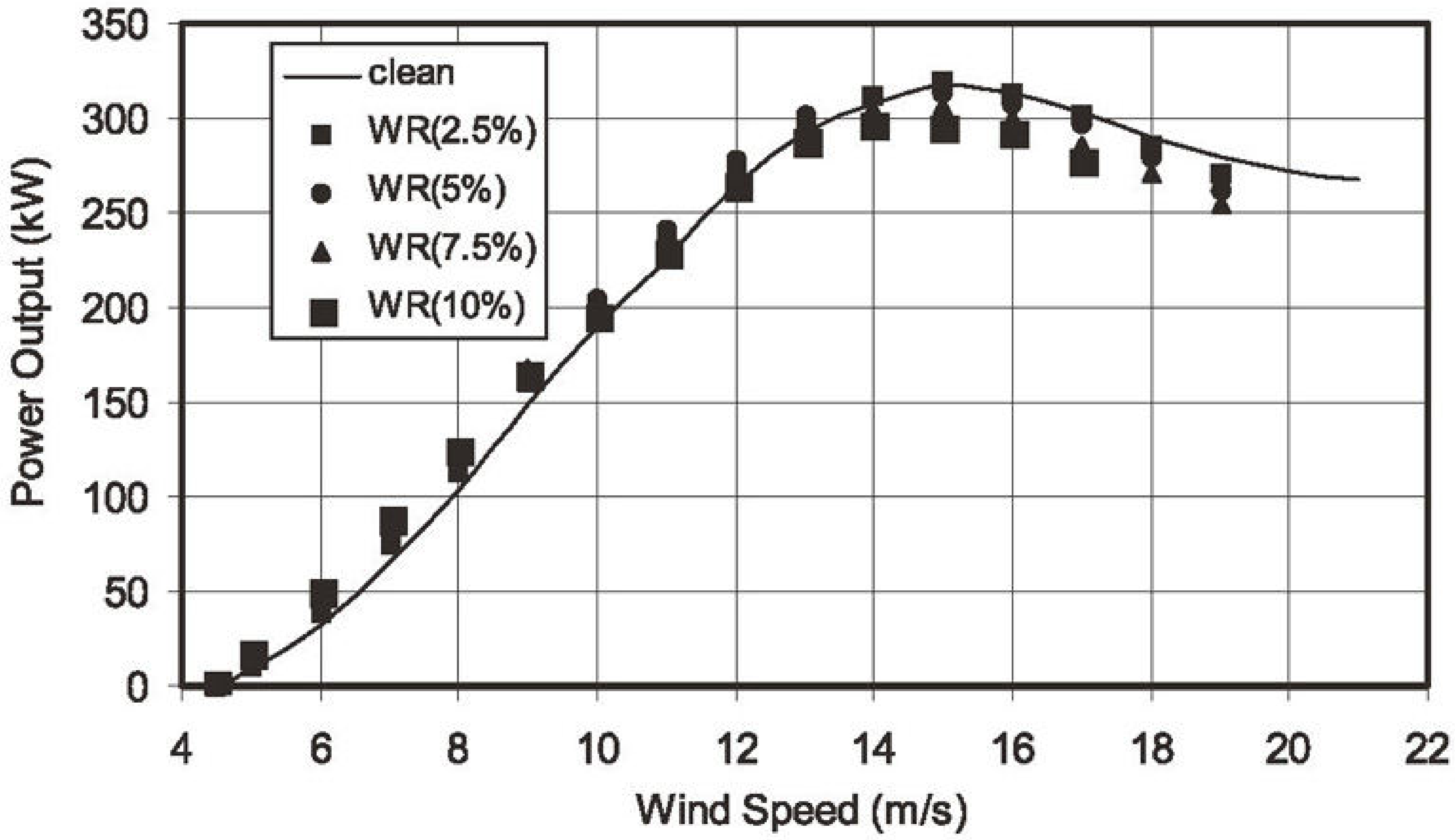

Figure 4. Wind turbine power for various rough-area width ratios. (Roughness Index P150 - Rough-area length ratio 10%)

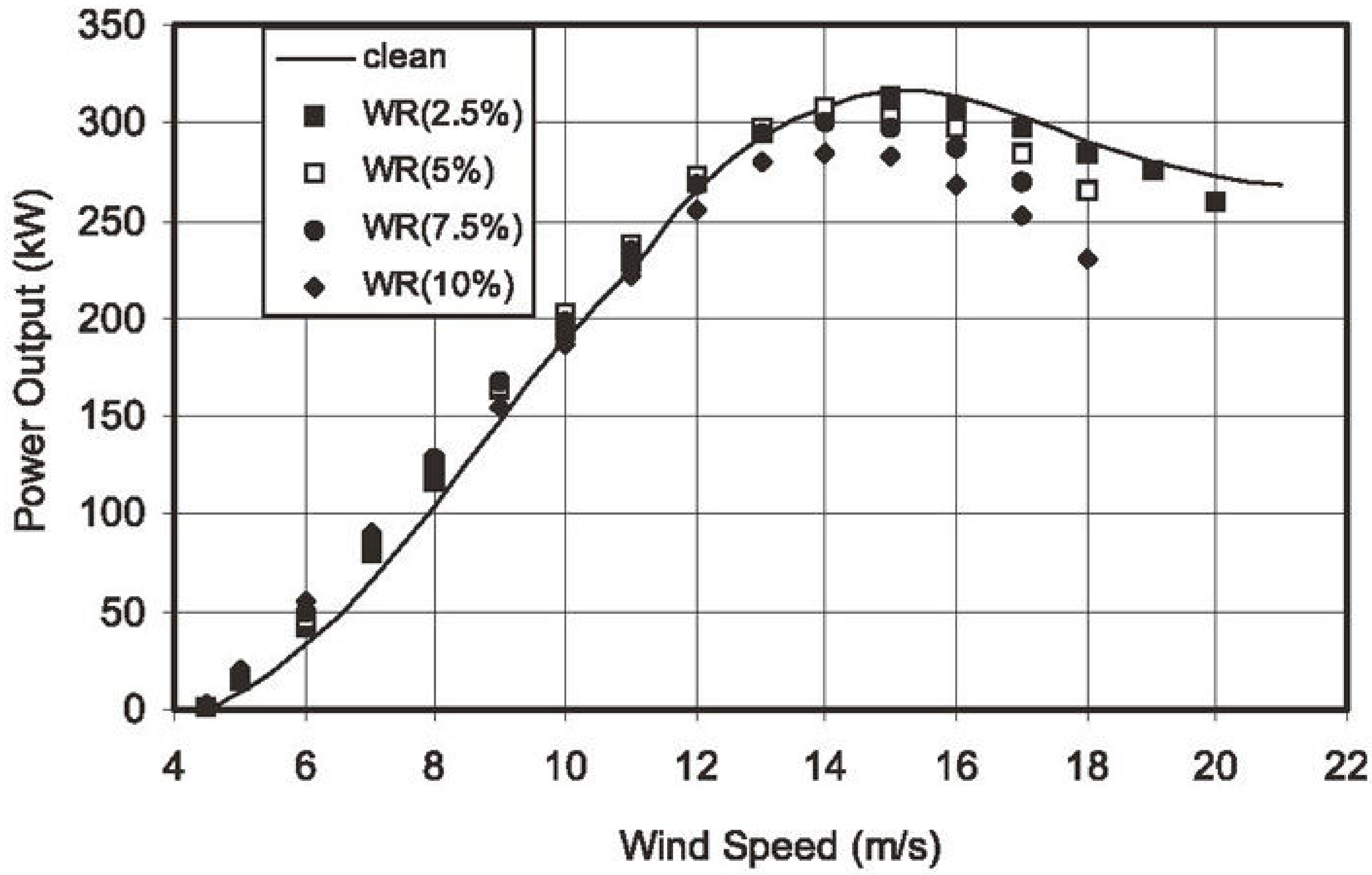

Figure 5. Wind turbine power for various rough-area width ratios. (Roughness Index P150 - Rough-area length ratio 20%)

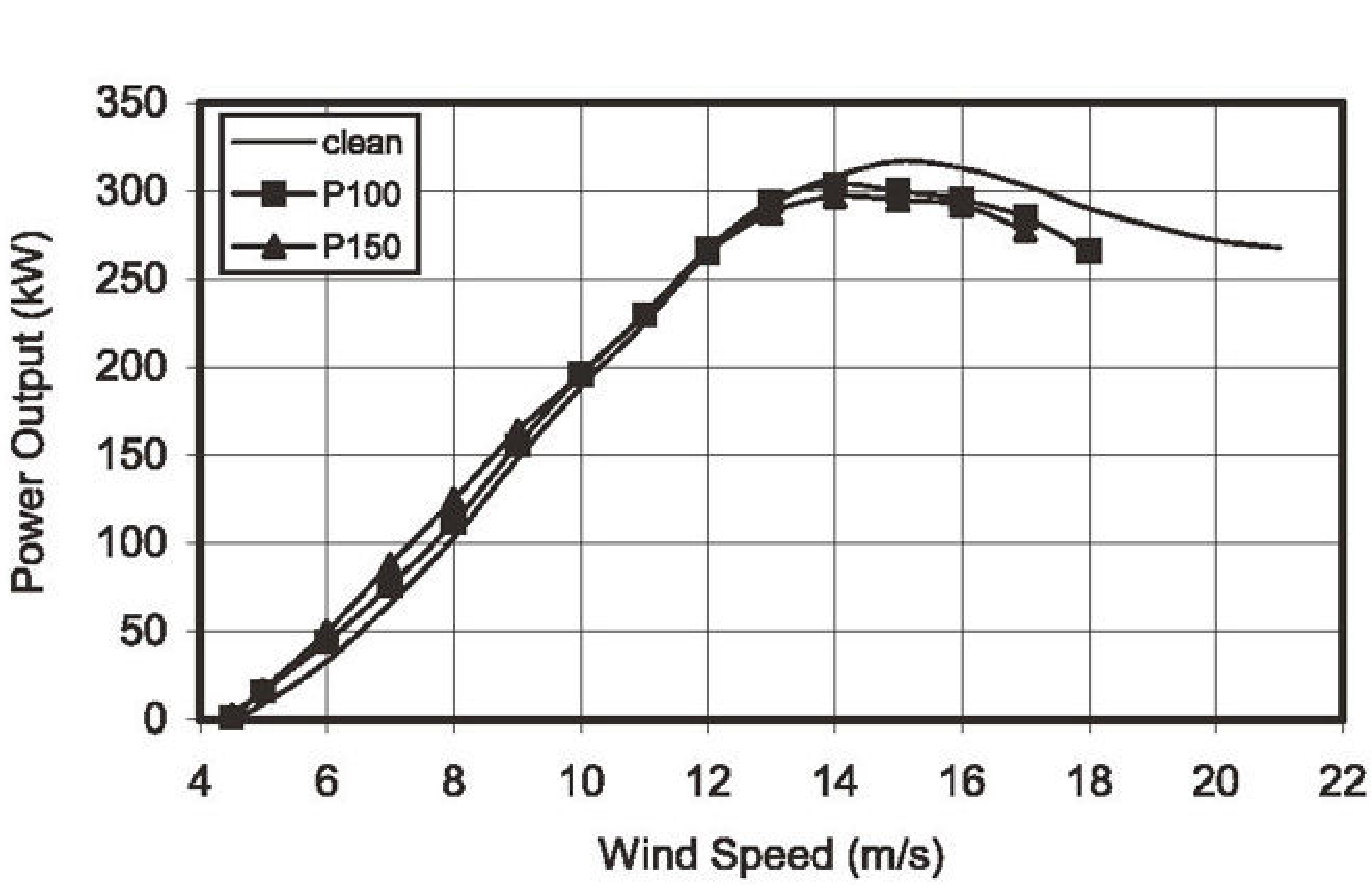

Figure 6. Roughness grade effect on the power output.
(Width ratio 10% & Length ratio 10%)

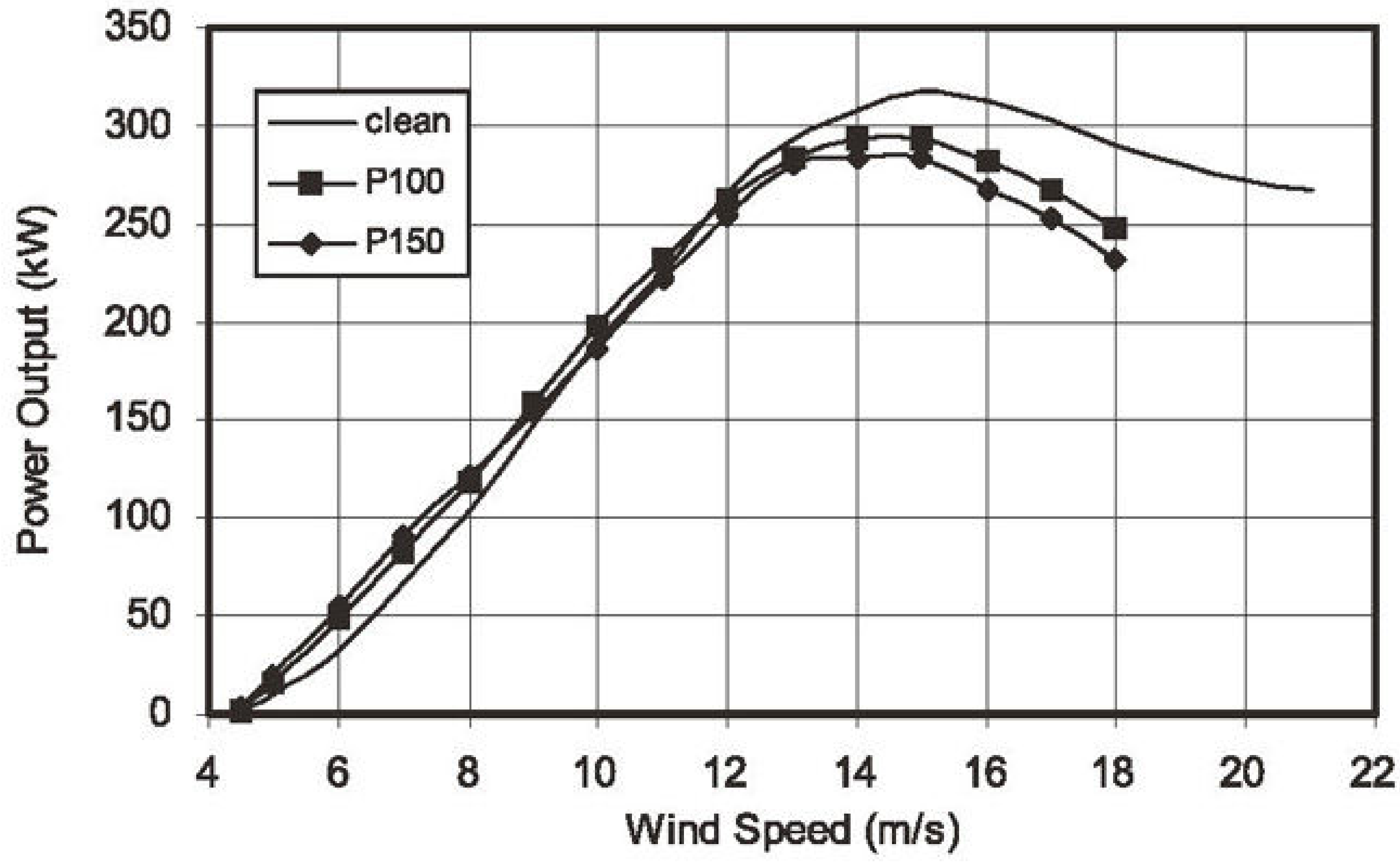

Figure 7. Roughness grade effect on the power output.
(Width ratio 10% & Length ratio 20%)

Figures (8) and (9) show the rate of improvement in wind turbine power for the previously discussed cases. The power output from turbine is improved sensibly for the low wind speeds. The best improvement case is for 7.5% roughened area width, 10% length and roughness index P100. The mean value of power output improvement reaches 21% at 7 m/s wind speed and the maximum percentage value is 56.5% at wind speed 5m/s. At rated wind speed (13m/s) the power increase is 4.8% approximately. In the case of 20% roughened area length, the best improvement in power output is shown for case of 7.5% roughened area width too. In this case, the mean value of improvement in power output is 29.5% at 7m/s and the maximum value is 66.5% at 5m/s, but at rated wind speed it is 2% only as shown in Figure (8).

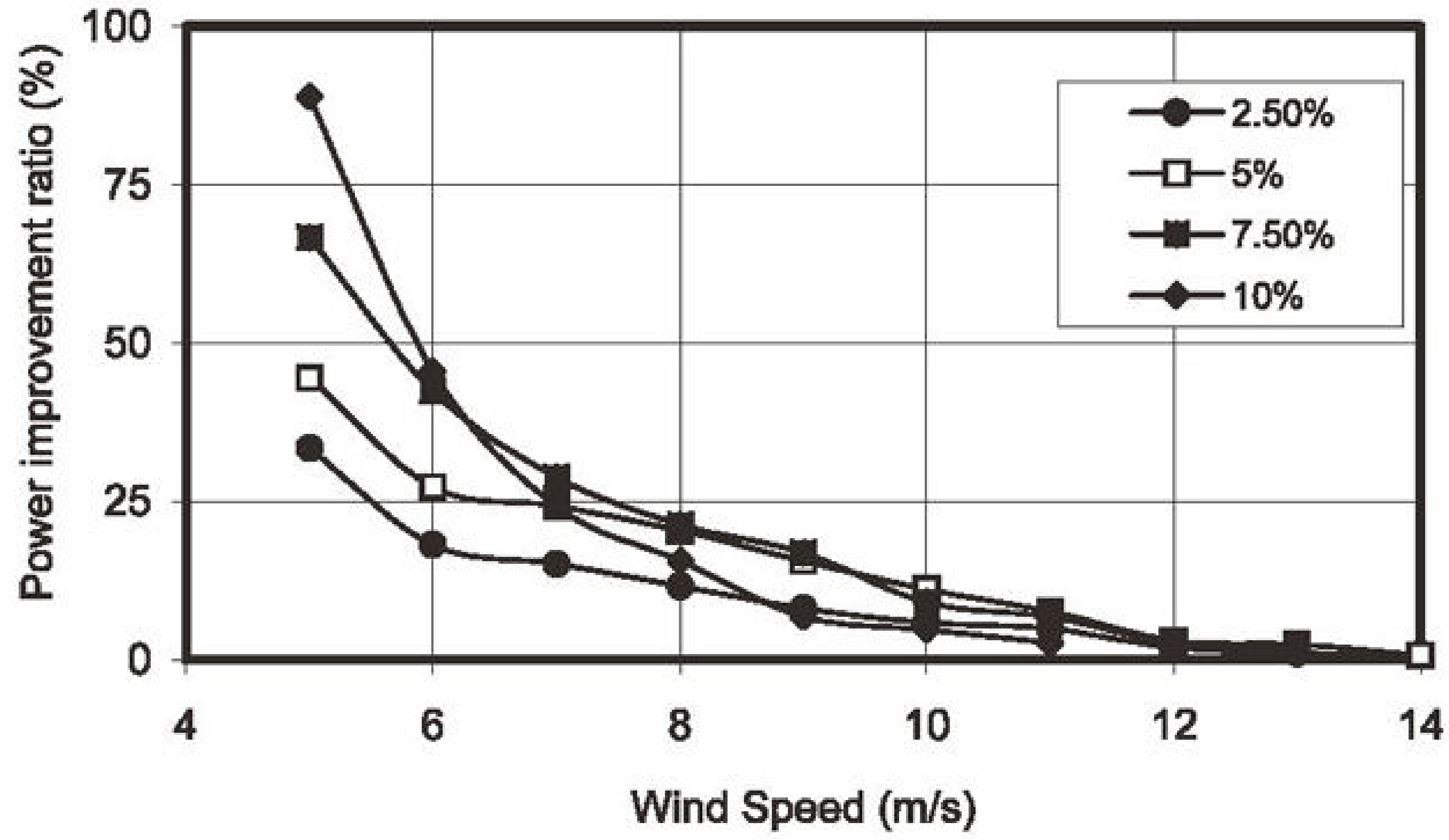

Figure 8. Ratio of power output improvement for roughness index P100 and 20% length ratio.

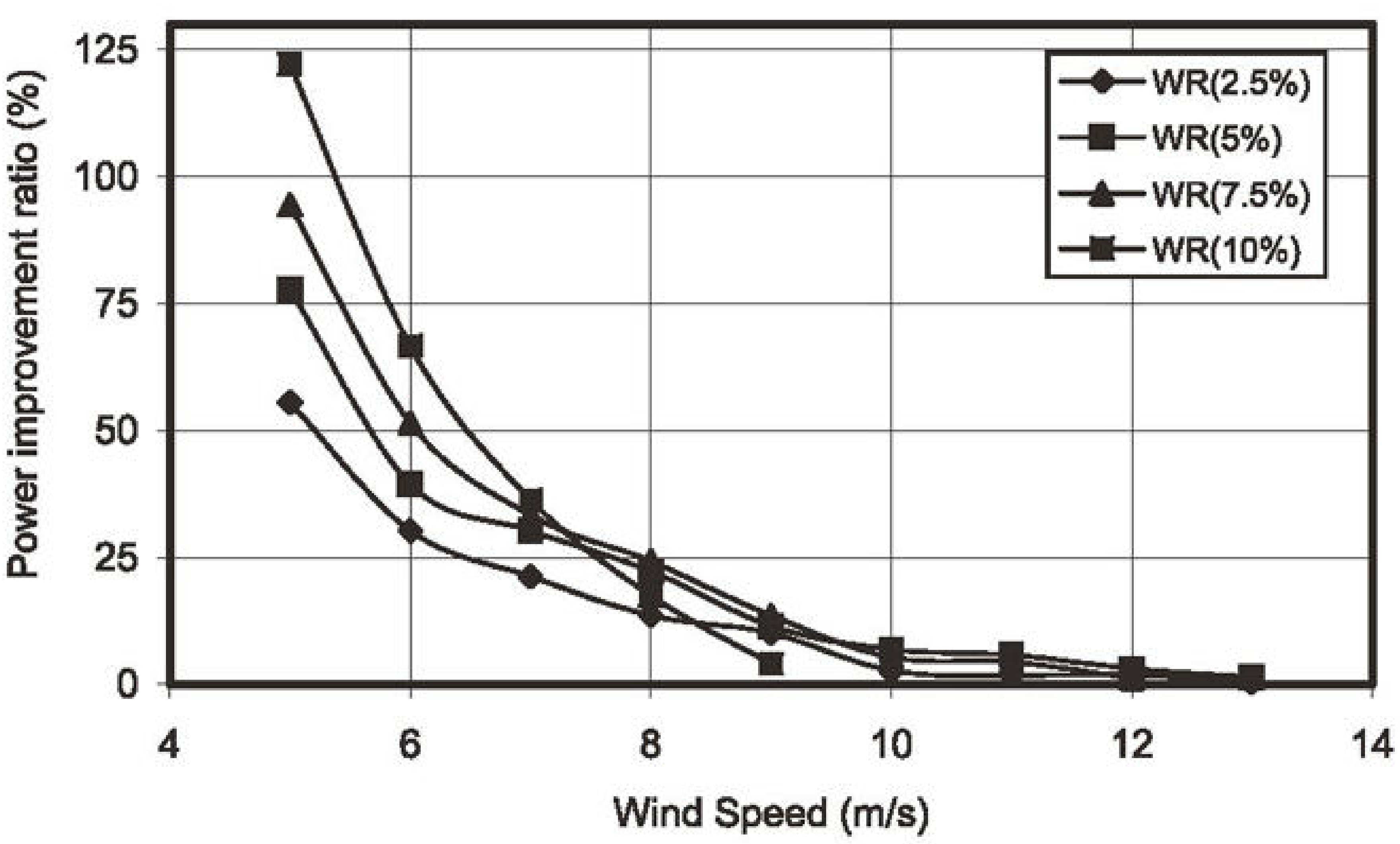

Figure 9. Ratio of power output improvement for roughness index P150 and 20% length ratio.

Generally it is shown that improvement ratio in wind turbine power output decreased by increasing wind speed especially with increase of blade local roughness. But for low blade roughened area width as in case (2.5%), the improvement ratio is lower than other cases at low wind speeds. The case of 10% roughened area width gave the best improvement in power produced up to 8 m/s wind speed only, after that the case 5% was the best. The case 5% roughened area coupled with lengths 10% & 20% gave the best results, whereas the mean improvement ratio in the two cases reached 21.4% and 20% respectively.

In general it is shown that the local blade surface roughness reduces the effectiveness of the airfoil at high wind speeds but at lower values, the local roughness is very useful for augmenting power.

CONCLUSION

The experimental work carried on a stall regulated wind turbine shows that applying artificial local roughness on some places of the blade surface is one of the possible methods to improve the wind turbine performance at sites of low annual mean wind speed as Hurghada wind farm. The annual mean wind speed is about 5.5m/s nearly at nacelle height of wind turbines (31m) in year 2001, while the all types of wind turbines in the farm have its nominal values at 13m/s approximately. In general it is shown that the local blade surface roughness reduces the effectiveness of the airfoil at high wind speed but at lower values, the local roughness was very efficient. The case of 20% roughened area length ratio and 7.5% width respectively gives the best improvement in power output, whereas, the mean value of improvement in power output is 29.5% at 7m/s and the maximum value is 66.5% at 5m/s, while at rated wind speed it is 2% only. For lower blade roughened area width ratio, as in case of (2.5%), the improvement ratio is lower than other cases at low wind speeds but the shortage in power output is the lowest among other cases at high wind speed due to stall regime effects.

ACKNOWLEDGEMENTS

The authors are very grateful to Eng. M. Galal, site manager and Eng. G. Saad director of operation and maintenance sector of WETC for their support and cooperation. Thanks are also due to all NREA & WETC staff. Experimental data and recommendations obtained from Riso center, Denmark is invaluable and is highly appreciated.

REFERENCES

1. Abdel-Rahman, A. A. and Chakroun, W. M., (1997). "Surface Roughness Effects on Flow Over Aerofoils", *Wind Engineering Journal*, Vol. 21, No. 3: pp 125 - 137.
2. Long, Ze-quiang and Xi-Bo, Wang, (1995). "Research of Airfoil Characteristics", Research Report of Chinese Aerodynamic Research Center.
3. Zhong, H., Meng, F., and Chen, Z., (1998). "A Numerical Investigation of the effect on Airfoil Lift-Drag Ratio of Locally Enhanced Surface Roughness", *Wind Engineering Journal,* Vol. 22 No. 3: pp. 143 - 148.
4. Wilson, R. E., Lissaman and Walker, S. N. (1976). "Aerodynamic Performance of Wind Turbines", E.R.D.A./NSF/0414 - 76/1.

تأثير خشونة سطح ريشة توربينة الرياح على أدائها

[1]كليب، أبواليزيد محمد ، [2]خلف الله، محمد جلال

[1]قسم ميكانيكا القوى و التبريد، كلية الدراسات التكنولوجية ، الشويخ، الكويت
[2]قسم الهندسة الميكانيكية، كلية الهندسة، جامعة القاهرة، جمهورية مصر العربية

الملخص

تقدم هذه الدراسة اقتراحاً لتحسين الكفاءة الإنتاجية والطاقة الكلية المنتجة من توربينات الرياح أفقية محور الدوران والتي تعمل بظاهرة التنظيم الانفصالي Stall-Regulated. لقد تم تحليل وبحث تأثير تغيير درجة خشونة السطح في أماكن معينة لريشة التوربينة على أدائها، حيث قد تم دراسة حالات مختلفة لدرجات الخشونة القياسية وذلك بنسب معينة ومحسوبة من المساحة السطحية الكلية للريشة. كما تم مقارنة النتائج العملية لمنحنيات أداء التوربينة في حالة استخدام درجات مختلفة للخشونة الصناعية للريشة مع نتائج الريشة الناعمة (العادية). أجريت هذه الدراسة بمركز تكنولوجيا الرياح بالغردقة (جمهورية مصر العربية) على توربينة رياح نوردتانك 300 كيلووات أفقية المحور، ثلاثية الريشة، وسرعة دورانها 34 لفة/دقيقة. اشتملت النتائج العملية للدراسة على اختبار خشونة سطح بنسب عرضية مقدارها 2.5% ، 5%، 7.5%، 10% من العرض الكلي للريشة وبنسب طول 10%، 20% من الطول الكلي للريشة وبدرجات خشونة قياسية P150، P100. كان من أهم نتائج هذا البحث أن كفاءة إنتاج توربينة الرياح من الطاقة الكهربائية المنتجة تتحسن وذلك عند استعمال خشونة سطح للريشة ناحية المقدمة القائدة للريشة عند مؤخراتها(Blade tip of leading area) وذلك عند تشغيل التوربينة في ظروف سرعات رياح منخفضة أو متوسطة نسبياً.