International Journal of Electrical, Electronics and Mechanical Controls
ISSN (Online) : 2319-7501
Volume 3 Issue 1 January 2014
Manuscript ID : ISSN23197501-V3I1M1-012014

A REVIEW ON: WIND POWER PARAMETERS & WIND TURBINE GENERATORS

PALLAVI KASHYAP
M.Tech.
Electrical Engineering Dept.
DIT, DEHRADUN

MR K. VENKATESHWARLU
M.Tech.
Asst. Prof.
Electrical Engineering Dept.
DIT, DEHRADUN

MR P.S. JAGADEESH KUMAR
M.Tech.
Associate Prof.
Electrical Engineering Dept.
DIT, DEHRADUN

International Journal of Electrical, Electronics and Mechanical Controls
ISSN (Online) : 2319-7501
Volume 3 Issue 1 January 2014
Manuscript ID : ISSN23197501-V3I1M1-012014

I. ABSTRACT

The aim of this paper is to give a brief description about the power parameters and generator of wind energy conversion system. The power parameters based on power coefficient, power efficiency, power curve and tip speed ratio is explained. It is known that, generator is used to convert mechanical energy into electrical energy. Two types of generators are most commonly used in WECS i.e., synchronous generator and induction generator. The synchronous generators have DC excitation as well as permanent magnet excitation. The whole description is given in the rest part of the paper.

KEYWORDS: - Power parameters, synchronous generators, induction generators.

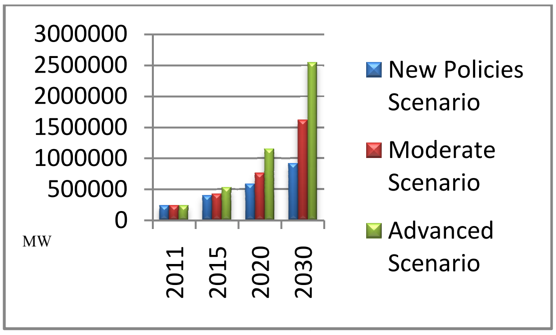
II. INTRODUCTION

In recent years, renewable energy is the most important form of energy due to its various forms, free availability and non-polluting properties. In this renewable energy wind energy is one of the famous form of energy being used to produce electricity. In engineering technology this type of energy is known as wind conversion energy. The difference in pressure caused due to (i) Earth's rotation and (ii) Heating of earth surface, causes wind to blow from higher atmospheric pressure to lower atmospheric pressure. [1]

First larger size wind turbine was discovered by Charles Brush in 1888, whose diameter was 17 meter and it used 12 kW generator which was a DC generator. In 1920 to 1950, 2 and 3 blades horizontal-axis WECS was developed. During this period the major change in generator take place i.e. AC generators replaced DC generators. In 1940 to 1960 rural electrification in US and Europe leads to decline in WECS use. [2], [3]

Depending on the wind energy at site the total cost of wind power ranges from 6.5 cents/kWh to 13.5 cents/kWh. By 2015 the wind energy cost will further reduce to about 5.3 cents/kWh to 6.3 cents/kWh making wind energy competitive with conventional source of power. Average life of wind turbine is about 20 years. [4]

The Global Cumulative Wind Power Capacity is shown in the graph below [5]:



III. WIND POWER PARAMETERS [6]-[9]

1. POWER COEFFICIENT: -

With the help of wind blades the kinetic energy of wind is converted into mechanical energy which is used to drive the shaft of wind generator.

The power coefficient C_p use foe converting efficiency in first stage is given us:

$$C_P = \frac{P_{me.out}}{P_w} = \frac{P_{me.out}}{(1/2)\rho A\bar{u}^3} \quad (1)$$

Where,

$P_{me.out}$ – Captured mechanical power

P_w – Available wind power

ρ – Air density

A – Blade swept area

ū – Wind speed

2. POWER CONVERSION EFFICIENCY:-

The total power conversion efficiency from wind to electricity is given by η_l

$$\eta_l = C_p\eta_{gear}\eta_{gen}\eta_{ele} \quad (2)$$

Where, η_{gear} – Gearbox efficiency

η_{gen} – Generator efficiency

η_{ele} – Electrical efficiency

The effective power becomes:

$$P_{eff} = C_p\eta_{gear}\eta_{gen}\eta_{ele}P_w = \eta_l P_w = \frac{1}{2}(\eta_l \rho A\bar{u}^3) \quad (3)$$

3. POWER CURVE: -

Power curve determines the curve between wind speed and the power output of wind turbine. The power output increases with the increase in with the increase in wind speed until it reaches thesaturated point where it is define as the rated output power. At the rated speed with the increase in wind speed the output power will not increase due to activation of power control and wind speed will reach up to cut-out speed where the wind turbine need to be shut down. The cut-in and cut-out speed is defined as the operating limit of wind turbine.

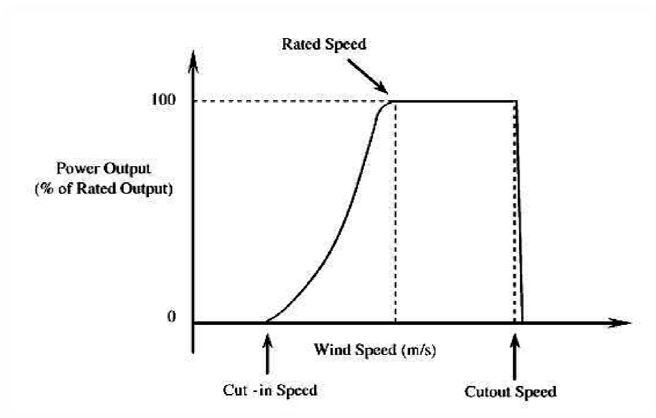


Fig: Typical Wind Turbine Power Curve

4. TIP SPEED RATIO: -

Rotor that space rotates slowly will allow the wind to pass uninterruptedly through the gaps between the blades. A rotor rotating rapidly will appear as a solid wall to the wind. For obtaining maximum or optimal speed ratio it is necessary to design wind turbine to match the angular velocity of rotor. Therefore the relationship between wind speed and rate of rotation of rotor is known as tip speed ratio or lambda.

$$\lambda = \frac{(l+r)\omega}{\bar{u}} \quad (4)$$

IV. TYPES OF WIND TURBINE GENERATORS

1. SQUIRREL CAGE INDUCTION GENERATOR (SCIG):-

SCIG is generally used due to their ruggedness, low cost and low maintenance. For frequency-insensitive load it is able to maintain near constant terminal voltage [10],[11]. Voltage equation for stator and rotor reference frame is [12]-[14]:

$$v_{ds} = R_s i_{ds} + \frac{d\lambda_{ds}}{dt} - \omega_s \lambda_{qs} \quad (5)$$

$$v_{qs} = R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega_s \lambda_{ds} \quad (6)$$

$$v_{dr} = 0 = R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega_s - \omega_r)\lambda_{qr} \quad (7)$$

$$v_{qr} = 0 = R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega_s - \omega_r)\lambda_{dr} \quad (8)$$

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr} \quad (9)$$

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \quad (10)$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds} \quad (11)$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs} \quad (12)$$

The electromagnetic torque is:

$$T_e = \lambda_{qs} i_{ds} - \lambda_{ds} i_{qs} \quad (13)$$

Active and reactive power can be given as:

$$P_s = v_{ds} i_{ds} - v_{qs} i_{qs} \quad (14)$$

$$Q_s = v_{ds} i_{qs} - v_{qs} i_{ds} \quad (15)$$

2. DOUBLY FED INDUCTION GENERATOR (DFIG): -

DFIG also known as wound rotor induction generator have application in WECS. When motoring operation is compared the power handling capability of DFIG is nearly double. It is coupled to wind turbine through gearbox. The gearbox gear ratio should be so chosen so that it's synchronous speed false nearly in middle of the allowable speed of turbine. The stator is directly connected to fixed-frequency utility grid whereas rotor is connected to the grid through back-to-back PWM converter. Rotor side PWM converter is stator flux controlled whichprovides independent control of active and reactive power.[15]

Synchronous reference frame equations are [16]-[19]:

$$v_{ds} = \frac{d\lambda_{ds}}{dt} - \omega_g \lambda_{qs} \quad (16)$$

$$v_{qs} = \frac{d\lambda_{qs}}{dt} + \omega_g \lambda_{ds} \quad (17)$$

$$v_{dr} = R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - \omega_s \lambda_{qr} \quad (18)$$

$$v_{qr} = R_r i_{qr} + \frac{d\lambda_{qr}}{dt} - \omega_s \lambda_{dr} \quad (19)$$

$$\lambda_{ds} = L_m i_{dr} \quad (20)$$

$$\lambda_{qs} = L_m i_{qr} \quad (21)$$

$$\lambda_{dr} = L_r i_{dr} \quad (22)$$

$$\lambda_{qr} = L_r i_{qr} \quad (23)$$

3. WOUND-FIELD SYNCHRONOUS GENERATOR (WFSG):-

In this type of synchronous generator DC excitation take place. Voltage equation for field winding in reference frame is given as[20]:

$$v_{ds} = R_s i_{ds} + p\lambda_{ds} - \lambda_{qs}\omega_e \quad (24)$$

$$v_{qs} = R_s i_{qs} + p\lambda_{qs} + \lambda_{ds}\omega_e \quad (25)$$

$$v_{os} = R_s i_{os} + p\lambda_{os} \quad (26)$$

$$0 = R_k i_{dk} + p\lambda_{dk} \quad (27)$$

$$0 = R_k i_{qk} + p\lambda_{qk} \quad (28)$$

$$v_f = R_f i_f + p\lambda_f \quad (29)$$

$$\lambda_{ds} = L_d i_{ds} + L_{md}(i_f + i_{dk}) \quad (30)$$

$$\lambda_{qs} = L_q i_{qs} + L_{mq} i_{qk} \quad (31)$$

$$\lambda_{os} = L_{ls} i_{os} \quad (32)$$

$$\lambda_{dk} = L_{md}(i_{ds} + i_f) + L_{dk} i_{dk} \quad (33)$$

$$\lambda_{qk} = L_{mq} i_{qs} + L_{qk} i_{qk} \quad (34)$$

$$\lambda_f = L_f i_f + L_{md}(i_{ds} + i_{dk}) \quad (35)$$

The electromagnetic torque in d^e-q^e frame is given as:

$$T_e = \frac{P}{2}(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad (36)$$

Torque and speed are related as:

$$T_e = \frac{2J}{P}\frac{d\omega_e}{dt} + T_l \quad (37)$$

4. PERMANENT MAGNET SYNCHRONOUS GENERATOR (PMSG):-

In PMSG, the DC field winding of rotor is replaced by permanent magnet. In this the excitation field is provided by permanent magnet of coil. Neither they require DC supply for excitation circuit, nor do they have slip rings and contact brushes[21]. Advantages-

i. Elimination of field copper loss
ii. Higher power density
iii. Lower rotor inertia
iv. Robust construction of rotor
v. No gearbox

Stator voltage equation by space vector theory is [22]-[24]:

$$v_d = L_d \frac{di_d}{dt} - R_s i_d + p\omega_r L_q i_q \quad (38)$$

$$v_q = -L_q \frac{di_q}{dt} - R_s i_q + p\omega_r(-L_d i_d + \Psi_f) \quad (39)$$

Where,

R_s- Stator resistance

v_d&v_q- 2-axis machine voltage

i_d&i_q- 2-axis machine current

p- Number of poles

ω_e- Generator electrical rotational speed

Mechanical output torque is given as:

$$T_e = \frac{3}{2}P\,[\,\Psi_f i_q - (L_d - L_q) i_d i_q\,] \quad (40)$$

When, $L_d = L_q = L_s$&$i_d = 0$:

$$v_d = \omega_e L_s i_q \quad (41)$$

$$v_q = -L_s \frac{di_q}{dt} - R_s i_q + \omega_e \Psi_f \quad (42)$$

And electromagnetic torque is given as:

$$T_e = \frac{3}{2}P\Psi_f\, i_q \quad (43)$$

V. CONCLUSION

The study on wind power parameters and generators has been done which give us the brief idea about wind energy conservation system and also the latest scenario has been given. Though this study we came to know about the factors on which wind power depends upon and how the modelling of different generators has been done.

VI. REFERENCES

1. A book on 'Wind Electricity System' by S. N. Bhadra, D. Kastha, S. Banerjee.
2. Practical action, The Schumacher Centre for Technology and Development 'Wind Electricity Generation'.
3. Wind Power Fundamentals Presented by: Alex Kalmikov and Katherine Dykes With contributions from: Kathy Araujo PhD Candidates, MIT Mechanical Engineering, Engineering Systems and Urban Planning MIT Wind Energy Group & Renewable Energy Projects in Action.
4. World Energy Scenarios to 2050: Issues and Options- Hameed Nezhad, Ph.D. Professor of Decision Sciences Metropolitan State University Minneapolis, MN.
5. 'GLOBAL Wind Energy Outlook – 2012' by Global Wind Energy Council.
6. A book on 'Wind Power Generation and Wind Turbine Design' by Wei Tong, *Kollmorgen Corp.*, USA.
7. IEC 61400-12-1. Power performance measurements of grid connected wind turbines, 2005.
8. Anahua, E., Barth, St. & Peinke, J., Markovian power curves for wind turbine. *Wind Energy*, 11(3), pp. 219-232, 2007.
9. Purdue University. 'Smart turbine blades' to improve wind power, http:// esciencenews.com/articles/2009/05/01/smart.turbine.blades.improve.wind.power
10. Rajakaruna, S. and R. Bonert 1993, 'A technique for the steady-state analysis of a self-excited induction generator with variable speed', *IEEE Transactions on Energy Conversion*, vol. 8, pp. 757-61.
11. Slemon, G.R. 1987, 'Modelling of induction machines for electric drives', *IEEE Transactions on Industrial Applications*, vol. IA-25, pp. 1126-31.
12. 'Study and Analysis on the Control of SCIG and its Responses to Grid Voltage Unbalance' M. Benchagra, Student Member *IEEE,* M. Maaroufi Department of Electrical Engineering, Ecole Mohammadia d'Ingénieur, Mohammed V University Rabat, Morocco M. Ouassaid, Member, *IEEE* Department of Industrial Engineering, Ecole Nationale de Sciences Appliquées de Safi,Cadi Aayad University, Morocco.
13. Ching-Yin Lee; Li Chieh Chen; Shao-Hong Tsai; Wen-Tsan Liu; Yuan Kang Wu."The impact of SCIG wind farm connecting into a distribution system" in 2009 power and energy engineering conference, Asia Pacific, pp. 1-7.

14. A Novel Variable-Speed Wind Energy System Using Induction Generator and Six-Switch ACIAC Converter M. Heydaril, Student Member, IEEE, A. Yazdian Varjani2, Member, IEEE and M. Mohamadian3, Member, IEEE Power Electronic and Protection Laboratory (PEP Lab.), Faculty of Electrical and Computer Engineering Tarbiat Modares University, Tehran, Iran.
15. Modeling and Control of a Doubly Fed Induction Generator (DFIG) Based Wind Conversion System T. Ghennam1, E.M.Berkouk2, B.François3 1Laboratoire d'Electronique de Puissance, UER : ELT-EMP, Algiers (Algeria) 2 Laboratoire de commande des Processus, ENP El-harrach, Algiers (Algeria) 3 Laboratoire d'Electrotechnique et d'Electronique de puissance, EC, Lille (France)
16. IEEE transactions on energy conversion, vol. 24, no. 4, December 2009 'Grid Synchronization of Doubly-fed Induction Generator Using Integral Variable Structure Control' Si Zhe Chen, Norbert C. Cheung, Senior Member, *IEEE*, Ka Chung Wong, and Jie Wu.
17. Petersson, T. Thiringer, L. Harnefors, and T. Petru, "Modeling and experimental verification of grid interaction of a DFIG wind turbine," *IEEE Trans. Energy Convers.*, vol. 20, no. 4, pp. 878–886, Dec. 2005.
18. Tapia, G. Tapia, J. X. Ostolaza, and R. J. Saenz, "Modeling and control of a wind turbine driven doubly fed induction generator," *IEEE Trans.Energy Convers.*, vol. 18, no. 5, pp. 194–204, Jun. 2003.
19. K. C. Wong, S. L. Ho, and K. W. E. Cheng, "Direct voltage control for grid synchronization of doubly-fed induction generators," *Electr. PowerCompon. Syst.*, vol. 36, no. 9, pp. 960–976, Sep. 2008.
20. Raina, G. and O.P. Malik 1985, 'Variable speed wind energy conversion using synchronous machine', *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-21, pp. 100-4.
21. Spooner, E., and A.C. Williamson 1992, 'Permanent Magnet Generators for Wind Power Applications', *Proceeding of the 1992 International Conference on Electrical Machines, Manchester*, pp. 1048-52.
22. Modelling and Control Strategy of PMSG Based Variable Speed Wind Energy Conversion System Y. Errami, *Student Member IEEE,* M. Maaroufi Department of Electrical Engineering, Ecole Mohammadia d'Ingénieur, Mohammed V University Rabat, Morocco M. Ouassaid, *Member, IEEE* Department of Industrial Engineering, Ecole Nationale de Sciences Appliquées de Safi, Cadi Aayad University, Morocco.

23. 2013 Third International Conference on Intelligent System Design and Engineering Applications Control of Direct-drive Permanent-magnet Wind Power System Grid-Connected Using Back-to-back PWM Converter Wang xin , Cao Mingfeng, Qiu Li, Chai Lulu, Qin Bin School of Electrical and Information Engineering, Hunan University of TechnologyZhuzhou, China,412008.
24. P.K .Goel, B. Singh, S.S. Murthy, S.K. Tiwari, “Parallel Operation of Permanent Magnet Generators in Autonomous Wind Energy Conversion System”, Proceedings of Industry Applications Society Annual Meeting IASIEEE Conferences , 2010.1 - 8 .