Fuzzy Logic Control of Maximum Power Point Tracking for Inverter based Wind Generators

S.Sundeep[1], G.MadhusudhanaRao[2], B.V.Sankar Ram[3]
[1]Research Scholar, Jawaharlal Nehru Technological University Hyderabad, Telangana, India
[2]Professor of EEE, TKR College of Engineering and Technology Hyderabad, Telangana ,India
[3]Professor of EEE, JNTU Hyderabad, Telangana, India,
sundeep.siddula@gmail.com, gurralamadhu@gmail.com, bvsram4321@yahoo.com

Abstract: This research work presents the wind energy conversion system with maximum power tracking system using an expert system like fuzzy logic. The extraction of the maximum possible power available wind energy is an important area of research among the speed sensorless MPPT control of wind area. This paper presents a power point tracking (MPPT) Technique for high performance wind turbine with induction machines based on expert systems (Fuzzy logic control). The reference speed of the machine is then calculated based on the control of the Tip Speed ratio (TSR). Voltage oriented control of the machine is further integrated with an expert sensorless technique. The fuzzy logic control is proposed here to evaluate the maximum power tracking point by the simulation and the results are shown.

Key words: MPPT, VOC, Fuzzy Logic control, computer simulation, wind energy conversion systems, incremental conductance.

◆

I. INTRODUCTION

Conservation of non-renewable energy motivates to explore the new avenues of resources for electricity generation which could be clean, safe and most valuable to serve the society for a long period. The option came with huge number of alternative sources whichare the part of our natural environment and eco-friendly renewable energy sources. These sources can be better replacement of depleting non-renewable sources in order to meet the growing demand for power due to rapidly growing economy and increasing population. As per World Energy Outlook (WEO)-2010 the prospects for renewable energy based electricity generation hinge critically on government policies to encourage their development. Worldwide, the share of renewables in electricity supply increases from 19% in 2008 to 32% in 2035 in the New Policies Scenario; it reaches only 23% in the Current Policies Scenario, but 45% in the 450 Scenario. In all three scenarios, rising fossil-fuel prices and declining costs make renewables more competitive with conventional Hydropower has been the dominant renewable source of electricity for over a century. The recent strong growth in new technologies for wind power and solar photo voltaic (PV) has created expectations among policy makers and the industry alike that these technologies will make a major contribution to meet growing electricity needs in the near future. It has also been forecasted that the increase in electricity generation from renewable sources between 2008 and 2035 will be primarily derived from wind and hydro power, which will contribute 36% and 31% of the additional demand respectively [1]. Wind power is projected to supply 8% of global electricity in 2035 up from just 1% in 2008. In the year 2010 the wind capacity has reached 196.630GW worldwide and it will reach 240GW by the end of 2011 as shown in Fig 1[2].

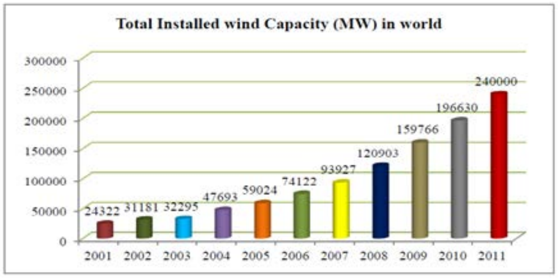
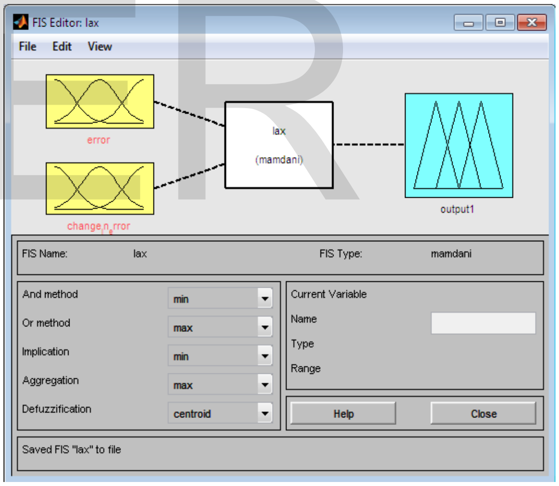


Fig1. Statistical data of total installed wind capacity in world

In high performance grid connected wind generators, the converter control is incorporated with any maximum power point tracking (MPPT) technique.According to the MPPT techniques, two main methods are presented in this paper: One is based on the torque control, and the other is based on speed control of the machine. The first method is based on the analytical expression of the optimal power torque as a function of the rotational speed of the machine, which is given as a reference to the power unit connected to the wind turbine. [3] The advantage is the simplicity of the technique, but the drawback is the torque control based drives, the base speed of the machine and the turbine speed should be, in any case, supervise online to prevent the system from having dangerous speed oscillations and go beyond the rated speed. Furthermore, the torque control means that no free variation result - the wind speed in a sudden torque variation in the machine. These rapid variations in torque do not lead to significant speed of the turbine due to the inertia of the system and thus create an inadequate mechanical stress on the shaft.By any contrast, in speed control of generators, at any sudden changes in wind speed is filtered by the control loop of the machine speed. In any case, torque controlled generators, the speed control is also essential for the generator to operate at high values of wind speed, where the values of power and torque exceed the rating of the machine. Finally, the torque control of the machine is based on the estimated torque, which can be affected by parameters mismatch and variations, with the consequent reduction of the maximum power. This is not the case in the speed control mode where the speed of the machine is generally measured with an encoder and the torque control loop is within the speed. Speed Control MPPTs are based on the incremental conductance method [18]–[22] or in appropriate relationships to calculate the reference speed of the optimum power unit on the basis of suitable modeling of wind turbine [4] - [8].

II. FUZZY RULE BASED SYSTEM

The fuzzy logic controller (FLC) is proposed to find the MPPT [23]. The fuzzy logic control is somewhat easy to implement, as it requires no mathematical model to any system. Since it gives a study performance, and interest in the practical application of fuzzy logic is growing quickly. Fuzzy logic controllers are used to control important electrical and electronic devices as well as industrial processes. Many control methods based on fuzzy logic is possible to define control laws rather than equations because a fuzzy controller can be constructed based on empirical rules.A set of rules is constructed for classifying water quality as highly acceptable, just acceptable, not acceptable (rejected) in order to aggregate the set of attributes. Each rule has antecedent propositions connected together using AND operator, resulting in some consequences .The assertions related to its antecedent part are obtained from the users, which are imprecise or fuzzy. Thus a fuzzy rule based system can be developed for the knowledge representation or reasoning process. Here the partial matching is allowed and the analyst can estimate the extent to which the assertion satisfies the antecedent part of the rule contrary to the rule- base system which examines as to whether the antecedent part is satisfied or not. Fuzzy Logic control incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FL model is empirically-based, relying on an operator's experience rather than their technical understanding of the system. For example, rather than dealing with temperature control in terms such as "SP =500F", "T <1000F", or "210C <TEMP <220C", terms like "IF (process is too cool) AND (process is getting colder) THEN (add heat to the process)" or "IF (process is too hot) AND (process is heating rapidly) THEN (cool the process quickly)" are used. These terms are imprecise and yet very descriptive of what must actually happen. Consider what you do in the shower if the temperature is too cold: you will make the water comfortable very quickly with little trouble. FL is capable of mimicking this type of behavior but at very high rate.



FIS Name: lax
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Saved FIS "lax" to file

Fig 2: Membership function for MPPT

A. Fuzzification

The numerical input variables CO and InCO are converted into linguistic variables based on the membership functions of Fig. 2 with a=0,18 and b=0,36 for CO and a=0,14 and b=0,28 for IncCo, respectively. Five linguistic variables are considered, they are PB (positive big), PS (positive small), ZE (zero), NS (negative small), NB (negative big).

B.Inferencing

The logical products for each rule must be combined or inferred (max-min'd, max-dot'd, averaged, root-sum-squared, etc.) before being passed on to the defuzzification process for crisp output generation. Several inference methods exist

C.Defuzzification:

The RSS method was chosen to include all contributing rules since there are so few member functions associated with the inputs and outputs. For the ongoing example, an error of -1.0 and an error-dot of +2.5 selects regions of the "negative" and "zero" output membership functions. The respective output membership function strengths (range: 0-1) from the possible rules (R1-R9) are:

A "Fuzzy Centroid" Algorithm

The defuzzification of the data into a crisp output is accomplished by combining the results of the inference process and then computing the "fuzzy centroid" of the area. The weighted strengths of each output member function are multiplied by their respective output membership function center points and summed. Finally, this area is divided by the sum of the weighted member function strengths and the result is taken as the crisp output. One feature to note is that since the zero center is at zero, any zero strength will automatically compute to zero. If the center of the zero function happened to be offset from zero (which is likely in a real system where heating and cooling effects are not perfectly equal), then this factor would have an influence. This type of the fuzzy is connected to the wind based system is as shown in figure 3.

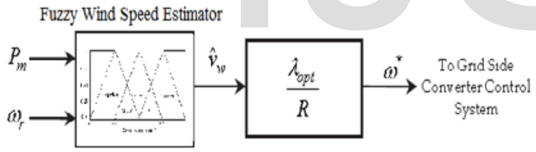


Fig 3: Fuzzy-based MPPT controller module

D. Tip speed ratio control (TSR):

A wind speed estimation based TSR control is proposed in [3] in order to track the peak power points. The wind speed is estimated using neural networks, and further, using the estimated wind speed and knowledge of optimal TSR, the optimal rotor speed command is computed. The generated optimal speed command is applied to the speed control loop of the WECS control system. The PI controller controls the actual rotor speed to the desired value by varying the switching ratio of the PWM inverter. The control target of the inverter is the output power delivered to the load. The block diagram of the Fuzzy-based MPPT controller module is shown in Fig. 3. The inputs to the Fuzzy are the rotor speed ω_r and mechanical power P_m. The Pm is obtained using the relation

$$P_m = \omega_r \left(J \frac{d\omega}{dt} \right) + P_e$$

Additionally, the VOC system on the machine side has been integrated with an intelligent speed sensorless technique. The proposed wind-generation system is thus without speed sensors, which means that, it does not require the sensor for measuring the free wind speed, since the free wind speed is estimated by the FUZZY, and also, it does not require the machine-speed sensor (encoder). Finally, a comparison with a classic Incremental conductance MPPT has been made on a real wind-speed profile.

III. SYSTEM CONTROL TECHNIQUE

1. Incremental ConductanceMethod:

Many algorithms have been developed for MPPT of a PV array [9] - [13]. Among the techniques of MPPT, the perturbation method and observation (P & O) is the most popular due to the simplicity of its control structure. However, in the present scenario it is rapidly changing with weather conditions, the P & O MPPT algorithm can be confused due to the fact that it is not able to distinguish variations in the output power caused by the tracker of disruption caused by varying irradiation [14] - [16]. Recently, improved P & O MPPT algorithms for changing environmental conditions have been proposed by Sera et al. [17]. The drawback of this method of P & O is the need to perform an additional measurement of energy in the middle of the MPPT sampling period to separate the effects of change of irradiation tracker disturbance. Herein, in order to generate the proper reference voltage under irradiation MPPT rapidly changing strong MPPT controller has been proposed. In this algorithm, the grid d-axis current component reflects off the power supply and the error signal of a voltage regulator external proportional-integral (PI) is designed to reflect the change in the power caused by irradiation variation. Therefore, with this information, the proposed algorithm can greatly reduce the power losses caused by tracking errors fast changing dynamic conditions of time. The superiority of the new proposed method is obtained based on the simulation results. The concept of incremental conductance method [18] - [22] is to determine the direction of variation of the terminal voltage of the PV modules by measuring and comparing the instantaneous conductance and incremental conductance photovoltaic modules. If the incremental conductance value equals the instantaneous conductance, which represents that there is the maximum power point.The basic theory is illustrated with Fig. 2.

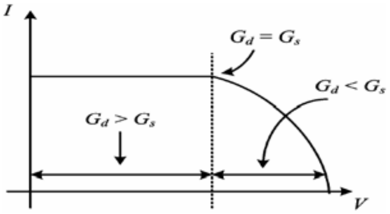


Fig.4. The schematic diagram of the incremental conductance method

When the operating behavior of PVmodules is within the constant current area, the output power is proportional to the terminal voltage. That means the output power increases linearly with the increasing terminal voltage of PV modules (slope of the power curve is positive, $dP/dV > 0$).When the operating point ofPV modules passes through the maximum power point, its operating behavior is similar to constant voltage. Therefore, the output power decreases linearly with the increasing terminal voltage of PV modules (slope of the power curve is negative, $dP/dV < 0$). When the operating point of PV modules is exactly on the maximum power point, the slope of the power curveis zero ($dP/dV = 0$)

$$\frac{dP}{dV} = \frac{dVI}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \text{ ---- } (1)$$

and can be further expressed as,

$$\frac{dI}{dV} = \frac{I}{V} \text{ ------------------------- } (2)$$

dI and dV represent the current error and voltage error before and after the increment respectively. The static conductance (G_s) and the dynamic conductance (G_d, incremental conductance) of PV modules are defined as follows,

$$G_s = \frac{1}{V} \text{ ------------------------- } (3),$$

$$G_d = \frac{dI}{dV} \text{ ---------------------- } (4)$$

The maximum power point (operating voltage is V_m) can be found

$$G_d|v = v_m = G_s|v = v_m \text{ ---------- } (5)$$

When the equation in (2) comes into existence, themaximum power point is tracked by MPPT system. However, the following situations will happen while the operating point is not on the maximum power point:

$$\frac{dI}{dV} > -\frac{I}{V};(G_d > G_s, \frac{dP}{dV} > 0) \text{ ----------- } (6),$$

$$\frac{dI}{dV} < -\frac{I}{V};(G_d < G_s, \frac{dP}{dV} < 0) \text{ ---------- } (7)$$

Equations (6) and (7) are used to determine the direction of voltage perturbation when the operating point moves toward to the maximum power point. In the process of tracking, the terminal voltage of PV modules will continuously perturb until the condition of (2) comesinto existence. Fig. 3 is the operating flow diagram of the incremental conductance algorithm.

The main difference between incremental conductance and P&O algorithms is the judgment on determining the direction of voltage perturbation. When static conductance *Gs*is equal to dynamic conductance *Gd*, the maximum power point is found [8]. From the flow diagram shown in Fig. 3, it can be observed that the weather conditions don't change and the operatingpoint is located on the maximum power point when $dV = 0$ and $dI = 0$. If $dV = 0$ but $dI > 0$, it represents that the sun irradiance increases and the voltage of the maximum power point rises. Meanwhile, the maximum power point tracker has to raise the operating voltage of PV modules in order to track the maximum power point. On the contrary, the sun irradiance decreases and the voltage of the maximum power point reduce if $dI < 0$. At this time the maximum power point tracker needs to reduce the operating voltage of PV modules.

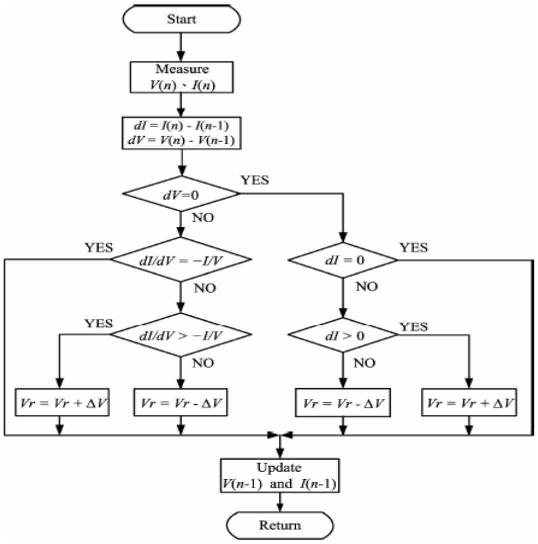


Fig.5. The flow diagram of the incremental conductance method

Furthermore, when the voltage andcurrent of PV modules change during a voltage perturbation and $\frac{dI}{dV} > -\frac{I}{V}(\frac{dP}{dV} > 0)$, the operating voltage of PV modules is located on the left side of the maximum power point in the P-V diagram, and has to be raised in order to track the maximum power point. $\frac{dI}{dV} < -\frac{I}{V} (\frac{dP}{dV} < 0)$, If the operating voltage of PV modules will be located on the right side of the maximum power point in the P-V diagram, and has to be reduced in order to track the maximum power point. The advantage of the incremental conductance method, which is superior to those of the other two MPPT algorithms, is that it can calculate and find the exact perturbation direction for the operating voltage of PV modules. In theory, when the maximum power point is found by the judgment conditions of the incremental conductance method, it can avoid the perturbation phenomenon near the $(\frac{dI}{dV} = -\frac{I}{V} anddI = 0)$, maximum power point which is usually happened for the other two MPPT algorithms. The value of operating voltage is then fixed. However, it indicates that perturbation phenomenon is still happened near the maximum power point under stable weather conditions after doing someexperiments. This is due to thereason that the probability of meeting condition $\frac{dI}{dV} > -\frac{I}{V}$ is extremely small.

Voltage Control:

A grid-side converter has been performed on the basis of a high-performance technique. VOC is based on the idea of decoupling instantaneously the direct (*d*) and quadrature (*q*) components of the injected current, working in the grid voltage vector reference frame. In this synchronous reference frame, the voltage space-vector equations of the system are

$$u_g^u = u_{sg}^u + L\frac{di_{sg}^u}{dt} Ri_{sg}^u + j\omega L i_{sg}^u \text{------------- (8)}$$

The decomposition of such equations on the direct (*d*) and quadrature (*q*) axes gives

$$\begin{cases} u_{gd} = u_{sgd} + Ri_{sgd} + \frac{Ldi_{sgd}}{dt} - \omega L i_{sgq} \\ u_{gq} = u_{sgq} + Ri_{sgq} + \frac{Ldi_{sgq}}{dt} - \omega L i_{sgd} \end{cases} \text{------ (9)}$$

Equation (9) shows that the direct component (quadrature) of the injected currents depends on the component of the voltages of the inverter. PI controllers are used to control the inverter current components in voltage oriented reference framework in the Simulink, as shown in Fig. 4. However, as it is electrically powered counterpart, there is some coupling terms in both axis equations, which must be compensated with terms of feed-forward control. Since the objective here is to directly control the DC bus voltage, the control system has been slightly modified by adding loop of the dc- link voltage, external to the loop of the direct current components whose output current is direct reference. The reference quadrature current is always set to zero, so it is to maintain zero reactive power exchanged by the wind generation system with the grid.

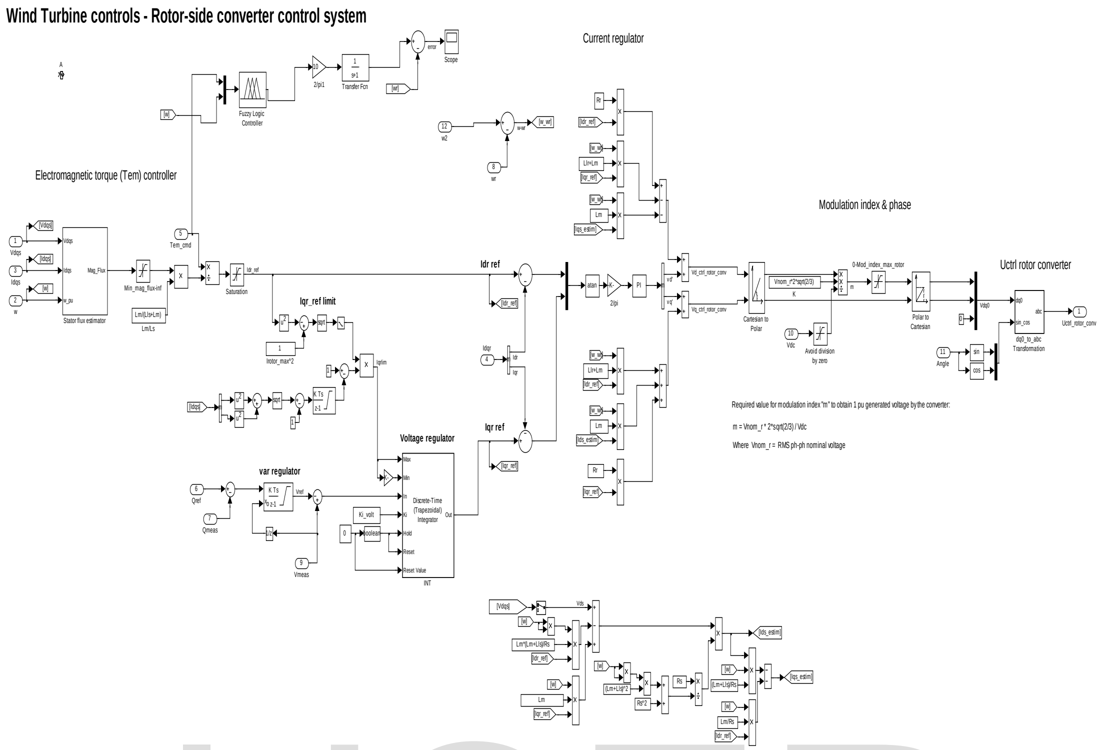


Fig.6. Fuzzy based wind turbine controls-rotor side control system

IV. WIND TURBINE SYSTEMS

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer, which converts the electricity from the generator at around 700V to the appropriate voltage for the power collection system, typically 33 kV. The power contained in the wind is given by the kinetic energy of the flowing air mass per unit time. That is

$$P_{air} = \frac{1}{2}\rho A V^3_{\infty} \text{----------------------- (a)}$$

Where Pair is the power contained in wind (in watts) , ρ is the air density (1.225 kg/m3 at 15°C and normal pressure), A is the swept area in (square meter), and V_∞ is the wind velocity without rotor interference, i.e., ideally at infinite distance from the rotor (in meter per second).

$$C_p = \frac{P_{windturbine}}{P_{air}} = \frac{1}{2}\rho C_p A V^3_{\infty} \text{------------------- (b)}$$

Power coefficient versus TSR Characteristics

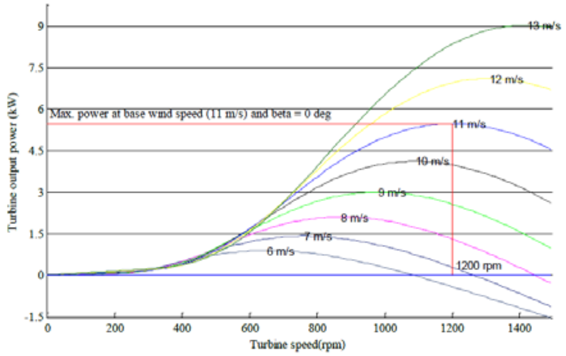


Fig 7. The typical power versus speed characteristics of a wind turbine

For a given wind turbine the power coefficient depends not only on TSR but also on the blade pitch angle. Fig 5 shows the typical variation of the power coefficient with respect to TSR (λ) with blade pitch control.

Where $\lambda = \dfrac{\omega R}{V\infty}$

Where ω is rotational speed of rotor (in rpm), R is the radius of the swept area (in meter).The power coefficient (λ) and the power coefficient CP are the dimensionless and so can be used to describe the performance of any size of wind turbine rotor.

$$P_m = \frac{1}{2}\rho C p \pi R^2 V^3_{\infty},$$

For a given wind speed the power extracted from the wind is maximized if Cp is maximized. Always there is an optimum value of TSR for an optimum value of Cp (Cp-optimum). This means for varying wind speed the rotor speed should be adjusted proportionally to follow to the optimum value of TSR (λ optimum) for maximum mechanical power output from the turbine.

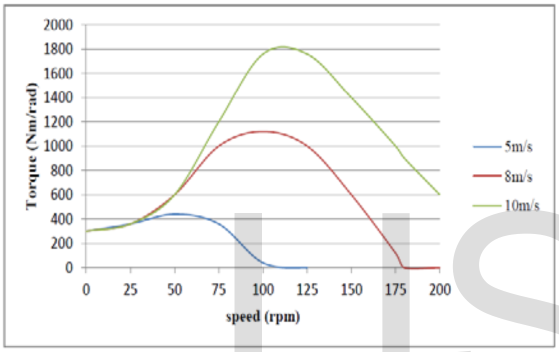


Fig 8. The torque versus speed characteristics of wind turbine (horizontal axis turbine)

$$T_m = \frac{P_m}{\omega} \text{------------------------} (2.7)$$

The curve in Fig 6 shows that for any wind speed the torque reaches a maximum value at a specific rotational speed, and this maximum torque varies approximately as the square of rotational speed. In the case of electricity production the load torque depends on the electrical loading. The torque can be made to vary as the square of the rotational sped by choosing the load properly.

V. RESULTS& ANALYSIS

In this application, a fuzzy with rule base system has been adopted. Linguistic variables are used to represent an Fuzzy Logic system's operating parameters. The rule matrix is a simple graphical tool for mapping the Fuzzy Logic control system rules. It accommodates two input variables and expresses their logical product (AND) as one output response variable. To use, define the system using plain-English rules based upon the inputs, decide appropriate output response conclusions, and load these into the rule matrix. Fuzzy Logic provides a completely different, unorthodox way to approach a control problem. This method focuses on what the system should do rather than trying to understand how it works.

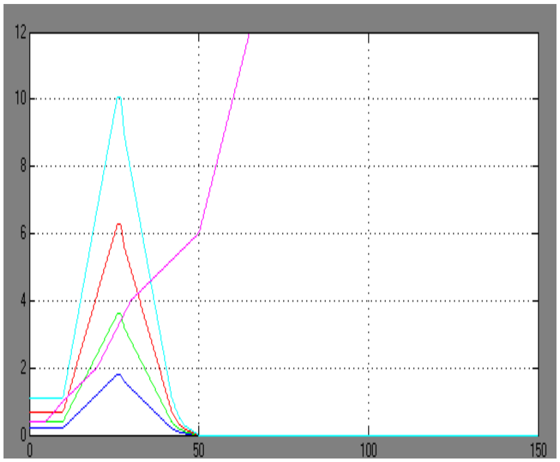


Fig. 9.Wind-speed Vs Torque estimation with different numbers membership functions.

This implies that the computational demands required by FUZZY for this type of application is significantly less than that of a classic conventional methods. Figure 8 shows the actual wind speed and estimated free wind speed during a simulated test composed of some parts in which the wind speed is constant and some others that are linearly variable. It shows the estimated wind speed with a different membership functions for the better the accuracy of the estimation, as expected. Note that there is no degradation of the accuracy of the estimation in transient wind speed, which is pretty good. Note that the oscillations in Fig. 8 are due to the fact that different membership functions belonging to the same group are activated depending on the variation of the input variable: If the resolution of the Grid capacity is increased (higher accuracy or zero sequence), then this ripple is reduced.

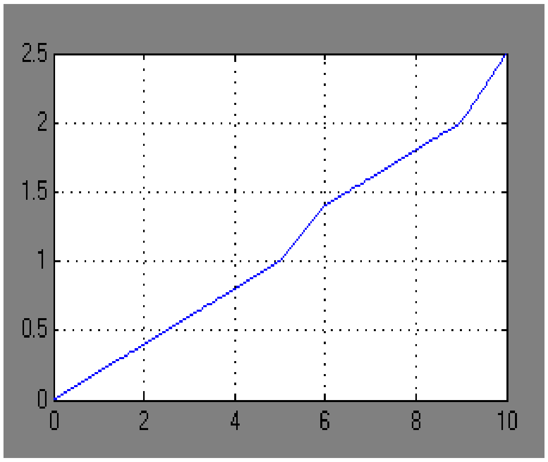


Fig 10: Energy of the wind generator is increased after the ripple is eliminated

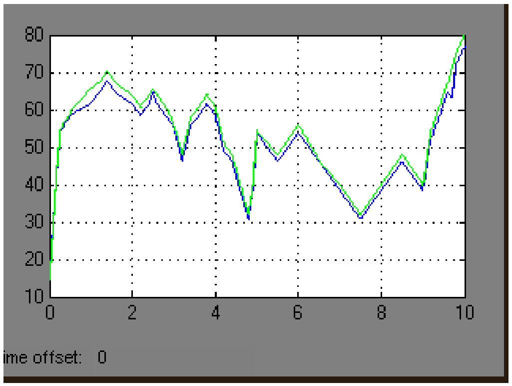


Fig 11: Estimated and filtered estimated wind speed

To show the best of the MPPT technique of Fuzzy logic control proposal based on coordinated with the sensorless control of the machine. Some considerations must be made in this regard. The oscillations of the estimated wind speed and consequently the speed of the machine can significantly reduce. Estimation errors of machine speed and torque errors involve in wind speeds, which leads to a wrong calculation of the optimum machine reference speed. However, once the speed of the machine is approaching its reference, the torque and speed estimation errors decreases therefore , a new wind speed is estimated, which is very near to vary the actual againcausing the reference speed of the machine. This means that the oscillationsof the machine speed around its final value do not significantly affect the generated power, which, on average, gets to its finalvalue after the first transient of the machine speed. The active power of the wind generator is improving as compared to conventional one. The figure shows the results of the active power with respect to the wind speed of the wind generator when it is running on the abnormal conditions also can be estimated and proved.

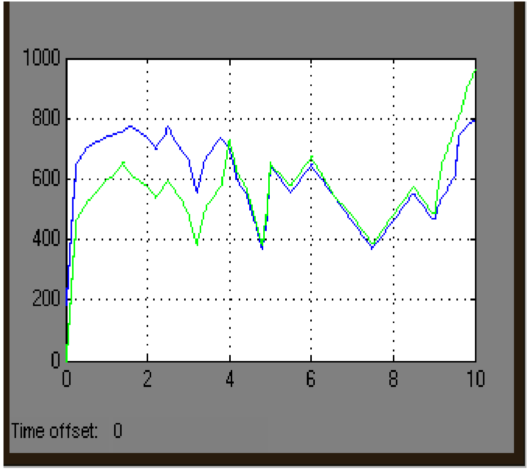


Fig.12. Wind and machine speeds Vs the wind machine power with the limitation of the rate of change of the wind speed

VI. CONCLUSION

This paper presents a Fuzzy logic control technique for high-performance wind turbine induction machines basedin integrating the estimated free - wind speed for Fuzzy logic cotrol. The combined use of the estimation of the wind speed by Fuzzy logic system to operate without any speed sensor neither a wind speed nor machine speed. Here, a system has been estimated with the membership fuctions in online to learn the inverse turbine model using information provided by the direct model of the machine torque and speed of the machine. The reference speed of the machine is then calculated based on the relationship of tip speed ratio (TSR). The simulation results show that this system is able to track the maximum power of wind system with respect conventional method insensitive to variations in external disturbances. In addition, the results of simulation have shown that the system can provide energy to a utility with low harmonics and high power factor.

VII. REFERENCES

[1] “*World Energy Outlook*,” International Energy Agencies, pp.303-338, 2010.

[2] “Worldwide energy report,” *Conf. World wind energy Renew. Energy Exhib.*, WWEA, Cairo, pp.6-8, 2010.

[3] S. Soter, R. Wegener, “Development of induction machines in wind power technology,” *Proc. IEEE Int. Electric Mach. Drives Conf.*, vol. 2, pp. 1490-1495, 2007.

[4] G. A. Smith, K. Nigim, A. Smith, “Wind-energy recovery by a static Scherbius induction generator,” *IEE Proc. C*, vol. 128, no.6, pp. 317-324, 1981.

[5] M. Mochmoum, R. Ledoeuff, F. M. Sargos, and M. Cherkaoui, “Steady state analysis of a doubly fed asynchronous machine supplied by a current controlled cyclo converter in the rotor,” *IEE Proc. B*, vol. 139, no. 2, pp. 114-122 , 1992.

[6] F. Blaabjerg, R. Teodorescu, M. Liserre, A.V. Timbus, “Overview of Control and Grid Synchronization for Distributed Power Generation Systems,” *IEEE Trans. Ind. Elect.*, vol. 53, no. 5, pp.1398-1409, 2006.

[7] R. Wu, S. B. Dewan, G. R. Slemon, “Analysis of an ac to dc voltage source converter using PWM with phase and amplitude control,” *IEEE Trans. Ind. Elect.*vol. 27, no. 2, pp. 355-364, 1991.

[8] O. S. Ebrahim, P.K. Jain, G. Nishith, "New Control Scheme for the Wind-Driven Doubly Fed Induction Generator under Normal and Abnormal Grid Voltage Conditions," *J. Power. Electron.*vol. 8, no. 1, pp.10-22, 2008.

[9] T. Shimizu, O. Hashimoto, and G. Kimura, "A novel high-performance utility-interactive photovoltaic inverter system," *IEEE Trans. Power Electron.*, vol. 18, no. 2, pp. 704–711, Mar. 2003.

[10] T. Esram, J. W. Kimball, P. T. Krein, P. L. Chapman, and P. Midya, "Dynamic maximum power point tracking of photovoltaic arrays using ripple correlation control," *IEEE Trans. Power Electron.*, vol. 21, no. 5, pp. 1282–1291, Sep. 2006.

[11] N. Femia, G. Petrone, G. Spagnuolo, andM. Vitelli, "Optimization of perturb and observe maximum power point tracking method," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 963–973, Jul. 2005.

[12] G. Carannante, C. Fraddanno, M. Pagano, and L. Piegari, "Experimental performance of MPPT algorithm for photovoltaic sources subject to inhomogeneous insolation," *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, pp. 4374–4380, Nov. 2009.

[13] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "Perturb and observe MPPT technique robustness improved," in *Proc. IEEE Int. Symp. Ind. Electron.* 2004, vol. 2, pp. 845–850.

[14] K. H. Hussein, I. Muta, T. Hoshino, and M. Osakada, "Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions," *Proc. Inst. Elect. Eng.—Gener.,Transm. Distrib.*, vol. 142, no. 1, pp. 59–64, Jan. 1995.

[15] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "A technique for improving P&O MPPT performances of double-stage grid-connected photovoltaic systems," *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, pp. 4473–4482, Nov. 2009.

[16] D. Sera, R. Teodorescu, J. Hantschel, and M. Knoll, "Optimized maximum power point tracker for fast-changing environmental conditions," *IEEE Trans. Ind. Electron.*, vol. 55, no. 7, pp. 2629–2637, Jul. 2008.

[17] D. Sera, T. Kerekes, R. Teodorescu, and F. Blaabjerg, "Improved MPPT method for rapidly changing environmental conditions," in *Proc. IEEE Int. Symp. Ind. Electron.* 2006, vol. 2, pp. 1420–1425.

[18] Jia-Chen Zhuang, Photovoltaic Engineering-Solar Cells, ChuanHwaBook CO., LTD, Taipei, 1997.

[19 D. P. Hohm, M. E. Ropp,"Comparative study of maximumpower point tracking algorithms," Progress in Photovoltaics: Research and Applications, vol. 11, no. 1, pp.47–62, January 2003.

[20] T. Esram, P. L. Chapman,"Comparison of Photovoltaic ArrayMaximum Power Point Tracking Techniques," IEEE Transactions onEnergy Conversion, vol. 22, no. 2,June 2007.

[21] Jae-Ho Lee, HyunSu Bae, Bo-Hyung Cho, "Advanced incremental conductance MPPT algorithm with avariable step size," 12thInternational Conference on PowerElectronics and Motion Control,2006 (EPE-PEMC 2006),pp.603-607, Aug.-Sept, 2006.

[22] Y. Yusof, S. H. Sayuti, M. AbdulLatif, M. Z. C. Wanik, "Modelingand simulation of maximum powerpoint tracker for photovoltaicsystem," Proceedings of Power andEnergy Conference, 2004 (PECon2004), pp. 88- 93, 29-30 Nov. 2004.

[23]. D. Menniti, A. Pinnarelli, G. Brusco, "Implementation of a novel fuzzy-logic based MPPT for grid-connected photovoltaic", generation system, IEEE Trondheim Power Tech conference, 2011.

AUTHOR'S BIOGRAPHY

[1]**S. Sundeep,** currently working as a Research Scholar in Jawaharlal Nehru Technological University Hyderabad. He received his M.Tech from K L University, Vaddeswaram, Guntur. He completed his B.Tech from JNTU Hyderabad. He has published 4 international conference papers and 5 International journals. His Area of interest is Hybrid power generation, Power semiconductor drives and Artificial Intelligence, and special machines.

[2]**Dr.G. Madhusudhana Rao,** Professor of the Department in EEE Department of TKR College of Engineering and Technology and Science. He received his Ph.D & M.Tech from JNT University Hyderabad. He has published more than 15 research papers in International Journals and 30 International conference/ national conference papers. He has more than 15 years of teaching experience. He is a member of IEEE, ISTE,

IACSIT etc., He is acting as reviewer for many journal like Industrial Electronics (IEEE). His Area of Interest is Power electronics and Drives, Artificial Intelligence and other Expert systems.

[3]**Dr.B.V.Sanker Ram** did his B.E OU. Obtained M.Tech OU and Ph.D in 2003 from JNTU. He has 70 technical papers to his credit in various international and national journals and conferences. He has guided 12 research scholars for Ph.D and 6 Candidates are still pursuing their research. His areas of interest include FACTS, Power Electronic Applications to Power Systems, Power Systems Reliability. He has more than 22 years of teaching experience. He is a member of IEEE, ISTE, IACSIT etc.,