# PMSG Based Wind Power System Using Anfis and Modify Sepic Converter

E.Radhakrishnan, PG Student ME Control System, MahendraEngineering College, Namakkal,India P.Umasankar, Professor MahendraEngineering College, Namakkal,India P.Mohana, Lecturer Government Polytechnic College, Palacode, India

**ABSTRACT:** Wind energy is becoming a very useful energy source at present. With the increasing wind power penetration, improvements are required in order to comply with the grid interconnection requirements. The focus of this paper is to maximize the output power and address the output control of a utility-connected Permanent Magnet Synchronous Generator (PMSG) for wind power generation systems. PMSG has a back-to-back converter to control the output of the PMSG driven by the wind turbine. To supply commercially the power of WPGS to the grid without any problems related to power quality, the real and reactive powers of PMSG are strictly controlled at the required level. In this paper it is realized with the Adaptive Neuro Fuzzy Inference System (ANFIS) controller based on the field orientation control. The DC voltage of the DC link capacitor is also controlled at a certain level with the conventional Proportion-Integral controller of the real power. Studies demonstrate that the performance of the system with the IS controller parameters permits an improvement of the converter capability and system performance.

**Key words:** Wind energy, Permanent Magnet Synchronous Generator, Adaptive Neuro Fuzzy Inference System, Proportion-Integral controller, real and reactive powers

# 1. INTRODUCTION

Due to the increasing concerns about pollution and improving environmental conditions, integration of large scale wind farms into electrical network system has increased significantly in recent years. Global Wind Energy Council predicted that global wind power generation capacity will reach 459 GW and new capacity of 62.5 GW will be added to the global total at the end of

2015 [1]. It is well known that power production of wind generator fluctuates depending on wind speed variations which affects power system stability and power quality [2]-[7]. Variable Speed Wind Turbine with Permanent Magnet Synchronous Generator (VSWT-PMSG) is an attractive type of wind turbine technology.

The VSWT-PMSG system is equipped with AC/DC/AC electronic converters in which the active and reactive power produced by PMSG can be controlled [8]-[10]. Conventional PI controller is very common in the control of the AC/DC/AC converter of PMSG due to its simple structure and acceptable performance in a wide range of operating conditions. The PI controllers are simple but cannot always effectively control systems with changing parameters or strong nonlinearities. Change of parameters in the grid system, especially in a fault condition, leads to a significant impact on the control system performance of the converter. Deviation of the grid system impedance will change gain margin and phase margin of the control system. Therefore, the PI controller should have a function of online retuning of its parameters.

Adaptive Neuro Fuzzy Inference System (ANFIS) controller has attracted the attention of researchers because it can deal with nonlinear systems and does not need precise mathematical modeling of the system [11]. Compared with the conventional PI controller, ANFIS controller has the potential to provide an improved performance even for a system with wide parameter variations [12]. The ANFIS controller has advantages of robust, simple, easy to be modified, usable for multi input and output sources, and to be implemented very quickly and cheaply. Use of ANFIS control instead of conventional PI controller can be an effective way to solve the problem of system parameter change. Hence, a good control performance can be achieved. Therefore, application of ANFIS controller on the PMSG converter controller system is proposed in this paper

# 2. LITERATURE SURVEY

Many methods are proposed in the literature for the FRT capability enhancement. The peak current limitation for a high-power PMSG was realized in Reference [15]. Maximum Power Point Tracking (MPPT) was implemented in the GSC and MSC. An active crowbar is kept the DC link voltage value by using this method [16]. A Superconducting Fault Current Limiter (SFCL) was implemented for the FRT enhancement of a PMSG in Reference [17]. However, this requires additional circuit links, which not only increases the design difficulty of WECS, but also increases the upfront investment and maintenance cost. The static synchronous compensator

(STATCOM) has been implemented to analyze a dynamic mechanism for a wind farm [18]. A coordinating control system for wind turbines was presented in Reference [18]. However, STATCOM has disadvantages, such as high cost and additional hardware needs. A Braking Chopper (BC) system was implemented for the FRT enhancement of a PMSG in Reference [19–21]. The presented method achieved reductions in the fault currents in DC systems. This method has some advantages, such as low cost and a simple control structure.

Recently, soft computing methods have started to develop rapidly with the development of computer technology. Soft computing methods are applied in real-world applications, such as renewable energy and automotive and motor control. Soft computing methods are widely implemented in wind power applications, such as for Maximum Power Point Tracking (MPPT) control, pitch control, fault diagnosis, wind power integration, wind turbine power control, and prediction of wind speed and power. Soft computing methods consist of four computing algorithms such as predictive method, genetic algorithm, artificial neural networks, and fuzzy logic controllers. The fuzzy logic controller has a number of distinguishing advantages over conventional controllers. It is not so sensitive to variations of system structure, parameters and operation points and can be easily implemented in a large-scale nonlinear system. Furthermore, the fuzzy logic controller is a sophisticated technique that is easy to design and implement. In the past decade, many researchers have attempted to combine conventional proportional plus integral plus derivative (PID) controllers with fuzzy logic to improve controller performance [22–24].

The fuzzy logic controller has two input signals, and the output signal of the fuzzy logic controller is the input signal of the conventional PID controller. Through fuzzy reasoning, the parameters are adjusted adaptively, and the transient process of the system is improved. But in the actual system, the derivative element is usually not used because of the noise signal. The sampling time of fuzzy controller determines the control precision. Too huge sample interval worsens the transition process, and too short sample time greatly increase the computation and input cost. In addition, the fuzzy logic control is a type of soft computing method that overcomes the uncertainties of some systems [25]. Uncertainty is a natural part of intelligent systems in many applications. However, fuzzy logic control does not fully deal with the uncertainties of intelligent systems.

# **3. PROPOSED SYSTEM**

The focus of this project is to maximize the output power and address the output control of a utility-connected Permanent Magnet Synchronous Generator (PMSG) for wind power generation systems. PMSG has modified SEPIC converter to control the output of the PMSG driven by the wind turbine. To supply commercially the power of WPGS to the grid without any problems related to power quality, the real and reactive powers of PMSG are strictly controlled at the required level. In this project it is realized with the Adaptive Neuro Fuzzy Inference System (ANFIS) controller based on the field orientation control.



Figure 1. Block Diagram of Proposed System

# **3.1 BLOCK DIAGRAM DESCRIPTION:**

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra. This paper contains a basic overview of the principles of fuzzy logic.

# 3.2 Fuzzy Logic System

Today control systems are usually described by mathematical models that follow the laws of physics, stochastic models or models which have emerged from mathematical logic. A general difficulty of such constructed model is how to move from a given problem to a proper mathematical model. Undoubtedly, today's advanced computer technology makes it possible; however managing such systems is still too complex.

These complex systems can be simplified by employing a tolerance margin for a reasonable amount of imprecision, vagueness and uncertainty during the modelling phase. As an outcome, not completely perfect system comes to existence; nevertheless in most of the cases it is capable of solving the problem in appropriate way. Even missing input information has already turned out to be satisfactory in knowledge-based systems.

Fuzzy logic allows to lower complexity by allowing the use of imperfect information in sensible way. It can be implemented in hardware, software, or a combination of both. In other words, fuzzy logic approach to problems' control mimics how a person would make decisions, only much faster.

FIS Editor: Unti	tled			
File Edit View				
input1	[	Untitlec (mamdar	0	
FIS Name:	Untitled		FIS Type:	mamdani
And method Or method Implication Aggregation	min max min max	<b>× × ×</b>	Current Variable Iame Ype Range	inputt input [01]
Defuzzification	centroid	×	Help	Close
Ready				

Figure 2: fuzzy logic analysis and control

The fuzzy logic analysis and control methods shown in Figure can be described as:

- i. Receiving one or large number of measurements or other assessment of conditions existing in some system that will be analyzed or controlled.
- Processing all received inputs according to human based, fuzzy "if-then" rules, which can be expressed in simple language words, and combined with traditional non-fuzzy processing.
- iii. Averaging and weighting the results from all the individual rules into one single output decision or signal which decides what to do or tells a controlled system what to do. The result output signal is a precise defuzzified value.

Fuzzy logic control system is created from four major elements presented on Figure: fuzzification interface, fuzzy inference engine, fuzzy rule matrix and defuzzification interface. Each part along with basic fuzzy logic operations will be described in more detail below.



Figure 3. Fuzzy logic controller

# **Fuzzy Logic Basic Operations**

Below some basic information about fuzzy logic will be presented, while a comprehensive theory of fuzzy logic can be found in.

# • Universe of Discourse

It is a range of all possible values considered as fuzzy system input.

• Fuzzy Set

A fuzzy set  $\mu$  is a function from the reference set X to the unit interval, i.e.

$$\mu: X \to [0,1] \tag{11}$$

 $\mu(X)$  represents the set of all fuzzy sets of *X*.

# • Membership Function

It is a graphical representation of fuzzy sets,  $\mu_F(x)$ .



Figure 4. An example of fuzzy logic membership function

Figure 4 shows the membership functions of three fuzzy sets, "slow", "average", and "fast", for a fuzzy variable *Velocity*. The universe of discourse creates all possible values of *Velocity*, i.e., X = 19. For *Velocity* value 19 km/h, the fuzzy set "slow" has the membership value 0.6. Hence,  $\mu_{slow}(19) = 0.6$ . Similarly,  $\mu_{average}(19) = 0.4$ , and  $\mu_{fast}(19) = 0$ .

# • Support

The support of a fuzzy set F is the crisp set of all points in the Universe of Discourse U such that membership function of F does not equal zero

$$\mu_F(u) > 0 \tag{12}$$

#### • Crossover point

It is an element in U where its membership function equals 0.5.

#### • Centre

The centre of a fuzzy set F is the point (or points) at which  $\mu_F(u)$  achieves its maximum value.

#### **Fuzzification Method**

First phase of fuzzy logic proceeding is to deliver input parameters for given fuzzy system based on which the output result will be calculated. These parameters are fuzzified with use of pre-defined input membership functions, which can have different shapes. The most common are: triangular shape, however bell, trapezoidal, sinusoidal and exponential can be also used. Simpler functions will not require complex computing and will not overload the implementation. The degree of membership function is determined by placing a chosen input variable on the horizontal axis, while vertical axis shows quantification of grade of membership of the input variable. The only condition a membership function must meet is that it must vary between zero and one. The value zero means that input variable is not a member of the fuzzy set, while the value one means that input variable is fully a member of the fuzzy set.

With each input parameter there is a unique membership function associated. The membership functions associate a weighting factor with values of each input and the effective rules. These weighting factors determine the degree of influence or degree of membership (DOM) each active rule has. By computing the logical product of the membership weights for each active rule, a set of fuzzy output response magnitudes are produced. All that remains is to combine and defuzzify these output responses.

#### **Rule Matrix**

The rule matrix is used to describe fuzzy sets and fuzzy operators in form of conditional statements. A single fuzzy if-then rule can be as follows

If x is A then y is Z,

Where A is a set of conditions that have to be satisfied and Z is a set of consequences that can be inferred.

In rule with multiple parts, fuzzy operators are used to combine more than one input: AND = min, OR = max and NOT = additive complement. Geometrical demonstration of fuzzy operators is shown in Figure 5.



Figure 5. Graphical interpretation of fuzzy operators

The rule matrix is a simple graphical tool for mapping the fuzzy logic control system rules. It accommodates two or more input variables and expresses their logical product (AND or OR) as one output response variable. The degree of membership for rule matrix output can take value of maximum, minimum of the degree of previous of the rule [1]. It is often probable, that after evaluation of all the rules applicable to the input, we get more than one value for the degree of membership. In this case, the simulation has to take into consideration, all three possibilities, the minimum, the maximum or an average of the membership-degrees.

#### **Inference Mechanisms**

Inference mechanism allows mapping given input to an output using fuzzy logic. It uses all pieces described in previous sections: membership functions, logical operations and if-then rules. The most common types of inference systems are Mamdani and Sugeno. They vary in ways of determining outputs.

# **Fuzzy Interference System (FIS)**

A fuzzy inference system (FIS) is a system that uses fuzzy set theory to map inputs (features in the case of fuzzy classification) to outputs (classes in the case of fuzzy classification). Some of the FIS types are

Mamdani method

# Mamdani method

An example of a Mamdani inference system is shown in following figure. To compute the output of this FIS given the inputs, one must go through six steps:

1. Determining a set of fuzzy rules

2. fuzzifying the inputs using the input membership functions,

3. Combining the fuzzified inputs according to the fuzzy rules to establish a rule strength,

4. Finding the consequence of the rule by combining the rule strength and the output membership function,

5. Combining the consequences to get an output distribution, and

6. defuzzifying the output distribution (this step is only if a crisp output (class) is needed). The following is a more detailed description of this process.



Figure 6: A two input, two rule Mamdani FIS with crisp inputs

# Creating fuzzy rules

Fuzzy rules are a collection of linguistic statements that describe how the FIS should make a decision regarding classifying an input or controlling an output. Fuzzy rules are always written in the following form:

*if* (input1 is membership function1) *and/or* (input2 is membership function2) *and/or*  $\clubsuit$ . *then* (output<sub>n</sub> is output membership function<sub>n</sub>).

For example, one could make up a rule that says:

# *if temperature is high and humidity is high then room is hot*.

There would have to be membership functions that define what we mean by high temperature (input1), high humidity (input2) and a hot room (output1). This process of taking an input such as temperature and processing it through a membership function to determine what we mean by "high" temperature is called fuzzification and is discussed in section . Also, we must define what we mean by "and" / "or" in the fuzzy rule. This is called fuzzy combination and is discussed in section.

# Fuzzification

The purpose of fuzzification is to map the inputs from a set of sensors (or features of those sensors such as amplitude or spectrum) to values from 0 to 1 using a set of input membership functions. In the example shown in their are two inputs,  $x_0$  and  $y_0$  shown at the lower left corner. These inputs are mapped into fuzzy numbers by drawing a line up from the inputs to the input membership functions above and marking the intersection point.

These input membership functions, as discussed previously, can represent fuzzy concepts such as "large" or "small", "old" or "young", "hot" or "cold", etc. For example,  $x_0$  could be the EMG energy coming from the front of the forearm and  $y_0$  could be the EMG energy coming from the back of the forearm. The membership functions could then represent "large" amounts of tension coming from a muscle or "small" amounts of tension. When choosing the input membership functions, the definition of what we mean by "large" and "small" may be different for each input.

# **Fuzzy Logic Controller**

The dc chopper present in the SMES circuit is switched according to the need that is charging or discharging. The duty cycle is controlled by the fuzzy logic controller taking the active power of the system and current through the coil. The rules as shown in table.1 are created according to the variation in the values of power and current in the system. Fig. shows the duty ratio according to the power and SMES current.



Figure 7 : Duty ratio for chopper from fuzzy logic controller

# **3.3 PERMANENT MAGNET SYNCHRONOUS GENERATOR: (PMSG)**

The amount of energy captured from a WECS depends not only on the wind at the site, but depends on the control strategy used for the WECS and also depends on the conversion efficiency. Permanent magnet synchronous generators (PMSG) wind energy converters system (WECS) with variable speed operation is being used more frequently in low power wind turbine applications. Variable speed systems have several advantages such as the reduction of mechanical stress and an increase in energy capture. In order to achieve optimum wind energy extraction at low power fixed pitch WECS, the wind turbine generator (WTG) is operating in variable-speed variable-frequency mode. The rotor speed is allowed to vary with the wind speed, by maintaining the tip speed ratio to the value that maximizes aerodynamic efficiency. The PMSG load line should be matched very closely to the maximum power line of the WTG. MPPT control is very important for the practical WECS systems to maintain efficient power generating conditions irrespective of the deviation in the wind speed conditions. To achieve optimal power output, a sensor-less scheme developed by Tan et al in [1] will be used in this work for extracting desired output power from the WTG over a wide range of wind speeds. In spite of, all this complex control theory to get MPPT on PMSG WECS the standard way to implement a grid connected PMSG WECS at variable speed is using two power conversion stages: the first one an AC-DC stage and the second one a DC-AC stage. To realize the first one a classical three phase full bridge rectifier associated to a bulky capacitor is used and the second stage could be implemented by two types of converters schemes Voltage source current controlled inverter (VS-CCI) and Line commutated inverter (LCI) as shown in Figure. 8.



Figure. 8. Wind Energy Conversion System

This paper has the main focus in the first energy conversion stage the AC-DC converter, which is responsible by an injection of a high harmonic current content into the PMSG. The circulation of harmonic currents into the generator will produce significant additional power losses. Normally, the useful life of an electrical machine is specified based on the assumption of operation under rated load. When considering the proper rating for a machine the voltages and load currents are usually assumed to be sinusoidal. Therefore, the additional increase in the stead-state temperature caused by the harmonics can lead to premature ageing of the insulation and breakdown. Also the mechanical stress due to harmonics can reduce the useful life of the machine [2]. This work applies three well-known approaches to harmonic mitigation in three-phase AC-DC energy conversion systems: a) harmonic trap filters, b) single-switch three-phase boost rectifier and c) three-phase boost type PWM rectifier [3, 4, and 5]. Using these approaches is possible to minimize or to eliminate the current harmonic content. A software simulation model developed in [1] using PSIM® software, which allows easy performance evaluations is

used to estimate the behaviour of these three different schemes associated with the PMSG WECS. Simulation results showed the possibility of achieving maximumpowertracking, output voltage regulation and harmonic mitigation simultaneously.

#### **3.4 MODIFY SINGLE-ENDED PRIMARY-INDUCTOR CONVERTER (MSEPIC):**



Figure9. Circuit diagram of Modify Single-ended primary-inductor converter

**Modify Single-ended primary-inductor converter** (**SEPIC**) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor. A SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0 V, following a fairly hefty transient dump of charge. SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output.

**Pulse-width modulation (PWM)**, or **pulse-duration modulation (PDM)**, is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches.

The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load is.

The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. Typically switchings have to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies.



Figure 10. Duty Cycle

The term *duty cycle* describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on.

The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel.

# 3.5. INVERTER

Figure 11 shows the three-phase inverter. A basic three-phase inverter consists of three single-phase inverter. Each of the three load terminals is designed to be connected to one of the switches. In the most basic control scheme, the operation of three switches is integrated so that a switch operates at every 60-degree point of the base output waveform. This creates a line-to-line output waveform that is six steps. There is a zero voltage step between the positive and negative sides of the square wave six-phase waveform. When the carrier-based PWM technology is applied to a six-step waveform, the basic overall shape, or envelope, the waveform is retained, so that the third harmonic and its multiples are canceled.



Figure 11: Three-phase inverter

The proposed ANFIS based PWM exchanging errors was diminished to substitute the status of turning levels with single-arrange voltage change and moreover to reduce the exchanging botches the proposed PWM system working was stopped at a specific time, around then the controller reaction relies upon the load power factor angle. The fundamental focal points of ANFIS - PWM pulses are broad straight modulation expands, low THD and least exchanging bumbles. The proposed ANFIS – PWM is straightly associated with control enter current and yield voltage.

#### 4. SIMULATION RESULTS AND DISCUSSION

The proposed technique is applied to the 1.5 MW wind turbine system described in the Appendix, simulated using MATLAB/Simulink and compared to the MPPT control.

It is assumed that the wind speed starts at 11m/s. It is changed to 9 m/s at 12 s. It is noticed from Figure.12 that at starting it takes about 8s to reach its rated speed with the conventional PI controller but with ANFIS controller it reaches its rated speed at 6s. This wind regime is chosen to test the proposed control technique in cases of increasing and decreasing wind speed. It is noticed in Fig. 4 that, when the wind speed is decreased from 11 m/s to 9 m/s at 12s, the generator speed falls from its rated speed of 1 p.u.to 0.82 p.u. that corresponds to the new wind speed.



Figure 12. Generator Speed

The active power and reactive power generated are shown in Figures.13 and 14, respectively .It is clear that the system with ANFIS controller behaves more stably and reacts faster than the system with conventional PI controller.



It is also noticed that the over-shoot at starting or variation in wind speed is reduced compared to the conventional system, which allows it to supply more energy to the grid in the transient periods. The Area difference between the two power curves in Figure.15 that represents the more energy delivered due to ANFIS controller is 0.8508 in 20 sec.





The DC link voltage is shown in Figure. 16, It is clear that the DC link voltage,1150 V, is fixed and follows the reference DC voltage



Figure 16. Direct and Quadrature Current



Figure 17. Three Phase Grid Current

The grid phase current for phases A, B and C are shown in Figure. 17. It is clear that the current is reduced at 12s according to the change in wind speed.



Figure 18. grid phase voltage and current for phase A

The grid phase voltage and current for phase A are shown in Figure. 18 It is clear that the current delivered to the grid is 1800 out of phase with respect to the voltage, that is the power delivered to the grid is negative as per the sign convention used and that the reactive power delivered to the grid is zero.

# 5. CONCLUSION

In this work, a novel architecture for a high Gain single switch Modify SEPIC boost converter with continuous input and output current is introduced. How to increase the voltage, time intervals of ON/OFF mode of the main power switch and all of the diodes are illustrated. In this topology the Wind power transfer ratio is improved without using any isolated transformers or coupled inductors. Compared to the conventional boost converter, this converter offers much lower voltage stress across its power switch which contributes to the much higher reliability in practice. Also, the voltage stresses across all diodes are same as voltage power switch which are considerably low. It should be noted that due to the presence of the inductor on the input and output of the converter, the proposed converter offers much proper choice to be used in applications such as wind power application.

# **REFERENCES:**

- 1. GWEC, "Global Wind Report 2017, Annual Market Update." Global Wind Energy Council (GWEC), Tech. Rep., 2018.
- WWEA, "2017 Small Wind World Report Summary," World Wind Energy Association, Tech. Rep., Jul. 2017. [Online]. Available: <u>http://www.wwindea.org/wpcontent/</u>uploads/filebase/small wind /SWWR2017-SUMMARY.pdf
- 3. H. Li and Z. Chen, "Overview of different wind generator systems and their comparisons," IET Renewable Power Generation, vol. 2, no. 2, pp. 123–138, Jun. 2008.
- 4. I. Schiemenz and M. Stiebler, "Control of a permanent magnet synchronousgenerator used in a variable speed wind energy system," in Electric Machines and Drives Conference, 2001. IEMDC 2001. IEEE International, 2001, pp. 872–877.
- 5. M. Pathmanathan, W. L. Soong, and N. Ertugrul, "Output power capability of surface PM generators with switched-mode rectifiers," in 2010 IEEE International Conference on Sustainable Energy Technologies (ICSET), Dec. 2010, pp. 1–6.
- 6. Y.-L. Juan, "An Integrated-Controlled AC/DC Interface for Microscale Wind Power Generation Systems," IEEE Transactions on Power Electronics, vol. 26, no. 5, pp. 1377– 1384, May 2011.
- 7. A. B. Raju, K. Chatterjee, and B. G. Fernandes, "A simple maximum power point tracker for grid connected variable speed wind energy conversion system with reduced switch

count power converters," in Power Electronics Specialist Conference, 2003. PESC '03. 2003 IEEE 34th Annual, vol. 2, Jun. 2003, pp. 748–753 vol.2.

- 8. Dewei Xu, & Zhenhan Luo. (2009). A novel AC-DC converter for PMSG variable speed wind energy conversion systems. 2009 IEEE 6th International Power Electronics and Motion Control Conference..
- 9. Shanker, T., & Singh, R. K. (2012). Wind energy conversion system: A review. 2012 Students Conference on Engineering and Systems
- Cordero, R., Suemitsu, W. I., & Pinto, J. O. P. (2011). New non-linear d-axis current controller for permanent magnet synchronous motor based on adaptive correction factor. 2011 International Conference on Electrical Machines and Systems.doi:10.1109
- Jena, N. K., Mohanty, K. B., Pradhan, H., & Sanyal, S. K. (2015). A decoupled control strategy for a grid connected direct-drive PMSG based variable speed wind turbine system. 2015 International Conference on Energy, Power and Environment: Towards Sustainable Growth (ICEPE).
- 12. Baby, C. M., Verma, K., & Kumar, R. (2017). Short term wind speed forecasting and wind energy estimation: A case study of Rajasthan. 2017 International Conference on Computer, Communications and Electronics (Comptelix)] 2017.
- 13. Singh, M., & Chandra, A. (2011). Application of Adaptive Network-Based Fuzzy Inference System for Sensorless Control of PMSG-Based Wind Turbine With Nonlinear-Load-Compensation Capabilities. IEEE Transactions on Power Electronics, 26(1), 165– 175.
- 14. Ali, A., Moussa, A., Abdelatif, K., Eissa, M., Wasfy, S., & Malik, O. P. (2014). ANFIS Based Controller for Rectifier of PMSG Wind Energy Conversion System. 2014 IEEE Electrical Power and Energy Conference.
- 15. Malekian, K., Shirvani, A., Schmidt, U., & Schufft, W. (2009). Detailed modeling of wind power plants incorporating variable-speed Synchronous Generator. 2009 IEEE Electrical Power & Energy Conference (EPEC)
- 16. Bayhan, S., Fidanboy, H., & Demirbas, S. (2013). Active and reactive power control of grid connected permanent magnet synchronous generator in wind power conversion system. 2013 International Conference on Renewable Energy Research and Applications (ICRERA)

- 17. J. W. Dixon, J. M. Contardo, and L. A. Moran, "A Fuzzy controlled active front-end rectifier with current harmonic filtering characteristics and minimum sensing variable," IEEE Transaction on Power Electronics, vol. 14, no. 4, pp. 724-729, July 1999.
- M. Rukonuzzaman, M. Nakaoka, "Fuzzy logic current controller for three-phase voltage source PWM-inverters", Industry Application Conference, Vol. 2, pp. 1163 - 1169, 8-12 October 2000.
- M. Aner, E. Nowicki and D. Wood; "Accelerated Starting by Motoring a Grid-Connected Small Wind Turbine Generator," Proc. International Conference Utility Exhibition (ICUE), Pattaya City, Thailand, Sept. 28- 30, 2011.
- 20. K. Tan and S. Islam, "Optimum control strategies in energy conversion of PMSG wind turbine system without mechanical sensors" IEEE Transactions on Energy Conversion, vol. 19, no. 2, June 2004, pp. 392-400.
- 21. F.A. Alturkı, A. Abdennour, "Design and Simplification of Adaptive Neuro-Fuzzy Inference Controllers For Power Plants", Electrical Power and Energy Systems, vol.21, pp.465-474, 1999.
- 22. Y.G. Yang, "A Modified Adaptive-Networks-Based Fuzzy Inference Controller", Ph.D.Thesis, Mechanical and Aerospace Engineering, North Carolina State University, 1998.
- 23. Abraham, A.: "Neuro-Fuzzy Systems: State-of-the-Art Modeling Techniques, Connectionist Models of Neurons, Learning Processes, and Artificial Intelligence", Springer-Verlag Germany, Jose Mira and Alberto Prieto (Eds.), Granada, Spain, pp. 269-276, 2001.
- 24. J.Kim, N.Kasabov, "HyFIS: adaptive neuro-fuzzy inference systems and their application to nonlinear dynamical systems", Neural Networks, vol. 12, pp.1301-1319, 1999.
- 25. J.G. Ziegler, and N.B. Nichols, "Optimum settings for automatic controllers". Transactions of the ASME. 64., 1942, pp. 759–768. Co, Tomas; Michigan Technological University (February 13, 2004). "Ziegler-Nichols Closed Loop Tuning". Retrieved 2007-06-24.