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Research Article

FUZZY LOGIC BASED ZSI USING PMSG FOR WECS

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ABSTRACT

In recent decades various renewable energy resources have attracted a lot of attention because they are pollution-free and inexhaustible. Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity, wind mills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships. Wind power consumes no fuel, emits no air pollution, unlike fossil fuel power sources. Most of the systems do not capture power at every wind speed. Especially low wind speeds which are low in power but can be very common. Reduce this problem proposed a power electronic converter, designed for efficiency, simplicity and ruggedness. Thus the existing synchronous generator converts the mechanical energy into electrical energy with high cost and low power generation. Permanent Magnet Synchronous Generator (PMSG) is used due to some special characteristics such as low weight, low volume, high performance and elimination of gear box. The advanced power electronic converters like Impedance Source Inverter (ZSI) are interface with the permanent magnet synchronous generator. Z-Source Inverter is used for maximum power tracking control and delivering power to the grid. Using fuzzy logic controller the output power will be constant. Because fuzzy logic controller is to maintain constant torque and give an input to the permanent magnet synchronous generator. Then the generator output can be boosted by using impedance source inverter.

Keywords: Wind Turbine, Permanent Magnet Synchronous Generator, Fuzzy Logic, Impedance Source Inverter.

INTRODUCTION

Wind turbines usage as sources of energy has increased significantly in the world. With growing application of Wind Energy Conversion Systems (WECSs), various technologies are developed for them. With numerous advantages, Permanent Magnet Synchronous Generator (PMSG) generation system represents an important trend in development of wind power applications.

Extracting maximum power from wind and feeding the grid with high-quality electricity are two main objectives for WECSs. To realize these objectives, the AC–DC–AC converter is one of the best topology for WECS. Fig.1 shows a conventional configuration of AC–DC–AC topology for PMSG.

In this paper, a new PMSG-based WECS with *Z*-Source Inverter is proposed. The proposed topology is shown in Fig. 2. With this topology, boost converter is omitted without any change in the objectives of WECS. Moreover, reliability of the system is greatly improved, because the short circuit across any phase leg of inverter is allowed. Also, in this configuration, inverter output power distortion is reduced, since there is no need to phase leg dead time.

Fig. 1 Conventional WECS with DC boost chopper

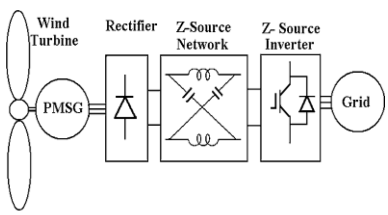
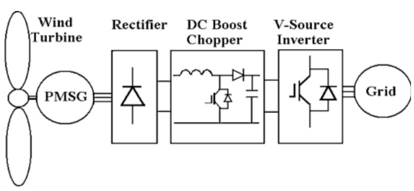


Fig. 2 Proposed WECS with Impedance Source Inverter



In this paper, a novel adaptive network-based fuzzy inference system (ANFIS) based position and speed estimator of PMSG has been proposed for wide range of speed operation. The ANFIS architecture has well known advantages of modeling a highly nonlinear system, as it combines the capability of fuzzy reasoning in handling uncertainties and capability of ANN in learning from processes. Thus, the ANFIS is used to develop an adaptive model of variable-speed PMSG under highly uncertain operating conditions, which also automatically compensates the distortion in measuring signal and any variation in parameters such as inductance, resistance, etc.

WIND TURBINE MODEL

There are two types of wind turbines namely vertical axis and horizontal axis types. Horizontal axis wind turbines are preferred due to the advantages of ease in design and lesser cost particularly for higher power ratings. The power captured by the wind turbine is obtained as

$$P = \frac{1}{2}\pi\rho R^3 V^2 C_p \quad (1)$$

The power co-efficient C_p is given by

$$C_p(\lambda) = \left(\frac{116}{\lambda I} - (0.4*\beta) - 5\right) 0.5e^{\frac{-165}{\lambda I}} \quad (2)$$

Where,

$$\lambda_1 = \frac{1}{\left(\frac{1}{\lambda+0.089\beta} - \frac{0.035}{\beta^3+1}\right)} \quad (3)$$

Generated emf / phase,

$$E = V_t + I_a(R_a + jX_s) = V_t + I_a Z_s \quad (4)$$

Where,

$$Z_s = \sqrt{Ra^2 + X_s} \quad (5)$$

FUZZY LOGIC CONTROLLER

The past few years have witnessed a rapid growth in the number and variety of applications of fuzzy logic. System modelling and system control are two closely related areas. In order to design a conventional controller for controlling a physical system, the mathematical model of the system is needed. The conventional controllers are unsuitable for modeled and non linear systems. Those problems are tackled by fuzzy logic controllers. Compared to the traditional control paradigm, the advantage of the fuzzy control paradigm are twofold. First mathematical model of the system to be controlled is not required, and second, a satisfactory nonlinear controller can often be developed empirically in practice without complicated mathematics.

Design Factors of Fuzzy Logic Controllers

The design of a fuzzy logic controller needs the selection of such control elements and parameters as scaling factor for input/output signals, a set of rule base, fuzzification and defuzzification methods and operations for the fuzzy reasoning, which include an implication operation, a compositional operation of antecedents and consequents. The performance of the fuzzy logic controller mainly relies on the configuration of these factors. The functional block diagram is shown in Fig. 3:

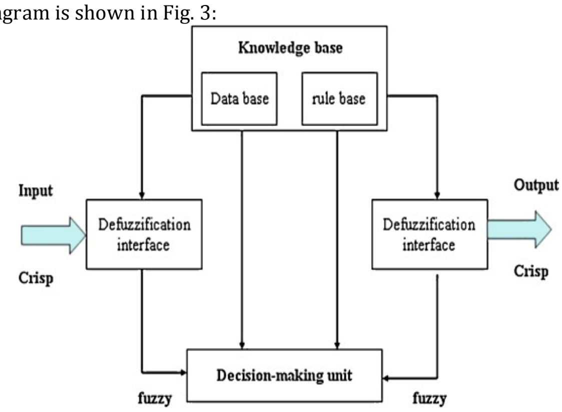


Fig. 3 Functional block diagram of fuzzy logic controller

Fuzzification

Fuzzification is the process of making a crisp quantity to fuzzy. If the form of uncertainty happens to arise because of imprecision, ambiguity or vagueness, then the variable is probably fuzzy and can be represented by a membership function. A fuzzification process the function that it converts crisp data into fuzzy sets. The fuzzification converts the input data into suitable linguistic values, which may be viewed as labels of fuzzy sets.

Table 1: Fuzzy Variables

Fuzzy Input Variables		Fuzzy Output Variables	
NB	- Negative big	S	- Small
NS	- Negative small	M	- Medium
ZE	- Zero	B	- Big
PS	- Positive small	VB	- Very Big
PL	- Positive large	VVB	- Very Very Big

Membership Function

Fuzzy variables are defined by membership function and characterized by shapes, position and width or whole overlap. The number of fuzzy variables that linguistic variable can take is known as fuzzy partition and determines the control obtainable from fuzzy logic control. A trial and error based on operators experience and engineering knowledge is extensively employed in the choice of membership function. As for a certain shape of a membership function, narrower membership functions, despite superiority in faster response and lower steady state error, may incur larger oscillation. Thus the triangular membership functions are successfully applied in the speed control.

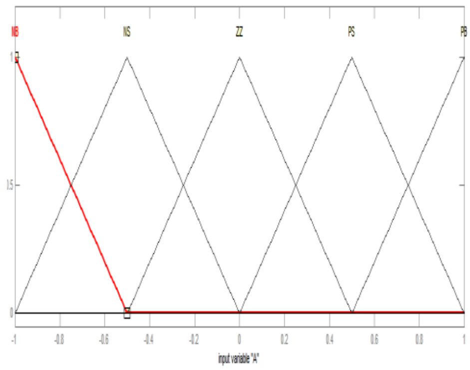


Fig. 4 Input Membership Function for error

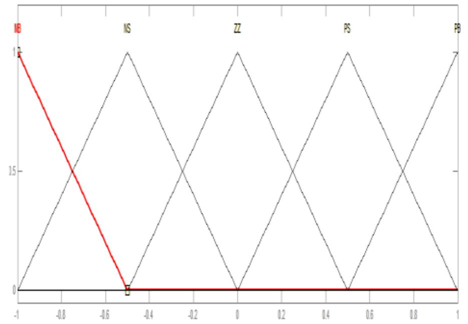


Fig. 5 Input Membership Function for change in error

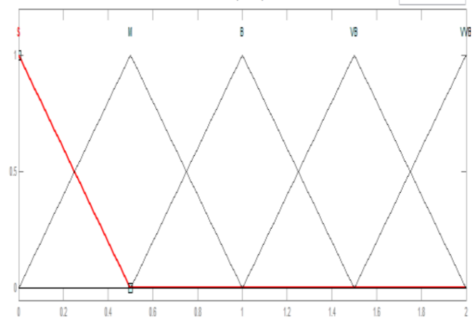


Fig. 6 Output Membership Function for error

PERMANENT MAGNET GENERATOR MODEL

Permanent Magnet Generator provides an optimal solution for varying-speed wind turbines, of gearless or single-stage gear configuration. This eliminates the need for separate base frames, gearboxes, couplings, shaft lines, and preassembly of the nacelle. The output of the generator can be fed to the power grid directly. A high level of overall efficiency can be achieved, while keeping the mechanical structure of the turbine simple.

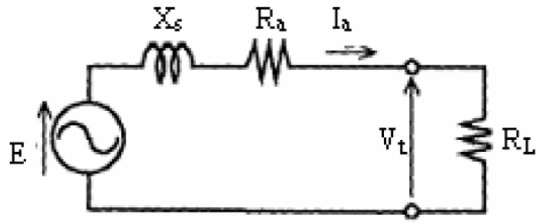


Fig. 7 Per phase equivalent circuit diagram of PMG

The rotor reference frames of the voltages are obtained as the rotor reference frames of the voltages are

$$V_q = -(R_s+L_q p)\, I_q - \omega_r L_d I_d + \omega_r \lambda_m \quad (6)$$

$$V_d = -(R_s+L_d p)\, I_d + \omega_r L_q I_q \quad (7)$$

The expression for the Electro Magnetic (EM) torque in the rotor is given by

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P_n}{2}\right)[(L_d - L_q)I_q I_d - \lambda m I_q] \quad (8)$$

The relationship between the angular frequency of the stator voltage (ω_r) and the mechanical angular velocity of the rotor (ω_m) is obtained as follows

$$\omega_r = \frac{P_n}{2}\omega_r G \quad (9)$$

$$p\omega_r = \frac{P_n}{2J_g}(T_m - T_e) \quad (10)$$

$$p\theta = \omega_r \quad (11)$$

Torque developed by the turbine Tt released to the input to the generator Tm is expressed as

$$T_m = \frac{T_t}{G} \quad (12)$$

IMPEDANCE SOURCE INVERTER

The Impedance Source Inverter (ZSI) is shown in Fig. 5. This inverter has an impedance network on its dc side, which connects the source to the inverter. The impedance network is composed of two inductors and two capacitors. The conventional voltage source inverters have six active vectors and two zero vectors. However, the *Z*-source inverter has one extra zero vector (state) for boosting voltage that is called shoot-through vector. In this state, load terminals are shorted through both the upper and lower devices of any one phase leg, any two phase legs, or all three phase legs.

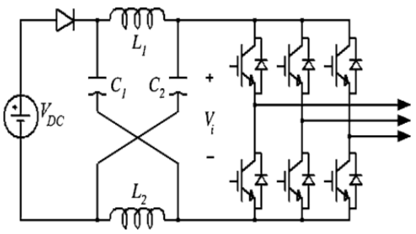


Fig. 8 Voltage type *Z*-Source Inverter

EQUIVALENT CIRCUIT

Fig. 9 shows the equivalent circuit of the Z-source inverter shown in Fig. 8 when viewed from the dc link. When viewed from the Z-source network, the inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot-through zero state, as shown in Fig. 7, whereas the inverter bridge becomes an equivalent current source as shown in Fig. 11 when in one of the six active states. Note that the inverter bridge can be also represented by a current source with zero value (i.e., an open circuit) when it is in one of the two traditional zero states. Therefore, Fig. 13 shows the equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight non shoot through switching states.

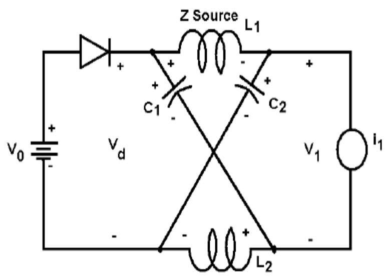


Fig. 9 Equivalent circuit of the ZSI viewed from the dc link

In the peak dc-link voltage across the inverter bridge is expressed

$$V_i = \frac{T}{T_1 - T_0}V_s \quad (13)$$

Where,

T_0 is the shoot through time period in sec

T_1 is the non shoot thro' time period or Active state

T is the Total time period in sec

V_S is the input source voltage

$$V_i = BV_0 \quad (14)$$

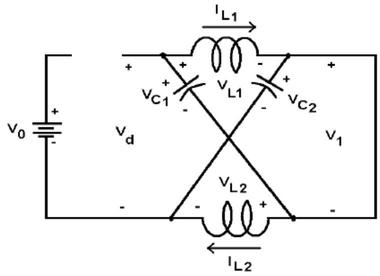


Fig. 10 Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in the shoot-through zero state

Where, B is the Boost factor resulting from the shoot through zero state. The dc link voltage V_i is the equivalent dc link voltage of the inverter. On the other side the output peak phase voltage from the inverter can be expressed in above equation.

$$V_{ac} = M.\frac{V_i}{2} \quad (15)$$

Where, M is the Modulation Index. V_{ac} is the output line voltage of ZSI.

$$V_{ac} = M.B.\frac{V_0}{2} \quad (16)$$

The output of ZSI mainly depends on the shoot through zero states. The voltage of dc link can be expressed as

$$V_i = B\,V_{dc} \quad (17)$$

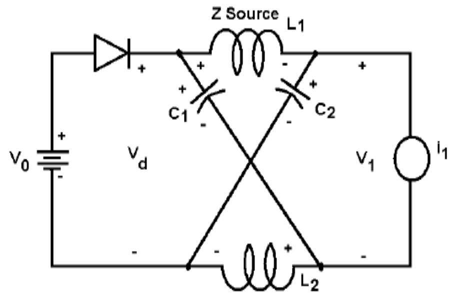


Fig. 11 Equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight non-shoot-through switching states

Where, V_{dc} is the source voltage and *B* is the boost factor that is determined by

$$B = \frac{1}{1-2(T_0 - T)} \quad (18)$$

Where, M is the modulation index. The capacitors voltage can expressed as

$$V_C = V_{C1} = V_{C2} = \frac{T_1}{T_1 - T_0}V_{dc} \quad (19)$$

Where,

$$T_1 = T - T_0 \quad (20)$$

Relation between V_i and V_c can be written as

$$V_i = 2V_c - V_{dc} \quad (21)$$

And current ripple of inductors can be calculated by

$$\Delta I = \frac{T_1 T_0}{T_1 - T_0}\frac{V_{dc}}{L} \quad (22)$$

The simple PWM control method is applied source inverter. This method employs two extra straight lines as shoot-through signals, V_{sc} and −Vsc. When the career signal is greater than Vsc or it is smaller than −Vsc, a shoot through vector is created by inverter. The value of V_{sc} is calculated by

$$V_{sc} = \frac{T_1}{T} \quad (23)$$

In the proposed WECS, a diode rectifier bridge with input capacitors (C_a, C_b and C_c) serves as the dc source feeding the *Z*-source inverter. This configuration is shown in Fig. 13. The input capacitors suppress voltage surge that may occur due to the line inductance during diode commutation and shoot through mode of the inverter.

At any instant of time, only two phases that have the largest potential difference may conduct, carrying current from the PMSG side to the impedance network side. Fig. 15 shows six possible states during each cycle. In any state, one of upper diodes, one of lower diodes, and the corresponding capacitor are active.

For example, when the potential difference between phases "*a*" and "*b*" is the largest, diodes D_{pa} and D_{nb} conduct in series with capacitor C_a, as shown in Fig.15.

Table 1: Comparison Of Zsi With Traditional Inverters

Current Source Inverter	Voltage Source Inverter	Z-Source Inverter
As inductor is used in the d.c link, the source Impedance is high; a constant current source is realized.	As capacitor is used in the d.c link, it acts as a low impedance voltage source.	As capacitor and inductor are used in the d.c link, it acts as a constant high impedance voltage source.
Used in boost operation of the inverter.	Used in a buck mode of operation of the inverter.	Used in both buck and boost operating modes of the Inverter.
Affected by the EMI noise. Considerable amount of harmonic distortion	Affected by the EMI noise Considerable Amount of Harmonic Distortion	Less affected by the EMI noise. Harmonics distortion is low

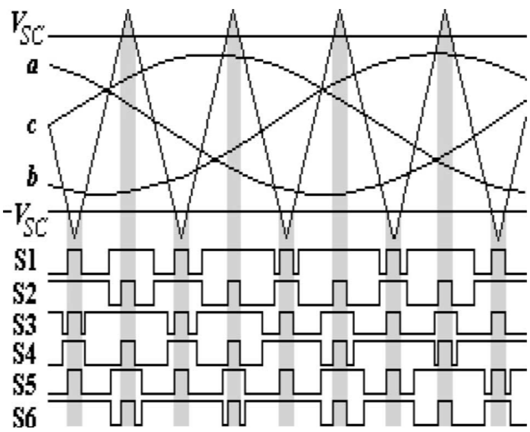


Fig. 12 PWM control method for ZSI

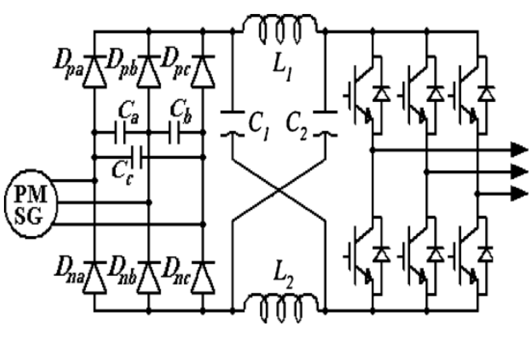


Fig. 13 ZSI with a diode rectifier bridge

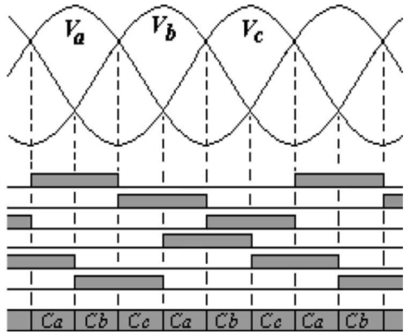


Fig. 14 Six possible conduction intervals for the rectifier

In each conduction interval, inverter operates in two modes. In mode 1, the inverter is operating in the shoot through state. In this mode, the diodes (D_{pa} and D_{nb}) are off, and the dc link is separated from the ac line. Fig. 16 shows the equivalent circuit in this mode. In mode 2, the inverter is applying one of the six active vectors or two zero vectors, thus acting as a current source viewed from the Z-source circuit with diodes (D_{pa} and D_{nb}) being on. Fig. 17 shows the equivalent circuit in this mode. The load current ii is zero during zero vectors.

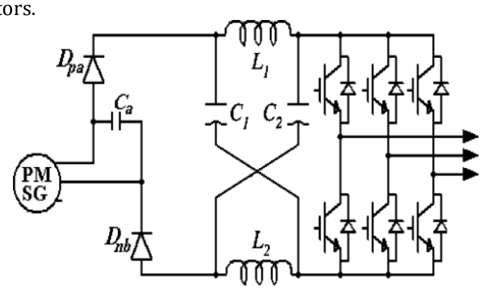


Fig. 15 Equivalent circuit when the potential difference between phases "a" and "b" is the largest

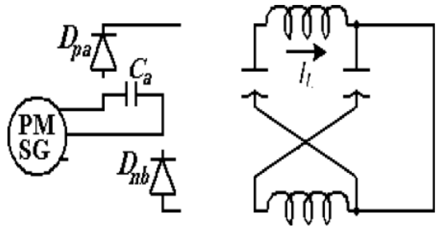


Fig. 16 Equivalent circuit of the Z-source inverter in mode 1

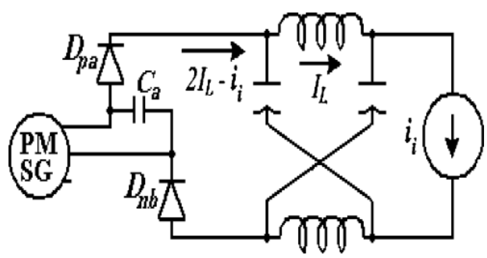


Fig. 17 Equivalent circuit of the Z-source inverter in mode 2

SIMULATION RESULTS

The proposed wind energy conversion system with ZSI is modeled in MATLAB/SIMULINK as shown in Fig.18. The value of inductor and capacitor in the Z-source network is 2mH and 2200μF respectively. The RC filter is used to suppress the harmonics in the output side of ZSI.

The gating pulses to the ZSI are generated by using three phase sine wave and triangular wave and the six separate pulses are generated along with shoot through zero states and active states.

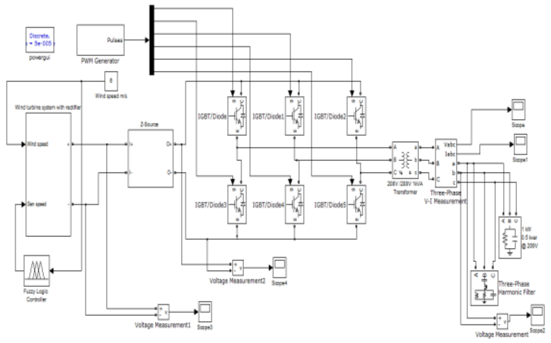


Fig. 18 Simulation diagram for proposed method

The PMSG generated voltage is shown Fig.19. The generated voltage and frequency varies with wind velocity and constant torque should be maintained using fuzzy logic controller. For getting desired voltage up to 100 volts and frequency of the PMSG generated voltage is given to bridge rectifier.

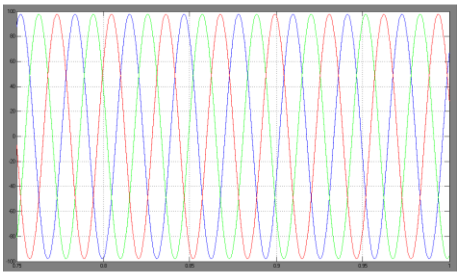


Fig. 19 PMSG output voltage

The output voltage of ZSI mainly depends on the Boost Factor B. During shoot through zero states of the gating pulse, the two inductors induce high voltages which appear across the two capacitors. During active state, the capacitors provide the stiff voltage across the inverter circuit.

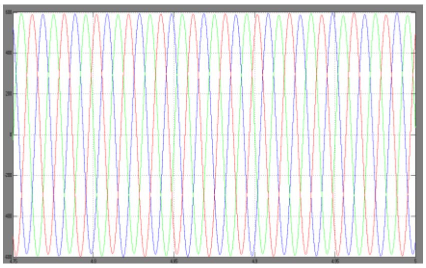


Fig. 20 Output voltage for proposed system

CONCLUSION

In this paper optimum fuzzy control of wind turbine in order to extract constant power is described and verified through the simulation. By using impedance source inverter permanent magnet synchronous generator power was increased up to 526 volts. A PMSG based WECS with *Z*-source inverter is proposed. *Z*-source inverter is used for maximum power tracking control and delivering power to the grid, simultaneously. A Z-source inverter for wind energy conversion system has been proposed and corresponding simulated waveforms are verified. The Z-Source inverter is specially suited for above applications.

APPENDIX

PMSG **-** 0.75kW, 380v, 1000rpm, 6poles

ZSI **-** 10A, 800v, $L1 = L2$ = 2mH, $C1 = C2$ = 2200µF

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