Permanent Magnet Synchronous Generator with Fuzzy Logic Controller for Wind Energy Conversion System

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Abstract-This paper deals with the fuzzy logic based voltage and speed controller for autonomous wind energy conversion system based on permanent magnet synchronous generator. The system consists of back-back connectedVSC anda VSI along with a battery energy storage system at itsintermediate dc link. Two fuzzy controllers are proposed the first one is for speed controller and second one is for voltage controller. These VSC and VSI are operated invector control mode. The battery energy storage system is used for load leveling and to ensure the reliability of the supply to consumersconnected at load bus under change in wind speed. The dynamic performance of the proposed controller is tested under fall in wind speed, increase in wind speed and fixed speed with balanced/unbalanced non-linear load.

Introduction

In recent days, permanent magnet synchronous generators are used in wind turbine because of its advantages: better reliability, less maintenance and moreeffective ([3],[4]). For remote sites located far from the utility, a practical approach for power generation is to use a variable speed wind turbine to create an autonomous system. It often includes batteries, used when the wind cannot provide sufficient power. If wind conditions are favorable, these autonomous wind energy systems can provide electricity at low cost. If wind power exceeds the load demand, the excess power can be stored in batteries and if wind power cannot meet load demand, the batteries can compensate it ([1],[6]).There are many research papers available on integration of PMSG based WECS with the grid [7-9]. Amie et al [7] have proposed a diode bridge rectifier with a boost chopper for the generator side control. The duty ratio of the boost chopper has been controlled to change the PMSG speed for maximum power point tracking (MPPT). In [8], authors have used diode bridge rectifier at the generator side and a line commutated thyristor based inverter at grid side. By firing angle control of a line commutated inverter, the PMSG speed and hence MPPT has been achieved. A Z-source inverter has been reported with PMSG based grid integrated WECS [9]. Haque et al [10] have proposed a control strategy with a new system configuration for a PMSG based variable speed autonomous wind energy conversion system

(WECS). In [10] authors have reported back-back connected voltage source converter (VSC) and a voltage source inverter (VSI) based PMSG based WECS. A bi-directional dc-dc converter has been used at the dc link for battery storage management. The maximum power tracking has been achieved using control of the generator-side VSC. In [11] authors have reported back-back connected voltage source converter (VSC) and a voltage source inverter (VSI) based PMSG based WECS.the control strategy is based on pi controller.

In this paper fuzzy logic based VFC is designed and modeled using matlab/Simulink The VFC consists of back-back connected pulse width modulated (PWM) controlled VSC anda VSI along with a battery energy storage system (BESS) at itsintermediate dc link. These VSC and VSI are operated invector control mode. The BESS is used for load leveling and to ensure the reliability of the supply to consumersconnected at load bus under change in wind speed. Thegenerator-side converter operated in vector control mode forachieving maximum power point tracking (MPPT) and to achieveunity power factor operation at PMSG terminals. The load-sideconverter is operated to regulate amplitude of the load voltageand frequency under change in load conditions. The three-phasefour wire consumer loads are fed with a non-isolated star-deltatransformer connected at the load bus to provide stable neutralterminal.

II.SYSTEM CONFIGURATION

Fig.1 shows the system configuration of a PMSG based AWECS for feeding three-phase four-wire (3P4W) consumerloads. The mid-point of each leg of machine-side voltagesource converter (VSC) is connected to the stator terminals ofa PMSG. A BESS is connected at the intermediate dc link of back-to-back connected VSC and VSI known as a generator sideconverter(GSC)anda load-sideinverter(LSI).The mid- point of each half bridge of load-side VSI is connected at the PCC through an interfacing inductor. The use of isolated star- delta transformer provides the stable neutral terminal for 3P4W consumer loads. A high pass RC filter is connected at point of common coupling (PCC) to absorb switching transients of LSI. The low speed PMSG is directly coupled to a variable speed wind turbine.

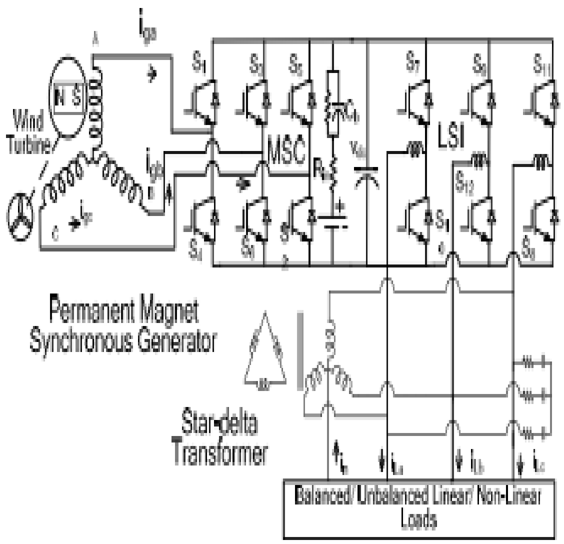


Figure 1.system configuration

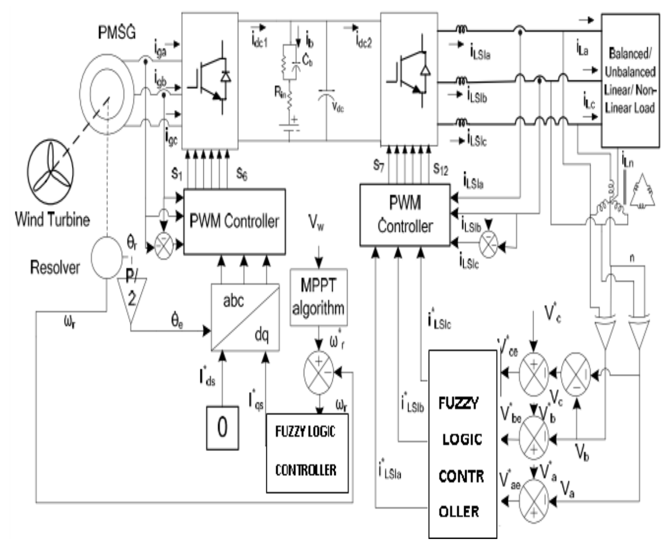


Figure 2.proposed control circuit

The BESS at the intermediate dc link provides the function of load leveling. Based on input wind speed, the reference prime-mover speed of PMSG is estimated to achieve MPPT using a 2-D look table with embedded wind turbine characteristics. The GSC allows the PMSG to operate at variable speed by regulating the active power component of generator currents and converts the variable frequency variable voltage supply to the dc supply. Further, to minimize losses of PMSG and to optimize rating of GSC, generator currents are kept minimum. To achieve this, the reference reactive power component of generator currents are set zero. It also leads to unity power factor operation of PMSG. The LSI is controlled to keep magnitude and frequency of the load voltage constant.

VI.FUZZY LOGIC CONTROLLERS

The conventional PI controllers are fixed-gain feedback controllers. Therefore they cannot compensate the parameter variations in the process and cannot adapt changes in the environment. PI-controlled system is less responsive to real and relatively fast alterations in state and so the system will be slower to reach the set point. Therefore the fuzzy control algorithm is capable of improving the tracking performance as compared with the classical methods for both linear and nonlinear loads. Also, fuzzy logic is appropriate for nonlinear control because it does not use complex mathematical equation.

The two FLC input variables are the error E and change of error ΔE. The behavior of a FLC depends on the shape of membership functions of the rule base. In this paper we use two fuzzy logic controllers. One fuzzy controller for generating reference voltage for pwm for load side converter.Another fuzzy controller for generating reference speed for pwm for load side converter

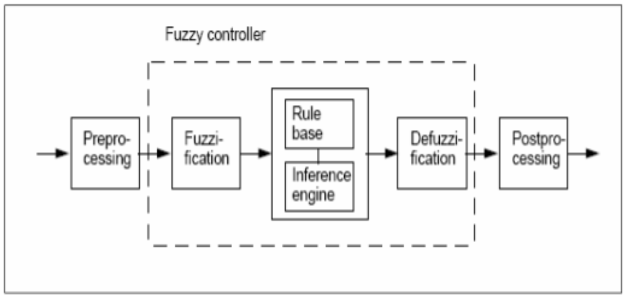
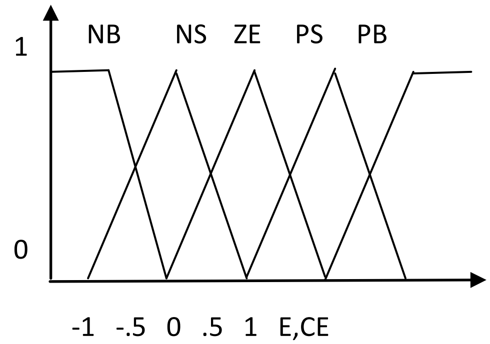


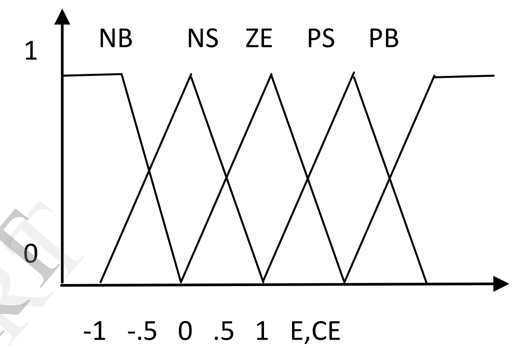
Fig3 .Structure of fuzzy logic controller

A.Fuzzification

The membership function values are assigned to the linguistic variables using seven fuzzy subset called negative big (nb), negative medium (nm), negative small (ns),zero(zr), positive small (ps), positive medium (pm), positivebig (pb). Fuzzy associative memory for the proposed systemis given in Table-1. Variable e and Δe are selected as theinput variables for FLC1 and Variable n and Δn areselected as theinput variables for FLC2, where e is the error between the referencesignal and actual signal of the system; Δe is thechange in error in the sampling interval. The output variableis the reference signal for PWM generator U. Triangularmembership functions are selected for all these process. Therange of each membership function is decided by theprevious knowledge of the proposed scheme parameters.



Membership Functions For voltage Controller



Membership Functions for Speed Controller

Rule Table of the Fuzzy Controller

Voltage &speed	Change in the voltage and speed(**δN, δv**)				
	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

B.Inference engine

Inference engine mainly consist of Fuzzy rule base and fuzzy implication sub blocks. The inputs are now fuzzifiedare fed to the inference engine and the rule base is thenapplied. The output fuzzy set are then identified using fuzzyimplication method. Here we are using MIN-MAX fuzzy implication method.

C.Defuzzification

Once Fuzzification is over, output fuzzy range is located. Since at this stage a non-fuzzy value of control is available adefuzzification stage is needed. Centroid defuzzificationmethod is used for defuzzification in the proposed.

SIMULATION RESULTS

The performance of the fuzzy logic based Voltage and frequency controller for PMSG based autonomous wind energy conversion system with Battery energy storage system is evaluated under rise and fall in wind speeds withbalanced linear consumer loads connected at load bus. The performance of thefuzzy logic based VFC is observed interms of PMSG currents (Ig), wind speed (Vw), PMSG speed(Wr), load line voltages (VLabc), load currents (Il), batteryvoltage (Vb), battery current (Ib), amplitude of load phase voltage (V),frequency (f), generatedpower (P),load power (PL) and battery power (P).

1. Performance of the fuzzy logic based VFC with fall in Wind Speed

The performance of the fuzzy logic based VFC is explained in Fig. 4 and Fig.5 with fall in wind speed with balanced consumer loads at load bus. It is observed that till 0.3s, the wind speed is 12m/s and PMSG rotor speed is 7.12 rad/s. after 0.3s wind speed is 8m/s and PMSG rotor speed is 4 rad/s At load bus 15 kW, 0.94 lagging pf tuned at half the PWM frequency is used to filter out switching ripples. The PWM frequency of LSI is selected as 10 kHz.

2. Performance of the fuzzy logic based VFC with increase in Wind Speed

Fig. 6 and Fig.7 shows the performance of VFC during rise in wind speed from 8m/s to 12m/s. The wind speed start rising at 0.3s from 8m/s and ramp up to 12 m/s at 0.308s. It is observed that PMSG rotor speed tracks the reference rotor speed obtained PMSG rotor speed tracks the reference rotor speed obtained from MPPT algorithm.

3. Performance of the fuzzy logic based VFC at Fixed Wind Speed and Balanced/unbalanced Non-Linear Loads

The wind speed is fixed at 12m/s and the performance of the fuzzy logic based VFC is explainedinFig.8andFig.9withbalanced/unbalanced nonlinear consumer loads. A three phase diode bridge rectifieris used as a non-linear consumer load. Thisrectifieris feeding RL load. Till 0.25s, these loads are balanced and there is a difference in Pg and P due to which battery is charging. At 0.255s, the load on phase ‘b’ is completely removed and at 0.35s, the load on phase ‘c’ is also removed. It is observed with such high unbalanced in load currents, the load voltages are balanced and sinusoidal. The harmonic spectra of load voltage (V) and load current for phase ‘a’ are shown in Fig.7. It is

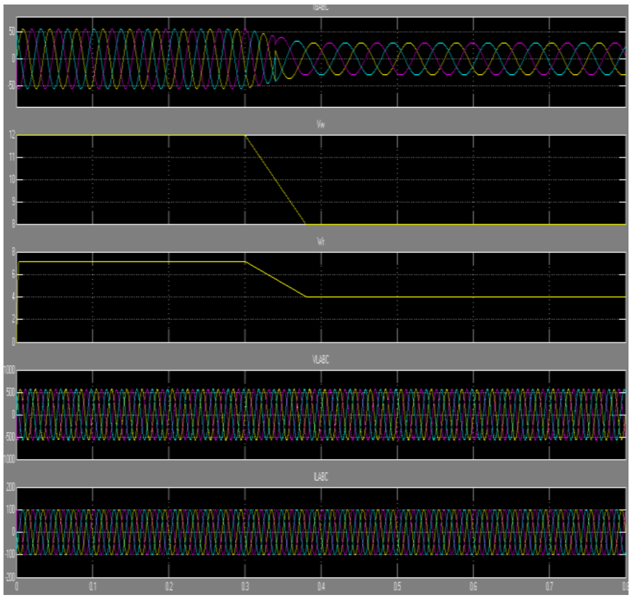


Fig4.performance during fall in wind speed

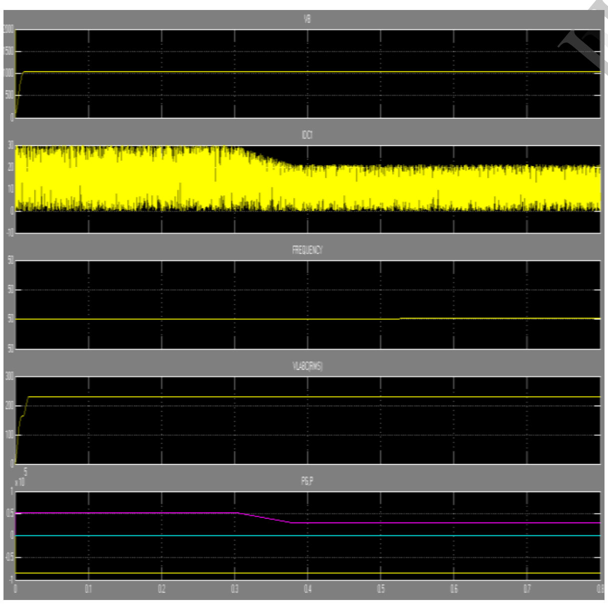


Fig5.performance during fall in wind speed

observed that even the load current total harmonic distortion (THD) is 35.75%, the load voltage THD (0.49%) is within allowable limits.

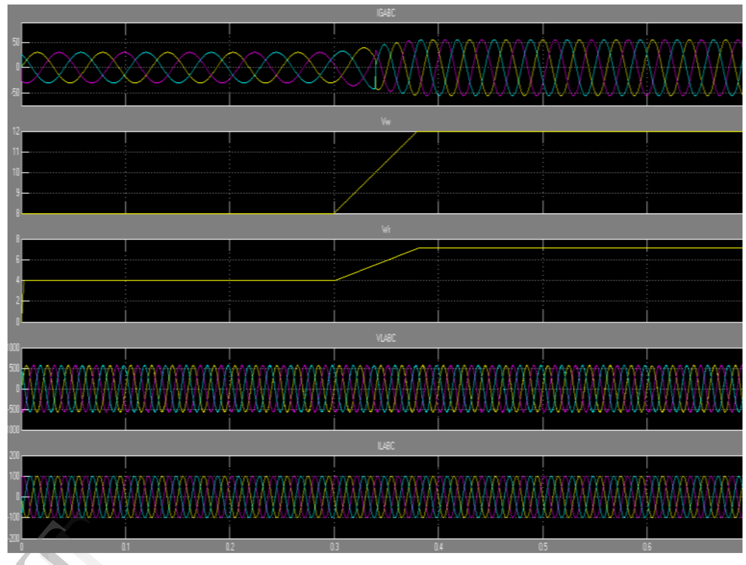


Fig6.performance during increase in wind speed

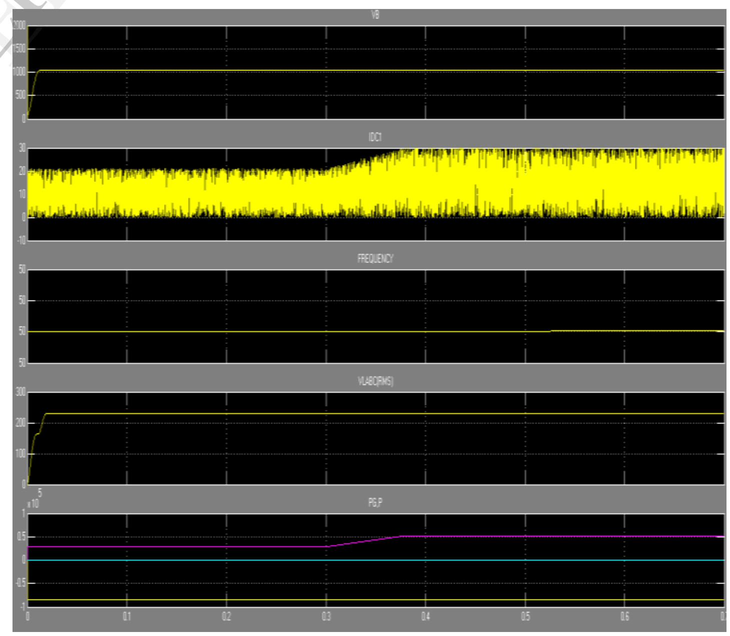


Fig7.performance during increase in wind speed

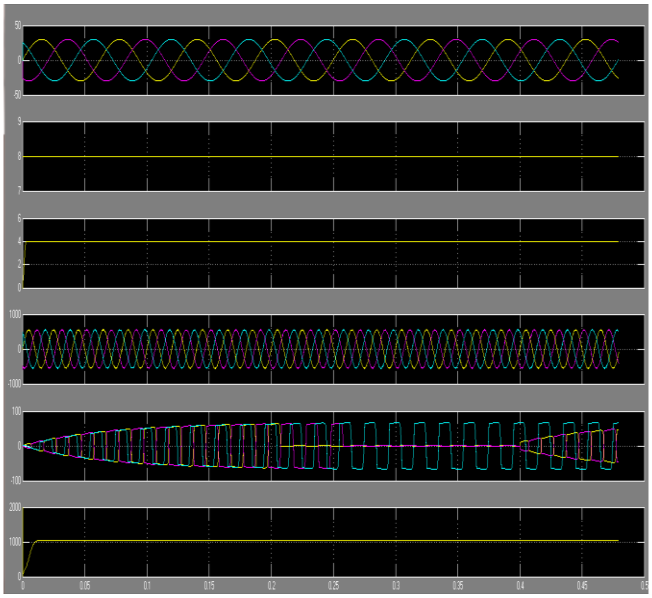


Fig8.performance during unbalanced load

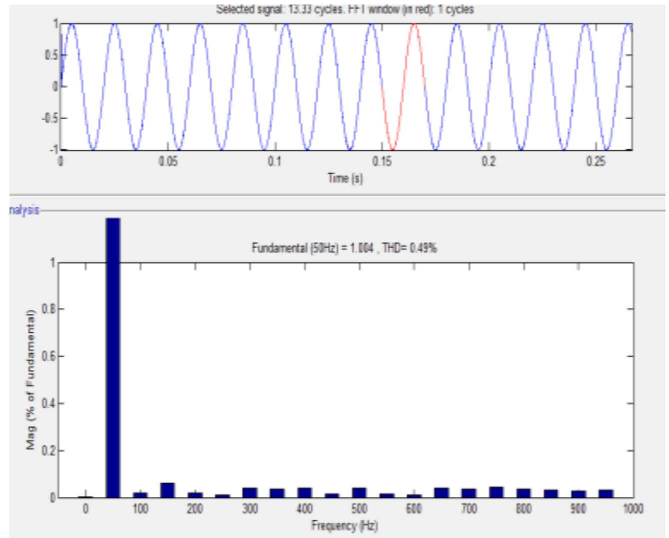


Fig10.FFT analysis for Load voltage

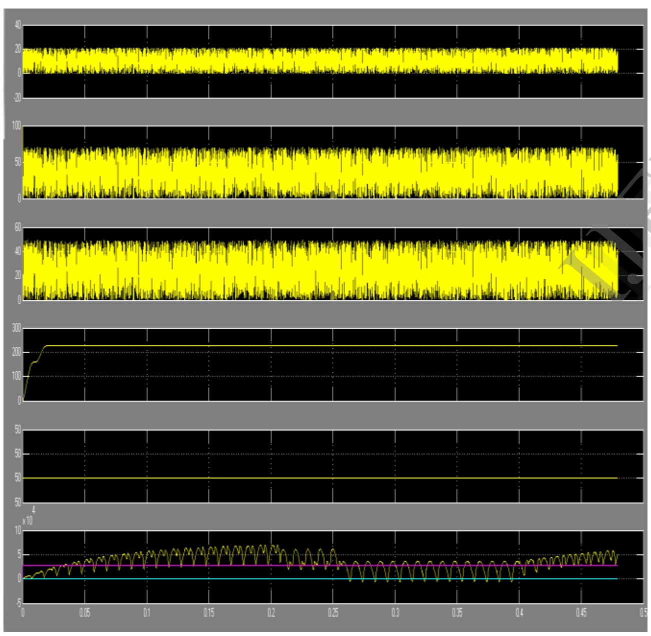


Fig9.performance during unbalanced load

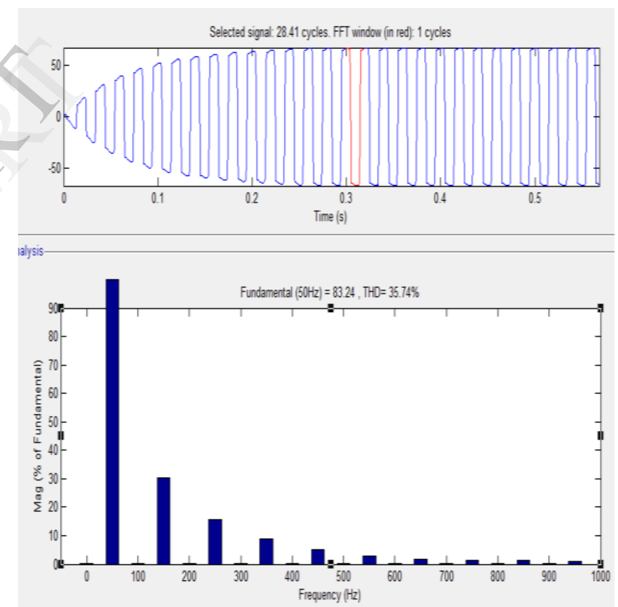


Fig11.FFT analysis for Load voltage

CONCLUSION

The performance of the fuzzy logic based voltage and speed controller for autonomous wind energy conversion system based on permanent magnet synchronous generator is good. With the pi controller the harmonic spectrum (THD) for load voltage and load current are 1.31% and 37.92% respectively. The harmonic spectrums (THD) for load voltage and load currents with fuzzy logic are 0.47% and 35.72% respectively. Simulation results and harmonic spectrum demonstrate that the fuzzy based controllerworks very well and shows very good dynamic andsteady-state performance.

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