Design and Modeling of Wind Fed Resonant DC-DC Converter through Synchronous Generator using MATLAB/Simulink

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ABSTRACT

This study presents the design, modelling and simulation of variable speed wind turbine through the LCL type DC-DC resonant converter for grid connected wind energy system using MATLAB/Simulink. Owing to enhancing the power demand and environmental issues, power generation from renewable energy is getting more consideration. The designed converter has main merits like reduced switching loss using soft switching methods, reduced transformer size, and filter size. In addition, this paper investigates the resonant converter application to obtain a constant D.C voltage at the output of the designed converter, reduced stress, EMI, and high power density. In this paper, fuzzy logic controller (FLC) is used to regulate the output voltage of resonant converter in comparison with PI controller. The simulation has been done in MATLAB/Simulink frame work. It is shown that a resonant converter enhances voltage profile of power grid containing synchronous generator based wind system.

Keywords
Resonant converter, synchronous generator, fuzzy logic controller, MATLAB/Simulink.

1. INTRODUCTION

Wind is one of the richest renewable sources of energy in natural history. The economical and environmental advantages offered by wind energy are the most key reasons why electrical systems based on wind energy are receiving vast global attention. Due to the increasing demand on electrical energy, a significant amount of effort is being made to generate electricity from harmless renewable energies.

Small-scale stand alone wind energy is increasingly viewed as a viable and occasionally preferred source of electrical energy; consider, for example, remote villages or ranches located far away from main power lines. Wind energy is a quiet option to remote diesel generation–generation that sometimes depends on excessive transportation and fuel storage costs-and an economically justifiable alternative to a grid connection. The need to integrate the renewable energy like wind energy into power system is to make it possible to minimize the environment impact on conventional plant has been well executed in [2].

There has been a wide growth and rapid development in the utilization of wind energy in recent years. The individual units can be of large capacity up to 2MW, feeding into distribution network, predominantly with customers connected in close proximity was presented in [3]. A typical, small-scale, stand-alone, wind electric system consists of a wind turbine, a permanent-magnet generator, a diode bridge rectifier, and a dc power system. In many small- scale systems, the dc system is at a constant dc voltage and is usually comprised of a battery bank, allowing energy storage; a controller to keep the batteries from overcharging; and a load. The load may be dc or may include an inverter to an ac system has been addressed in [1]. Today, more than 28,000 wind generating turbines are successfully operating all over the world. Fluctuations in the wind speed are transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. Fluctuations in network, such as voltage sag, swells, flickers, harmonics etc has been discussed in [4]. From the literature reviews, it is clearly observed that the simulation of fuzzy logic control of dc to dc resonant converter using wind model has not been implemented in [5]-[14]. Therefore, in this paper, it is proposed to design the simulation of fuzzy controlled dc to dc converter wind system modeling. The DC-DC resonant converter with fuzzy logic controller that achieves high wind turbine efficiency across a wide range of wind speeds. The system is designed for use in remote locations and therefore, includes a simple fuzzy logic control strategy and a fault tolerant topology. This paper mainly focuses on simulation of closed loop controlled DC-DC converter with wind system modeling.
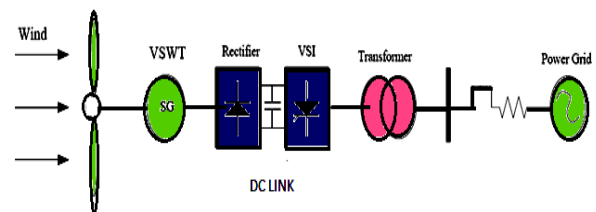

Fig.1.Schematic representation of modeled VSWT coupled synchronous generator.

The schematic diagram of variable speed wind turbine (VSWT) model is shown in Fig. 1 and Fig.2.

Table 1. Specification of wind energy system data

Effective turbine radius	1.0 m
phase to phase winding inductance	3.3mH
Phase to phase winding resistance	0.71Nm/A
Poles	8
System inertia	1.2kg m^2
System damping	0.16Nm/k

Table.2. Specifications of generator, transformer and converter data

Synchronous generator
Nominal power:1.5 MVA
Line to line voltage:600v
Reactance(x$_d$=1.305,x$_d'$=0.296,x$_d''$=0.252,x$_q$=0.474,x$_q''$=0.243, xl=0.18)
Stator resistance(R$_s$) :0.00285 ohms
3-phase transformer:1.5MVA,0.6kv/48v
Transformer
Nominal power:300v
Winding$_1$:48v, R$_1$=0.02ohms, L=0.001H
Winding$_2$:11.68v, R$_1$=0.02ohms, L=0.001H
Magnetization resistance& inductance: (R$_m$)=500ohms,L$_m$=500H
Converter
Diode resistance(D$_1$)=0.001, FWD voltage=0.8v,snubber resistance(R$_s$)=5000ohms.
MOSFET
FET Resistance :0.1ohms
Internal diode resistance R$_d$=0.01ohms
Snubber resistance R$_S$=100000ohms
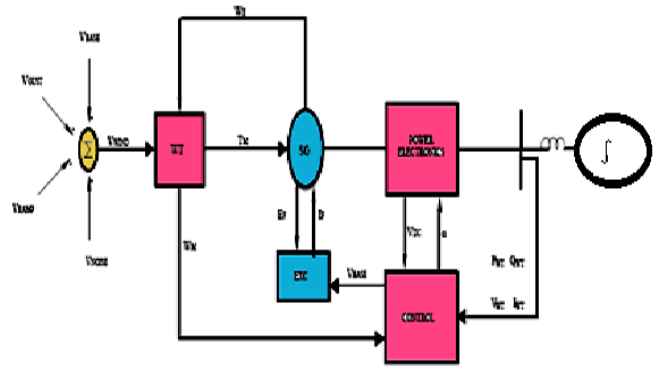
Fig.2. MATLAB/Simulink simulation model of a VSWT coupled Synchronous generator.

2. THEORITICAL ANALYSIS

The essential objective of utilizing a wind turbine is to convert the kinetic energy into mechanical energy, which can be applied to drive the shaft of an electrical power captured from the wind into electrical power. The power captured from the wind P$_w$ can be designed from [5]-[6].

$$p_w = \frac{1}{2}\rho c_p A V_w^3$$
(1)

Where,

p_w is turbine power,

ρ is the air density in kg/m^3,

c_p is the power coefficient,

A is the wind turbine rotor swept area in m^2,

and v_w is the wind speed in m/s.

The mechanical power p_m produced by the wind turbine due to p_w depends on the power co-efficient c_p of the wind turbine and can be expressed as.

$$p_m = c_p(\lambda, \beta) p_w$$
(2)

The co-efficient of performance is a function of Tip speed ratio (TSR) and is given by

$$TSR = \frac{\gamma_{\omega_m}}{V_\omega}$$
(3)

Where

ω_m : Rotational speed

γ : Turbine

V_ω : Wind speed

A typical curve is shown in fig (3). The maximum power captured by the wind turbine will occur when the TSR is approximately 7.5, corresponding to a C_P Of 0.35.
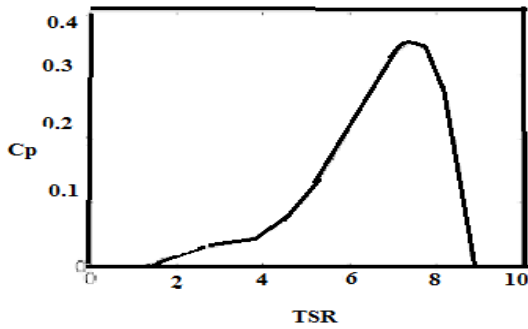

Fig 3. Typical C_p curve.

The VSWT model consists of the following components; they are

- Wind model
- Wind turbine and control
- Synchronous generator
- Rectifier and inverter

2.1 Wind model

A wind model selected for this study is contains four components [15], and can be mathematically expressed as

$$V_W = V_B + V_G + V_R + V_N \qquad (4)$$

Where

V_B = base wind speed component (m/s)

V_G = gust wind component (m/s)

V_R = ramp wind component (m/s)

V_N = Noise wind component (m/s)

The base component is a stable speed and wind gust component can be usually expressed as a sine or cosine wave function. In this simulation, wind speed represent the constant block in MATLAB/Simulink.

2.2 Design of wind turbine and control

The wind turbine can be described by the following equations (5), (6), and (7) collectively.

$$\lambda = \frac{\omega_m R}{V_{WIND}} \qquad (5)$$

$$P_m = \frac{1}{2} \rho \pi R^2 C_p V_{WIND}^3 \qquad (6)$$

Eqn (5) gives :

$$V_{WIND} = \frac{\omega_m . R}{\lambda} \qquad (7)$$

$$P_m = \frac{1}{2} \rho \pi R^2 C_p (\frac{\omega_m . R}{\lambda})^3$$

$$P_m = \frac{1}{2} \rho \pi R^5 C_p (\frac{\omega_m}{\lambda})^3 \qquad (8)$$

$$T_m = \frac{p_m}{\omega_m} \qquad (9)$$

Where λ= tip speed ratio, m=blade angular speed [mechanical rad/s], R=blade radius[m], V_{wind}=wind speed[m/s], P_m=mechanical power from wind blade[kw], ρ=air density [kg/m³], C_P=power co-efficient, T_m= mechanical torque obtained from equation (9) is the input torque to the synchronous generator and is driving the generator. C_p may be expressed as a function of the tip speed ratio (TSR) λ is given by equation (2) [5].

$$c_p = (0.44 - 0.0167\beta)\sin\frac{\pi(\lambda-2)}{(13-0.3\beta)} - 0.00184(\lambda-2)\beta \qquad (10)$$

Where

B is the blade pitch angle, for a fixed pitch type the value of β is set to a constant value.

2.3 Mathematical analysis of synchronous generator

The MATLAB/ Simulink gives a fully designed and developed synchronous generator model, which is purely based on generalized machine theory [14] and with model both sub-transient and transient behavior of the system is clearly examined. This model is considered that the synchronous generator is equipped with an exciter identical to IEEE type 1 model [10].

The exciter can be adjusted to meet out dc link voltage requirement and also synchronous generator can be operating at different power factor. Since the generator is a direct drive type with low speed and a high number of poles, the wind turbine and the generator are rotating at the same mechanical speed via the same shaft. Therefore, shaft dynamics can be characterized by a swing equation on a single mass rotating shown in equation (9). The shaft dynamics and the rotating mass can be represented by multi-mass torsion shaft model of MATLAB/Simulink, which can be easily interfaced with synchronous machine model.

$$J_m \frac{d\omega_m}{dt} = T_m - T_E - D\omega_m \qquad (11)$$

Where

J_m= a single rotating inertia(k_g-m^2)

T_E= electrical torque produced by generator (N-m).

D=damping (J-s/rad).

In variable speed operation, the rotating speed of the wind generator is not consistent with the electrical synchronous speed of the electrical network and generally much slower. The electrical base frequency of the machine in the built in models must be set to a value corresponding to the rated mechanical speed of the wind turbine specified by a manufacturer or a designer. Equations (12) and (15) gives the value for the electrical base speed of the synchronous machine W_B.

$$f_B = \frac{p}{2} \cdot \frac{RPM_{TURBINE}}{60} \qquad (12)$$

$$\omega_B = 2\pi f_B \qquad (13)$$

$$\omega_B = 2\pi \left(\frac{p}{2} \cdot \frac{RPM_{TURBINE}}{60} \right) \qquad (14)$$

$$\omega_B = \pi \cdot p \cdot \frac{RPM_{TURBINE}}{60} \qquad (15)$$

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3. SIMULATION RESULTS

Simulation is performed by using MATLAB/Simulink and its model is indicated in Fig.4 and Fig. 5 with specifications is listed in Tables 1 & 2. The wind turbine model is coupled to the input side of the resonant DC-DC converter. The output waveform of wind turbine model fed AC-DC converter output is 48 V, which is given as input to the DC-DC converter. Fig. 6 show the output voltage of resonant DC-DC converter using fuzzy logic controller in start-up region. From the result, it is clearly found that output voltage of the converter has no overshoot and quick settling time of 0.02s. The output waveform of wind turbine model fed AC-DC converter output is 48 V, which is given as input to the DC-DC converter as depict in Fig.7. In Fig. 8 show the output voltage and wind velocity of designed model. From the figure, tit is observed that the output voltage of converter is independent of wind velocity. In order to access the capability of the system in tracking maximum power point at varying wind velocity, a step change in the wind velocity is applied to the system. The system is first operating at the wind velocity of 8m/s. At this velocity, maximum output of converter is 12v. At time of 0.1 sec, the wind velocity is changed to 10m/s. The maximum output of converter corresponding to this velocity is 12V. The system output is free from ripple and peak overshoot. It gives constant output voltage compared with PI controller system. This fuzzy controller-based closed loop system is superior to the commonly used PI controller-based closed loop control. Simulation results show successful tracking of maximum power from the wind at all wind velocities. The output voltage is sensed and it is compared with a reference voltage of 12v. The error is given to a fuzzy logic controller. The output of fuzzy controller generates pulses with reduced width. When these pulses are applied to the MOSFET's in the output rectifier, the output reduces to the set value. Thus the closed loop system is capable of reducing the steady state error. The parameters of k_p =4 and k_1=0.1 are used for simulation studies.
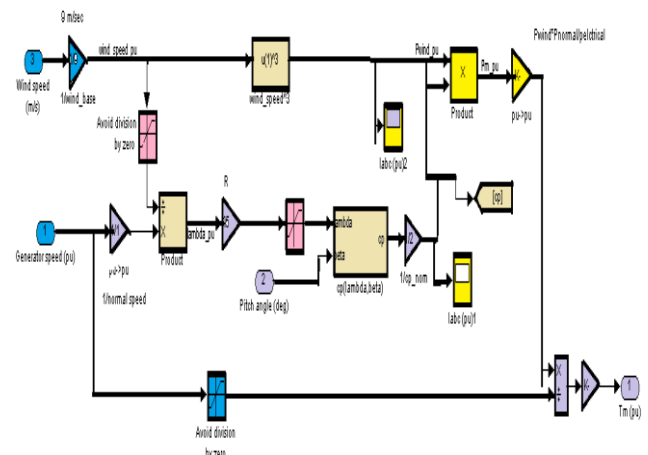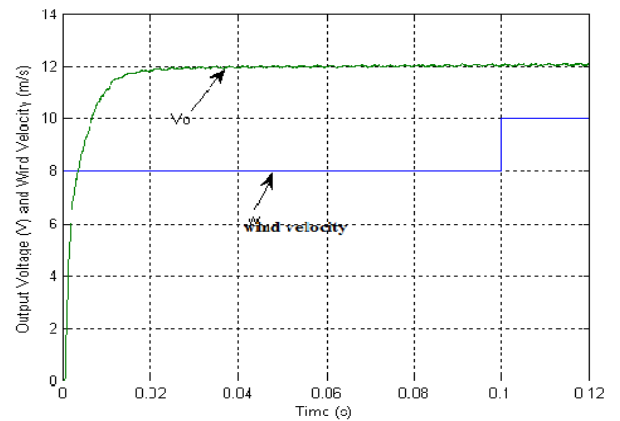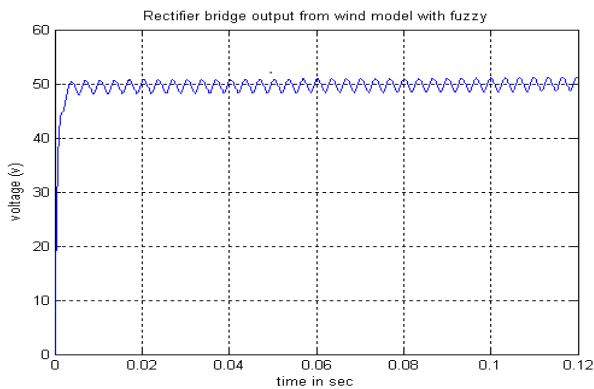

Fig .4. Wind turbine model.
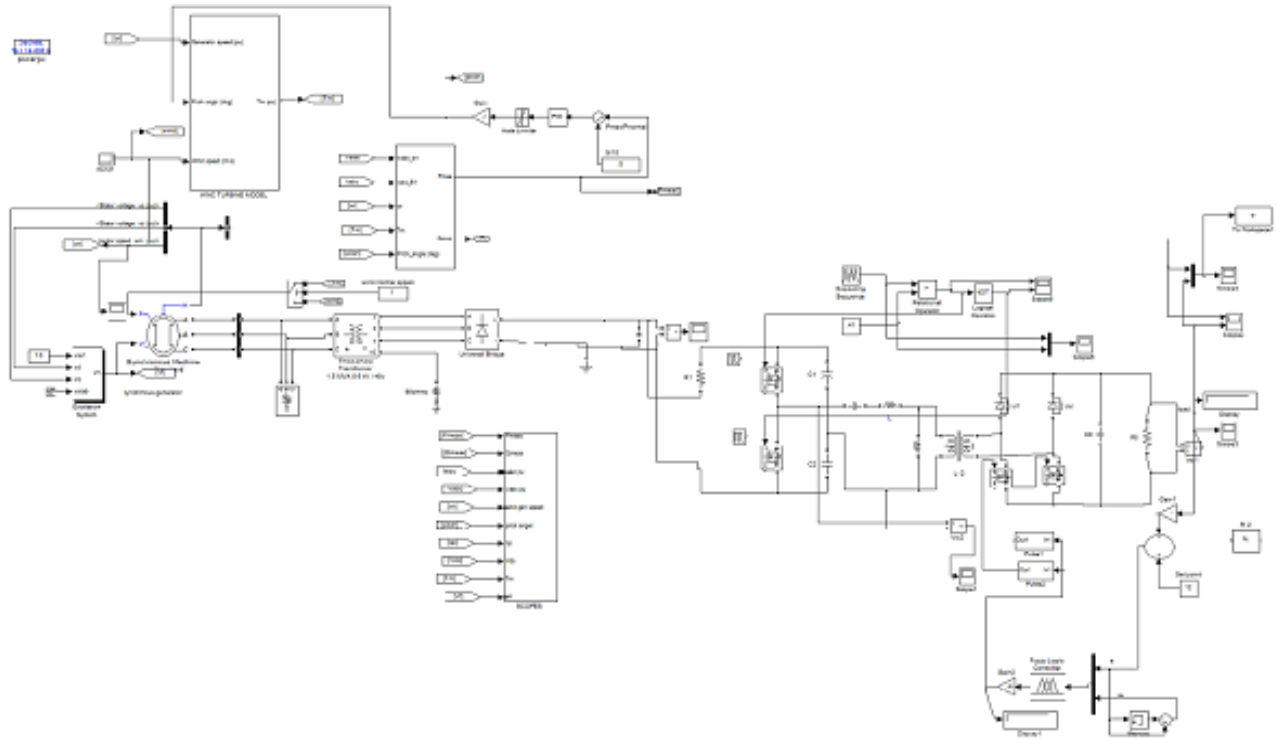
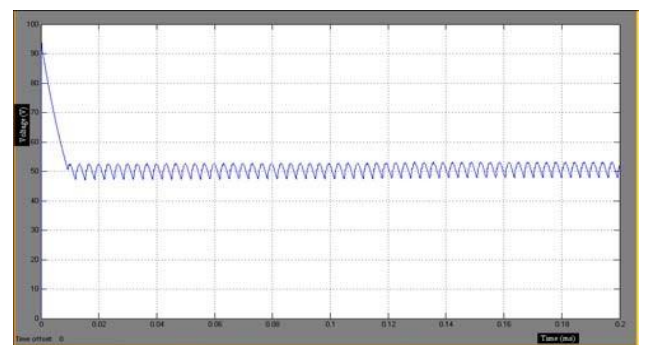**Fig .5. DC-DC Converter circuit with Wind Turbine model at Input side.**
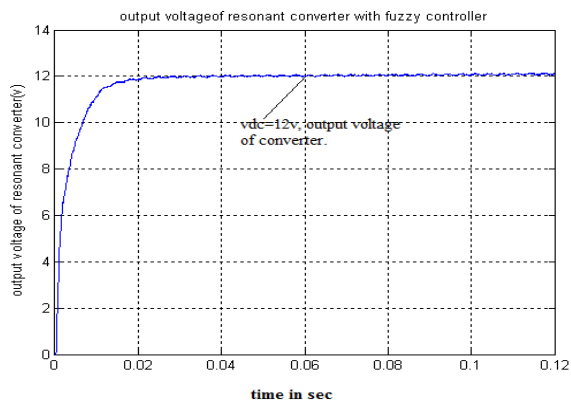
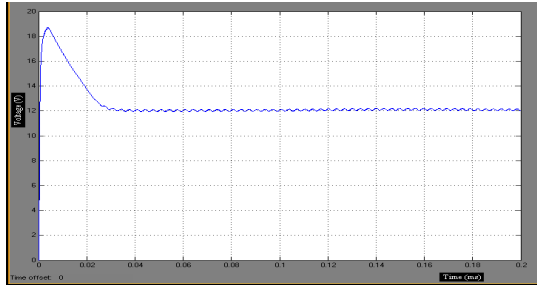**Fig.6. Output voltage of resonant converter with wind model using FLC.**

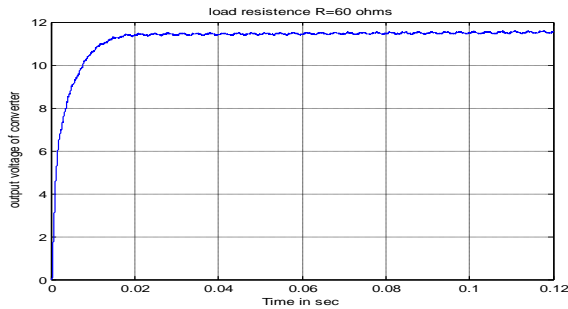**Fig.8. Output voltage of dc-dc converter using FLC with wind velocity.**

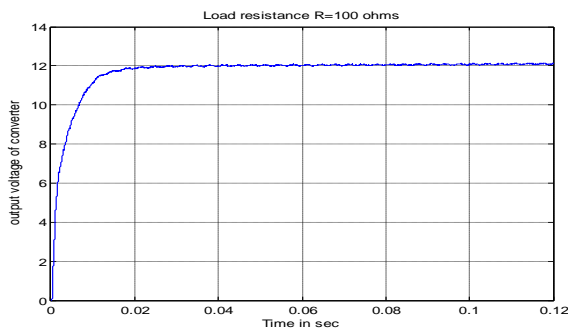**Fig.7. Output voltage of AC-DCc converter from wind model using FLC.**

Fig.9.Output voltage of AC-DC converter from wind model using PI controller.

Fig.10. Output voltage of DC – DC converter using PI controller.

Fig.11. Output voltage of resonant converter using FLC with load resistance variation R=60ohms.

Fig.12. Output voltage of resonant converter using FLC with load resistance variation R=100ohms.

Figs. 9 and 10 shows the simulated results of output voltage of both AC-DC converter and resonant DC-DC converter using P.I and fuzzy controller. From the simulation results were showed more overshoot of (45V and 7V) and long settling time of 0.04s respectively in case of P.I controller. The electrical performances of the converter have been analyzed by simulation runs. The output of converter is held constant irrespective of change in R-values. Figs. 11, and 12 shows the simulation result of converter using fuzzy logic controller at different load resistance of 60ohms, and 100ohms has been presented clearly below in Figs. 11, and 12. In summary from the Fig.6 to Fig. 12, the simulation results of PI controller produced more overshoots and long settling time in comparison with fuzzy logic controller.

4. CONCLUSIONS

In this paper, design, modeling and simulation of fuzzy logic loop controlled DC-DC converter with grid connected wind generator has been successfully implemented in MATLAB/Simulink. In this paper, the LCL type DC-DC resonant converter was mastery in reduced EMI effect, stresses and high power density. The simulated results of designed controller with system were showed that successful tracking of maximum power from the wind at all wind velocities, good load voltage regulation of converter in comparison with PI controller has been obtained.

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