Implementation of Improved BLDC based Ceiling Fan Control Using Zeta Converter with Fuzzy Controller

D. Karthikeyan, K. Vijayakumar, Tejas Saptarshi, Mayank Kheria, Snigdha Kumari

Abstract--- This paper deals with the implementation of Zeta Converter fed BLDC motor using fuzzy logic control with PV as source. The idea is to reduce the torque ripples and improve the speed and power factor keeping the cost and the maintenance factors minimum. The suggested model is compared with the boost converter fed BLDC motor using PI control and the comparative analysis is made on the basis of torque, power factor and speed. Moreover, the ease of compensation with smooth and stable operation of the system is also being considered as a priority. The evaluation is made using the Matlab Simulink and the hardware of the suggested model is successfully implemented. Through the comparative analysis Zeta converter fed BLDC motor with fuzzy logic control is found to be superior in terms of speed, torque and power factor.

Keywords--- Boost-converter, Zeta converter, PI control, Fuzzy Logic, BLDC Motor, Ceiling Fan, Matlab.

I. INTRODUCTION

Renewable energy systems are widely getting accepted and becoming well-organized. These are alternate ways that could possibly lead us away from the petroleum dependent energy resources. Among them solar energy is one of the important resource that will increase the energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource and enhance sustainability with reduced pollution [4].The major cost involves in interfacing PV module with a particular application. In this work an attempt has been made to integrate PV module with the BLDC motor via Zeta converter and Fuzzy logic control for various domestic load with satisfactory output and a cost-effective approach so that it can be accepted and implemented widely and a step more closer towards green-technology can be taken. The conventionally used Induction motor is robust, having low cost, widely available in the market and requires low maintenance. However, induction motor possesses various disadvantages such as complex control requirement and overheating problem, hence not adapted [1]. The proposed BLDC motors posses a higher efficiency, low EMI, low torque ripple, improved power factor and requires no maintenance thus, cost efficient.Hence, the proposedmodelisfoundtobe efficient compared to the boost converter fed BLDC motor.

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II. BLDC MOTOR

Brushless DC motor are over shadowing the existing one's because of its phenomenal performance and industrial applications across the world. These are quiet, lighter and having much life span with almost no maintenance. Since, electric current can be controlled by micro-controllers or computers they can achieve more accurate speed and position control [2].In brushes motors,permanent magnets are present on the outside and an electromagnet is contained inside a spinning armature. Electromagnets present here helps in creating a magnetic field in the armature of the motor when it is plugged on to the supply and thus helps to rotate the armature. The brushes help in changing the polarity of the pole and also to continue the rotation of the armature. Working principles for both brushed DC motor and for BLDC motor are the same i.e., internal shaft position feedback. BLDC motor consists of majorly two parts, which are rotor and stator. The rotating part is known as rotor. It has the rotor magnets. Whereas the stationary part is known as stator. Stator has the stator windings in it. In brushless DC motors electromagnets are attached with the stator and permanent magnets are combined in the rotor.

Advantages of BLDC motor

Since there are no brushes in the BLDC motor, the efficiency increases due to reduced loss of mechanical energy from friction. High speed operations can be achieved using BLDC motor under any circumstances. There are no sparks produced andnoise is less during the operation. Precise control can be achieved by using a greater number of electromagnet son the stator. Due to lower rotor inertia BLDC motors can easily accelerate and decelerate. BLDC motor provides huge torque and is a high performing motor. These motors provide various other advantages such as they are more reliable, give higher life expectancies, and provide maintenance free operations as they lack brushes in them.

III. BOOST - CONVERTER

A Boost converter is a DC-DC converter that steps up the voltage and steps down the current from itsinput towardsthe output. It is also known as step-up converter. It is a class of SMPS containing minimum two semiconductors and an energy storage element as shown in Fig1.

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When the triggering pulse current flows through the inductor the switch is turned on and the energy is stored in it by generation of magnetic field [5]. When the switch is opened, the magnetic field which was created earlier is destroyed to maintain the current towards the load and thus both the sources will come in series which causes a boost in the voltage for charging the capacitor through the diode D.

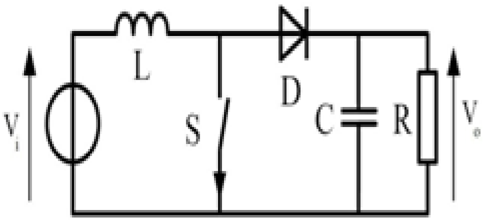
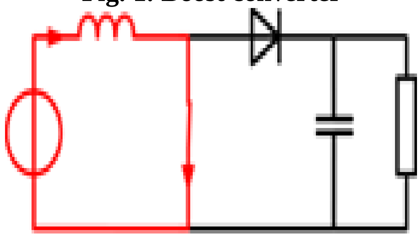
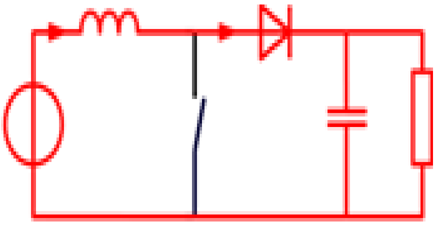


Fig. 1: Boost converter



Switch is ON



Switch is OFF

IV. DESIGN OF BOOST CONVERTER

In Maximum Power Point Tracking the converter is used to shift the input source voltage (Vi) corresponding to the value of Vmpp to keep up the maximum power. The design of Boost Converter depends on duty cycle as

$Zsource = \frac{Vi}{Ii}$ (1.1)

Where, Vi- input voltage and Ii- input current

For boost converter input voltage and current is shown in equation (1.2) and (1.3) ,

$$Vi = Vo(1-D)(1.2) and Ii = \frac{Io}{1-D} \quad (1.3)$$

Where, Vo- output voltage, Io- output current D-Dutycycle

Substituting these values in equation (1.1)

$$Zsource = \frac{Vo}{Io}(1-D)^2 = Zo(1-D)^2$$

Modifying the above equation

$$D = 1 - \sqrt{\frac{Zsource}{Zo}} \quad (1.3)$$

For the transfer of maximum power,

Source=Zmpp

Thus, duty ratio in equation (1.3) is modified to:

$$D = 1 - \sqrt{\frac{Zmpp}{Zo}} \quad (1.4)$$

From Equation (1.4) duty cycle (D) required formaximum power point can be obtained for $0 \le D \le 1$ and load impedance must be $Zo \ge Zmp$.

Inductor value can be calculated from equation (1.5) shown below:

$$L = \frac{D \times Vi}{\Delta Il \times Fs} \quad (1.5)$$

V. PI CONTROLLER

The priority of controller is always to minimize the error between the actual output and the set point. The actual output is the one which needed to be controlled and the set point is the expected output. In terms of speed control the error can be given by the equation: e(t) = ω$SP(t) - $ω$PV(t)$ (1) Where e(t) is the error function with respect to time, ω$SP(t)$ is the reference speed,and ω$PV(t)$ is the actual motor speed as function of time. The PI term stands for Proportional Integral which has 2 parts and each having its own gain. The proportional part is the errormultiplied by a constant gain known as KP and the integral part is the integration of time with respect to time multiplied by a constant gain known as KI. The equation for the PI controller can be given by: u (t) = K$Pet + KIetdt$, Where u(t) is the PI output, KP is the proportional gain, KI is the integral gain, and e(t) is the error function shown in equation (1).

Advantages of PI controller

In PI controller integral of the input signal is always proportional to the Output. Since, the integrator is indulged in the case, the type of the system is increased which in turn reduces the steady state error and thus enhances the accuracy.

Drawbacks of PI controller

PI controllers have high starting overshoot and are sensitive to controller gain. To the sudden disturbance response is very slow. No guarantee of good performance. Evaluation of gain coefficients requires complex calculations. The system can become unstable for higher order and complex ones and thus it is not recommended.

Existing Circuit Block Diagram

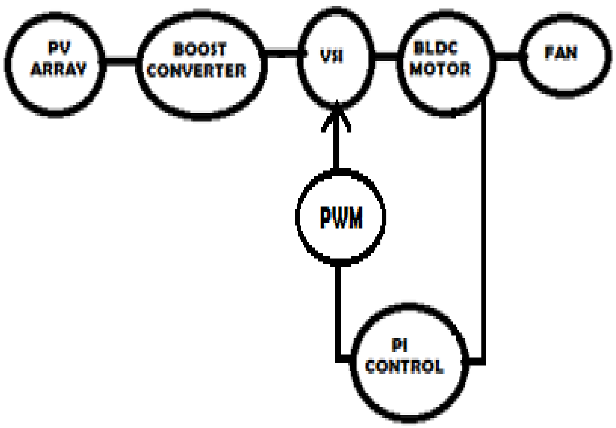


Fig. 2: Block diagram

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Circuit Diagram

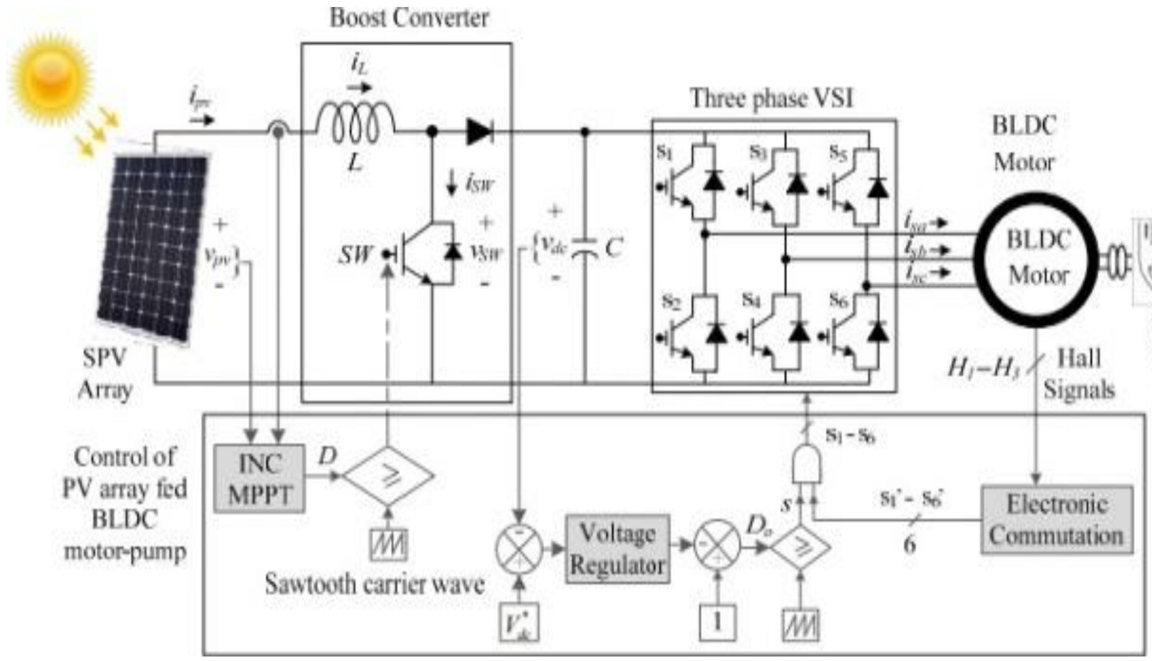

Fig. 3: Boost fed BLDC motor

VI. EXPLANATION FOR THE EXISTING MODEL

In the existing system block diagram as shown in Fig 2, boost converter is used to trap the energy from the PV array which is then converted into ac using VSI. The speed of BLDC motor is governed by pulse width modulation (PWM) of VSI using a DC link voltage regulator. Here, no additional current sensing element is used. Since, the BLDC motor speed is commanded by pulse width modulation (PWM) of VSI using a DC link voltage regulator, no additional current sensing element is used. The PI controller is used in order to control the speed of the BLDC motor. An inbuilt encoder, mounted on the BLDC motor itself, provides three Hall signals following the rotor position which are further converted into six pulses for the switching of three phase inverter. The circuit diagram of existing model is shown in Fig 3.

VII. SIMULATION DESIGN OF BOOST CONVERTERWITH OPEN LOOP

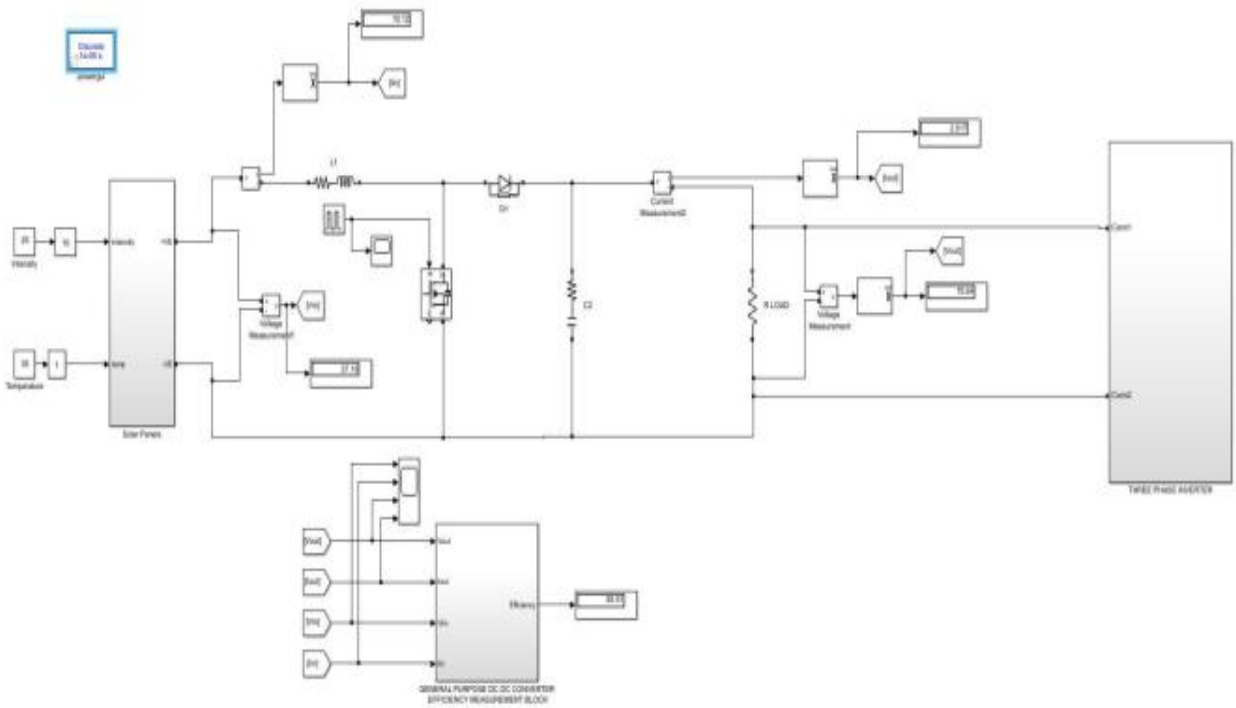

Fig. 4: Simulation circuit of existing model with open loopOutput of Boost Converter

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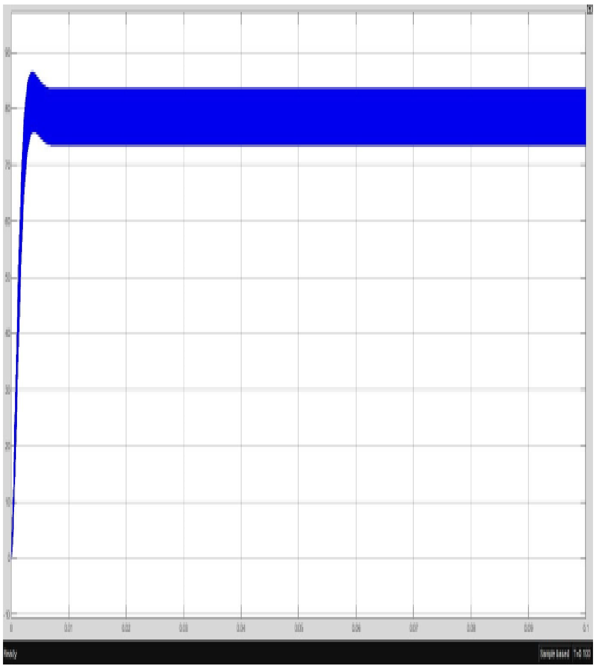

Fig. 5: Output waveform from boost converter

Output of three phase VSI fed with Boost Converter

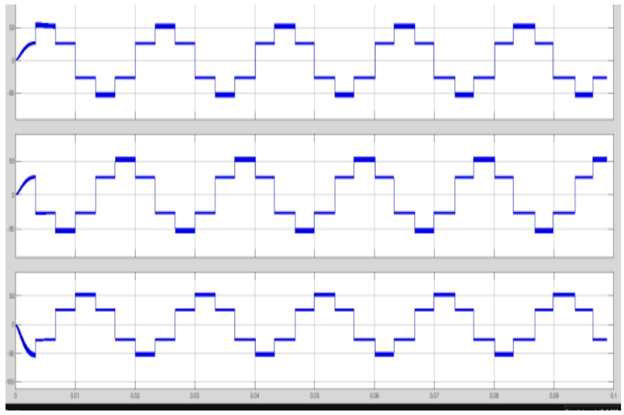

Fig. 6: Output waveforms from the inverter

Open loop simulation of existing circuit with Boost converter is shown in Fig 4. Boost converter provides an output voltage of 75.6V with ripples of 10V which is shown in Fig 5. Fig 6 shows the output waveforms from the inverter with ripples and a voltage of 50V.

VIII. DESIGN OF CLOSED LOOP BOOST CONVERTER FED BLDC MOTOR WITH PI CONTROLLER

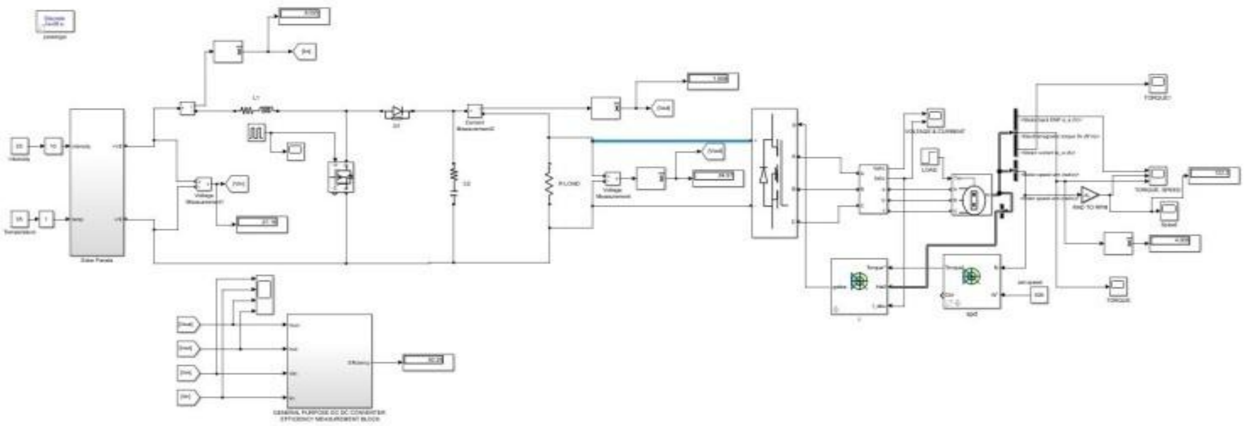

Fig. 7: Closed loop circuit for the existing model

Speed control with PI

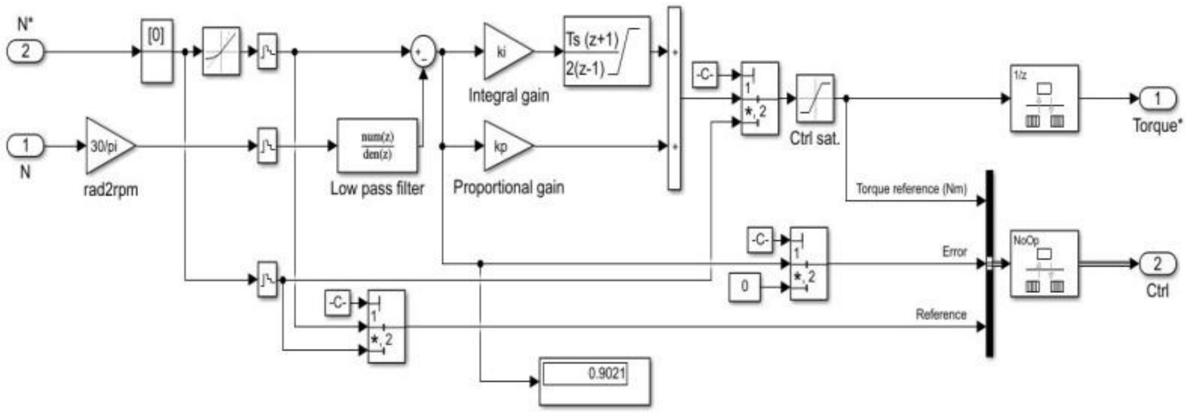

Fig. 8: Speed control block using PI control

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Speed Waveform

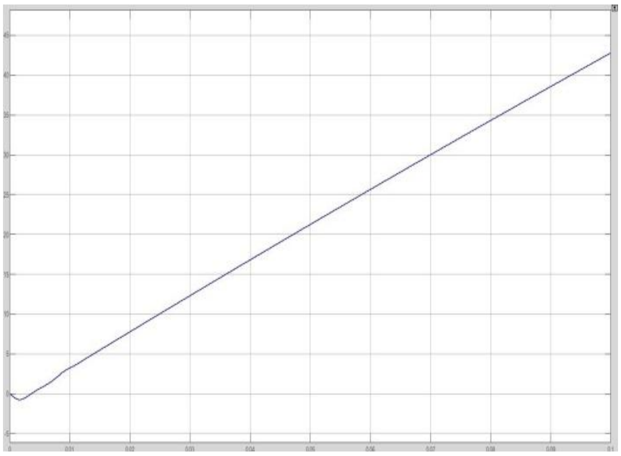

Fig. 9: Output waveform for speed

Current Waveform

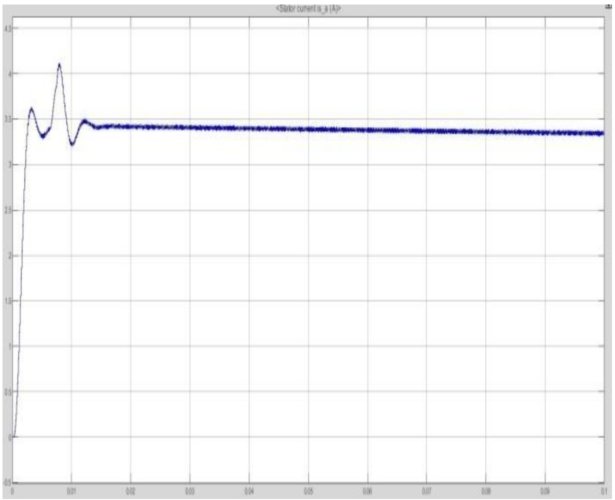

Fig. 10: Output waveform of stator current

Torque Waveform

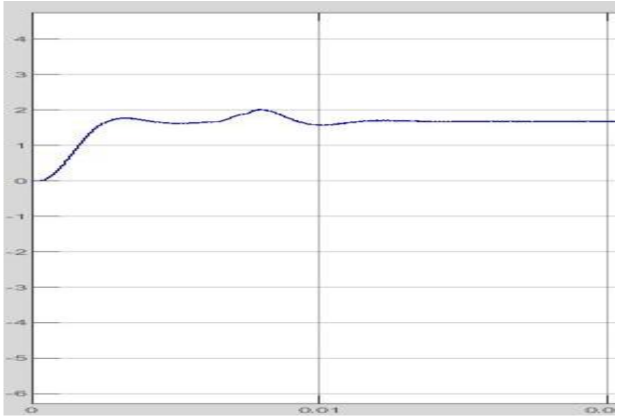

Fig. 11: Output waveform for torque

Closed loop circuit of Boost converter fed BLDC motor with PI controller is shown in Fig 7. Subsystem block for speed control with PI control is shown in Fig 8. Speed of the motor in this existing system is 42 rpm as shown in Fig 9. Stator current in the system shown above is 3.4A, waveform is shown in Fig10. This system produces an output torque of 1.7 N-m which is shown using waveform in Fig 11.

IX. PROPOSED MODEL BLOCK DIAGRAM

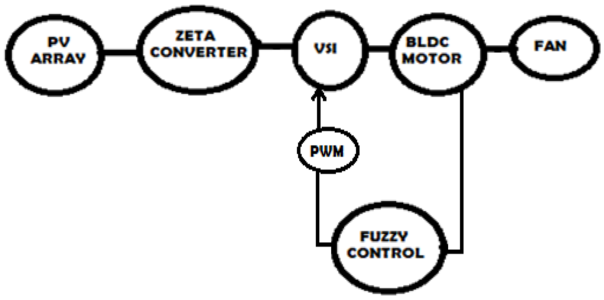

Fig. 12: Block diagram of Proposed model

Proposed Circuit Diagram

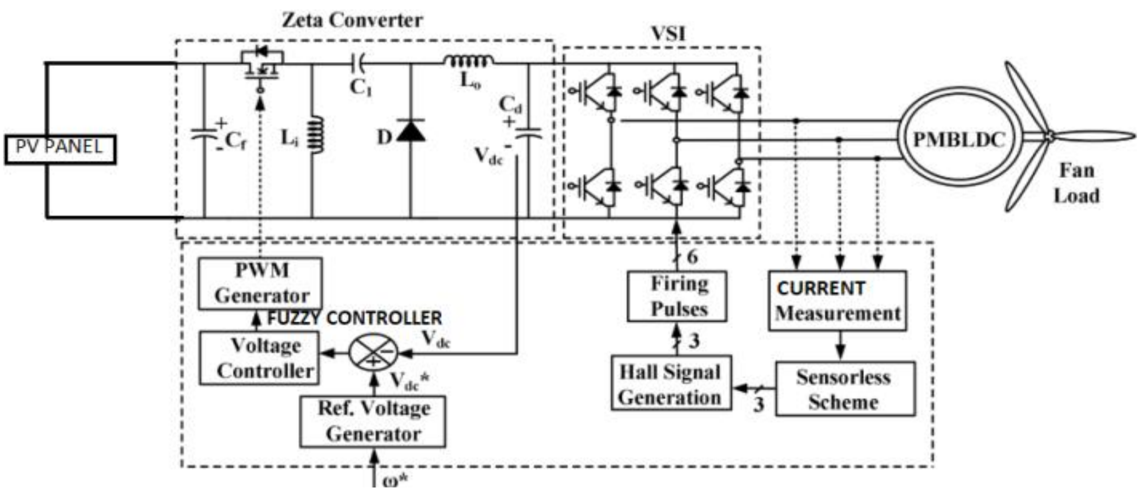

Fig. 13: Circuit Diagram of Proposed model

Circuit Explanation

The proposed model uses a PV array system connected to a Zeta Converter fed BLDC motor for ceiling fan applications as shown in Fig 12. Zeta Converter is also known as Inverse SEPIC Converter, it is a fourth order converter. The electronic commutation of BLDC motor controls the switching frequency of the inverter which reduces the inverter losses of high switching frequency. Speed control of the motor is achieved by using fuzzy logic controller. The circuit diagram of proposed model is shown in Fig 13. The model aims to improve the speed, power factor and torque ripple of the system.

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X. ZETA CONVERTER

ZETA converter is a dc/dc converter that provides a positive output voltageand can work in both step up and step-down mode. The ZETA converter consists of two inductors and a series capacitor, also called a flying capacitor. In the continuous current mode when Q1 is on both the inductor gets charged and the diode D1 is in reverse bias. When Q1 is off polarity of both the inductor reverses and it start getting discharge through the capacitors. The Duty cycle and output voltage is shown in equation 2.1 and 2.2 respectively.

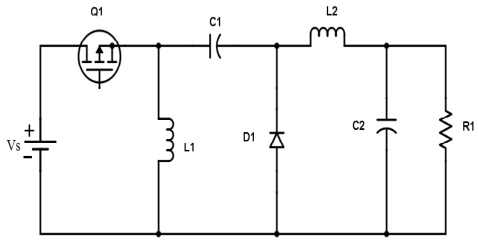
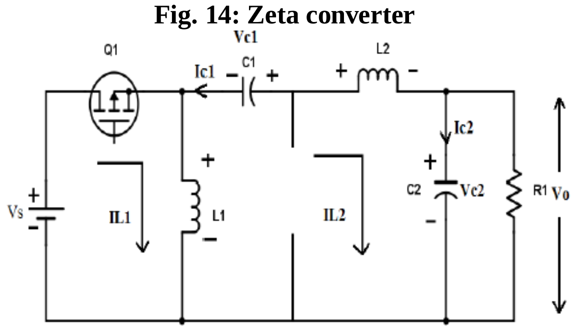
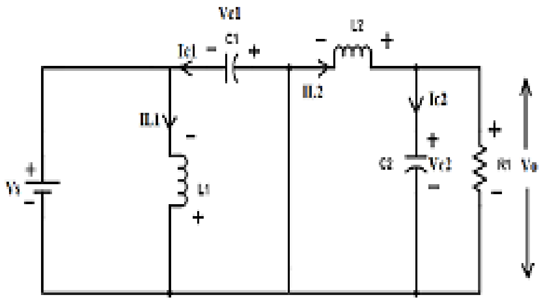


Fig. 14: Zeta converter



when q1 is ON



when q1 is OFF

$$D = \frac{Vo}{Vo + Vs} (2.1) Vo = \frac{D}{D-1} * Vs \ (2.2)$$

XI. FUZZY LOGIC

Fuzzy logic is a superset of boolean logic which is extended to handle the concept of partial truth – truth values between completely false and completely true. Fuzzy controller is a logistic controller based on fuzzy logic. Fuzzy controllers depend on rules and conditions between inputs to get the output. Fuzzy controller rules are designed in suchways that human can easily understand like short, medium, large and hence it is easier for human to design the controller if he knows well about the system that has to be controlled. In fuzzy logic everything is a matter of degree which ranges between 0 to 1. Any logical system can be fuzzified. Exact reasoning is viewed as a limiting case of approximate reasoning in fuzzy logic.

Advantages of Fuzzy logic Controllers

Fuzzy controllers are more flexible. There is no need of tuning in case of fuzzy controllers. They cover a wide range and are easier to develop. These controllers are more readily customizable. It improves the stability of the system. System response becomes faster.

Principle of Fuzzy modelling

i. Fuzzification- Process in which membership functions are used to change the real scalar value into a fuzzy value.
ii. Fuzzy Inference- A system that maps input to the output using fuzzy set theory.
iii. Defuzzification- It is the last step for producing quantifiable result in crisp logic using the given fuzzy set and membership function.

e / de	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NL	NM	NS	ZE	PS	PM	PL

Fig. 15: Rules of Fuzzy logic Control

XII. SIMULATION CIRCUIT OF PROPOSED MODEL WITH OPEN LOOP

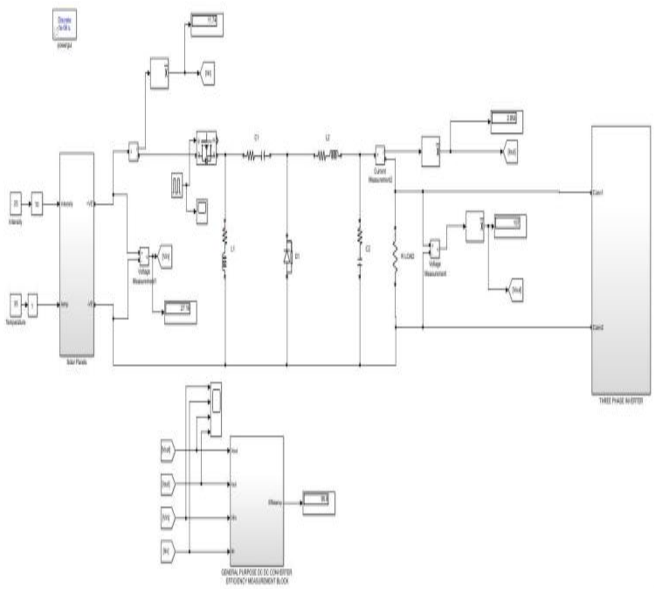


Fig. 16: Simulation model of Propsed Circuit

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Output of Zeta Converter

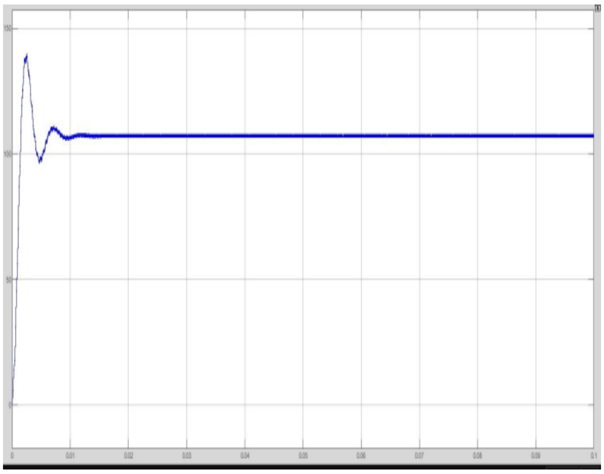

Fig. 17: Output waveform of Zeta Converter

Output of inverter

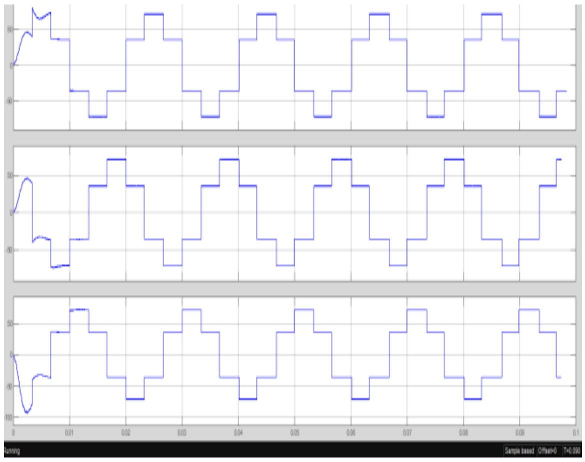

Fig. 18: Output waveform of inverter fed with zeta converter

Open loop simulation circuit of the proposed model is shown in Fig16. The output voltage of Zeta converter is of 107V and the ripples are reduced to 1.5V as shown in Fig 17. Fig 18 shows the output waveform of inverter fed Zeta converter with the increased voltage of 75V as compared to Boost converter.

XIII. CLOSED LOOP SIMULATION CIRCUIT OF PROPOSED MODEL

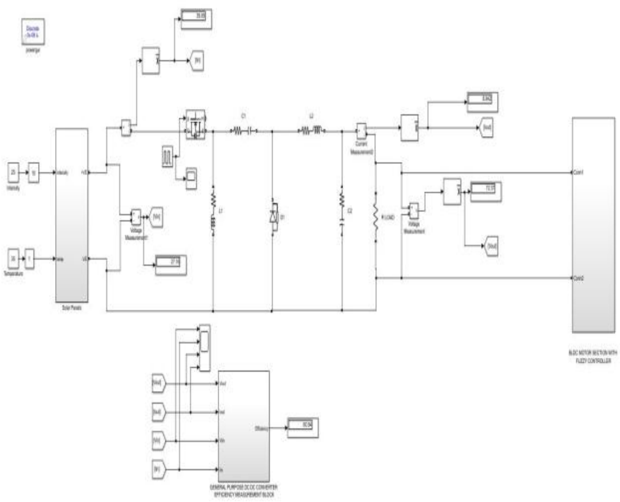

Fig. 19: Simulation circuit of proposed model in closed loop

BLDC Motor control with Fuzzy

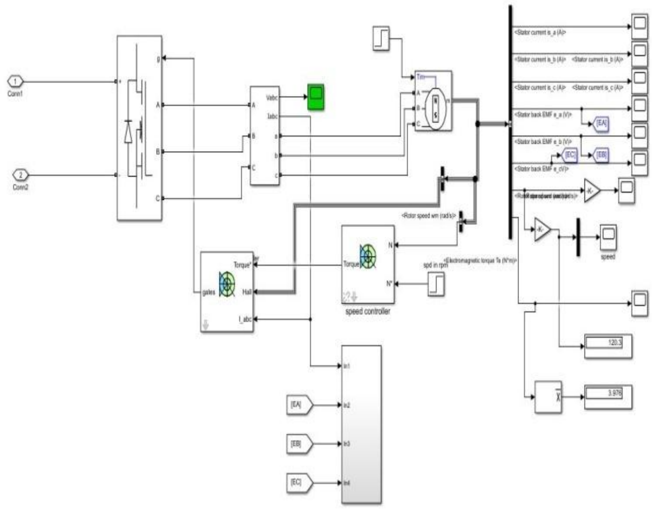

Fig. 20: Inverter and motor feedback

Speed Control with Fuzzy logic

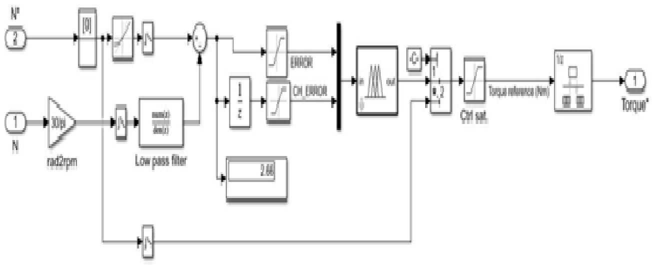

Fig. 21: Speed control block using fuzzy logic

Output Waveform of Speed

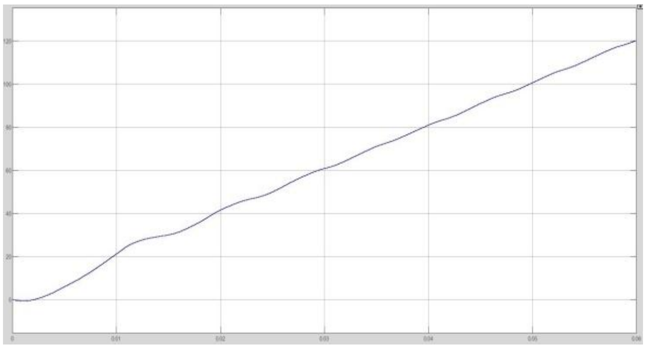

Fig. 22: Speed Waveform

Current waveform

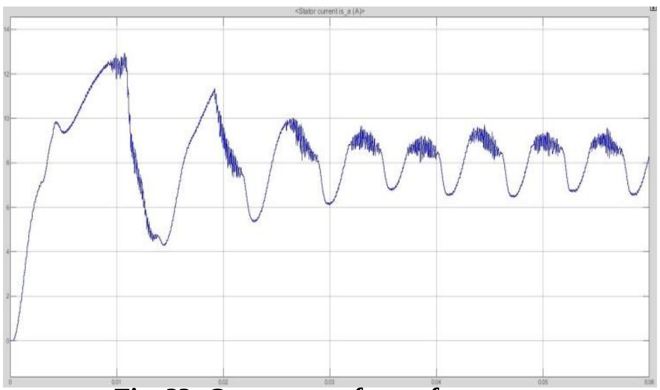

Fig. 23: Output waveform of current

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Torque waveform

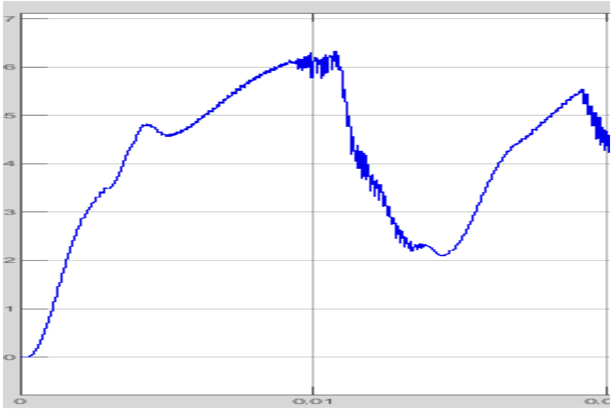
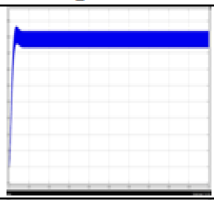
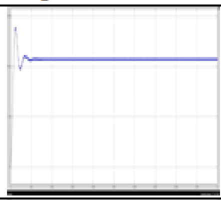
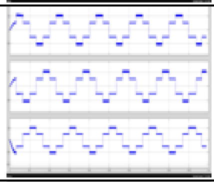
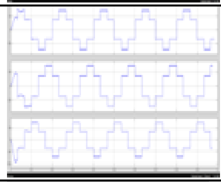
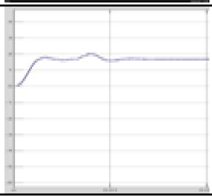
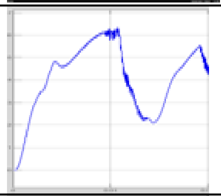
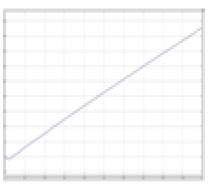
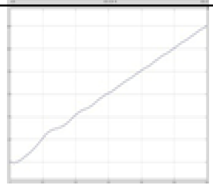
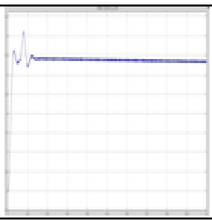
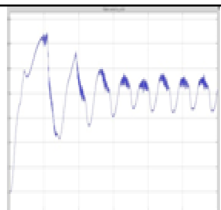


Fig. 24: Output waveform of torque

Simulation circuit of proposed closed loop model is shown in Fig 19 along with inverter and motor subsystem shown in Fig 20. Fuzzy logic control subsystem is shown in Fig 21. Speed of BLDC motor in the proposed system is120rpm as shown in Fig 22. Stator current in this model is 8A and output torque is 4N-m, waveforms are shown in Fig 23 and 24 respectively.

XIV. COMPARISON BETWEEN THE EXISTING AND PROPOSED MODEL IN TERMS OF WAVEFORM

Table 1: Comparison between existing and proposed modelusing waveforms

Parameters	Existing model	Proposed model
Converter output		
Inverter output		
Closed loop torque profile		
Closed loop speed profile		
Stator current		

Comparison In terms of Numerical Figure

Table 2: Comparison between existing and proposed model with numerical data

Parameters	Existing model	Proposed model
PV Input (V)	22.7	22.7
TORQUE (N-m)	1.7	4
POWER FACTOR	.93	.99
SPEED (Rpm)	42	120
CURRENT(A)	3.4	8

Both existing and the proposed model are given an input of 22.7 from PV source. The torque produced using the existing model is 1.7 N-m whereas it is improved in the proposed model with 4 N-m. The motor speed in the existing model is 42 rpm whereas in the proposed model it is 120 rpm. Power factor is slightly improved from 0.93 to 0.99. Also, stator current is improved from 3.4A to 8A in the proposed circuit with Zeta converter.

XV. HARDWARE IMPLEMENTATION& TESTING RESULTS

Rating of the Components

Table 3: List of components and ratings

Components	Rating
BLDC Motor	2200 KV
Capacitor	100 mf
IC 7805	
Capacitor	1000mf
Mosfet	IRFP250N
Driver	TLP 250
Six Tapping Transformer	1A each
Rectifier Board	
Inductor	1mh, 8mh (solenoid type)
Diode	1N4007, 5008
Arduino Nano	
Pot	10k

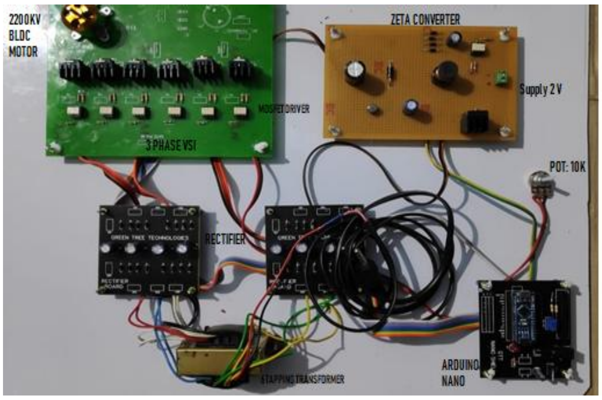


Fig. 25: Hardware model of the proposed circuit

Fig. 26: Speed of BLDC motor

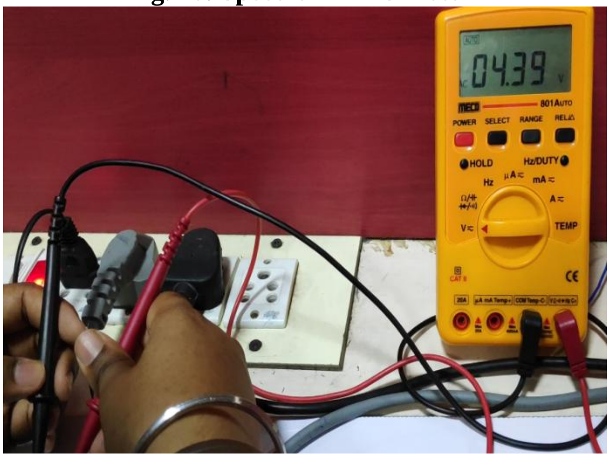


Fig. 27: Back EMF at the motor

XVI. CONCLUSION

Zeta converter fed BLDC motor with fuzzy control and boost converter fed BLDC motor with PI controller has been successfully simulated via Simulink and the hardware implementation of proposed model has also been done. A comparative analysis is being made considering various parameters on the basis of Simulink model. During the study proposed model with zeta converter and fuzzy logic is found to be superior based on torque, power factor and speed.

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