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Analysis of PFC BL-SEPIC Converter Based Intelligent Controller Fed BLDC Motor Drive

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Abstract : This paper presents comparative study of various Intelligent controllers for Bridgeless-Single Ended Primary Inductance Converter (BL-SEPIC) fed Brushless DC (BLDC) motor Drive. By adjustment of the DC link voltage of the VSI, the speed of the BLDC motor can be controlled. The voltage source inverter is used as an electronic commutator of PMBLDCM. The Bridgeless PFC SEPIC Rectifier performs power factor correction and DC voltage control in single stage using only one controller. The most commonly used controller for the speed control of BLDCM is Proportional Integral (PI) controller. Further, ANFIS controller has the ability to automatically learn and adapt with a state of plant. Also, we design and implement sliding mode controller (SMC) and its performance is compared with PI and ANFIS controller to show its capability to track the error and usefulness of Sliding mode controller in control applications. The sliding mode control technique for permanent magnet brushless DC motor is used to improve its dynamic performance with high accuracy. The Performance of the converter is analyzed and the results are discussed to arrive at the best suited controller. The drive has been simulated using the MATLAB/Simulink environment and the performance has been studied.
Key Words : Bridgeless-SEPIC, Permanent Magnet Brushless DC Motor (PMBLDCM), Proportional Integral (PI) Controller, ANFIS Controller, Sliding Mode Control (SMC), Power Factor Correction (PFC), Voltage Source Inverter (VSI).

Introduction

The Power Factor Corrected (PFC) converter plays a vital role in the area of research in power electronics [1]. This AC-DC converters provides stable DC output voltage with improved power factor. This criteria makes the converter applicable for offline power supplies and other AC-DC conversion applications for meeting the guidelines of various power quality standards [2].These converters finds applications in robotic control, air conditioners, washing machines, lighting, heat pumps, computers, servers, printers, TV and VCRs.

Conventionally, In case of a diode bridge rectifier (DBR), a highvalue of the smoothening capacitor is used for feeding the BLDC motor. It draws a high peak current from AC mains due to uncontrolled charging

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and discharging of the DC link capacitor[3]. Such peaky supply current has a very high total harmonic distortion (THD) of the order of 65-70% which results in a very poor power factor (PF) of the order of 0.7-0.72 at AC mains. Such power quality indices are not acceptable within the limits of IEC 61000-3-2 [4].Also, DC link voltage is maintained constant at the DC link capacitor of the VSI and pulse width modulation (PWM) based current control is used for varying the speed of BLDC motor. It suffers from high switching losses in three-phase VSI because of high frequency switching of PWM signals. Moreover, there is an extra associated cost of the current sensors required for current control of BLDC motor.Such high switching losses are reduced by electronically commutating the BLDC motor [5]. Moreover, the speed is controlled by varying the DC link voltage of VSI [5].This reduces the switching losses of VSI and eliminates the requirement of current sensors for PWM based current control of BLDC motor for speed control.

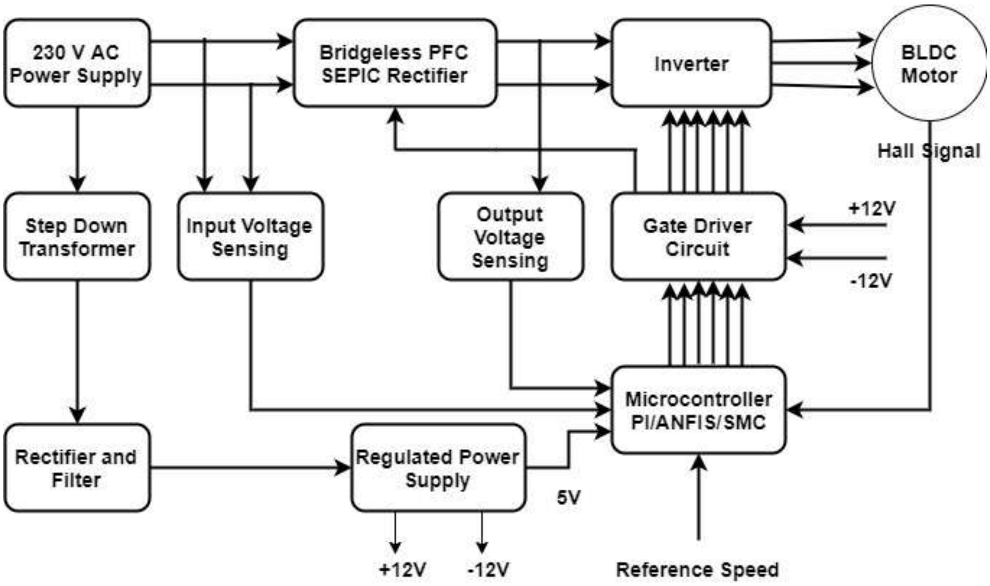


Fig.1: Block Diagram

The block diagram of the proposed system is shown in Fig.1. Bridgeless PFC converters have gained importance due to low conduction losses at the front end [6-14].This is formed by partial or complete elimination of theDBR; thereby the conduction losses associated with it are reduced.Among these configurations, a bridgeless buck converter can provide a voltage bucking operation and hence the output cannot be controlled over a wide range. [6]. A bridgeless boost converter can provide only voltage boosting, therefore, can’t be used for widerange of voltage control at higher values of supply voltages [7].Therefore, PFC BL-buck-boost converters are used for control of voltage over a wide range [8]. A SEPIC is a good trade-off between the buck-boost configurations having theadvantages of lower EMI and simplified low-side gate driverdesign [10-13].

Operation of PFC BL-SEPIC Fed BLDC Motor Drive

A single-phase AC supply is given to DBR followed by a filter and a bridgeless SEPIC feeding a BLDCmotor. This bridgeless-SEPIC is made to operate in discontinuous inductor current mode (DICM) such that voltage control and inherent power factor correction is achieved at AC mains by means of single voltage sensor. Thus a BLDC motor is controlled by combination of DBR and PFC converter via a three-phase VSI is shown in Fig.2. The speed of BLDC motor is controlled by adjusting the DC link voltage of the VSI via the PFC converter. The VSI is operated in a fundamental frequency switching mode to achieve an electronic commutation of the BLDC motor for reducing the switching losses associated with it.

The operation of proposed PFC BL-SEPIC is divided into two different sections (i.e. positive and negative half cycles of supplyvoltage) and complete switching cycle, respectively [15].

During the positive half cycle, switch Sw_1, input inductor L_{i1}, output inductor L_{o1},intermediate capacitor C_1 and diode D_1 conducts and vice-versa for negative half cycles of supply voltage. When switch (Sw_1) is turned-on, the input inductor (L_{i1}) and output inductor (L_{o1}) start charging. The intermediate capacitor (C_1) discharges through the output side inductor (L_{o1}) and the voltage across it decreases. The diode (D_1) remains in non-conducting state and the DC link capacitor (C_d) supplies the required energyto the VSI fed BLDC motor.When switch (Sw_1) is turned-off, the input inductor (L_{i1}) and output inductor (L_{o1}) starts discharging via diode (D_1)[15].Moreover, the intermediate capacitor (C_1) gets charged in this mode. The DC link capacitor (C_d) charges and the voltage (V_{dc}) across the DC link increases in this mode of operation.

In a similar way, the operation for the negative half cycle ofthe supply voltage can be realized.

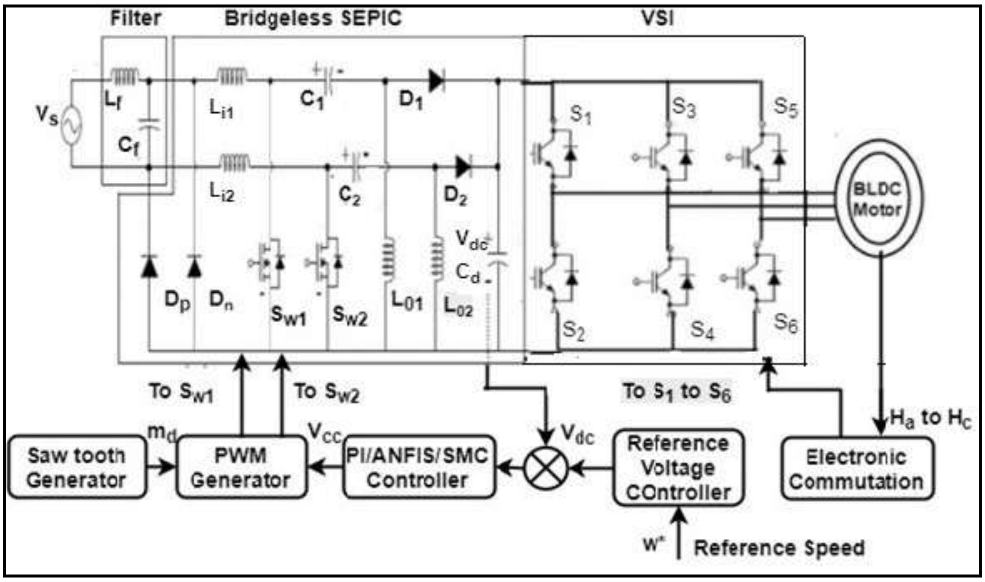


Fig.2: PFC based BL-SEPIC fed BLDC motor drive

Design of PFC BL-SEPIC in DICM

The proposed PFC BL-SEPIC [15] is designed to operate in DICM such that the current flowing in output inductors ($L_{o1}$and L_{o2}) becomes discontinuous in a switching period.

The input voltage, V_s of the PFC converter is given below

$$V_s(t) = V_m Sin(2\pi f_L t) = 220\sqrt{2}Sin(314t)V$$

Where V_m represents the peak input voltage , f_L denotes the line frequency i.e. 50 Hz.

The instantaneous output voltage of the filter is given as,

$$V_{in}(t) = |V_m Sin(wt)| = |220\sqrt{2}Sin(314t)|V$$

The output voltage, V_{dc} of a BL-SEPIC is expressed interms of duty ratio (D) as

$$V_{dc} = \frac{D}{(1-D)} V_{in}$$

The instantaneous value of duty ratio, D(t) depends on the input voltage, $V_{in}(t)$ and the required DC link voltage, V_{dc}.

Control of front end PFC Converter

There are several approaches in variable speed drive control of BLDC motors.In this paper we made a comparison between PI, ANFIS and SMC control of BLDC drives. This work was applied to three controller modes such as PI, ANFIS and SMC to control the speed ofBLDCM. The aim is to obtain a better performance of control using MATLAB Simulink. Simulation results are presented and analyzed for all the three controllers.

(a) PI controller:

The proportional integral controller is the most common and useful algorithm in control system engineering. The feedback loops are controlled using PI algorithm. Feedback is very important in systems in order to attain a set point irrespective of disturbances or any variation in characteristics of anyform. PI controller is designed to correct error between the measured process value and a particular desired set point in a system [16].

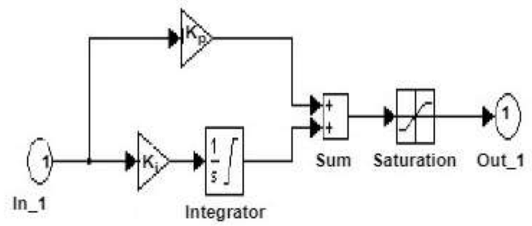


Fig.3: Block diagram of PI Controller

The Proportional (P) and Integral (I) controls the system S, using the controller C where the controller efficiency depends on P and I parameters.

 A PI speed controller has been chosen with gain parameters Kp and Ki.

 The speed of the motor is compared with the reference value and the error in speed isprocessed by the speed controller.

 The output of the PI controller at any instant is the reference torque given by-

$$T_{ref} = \left(K_p + \frac{K_i}{s} \right) \left(w_{ref} - w_r \right)$$

Where T_{ref} is the reference torque , K_p is the proportional gain of the PI controller. K_i is the integral gain of the PI controller. w_{ref} is the reference speed in rad/sec. w_r is the actual speed inrad/sec.

Fig.3. presents a block diagram for the control scheme of current implemented by PI controller with a saturation module. The actual value of current or speed is sensed from the output and sent to proportional and integral terms which contains the proportional term with gain and integral term with gain. The outputs are summed using a Sum block and the output is sent to saturation block for saturation purpose and output from this block gives the error between the reference value and actual value of the motor.

In PI controlled PMBLDC motor starting speed is greater than reference speed while in no load and onload condition. When loaded, the time taken for speed to settle at reference speed is less. Speed drop is less when load is applied. Also, the time taken for torque to settle at reference torque after the application of load is low.

(b) Sliding Mode Control

Sliding mode control (SMC) is a nonlinear control method including striking properties of accuracy, robustness, and easy tuning and implementation. This system is designed to drive the system states onto a particular surface in the state space, named sliding surface. Once the sliding surface is reached, sliding mode control keeps the states on the close neighbourhood of the sliding surface. Hence the sliding mode control is a two part controller design. The first part involves the design of a sliding surface so that the sliding motion satisfies design specifications. The second is concerned with the selection of a control law that will make the switching surface attractive to the system state. First is that the dynamic behaviour of the system may be tailored by the particular choice of the sliding function. Secondly, the closed loop response becomes totally insensitive to some particular uncertainties. This principle extends to model parameter uncertainties, disturbance and nonlinearity that are bounded.[17]

Bridgeless SEPIC converter is used for power factor correction and the PWM signal to the Bridgeless SEPIC convertor is given by using SMC algorithm. Error voltage can be avoided by considering inductor voltage , inductor current, capacitor current, DC link voltage. Thus it reduces oscillations and operates under uncertain conditions. It is one of the main advantage of SMC .This could be used in several applications such as Overhead crane, Marine vehicles, electrohydraulic valve actuator, Combined Cycle etc.,

(c) ANFIS Controller

A typical architecture of an ANFIS which is used is Sugenofuzzy[18] models consist of five layers that every layer has the node. There are two kind of nodes. One is the adaptive node (square symbol) and the other is the fixed node (circle symbol) as shown Fig. 4. The mechanism is designed using Sugeno which has two inputs x_1 and x_2 and one output y. For a first order Sugeno fuzzy model [19],[20], a common rule set with two fuzzy if-then rules is the following

If x_1 is A_1 and x_2 is B_1 Then $y_1 = c_{11}.x_1 + c_{12}.x_2 + c_{10,}$

If x_1 is A_2 and x_2 is B2 Then $y_2 = c_{21}.x_1 + c_{22}.x_2 + c_{20}$

If α is predicated for two roles are w_1 and w_2, then can be determined the weight average as below

$$y = \frac{w_1 y_1 + w_2 y_2}{w_1 + w_2}$$

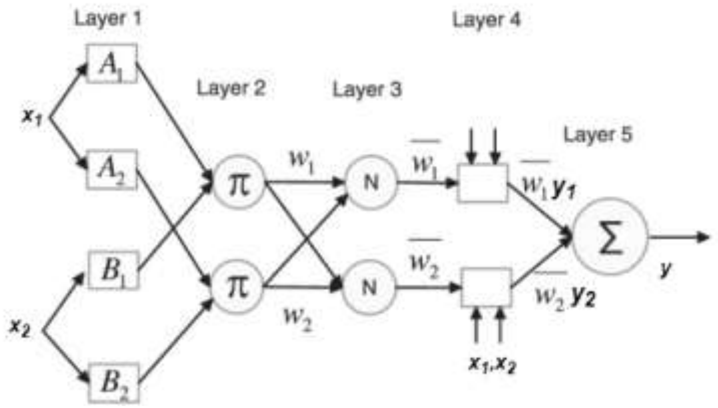


Fig.4: The Architecture of ANFIS

Layer 1: Each neuron "i" in layer 1 is adaptive with a parametric activation function. Its output is the grade of membership function; an example is the generalized bell shape function.

$$\mu(x) = \frac{1}{1 + \left(x - c/a\right)^{2b}}$$

Where [a, b, c] is the parameter set. As the values of the parameters change, the shape of the bell-shape function varies.

Layer 2: .Every node in layer 2 is a fixed node, whose output is the product of all incoming signals.

$w_i = \mu_{Ai}(x)\ \mu_{Bi}(y)$, i=1,2

Layer 3: This layer normalizes each input with respect to theothers (The i^{th} node output is the i^{th} input divided the sum of all the other inputs).

$$\overline{w_i} = \frac{w_i}{w_i + w_2}$$

Layer 4: This layer'si^{th}node output is a linear function of the thirdlayer's i^{th} node output and the ANFIS input signals.

$$\overline{w_i} f_i = \overline{w_i}(p_i x + q_i y + r_i)$$

Layer 5: This layer sums all the incoming signals.

$$f = \overline{w_1} f_1 + \overline{w_2} f_2$$

Simulation Results and Discussion

The block diagram in Fig.1 has been successfully simulated in the MATLAB R2013a simulink environment and the following results have been observed for the BLDC drive fed by PFC Bridgeless SEPIC converter controlled by PI, ANFIS and SMC. The Simulink diagram was shown in Fig. 5.

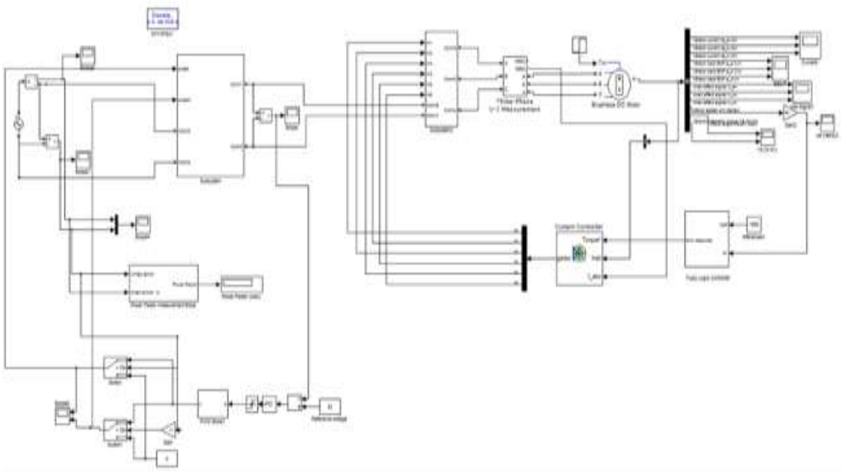
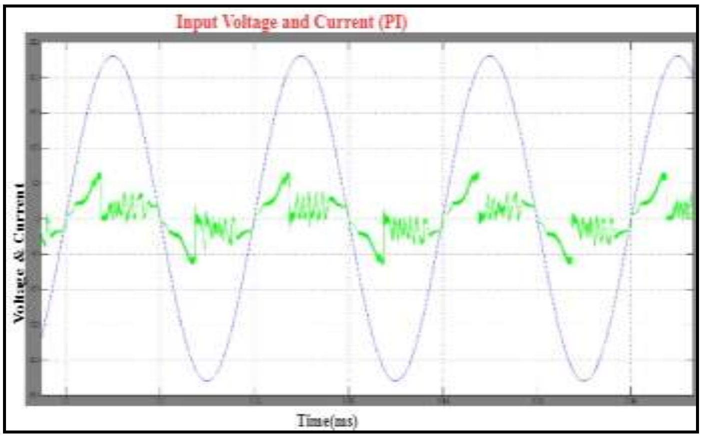


Fig.5: Simulink model of PFC Bridgeless SEPIC fed BLDC Motor with SMC

The below Fig. 6 shows the Input voltage, Input current, Power Factor, Converter output voltage and current, Motor Speed and Converter Efficiency with PI Controller.



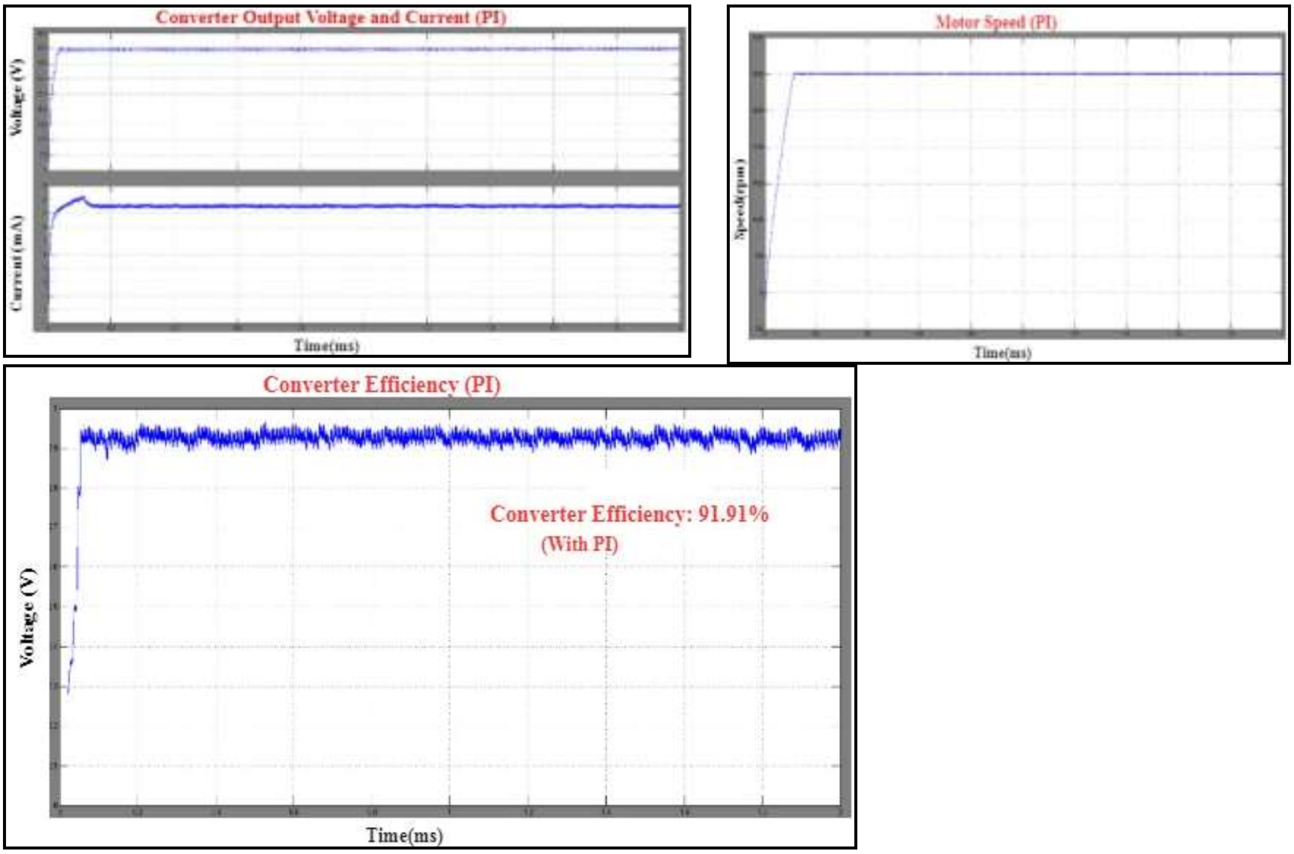


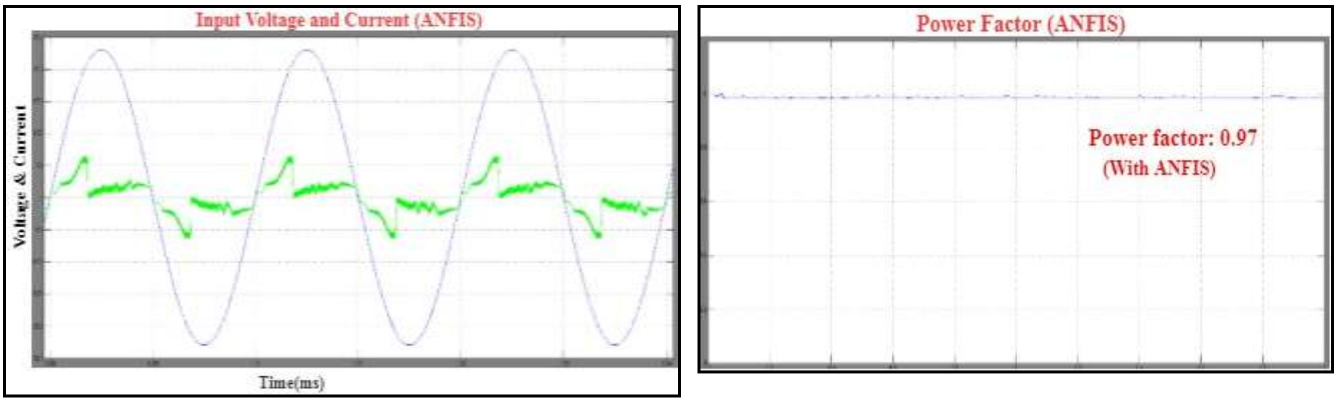
Fig.6: Waveforms of Input Voltage, Input Current, Power Factor, Converter output voltage and current, Motor Speed and Converter Efficiency (with PI)

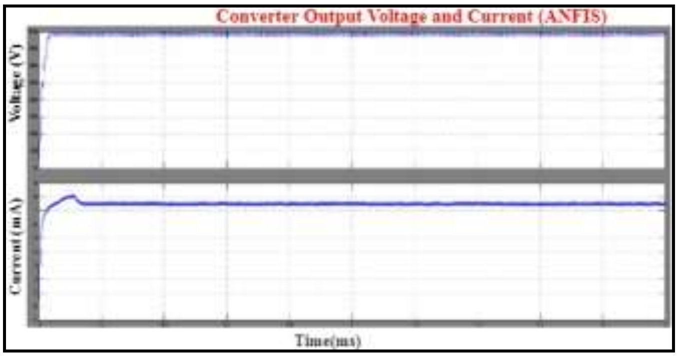
The power factor is calculated from the power factor measurement block. Powerfactor is the ratio of active power to apparent power.

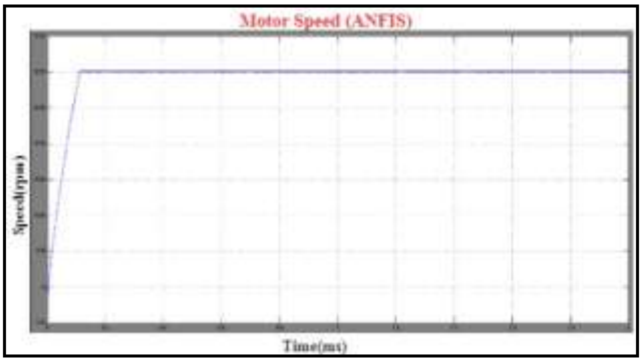
P.F.=$cos(\phi) = VI\ cos(\phi)/VI$

For the Bridgeless SEPIC converter fed BLDC motor drive with PI controller, the power factor observed is as follows. It reaches value close to unity at rated speed (0.95).The Converter Efficiency with PI controller was found to be 91.9%.

The below Fig. 7 shows the Input voltage, Input current, Power Factor, Converter output voltage and current, Motor Speed and Converter Efficiency with ANFIS Controller.







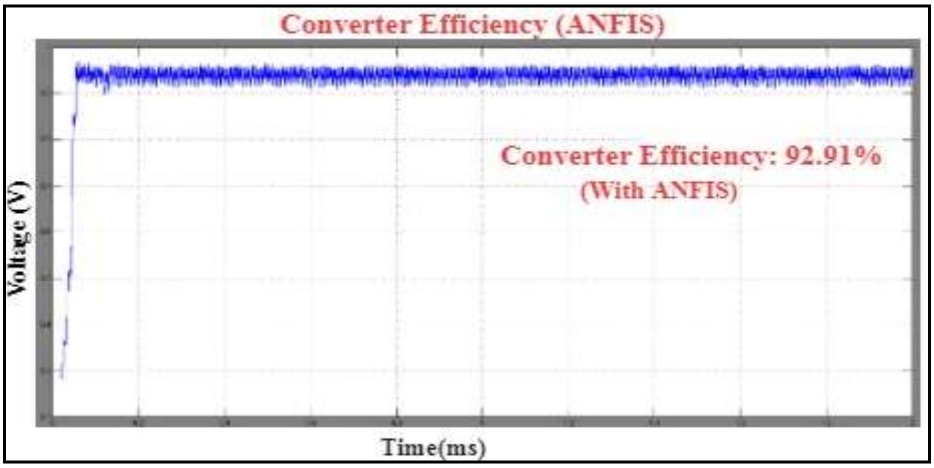
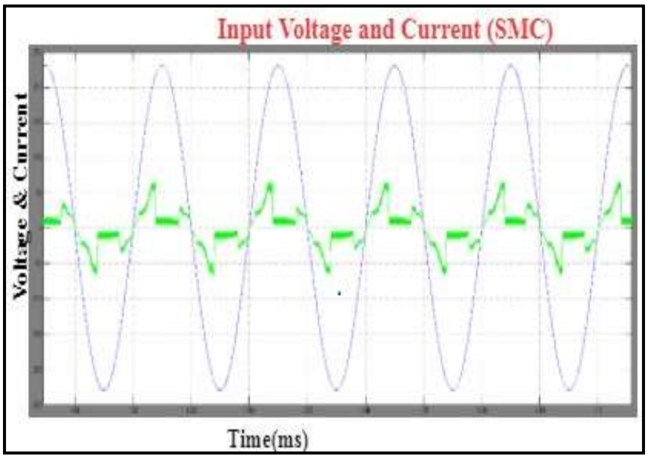
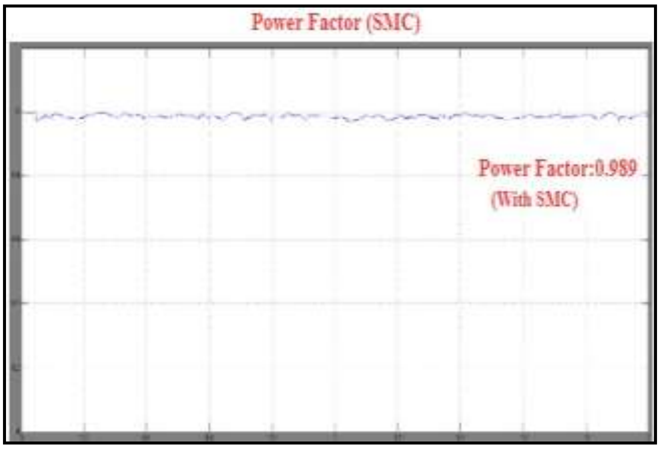


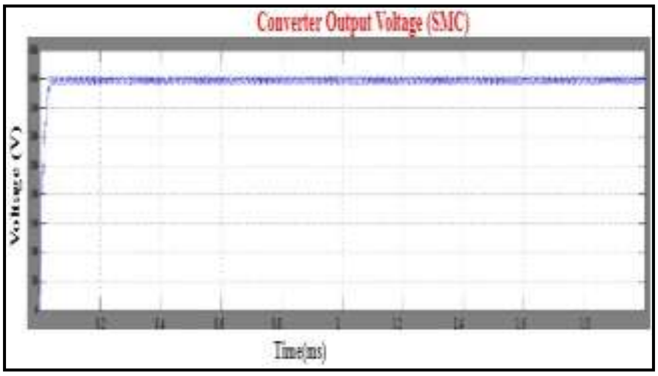
Fig.7: Waveforms of Input Voltage, Input Current, Power Factor, Converter output voltage and current, Motor Speed and Converter Efficiency (with ANFIS)

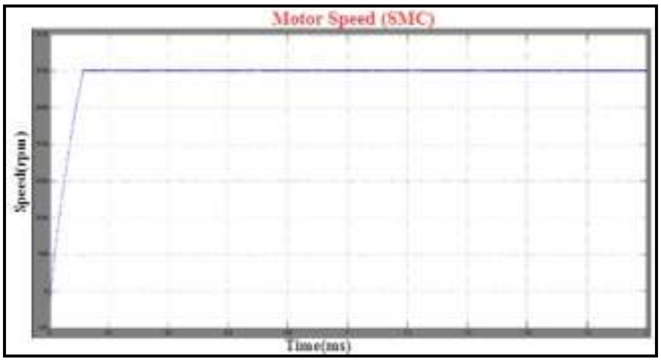
The Converter Efficiency with ANFIS controller was found to be 92.9%

The below Fig. 8 shows the Input voltage, Input current, Power Factor, Converter output voltage and current, Motor Speed and Converter Efficiency with Sliding Mode Controller.









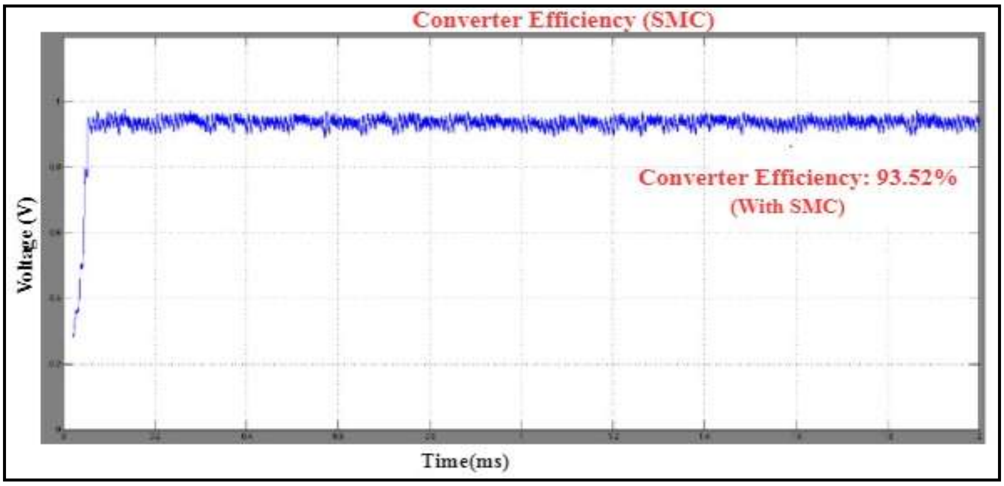


Fig.8: Waveforms of Input Voltage, Input Current, Power Factor, Converter output voltage and current, Motor Speed and Converter Efficiency (with SMC)

The Converter Efficiency with SMC controller was found to be 93.52% and the Power Factor was measured as 0.989.

Comparison of Performance Indices between different Controllers

A comparison of PI, ANFIS and SMC controller is carried out in terms of different parameters. Table 1. Shows the Performance Comparison of PI, ANFIS and SMC controllers with Bridgeless SEPIC Converter fed BLDC motor drive.The Efficiency and Power Factor are found to be greatly increased when controlled with SMC controller.So, We can conclude that SMC Controller is found to be the better choice for Bridgeless SEPIC driven BLDC motor drive in terms of Power factor and Efficiency.

Table 1: Performance Comparison of PI, ANFIS and SMC

Parameters	**PI**	**ANFIS**	**SMC**
Power Factor	0.95	0.97	0.989
Output Voltage	400±10V	400±15V	400±7V
Speed(rpm)	3000	3000	3000
Efficiency (%)	91.9	92.91	93.52

Conclusion

The performance of the proposed BL-SEPIC based BLDC motor drive was compared with three controllers-PI, ANFIS and SMC and simulation model was developed. The speed of the BLDC motor can be controlled by varying the DC link voltage. With this PFC converter, three–phase VSI has been operated in low frequency switching mode with reduced switching losses. A front-end BL-SEPIC operating in Discontinuous Conduction mode has used for DC link voltage control and with power factor correction at AC mains. The SMC controller gives better performance during different operating conditions at all speeds as compared to PI and ANFIS. Also it is found to be more robust and appropriate control scheme for PFC converters as compared toconventional linear controllers.

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