Design of Hybrid-Fuzzy Controlled SEPIC Converter Fed BLDC Motor Driven for Enhanced PQ Features

[1]M. Sriramulu Naik, [2]V. Veera Naga Venkat, [3]K. Pavan Kalyan Reddy, [4]M. Ramakrishna, [5]K. Sampath Kumar

[1]Assistant Professor, [2,3,4,5]UG Student
[1,2,3,4,5]Department of Electrical & Electronics Engineering
[1,2,3,4,5]Kallam Haranadhareddy institute of Technology, chowdavaram, Guntur (Dt); Andhra Pradesh, India.

ABSTRACT

Permanent Magnet BLDC motor drive connected with the diode bridge rectifier and high value of the capacitor due to which poor power factor and higher THD (Total harmonic distortion) value at the input side. This scheme also used for speed control of BLDC motor by controlling the VSI (voltage source inverter) feeding the BLDC drive. The Active-PFC device acts as front-end of VSI fed BLDC motor for better speed control features by changing the PWM duty cycle through closed loop controller. The DC link voltage regulation in conventional PI control scheme is not suitable for getting enhanced PQ features. But, this controller is unpopular due to tuning issues of current controller; the above-mentioned issues are regulated by using novel intelligent based Fuzzy-Logic controller achieving good performance features. The proposed intelligent Hybrid-Fuzzy control scheme is highly used in several applications, has been greatly recognized due to enhanced performance over the classical PI and Fuzzy-Logic controllers. This work compares the improvement of power-factor, harmonic profile, THD with classical PI and intelligent Fuzzy-Logic controlled SEPIC Fed BLDC motor drive has been proposed by using Matlab/Simulink platform, and results are presented.

Keyword: *- Active Power-Factor Correction, Fuzzy-Logic Controller, Hybrid-Fuzzy Logic Controller, SEPIC Converter, Total Harmonic Distortions*

1. INTRODUCTION

Normally for drive application induction motor were used because it has own advantages like rugged construction, low maintenance, low cost, available in different ratings. But sometimes induction motor not use because of its difficulty in speed control and also not useful for low voltage application. All the above problems overcome in BLDC (Brushless DC) motor. It also has rugged construction, high torque per weight ratio, simple in construction and a wide range of speed control. Most of the time BLDC motor works with voltage source inverter and with a diode bridge rectifier. But in this scheme, the high pulse modulation frequency is used for an inverter. Due to this large amount of switching loss takes place in an inverter. Also, this system draws a very large amount of current from the supply side with poor power factor and high THD value due to presence of harmonics [1].

Harmonics can be defined as the spectral components at frequencies that are integer multiples of the ac system fundamental frequency. The harmonic voltage and current distortion are strongly linked with each other because harmonic voltage distortion is mainly due to non-sinusoidal load currents. Current harmonic distortion requires over-rating of series components like transformers and cables. As the series resistance increases with frequency, a distorted current will cause more losses than a sinusoidal current of the same rms value [2]. The most common harmonic current drawn nonlinear loads are all single and three phase power converters which contains rectifiers such as DC motor drives, adjustable speed drives (ASD), uninterruptable power supplies (UPS), switched mode power supplies (SMPS) etc.; cyclo-converters, fluorescent lighting, electrical heating furnaces, welding machines, arc furnaces. Besides these nonlinear loads, AC generators, AC motors and transformers also produce harmonic currents. However; besides poor design or fault conditions of these devices, harmonic currents of them are negligible when compared to their fundamental currents. In order to understand the amount of harmonic distortion in non-sinusoidal voltage or current waveforms and set the limits related with harmonic distortion, some indices are defined in IEEE and IEC standards [3].

This high THD value and poor power factor are not acceptable according to the IEC standard. To overcome this problem now a day's converters are used. The converter can work in (CCM) continuous conduction mode and discontinuous conduction mode (DCM). Both modes have their own advantage and disadvantage. Size and cost of the converter mostly depend on these modes. In Continuous conduction mode current through inductor remain continuous and in discontinuous conduction mode current through the inductor is discontinuous. In CCM two voltage sensors and one current sensor are required but in DCM only one voltage sensor required. In DCM current through the inductor is reaches zero hence electrical stress is more on switches so for low power application DCM mode is preferred and for high power application, CCM mode is preferred [4].

The Active-PFC device acts as front-end of VSI fed BLDC motor for better speed control features by changing the PWM duty cycle through closed loop controller. The DC link voltage regulation in conventional PI control scheme is not suitable for getting enhanced PQ features. But, this controller is unpopular due to tuning issues of current controller; the above-mentioned issues are regulated by using novel intelligent based Fuzzy-Logic controller achieving good performance features. The proposed intelligent Hybrid-Fuzzy control scheme is highly used in several applications, has been greatly recognized due to enhanced performance over the classical PI and Fuzzy-Logic controllers. This work compares the improvement of power-factor, harmonic profile, THD with classical PI and intelligent Fuzzy-Logic controller in BLDC motor drive has been proposed by using Matlab/Simulink platform, and results are presented.

2. SEPIC CONVERTER FED BLDC MOTOR DRIVE

The Single- Ended Primary-Inductor Converter (SEPIC) is a DC-DC converter. It gives output voltage greater than, less than, or equal to that of the input voltage. The output of the SEPIC converter is controlled by the duty cycle of the semiconductor devices. SEPIC provides the input-to-output gain, thus making it popular in BLDC drive systems. Unlike buck-boost converter, it has non-inverting output. This is achieved by using a series capacitor to couple energy from the input to the output. Applications of SEPIC are where the output voltage can be above or below than that of the input voltage. SEPIC has pulsating output current. Since the SEPIC converter transfers all its energy via the series capacitor, the capacitor should have high capacitance and current handling capability [5].

2.1 Operation of SEPIC Converter:

The circuit diagram of the SEPIC converter is shown in Fig.1. It is less popular topology for PFC converter design since the control is not simple. Also due to the complexity of control, it is suitable only for very slow varying applications. The output voltage is not necessarily limited by its input voltage. Furthermore, SEPIC PFC converter does not require an additional DC-DC stage for BLDC drive system. Input current ripple can also be reduced by using two wound inductors. Thus power loss due to current ripple can be reduced. The SEPIC converter operation consists of two-part when MOSFET is ON and when MOSFET is OFF is depicted in Fig.2 and Fig.3.

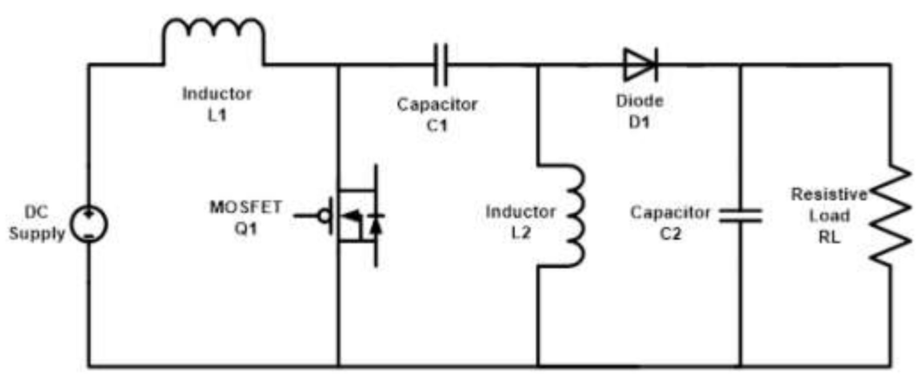


Fig.1 Circuit Diagram of SEPIC Converter

Mode-1 (When MOSFET ON)

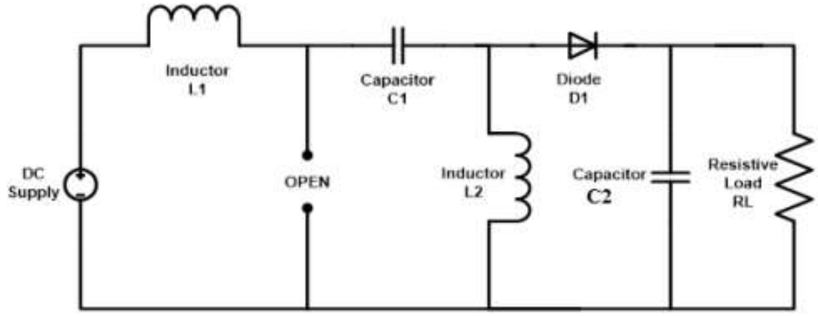


Fig.2 operation (when MOSFET OFF)

DCM mode considers here it means that current in inductor falls to zero. When MOSFET Q1 ON inductor L1 charge to Va and average voltage across capacitor also Va and voltage across inductor L2 is –Va so this reason we can wound inductor L1 and L2 on the same core. Due to negative polarity anode of the diode, the diode will not conduct so zero current flowing through the diode. At this time Output voltage maintained by Filter capacitor. DCM mode considers here it means that current in inductor falls to zero. When MOSFET Q1 ON inductor L1 charge to Va and average voltage across capacitor also Va and voltage across inductor L2 is –Va so this reason we can wound inductor L1 and L2 on the same core. Due to negative polarity anode of the diode, the diode will not conduct so zero current flowing through the diode. At this time Output voltage maintained by Filter capacitor.

Mode-2 (When MOSFET OFF)

When MOSFET is OFF polarity of inductor will reverse as shown in figure but even though polarity changes current through inductor will not changes instantly. It will change if the width of MOSFET is too long and current through inductor will reverse the direction and converter fails.so width of pulse should less. Due to Changing polarity of inductor diode D anode is more positive with respect to cathode and diode will ON and current flowing through it.

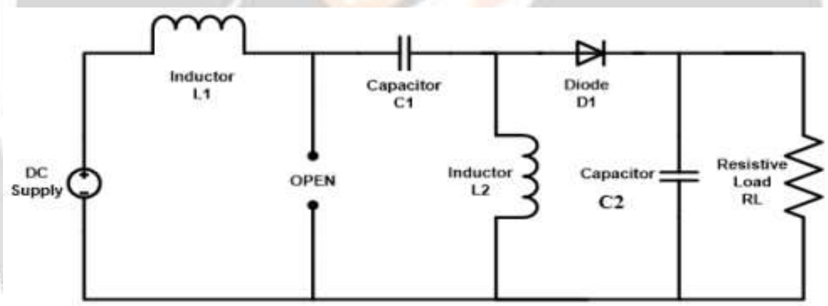


Fig.3 operation (when MOSFET OFF)

Theoretical waveform shown below

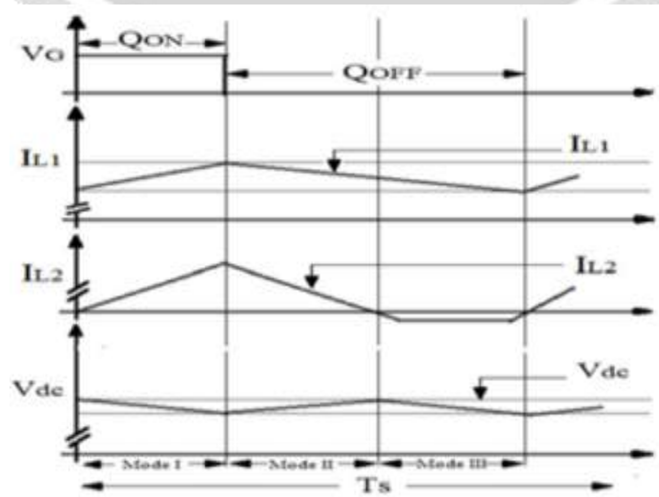


Fig.4 Typical Waveforms of SEPIC Converter

2.2 BLDC Motor Drive Without SEPIC Converter

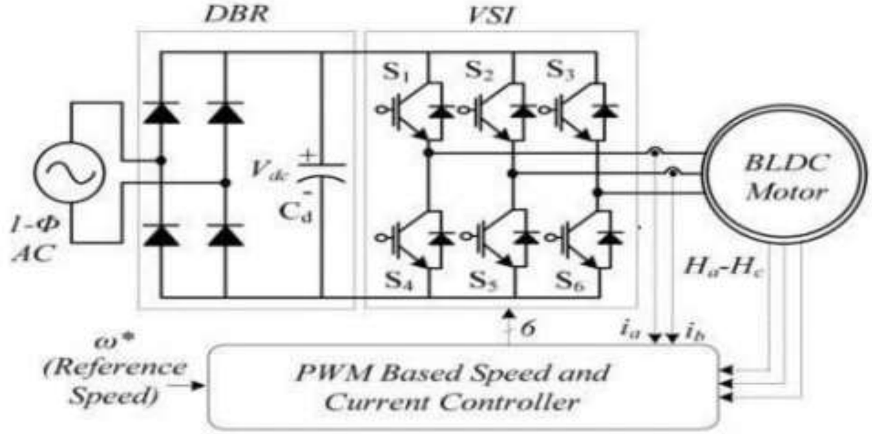


Fig.5. BLDC Drive without Converter

The proposed scheme shown in the figure the diode bridge rectifier is connected to voltage source inverter via DC link capacitor. Value of the link capacitor is calculated by the following formula..

$$C_d = \frac{I_d}{2\omega\delta V_{dc}} = \frac{P_i/V_{dc}}{2\omega\delta V_{dc}} = \frac{P_i}{2\omega\delta {V_{dc}}^2}$$

2.3 BLDC Motor Drive with SEPIC Converter

SEPIC converter fed by diode bridge rectifier which is an uncontrolled rectifier. This rectifier fed from AC supply mains Output of SEPIC converter given to voltage source inverter. Here discontinuous mode considers so we required only one voltage sensor to control the measure and actual voltage which directly results in controlling the speed of the motor. VSI used here to reduce switching losses by using electronic commutation at low frequency.

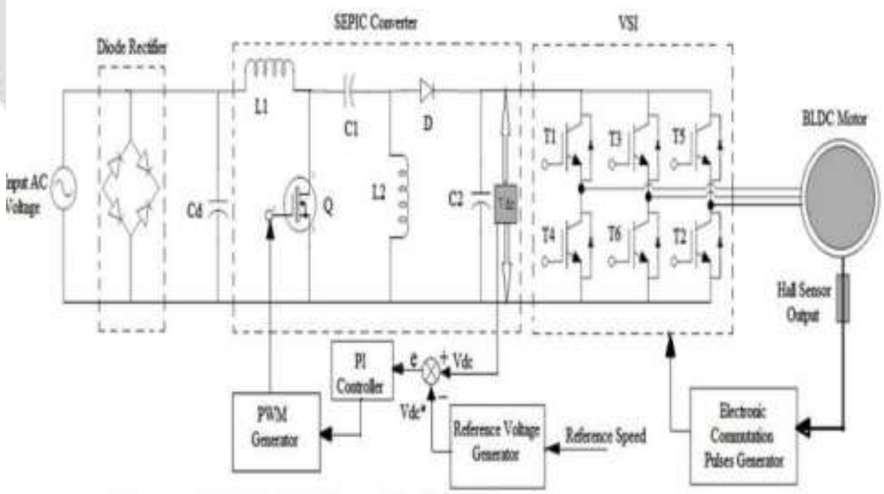


Fig.6 BLDC Drive with Converter

2.4 Control Technique for SEPIC Converter Fed BLDC Motor Drive Circuit

There are two control techniques used to control the BLDC motor drive A) Control technique for converter B) Control technique for BLDC motor. A: Control technique for SEPIC converter [6]. The main objective in this system is to provide PWM pulses for switch Q which is MOSFET. The output of SEPIC converter Vdc compares with V* which produces "error voltage".

$$Ve = Vdc - V*$$

This error voltage gives to PI controller which would give to desire voltage Vd.

$$Vd(k) = Vd(k-1) + Kp\{Ve(k) - Ve(k-1) + Ki\,Ve\,(k)$$

Where K th sample instant can take by k and Kp and Ki are take action on error voltage from the PI controller respectively

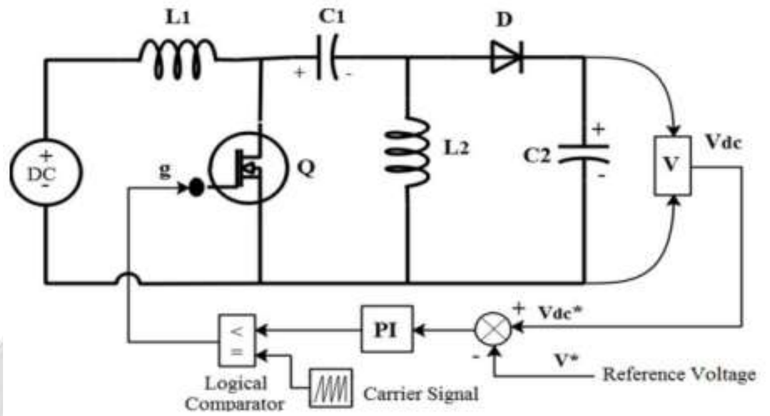


Fig.7 Closed Loop Controlling of SEPIC Converter

The reference voltage signal is compared with actual measured voltage output obtained from SEPIC converter to drive the BLDC motor. The error signal is passed through PI controller and the PI controller reduces the error and yields a reference signal for pulse generation. This reference signal is related with carrier signal (saw-tooth shape) with the help of a relational operator to produce pulses to switch in SEPIC converter. The SEPIC converter with high voltage gain switching according to triggering pulses and operates to give out required voltage level that will be sufficient to drive the BLDC motor [7]-[9]. The DC link voltage regulation in conventional PI control scheme is not suitable for getting enhanced PQ features. But, this controller is unpopular due to tuning issues of current controller; the above-mentioned issues are regulated by using novel intelligent based Fuzzy-Logic controller achieving good performance features.

3. PROPOSED FUZZY LOGIC CONTROL SCHEME BASED SEPIC CONVERTER FED BLDC MOTOR DRIVE

The proposed fuzzy controller has been used extensively for many applications in control engineering, automation which is related to associate problems is designed easily. By utilizing the fuzzy evolution method which is relative functions of qualities work for designing the real time control objective [10]. The fuzzy system in the process/plant is reflected by the control action of the design capabilities in both experience as well as intuitive specific functioning manner. It is mostly commanded for the control scheme of resembled on efficient mathematical plant model. The fuzzy control strategy uses the linguistic information which has many advantages may include the high robust performance, greater strength, model free, attain the universal approximation theorem with rule based algorithm has been selected.

The fuzzy logic controller has been distinctly characterized by the input data coming from the fuzzy scheme as depicted in Fig.8. Automatic translation of fuzzy from the overall fuzzification process, this fuzzy process is carried out by the effective control action. The creation of input information with the evaluation of the IF....THEN rules which are produced by the several linguistics logics. After the fuzzification process the rule processing stage reaches at the point of outcome summary, de-fuzzification process is started. The de-fuzzification process is carried during the final stage; the coming inferences are transformed to real data output by fuzzy enhancer. Hence, data is utilized as interfaced module for the need of processing.

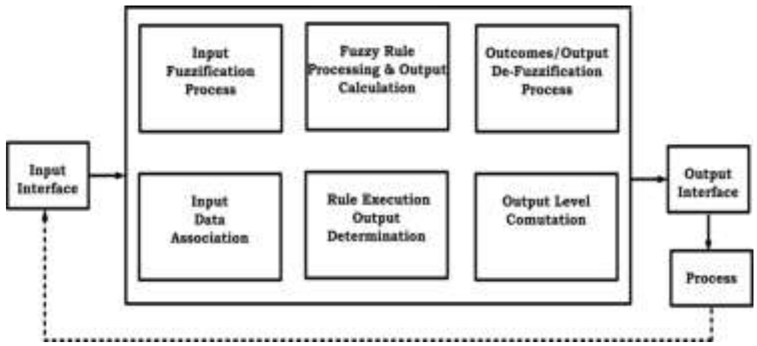


Fig.8 Block Diagram Representation of Fuzzy Control Logic

The operational logics of the fuzzy logic control objective have been illustrated by linguistic nature is differentiated from the mathematical notations. In spite of linguistic terms delivers the derived methods that are most enhanced and feasible operational characteristics [11]. This fuzzy logic control objective belongs to the symbolic nature control action that regards to a special class. The configuration of fuzzy logic inference control objective is depicted in Fig.9. The proposed fuzzy-logic controller membership functions are depicted in Fig.10 and the rule base is illustrated in Table.1. The block diagram of proposed Fuzzy-Logic Controlled SEPIC Converter is depicted in Fig.11.

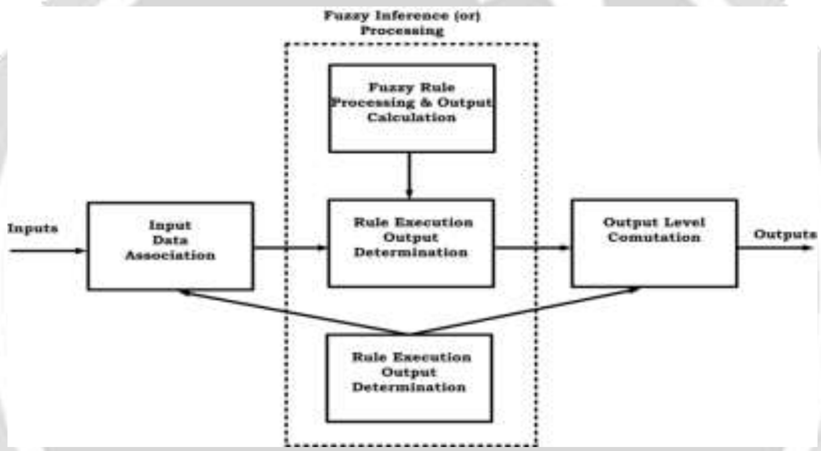


Fig.9 Configuration of Fuzzy Logic Inference Control Objective

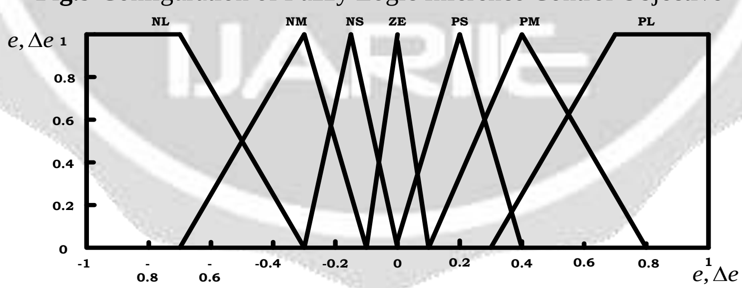


Fig.10 Fuzzy Logic Membership Functions

Table.1 Fuzzy Logic Rules

e / Δe	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	NM	NS	ZE	PS	PM	PB

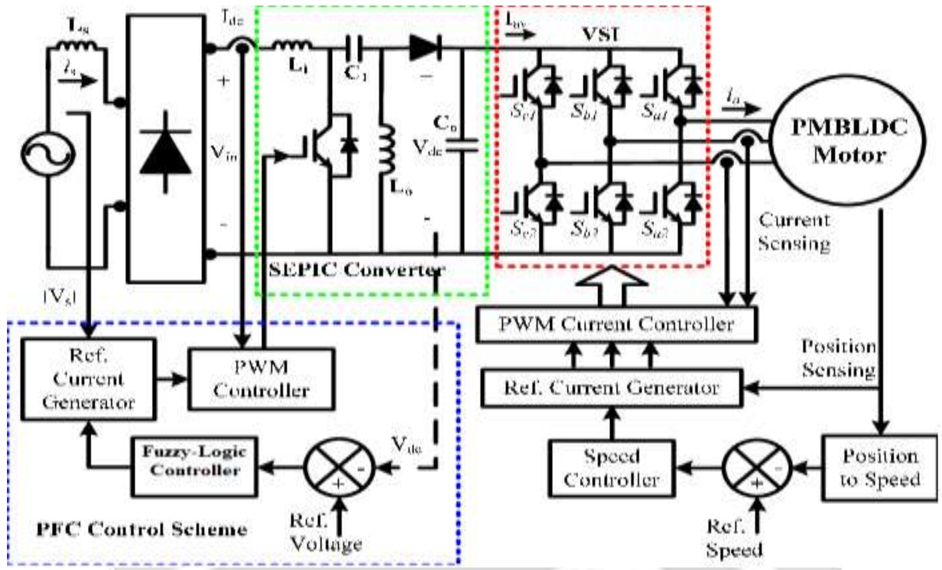


Fig.11 Block Diagram of Proposed PFC-SEPIC DC-DC Converter by using Proposed Fuzzy-Logic Control Scheme

4. PROPOSED HYBRID FUZZY CONTROLLER BASED SEPIC CONVERTER FED BLDC MOTOR DRIVE

The objective of the hybrid controller is to utilize the best attributes of the PI and fuzzy logic controllers to provide a controller which will produce better response than either the PI or the fuzzy controller. There are two major differences between the tracking ability of the conventional PI controller and the fuzzy logic controller. Both the PI and fuzzy controller produce reasonably good tracking for steady-state or slowly varying operating conditions. However, when there is a step change in any of the operating conditions, such as may occur in the set point or load, the PI controller tends to exhibit some overshoot or oscillations [12]. The fuzzy controller reduces both the overshoot and extent of oscillations under the same operating conditions. Thus, after designing the best stand-alone PI and fuzzy controllers, one needs to develop a mechanism for switching from the PI to the fuzzy controllers, based on the following two conditions:

1) Switch when oscillations are detected;
2) Switch when overshoot is detected.

The switching strategy is then simply based on the following conditions: IF the system has an oscillatory behaviour THEN fuzzy controller is activated, Otherwise PI controller is operated. IF the system has an overshoot THEN fuzzy controller is activated, Otherwise PI controller is operated. The system under study is considered as having an overshoot when the error is zero and the rate of change in error is any other value than zero. Accordingly, the switching between the two controllers reduces to using PI if the fuzzy has null value; otherwise, the fuzzy output is used. In particular, the fuzzy controller can be designed so that a normal behavior. The block diagram of proposed Hybrid-Fuzzy-Logic Controlled SEPIC Converter is depicted in Fig.13.

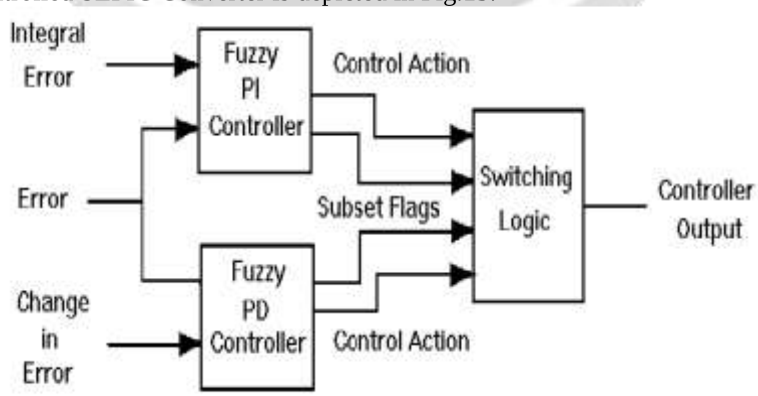


Fig.12 Block Diagram of Hybrid-Fuzzy Logic Controller

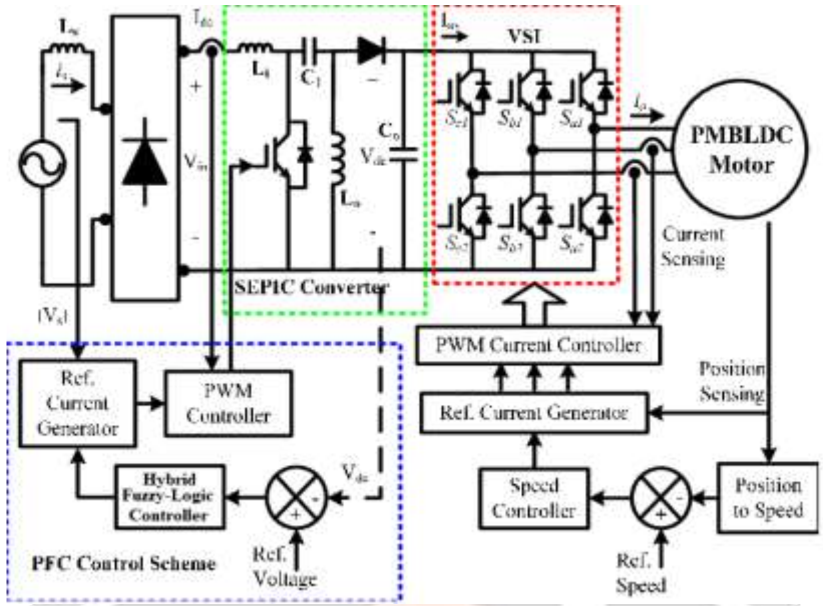


Fig.13 Block Diagram of Proposed PFC-SEPIC DC-DC Converter by using Proposed Hybrid-Fuzzy-Logic Control Scheme

5. MATLAB/SIMULINK RESULTS AND DISCUSSION

The Matlab/Simulink modelling is carried based on various cases and the proposed models are developed by using described system specifications illustrated in Table.2.

Table.2 System Specifications

S.NO	System Specifications	Values
1	Input Source Voltage	Vrms-230V, Fs-50Hz
2	SEPIC Converter	L1-1mH, L2-5.09mH, C1-47µF, C2-1000µF
3	DC-Link Capacitor	Vdc-350V, Cdc-1000 µF
4	Switching Frequency	Fs-50KHz
5	BLDC Motor	V-350V, Rs-2.8Ω, Ls-8.5mH
6	PI Controller	Kp-0.5, Ki-0.125

5.1 Design of Front-End Diode-Bridge Rectifier powered SEPIC Converter with classical PI Controller

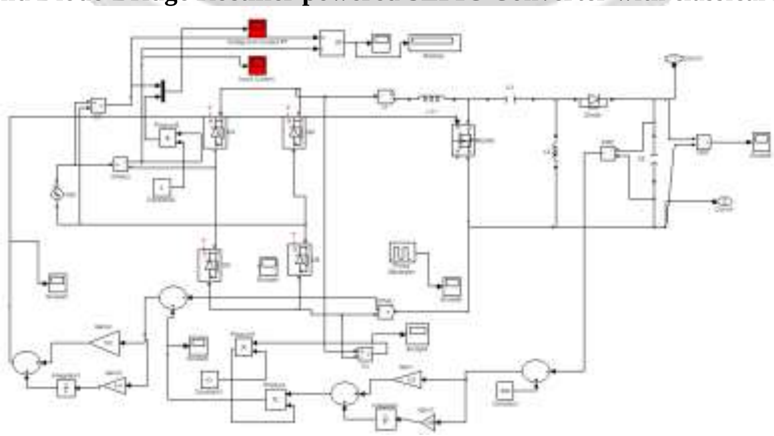
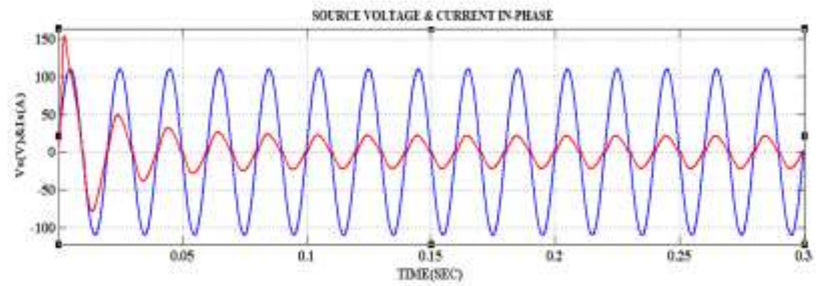
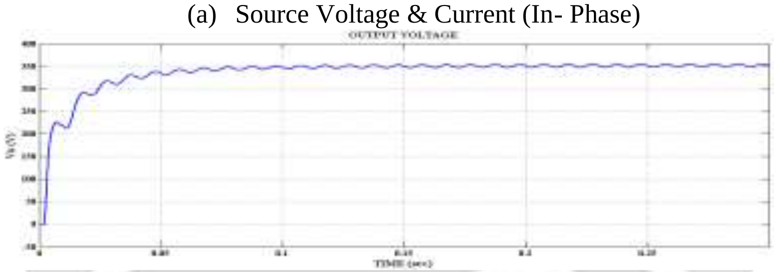


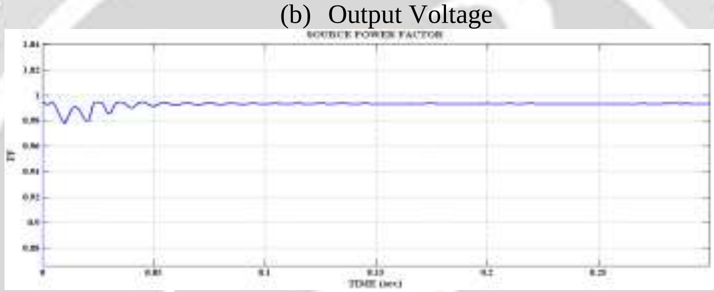
Fig.14 Matlab/Simulink model of Front-End Diode-Bridge Rectifier powered SEPIC Converter with classical PI Controller



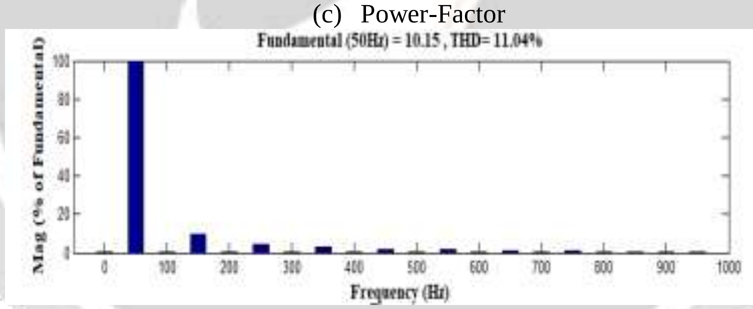
(a) Source Voltage & Current (In- Phase)



(b) Output Voltage



(c) Power-Factor



(d) THD Value of Source Current

Fig.15 Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter with classical PI Controller

The Matlab/Simulink model of Front-End Diode-Bridge Rectifier powered SEPIC Converter with classical PI Controller is depicted in Fig.14. Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter with classical PI Controller is depicted in Fig.15. It includes, (a) Source Voltage & Current (In- Phase), (b) Output Voltage, (c) Power Factor, (d) THD value of Source Current, respectively. The single-phase voltage source is used to drive the DC load by using front-end with SEPIC converter with a source voltage of 230V, 50Hz supply. The output voltage of SEPIC converter with PI controller produces the constant DC output voltage with a value of 340V and load works properly. The source power factor is enhanced with a value of 0.9934. The THD value of source current is 11.04%, it is moderately comply with IEEE-519 standards.

5.2 Design of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Fuzzy-Logic Controller

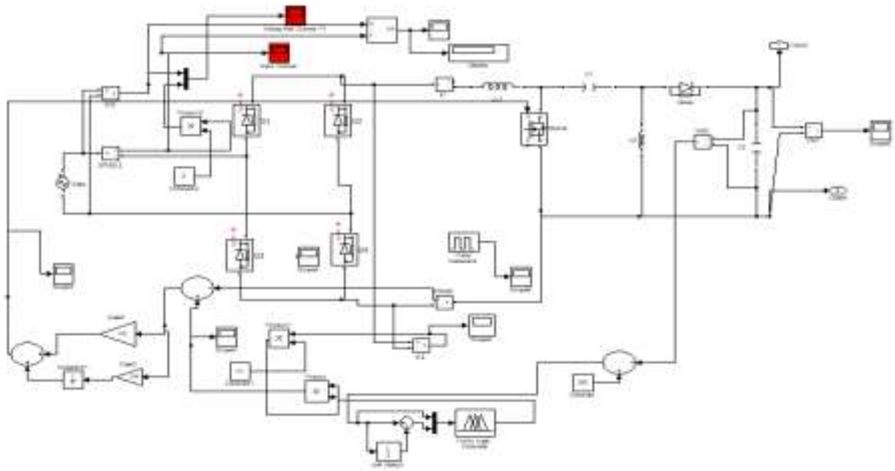
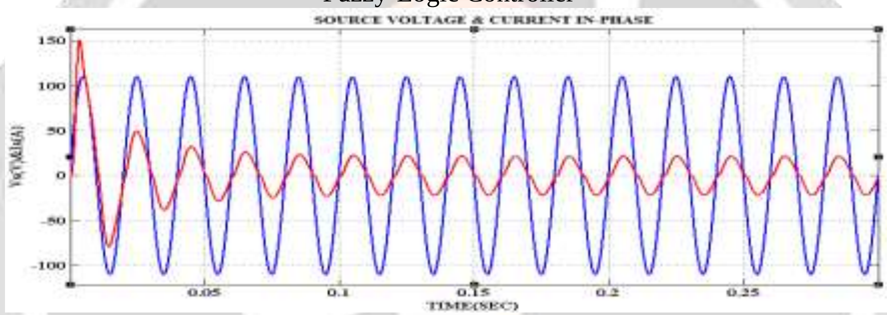
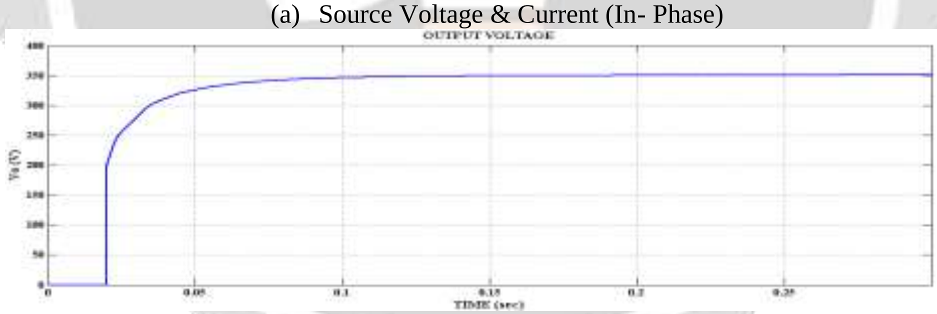


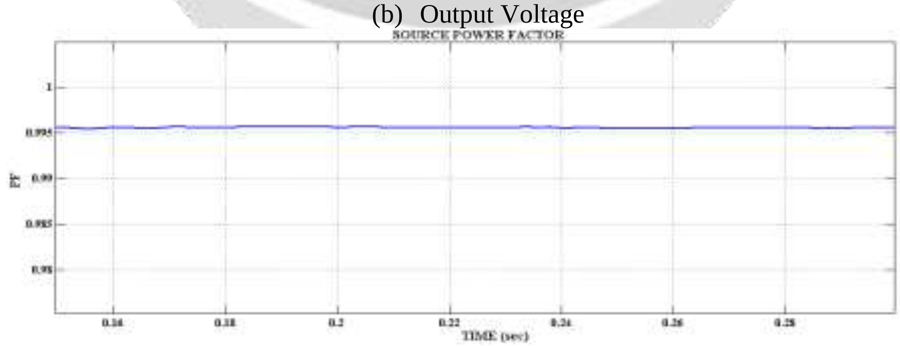
Fig.16 Matlab/Simulink model of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Fuzzy-Logic Controller



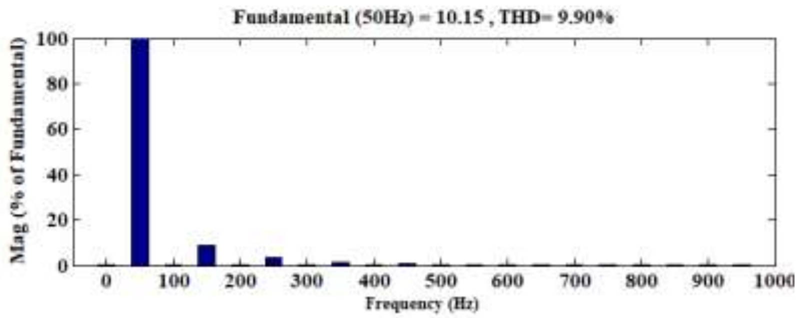
(a) Source Voltage & Current (In- Phase)



(b) Output Voltage



(c) Power-Factor



(d) THD Value of Source Current

Fig.17 Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Fuzzy-Logic Controller

The Matlab/Simulink model of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Fuzzy-Logic Controller is depicted in Fig.16. Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Fuzzy-Logic Controller is depicted in Fig.17. It includes, (a) Source Voltage & Current (In- Phase), (b) Output Voltage, (c) Power Factor, (d) THD value of Source Current, respectively. The single-phase voltage source is used to drive the DC load by using front-end with SEPIC converter with a source voltage of 230V, 50Hz supply. The output voltage of SEPIC converter with proposed fuzzy-logic controller produces the constant ripple-free DC output voltage with a value of 340V and load works properly. The source power factor is enhanced with a value of 0.9956. The THD value of source current is 9.90%, it is nearly comply with IEEE-519 standards.

5.3 Design of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Hybrid Fuzzy-Logic Controller

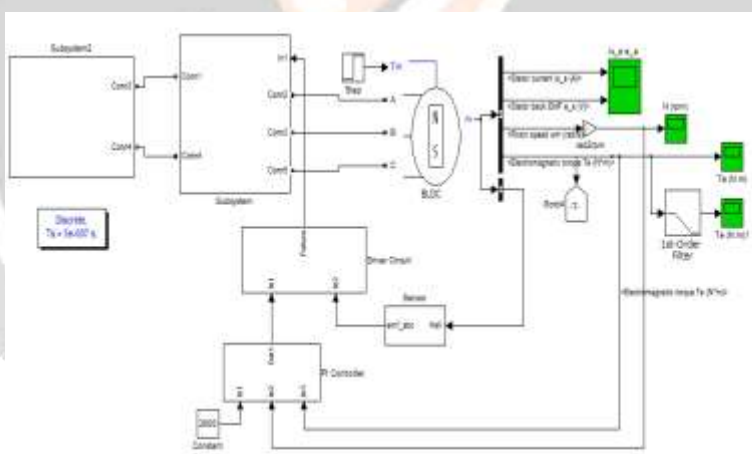
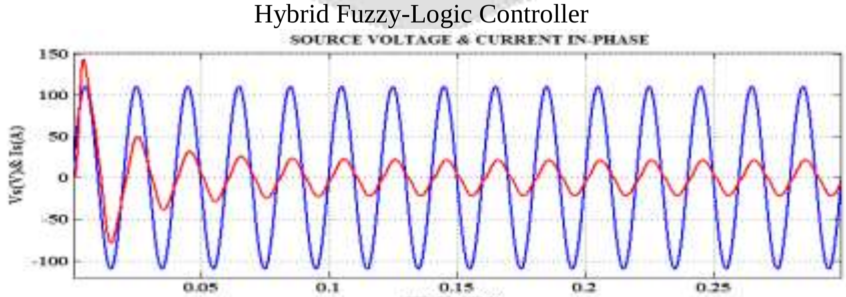
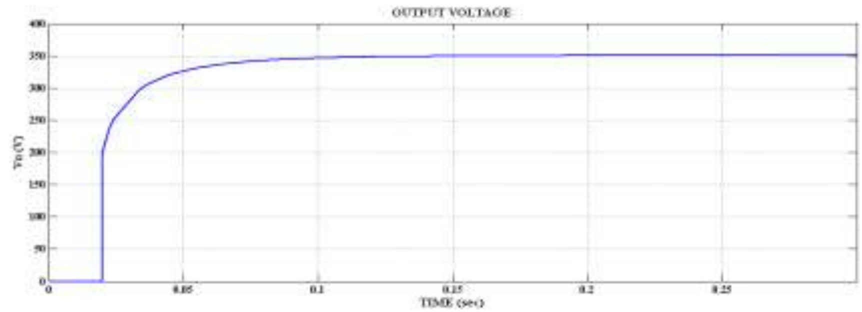


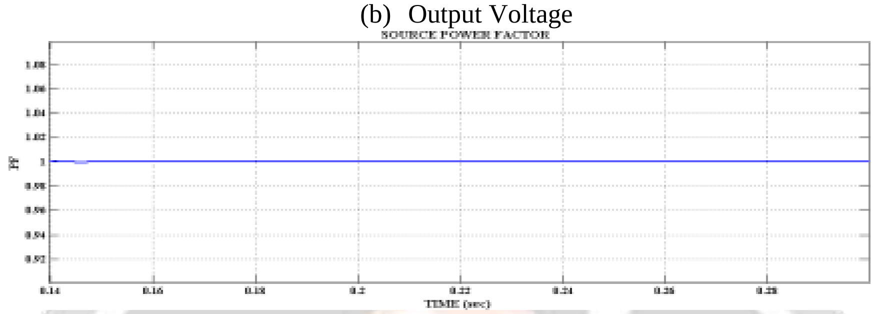
Fig.18 Matlab/Simulink model of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Hybrid Fuzzy-Logic Controller



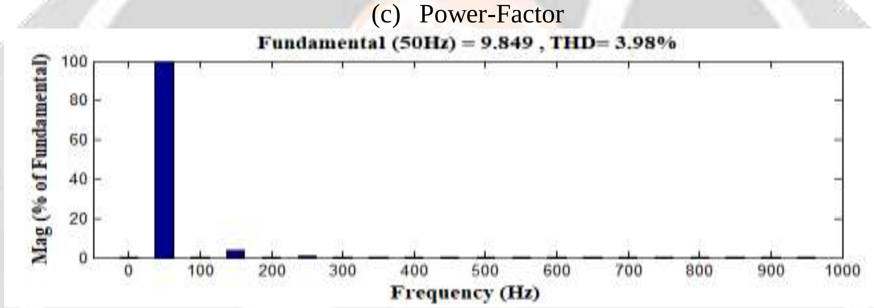
(a) Source Voltage & Current (In- Phase)



(b) Output Voltage



(c) Power-Factor

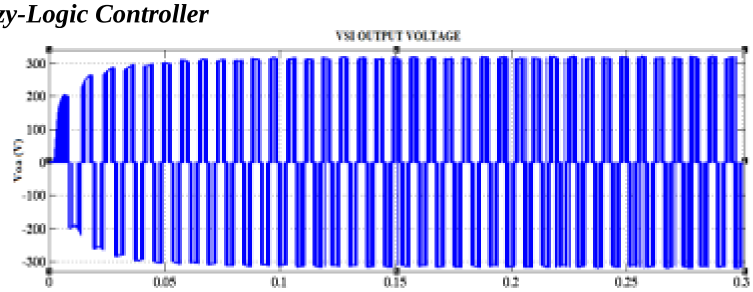


(d) THD Value of Source Current

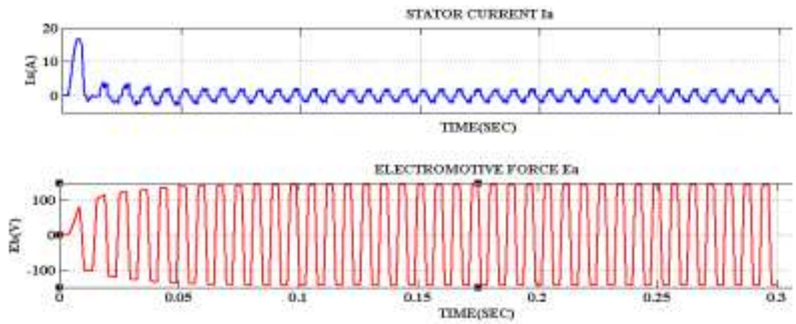
Fig.19 Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Hybrid Fuzzy-Logic Controller

The Matlab/Simulink model of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Hybrid Fuzzy-Logic Controller is depicted in Fig.18. Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter with Proposed Hybrid-Fuzzy-Logic Controller is depicted in Fig.19. It includes, (a) Source Voltage & Current (In- Phase), (b) Output Voltage, (c) Power Factor, (d) THD value of Source Current, respectively. The single-phase voltage source is used to drive the DC load by using front-end rectifier with SEPIC converter with a source voltage of 230V, 50Hz supply. The output voltage of SEPIC converter with proposed hybrid fuzzy-logic controller produces the constant ripple-free DC output voltage with a value of 340V and load works properly. The source power factor is enhanced with a value of 0.999. The THD value of source current is 3.98%, it is comply with IEEE-519 standards.

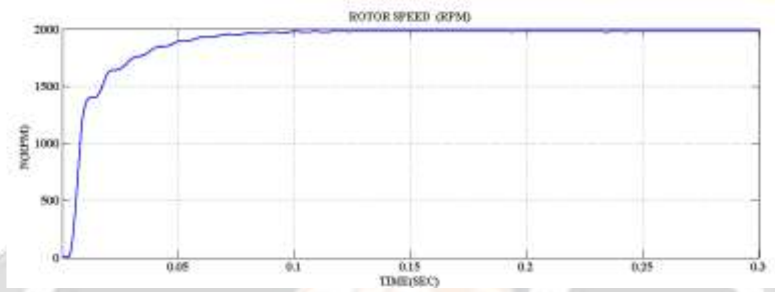
5.4 *Design of Front-End Diode-Bridge Rectifier powered SEPIC Converter to drive the BLDC Motor with Proposed Hybrid Fuzzy-Logic Controller*



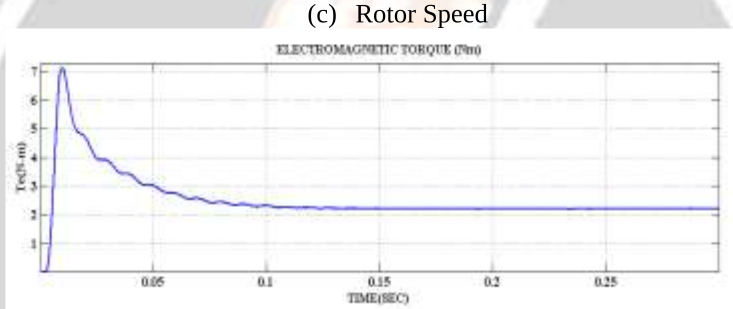
(a) VSI Output Voltage



(b) Stator Current and Back-EMF



(c) Rotor Speed



(d) Electromagnetic Torque

Fig.20 Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter to drive the BLDC Motor with Proposed Hybrid Fuzzy-Logic Controller

Simulation Result of Front-End Diode-Bridge Rectifier powered SEPIC Converter to drive the BLDC Motor with Proposed Hybrid-Fuzzy-Logic Controller is depicted in Fig.20. It includes, (a)VSI Output Voltage, (b) Stator Current and Back-EMF, (c) Rotor Speed , (d) Electromagnetic Torque, respectively. The single-phase voltage source is used to drive the BLDC motor by using front-end rectifier with SEPIC converter with a source voltage of 230V, 50Hz supply. The output voltage of SEPIC converter with proposed hybrid fuzzy-logic controller produces the constant ripple-free DC output voltage with a value of 340V to drive the BLDC motor drive. The stator current and back-EMF maintain as constant with a value of 2.5A and 110V. The rotor of BLDC motor rotates with a speed of 2000 rpm to achieve the required electromagnetic torque of 2 N-m. The proposed intelligent Hybrid-Fuzzy control scheme is highly used in several applications, has been greatly recognized due to enhanced performance over the classical PI and Fuzzy-Logic controllers is depicted in Table.3.

Table.3 Comparison of Power-Factor & THD under Conventional PI and Proposed Fuzzy-Logic and Hybrid-Fuzzy Logic Controllers to drive the SEPIC Converter

S.No	Type of PFC Method	Power-Factor	THD (%)
1	AC-DC Converter without Filter	0.999	0.38%
2	AC-DC Converter with Filter	0.48	227.06%
3	SEPIC Converter with PI Controller	0.9934	11.04%
4	SEPIC Converter with Fuzzy Controller	0.9956	9.90%
5	SEPIC Converter with Hybrid Fuzzy Controller	0.999	3.98%

6. CONCLUSION

This work proposes a new Hybrid-Fuzzy controlled SEPIC converter for enhancing power-quality features and power-factor correction in a VSI fed BLDC motor drive system. The proposed PFC converters operates with wide output voltages for universal input voltages. The various modes of operation of the converter are detailed in the work. Moreover, the converter is operated above and below the peak of the input voltage to provide a wide DC link voltage with smooth input current. The design considerations and the control loop to achieve the wide output voltages is also discussed in the work. The proposed converter achieves high input power factor of 0.99 and able to drive the BLDC motor drive with improved power-quality features and attain high voltage gain over conventional DC-DC converter. The proposed PFC SEPIC converter is developed as single-stage PFC technique which is simulated and the results are presented to validate the concept of achieving wide output with reduced voltage and low current ripple, low THD profile, improved power-factor.

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