International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 04 Issue: 06 | June -2020 ISSN: 2582-3930

Comparative Performance Analysis of Dual Input Single Ended Primary Inductor Converter with PID and Fuzzy Logic Controller

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Abstract - The use of Renewable sources is increasing day by day to reduce the usage of non-renewable sources. In this work, a Renewable energy source dependent Dual Input SEPIC converter is developed with a 12V DC output voltage with a control methodology of maintaining output voltage within 12V when input sources are varying in the range of 6V to 24V. Combining two input energies from dual inputs by using the output capacitor method is one of the multi-input methods. This system contains a feedback system and is designed by using Proportional Integral Derivative (PID) controller and Fuzzy Logic Controller to ensure the output voltage is 12V. The converter with the controllers has no overshoot, it settling time is about 0.02 second with PID and 0.01 second with Fuzzy and the rise time is about 21ms. Thus, it is proved the converter with Fuzzy Logic Controller is capable to reduce the settling time and rise time compared to the converter without a controller.

Key Words: Dual Input Single Ended Primary Inductor Converter, Proportional Integral Derivative Controller, Fuzzy Logic Controller, Photovoltaic panel.

1. INTRODUCTION

DC-DC converter is a power electronics device which converts a dc voltage from one level of voltage to `other voltage .Various types of DC-DC converter has a wide industrial Application in electrical systems like automobiles, marine hoists, voltage regulators, batteries, mine haulers etc. specifically it is used for the transformation of constant to variable DC voltage source. DC-DC converters can increase output voltage from a low input battery voltage thereby saving space without using a greater number of number of batteries. Power system conversion for DC-DC converter consists of a single or various input energy sources, unite them through a converter that can take a variety of input sources and combine their advantages to carry a controlled output for various applications. But, In a power electronic interface, there will be an imbalance between input power and output power demand. Therefore, there is a need to effectively interconnect them by matching their characteristics. The traditional way of connecting multiple energy sources to the system was done in parallel or through a series connection. All the sources connected to the system need to conduct the same current when they are connected in series which is not possible all the time. Furthermore, if they have different voltage levels, they cannot be connected in parallel. A solution to combine the power from multiple sources of different characteristics is a multiple-input power electronic converter integrated into a single system.

Recently many multiple-input converter (MIC) topologies that act as an interface between renewable energy module and load have been proposed every type has its advantages and disadvantages. The MI DC-DC converters such as Buck and Boost converters provide a limited range of output voltages as they only step-down and step-up voltages respectively. The Buck-Boost and Cuk converter topologies provide a wider range of output voltages but with inverted polarity. The MISEPIC has the advantage of an increased lifetime of sources because of its current-source interface. This topology is capable of generating a high voltage level to feed the 240V H-bridge inverter from a low voltage input. In this paper, a 2ISEPIC with a time-sharing switching strategy is implemented. The idea behind this scheme is that the effective duty ratio of each switch is derived from the common switching frequency.

Joo and Hur (2014) have been presented design guideline of portable emergency power supply with multi input and output requirements. The available structures which satisfy design considerations are proposed and analyzed. Based on the chosen structure, suitable topology and controller of each part applied to charge a battery in a wide range of input condition [1].

Kashif and Khan (2016) have been developed a multi-input dc/dc converter with two renewable energy sources at input and one dc load at the output is proposed. The proposed converter draws power from two different sources. The converter maintains regulated output voltage even when one of the input sources diminish [2]. Alzgool and Nouri (2017) have been reported on the design, control and modelling of a novel Multi-Input-Multi-Output Boost Converter topology and the regulated output voltage levels are achieved via classical PID controllers which utilize the concept of closed-loop voltage mode control [3].

Shiyas et al. (2012) have been proposed a multiple input power conditioner topology with Fuzzy controller to integrate intermittent nature of renewable sources such as solar, wind, etc. Solar PV and wind generator are utilized as the primary energy source to meet the load demand and well-regulated output voltage is obtained from the multiple input power conditioner [4].

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Anantha Kumar and Sudha (2016) have been presented the design of a Dual input Cuk-SEPIC fused DC-DC converter is proposed, using solar and wind sources as input and providing a constant 12V output which is used for battery charging applications. Since Solar and Wind sources usually complement one another i.e. if a solar output is unavailable the wind output is available and vice-versa, this system would provide a constant voltage throughout [5].

Danamma et al. (2015) have been presented a Design and Analysis of Dual Input SEPIC Converter for Renewable Energy Sources. And The regulated output voltage levels are achieved by using PI controllers [6]. Chiang et al. (2009) have been presented the modeling and controller design of the PV charger system implemented with the single-ended primary inductance converter (SEPIC). . The designed SEPIC employs the peak-current-mode control with the current command generated from the input PV voltage regulating loop, where the voltage command is determined by both the PV module maximum power point tracking (MPPT) control loop and the battery charging loop [7].

Wong and Man (2009) have been presented the application of a signal flow graph and the Mason's gain formula for deriving small signal models of open-loop single ended primary inductance converter (SEPIC) converters. The control to output and the input to output transfer functions are derived. And the application of the signal flow graph and the Mason's gain formula help the manipulation of equations. Thus, derivation of small signal models can be easily carried out in detail [8].

2. METHODOLOGY

Dual input topologies use two inputs for a Load. Since there are two inputs, even if one source is not available the other source can be utilized. Dual input converter topologies reduce the filter size as well as losses, thus increasing the efficiency.

2.1 Conventional System

Many Dual input converters use a DC source as inputs. They have used multiple Dc sources. Two Separate DC-DC converter (boost, buck and buck boost) is used, which can increase or decrease the input voltage according to the Load. Using of two converters will increase the filter size, losses and cost. Fig -1shows the Block Diagram of Conventional System

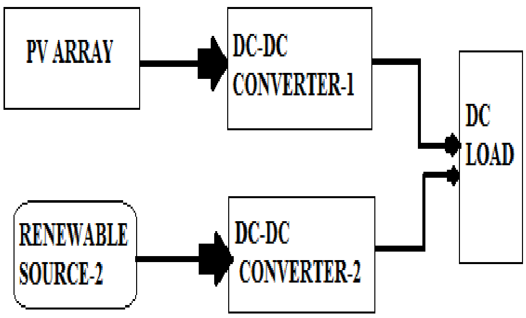


Fig -1: Block Diagram of Conventional System

2.2 Proposed System

In Proposed system DC input sources replaced by renewable resources. This configuration allows the two sources to supply the load separately (PV/AC supply) or simultaneously together (Hybrid) depending on the availability of the energy sources. The main purpose of this hybrid topology is to meet our daily demand effectively and to get an uninterrupted power supply. Filter size and losses are reduced considerably in this proposed system. Fig -2 shows the Block Diagram of proposed System

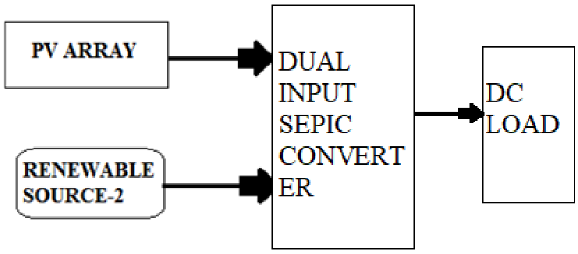


Fig -2: Block Diagram of Proposed System

2.3 Proposed System Converter

Circuit Diagram of the dual input SEPIC (DISEPIC) converter shown in Fig.3. Assume that the converter operates in continuous conductance mode (CCM). Input voltage from source one $\mathbf{V_1}$ is greater than the source two $\mathbf{V_2}$ ($\mathbf{V_1 > V_2}$).Here two SEPIC converter connected in parallel, different switching period is given to the switches MOSFET_1 and MOSFET_2. In this proposed system Solar PV array is taken as input 1 and other renewable system as input 2. And this converter shares same output capacitor. The blocking diode is added to prevent the backflow of current from the higher voltage source to the lower voltage source through theinductor itself.

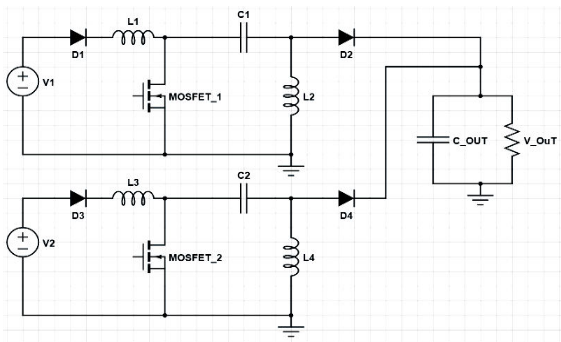


Fig -3: Dual Input Single Ended Primary Inductor Converter

During the charging phase from the input source, the inductor current is stored in the both inductors. One of the inductors is discharging into DC blocking capacitor while the other is to the FET. When the input side inductor, L is charged, its current rises and temporarily stores current until a certain amount. Next, the current stored in the inductor decreases during the discharge phase for supplying current to the output load. T The overall system is designed to run in continuous conduction mode (CCM) to assure the current in the energy transfer inductor never goes to zero between switching cycles.

The CCM operation is preferred in this research for reducing the input- current ripple and reduced the switch-current stress, thus the system is suitable for charging battery. The highest value of the input voltage source will be assigned as V1 while lowest voltage source will be V2. In other words, solar or other renewable source can be either V1 or V2 and may keep changing in real time depending on the input voltage value.

2.4 Operation of Dual Input Single Ended Primary Inductor Converter

The operation of the switch, S1 and S2 in the converter controlled by PID and Fuzzy Logic Controllers. It consists of three modes as shown in Table 1.

Table -1: Operation of switches according to modes

MODE 1		MODE 2		MODE 3	
S1	**S2**	**S1**	**S2**	**S1**	**S2**
ON	OFF	OFF	ON	ON	ON

MODE 1:

Equivalent circuit of the converter in this mode is shown in Fig. 4.

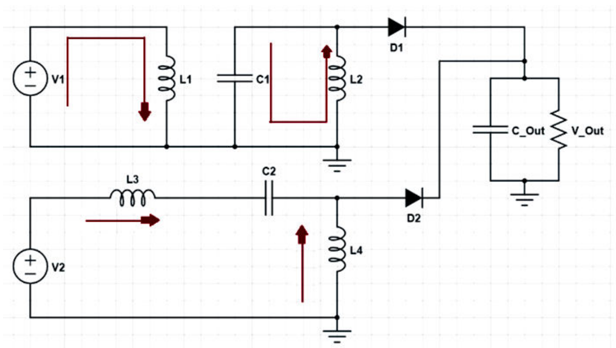


Fig -4: Equivalent circuit of DISEPIC in MODE 1

In this state, the switch S1 is on while S2 is off. Inductors L1 and L2 are energized while both free-wheeling diode are still reverse biased therefore not conducting any current. In this mode, S2 still has the chance to turn on when the dual input converter is stepping up the voltage. Only higher voltage will be transferred to the load after this mode.

MODE 2:

Equivalent circuit of the converter in this mode is shown in Fig. 5. In this state, the switch S2 is on while S1 is off, Inductors L3 and L4 are excited while the energized inductance of L1 and L2 supplied to the load through the free-wheeling diode, D1.

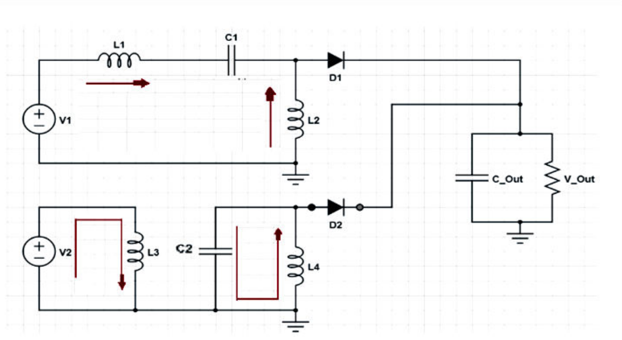


Fig -5: Equivalent circuit of DISEPIC in MODE 2

MODE 3:

Equivalent circuit of the converter in this mode is shown in Fig. 6. In this state, the switches S1 and S2 are on together. The energy will be stored in L1, L2, L3, and L4 and are waiting for release while both free-wheeling diode are reverse biased. After the switch is closed, the higher voltage source will be delivered to the load. This mode happens only when both of the input voltages are less than 12V, so the converter requires to step up the voltage in order to reach the desired output voltage. In this case, the duty cycle of both switches will be more than 0.5.

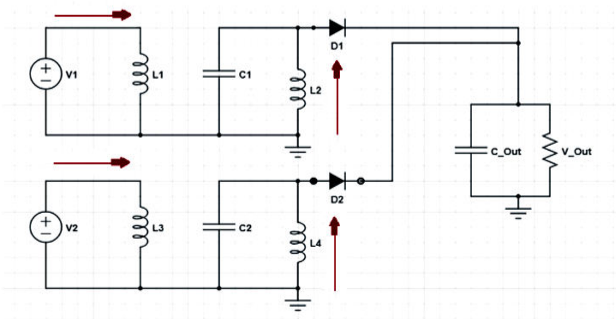


Fig -6: Equivalent circuit of DISEPIC in MODE 3

3. SWITCHING EQUATIONS

The inductor currents, I_L are supposed to be zero while the average current of the capacitor, C is zero for steady-state operation. Kirchhoff's voltage law throughout the path consists of VS1, VS2, VL1, VL2, VL3, VL4, C1 and C1 as

For loop

$$V_{S1}+V_{L1}+V_{c1}-V_{L2}=0$$

$$V_{c1}=V_{s1} \tag{1}$$

For loop

$$V_{S2}{:}-V_{s1}+V_{L3}+V_{c2}-V_{L4}=0$$

$$V_{C2}=V_{s2} \tag{2}$$

When S1 is closed while S2 is opened and both diodes are off, the voltage across L1 for the interval 0 < t < DT is given in (3)

$$V_{L1} = V_{S1}$$
$$V_{L3} = -V_0 \quad (3)$$

When S1 is open while S2 is closed and diode 1 is on, assuming that the voltage across C1 and C2 remains constant at its average value of VS1 and VS2 respectively, the voltage across L1 and L3 for the interval D1T < t < D2T is

$$V_{L1} = -V_0$$
$$V_{L3} = V_{S2} \quad (4)$$

When both switches are open, the voltage across L1 and L3 for the interval (0 < t < DT) is

$$V_{L1} = -V_0 \qquad V_{L3} = -V_0 \quad (5)$$

Since the average voltage across both inductor size zero for periodic operation, equation (3), (4) and (5) are combined to get

$$(V_{L1,SW_{Closed}})(D_1T) + \left(V_{L1,SW_{Opened}}\right)(1-D_1)T + \left(V_{L3,SW_{Opened}}\right)(1-D_2)T = 0$$

$$V_{s1}D_1 - V_0(1-D_1) + V_{s2}(1-D_2) = 0 \quad (6)$$

$$V_0 = \frac{V_{s1}D_1 + V_{s2}(1-D_2)}{1-D_1} \quad (7)$$

$$I_L = \frac{V_0^2}{V_s R} \quad (8)$$

When V_{S1}or V_{S2} is absent, the equation of the $D_1$and D_2 that derived for (7) are given in (9) and (10) respectively. Besides that, this equation reflects the resistance of the diode in order to get a more accurate result.

$$D_1 = \frac{V_0 + V_{FWD}}{V_{s1} + V_0 + V_{FWD}} \quad (9)$$

$$D_2 = \frac{V_0 + V_{FWD}}{V_{s2} + V_0 + V_{FWD}} \quad (10)$$

The highest value of the input source will be selected as D1 while the other source will be D2. Once the higher value input source becomes lower than the other source or is absent, the second source will replace it and will be assigned as D1. In this situation, the feedback signal drive to PID controller and FUZZY Logic Controller and PI Controller can run properly to regulate the output voltage to the desired value

The parameters of the elements in the proposed converter topology are presented in this section. Components of converter such as inductors, capacitors, switching period and filter components are designed using following formulas

A. Inductor Current

$$I_L = \frac{V_0^2}{V_s R} \quad (11)$$

Here change in inductor current is taken as 40% of I_L

$$\Delta I_L = 40\% \ of \ I_L \quad (12)$$

B. Inductor Values

$$L_{1[min]} = L_2 = L_3 = L_4 = \frac{V_s D}{\Delta i_L F_{SW}} \quad (13)$$

C. Capacitor Values

$$C_1 = C_2 = \frac{DV_0}{R\,\Delta V_0 F_{SW}} \quad (14)$$

$$C_{out} = \frac{2DV_0}{R\,\Delta V_0 F_{SW}} \quad (15)$$

Table -2: Design Specifications of DISEPIC

S. No	PARAMERTERS	VALUE
1	Input Voltage1 PV (V_{S1})	24V
2	Input Voltage1 PV (V_{S2})	12V
3	Duty Cycle, D_1	34.2%
4	Duty Cycle, D_2	67.6%
5	Switching Frequency, f	40KHz
6	Output Voltage, V_0	12V
7	Output Resistor, R	10Ω

4. SIMULATION AND RESULTS

4.1 Open-Loop Simulation and Results

The open-loop circuit is simulated as shown in Fig. 7. Schottky diode is used and its voltage drop is approximate 0.5V. Thus, the calculation result will be pretty different compared to the simulation due to some of the power loss in these elements.

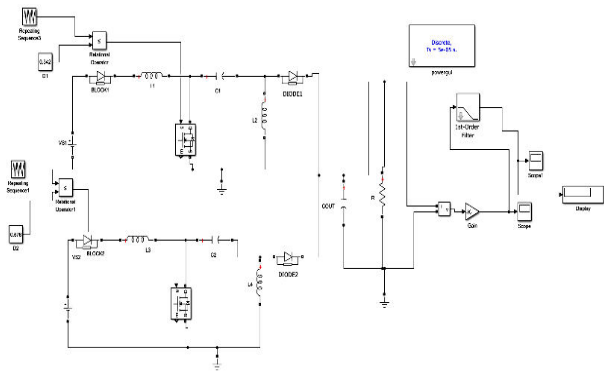


Fig -7: Simulink Model for Open Loop DISEPI

The input voltage and duty cycle of DISEPIC are set manually and tested using MATLAB Simulink software to find the stability of the output voltage.

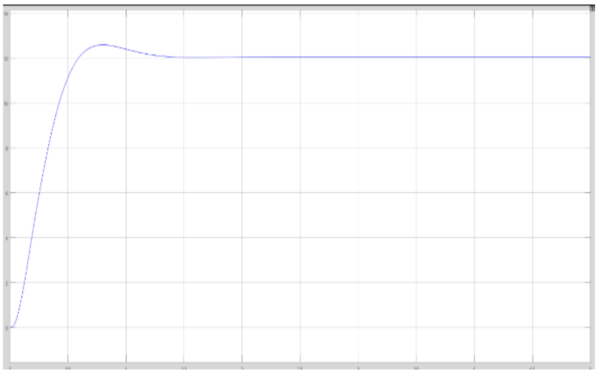


Fig -8: Output Waveform of Open Loop DISEPIC

Output of Open Loop DISEPIC is obtained using MATLAB software show in Fig. 8. From Output Waveform of Open Loop DISEPIC states that the output voltage is Almost 12volts while its settling time is about 1.4s and Rise time is about 378ms and voltage overshoot about 5.1%.

4.2DISEPIC with PID Controller Simulation and Results

The closed-loop converter with PID circuit is shown in Fig.9. The PID subsystem is shown in Fig. 10. The closed loop dual input SEPIC converter uses the PID controller in order to achieve the desired output voltage of12V.

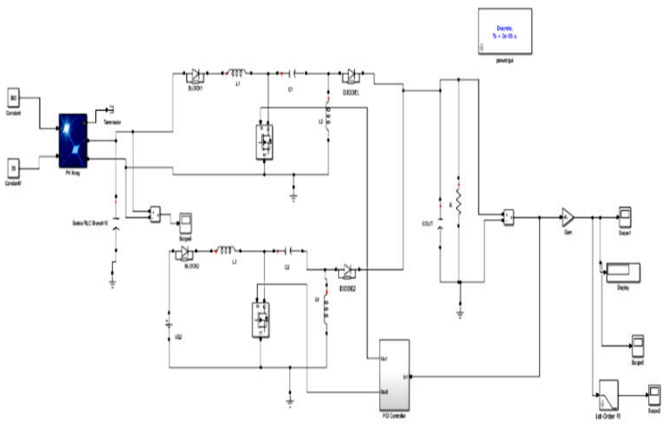


Fig -9: Simulink Model for DISEPIC with PID Controller

The repeating sequence 1 is inverse to the repeating sequence 2, thus the signal generated for both switches is one turn on while the other is turn off. Both of the switches turn on simultaneously only if the converter operates in mode 3.

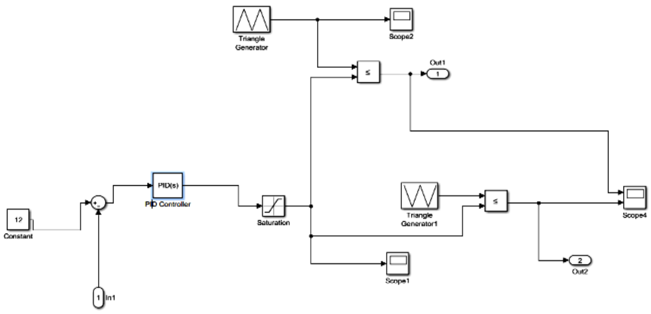


Fig -10: Simulink Model for PID Controller Sub Block

The Triangular Generator 1 is inverse to the Triangular Generator 2, thus the signal generated for both switches is one turn on while the other is turn off. Both of the switches turn on simultaneously only if the converter operates in mode3. The parameter of the PID controller is determined by PID Tuning Algorithm [MATLAB] to achieved a good balance between performance and robustness as shown in Table3. Output of DISEPIC with PID is obtained by using MATLAB software shown in Fig. 11.

Table -3: Parameters of the PID Controller

Parameter	Value
Proportional gain, Kp	0.02
Integrator gain, Ki	2
Derivative gain, Kd	4.6
Filter coefficient (N)	144406496

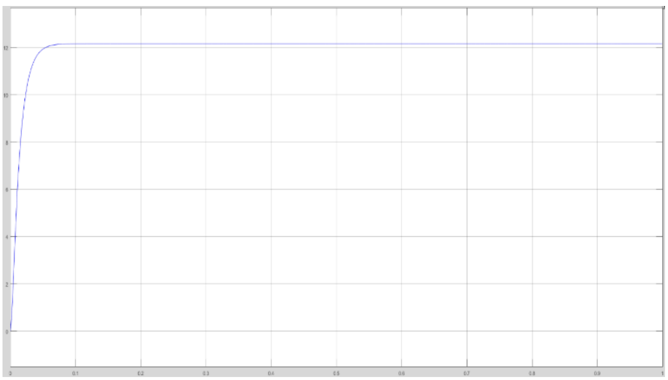


Fig -11: Output Waveform of DISEPIC with PID Controller

The Output Voltage of DISEPIC with PID Controller is 12V while its Rise time is 26ms and its Settling time is 0.03sec and Voltage Overshoot is almost reduced to 0 as compared to open loop.

4.3DISEPIC with Fuzzy Logic Controller Simulation and Results

The closed-loop converter with Fuzzy Logic ControllercircuitisshowninFig.12.while the Fuzzy subsystem is shown in Fig 14. The closed loop dual input SEPIC converter uses the Fuzzy controller in order to achieve the desired output voltage of 12V. Table 4 shows the FLC rule table used for this work. Fig-13 shows the membership function.

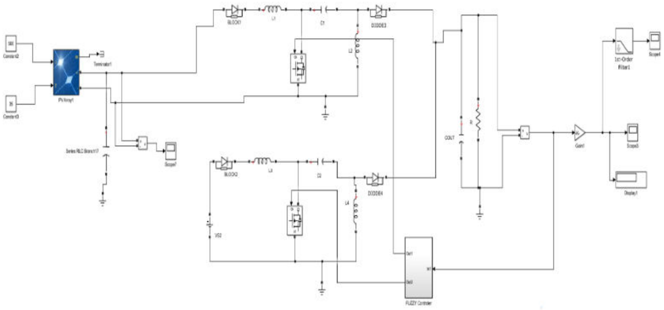


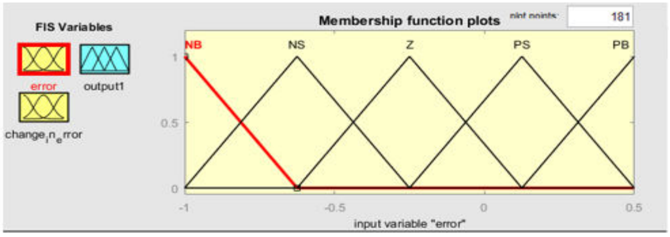
Fig -12: Simulink Model for DISEPIC with FUZZY LOGIC Controller

Following steps are followed to compute the output from the Mamdani's architecture

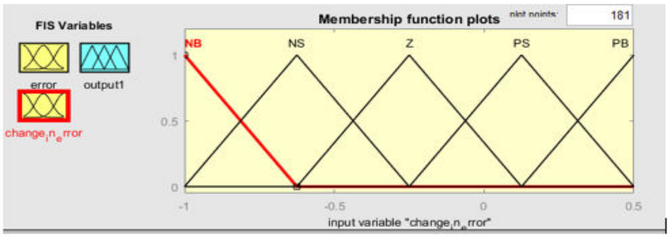
i. In this work Mamdani style is chosen for designing fuzzy logic controller. 'Error' and 'change error' are taken as Input variables
ii. Variables and "duty" are taken as Output variable for Switch (MOSFET) each input is divided into five groups for DC-DC Converters.
iii. Two inputs of the FLC Rule base ('error' and 'change error') are divided into five groups which are NB: Negative Big, NS: Negative Small, Z: Zero Area, PS: Positive small, and PB: Positive Big.
iv. Combining the fuzzifier input according to the fuzzy rules for establishing rule strength.

Table -4: FLC Rule Table

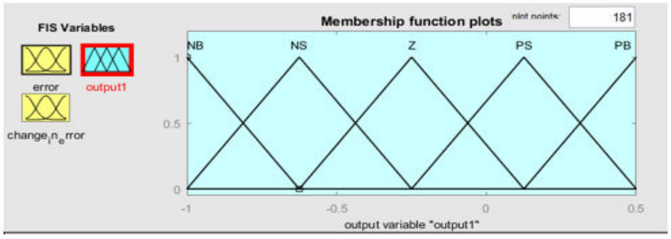
E \ ΔE	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PB
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB



Input 1 membership function plot



Input 2 membership function plot



Output membership function plot

Fig -13: Membership Functions

Fuzzy Logic Controller Sub Block is shown in Fig. 14. In fuzzy controller sub block the Triangular Generator 1 is inverse to the Triangular Generator 2, thus the signal generated for both switches is one turn on while the other is turn off. Both of the switches turn on simultaneously only if the converter operates in mode3.

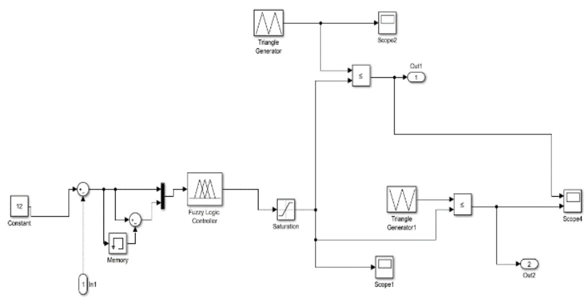


Fig -14: Simulink Model for Fuzzy Controller Sub Block

Output of DISEPIC with Fuzzy Logic Controller is obtained by using MATLAB software show in Fig. 15

Fig -15: Output Waveform of DISEPIC with Fuzzy Logic Controller

The Output Voltage of DISEPIC with Fuzzy Logic Controller is 12V while its Rise time is 26ms and its Settling time is 0.01sec and Voltage Overshoot is almost reduced to 0.

4.4 Comparison of Performance of Dual Input SEPIC converter with PID and Fuzzy Logic Controller

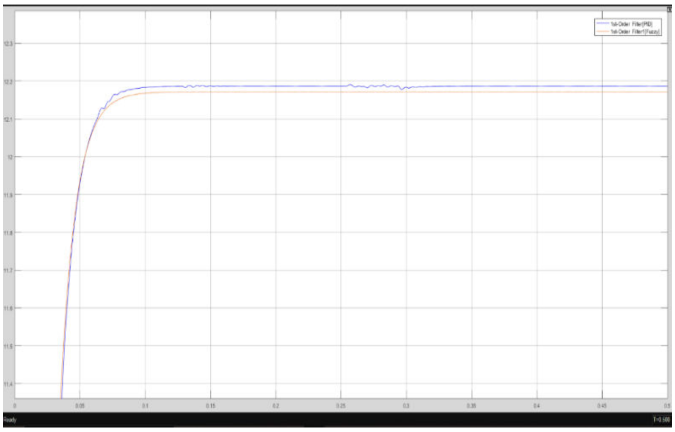


Fig -16: Output Waveforms of DISEPIC with PID and Fuzzy Controllers

Voltage Responses of DISEPIC with PID and Fuzzy Controller shown in above Fig. 16. The Output voltage response of DISEPIC with FUZZY Logic Controller gives best results as compared to PID Controller. DISEPIC with PID Controller has Rise time of 26ms and Settling time of 0.03sec and overshoot is zero. While DISEPIC with Fuzzy has Rise time of 26ms and settling time of 0.01sec. Thus, the DISEPIC with Fuzzy Logic Controller is capable to reduce Settling time and Rise Time and eliminate Steady State Error and gives best results as compared to PID Controller.

5. CONCLUSIONS

The design and analysis of the dual input SEPIC converter with Fuzzy Logic controller were presented. This topology is flexible due to it can provides a stable output voltage even though the input source value is in wide range which is 6V until 24V. The design takes into consideration the practical features of the converter while the stability can be judged by observing the output waveform. The higher voltage of the input source will be the priority be the feedback signal to the fuzzy controller, whereas the lower voltage will be the backup source. Converter with the controller is proved can generate 12V and it settling time is shorter and less over shoot compared to without controller and PID Controllers. Simple structure and high power efficiency modifications are suggested as a future scope of this design.

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