COMPARISON BETWEEN VARIOUS CONTROL STRATEGIES OF SEPIC CONVERTER

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***Abstract*—The SEPIC(Single Ended Primary Inductance Converter) a DC-DC converter which allows a range of DC voltage to be adjusted to maintain a constant voltage output and capable of operating both in step-up or step-down mode and is widely used in battery-operated applications. This paper presents the importance of DC-DC converters and why SEPIC converters are used instead of other DC-DC converters. Here the output of the converter is controlled by applying various control strategies with feedback to show how it can be implemented in a circuit. The DC-DC converter optimization and control is implemented in this paper. There are two possible modes of operation in the SEPIC converter one is the Continuous Conduction Mode(CCM) and another one is the Discontinuous Conduction Mode(DCM). Here it is used in CCM mode. Here the design and implementation of SEPIC Converter is done by using MATLAB Simulink.**

Keywords : *DC–DC converter , SEPIC , CCM , DCM , Controllers*

I. INTRODUCTION

Now in the age of power electronics the DC-DC converter like buck converter, boost converter, buck-boost converter, flyback converter, push-pull converter, forward converter, cuk converter etc. has been designed for different application purpose. The soft switching technique is used in these converters which helps to transfer the energy from load to source. The SEPIC converter is simply a DC-DC converter which step up or step down the output voltage as compare to the input voltage with the help of soft switching operation and energy storage elements like inductor and capacitor. The SEPIC increases or decreases the output voltage by varying the duty cycle. If the duty cycle is above 50% then the Output voltage is more than the input voltage and if the duty cycle is less than 50% then the output voltage is less than the input voltage. When the duty cycle is equal to 50% then the input voltage is equal with the output voltage. The operating mode of the converter depends upon the flow of the load current which can be continuous or discontinuous. So the converter can be operated as Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM) which depends on the load condition. The switching operation takes place at a higher frequency which increases the response of the system. The SEPIC converter is a 4th order converter where two inductors and two capacitors are used. Since the system is nonlinear, the controller design is very difficult. This paper presents the SEPIC by using various suitable controllers' technique for controlling the output voltage and also gives a comparison for better study. The model is designed and with the help of state space analysis, the system is converted in the form of transfer function[1].

II.MODEL DESCRIPTION

It is a type of DC-DC converter, that allows the voltage at its output to be more than, less than, or equal to that at its input. The output voltage of the SEPIC is controlled by the duty cycle of the MOSFET. A SEPIC is similar to a cuk or buck-boost converter, but has advantages of having non-inverted output, by means of coupling energy from the input to the output is via a series capacitor. When the switch is turned off output voltage drops to 0 V. SEPIC is useful in applications like battery charging where voltage can be above and below that of the regulator output[1].

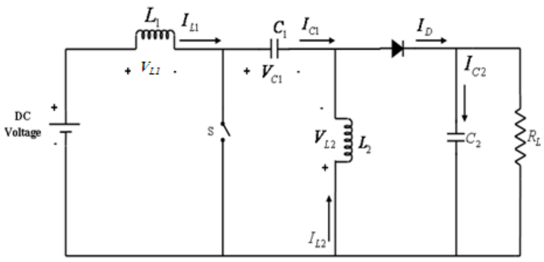

Fig.1 Basic SEPIC Converter

The SEPIC converter (Fig. 1) consists of a switch (Q) with duty cycle d, a diode (D), two inductors (L_1 and L_2), two capacitors (C_1 and C_2) and a resistor load (R_L). When (Q) turns ON, the energy is stored in the inductor (L_1). At this time the inductor voltage equals to input voltage, and the energy stored in capacitor (C_1) will be transferred to inductor (L_2). The load is supplied by capacitor (C_2). When (Q) turns OFF, the energy stored in inductor (L_1) is transferred to (C_1). The energy stored in (L_2) is transferred to (C_2) through (D) and supplying the energy to load. The Output voltage for duty cycle (d) is given by as follows.

$$V_0 = V_S \times \frac{D}{(1-D)} \quad \text{and} \quad D = \frac{V_0}{(V_0 + V_S)}$$

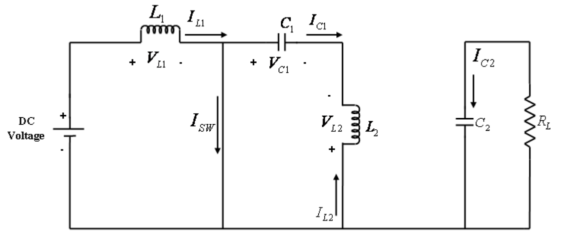

Fig.2 SEPIC When Switch Closed and Diode Off

The fig. 2 and fig. 3 represent the operation of SEPIC converter when the switch is closed and open respectively.

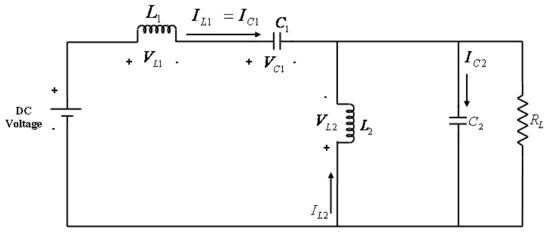

Fig. 3 SEPIC When Switch Open and Diode On

III.STATE SPACE ANALYSIS

The converter can be analyzed by using the state space analysis for checking its stability. It is a technique in which the converter is converted into its equivalent mathematical differential equation which must be equal with the no. of energy storage element present in the converter. Then the equations are converted into its equivalent matrix form. Here the SEPIC is operated in CCM for which it can be operated in 2 modes of operation as shown in the fig. 2 and 3.

Now from fig. 2; During 0<t<DT interval (When MOSFET is turned ON);

$$\frac{dI_{L1}}{dt} = -\frac{V_S}{L_1} \qquad (1)$$

$$\frac{dI_{L2}}{dt} = \frac{V_{C1}}{L_2} \qquad (2)$$

$$\frac{dV_{C1}}{dt} = -\frac{I_{L2}}{C_1} \qquad (3)$$

$$\frac{dV_{C2}}{dt} = -\frac{V_{C2}}{RC_2} \qquad (4)$$

Similarly from fig. 3; During DT<t<(1-D)T interval(When MOSFET is turned OFF);

$$\frac{dI_{L1}}{dt} = -\frac{V_{C1}}{L_1} - \frac{V_{C2}}{L_2} + \frac{V_S}{L_1} \qquad (5)$$

$$\frac{dI_{L2}}{dt} = -\frac{V_{C2}}{L_2} \qquad (6)$$

$$\frac{dV_{C1}}{dt} = \frac{I_{L1}}{C_1} \qquad (7)$$

$$\frac{dV_{C2}}{dt} = -\frac{V_{C2}}{RC_2} + \frac{I_{L1}}{C_2} + \frac{I_{L2}}{C_2} \qquad (8)$$

When the MOSFET is ON the State Space equation is ;

$$\begin{bmatrix} \frac{dI_{L1}}{dt} \\ \frac{dI_{L2}}{dt} \\ \frac{dV_{C1}}{dt} \\ \frac{dV_{C2}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L_2} & 0 \\ 0 & \frac{-1}{C_1} & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{RC_2} \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{C1} \\ V_{C2} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} [V_{IN}] \qquad (9)$$

When the MOSFET is OFF the state space equation is;

$$\begin{bmatrix} \frac{dI_{L1}}{dt} \\ \frac{dI_{L2}}{dt} \\ \frac{dV_{C1}}{dt} \\ \frac{dV_{C2}}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-1}{L_1} & \frac{-1}{L_1} \\ 0 & 0 & 0 & \frac{-1}{L_2} \\ \frac{1}{C_1} & 0 & 0 & 0 \\ \frac{1}{C_2} & \frac{1}{C_2} & 0 & \frac{-1}{RC_2} \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{C1} \\ V_{C2} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} [V_{IN}] \qquad (10)$$

and $$Vout = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_{C1} \\ V_{C2} \end{bmatrix} \qquad (11)$$

The transfer function of the system is given by;

$$\frac{Vo}{Vin} = \frac{1.998S^3 + 2.496\times10^6 S^2 + 1.056\times10^8 S + 2.13\times10^{13}}{S^4 + 3.735S^3 + 8.88\times10^6 S^2 + 2.91\times10^9 S + 3.215\times10^{12}} \qquad (12)$$

IV. CONTROL SCHEMES

The system can be designed by open loop and closed loop configuration .An open loop control system acts on the basis of input and the output has no effect on the control action for which the optimization can not be possible in this configuration. The closed loop control system is a system where the actual behaviour of the system is sensed and then fed back to the controller and mixed with the reference or desired state of the system to adjust the system to its desired state. So the optimization is possible in this configuration. To implement the system in closed loop configuration there are various control strategies are used to control the system output and to give good response. Here in this paper some controllers like PI, PID, FLC , SMC , PI with SMC are used for design and implementation with the SEPIC converter. The below Fig .4 shows the basic structure of the whole system configuration. The output voltage is fed back to the controller with the reference voltage and given to the switch of the converter for operation of the system.

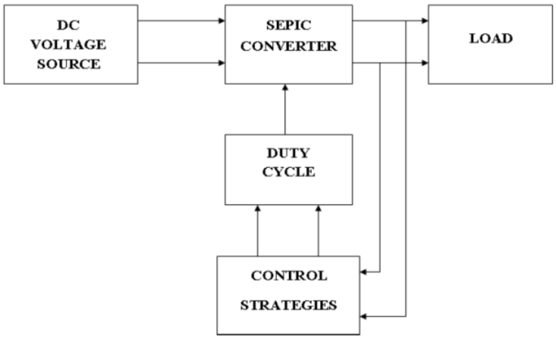

Fig.4 System Configuration

The **PID controller** i.e. Proportional Integral Derivative Controller is the basic linear closed loop technique. It is a popular linear feedback controller used in industrial application due to its feasibility easy implementation and to achieve better steady state error operation. The PID assumes the system as Black Box and tracks the error for unknown and complex system. P is dependency on the present error and eliminates the transient error, I is accumulation of past error and eliminates the Steady state error and D is the predictive of the future error and enhances the speed of the system. A PID controller calculates an error value as the difference between the measured process variable and the desired set-point . It has to adjust three-gain impact to the system which would affect the transient response, rise time, settling time, steady-state error, overshoot and stability[2]. It is not necessary that the system has to use all the three controller simultaneously; it may only use one or two actions i.e. PI, PD, ID, P, I or D. The PI controller can be mathematically denoted as ;

$$G_C(s) = K_P + \frac{K_I}{s} + K_D S \quad (13)$$

$$G_C(s) = K_P(1 + \frac{1}{T_I s} + T_D S) \quad (14)$$

Where K_P is the proportional gain, K_I is the integral gain, T_I is integral time or reset time, K_D is Derivative gain , T_D is Rate time or derivative time. The proportional part is responsible for following the desired set point while the integral part account for the accumulation of past errors in the process. The PI controller can be designed by various tuning methods like Ziegler-Nichols method, Cohen-Coon method , Lambda Tuning method etc. But the Ziegler-Nichols method is adopted as compared to others due to it provides very good disturbance response[3].

Controllers of DC-DC converters are usually designed based on the mathematical models. It is difficult to obtain a mathematical model in many non-linear systems. The **Fuzzy Logic Controller(FLC)** do not require a precise mathematical model and controls non-linear time variant systems where an inexact model exists. The Fuzzy control systems are rule based intelligent systems in which a set of fuzzy rules represent a control decision mechanism for adjusting the duty cycle of the converter.

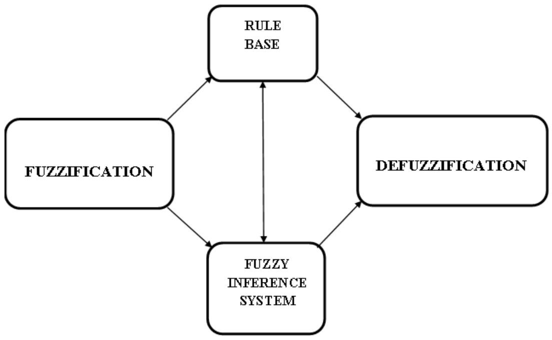

Fig.5 Block Diagram of Fuzzy Logic Controller

It is very useful due to the fact that the human reasoning and thought formation is interconnected very strongly with the ways in which the fuzzy logic is implemented[5]. It is frequently used in stability studies, load frequency control, unit commitment, and to reactive compensation in distribution network and other areas in the area of power system. The most important specifications of fuzzy control method are their fuzzy logical ability in the quality perception of system dynamics and the application of these quality ideas simultaneously for power systems . A simple block block diagram of Fuzzy logic Controller is shown in Fig.5. The Fuzzy logic Controller has 4 important parts i.e. Fuzzy Rule Base, Fuzzification , Defuzzification and Fuzzy Inference System as shown in the Fig.5.

The Fuzzy Control Rule Base with Fuzzy Sets or Data Base is combinedly known as Knowledge Base. The fuzzy sets are used to characterize fuzzy control rules and fuzzy data manipulation in an FLC. The correct choice of the membership functions of a term set plays an essential role in the success of an application as the concept of the fuzzy set is subjectively defined and based on experience.

The fuzzy rule base is simply consists a set of IF – THEN rules. The main principle of If –Then Rule is "IF a set of conditions are satisfied; THEN a set of consequences are inferred". The collection of fuzzy control rules that are expressed as fuzzy conditional statements forms the rule base of FLC. The choice of linguistic variables and their membership function have a strong influence on the linguistic structure of an FLC[5]. The linguistic variables mainly are the state, state error, state error derivative, state error integral, etc. in Fuzzy Logic Controller. There are four models of implementation of fuzzy control rule.

- The experience and knowledge of an expert is very useful to implement the fuzzy rule.
- The control actions of the operator can be modelled to implement fuzzy rule.
- The fuzzy model of a process can be used to implement fuzzy rule.
- The self-organized fuzzy controllers also can be used to implement fuzzy rule.

The human decision making based on fuzzy concepts and of inferring fuzzy control actions using fuzzy implication and the rules of inference in fuzzy logic is simulated by the Fuzzy Inference System. It is the main

part of the Fuzzy Logic Controller. It handles the rule inference where human experience can easily be injected through linguistic (If-Then) rules.
The Defuzzification converts the range of values of output variables into corresponding universes of discourse by performing Scale Mapping. It transforms the fuzzy control actions to continuous (crisp) signals, which can be applied to the physical plant .

Sliding-mode control is the extension of the properties of hysteresis control to multi-variable environments. The Sliding Mode Control can be applied to any Variable Structure Systems (VSS). According to the switching condition; the DC-DC converters have different structures which lead them into VSS. The sub-topologies are derived based on the switching. This motion of the system representative point along a trajectory, on which the structure of the system changes and which is not part of any of the substructure trajectories, is called the sliding mode and the switching surface is called the sliding surface. On the existence of the sliding mode ; the performance of the resultant system is independent of the sub-topologies and it depends only on the control law. The Existing Condition , Hitting Condition and the Stability Condition must be ensured by the Sliding Surface. In Existence condition, the system trajectories near the surface (in both the sub-topologies) are directed toward the sliding surface. In Hitting condition, the sliding surface must be reached by all the system trajectories irrespective of their initial status of the system. In the stability condition, the system under sliding mode should operate in the stable point.
The state-space average model of the converter is used in the mathematical expressions of the Sliding Mode Control. Let us consider a Single Input Single Output system which is controlled by a switch, the state space average model of the system is represented by ;

$$\dot{x} = Ax + B\sigma + G \tag{15}$$

Where; σ is the switch status,
A,B,G are state matrices,
x is the vector of state variable errors.

$$x = v - V^{*} \tag{16}$$

Where; v is the state variable vector and V^{*} is the vector of their DC references
The sliding surface can be a line, plane or any surface. So we can consider a hyper plane as a sliding surface which is expressed as,

$$\Psi = K^{T} x \tag{17}$$

Where ; K^{T} is the sliding surface,
Ψ is the vector of the sliding coefficients
When the sliding coefficients are selected properly, the advantages of the Sliding Mode Control such as fast response, high control robustness, stability, order reduction, etc., can be achieved in any operating condition. In mathematical terms, the existence condition is expressed as ;

$$\frac{\partial \psi}{\partial t} = K^{T} Ax + K^{T} G < 0; (0 < \psi < \varepsilon) \tag{18}$$

$$\frac{\partial \Psi}{\partial t} = K^{T} Ax + K^{T} B + K^{T} G > 0; (-\varepsilon < \Psi < 0) \tag{19}$$

Here the switch is kept on when Ψ is negative and off when Ψ is positive, where **ε** is a small positive quantity. When the existence condition is satisfied, then the hitting condition can be achieved by the expression,

$$K^{T} A_4 \leq 0 \tag{20}$$

Where; A_4 is the 4-th column of matrix A.
In order to maintain the sliding surface near zero, a hysteresis block is used in the control circuit. In practice, an additional hysteresis block is used to prevent the system from input over-current. The existence condition and the hitting condition expressions have inequalities which shows the degree of freedom in choosing the sliding coefficients[6].
For an ideal sliding mode operation, the switching frequency is infinite. Practically it is not possible to attain infinite switching frequency. In order to make the system work in a finite switching frequency, the equivalent control method is utilized in the sliding mode operation of a converter. The stability condition has to maintain the system RP in the sliding surface, this condition is given by the expression as in;

$$\Psi = 0 \tag{21}$$

The equivalent control method replaces σ by σ_{eq} so that the system equation becomes,

$$\dot{\Psi} = K^{T}(Ax + B\sigma_{eq} + G) = 0 \tag{22}$$

From this equation; expression for σ_{eq} is derived;

$$\sigma_{eq} = -(K^{T} B)^{-1}.[K^{T} Ax + K^{T} G] \tag{23}$$

Substituting σ_{eq} in equation (15)

$$\dot{x} = [1 - B(K^{T} B)^{-1} K^{T}].(Ax + G) \tag{24}$$

The system Eigen values are calculated as a function of coefficients K^{T} . To find the solutions the Eigen values should have negative real part and suitable damping factor. In practice, several solutions are found, those values ensuring the stability, robustness and good dynamic response are selected.
For second order control $K^{T} = [K_1 0 \; 0 \; K_4]$, here also one of the coefficient is assumed as one. Here two of the coefficients are zero and one of it is one making the calculation simple and easy.
The state space equations of a SEPIC converter from equation (24) ;

$$L_1 \frac{di_1}{dt} = -(1-u)(V_1 + V_2) + V_S \tag{25}$$

$$L_2 \frac{di_2}{dt} = uV_1 - (1-u)V_2 \tag{26}$$

$$C_1 \frac{dV_1}{dt} = (1-u)i_1 - ui_2 \tag{27}$$

$$C_2 \frac{dV_2}{dt} = (1-u)(i_1 + i_2) - \frac{V_2}{R} \qquad (28)$$

Where; i_1, i_2, V_1, V_2 are State Variables

V_S is the Source Variable and u is the Control Variable.

The second order Sliding Mode Controller is implemented and the results are shown.

The state reference values should be calculated, whenever the source or load or reference value is changed. This drawback can be overcome by using the **PI + SMC** together in the system.

In this technique, the output of the PI controller is added with the feed forward signal and given as the current reference for the Sliding Mode Control. PI controller eliminates forced oscillations and steady state error resulting in operation of P controller. It has a negative effect on speed of the response and overall stability of the system[6]. The PI controller operates based on the expression,

$$i_{pi} = K_P e_t + K_I \oint e_t dt \qquad (29)$$

The K_p and K_I values are to be calculated. These values should keep the system stable. In order to calculate PI gains; Routh-Hurwitz Stability criterion and root locus methods are used.

The Routh-Hurwitz criterion is given by;

$$\begin{array}{llll} q^4 & a_4 & a_2 & a_0 \\ q^3 & a_3 & a_1 & 0 \\ q^2 & h_1 & h_2 & 0 \\ q^1 & h_3 & 0 & 0 \\ q^0 & h_4 & 0 & 0 \end{array} \qquad (30)$$

Where $h_1 = \frac{a_3 a_2 - a_4 a_1}{a_3}$ (31)

$$h_2 = 0 \qquad (32)$$

$$h_3 = \frac{h_1 a_1 - a_3 h_2}{h_1} \qquad (33)$$

$$h_4 = a_0 \qquad (34)$$

For stable system $a_4 > 0, a_3 > 0, h_1 > 0, h_3 > 0, h_4 > 0, a_4 > 0$

The K_p range can be obtained by solving $a_3 > 0$ and the K_I value can be obtained by solving $h_4 > 0$. The numerical methods is used to find the solutions to $h_1 > 0$ and $h_3 > 0$.

There are many solution for K_p and K_I values, in order to find the exact value, root locus method is used. By keeping K_p constant and K_I varying or vice versa the constant values are found and used for stable operation. When either K_p or K_I is fixed and the other one varies, the poles which are closer to the imaginary axis are removed and the ones move away from the imaginary axis are chosen. Therefore, if K_p is fixed, K_I with a value in the mid-range may be selected and vice versa.

The values of K_p and K_I in their mid-ranges are preferred. In this way, the four poles could be in the moderate positions so that no pole is too far or too close to the imaginary axis. Ideally, the four real and negative poles are desired so that the system response has no oscillation or overshoot. The values of these poles affect the zeros and thus the phase behaviour. The feed forward signal uses the equilibrium points. The current i_1 at the equilibrium point is taken as the feed forward signal. The current i_1 at equilibrium point is denoted by i_{1a}. The Sliding Mode Control here used is first order control which uses only the current signal. The reference current is the sum of PI signal and feedback signal,

$$i^* = i_{1a} + i_{pi} \qquad (35)$$

The existence condition of the sliding mode is derived using the Lyapunov function. After deriving the existence condition, the equivalent control method is used. This method makes the discontinuous control σ into continuous control σ_{eq}. The equation for σ_{eq} is derived using the sliding surface. The sliding surface $\Psi = 0$, which means that the derivative of the sliding surface is also zero, $\dot{\Psi} = 0$. Using this condition σ_{eq} is derived and substituted in the state equation of i_1.

V. SIMULATION RESULTS AND DISCUSSION

A. SEPIC with PI and PID Controller

The closed loop configuration of SEPIC with PI controller is implemented and the output voltage is controlled by PI controller. The fig.6 and 7 shows the output voltage waveform of SEPIC with PI controller and fig. 8 and 9 shows the output voltage waveform of the PID controller.

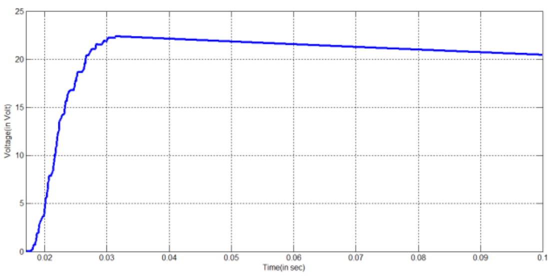

Fig.6 Output Voltage Response of SEPIC with PI Controller in Boost Mode

It can be observed that the settling time is good. It reduces the steady state error greatly due to the presence of an Integrator.

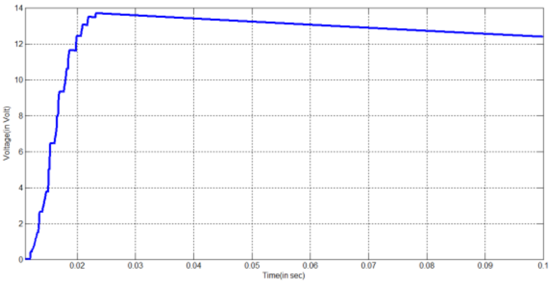

Fig.7 Output Voltage Response of SEPIC with PI Controller in Buck Mode

It bucks or boosts the input voltage according to the reference value given to the PI controller. As the settling time is more, the system response is sluggish.

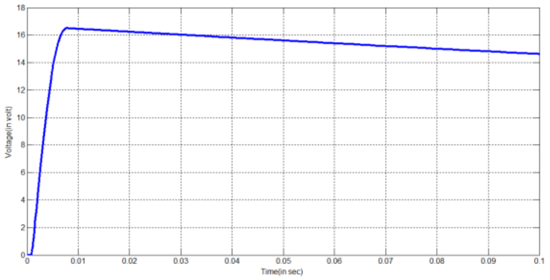

Fig.8 Output Voltage Response of SEPIC Converter with PID Controller in Boost Mode

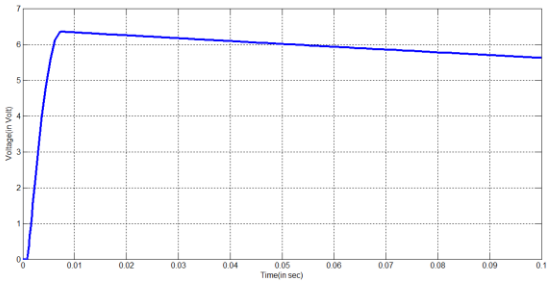

Fig.9 Output Voltage Response of SEPIC Converter with PID Controller in Buck Mode

B. SEPIC with Fuzzy Logic Controller

The closed loop configuration of the SEPIC with fuzzy logic is implemented. Here MAMDANI method is used as fuzzy inference system. This method is performed by using four steps i.e. Fuzzification , Defuzzification, Rule Base and aggregation of rule outputs as stated above in the section IV. The error and change in error are taken as the inputs for fuzzy controller.

The input variables of the FLC are the output voltage error $e(n)$ and the change of this error $\Delta e(n)$. The output of the FLC is the duty cycle of $d(n)$ of the PWM signal, which regulates the output voltage. Fig. 7 and Fig.11 show the membership functions of the inputs and the 3 - D control surface of the FLC. The triangular membership functions are used for the FLC for easier computation. A five-term fuzzy set, i.e., negative big (N-II), negative small (N-I), zero (Z), positive small (P-I), and positive big (P-II), is defined to describe each linguistic variable[4].

The fuzzy rule base matrix is given in table 1.

Δe \ e	N-II	N-I	Z	P-I	P-II
N-II	N4	N4	N4	N3	Z
N-I	N4	N2	N1	Z	P3
Z	N4	N1	Z	P1	P4
P-I	N3	Z	P1	P2	P4
P-II	Z	P3	P4	P4	P4

Table 1 Fuzzy Rule Base Matrix

The membership functions of the output variables are nine term fuzzy sets with classical triangular shapes, i.e., negative very big (N4), negative big (N3), negative small (N2), negative very small (N1), zero (Z), positive very small (P1), positive small (P2), positive big (P3), and positive very big (P4). The Mamdani fuzzy inference method is used for the proposed FLC, where the maximum of minimum composition technique is used for the inference and the centre-of-gravity method is used for the defuzzification process[4].

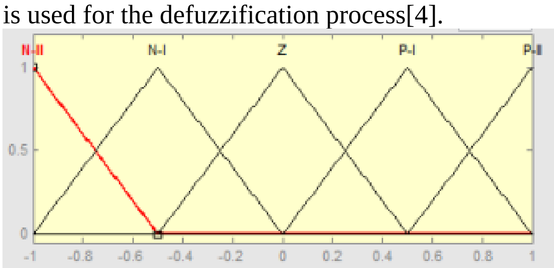

Fig.10 Membership function of Fuzzy logic controller

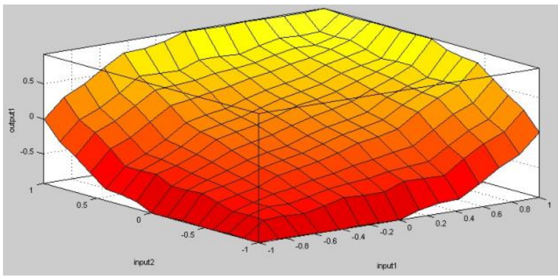

Fig.11 3-dimensional control surface corresponding to the membership functions and rules for Fuzzy Logic Controller

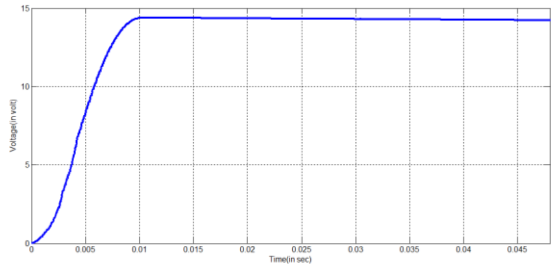

Fig.12 Output voltage response of SEPIC with Fuzzy Logic Controller in Boost Mode

Here the time required to settle down the response is very less as shown in the Fig. 12.
It provides faster system response than PI controller.

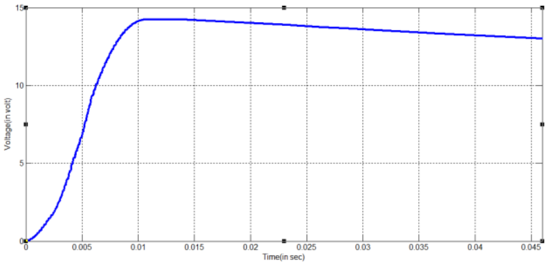

Fig.13 Output voltage response of SEPIC with Fuzzy Logic Controller in Buck Mode

C. SEPIC with Sliding Mode Controller

The sliding coefficients and the reference values are the main parameters in Sliding Mode control. The concept of input power equal to output power is used in second order control of Sliding Mode Control for calculating the reference current. The reference voltage is also taken into consideration. In this control also high pass filter is used. The high pass filter is used only for the sliding surface current error. The output voltage error is directly given to the gain and then to a hysteresis control. The second order control limits only the output voltage and the input current. The complexity in calculating Sliding coefficients is reduced in second order control. The simulation result of SEPIC with Sliding mode coefficient is shown in the Fig.14 and Fig.15.

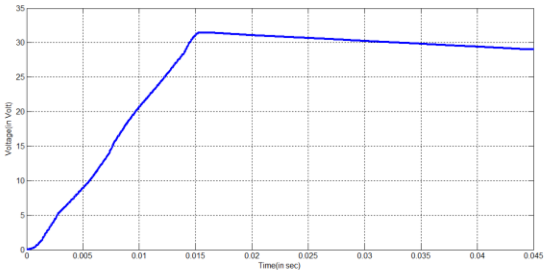

Fig.14 Output Voltage Response of SEPIC Converter using Sliding Mode Controller in Boost Mode

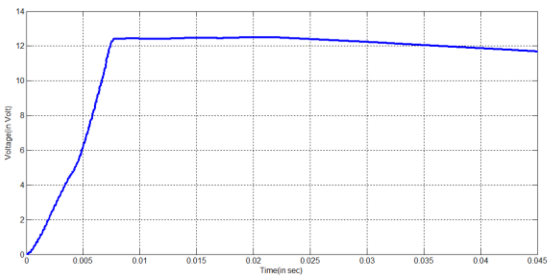

Fig.15 Output Voltage Response of SEPIC Converter using Sliding Mode Controller in Buck Mode

It has good dynamic response and less complexity. Here the calculation of sliding coefficient is easy due to consideration of two state variables.

E. SEPIC with PI and Sliding Mode Controller

The Sliding Mode Control used in this technique is the first order Sliding Mode Control. Only the input current is controlled using Sliding Mode Control. The output voltage measured and compared with the reference voltage, the error signal is given to the PI controller. The reference voltage is feed forwarded and the output of the feed forward signal is added with the output of the PI controller. The added signal is considered as the reference current and it is compared with the actual current or measured current. The current error is given to the Sliding Mode Controller which controls the switch in the SEPIC converter. The reference current is the sum of feed forward output and PI controller output. The feed forward output value is the source current at its equilibrium point. The Simulation result of SEPIC with PI + SMC is shown in Fig.16 and Fig.17.

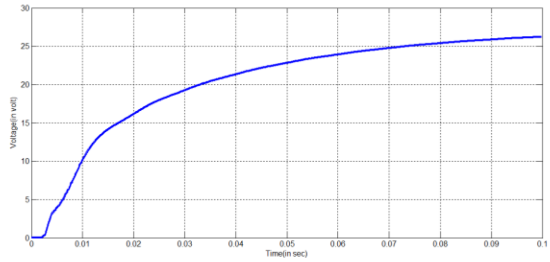

Fig.16 Output Voltage Response of SEPIC Converter with PI + SMC in Boost Mode

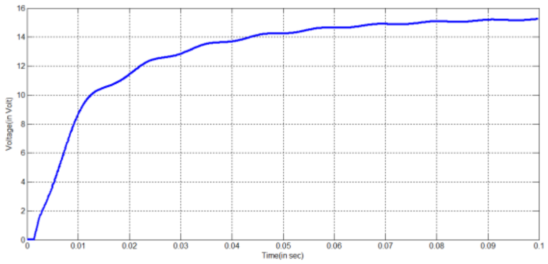

Fig.17 Output Voltage Response of SEPIC Converter using PI + SMC in Buck Mode

Here the output reference is the only state reference. Even though the dynamic response of the output is slower than that of sliding mode control, the control can be implemented without changing the state reference when there is any change in the source or load or in the reference value. If there is any perturbation in the source or load the current reference is calculated directly by the controller. The current reference is generated by the feed forward and PI controller even before there is any change in the output. The PI gain calculation is more straight-forward and not as tedious as the calculation of sliding coefficients.

VI. Comparison between Various Control Strategies of SEPIC Converter

The SEPIC Converter is implemented with various control strategies like PI, PID, SMC, PI with SMC and FLC in step up and step down mode.

Controllers	Rise Time (in sec.)	Settling Time (in sec.)
PI	0.018	0.09
PID	0.003	0.09
SMC	0.022	0.07
PI+SMC	0.041	0.09
Fuzzy	0.014	0.021

Table 2 Comparison Table between Various Control Strategies

The table 2 shows the comparison between the implemented control strategies of SEPIC converter in the Step up mode. The rise time and settling time of all the control strategies are shown in the above table. From the above table it is observed that the FLC has good rise time and settling time as compared to others.

VII. CONCLUSION

The design and implementation of SEPIC converter is done. The closed loop configuration of SEPIC converter is simulated with PI Controller, PID Controller, Fuzzy Logic Controller, Sliding Mode Controller and PI with Sliding Mode Controller. The result are shown and discussed successfully.

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