CHAPTER 1

INTRODUCTION

1.1 POWER ELECTRONIC CONVERTERS

In the present scenario, the need for regulated and efficient power supplies has been increasing day by day. Power electronic converters are the system of electrical circuits which convert the electrical power from one level of voltage or current to the desired level by using semiconductor based electronic switches. The main feature of the power electronic converters is the static switches (MOSFET or IGBT etc.) present in them. These switches operate in either of the two distinct states, namely ON or OFF condition. Power electronic converter applications have rapidly been expanded in many sectors in the society. The surge is due to a number of factors such as the advancement of technology in electronics, fast growth of semiconductor industries and availability of lighter weight and smaller size power electronic devices. The present day electronic equipments are more sensitive to supply disturbance. Hence the DC power supply in the electronic equipments has to produce regulated output with fast response and it has to be less sensitive to change in parameters and change in load, etc. Hence, to get the desired performance, it is essential to control the above DC power supply using feedback controllers. The design of feedback controllers for the DC power supply has to be efficient and effective to achieve better performance.

1.1.1 DC-DC Converters

Most of the industries and consumer electronic equipments require constant DC power supplies. DC-DC converters, such as buck, boost, fly back, Single Ended Primary Inductor Converter (SEPIC) and Cuk converter have long been attractive and often chosen for implementing simple, low cost and low power DC power supplies. The use of a single active switch with relatively simple control circuit is a valid reason for the choice of these converters. Later, DC-DC converters have created significant attention towards their implementation. It is found that DC-DC converters have operational problems in control techniques and switching methods to ensure the effective operation because of nonlinearity. DC-DC converters must provide a good interface between the source and load. The DC-DC converters exhibit nonlinear nature due to the switching action of the converters. Hence, proper feedback controllers have to be designed for the DC-DC converters so as to control their output for efficient operation during the input supply and load disturbances and change in the parameters of the converters.

1.2 SINGLE ENDED PRIMARY INDUCTOR CONVERTER

In the mid 1980's, the basic PWM converters used were Buck, Boost and Buck-boost converters. The Buck and Boost converters are dual of each other in topology. In the mid-1970's, a new type of PWM DC-DC converters were developed and the number of basic converters had been increased to four after the mid-1980's. In 1976, a converter namely an isolated Primary Inductance Converter (PIC) was developed. Based on this, Primary Inductance Converter, Bell Labs developed an isolated 'Single Ended Primary Inductor Converter' (SEPIC) in 1977 and in this topology, a transformer was used in the load side. The topology of SEPIC had been developed by replacing the transformer with a single inductor. The advantage of using an inductor than transformer is that the effect of transformer saturation due to DC-DC offset can be eliminated. The dual of SEPIC is the Zeta converter, whose conception was developed in the year 1989.

The unique advantages of SEPIC topology over other topologies are as follows:

1. Either steps up or steps down its input voltage.
2. Produces non-inverted voltage output.
3. Non-pulsating input current reduces the EMI and eliminates the need of input filters for battery sources.
4. Reduced output ripple, high efficiency and high voltage transfer gain.

The SEPIC converter topology represents a fourth order voltage converter corresponding to the four independent energy storage elements. For any switching condition, four independent first order differential equations are required to describe the total behaviour of the SEPIC.

The switch of the SEPIC can be controlled by varying the duty cycle of the gate pulse in order to control the output voltage. Though the SEPIC is like a buck-boost converter, it has the unique feature of giving a non-inverted output. A series capacitor is used to couple the energy from the input to the output. The SEPIC responds quickly to a short-circuit condition and works in a true shutdown mode, when the switch is turned off. The SEPIC transfers energy between the capacitors and inductors, through the switching operation in order to convert the input voltage from one voltage to another. The amount of energy transferred is controlled by changing the duty cycle of the switch which can either be MOSFET or IGBT.

1.2.1 Operating Principle of the SEPIC

The power circuit diagram of the SEPIC is shown in Figure 1.1. It includes DC input supply voltage v_{in}, capacitors C_1 and C_2, inductors L_1 and L_2, switch S (MOSFET), diode D_1 and the load resistance R. It is assumed that the components are ideal and also SEPIC operates in Continuous Conduction Mode (CCM).

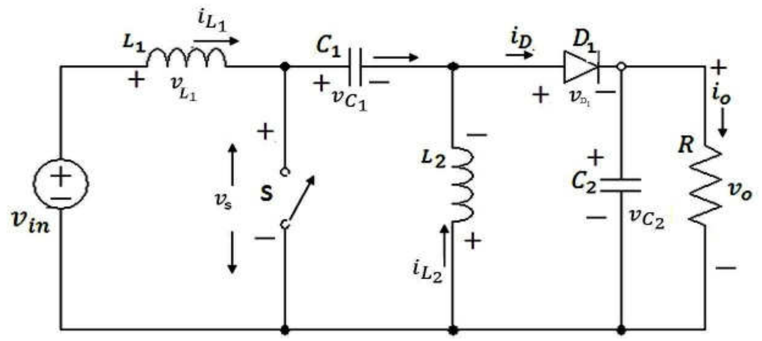

Figure 1.1 Basic SEPIC converter

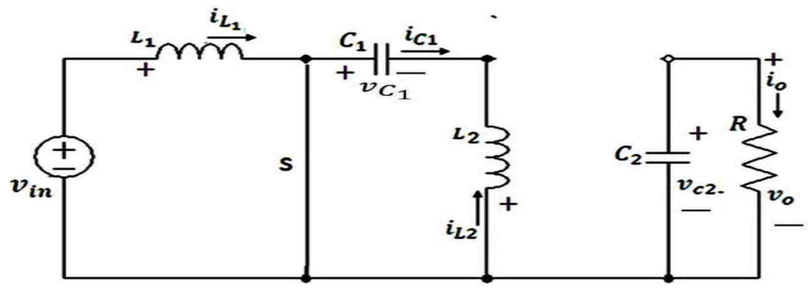

Figure 1.2 SEPIC converter during switch in ON condition

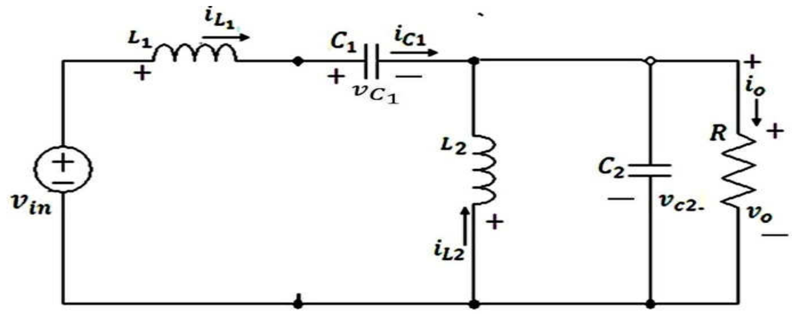

Figure.1.3 SEPIC converter during switch in OFF condition

Figure 1.2 and Figure 1.3 show the modes of operation of the SEPIC. In Figure 1.2, when the switch S is closed, the diode is reverse biased, the inductor L_1 is energised by the source voltage v_{in} , while the L_2 charges the capacitor C_1.The polarity of the inductor current and capacitor is shown in Figure 1.3. The current i_{L_1} increases at the rate given by equation (1.1)

$$\frac{di_{L_1}}{dt} = \frac{v_{in}}{L_1}, 0 \leq t \leq dT \qquad (1.1)$$

$$v_{in} = v_{c_1} \qquad (1.1a)$$

where v_{c_1} is the voltage across the capacitor C_1, d is the duty cycle and T is the switching period. In Figure 1.3, when the switch is open, diode D_1 is forward biased, the inductor L_1 charges the capacitor C_1 and the inductor L_2 charges C_2 . Under this condition, the equations (1.2) and (1.3) are valid.

$$i_{in} = i_{L_1} \qquad (1.2)$$

$$i_{L_2} = i_D = i_o \qquad (1.3)$$

where i_{Da} is the average current of diode D_1 and i_o is output current. When the SEPIC is operating in CCM, the voltage conversion ratio of the SEPIC can be obtained from the volt second balance of the inductor L_1 in one switching period and is given by equation (1.4).

$$\frac{v_o}{v_{in}} = \frac{d}{1-d} \qquad (1.4)$$

where v_o is the output voltage of the SEPIC converter. Even though the behaviour of SEPIC is very attractive, it has been found that the controller design of SEPIC is very complicated since the SEPIC converter is a fourth order non- minimum phase system.

The theoretical analysis of SEPIC is considered to determine the value of capacitors and inductors used in it. The analysis of the waveforms in SEPIC is given in the Figure 1.3a. The MOSFET gate is triggered by squre wave pulse.. The MOSFET is a switching device and when it turns on, the voltage across the MOSFET is zero. When the MOSFET turns off, supply voltage is built up across MOSFET. So, according to on and off condition of MOSFET, a square pulse is obtained across the drain to the source of the MOSFET. When the MOSFET is switched on, inductor L_1 starts charging through the MOSFET. So current through inductor L_1 and MOSFET increases. When the MOSFET is switched off current through L_1 decreases.

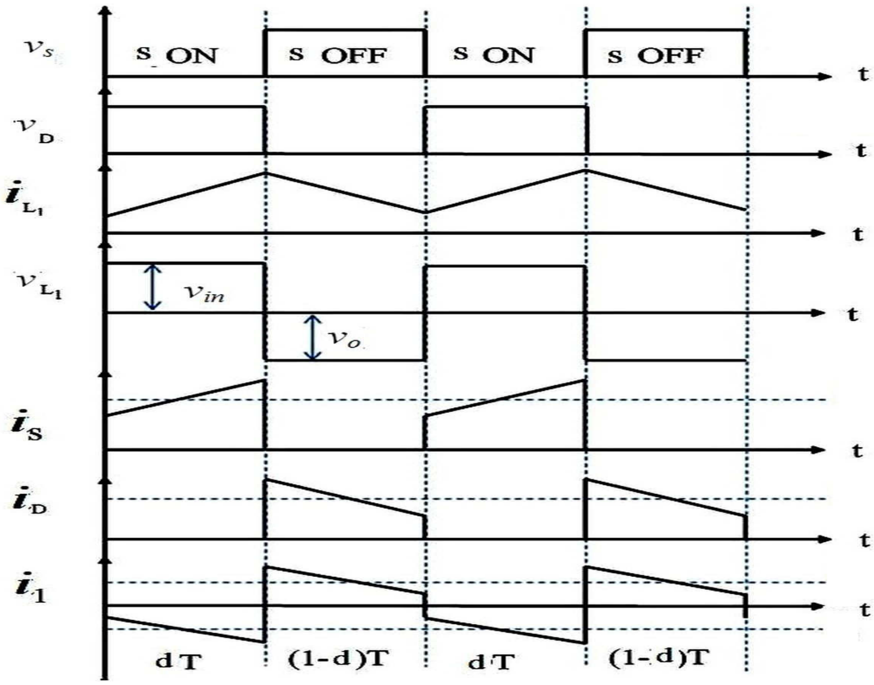

Figure 1.3a Waveforms of different currents and voltages in SEPIC

The diode is the switching device in SEPIC. It gets switched on, when anode voltage is more than cathode voltage. As it is unidirectional one, during MOSFET switched on condition, no current flows through diode as the voltage across the diode is negative. When the MOSFET turns off, coupling capacitor start charging and inductor L_2 is discharging through the diode. So, initially current is at peak value and then current is slowly decreases. When capacitor C_1 starts charging, the current through it gets decreased and when it discharges, the current through it gets increased. In SEPIC, during T_{on} period, capacitor C_1 starts discharging through the inductor, so current in the capacitor starts increasing, but in a reverse direction. So current is negative. During $T_{off,}$ capacitor C_1 starts charging and current is in the forward direction. When the MOSFET is switched on, inductor L_1 is charging through the MOSFET. Hence current through the inductor and the MOSFET is increased to a definite value till the MOSFET turns off. When the MOSFET is off, inductor L_1 current gets decreasing. Current through both the inductors is same as both the inductors charging and discharging simultaneously.

1.3 IMPORTANCE OF THE RESEARCH

The SEPIC converter is an important converter because of the growing applications of DC-DC converters in most of the emerging electronic equipments and consumer electronic equipments which require a DC power supply. The design of the DC power supply varies depending on the type of load and source in electronic equipments. Even though many DC-DC converters are available in the field, the SEPIC converter has unique features like non-inverted output voltage, buck- boost capability and true shutdown mode, etc. SEPIC is largely employed in various applications such as renewable energy conversion, battery chargers, biomedical equipments, AC-DC converters etc. The importance of this research work on SEPIC is to improve the feedback control technique employed in SEPIC so as to enhance its performance.

The development of dedicated controller ICs has led to the improvement of SEPIC converter control. The main work of the feedback control employed in SEPIC is to maintain the output voltage constant at the reference value at any varying operating conditions. Further, in order to improve the performance of the SEPIC, in this research work four feedback controllers are developed, namely Ziegler Nichols tuned PI controller, Neural network tuned PI controller, Fuzzy logic controller and Sliding Mode controller.

In this research work, coupled inductor technique is implemented successfully for the two SEPICs operating in parallel. This implementation reduces the components count and minimizes loss, cost and size. PI controller is used to achieve the desired performance in it. SEPIC is also implemented for solar energy application for low cost with the soft start feature using dedicated controller IC. All the proposed feedback controllers of SEPIC are simulated by using Matlab Simulink. Practical implementation and verification is done for some of the feedback control techniques.

1.4 LITERATURE REVIEW

Research works on the topic relevant to the investigation of Single Ended Primary Inductor Converter (SEPIC) are too numerous and hence, only those important works, which are more related to the present work, are discussed in this section.

1.4.1 Ziegler – Nichols tuned PI Controller for SEPIC Converter

Hren & Slibar (2005) have discussed full order dynamic model of SEPIC converter. Jaafar et al (2013) have identified a procedure to design globally asymptotically stabilizing linear PI controllers for switched power converters including SEPIC.

1.4.2 Control of SEPIC Converter using Neural Network Tuned PI Controller

Tsang & Chan (2012) have proposed a multiloop controller for SEPIC to improve the speed of response in tracking the required current and the effect of load rejection. Instead of designing a single controller for a fourth-order system, the system is decoupled into simple first-order systems and simple proportional plus integral (PI) controllers are designed for the decoupled first-order systems. The PI controllers are then combined to form a multiloop feedback control system. De Melo et al (2010) have developed a modified version of the SEPIC converter for high power factor rectifier suitable for universal line applications.

1.4.3 Fuzzy Logic controller for PV Energy System with SEPIC Converter

Adhikari et al (2011) have made the effort to evaluate the performance of the solar energy conversion system with a SEPIC converter with the maximum power point tracking controller. Veerachary (2005) have developed Maximum Power Point Tracking (MPPT) scheme using a coupled inductor SEPIC converter in photovoltaic generation system.

1.4.4 Sliding Mode Controller for SEPIC Converter

Kalantar & Mousavi (2010) have designed a posicast controller with feedback structure for the SEPIC to deal the overshoot with the system step response and sensitivity to parameter uncertainty and eliminated the above problems in the output response. Sliding mode control of the SEPIC converter has been proposed by Ezhilarasi & Ramasamy (2009) but only two sliding surfaces of inductor current and output voltage are considered in their work. Reduced order averaged modeling of an active clamp SEPIC is discussed by Chen & sen (2006).

1.4.5 Low cost SEPIC based Photovoltaic System for Constant Output Voltage with Maximum Power Point Tracking

In the recent years, many research works have addressed the development of solar energy conversion system. Chiang et al (2009) have developed a SEPIC supplied by a Photo Voltaic (PV) module and the peak current- mode control is applied along with the PV voltage controller and the MPPT controller. Chung et al (2003) have developed a novel technique for SEPIC/CUK to maximize the output power of a solar panel supplying a load or battery bus under varying meteorological condition.

1.4.6 Parallel Operated SEPIC Converter Using Coupled Inductor

Al-Saffar et al (2008) have developed, an improved topology of the SEPIC converter with reduced output voltage ripples. In their work, the voltage conversion ratio characteristics, semiconductor device's voltage and current stresses are characterized. Mazumder et al (2008) have discussed the master-slave load-sharing control of a parallel operated DC-DC converters and by using it, they eliminated the need of physical connection to distribute the control signals among the converter modules.

1.5 RESEARCH GAP IDENTIFIED

From the literature survey, it is identified that more scope is present in developing new control strategies for SEPIC converters. The main complexity of the control arises from the non-linear nature of the SEPIC system due to the presence of semiconductor switch that operate at high switching frequency. The fourth-order nature of the SEPIC converter makes it difficult to control.

The output of the SEPIC is affected by the system parameter variations. To ensure correct operation in the SEPIC in any working condition, a PI control is a more feasible approach. Though the SEPIC is a known converter, it is difficult to control because of the measurement of the full state of the system, is practically often unavailable. The proposed PI controller designed using Ziegler-Nichols method in this work, is simulated using Matlab Simulink and the above PI controller acts as a good alternative to control the SEPIC. In this work, state space model of SEPIC for the study brings out the fact that the application of the PI controller ends up with low steady state error and fast response which is an essential feature of SEPIC converter control.

The major problem identified in the above control is, change in output response when wide variation in output voltage is required. A new method, namely neural network tuned PI controller is used to maintain the stability of the output voltage for a wide range of its reference value. For different reference output voltages , best kp and ki values are identified in the PI controller and then the same data are used for training the neural network.

A new fuzzy logic based stand-alone solar Photo Voltaic (PV) system is implemented which feeds power to supply single phase AC load through a single phase voltage source inverter. The SEPIC provides a constant DC bus voltage. The duty cycle can be controlled by MPPT controller. This fuzzy logic control algorithm can be used to generate the PWM signal for the SEPIC converter to extract maximum power.

The PV system gives the variable output voltage due to temperature and insolation variation with respect to time. Hence a new method has been developed for obtaining constant voltage with MPPT control using simple analog control circuit for SEPIC converter. A soft start feature is implemented in order to withstand any variation in load or input voltage.

The problem of using separate inductors in SEPIC is eliminated by using a single coupled inductors and it shares the same ripple current. In this work, it is found that sharing the load current can be achieved by parallel connected SEPIC topology. It is also noted that two separate inductors require different ripple current but coupled inductor has an advantage of using the same ripple current. The coupled inductors utilize only half of the ripple current than the two separate inductors. In this work, the tightly coupled inductors are used which afford an efficient output than using separate inductors. The analog control circuit is designed to generate PWM signals to fulfil the closed loop control function of parallel operated SEPIC that uses coupled inductors.

1.6 OBJECTIVES OF THE THESIS

The main objectives of the thesis are as follows:

- Control of the SEPIC using a PI controller is implemented as a basic investigation for which the kp and ki values are obtained by the Ziegler Nichols method. The performance of the SEPIC converter under startup, load and line variations is analyzed by doing simulation using Matlab Simulink. The results are verified in the experimental setup.
- Control of SEPIC using neural network tuned PI controller is implemented to give better performance under wide variation in output voltage requirement. The results are verified through simulation using Matlab Simulink.
- Fuzzy Logic based control is developed for a stand-alone solar Photovoltaic (PV) system with the isolated SEPIC converter. This system includes solar panel, Maximum Power Point Tracking (MPPT) controller, a SEPIC converter and a single phase Voltage Source Inverter (VSI). The performance of the SEPIC converter is analysed by doing simulation using Matlab Simulink.
- Control of the SEPIC converter using Sliding Mode Controller (SMC) is done in order to improve the performance of the SEPIC. The SMC is designed using a state space average model. The designed SMC is compared with the Proportional-Integral controller. It is found that the SMC improves the transient and steady state performance of the SEPIC. The performance of the

SEPIC with SMC is verified by doing simulation using Matlab Simulink. An experimental prototype is also developed to verify the results practically.

- A low cost Photo Voltaic (PV) system that uses SEPIC with MPPT control is designed and it gives a constant output voltage even though the temperature and insolation vary with respect to time. The performance of the SEPIC converter is analysed with the simple analog control circuit.
- Two Parallel SEPIC (PSEPIC) converters that use coupled inductors for low voltage application is constructed. This allows sharing of load current with constant output voltage. PI controller is used to control the above converters. The advantages of the proposed converter are less components count, low losses, cost and size. The performance of the PSEPIC is verified by doing simulation and it is verified in an experimental prototype.

1.7 CONTRIBUTIONS OF THE RESEARCH

The main contributions of this research work are summarized as follows:

- Four feedback controllers such as PI controller tuned using the Ziegler Nichols method, Neural network tuned PI controller, Fuzzy Logic controller and Sliding Mode Controller for SEPIC are designed for efficient operation under any varying conditions such as line variation, load variation, parameter variations, and in the steady stage region of operation and their performance are analysed.
- Coupled inductor is used in the two SEPICs operating in parallel, which reduces the component count, size and gives better performance. The two converters share the load current equally.

- SEPIC is implemented for solar energy applications with low cost control circuit that has the soft start feature and MPPT control.

1.8 CHAPTER SUMMARY

In this research work, various feedback controllers are developed for Single Ended Primary Inductor Converter (SEPIC) such as Ziegler Nichols turned PI controller, neural network tuned PI controller, fuzzy logic controller and Sliding Mode Controller. In addition, control of two SEPIC converters that uses coupled inductor and operating in parallel is done. Also a low cost SEPIC for solar energy application with soft start feature along with the MPPT control is developed.

The performances of the proposed feedback controllers for SEPIC are evaluated by doing simulation in Matlab Simulink. Experimental verifications are also done for some of the feedback controllers. Using above feedback controllers, it is determined that it is possible to control the SEPIC under line variation, load variation, parameter variations, and in the steady stage region of operation.

1.9 ORGANISATION OF THE THESIS

The Thesis is organized as eight chapters as follows:

Chapter 1: Discusses the operation of the SEPIC converter and its control requirement.

Chapter 2: Detailed literature survey of existing controllers for the SEPIC converter has been discussed and a proportional integral controller for the SEPIC converter is proposed and that is tuned using Ziegler-Nichols. Its performance is verified by doing simulation using Matlab and experimentally.

Chapter 3: A new method for control of SEPIC converter using neural network tuned PI controller is proposed. It gives better performance when wide variation in reference output voltage is required.

Chapter 4: Fuzzy logic control is applied for the SEPIC converter along with the MPPT control and is implemented for solar energy conversion. The results are verified using Matlab Simulation.

Chapter 5: Detailed literature survey of existing sliding mode controller for the SEPIC converter has been discussed and a new SMC method for SEPIC is proposed. The proposed method is verified using Matlab, Simulink and then it is implemented practically to verify the result.

Chapter 6: Detailed literature survey of solar energy conversion using SEPIC has been discussed and design of a low cost SEPIC based photovoltaic system for constant output voltage with MPPT control is done. This method is implemented in experimental circuit and the results are verified.

Chapter 7: Detailed literature survey of parallel SEPIC converter control is discussed and a new control method for PSEPIC using coupled inductor is proposed. The performance of the feedback controller for PSEPIC is verified for line, load variation and sharing of the load.

Chapter 8: Discussed main advantages of proposed works over the existing works. This chapter also discusses the future scope of the proposed work.