CHAPTER 3

CONTROL OF SEPIC CONVERTER USING NEURAL NETWORK TUNED PI CONTROLLER

3.1 INTRODUCTION

Generally, the input supply given to SEPIC converter is unregulated, which needs to be regulated, Many control methods are developed for the control of SEPIC converter to maintain constant output voltage. SEPIC converters are used in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement which is different from that supplied by the battery or an external supply and often sometimes higher or lower than the supply voltage. Additionally, the battery voltage reduces, as its stored energy is drained. The SEPIC converter offers a technique to increase voltage from a partially lowered battery voltage as it has buck-boost feature.

Williams (2014) has discussed that the identical control can be established by indirectly controlling the ripple voltage, duty cycle of the capacitor, which controls the dc current transfer for DC-DC converters. Kurokawa et al (2009) has presented a new control method of the forward type multiple-output DC-DC converter with both a PID feedback and a new feed forward control and the dynamic characteristics of DC-DC converter have been found.

Veerachary et al (2003) have used an off line tuned neural network to adjust the duty cycle of the switch in boost converter. Wai & Shih (2012) have designed an adaptive fuzzy neural network control scheme for the voltage tracking control of conventional DC-DC boost converter.

Mahdavi et al (2005) have presented an output feedback neural controller for the implementation of sliding mode controller of DC-DC converter. They have achieved the fastest dynamic behavior of the converter with low cost.

Babaei et al (2014) have designed a method for finding the equivalent inductance and capacitance of the SEPIC. The relations of the output voltage ripple of the SEPIC converter are obtained in various conduction modes. Kwon et al (2006) have proposed SEPIC converter which operates in CCM with low reverse recovery time. It reduces the reverse recovery loss of the diodes and improves the power efficiency

The SEPIC configuration of non isolated high step-up conversion technique finds increasing applications, such as electric vehicles, Uninterrupted Power Supplies (UPS), High-Intensity Discharge (HID) lamp, fuel cell system, and photovoltaic systems. The SEPIC converters have wide range of applications in renewable energy, power factor correction, SMPS supply, etc. as given by Park et al (2010). The utilization of conventional AC-DC power supply has faced the drawback of current distortion and low power factor. Many portable electronic applications could benefit from a SEPIC power converter, as it is able to achieve high efficiency across wide input and output voltage ranges at a small size as discussed by Hu et al (2012). A modified version of the SEPIC converter has been discussed for implementation of a high-PF rectifier suitable for universal line application by De Melo et al (2010).

Low voltages, high currents, and fast load transients are emerging challenges in power delivery for high-performance digital electronic circuits.

Power converters for these applications need to have a fast response, high efficiency, and a small size as discussed by Al-Saffar et al (2008). Most active Power Factor Control (PFC) circuits and Switched-Mode Power Supplies (SMPSs) in the market today comprise a front-end bridge rectifier as discussed by Sabzali et al (2014). One of the most important applications of SEPIC converter is in renewable energy systems such as autonomous wind-solar hybrid power generation system as discussed by Kalantar & Mousavi (2010). In this chapter, a Neural Network tuned PI controller is developed for SEPIC and its performance are compared to PI Controller.

3.2 ARTIFICIAL NEURAL NETWORK

The control system proposed for the control of SEPIC in this chapter is based on a neural network. The term neural network was traditionally used to refer to a network or circuit of biological neurons. The modern usage of the term often refers to Artificial Neural Network (ANN), which is composed of artificial neurons or nodes.

ANN is a computational model that is developed based on the biological neural networks. An ANN is made up of artificial neurons, which are connected with each other. Typically, an ANN adapts its structure based on the information coming to it. A set of systematic steps called learning rules needs to be followed when developing an ANN. Further, the learning process requires learning data to discover the best operating point of the ANN. ANNs can be used to learn an approximation function for some observed data. The learning process becomes harder, when complex models are used unnecessarily. The model has to be carefully selected depending on the data. Choosing the correct learning algorithm is also important, since some learning algorithms perform better with certain types of data.

Artificial neural networks are algorithms that can be used to perform nonlinear statistical modeling of a system and provide a new alternative to logistic regression. Neural networks offer a number of advantages, including requiring less formal statistical training, ability to implicitly detect complex nonlinear relationships between dependent and independent variables, ability to detect all possible interactions between predictor variables, and the availability of multiple training algorithms. Disadvantages include its 'black box' nature, greater computational burden, proneness to over fitting, and the empirical nature of model development.

3.3 CONTROL METHODS FOR SEPIC

Control techniques adopted for a SEPIC converter are introduced in various works. SEPIC converter is very difficult to satisfy both high voltage conversion ratio and high efficiency at once. This is primarily due to the parasitic resistances, which cause serious degradation in the step-up ratio and efficiency, as the operating duty increases. Moreover, in high output voltage applications, a high-voltage rating diode causes a severe reverse recovery problem, which requires a snubber circuit. As a result, a general boost converter would not be acceptable for high step-up applications. To overcome these limitations, various types of step-up converters, utilizing the voltage conversion ability of a transformer, a coupled-inductor, and a multiplier cell, have been adapted by Park et al (2010). The control strategy employed is an ON–OFF control scheme, in which switch of the converter is gated ON and OFF to control the average power delivered to the output. The frequency, at which the converter is modulated ON and OFF, is much lower than the converter switching frequency. Hu et al (2012) explained that, the power stage components of SEPIC converter are sized for very high switching frequency, while the converter input and output filters are sized for the lower modulation frequency.

The control algorithm for the SEPIC converter is based on the classical structure of the average current-mode control with the digital implementation and the converter operate in continuous conduction mode. The implementation of the control system for the SEPIC converter is accomplished by using exactly the same control designed for the classical boost converter. This method is adapted to obtain the high power factor rectifier for universal voltage applications as discussed by De Melo et al (2010). Al-Saffar et al (2008) have explained that while implementing an active-clamping to the SEPIC offers several important advantages such as lower voltage stress on the main power switch, reduced Electro Magnetic Interference (EMI) and improved conversion efficiency.

In order to control a SEPIC converter, several controllers are used such as classical PID and Posicast controllers. The Posicast controller improves the steady state performance and damp resonant behavior of responses. It causes that gain parameter of the controller to be easily determined and sensitivity to parametric uncertainty and load change have been reduced.

Furthermore, Posicast control is given within a feedback system and utilized to damp oscillations in lightly damped control systems as discussed by Kalantar & Mousavi (2010). To improve the speed of response in tracking the required current and the effect of load rejection, a multi loop controller design is proposed for the SEPIC converter. Instead of designing a single controller for a fourth-order system like SEPIC, the system is decoupled into simple first-order systems. Simple PI controllers are designed for the decoupled first-order systems. The PI controllers are then combined to form a multi loop feedback control system as proposed by Tsang & Chan (2012). Small-signal and steady-state modeling are vital in designing the closed-loop control and to determine the required parameters of the SEPIC converter.

3.4 CONTROL SYSTEM

The control system proposed in this work is based on a neural network. The term neural network has traditionally been used to refer to a network or circuit of biological neurons. The modern usage of the term ANN often refers to artificial neural networks, which comprise artificial neurons or nodes. An Artificial Neural Network, often called as neural network is a mathematical model inspired by biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases, a neural network is an adaptive system that changes its structure during a learning phase. Neural networks are used to model complex relationships between inputs and outputs or to find patterns in data. The structure of neural network is shown in Figure 3.1.

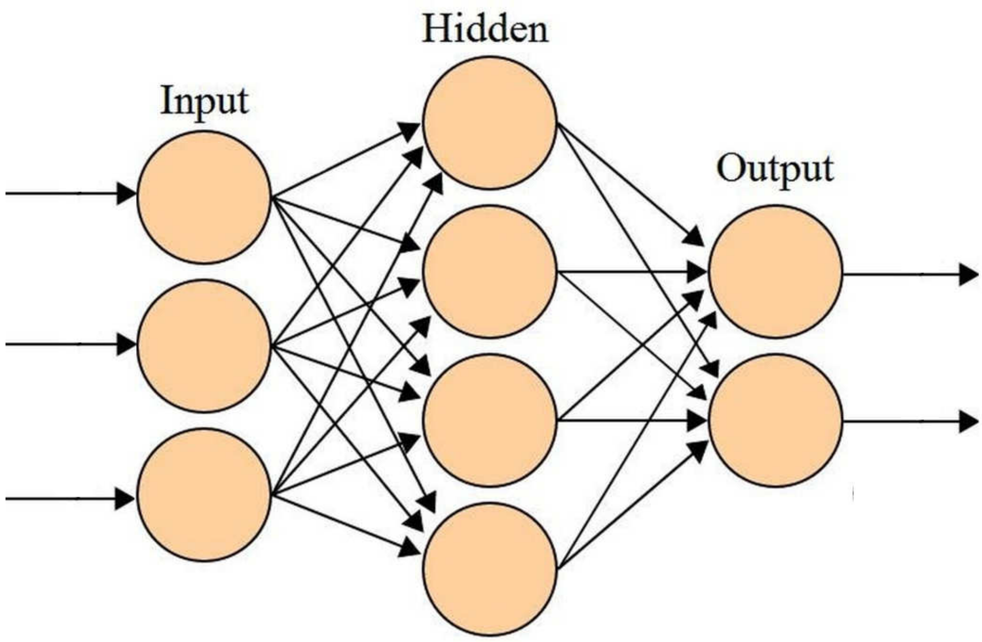

Figure 3.1 ANN structure

ANN is typically defined by two types of parameters namely, the interconnection pattern between different layers of neurons, the learning process for updating the weights of the interconnections The activation function in the neuron converts a neuron's weighted input to its output.

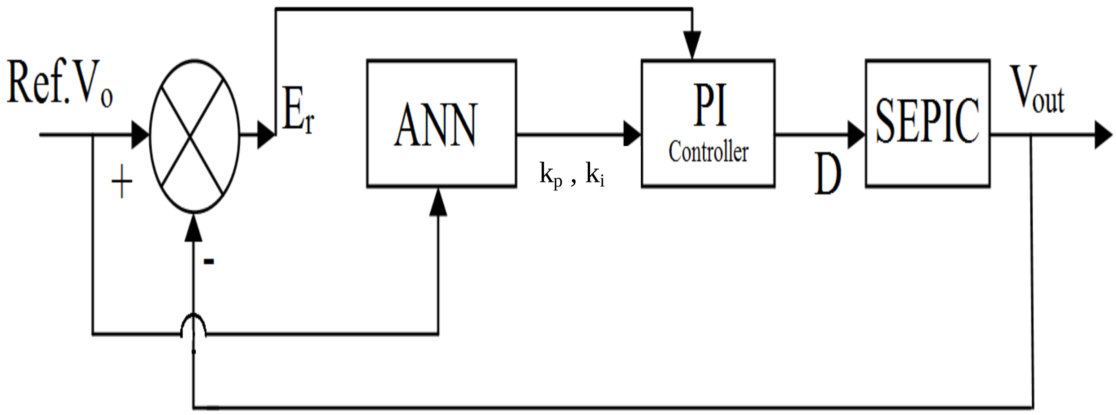

Figure 3.2 Closed loop control of SEPIC

The simplified block diagram of neural network tuned PI controller for SEPIC to get the required output voltage is shown in the Figure 3.2. The actual output voltage is compared to the reference output voltage V_{ref}. The error signal E_r is obtained and is applied to the Neural Network tuned PI controller or PI controller. The output signal from the controller is applied to the power switch as gating signal .The neural network is trained with the best k_p and k_i values of the PI controller for various reference output voltages of SEPIC. Control algorithm developed using a neural network tuned PI controller makes the output voltage to vary from the low value to maximum value.

The results obtained by using PI controller and NN tuned PI controller for SEPIC by doing simulation are compared. The Neural network tuned PI controller has given more improvement in achieving the output voltage. The load resistance is made constant in both the system. The input voltage is also maintained constant and required output voltage is set at the desired level.

3.5 SIMULATION RESULTS

The specification of simulated SEPIC converter is given in Table 3.1. The simulation diagram which is developed to verify using the operation using Matlab simulink is shown in Figure 3.3.

Table 3.1 Specification of SEPIC converter

S. No	Components/Parts	Value
1	Inductance L_1	500mH
2	Inductance L_1	500mH
3	Capacitor C_1	660µF
5	Capacitor C_2	500µF
6	Input voltage	230µF

The PI controller is used in this work . Here, the simulation circuit consists of the bridge rectifier to supply DC to the SEPIC converter. The supply is 230 V, 50 Hz AC. It is rectified by a diode bridge rectifier and the output dc voltage is given to SEPIC. The circuit has two inductances L_1 and L_2, two capacitors C_1, and C_2, switch IGBT and diode D. The load is maintained constant at R at 160 ohm. . The PI controller is used to vary the duty cycle of the IGBT. The AC input voltage is shown in Figure 3.4. The k_p and k_i values are varied by trial and error method in the PI controller and the best k_p and k_i that give good performance are noted for various reference output voltages .The output voltage when the reference is set at 250 V is shown in Figure 3.5 while using PI controller . The output voltage settled at t = 40ms. The best k_p and k_i values are given Table 3.2.

Neural Network tuned PI controller for SEPIC converter is implemented in Matlab simulink as shown in Figure 3.6. The neural network is trained using the data available from Table 3.2 by using the neural network tool box in Matlab. The AC voltage source with full bridge rectifier is connected to the input of the converter. The output can voltage range from $50V_{DC}$ to 260 V_{DC}. In order to compare the performance of both controllers during step change in reference output voltage, the following procedure is done. Initially, at time t = 0, the output voltage is set at 150V while using PI controller, the steady state output error is 1.5V. But neural network tuned PI controller gives a steady state output error of 0.1V which is shown in Figure 3.8. At time t = 5ms, output reference voltage is changed to 250V. Now, the PI's steady state output error is 1.4V and neural network tuned PI controller gives a steady state output error of 0.2 V. Thus, the neural network tuned PI controller gives less steady state output error and low settling time, when compared with that of the PI controller at different output voltages.

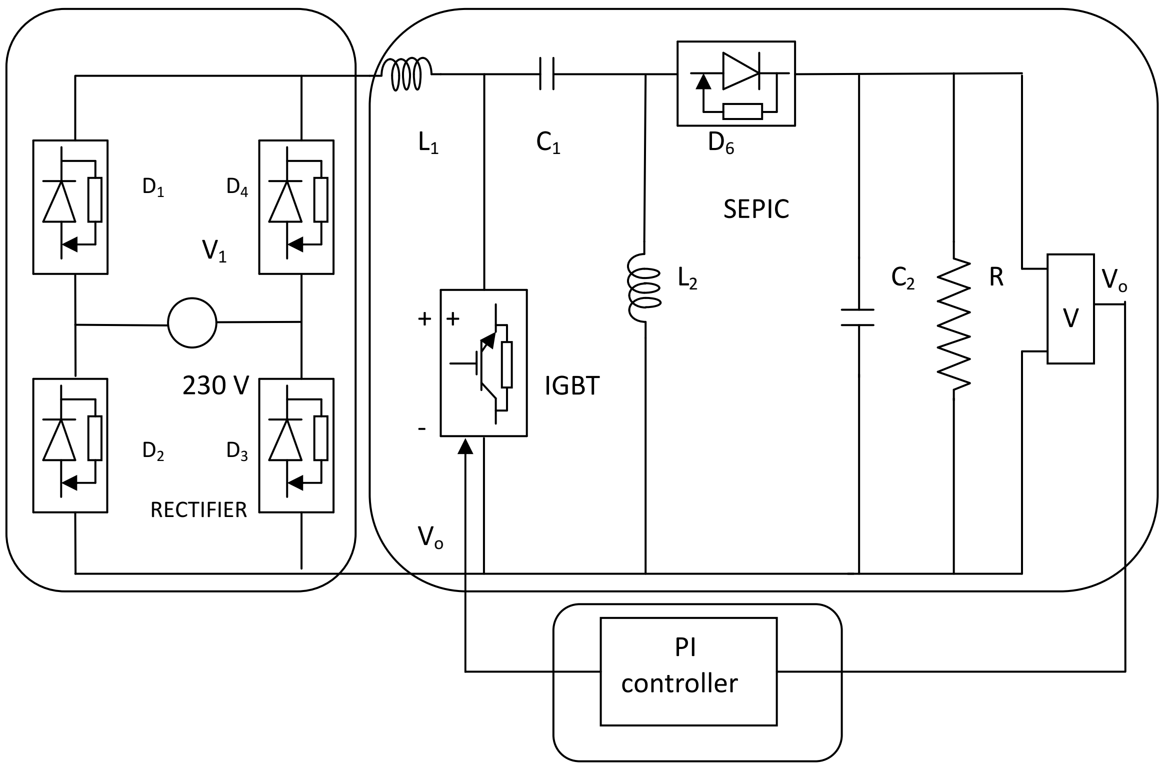

Figure 3.3 Simulation Circuit for SEPIC converter with PI controller

Table 3.2 Sample kp and ki values

Sl. No	k_P	k_i	DC Output Voltage (V)
1	11	1	260
2	11	1	250
3	8	0.5	220
4	5	0.5	190
5	6	1	160
6	5	1	160
7	5	1	100
8	16	0	70
9	18	0	60
10	28	0	50

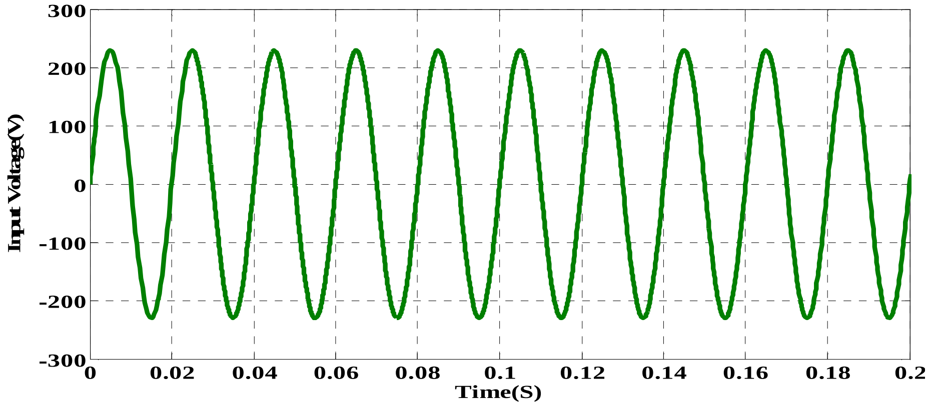

Figure 3.4 AC input to the rectifier

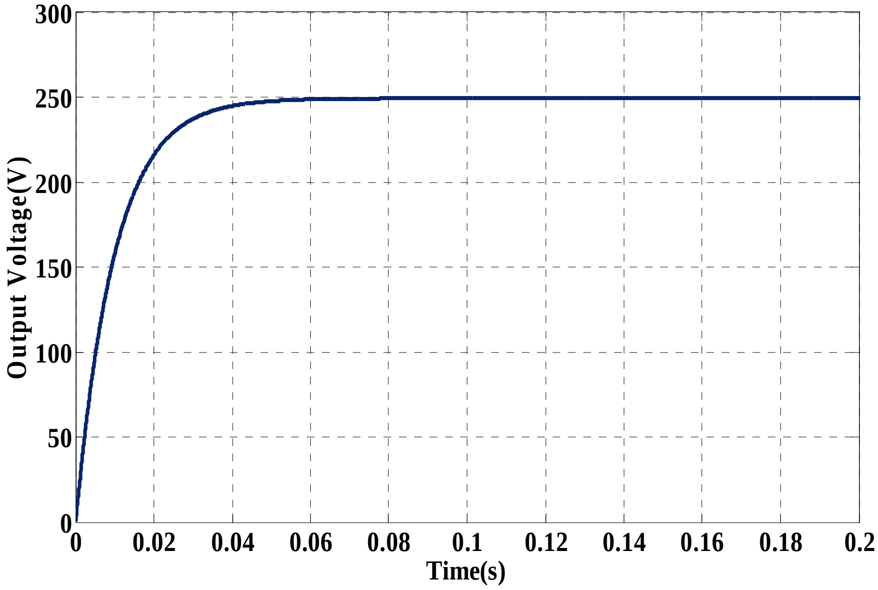

Figure 3.5 SEPIC output voltage using PI controller

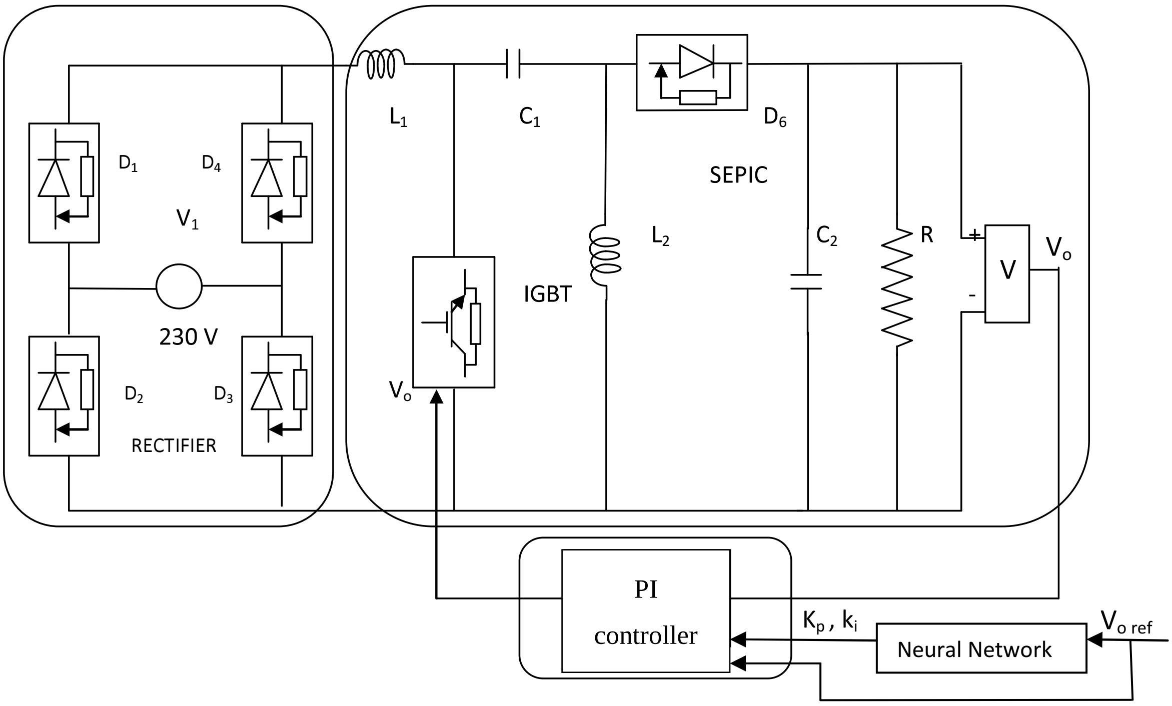

Figure 3.6 Simulation circuit for SEPIC Converter with NN tuned PI controller

It is found that the NN tuned PI controller exhibits better output than PI controller. From the Figure 3.7, it is found that the output voltage is maintained constant and there is a better steady state condition than PI controller. The time needed to reach the reference value is 0.003s in NN tuned PI controller where as in PI controller is 0.04s.and hence, the NN tuned PI controller improves the performance of the SEPIC converter control.

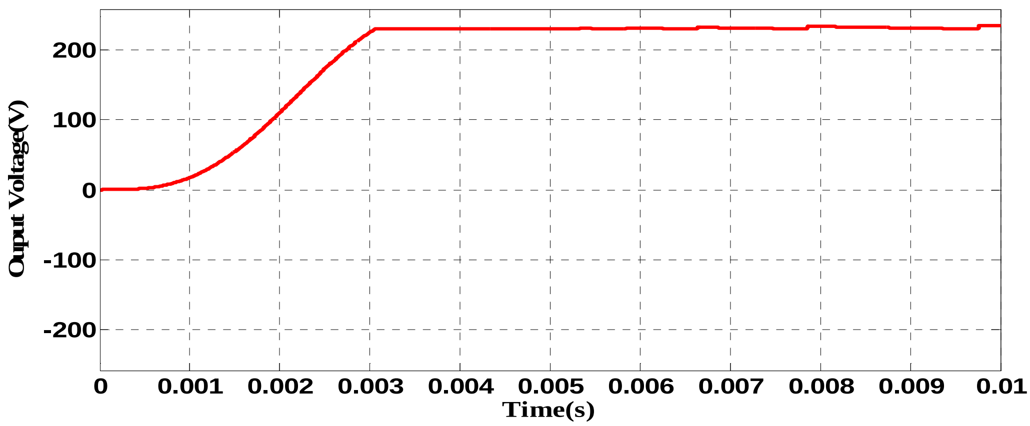

Figure 3.7 SEPIC output voltage using NN tuned PI controller

In this Neural Network tuned PI controller the output response when the reference value is changed from 150V to 250 V at time = 0.005s is showm in Figure 3.8 and is compared with the response of PI controller. The NN tuned PI controller exhibits better performance than PI controller. From Figure 3.8, it is found that NN tunned PI controller's response is fast when compared with that of PI controller.

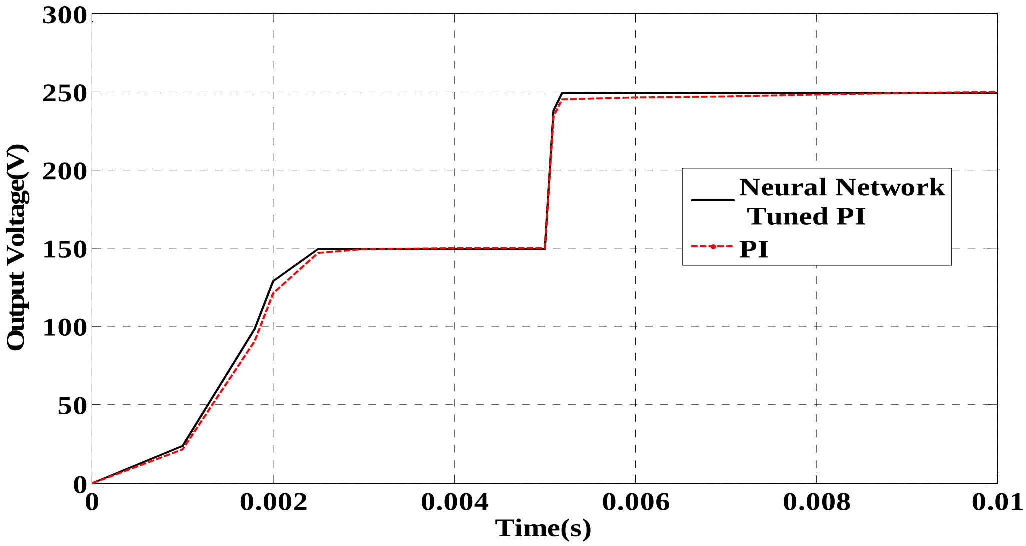

Figure 3.8 Response while changing reference output voltage using NN tuned PI controller and PI controller

3.6 CHAPTER SUMMARY

A neural network tuned PI controller has been designed for a SEPIC converter. The neural network is trained with the best kp and ki values of PI controller for various output reference voltages. Neural network toolbox in Matlab is used to train the neural network. The performance of the above controller is verified by doing simulation using MATLAB simulink and the results are compared with a PI controller. It is found that the neural network tuned PI controller gives less steady state output error and low settling time compared to the PI controller.