Abstract: In this study, an IGBT equipped boost converter is proposed. A fuzzy logic controller is used to control the output voltage of the boost converter. Simulation and experimental results show that fuzzy logic controlled boost converter has fast transient response, better steady-state response, and the proposed converter is less sensitive to load changes.

1. INTRODUCTION

DC-DC converters are widely used in switched-mode power supplies, adjustable speed drives, uninterruptible power supplies and many other applications to change the level of an input voltage to fulfill required operating conditions. These converters are usually subjected of large load variations when operated in these applications. Therefore, the main objective of a good control strategy to be developed for such converters must be to achieve an output voltage regulation, under large load variations, as fast as possible without having any stability problem [1].

Many control strategies have been proposed in recent publications. Linear PID and PI controllers are usually designed for DC-DC converters using standard frequency response techniques based on the small signal model of the converter. A Bode plot is used in the design to obtain the desired loop gain, crossover frequency and phase margin. These control strategies that are based on the linearized small-signal model of the converter have good performance around the operating point. However, a boost converter’s small signal model changes when the operating point varies. The poles and a right-half plane zero, as well as the magnitude of the frequency response, are all dependent on the duty cycle. Therefore, it is difficult for the PID controller to respond well to changes in operating point, and they exhibit poor performance when the system is subjected of a large load variation [2-3].

Fuzzy logic control theory is a mathematical discipline based on vagueness and uncertainty. The fuzzy control does not need an accurate mathematical model of a plant. It allows one to use non-precise or ill-defined concepts. Fuzzy logic control is also nonlinear and adaptive in nature that gives it robust performance under parameter variation and load disturbances [4]. This control technique relies on the human capability to understand the system’s behavior and is based on qualitative control rules. Thus, control design is simple since it is only based on IF....THEN linguistic rules [5].

In this paper, a fuzzy logic controlled boost converter is proposed. A Fuzzy Logic Controller (FLC) is used to control the converter output voltage. The boost converter is designed and simulated by using MATLAB/Simulink software. Then dSPACE based fuzzy logic controlled boost converter is implemented and tested under large load changes. Simulation and experimental results shows that fuzzy logic controlled boost converter has fast transient response and better steady-state response.
This paper organized as follows: Section II describes mathematical model of the boost converter. Section III introduces the FLC. Section IV presents the simulation and experimental results of fuzzy logic controlled boost converter and Section V is the conclusions.

2. MATHEMATICAL MODEL OF THE BOOST CONVERTER

The dc-dc boost converter circuit is shown in Fig. 1. By considering this circuit, the equations describing the operation of the converter can be written as:

\[ L \frac{dI_L}{dt} = V_S - dV_0 \]  
\[ C \frac{dV_0}{dt} = dI_L - \frac{V_0}{R} \]

where \( d \) is the control signal equal to “1” when the switch is ON and “0” when the switch is OFF. The above equations can also be written as [1]:

Switch ON:

\[ L \frac{dI_L}{dt} = V_S - V_0 \]  
\[ C \frac{dV_0}{dt} = I_L - \frac{V_0}{R} \]

Switch OFF:

\[ L \frac{dI_L}{dt} = V_S \]

3. FUZZY LOGIC CONTROLLER FOR BOOST CONVERTER

Fuzzy Logic Controller is one of the most successful applications of fuzzy set theory, introduced by Zadeh in 1965 [6]. Its major features are the use of linguistic variables rather than numerical variables. The general structure of the FLC is shown in Fig 2. As seen from Fig. 2, a FLC is comprises fuzzifier, knowledge base, inference engine and defuzzifier.

Defining the input and output variables is one of the important steps in the fuzzy controller design. In this study, the output voltage error and its rate of change are defined as input variables and change in duty cycle is the controller output variable.

The three variables of the FLC, the error, the change in error and the change in duty cycle, have seven triangle membership functions for each. The basic fuzzy sets of membership functions for the variables are as shown in the Figs. 3 and 4.
The fuzzy variables are expressed by linguistic variables ‘positive large (PL)’, ‘positive medium (PM)’, ‘positive small (PS)’, ‘zero (Z)’, ‘negative small (NS)’, ‘negative medium (NM)’, ‘negative large (NL)’, for all three variables. Table 1 shows the rule base for the FLC. A rule in the rule base can be expressed in the form: If (e is NL) and (de is NL), then (cd is NL).

The rules are set based upon the knowledge and working of the system. The rule base adjusts the duty ratio for the PWM of the boost converter based upon the changes in the input of the FLC. The number of rules can be set as desired. The rule base includes 49 rules, which are based upon the seven membership functions of the input variables. The rule base of the FLC is shown in Table 1.

The commonly used Min–Max inference method is implemented. Defuzzification is done using center of gravity method to generate nonfuzzy control signal for change in duty cycle of the PWM switching of boost converter [7].

Table 1. Rule base of FLC

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<tr>
<th>Error (e)</th>
<th>NL</th>
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<th>NS</th>
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Fig. 5. Simulink model of the boost converter.
4. SIMULATION AND EXPERIMENTAL RESULTS

A fuzzy logic controlled boost converter is design and implemented. Firstly, boost converter is modeled and simulated with MATLAB/Simulink [8]. Output voltage of the boost converter is control with FLC. The FLC is designed with Fuzzy Logic Toolbox [9]. Simulink model of the simulated system is shown in Fig. 5. IGBT is used in boost convert and switching frequency chosen as 20kHz. So it can be said that only the boost inductor limits the output power of the converter, and a high power converter can be easily implemented.

DS1104 dSPACE controller board is used in boost converter controller system. dSPACE control cards are quite popular because of integrating the MATLAB/Simulink simulations and hardware control in a system and widely used in controlling motors and power electronic converters [10]. DS1104 Controller Board is placed in the PCI slot on the mainboard of PC. The DS1104 contains a main processor and a slave Digital Signal Processor (DSP). The main processor is a 603 PowerPC, running at 250MHz with 32 MB of SDRAM, and the slave DSP is a TMS320F240, Texas Instrument floating-point DSP, 20MHz CPU clock [11]. Moreover, the dSPACE software includes a graphical object-oriented package (the Control Desk) to develop user-friendly graphical user interfaces (GUI) for on-line monitoring and supervision. Operation, all kind of analog and digital signals and variables of the system can be monitored in real time by using GUI. The ControlDesk is also used to load code to board, run or stop the program [11,12]. These GUIs shorten the design period and can visualize the control parameters [10]. In Fig 6, the GUI whish is designed for fuzzy logic controlled boost converter is shown.

Fig. 7 shows the transient response of the boost converter when the reference voltage is changed. Reference voltage (VREF), converter output voltage (V0), converter input voltage (Vin) and converter output current (Io) is seen in figure. The reference voltage is switched 40V to 50V at t=25ms. As seen from figure, output voltage is tracks the reference voltage with a small overshot and small settling time. Improved steady-state performance of the controller is also shown in the figure.
Boost converter output voltage transient response is shown in Fig. 8 when the load is changed from 50% to 100% and from 100% to 50%. It is seen large load variations have very limited effects on the output voltage of the fuzzy logic controlled boost converter. A very small voltage decrease and overshoot occurs on output voltage, and this voltage disturbance is removed in 2 milliseconds. The boost converter has fast transient response and very small steady-state error.

After the simulation task is completed, the dSPACE blocks that are used to read analog signals and generate switching signals are added to Simulink model. When this model is “Build”, the C source code is generated and loaded to the processor automatically. Experimental results for

The transient response of the boost converter when the load changes from 50% to 100% and from 100% to 50% in Figs. 10 and Fig. 11, respectively. Experimental results are similar with the simulation results. The FLC has improved transient response and so, load changes have very limited effect on the boost converter output voltage and FLC removes the voltage error quickly.

Fig. 7. Transient response for reference voltage variation

Fig. 8. Transient response for load variation

Fig. 9. Boost converter response for reference voltage variation

Fig. 10. Half to full load switching interval
5. CONCLUSIONS

In this study a dSPACE based fuzzy logic controlled boost converter is designed and implemented. The boost converter is IGBT equipped and the switching frequency is selected as 20 kHz. So, only the inductor size may limit the power level of the converter, and it can be said that the converter can be easily implemented in high power levels. The FLC is designed with Fuzzy Logic Toolbox and the simulations are performed in MATLAB/Simulink. Simulation and experimental results show that boost converter has fast transient response and better steady-state response under the variable load conditions. The GUI designed with ControlDesk provides to monitor the analog and digital signals, and control variables. The system design duration is shortened by using of the dSPACE control system.

REFERENCES