Design and Simulation of Fuzzy Logic Controller for Power Electronics Converter Circuits

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Abstract

Traditional methods require a mathematical model for a system but the fuzzy logic controller does not require any mathematical model and is very simple to implement. Recently, Fuzzy Logic applications to the control of power electronics and drives are on rise. Power electronics converter circuits possess inherent characteristics, such as non-linearities, unavailability of a precise model or its excessive complexity, that make them well suited for Fuzzy Logic Control. The design of a Fuzzy Logic Controller for power electronics converter circuits is described in this paper. The simulation of the proposed controller is done using MATLAB-SIMULINK for the performance evaluation.

Keywords: Fuzzy Logic Controller, DC-DC (Buck/Boost) converter

I. INTRODUCTION

The main component of power electronics systems are power electronics circuits, which allow to produce a desired effect (energy conversion, motion, torque etc) by controlling adequately the system variables i.e. voltages and currents. Design and implementation of a control system require the use of efficient techniques that provide simple and practical solution in order to fulfill the performance requirement despite the system disturbances and uncertainties

Power Electronics is Power Processing. It is an application of electronic circuits to control a power converter in order to provide adjustable DC or AC voltage for different loads. Power Electronics can be split into a Power and an Electronic circuit. The power circuit converts an unregulated input power from AC or DC type to a regulated AC or DC voltage or current and delivers it to a load. The electronic circuit controls the converter by measuring the input and output voltages and/or currents and generates signals for the power circuit [1].

Traditionally, the design of a control system is dependent on the explicit description of its mathematical model and parameters. Often, the model and the parameters are unknown, or ill-defined. The system may be further complicated by the presence of nonlinearity and parameter variation problems. This reality, inevitably promotes the endeavor to control methods that incorporates non-linear dynamics into the design. Among the non-linear control methodologies, fuzzy logic has recently been applied widely in power electronics. The success of fuzzy logic controllers seems to be mainly due to their ability to incorporate experience, intuition and heuristics into the system instead of solely relying on mathematical models. The use of Fuzzy Logic is to guarantee simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the system. The primary objective of the proposed controller is to reduce the steady state error, overshoot, and undershoot, recovery time and settling time [2, 3].

II. FUZZY LOGIC CONTROLLER

A Fuzzy Logic Controller (FLC) uses fuzzy logic as a design methodology, which can be applied in developing nonlinear systems for embedded control. Fuzzy logic possesses the following advantages: (1) the linguistic, not numerical, variables make the process similar to the human think process. (2) It relates output to input, without understanding all the variables, permitting the design of system more accurate and stable than the conventional control system. (3) Simplicity allows the solution of previously unsolved problems. (4) Rapid prototyping is possible because, a system designer doesn't have to know everything about the system before starting work. (5) It has increased robustness. (6) A few rules encompass great complexity. The basic Fuzzy Logic Controller(FLC) consists of four principal components : a Fuzzification, which converts input data value into suitable linguistic values; a knowledge base, which consists of control rule set and a data base with the necessary linguistic definitions; a Decision-Making logic, which is used to simulate a human decision process and infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; and a Defuzzification interface, which yields non fuzzy control action from an inferred fuzzy control action.

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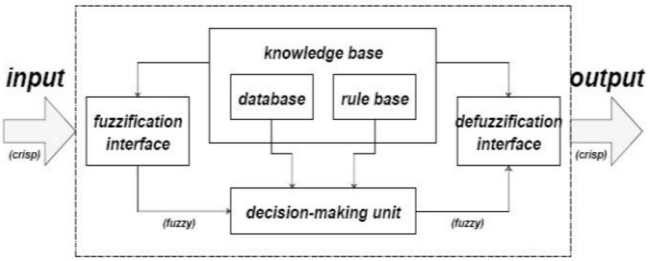

Fig. 1: General structure of Fuzzy Logic Controller (FLC)

Fuzzy logic has rapidly become one of the most successful technologies for developing sophisticated control systems. Various researchers have devised advanced control techniques for power electronics circuits based on fuzzy logic[3-11].

III. DESIGN OF PROPOSED FUZZY LOGIC CONTROLLER AND CONVERTER TOPOLOGY

In power converters, efficiency is a main concern. Power circuits consist of capacitors, magnetic elements and transistors in switched mode. Resistors and power switches in linear mode are not used in most power circuits due to significant losses generated by current through these components which decrease the efficiency and cause thermal problems. It is desirable that the conversion be made with low losses in the converter. To obtain low losses, resistors are avoided in the power electronics converter circuits. Capacitors and inductors are used instead since ideally they have no losses. The electrical components can be combined and connected to each other in different ways, called different converter (DC-DC, AC-DC) topologies, each one having different properties.

A modern power electronic system is a power processing system based on Pulse Width Modulation (PWM) technique. In a control system, a desired PWM signal is synthesized and transferred to power switches through gate drives to generate the same waveform at different voltage or current level. Thus, the power switches chop high voltages and/or currents when they are turned on and off. By using pulse-width modulation (PWM) control, regulation of output voltage is achieved by varying the duty cycle of the switch. The proposed converter circuit uses Insulated Gate Bipolar Transistor (IGBT) as the switching device. Use of IGBTs allows building cheaper and better converters.

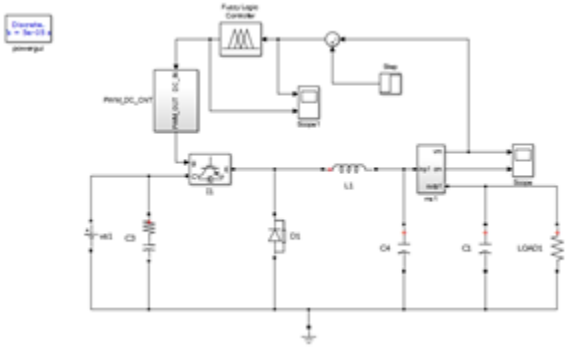

Fig. 2: Simulink model of DC-DC (buck) converter

IGBTs have three attractive advantages: higher switching frequency, easy and simple gate control and no need for snubber circuits. IGBTs are continuously controllable during turn on and turn off. This makes overcurrent limitation much easier and allows dV/dt control to reduce the and dV/dt stresses. MATLAB-SIMULINK is used to design and simulate the proposed controller circuit for various power electronics converters [12]. Fig 2 shows simulink model of DC-DC (buck) converter using Fuzzy Logic Controller (FLC).

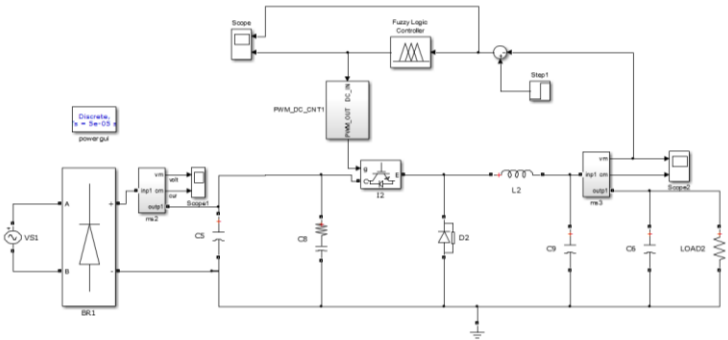

Fig. 3: shows simulink model of DC-DC(buck) converter with AC input

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Fig 3: Simulink model of AC-DC (rectifier-step down chopper) converter

The model has AC input which is first converted to DC by using a uncontrolled bridge (diode bridge) rectifier. The output of rectifier is given as input to DC-DC converter (buck/boost) circuit which uses FLC to generate the required regulated DC output voltage.

In order that the regulated converter circuit has good transient and steady- state responses, a controller with the following properties are desirable:

1) it does not rely on an accurate model of the plant;
2) It is robust to the uncertainties of the plant parameters.

Simplicity and less intensive mathematical design requirements are the most important features of proposed Fuzzy Logic Controller. The proposed controller structure uses error voltage of the converter circuit (difference between actual output voltage and reference output voltage) as the only input and has one output and one dimensional rule-base. A Mamdani type inference method is used for the design of proposed controller. Two fuzzy subsets are used and two rules are designed. Triangular membership function is used for input and output. Defuzzification method used is Centroid. The output of FLC generates a PWM signal which drives the switching IGBT.

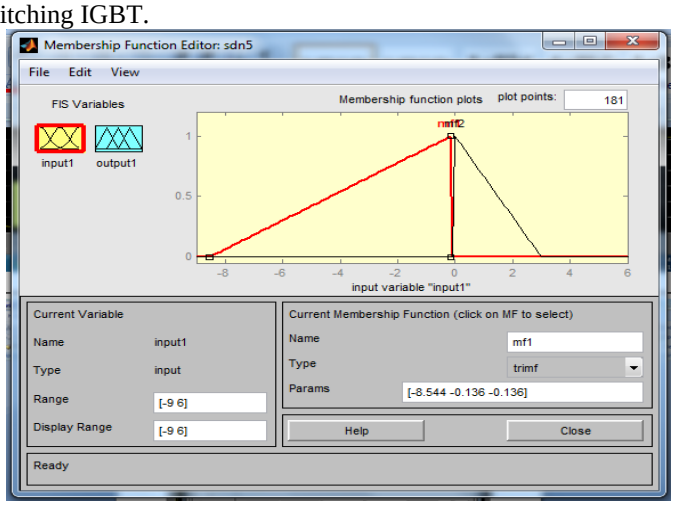

Fig. 4: Input Membership Functions

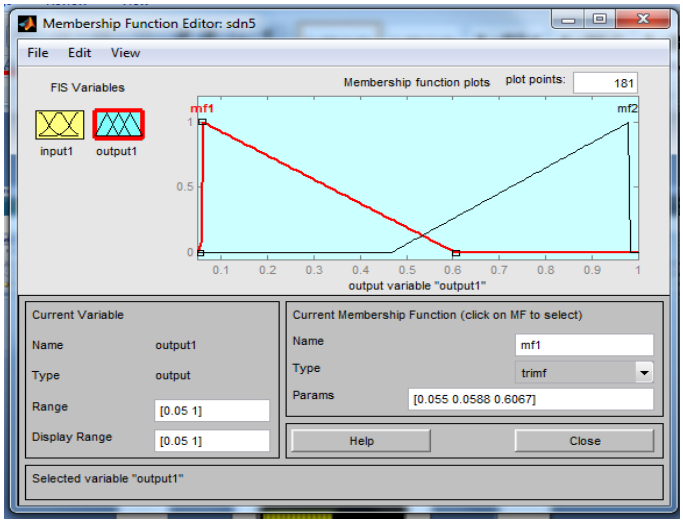

Fig. 5: Output Membership Functions

Figures 4 and 5 shows the design steps of Fuzzy Logic Controller (FLC) having only one input and one output.

IV. SIMULATION RESULTS

Simulation of the simulink model of the designed converter circuits using proposed FLC with the variation in input voltage at different loads is done. The input voltage is taken as 12 V DC. The simulation results show that the proposed FLC works efficiently and converter tracks the reference step voltage to generate the required output. In case of AC input voltage, a diode rectifier produces unregulated DC output voltage of 12V.

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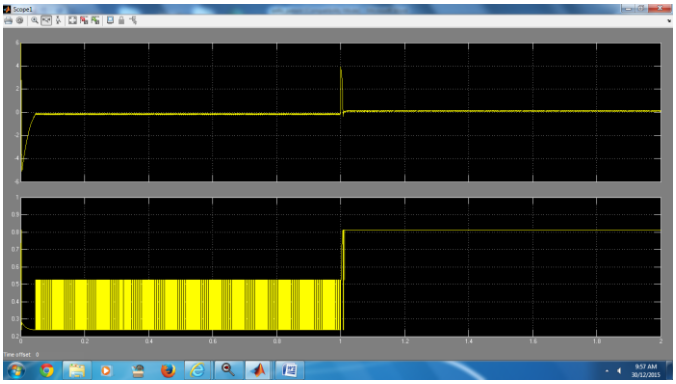

Fig. 6: Output of FLC

This is given as input to the power electronics converter circuit which produces constant regulated output which shows efficient working of proposed FLC.

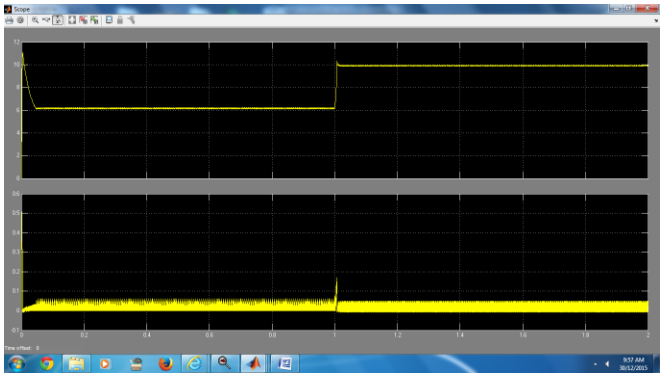

Fig. 7: Output of DC-DC (buck) converter

The simulation results for DC-DC (buck) converter are shown in figures 6 and 7.

V. CONCLUSIONS

This paper proposes the design of Fuzzy Logic Controller which can be used with any power electronics converter circuits like DC-DC (buck/boost) or AC-DC. The proposed Fuzzy Logic Controller with simple design approach and smaller rule base can provide better performance compared to classical Proportional-Integral-Derivative (PID) controller. The proposed novel controller gives minimum settling time, allowable transient overshoots and has much improved performance compared to the conventional controllers. The proposed controller is adaptive for all the operating point as compared to conventional controllers.

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