CISET - 2nd Cilicia International Symposium on Engineering and Technology
10-12 October, 2019, Mersin / TURKEY

ROBUST CONTROL OF BOOST CONVERTER USING INTERVAL TYPE-2 TSK FUZZY LOGIC CONTROLLER

Ö. Fatih Keçecioğlu [1], Ahmet Gani *[2] and Erdal Kılıç[3]

1 Kahramanmaraş Sütçü İmam University, Faculty of Engineering and Architecture, Department of Electrical and Electronics Engineering, Turkey, Kahramanmaraş, fkececioglu@ksu.edu.tr

2 Kahramanmaraş Sütçü İmam University, Faculty of Engineering and Architecture, Department of Electrical and Electronics Engineering, Turkey, Kahramanmaraş, agani@ksu.edu.tr

3 Kahramanmaraş Sütçü İmam University, Faculty of Engineering and Architecture, Department of Electrical and Electronics Engineering, Turkey, Kahramanmaraş, ekilic@ksu.edu.tr

ABSTRACT

DC-DC converters are electronics elements which change voltage level based on switching. Unlike linear circuit topologies, modeling and controlling of DC-DC converter circuits are very difficult because of their switched structure. Conventional controllers such as PI, PD and PID are insufficient to control non-linear systems. These controllers cannot give good performance under transient and steady state conditions. Intelligent controllers based on fuzzy logic are required in order to improve the performance of non-linear systems. Fuzzy logic control methods are used to solve many engineering problems. Interval Type-2 Takagi-Sugeno-Kang Fuzzy Logic controller (IT2TSKFLC) is more robust to overcome uncertainties and nonlinearities compared to Type-1 Fuzzy Logic controller (T1FLC). In the present study, an IT2TSKFLC is proposed for the robust control of boost converter. The dynamic performance of proposed controller was analyzed under disturbances such as input voltage change and output load change using MATLAB/Simulink.

Keywords: *Robust Control, Boost Converter.*

*Ahmet GANİ

1. INTRODUCTION

DC-DC converters are circuits which change the voltage level to another one depending on the state of the switching element. While some converters are used to decrease or increase voltage, some types are used to both increase and decrease voltage such as buck, boost, buck-boost type. Boost DC-DC converters are circuits which convert input voltage level to an output voltage level upper than the input voltage level [Kececioglu et al., 2018]. Boost DC-DC converters are particularly used renewable energy applications. Many studies are available in the literature to control boost type DC-DC converters. The dynamic characteristic of boost DC – DC converters are non-linear due to parasitic resistances, stray capacitances and leakage inductances of the components [Ozarslan et al., 2014]. PI controller has many disadvantages such as slow transient response and more overshoot. To overcome these problems, there are various intelligent control methods such as fuzzy logic control (FLC), artificial neural network control (ANNC) and neuro-fuzzy control (NFC) in the literature. Among the various control techniques, the most commonly used technique in control systems is fuzzy logic. Fuzzy logic can be used to describe the behavior of complex systems which are difficult to modeling mathematically. Fuzzy logic control is the mathematical expression of linguistic variables by means of experience. For that reason, fuzzy logic is frequently used in various academic fields such as decision-making, pattern recognition, nonlinear approach and data analysis [Acikgoz, 2018]. There are uncertainties in many of the systems in the real world. Various fuzzy control methods have been implemented in many nonlinear systems. Type-1 fuzzy logic control (T1FLC) has some limitations for the expression of uncertainties. However, the main feature of Interval Type-2 Takagi-Sugeno-Kang Fuzzy Logic controller (IT2TSKFLC) is the footprint of uncertainty (FOU) that describes the uncertainties. Moreover, IT2TSKFLC is more robust to overcome uncertainties compared to T1FLC [Acikgoz et al., 2017]. The present study is organized as follows: Boost DC-DC converter is analyzed in Section 2. The design of IT2TSKFLC structure is explained in Section 3. Simulation results are presented in Section 4. The conclusions of the present study are given in Section 5.

2. ANALYSİS OF BOOST CONVERTER

Boost DC-DC converter circuit model is composed of a switch S, a diode D, an inductor L, a capacitor C and a resistance R that is used as a load. The circuit model of a boost DC-DC converter is shown in Fig. 1.

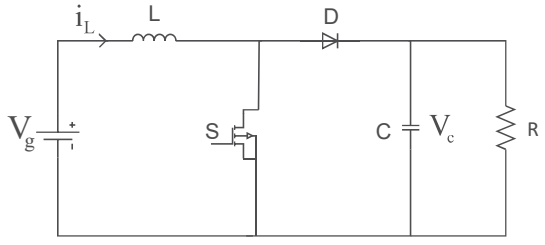


Fig. 1. Boost DC-DC Converter Circuit

At a steady state mode, boost converter has two operating modes. In the first operating mode, switch S is turned on, and the diode is reverse biased. The equivalent circuit of the first operating mode is shown in Fig.2.

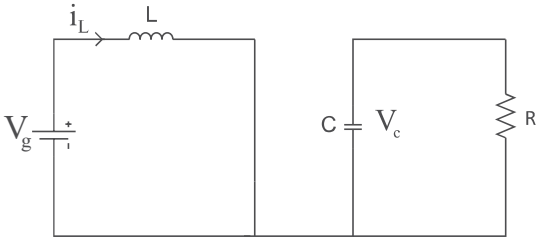


Fig. 2. Equivalent Circuit of First Operating Mode

$$L\frac{di_L}{dt} = V_g \tag{1}$$

$$C\frac{dV_C}{dt} = \frac{-V_C}{R} \tag{2}$$

In the second operating mode, switch S is turned off, and the diode is forward biased. The equivalent circuit of second operating mode is shown in Fig.3.

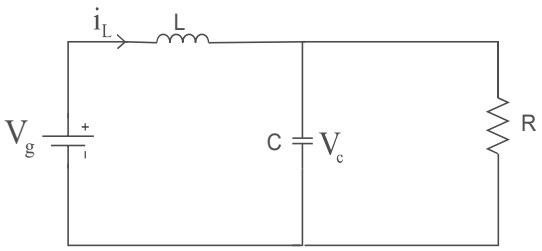


Fig. 3. Equivalent Circuit of Second Operating Model

The equations defining the dynamic behavior of the circuit are given in Eqs.3 and 4 using Kirchoff's current and Kirchoff's voltage laws for the second operating mode.

$$V_g - L\frac{di_L}{dt} - V_C = 0 \tag{3}$$

$$C\frac{dV_C}{dt} = \left(i_L - \frac{V_C}{R}\right) \tag{4}$$

The relationship between the output and input voltage at steady state mode for boost DC-DC converter is defined in Eq. 5.

$$V_0 = \frac{1}{1-D}V_g \tag{5}$$

The duty cycle rate for a boost DC-DC converter is given in Eq. 6.

$$D = \frac{T_{on}}{T} = \frac{T_{on}}{T_{on} + T_{off}} \quad (6)$$

T_{on} denotes logic 1 duration of PWM, T_{off} is the logic 0 duration of PWM, T represents the period of PWM, and D defines the duty cycle [Kececioglu et al., 2019].

3. THE DESIGN OF INTERVAL TYPE-2 TSK FUZZY LOGIC CONTROLLER

The expert is required to solve the problem of defining the rules and parameters of the membership function in the design of T1FLC. The expert's linguistic definitions may result in various uncertainties. In addition, defining the crisp values required for the membership function may also be problematic (Karanjkar, 2014). Such problems may lead to some instabilities such as measurement errors and changes in operating conditions of the controller. Moreover, in IT2TSKFLCs, these instability conditions can be listed as membership function uncertainties, which can eliminate adverse effects arising out of instability conditions. The four main parts of IT2TSKFLC are fuzzifier, a rule base, fuzzy inference, and type reducer. IT2TSKFLC and T1FLC significantly differs from each other in terms of type reduction. Type reducer converts Type-2 information to Type-1 information, and the output of type-reduction block is called type-reduced set. Then, this type reduced set is used in the defuzzification process (Kumbasar *et al*., 2012).The internal structure of IT2TSKFLC is shown in Fig. 4.

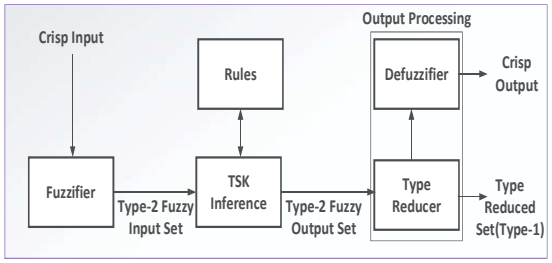


Fig. 4. The internal structure of IT2TSKFLC

Takagi-Sugeno-Kang (TSK) is a fuzzy modelling method proposed by Takagi, Sugeno and Kang. It can comprise high-dimensions, nonlinearity and complexity (Takagi et al., 1985). The structure of an interval type-2 TSK model offers two inputs and a single output using rules in Eq. 7 (Mendel, 2001):

$$R_i : IF\ x_1 \text{ is } \tilde{A}_{1i} \text{ AND} \ldots x_n \text{ is } \tilde{A}_{ni} \text{ THEN } LF_i = c_{0i} + c_{1i}x_1 + \ldots + c_{ni}x_n \quad (7)$$

Here i = 1…r represents the IF-THEN rules of the fuzzy system; $x_1, \ldots, x_n$ are input variables and $\tilde{A}_{ni}$ is membership function (MF) of IT2TSKFLC for the variable n and rule r; LF_i is the rule output; and $c_0 + c_1 + \ldots + c_n$ are the consequent parameters. As shown in Fig.5, Gaussian type MF is used in the present study. The mathematical equations for Gaussian type MF are given in Eqs 8-9:

$$\bar{\mu}_{ij} = \exp\left\{-\frac{1}{2}\left(\frac{x_i - c_{ij}}{\bar{\sigma}_{ij}}\right)^2\right\} \quad (8)$$

$$\underline{\mu}_{ij} = \exp\left\{-\frac{1}{2}\left(\frac{x_i - c_{ij}}{\underline{\sigma}_{ij}}\right)^2\right\} \quad (9)$$

where c_{ij} is the mean value, σ_{ij} is the standard deviation, and x_i is the input variable.

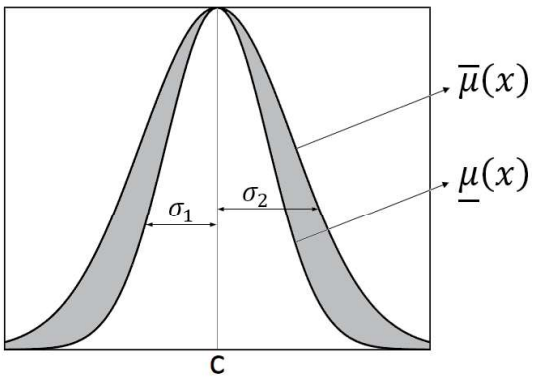


Fig. 5. Gaussian type-2 fuzzy set

The t-norm operation is defined in Eq. 10:

$$f_i = \prod_{j=1}^{n} \mu(x_j) \quad (10)$$

A normalized firing strength is expressed in Eq. 11:

$$\bar{f}_i = \frac{f_i}{\sum_{k=1}^{r} f_k} \quad (11)$$

$\bar{f}_i$ represents normalized firing strength. IT2TSKFLC contains lower and upper membership functions in case of uncertainties (Chang et al., 2011). The firing strengths of a fuzzy rule are given as lower and upper in Eqs.12-13 using the t-norm operator, respectively.

$$\underline{f}_i = \prod_{j=1}^{n} \underline{\mu}(x_j) \quad (12)$$

$$\bar{f}_i = \prod_{j=1}^{n} \bar{\mu}(x_j) \quad (13)$$

One of the closed-form type reduction and defuzzification methods, Biglarbegian-Melek-Mendel (BMM) is preferred in IT2TSKFLC (Biglarbegian *et al*., 2010). Closed mathematical form type reduction and the defuzzification process of the proposed IT2TSKFLC can be calculated using Eq. 14.

$$Y_{BMM} = q\frac{\sum_{i=1}^{r} f_i\, LF_i}{\sum_{i=1}^{r} f_i} + (1-q)\frac{\sum_{i=1}^{r} \bar{f}_i\, LF_i}{\sum_{i=1}^{r} \bar{f}_i} \qquad (14)$$

4. SIMULATION STUDIES

In the proposed IT2TSKFLC, inputs are the error (e) and change of error (de) between reference output voltage and measured output voltage of boost converter. A Gaussian membership function was selected for each input as shown in Fig. 6.

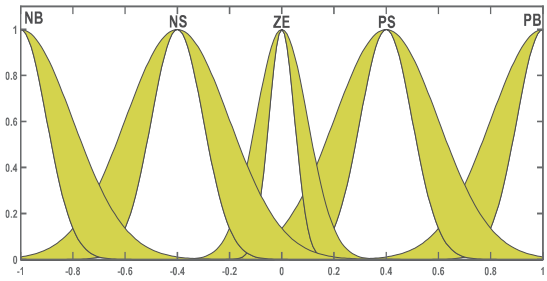


Fig. 6. Gaussian membership functions selected for e and de

The value range was selected as [-1, 1] for Gaussian membership functions. The linguistic expressions used for e and de in the model designed in Matlab/Simulink are Negative Big (NB), Positive Big (PB), ZE (S), Negative Small (NS), and Positive Small (PS). The rule base consisting of these linguistic expressions are given in Table 1.

Table 1. 5x5 rule base

$x_2(de)$ / $x_1(e)$	NB	NS	ZE	PS	PB
NB	LF_1	LF_2	LF_1	LF_1	LF_5
NS	LF_6	LF_7	LF_8	LF_9	LF_{10}
ZE	LF_{11}	LF_{12}	LF_{13}	LF_{14}	LF_{15}
PS	LF_{16}	LF_{17}	LF_{18}	LF_{19}	LF_{20}
PB	LF_{21}	LF_{22}	LF_{23}	LF_{24}	LF_{25}

In general, some assumptions are made in the circuit design process. Circuit parameters of the designed DC-DC boost converter circuit are given in Table 2.

Table. 2 Circuit parameters of the designed DC-DC boost converter

Parameters	**Symbol**	**Value**
Input Voltage	V_g	30.7 V
İnductor	L	0.1 mH
Capacitor	C	81.6 µF
Load resistance	R	15 Ω
Output (Load) Voltage	V_c=V_o	60 V
Switching frequency	f_s	40 Khz
Duty Cycle	D	0.49
Inductor current change	Δi_L (%20 ripple)	1.628 A
Output (Load) Voltage Change	ΔV_c (%1 ripple)	0.6V
Output Power	P_0	250W

Output voltage level was set to 60V DC, and an output power of 250W was aimed. All circuit elements were assumed to be ideal, and power losses were ignored. When so, output power was assumed to be equal to input power. The input current of the circuit is calculated using Eq. 15:

$$I_g = \frac{P_i}{V_g} \qquad (15)$$

When the ripple in the inductor current is assumed to be 20%, the inductor current change can be calculated as follows:

$$\Delta I_L = \%c.I_g \qquad (16)$$

The necessary inductance value can be calculated using Eq. 17:

$$L = \frac{V_0 D(1-D)}{f\Delta I_L} \qquad (17)$$

Similarly, the output capacitor value bears importance in ensuring a sufficient output voltage ripple. The capacitor value for an output voltage ripple of 1% is calculated using Eq. 18:

$$C = \frac{I_0 D}{f\Delta I_C} \qquad (18)$$

Two different controlling scenarios were applied in order to test the dynamic performance of IT2TSKFLC. In the first scenario, the input voltage was changed. In the second scenario, the output load was changed.

The structure of IT2TSKFLC boost converter controller is shown in Fig.7.

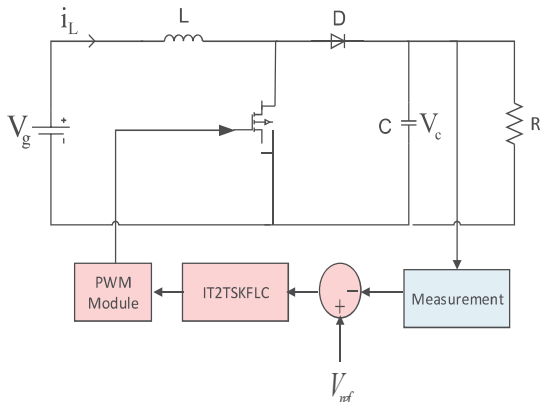


Fig. 7. The structure of the proposed IT2TSKFLC boost converter controller

In the first scenario, the input voltage was increased from 30.7V to 32V at 0.1 secs. The response of the proposed controller for the input voltage changes is shown in Fig.8.

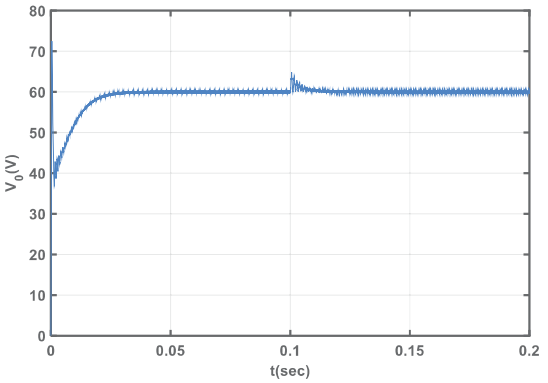


Fig.8. The response of the proposed controller for the input voltage change

As shown in Fig.8, a The proposed controller tracked again reference voltage at a duration as short as 0.01 secs after the input voltage was increased to 32V at 0.1 secs. In the second scenario, the load resistance was decreased from 15 Ω to 7.5 Ω at 0.1 secs. The response of the proposed controller for the load change is shown in Fig.9.

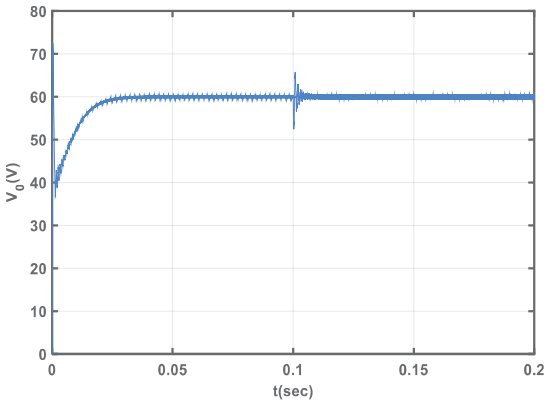


Fig.9 The response of the proposed controller for the load change

As shown in Fig.9, the ripple value increased from 0.6 V to 1.3V when the output load resistance was decreased. The proposed controller tracked again reference voltage at a duration as short as 0.004 secs, and thus showed a successful tracking performance.

5. CONCLUSION

In the present study, the dynamic performance of IT2TSKFLC was analyzed for controlling a boost converter. A simulation model was created using MATLAB/Simulink in order to evaluate the dynamic performance of the proposed controller. Two different simulation scenarios (input voltage change and output load change) were applied in order to test the stability and robustness of the proposed controller. The findings of the simulation studies demonstrated that the proposed controller showed an effective dynamic performance.

REFERENCES

Acikgoz, H. (2018). "Speed Control of DC Motor Using Interval Type-2 Fuzzy Logic Controller." *International Journal of Intelligent Systems and Applications in Engineering*, Vol. 6, No. 3, pp. 197-202.

Biglarbegian, M. Melek, W. W., and. Mendel, J. M.(2010). "On the stability of interval type-2 TSK fuzzy logic control systems," Systems, Man, and Cybernetics, Part B: Cybernetics, IEEE Transactions on, Vol. 40, No. 3, pp. 798–818.

Chang, C.C. Lin, C.J. (2011). "LIBSVM: A library for support vector machines," ACM Trans. Intel. Sys. and Tech., Vol. 2, No.3, pp. 1–27.

Karanjkar, D.S. Chatterj, S. Kumar, A. Shimi, S .L. (2014)."Fuzzy Adaptive Proportional-Integral-Derivative Controller with Dynamic Set-Point Adjustment for Maximum Power Point Tracking in Solar Photovoltaic System", Systems Science & Control Engineering, Vol. 2, No.1, pp.562-582.

Kumbasar, T. Eskin, I. Guzelkaya, M. Yesil, E., (2012). "Type-2 Fuzzy Model Based Controller Design for Neutralization Processes", ISA Transactions, Vol. 51, No. 2, pp. 277-287.

Mendel, J.M. (2001). "Uncertain Rule-Based Fuzzy Logic Systems" Introduction and New Directions. Prentice Hall.

Takagi, T. Sugeno, M. (1985) "Fuzzy Identification of Systems and Its Applications to Modeling and Control," IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-15, No. 1, pp. 116–132.