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A High Performance Direct Torque Control of PMBLDC Motor using AI

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This paper deals with the direct torque control (DTC) of PMBLDC motor using Artificial Intelligence (AI) to improve the performance of the DTC scheme. Though the conventional controllers are commonly used in practice, they have failed to perform satisfactorily under nonlinear conditions and parameter variations. In the proposed work, an AI based control scheme is introduced to control the torque and the flux linkage angle of the DTC scheme. Torque error and flux linkage angle of the DTC scheme are fuzzified and it is auto tuned by GA to improve the dynamic characteristic. Simulation results of the conventional control scheme are compared with the AI based control scheme and the later is found to be satisfactory with improved performance.

Keywords: PMBLDC motor, Direct Torque Control, Fuzzy logic control Genetic algorithm.

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1. Introduction

Direct torque control scheme has emerged over the last decade to become one possible alternative to the well known vector control of electrical machines. Direct torque control (DTC) is used in variable frequency drives to control the torque (and thus finally the speed) of three-phase AC electric motors and permanent magnet motors. This involves the estimation of the motor's magnetic flux and torque based on the measured voltage and current of the motor. Its main characteristics is the good performance, obtaining results as better as the classical vector control method added with certain advantages based on its simple structure and control diagram based on some attractive features like fast dynamic response, smooth and fast control of torque and flux angle [1][2]. Significance of DTC scheme are direct control of flux and torque, Indirect control of stator currents and voltages, High dynamic performances even at stand still, Approximately sinusoidal stator fluxes and currents.

Application of artificial intelligence (AI) tools for electrical machines and drive systems is an interesting research topic that has recently received increasing attention. Fuzzy logic and Fuzzy set was introduced by Zadeh. Fuzzy logic control is a effective and versatile tool to approach and deal with the non-linear and uncertain system. Even if a fuzzy logic controller (FLC) can produce arbitrary non-linear control law, the lack of systematic procedure for the configuration of its parameters remains the main obstacle in practical applications. In [5] a FLC for BLDCM has been proposed. But the parameters of the FLC cannot be auto-tuning and not be suitable for difference conditions. Recently, the design of FLC has also been tackled with genetic algorithm (GA). These are optimization algorithm performing a stochastic search by iteratively processing 'populations' of solutions according to fitness [6]. In control applications, the fitness is usually related to performance measures as integral error, setting time, etc.. The application of a FLC in the field of electric drives especially in switched reluctance motor, induction motor and PMBLDC motors have increased in recent times [5]. However the conventional FLC with multiple inputs having multiple membership functions and multiple rules have been facing some disadvantages due to its high computational burden [6]. GA's are general purpose

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optimization techniques which use a direct analogy of natural evolution where stronger individuals would likely be the winners in, a competing environment. Efficacy of GA as an optimization tool has already been observed in Process Control, Design and Training of Neural Networks, VLSI design, and for Economic operation of Power Systems. Successful implementations are also found in pM neutralization process and heat exchanger systems [4]. But however, application of GA in Electrical Machines anti control systems is quite new. Given the clearly defined problem to be solved and a bit string and the candidate solutions, a simple GA works as follows: Start with a randomly generated population of 'n' k-bit chromosomes (Candidate solutions to the problems) Calculate the fitness F(x) of each of the chromosome 'x' in the population. Create 'n' offspring from current population using the three operators namely selection, crossover and mutation. Replace the current population with the new population. Repeat the above steps until the termination criterion is reached.

This paper considers the application for the AI based control scheme of DTC of PMBLDC motor to improve the performance. Simulation and experimental results are presented to illustrate the applications of DTC to PMBLDC motor using AI control scheme.

2. DTC of a BLDC drive

In the mid 1980's, an advanced scalar control technique, known as direct torque and flux control was introduced for voltage fed PWM inverter drives. This technique is found to be nearly comparable performance of vector controlled drives.

The stator flux linkages of PMBLDC motor in rotor *dq* reference frame can be written as,

$$\begin{pmatrix} v_d \\ v_q \\ v_0 \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ -\sin\theta & -\sin(\theta-120) & -\sin(\theta+120) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \quad (1)$$

$$[Vd, q, 0] \ = \ C[Va, b, c]$$

$$\begin{pmatrix} v_d \\ v_q \\ v_0 \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ -\sin\theta & -\sin(\theta-120) & -\sin(\theta+120) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \frac{1}{2} \\ -\frac{1}{2} \\ -\frac{1}{2} \end{pmatrix} V_{dc} \quad (2)$$

$$V_d = \sqrt{\frac{2}{3}} (\cos\theta \cos(\theta-120) \cos(\theta+120)) \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} V_{dc}/2 \quad (3)$$

$$= \sqrt{\frac{2}{3}} V_{dc} \cos(\theta) \quad (4)$$

$$V_q = -\sqrt{\frac{2}{3}} V_{dc}(\theta - 60) \quad (5)$$

$$V_q = -\sqrt{\frac{2}{3}} V_{dc} \cos(\theta - 60 + 90) \quad (6)$$

$$V_d = rI_d + P\psi_d - \omega\psi_q \tag{7}$$

$$V_q = rI_q + P\psi_q + \omega\psi_d \tag{8}$$

$$Vd = rId + Ld\left(\frac{dId}{dt}\right) - \omega rLqIq \tag{9}$$

$$\frac{d\theta}{dt} = \omega r \tag{10}$$

$$T_{em} = \frac{P}{2}\left[\psi_d I_q - \psi_q I_d\right] \tag{11}$$

$$\frac{1}{2}\frac{d}{d\theta}(\omega_r^2) = \frac{1}{J}\left[\left(\frac{P}{2}\right)^2 \left(\psi_d i_q - \psi_q i_d\right) - f_m\omega_r - \left(\frac{P}{2}\right)T_1\right] \tag{12}$$

$$\psi_d = L_d i_d + \psi_0 \tag{13}$$

$$\psi_q = L_q i_q \tag{14}$$

$$p\psi_d = (v_d - ri_d + \theta\psi_q) \tag{15}$$

$$p\psi_q = (v_q - ri_q + \theta\psi_d) \tag{16}$$

$$i_q = \psi_q / L_q \tag{17}$$

$$i_d = \frac{\psi_d - \psi_0}{L_d} \tag{18}$$

$$Tem = \frac{P}{2}\left[\psi dIq - \psi qId\right] \tag{19}$$

$$= \frac{J}{P/2}\frac{d^2\theta}{dt^2} + \frac{f}{P/2}\frac{d\theta}{dt} + T_l \tag{20}$$

In general, neglecting the influence of mutual coupling between direct and quadrature axis, the electromagnetic torque of a PMBLDC motor in *dq* reference frame can be expressed as,

$$\bar{v}_d = r\bar{\imath}_d - \bar{\omega}\bar{\psi}_q \tag{21}$$

$$\bar{v}_q = r\bar{\imath}_q - \bar{\omega}\bar{\psi}_d \tag{22}$$

$$V_d = rI_d + P\psi_d - \omega_r\psi_q \tag{23}$$

$$V_q = rI_q + P\psi_q + \omega_r\psi_d \tag{24}$$

(1) Considering starting and very low speed operation

$$\bar{\iota}_d \cong \frac{\bar{v}_d}{r} = \frac{K\ \cos(\alpha-30)}{r} \tag{25}$$

$$\bar{\iota}_q \cong \frac{\bar{v}_q}{r} = \frac{K\ \sin(\alpha-30)}{r} \tag{26}$$

$$T_{em} \cong \frac{P}{2}\left[\psi_0\ \frac{K\sin(\alpha-30)}{r}\right] \tag{27}$$

(2) At high speeds

$$T_{em} = \frac{P}{2}\left[\bar{\psi}_d\bar{I}_q - \bar{\psi}_q\bar{I}_d\right] \tag{28}$$

$$T_{em} = \frac{P}{2}\left[-\frac{K\ \sin(\alpha-30)}{\varpi}\ \frac{K\ \cos(\alpha-30)}{\varpi L_q} + \frac{K\ \cos(\alpha-30)}{\varpi}\ \frac{1}{L_d}\overline{\frac{K\ \sin(\alpha-30)}{\varpi} - \psi_0}\right] \tag{29}$$

T_{em} is maximum when (α-30^o) = 180^o, or α=120^o

Torque is estimated from the above equation and the speed signal is allowed to pass through a low pass filter circuit to remove the ripples and noise. Thus this is a compact and effective speed estimation scheme.

TABLE I
DTC SWITCHING TABLE

Ø	τ	Θ					
		θ1	θ2	θ3	θ4	θ5	θ6
Ø =1	τ=1	V2(110)	V3(010)	V4(001)	V5(101)	V6(110)	V1(110)
	τ=-1	V6(101)	V1(100)	V2(010)	V3(011)	V4(110)	V5(110)
Ø=-1	τ=1	V3(010)	V4(011)	V5(101)	V6(100)	V1(110)	V1(110)
	τ=-1	V5(001)	V6(101)	V1(110)	V2(010)	V3(110)	V4(110)

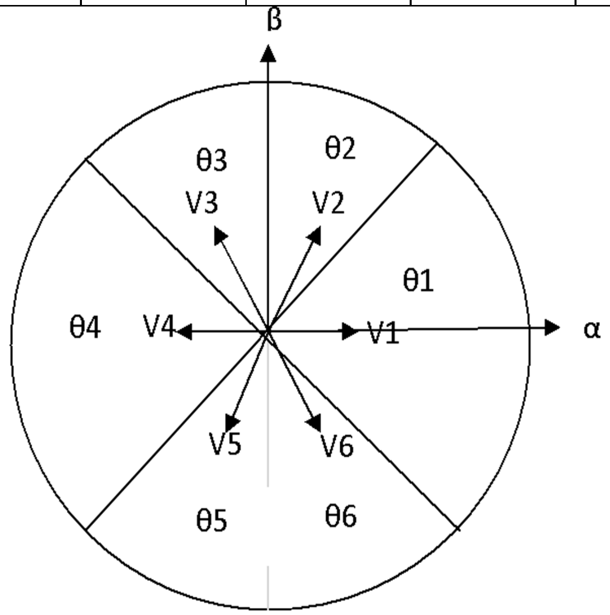


Fig. 1. Stator flux linkage vector

3. Proposed high performance DTC scheme using AI

In the proposed work seven triangular fuzzy sets have been used to partition the input and output spaces: negative large (NL), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), positive large (PL).the rule set then contains forty nine (7x7) rules to account for every possible combination of the input fuzzy sets. The rules are of the form, IF (x is {NL, NM, NS, ZE, PS, PM, PL}) and (v is {NL, NM, NS, ZE, PS, PM, PL}) THEN {output}, where output is one of the fuzzy sets used to partition the outer space as listed in table I. The basic block diagram of the proposed GA [7] based FLC is shown in Fig. 1. GA parameters in table II consists of a voltage and current measurement block from where the measured Dc bus voltage and current are given to the torque and flux calculator and the abc variables are transformed to dq variables. The optimized values are defuzzified and again transformed to abc variables and the same is given to the switching circuit.

TABLE II
RULE BASE FOR DTC SCHEME

e(u) / ce(u)	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

TABLE III
PARAMETERS OF GENETIC ALGORITHM

GA parameters	Values
Population crossover	0.8
Population mutation	0.03
Generation	20
Maximum iteration	15

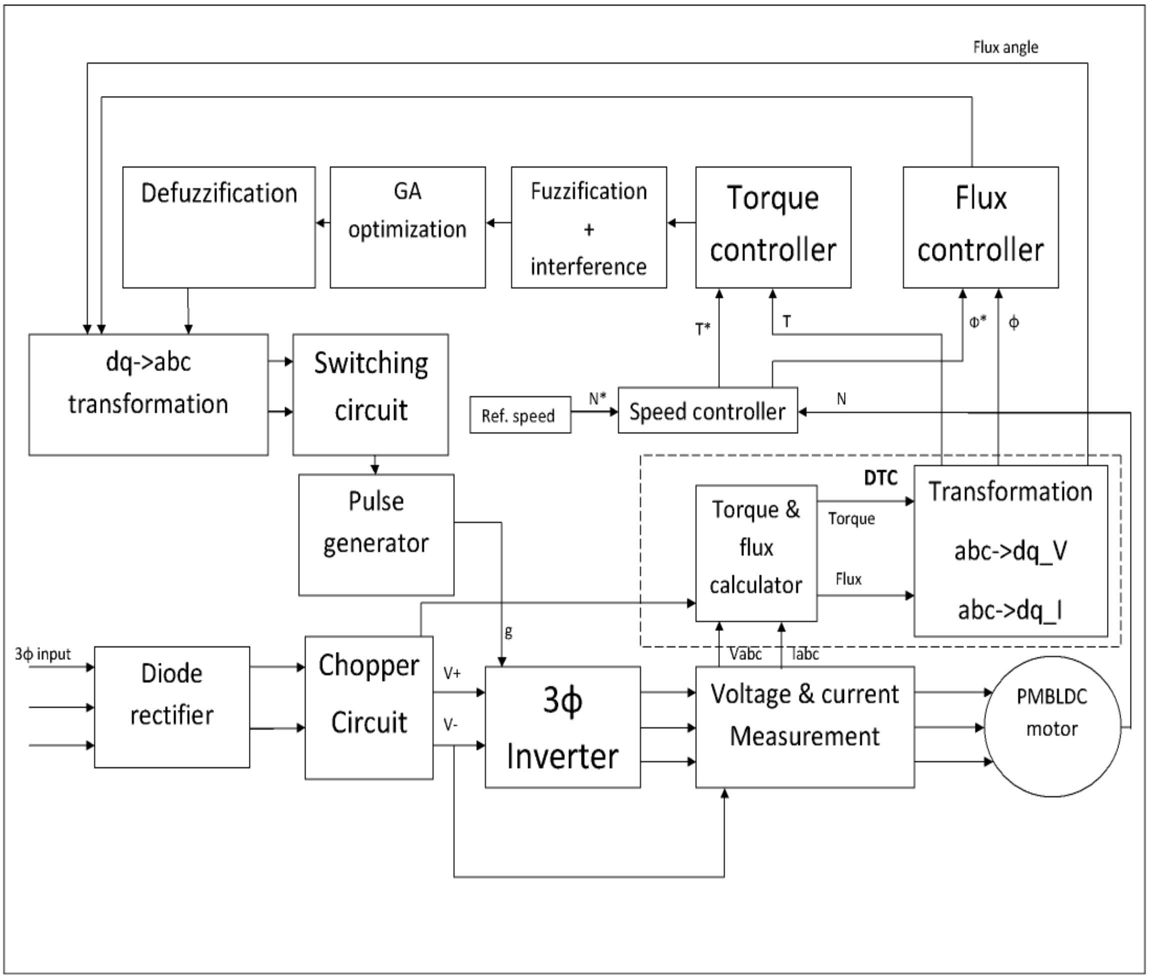
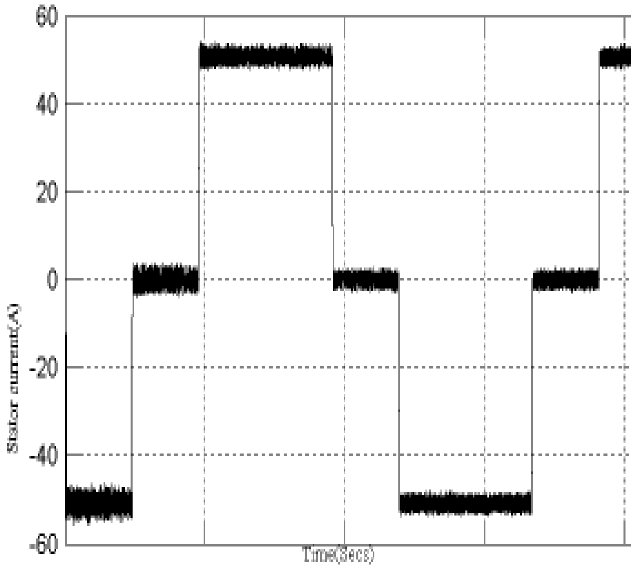


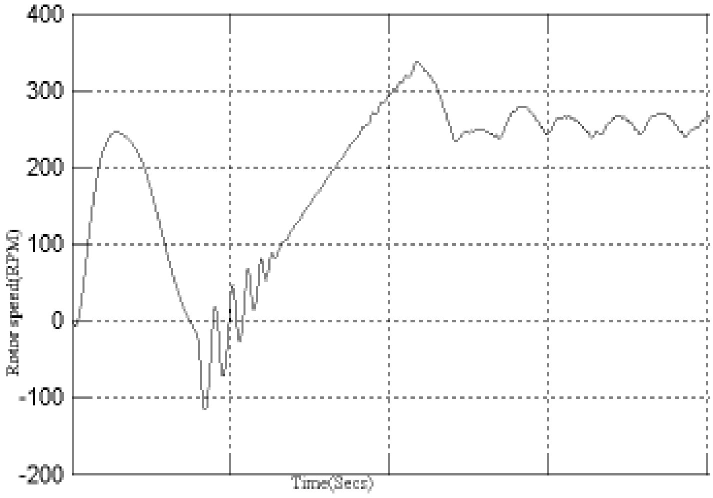
Fig. 2. Basic block diagram of the proposed DTC scheme using GA based FLC

4. Simulation results & discussion

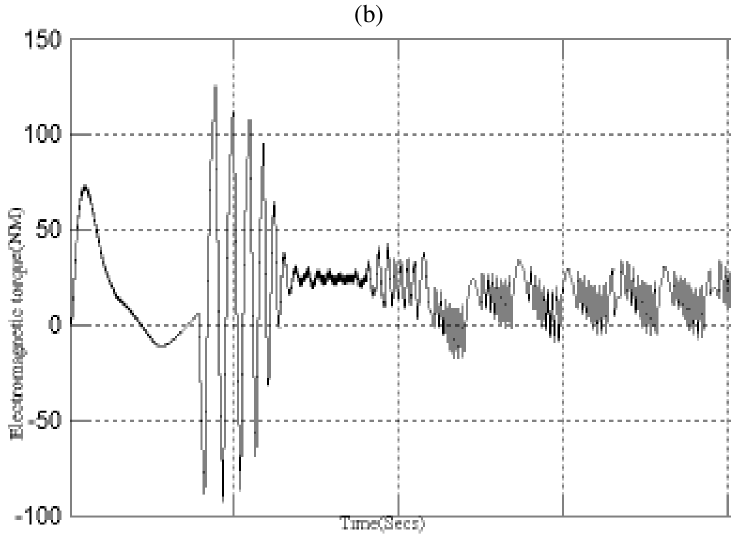
To verify the applicability of the proposed DTC scheme using the hybrid (GA based fuzzy logic) controllers for the PMBLDC motor, simulations were carried out using Matlab. Fig. 2 and 3 shows the performance comparison of the conventional Fuzzy controller and the proposed method using GA based Fuzzy Logic controller for DTC. Initially DTC scheme using conventional fuzzy logic controller was developed and the performance were compared with the proposed hybrid (GA based fuzzy logic) controller, and the later has an improved performance than the conventional fuzzy logic controller overcoming the drawbacks of the conventional controller.



(a)



(b)



(c)

Fig. 3. Simulated performance with conventional Fuzzy logic controller (a) Stator current (b) Rotor speed (c) Electromagnetic torque

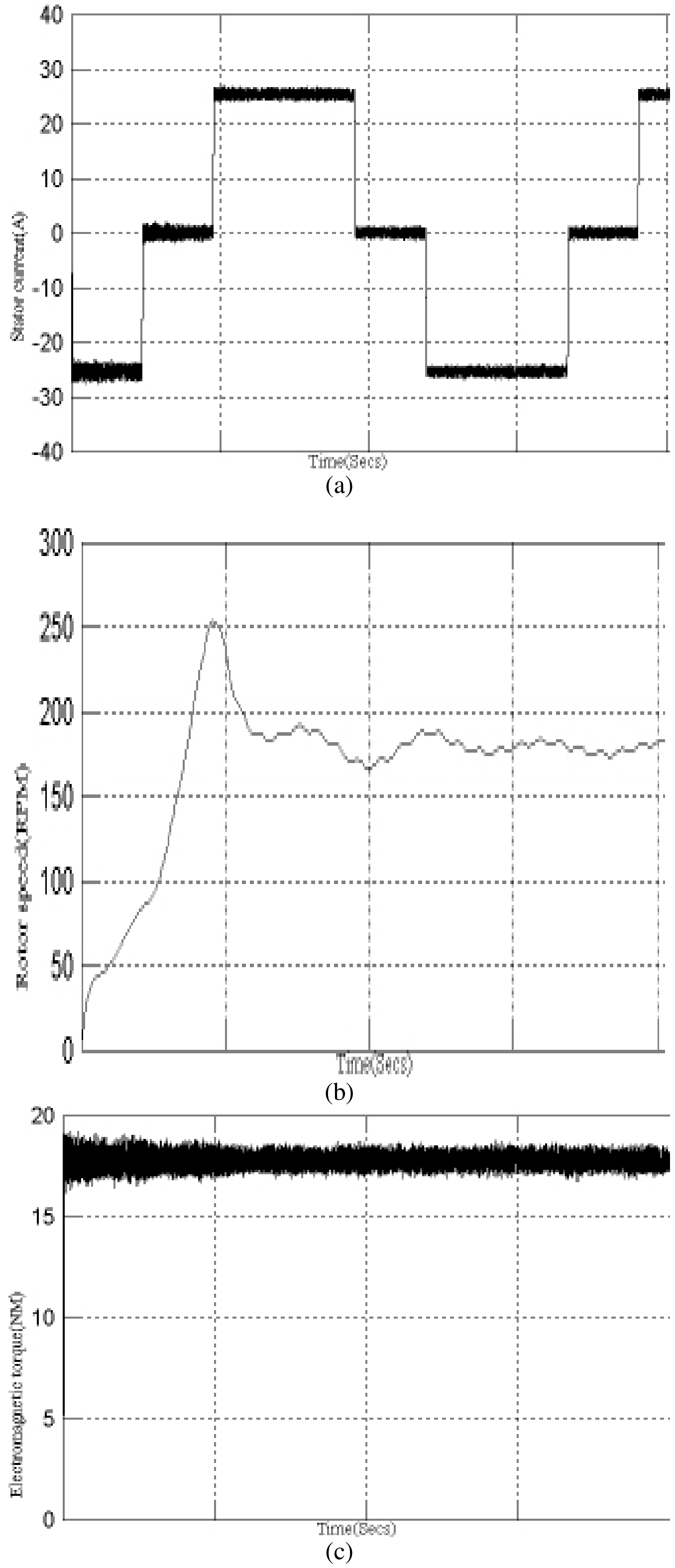


Fig. 4.Simulated performance of the proposed GA based Fuzzy logic controller (a) Stator current (b) Rotor speed (c) Electromagnetic torque

5. Conclusion

In order to prove the superiority of the proposed controller, a performance comparison with conventional FLC has been provided. Simulated results show a better control performance than that of the conventional DTC. The proposed control scheme uses a conventional control rule of DTC, but the switching pulse width is controlled by the torque error. Therefore, a simple implementation but a high control performance can be obtained. The unique feature of this paper is that GA based FLC is very simple with lesser number of membership function and rules.

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