A RULE BASED CONTROLLER FOR DC MOTOR DRIVES

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ABSTRACT

The paper presents a rule based controller (RBC) for speed regulation of seperately excited dc motor drives. This algorithm is described as the ratio of derivative of error to error and ratio of the second derivative to the first derivative of error. RBC algorihtm is used to find the duty ratio of dc-dc converter for a crisp output voltage. Simulations results of experiment show a large improvement in the transient response when compared to a classical PI controller, and confirm validity of the proposed approach.

I. INTRODUCTION

DC motor drives are highly controllable and are used in many applications such as robotic manipulators, position control, steel mining, paper and textile industries [1]. In some industrial application the high dynamic response of drivers is bounded by certain limitations such as transient time and steady state error. To achieve these limitations, different control strategies have been implemented to regulate the dc motor drive including PI, adaptive control, fuzzy logic control, neural network and nonlinear digital control [1-5].

It is a very common fact that the systems which are contain switching devices, generally exhibit non-linear feature and/or have some kinds of uncertainty. It is also known that it is usually very difficult to draw an exact model of these kinds of systems. Rule-based controllers mainly find solve in these cases of applications [6].

The constructed system in this work can be defined as a rule based controller (RBC) for speed regulation of seperately excited dc motor drives. In this algorithm, inputs of RBC are the ratio of derivative of error to error and ratio of the second derivative to the first derivative of error [7]. RBC is used to find the duty ratio of dc-dc converter for a crisp output voltage.

Comprehensive analysis and design with experimental verification are performed particularly for a dc motor drive. A rule based controller was designed, implemented, and experimentally tested. Finally, the experimental results are discussed to confirm the performance of the proposed control approach.

II. RULE BASED CONTROLLER ALGORITHM

Designed dc motor drive and digital control system are shown in Fig. 1. The dc motor drive is formed by a seperately excited dc motor and a dc-dc converter. The control system is formed by a feedback loop of speed.

The algorithm can be explained as follows:
Since y(k) is process output and error e(k), first derivative error de(k), second derivative error dde(k) are as:

$$e(k)=y(k)-y(k-1) \tag{1}$$

$$de(k)=e(k)-e(k-1) \tag{2}$$

$$dde(k)=de(k)-dde(k-1) \tag{3}$$

There are two ratio such as

$$\mathrm{ratio}_1=\frac{de(k)}{e(k)} \tag{4}$$

$$\mathrm{ratio}_2=\frac{dde(k)}{de(k)} \tag{5}$$

After these definitions, the algorithm can be divided three logical parts.

Part 1: The goal is to increase the value of ratio1 to some positive value from its initial value of zero. Although the specific increase in value depends on type of process, an increase between 0.01 and 0.2 generally gives reasonable results. In this part ratio_1 takes negative and ratio_2 takes positive values. Therefore process output approaches to the reference point.

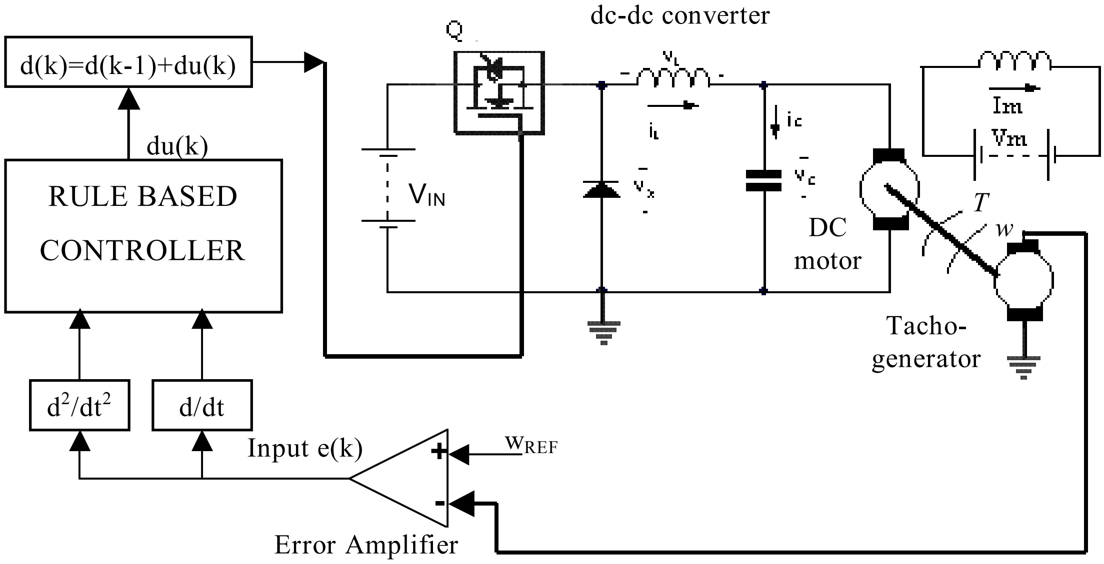

Figure 1 Speed regulation of seperately excited dc motor drives with rule based controller.

Part 2: This part aims are to avoid ratio2 rising without bounds when ratio1 and ratio2 are both positive (error is decreasing while its first derivative is increasing) so that system output doesn't exceed reference point.

Part 3: In this part $ratio_1$ and $ratio_2$ are negative hence error term and its first derivative are decreasing. The goal is to keep $ratio_1$ and $ratio_2$ close enough so that error term and its derivative approach to zero. This implies process output convergence reference point without exceeding it. Therefore, the u control value must be chosen such that $ratio_1$ and $ratio_2$ doesn't far from one another.

The reason behind chosing the change in control value dependent on the error value is to change the control value more when error is high and to change it a little when the error is low. This specification ensures fast convergence. Possible cases for ratio of e to de are shown Figure 2 and possible cases for ratio of de to dde are shown Figure 3.

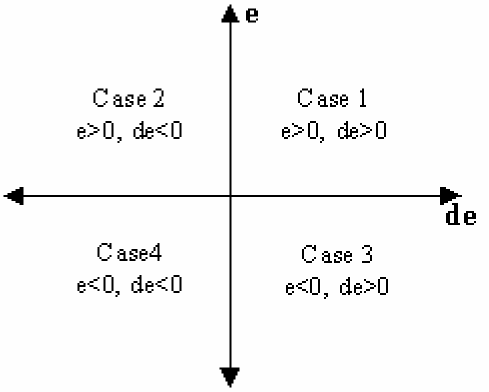

Figure 2 Possible cases for e and de

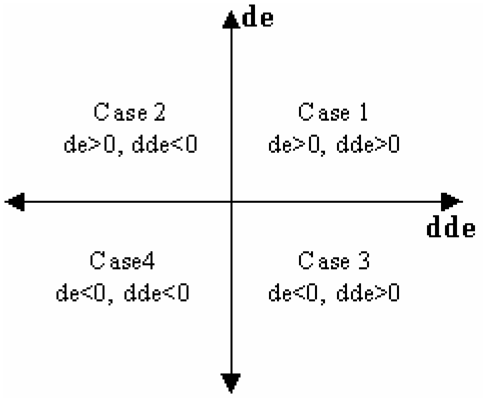

Figure 3 Possible cases for de and dde

Let d_1, d_2, d_3, d_4, d_5 and s_1 are positive parameters. The choice of specific values for these parameters is left to designer. The value of s_1 depends on the structure of process. It takes values between 0.01 and 0.5 and generally gives satisfactory results. High values of s_1 imply less rise time but also cause higher possibility of overshooting.

It is generally recommended to choose parameters d_1-d_5 between 0.01 and 10. But adaptation method can also be used. It also possible to choose some of these parameters equal to each other and leave less then three of them free in order to perform control. Moreover, the parameter s_1 which is used to define level in $ratio_1$ can further divided to include s_2 and s_3 parameters in order to increase number of partions.

A small complication can arise from situations when process output gets closer and closer to the reference point. In this case, error term and its derivative may take a value of zero, which implies denominators of $ratio_1$ and $ratio_2$ being zero.

The control algorithm is as below:

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1- muto1=abs(ratio1) and muto2=abs(ratio2)
2- If case1, then du(k)=d5.e(k)
3- If case2, then
    3.1 If muto1<s1 then du(k)=d1.e(k)
    3.2 If ratio1 negative and ratio2 positive, then du(k)=d1.e(k)
    3.3 If ratio1 and ratio2 negative, then
        If muto1≤muto2, then du(k)=d3.e(k)
        If muto2<muto1, then du(k)=-d4.e(k)
4- If case3, then
    4.1 If muto1<s1 then du(k)=-d1.e(k)
    4.2 If ratio1 negative and ratio2 positive, then du(k)=d2.e(k)
    4.3 If ratio1 and ratio2 negative, then
        If muto1≤muto2, then du(k)=-d3.e(k)
        If muto2<muto1, then du(k)=d4.e(k)
5-If case4, then du(k)=-d5.e(k)
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III. COMPUTER SIMULATION

In this section, authors show the simulation results for dc motor drive using controllers optimally designed by the RBC and classical PI controller.

The state space model of separately excited dc motor is as follows:

$$\dot{x} = A \cdot x + B \cdot u \tag{6}$$

$$y = C \cdot x + D \cdot u \tag{7}$$

Where state matrixes are as,

$$A = \begin{bmatrix} -\dfrac{B}{J} & \dfrac{K_t}{J} \\ -\dfrac{K_m}{L_a} & -\dfrac{R_a}{L_a} \end{bmatrix} \tag{8}$$

$$B = \begin{bmatrix} 0 & -\dfrac{1}{J} \\ \dfrac{1}{L_a} & 0 \end{bmatrix} \tag{9}$$

$$C = \begin{bmatrix} 1 & 0 \end{bmatrix} \tag{10}$$

$$D = \begin{bmatrix} 0 & 0 \end{bmatrix} \tag{11}$$

$$x = \begin{bmatrix} w_m(t) & i_a(t) \end{bmatrix} \tag{12}$$

$$y = \begin{bmatrix} w_m(t) \end{bmatrix} \tag{13}$$

$$u = \begin{bmatrix} V_i \cdot \dfrac{t_{on}}{T_s} \cdot T_m \end{bmatrix} \tag{14}$$

Where, $w_m(t)$ is rotor speed rad/s, $i_a(t)$ is armature current A., J is inertia constant Nm^2, B is damping constant Nm/rad/s, R_a is armature resistance Ω, L_a is armature inductance H, V_i is constant dc supply voltage V, T_m is the load torque and can constant or function of speed, T_s is switching time of dc-dc converter and F_s is switching frequency of dc-dc converter ($T_s=1/F_s$), K_t is torque constant and K_m is back emf constant. Motor paramaters are given in Table 1.

Table 1 DC motor simulation parameters

Parameter	**Value**
DC supply voltage V_i	240 V
Armature resistance R_a	0.1 Ω
Armature inductance L_a	0.055 H
Inertia constant J	0.25 Nm^2
Damping constant B	0.136 Nm/rad/s,
Switching time T_s	$2.0.\ 10^{-5}$ s
Torque constant parameter K_t	2
Back emf constant K_m	4.2
For PI Controller	
K_i	100
K_p	0.91
For Rule-Based Controller	
d_1	0.0365
d_2	0.0664
d_3	0.0664
d_4	0.0664
d_5	0.0664
s_1	0.02

The experimental results for RBC and PI controller are shown in Figure 4 and Figure 5, respectively. In those figures show the responses of under the RBC and PI controller with optimum parameters due to torque constant parameter K_t is changed from 2 to 3 at 0.03 second later. It can be seen from the figures that RBC forces the motor speed to reach the reference point in lesser time than PI controller with a smaller control effort.

IV. RESULTS AND DISCUSSION

Figure 4 shows the dynamic response of dc motor for PI controller when it is started small load after 0.03 second suddenly applied the full load with different value of K_t. It is obvious that initially, decreased the value of K_t reduces the overshoot in the motor speed and reduce both the rise and transient time. On the other hand, it increases the steady state error in motor speed w and creates a sustained armature current oscillation. So solve this problem the RBC is required.

The RBC design introduces several comforts in to designer. Such as, number of rules used in controller is reduced considerably from fuzzy logic controller. That number is rougly shrinked to one third of previous number.

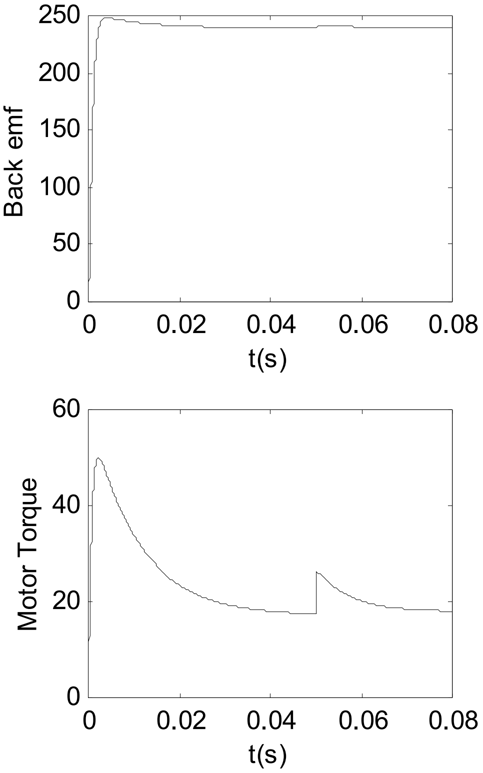

Figure 4 The experimental results for PI controller

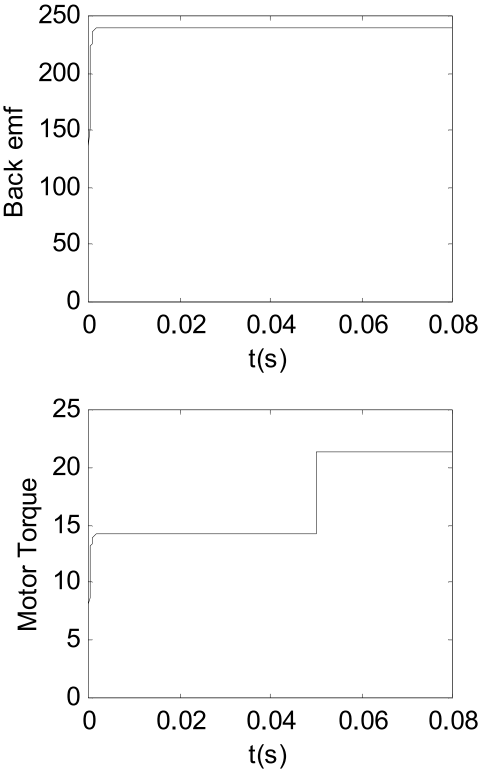

Figure 5 Experimental results for rule based controller

The proposed controller is easier to design and implement because it doesn't contain stages that are used in fuzzy, neuro-fuzzy or neural network. Another comfort is made in terms of number of calculations required for operation. Required number of calculations is reduced about %80. Therfore smaller computing power can enough for complex operations.

V. CONCLUSION

A rule based controller for seperately excited dc motor drives is presented. There are experimental results in minimizing the percentage overshoot in motor speed, the steady state error and also limiting the motor inrush current during the starting. The online control adapts result in robust and effective controller with test dynamic response minimum overshoot and eliminated inrush current. Rule based controller structure has the advantage of tolerating systems and load excursions.

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