Load Balancing of The Electric Drive System Using Two Rigid Shaft Motors with Adaptive Fuzzy Controller

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Abstract *The electric drive systems using high-power motors to meet the requirements of the load often have many difficulties both economically and technically. The high-power motor has a high manufacturing cost and requires the need for a high power transform device (controlled rectifier for DC motor, inverter for AC motor). Therefore, the solution using electric drive system using two rigid shaft motors to reduce the capacity of each motor is very needed. This paper introduces the method to design an adaptive fuzzy controller that is able to keep the load* blancing, *this model is the motors of the electric drive system using two rigid shaft motors to ensure control quality when speed, load and parameters of motors are changed.*

Keywords: *Motor; PID; Fuzzy; Adaptive Fuzzy; Load Balancing.*

I. INTRODUCTION

Controlling the electric drive system using two rigid shaft motors needs to achieve two goals: ensuring the quality of control and load balancing for the motors. This paper proposes a method for designing an adaptive fuzzy controller to achieve the above objectives. The results are verified by simulation on Matlab-Simulink software to guarantee control quality and load balancing for the electric drive system using two rigid shaft DC motors in different working modes: with load, without load and changing motor parameters (or the parameter of one motor is different from the manufacturer default).

II. CONTENS

A. *The Problem of Control Two Rigid shaft Motors*

In fact, many industrial production lines require the use of DC motors with capacities up to hundreds or even thousands of KW. The use of high-power motor to meet the requirements of the load is difficult. That includes difficulties in design, manufacture and the cost of high-power motors. Moreover, to transport the motors from manufacturing place to the destination as well as the installation of them in the working place have many obstacles because of the size and weight factors. Operating a high-power motor requires high-power converter. To solve those problems, the method using two rigid shaft motors is applied as shown in Fig. 1.

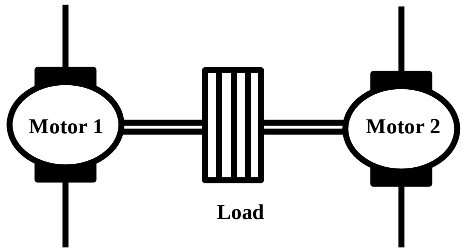

Fig 1: Solution of using two rigrid shaft motors

B. *Controlling of two rigrid shaft motors*

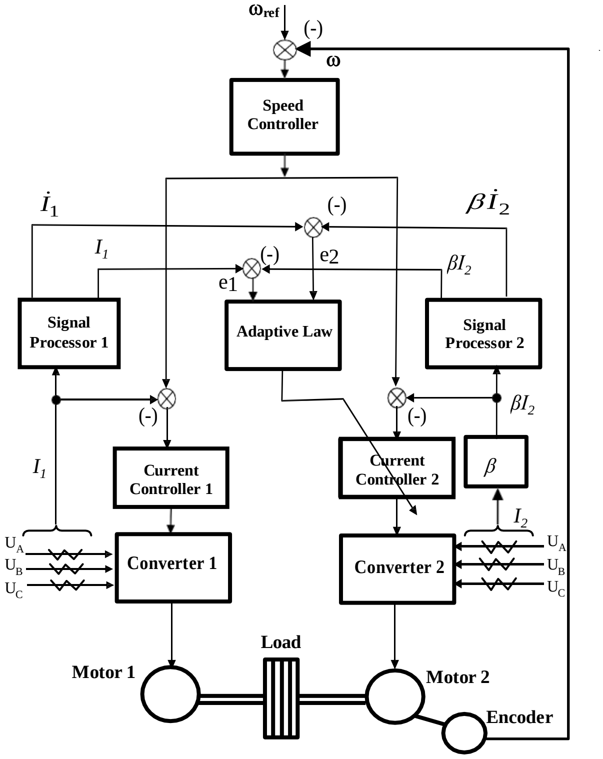

Fig 2: The block diagram of the drive system using model reference adaptive fuzzy controller

This paper introduces the control solution with 2 control loops. The external loop with only one controller is the speed controller for both motors with the fixed parameters (PID controller can be used). The separated internal control loop with two current controllers (one for each motor) uses the adaptive furry controller. In which, the current controller for motor 1 uses a classical PID controller and the current controller of motor 2 is an adaptive fuzzy controller with output signal of the current control loop of motor 1 is used to be the sample for the current control loop of motor 2. The parameters of the adaptive fuzzy controller of motor 2 have adjusted according to the difference between the current of two motors, that is shown in Fig. 2 [1], [9], [10].

During the operation following this model, the current of motor 1 is considered as the sample current. Then, the current of motor 2 always tracking the current of motor 1 with the smallest error. That means the armature currents of both motors are always be the same as expected.

From the block diagram of Fig. 2 and according to [7], the control structure of the electric drive system using two rigid shaft motors is built with the control structure of the motor 1 considered as the model to create the adaptive law for motor 2 as shown in Fig. 3:

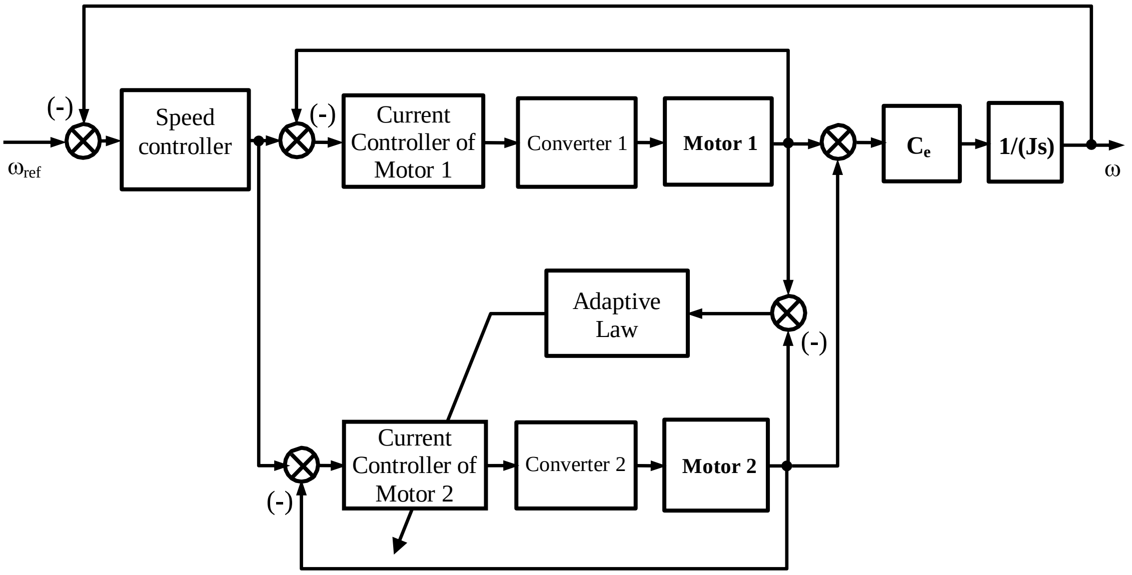

Fig 3: Adaptive control structure of the electric drive system using two rigid shaft DC motors

C. Parallel model adaptive fuzzy control structure design

1) Model adaptive control system using classic adaptive theory

Consider an object described by the equation:

$$\frac{dy}{dt} = -ay + bu \qquad (1)$$

Reference model with equation:

$$\frac{dy_m}{dt} = -a_m y_m + b_m u_c \qquad (2)$$

Control signal: u= $K_1u_c - K_2y$ with error $\varepsilon = y_m - y$.

The expression ε contains an adjustment parameter. We need to find the adaptive structure to adjust the parameters K_1 and K_2 to the desired value so that the error ε approaches 0. To find out this adaptive mechanism, the Liapunov stability theory or the Gradient method can be used:

- Adaptive law using Lyapunov:

Assump that $b\eta > 0$ and choose the ***Lyapunov function***:

$$V(\varepsilon, K_1, K_2) = \frac{1}{2}\left[\varepsilon^2 + \frac{1}{b\gamma}(-bK_2 - a + a_m)^2 + \frac{1}{b\gamma}(-bK_1 + b_m)^2\right] \qquad (3)$$

Following the regulating law, the parameters K_1 K_2 in order to let ε→0 is:

$$\frac{dK_1}{dt} = \gamma u_c \varepsilon \ ; \qquad \frac{dK_2}{dt} = -\gamma y \varepsilon \qquad (4)$$

If there is only one variable parameter, the parameter adjustment law (4) becomes:

$$\frac{dK}{dt} = \gamma u_c \varepsilon \qquad (5)$$

- Adaptive Law using Gradient:

Assumpting that $\underline{K}$ is a parameter vector needs to be determined, and depends on the output error of the object (y) and the model output (y_m). The criteria for response error of the system is chosen:

$$J(\underline{K}) = \frac{1}{2}\varepsilon^2 \to 0 \qquad (6)$$

Then the regulation rule to adjust $\underline{K}$ following of the direction of the Gradient of J is:

$$\frac{d\underline{K}}{dt} = -\gamma\frac{\partial J}{\partial \underline{K}} = -\gamma\varepsilon\frac{\partial \varepsilon}{\partial \underline{K}} = \gamma\varepsilon\frac{\partial y}{\partial \underline{K}} \qquad (7)$$

The classical adaptive control does not need a perfect reference model. However, the difference of the model and the object as well as the their nonlinearity are only within certain limits. If the limit is exceeded, the controller will not work effectively. To overcome this disadvantage, this paper uses parallel model reference adaptive fuzzy control.

2) Structure of parallel model reference adaptive fuzzy control

One of the most common structures of fuzzy logic systems (FLC - Fuzzy Logic Control) is the type of error feedback. Structure diagram is shown in Fig. 4:

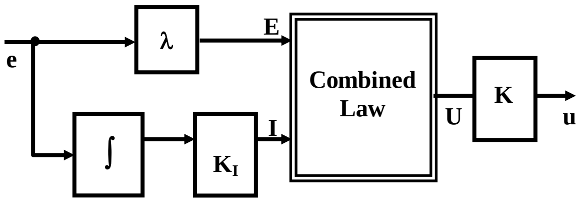

Fig 4: The basic structure of the fuzzy control system with two inputs

With K_I, λ are the input amplification coefficients and K is the output amplification coefficient. The reality shows that adjusting FLC is much more difficult than adjusting the classic controller, one of the main reasons is the flexibility of the basic identification area of the fuzzy controller and the connection of parameters. However, there is no systematic way to get all parameters.

This paper uses the adaptive methods according to Lyapunov and Gradient laws to adjust appropriately the K output amplifier coefficient of the fuzzy controller.

The Model Reference Adaptive Fuzzy Controller (MRAFC) as shown in Fig. 5

In which the control object has the transfer function G, the model has the transfer function G_m, the fuzzy controller consists of the basic fuzzy controller in combination with the amplifier K. It is necessary to determine adaptive law to adjust K similar to the straight-forward model reference adaptive fuzzy control structure to ensure difference between the model and the object reaches to zero ($\varepsilon \to 0$).

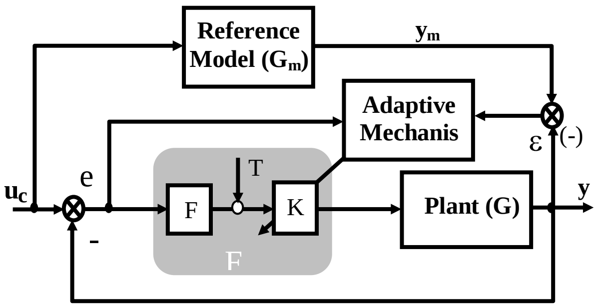

Fig 5: MRAFC adjusts output amplification coefficient

The closed-loop system around equilibrium becomes linear with the closed-loop equation:

$$y=\frac{KFG}{1+KFG}u_c \qquad (8)$$

Assuming y reaches to y_m, can approximate:

$$\frac{KFG}{1+KFG}\approx G_m$$

Then (deduce):

$$\frac{\partial\varepsilon}{\partial K}=-\frac{\partial y}{\partial K}=-\frac{KFG}{1+KFG}\cdot\frac{e}{K}\approx -G_m\frac{e}{K} \qquad (9)$$

Then, the adaptive law for FLC's output amplification coefficient following the Gradient can be determined from (7):

$$K=\gamma\frac{1}{s}G_m\frac{\varepsilon e}{K} \qquad (10)$$

Or following the Lyapunov (5):

$$K=\gamma\frac{1}{s}u_c\varepsilon \qquad (11)$$

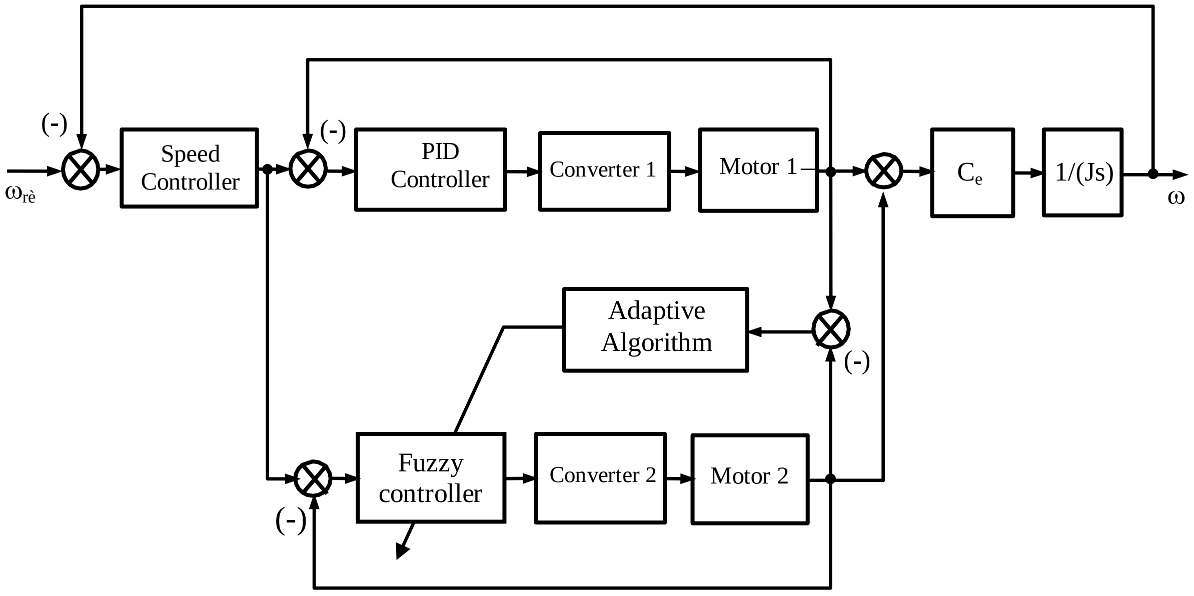

Fig 6: Structure of Model Reference Adaptive Fuzzy Controller (Motor 1)

With γ in (10) and (11) shows the convergence rate of adaptive algorithm.

Based on the design method of adaptive fuzzy controller is described, the control structure for the drive system using two rigid shaft DC motors with adaptive fuzzy controller is built as shown in Fig. 6. The adaptive law is designed following (10) or (11).

D. Controller Design

1) Current Controller Design for Motor 1

We have the control structure for motor 1 as shown in Fig. 7:

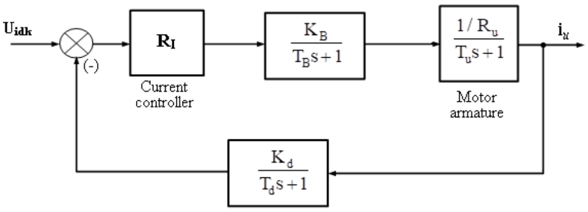

Fig 7: Current control loop

To design the controller, the parameters of the motor in the diagram in Fig. 7 need to be determined, the motor with the parameters were chosen as in the following table 1 [7]:

TABLE 1

Parameters	Meaning	Value
P	Power	2.2 (*KW*)
$\mathbf{U_{nom}}$	Nominal voltage of the motor	220 (*V*)
$\mathbf{I_{nom}}$	Nominal current of the motor	12 (*A*)
$\mathbf{n_{nom}}$	Nominal speed of the motor	1430 (*rpm*)
$\mathbf{R_a}$	Resistor of motor armature circuit	0.5 (Ω)
$\mathbf{L_a}$	Inductance of the armature circuit	50 (*mH*)
η	Efficiency	0.85
$\mathbf{C_e}$	Coefficient of electromotive force	1.37 (*V.s/rad*)
J	Moment of inertia of the system converted to the motor shaft	0.1 ($kg.m^2$)

From the motor parameters, the transfer function of the plant is determined:

$$G_u(s)=\frac{1/R_u}{T_u s+1}=\frac{2}{0,1s+1} \qquad (12)$$

Transfer function of a half-wave 3-phase rectifier:

$$G_{BD}(s)=\frac{K_B}{T_B s+1}=\frac{10}{0,0033s+1} \qquad (13)$$

And the current sensor has a transfer function:

$$G_d(s)=\frac{K_d}{T_d s+1}=\frac{0,6}{0,0237s+1} \qquad (14)$$

Using the optimal module method, we got the transfer function of the current controller [5]:

$$R_I=0,1543(1+\frac{1}{0,1s})=\frac{1+0,1s}{0,648s} \qquad (15)$$

2) Adaptive Fuzzy Controller Design

To design the parallel model reference fuzzy controller, we implement in 2 parts:

Part 1: Design fuzzy controller

Normal fuzzy controllers are designed in 3 steps:

- *Step 1:* Select the related functions
- *Step 2:* Select the control law
- *Step 3:* Fuzzy actions in the deductive box:
  - + Translucent
  - + Dull deduction
  - + Fuzzy

Part 2: Use adaptive laws according to (10) or (11) to adjust the fuzzy controller.

3) Design of the Speed Control Loop

Since the reaction of the current loop is very fast compared to the speed loop, for simplication, it is possible to approximate the closed transfer function of the current loop into a first degree [1]:

$$G(s)=\frac{K}{T_R s(T_s s+1)+K}=\frac{1}{2T_s^2s^2+2T_s s+1}\approx\frac{1}{0,054s+1} \qquad (16)$$

The target of the adaptive fuzzy controller model of motor 2 is to let the closed loop control system of motor 2 be the same as the closed loop control system of motor 1. Considering the transfer funstion of all closed loop control system of motor 2 are the same as that of motor 1 when designing the speed controller, the speed controller for both motors was designed according to [5], we have:

$$R_\omega=0,3379(1+\frac{1}{0,216s}) \qquad (17)$$

E. Evaluation of Controller Using Matlab/Simuink

1) Simulation Structure

The simulation structure diagram of current loop of two motors with adaptive fuzzy controller for motor 2 as, shown in Fig. 8.

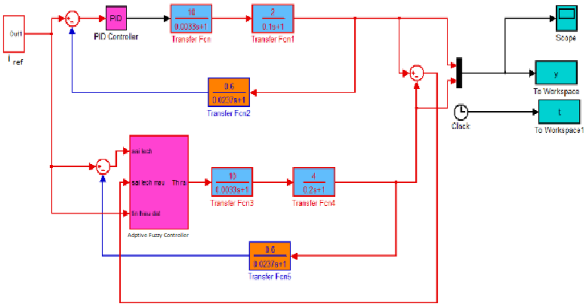

Fig 8: The simulation structure of the current loops of the drive system using two rigid shaft motors

The simulation structure of the two-loops system (current and speed) of the system with the adaptive fuzzy controller for the current loop of motor 2, as shown in Fig. 9.

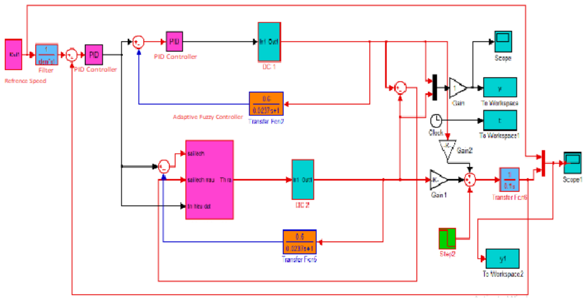

Fig 9: The simulation structure of the system using two rigid shaft motors

2) *Simulation Results*

**. With current control loop*

- In case of similar parameters of two motors:

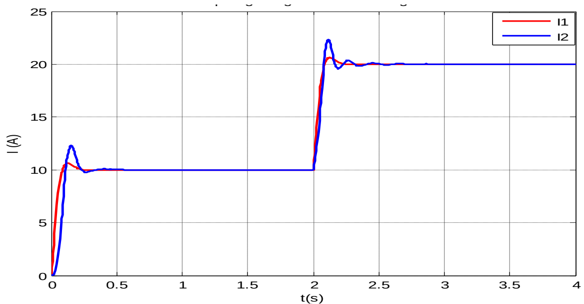

Fig 10: Current response of two motors with equal parameters

- In case the armature parameter of motor 2 is changed (1 / R_u changes from 2 to 4):

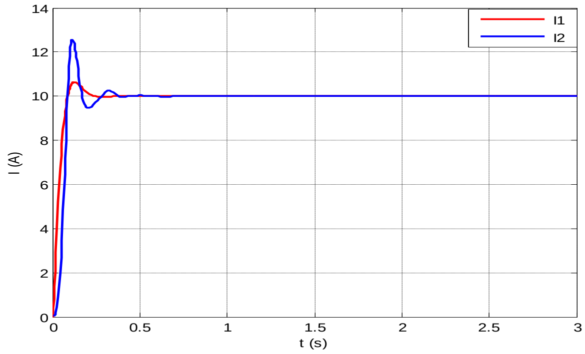

Fig 11: Current response of two motors with the different bettween parameters of motor 2 and motor 1

- In case the armature parameter of motor 2 changed (1 / R_u changed from 2 to 4 and T_u changed from T_u = 2 to T_u = 0.4):

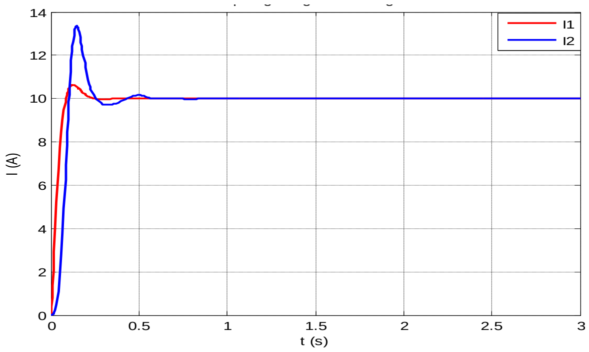

Figure 12: Current response of two motors with two different between parameters of motor 2 and motor 1

Remark:

From the simulation results from Fig. 10 to Fig. 12, the quality of the model reference adaptive fuzzy controllers has been guaranteed that the current of the motor 2 is very close to the current of motor 1 (sample). The simulation results show that when the parameters of motor 2 is changed, the current of the motor 2 is still tracking to the current of motor 1 and guarantee the quality of tracking control. As a result the model reference adaptive fuzzy controller for the motor 2 has worked well, always guarantee the current of the two motors follow each other, even in the case parameters of the second motor are changed

**. With speed control loop*

- Consider the case of speed changed and no load:

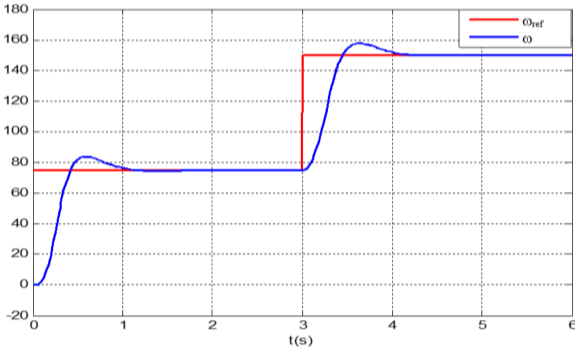

Fig 13: Speed response of two motors (same speed) with speed changed and without load

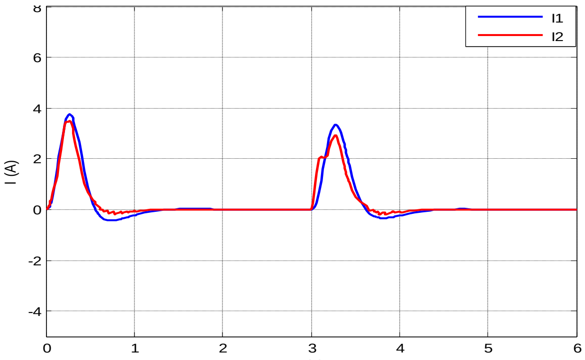

Fig 14: Current response in without load working mode

- Consider the case of speed changed and with load:

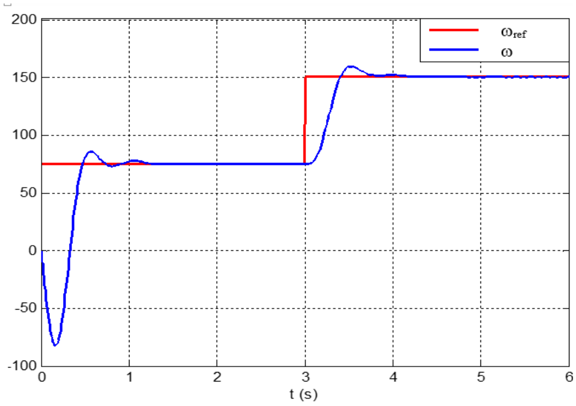

Fig 15: Speed response of two motors (the same speed) when speed changed and with load

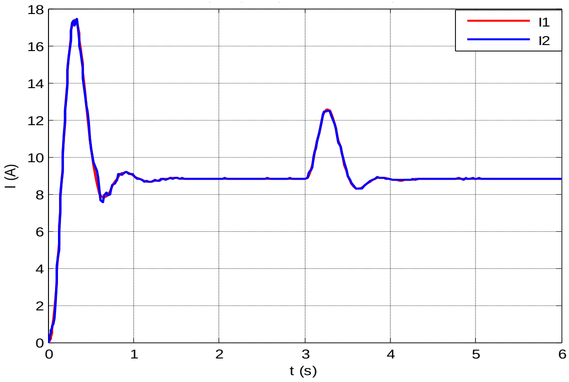

Fig 16: Current response with load

Remark:

From the simulation results (Fig. 13 to Fig. 16), the speed controller worked well in any case such as working with load and without load and even with speed changed. The speed of motors are tracking the set value in different working modes such as working with load, without load and when the parameters of motor 2 are changed. The simulation results shown that the adaptive fuzzy controller of motor 2 is guaganteed.

III. CONCLUSIONS

The article proposed the controller for the two rigrid shaft motor system guarantee the load balancing by parallel model reference adaptive fuzzy controller.

The simulation results of current and the speed of both motors in different working modes show that the quality of the designed controllers have guaranteed as required.

REFERENCES

[1] Nguyen Duy Cuong (2014), Ministry-level Science and Technology topic: "Balancing load for two parallel rigrid coupling motors".

[2] Lai Khac Lai (2003), “Some methods of synthesizing controllers based on of fuzzy logic and adaptation”, Technical doctoral thesis, Hanoi University of Technology.

[3] Phan Xuan Minh and Nguyen Doan Phuoc (2002), “Fuzzy logic control 3rd printing with additional”, Science and Technology Publishing.

[4] Nguyen Doan Phuoc (2012), “Analyze and Control of Nonlinear system”, Bach Khoa Publishing.

[5] Nguyen Doan Phuoc (2002), “Nonlinear control theory”, Hanoi University of Science and Technology.

[6] Nguyen Phung Quang (2006), “Matlab & Simulink”, Science and Technology Publishing, Hanoi.

[7] Vu Gia Hanh, Tran Khanh Ha, Phan Tu Thu (1998), “Electrical Machine T1”, Science and Technology Publishing

[8] Bui Quoc Khaánh, Nguyen Van Lien, Nguyen Thi Hien (2008), “ Electrical Transmission”, Science and Technology Publishing

[9] Vo Minh Chinh, Nguyen Quoc Hai, Tran Trong Minh, “Power Electronics”, Science and Technology Publishing

[10] Astrom K.J. (1994), Wittenmark B., “Adaptive Control”, Prentice Hall.

[11] Job van Amerongen (2004), “Inteligent Control, Part 1: Model Reference Adaptive Control”, University of Twente.