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HYBRID CONTROLLER BASED ON INTELLIGENT SPEED SYNCHRONIZATION INDUCTION MOTOR FOR THE FOUR WHEEL DRIVE OF ELECTRIC CAR

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ABSTRACT

This paper describes the use of two dual induction motors as the driving electric cars for both the front and rear wheels. The two motors do not only have a synchronous speed used simultaneously but also support torque to drive this car. So modeling a three-phase induction motor is developed by employing a simulated motor speed control system using fuzzy controller. Then a test is conducted to the simulated motor speed rotation that has been designed with a fuzzy controller. After that the second electric motor rotation is also simulated at the front wheels and rear wheels of the car. To view the synchronization speed of the two motors synchronization, a test is performed to the two motor speeds. Two speed motor coordination systems for synchronization are controlled by using a Neural Network controller. The synchronization for the transient response is performed by the learning process on Neural Network with back-propagation method to get the weighted value for the different speeds. The simulation results are taken from the coordination model, and then the running simulation system is also performed to get an overview of the system output. The simulation shows that, after coordination with each system motor, the results of speed control are obtained with a small error value although the various amount of nominal disturbance load is changed.

Key-words: *Systems Of Coordination, Synchronization Speed, Fuzzy And Neural Network Controller*

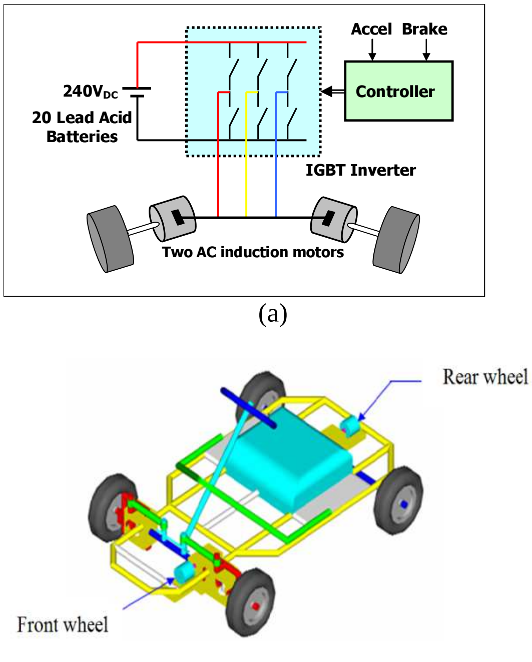
1. INTRODUCTION

It is generally difficult to measure the calculation of the motor speed parameters if there is no performance induction motor control with the help of technical implementation and use of the motor model. The use of induction motor regulation technique has been widely performed by several methods but the results are still felt less satisfactory [1]. The use of these systems is often faced with many obstacles in the process of setting the double drive system. Double Activator means that the two motors drives are controlled by an equipment system. The second mover is required to coordinate the identification of parameters for the coordination system. To overcome these problems an induction motor control system is then arranged by using a fuzzy controller that functions as a speed control on each of the induction motor and a method of Artificial Neural Network (ANN) setting that serves as the system coordination. Development in the ongoing motor speed settings, especially the induction motor speed control, has excellent performance [2]. When the setting is done, an inverter is employed to run the two induction motors, as in figure 1.

Therefore, this research should be able to:

- Determine the membership function of fuzzy controller in the controller design on each motor for speed control.
- Design mechanical systems adequate for the coordination of two motors that can respond to changes in speed.
- Design a network weighting value Neural Network that has a learning capability to map the input patterns into output patterns, and function as a devise for the adequate system of coordination to provide response to speed changes.

In this paper, two speed controls of induction motors are provided to each motor with an inverter to synchronize the speed of both motors. Next on the preparation of each section, mathematical modeling of three-phase induction motors is discussed to give control coordination for the preparation on two motors and act as a model of simulation with simulink.



(a)

(b)

Figure 1 Driving two motors
(a) One inverter with two motors (Simon Roud, IEEE, 2004)
(b) Two inverters for two separate motors (front and rear drives)

2. MODELING THREE-PHASE INDUCTION MOTOR

By modeling like d-q, some basic equations of induction motor can be stated in vector notation:

2.1 Electromagnetic Torque

Electromagnetic torque is a function of the stator and rotor currents such as follows:

$$T_e = \frac{3}{2} PM \left(i_{dr} i_{qs} - i_{qr} i_{ds} \right) \qquad (1)$$

Note: P = number of pairs of poles.

2.2 The speed of motor

Motor speed is a function of motor torque and load torque, expressed as follows:

$$\frac{J}{P}\frac{d}{dt}\omega_r + B\omega_r = T_e - T_L \qquad (2)$$

In induction motors with cage motor type, voltage on the rotor is equal to zero (Vr = 0). Equation (2) can be written in the form:

$$\frac{d}{dt}\omega_r = \frac{P}{J}(T_e - T_L) - \frac{B}{J}\omega_r$$

(3)

Rotor position is: $\frac{d}{dt}\theta_r = \omega_r$

(4)

For motors with P pairs of poles, the mechanical rotation speed of the motor is:

$$n = \frac{60}{2\pi}\frac{\omega_r}{P} \text{ [rpm]}$$

(5)

For a symmetrical stator voltage, the equation is:

$$V_{abc} = \sqrt{2}\, V \operatorname{Re}\left(e^{j(\omega_s t - (k-1)\frac{2\pi}{3})}\right) ,\ k = 1,2,3$$

(6)

Complex phase form is:

$$\vec{V}_s = \frac{2}{3}\left(V_a + aV_b + a^2 V_c\right)$$

(7)

Note : $a = e^{j\frac{2\pi}{3}}$

If the coordinate system rotates at an angle θ_b of the stator phase, the average speed is:

$$\vec{V}_{sb} = \vec{V}_s e^{-j\theta_b} \qquad (8)$$

Note : $\vec{V}_{sb} = V_d + jV_q$

thus obtained equation is :

$$V_d = \operatorname{Re}(\vec{V}_{sb}) = \frac{2}{3}\left[V_a \cos(-\theta_b) + V_b \cos(-\theta_b + \frac{2\pi}{3}) + V_c \cos(-\theta_b + \frac{4\pi}{3}) \right]$$

(9)

$$V_q = \operatorname{Im}(\vec{V}_{sb}) = \frac{2}{3}\left[V_a \sin(-\theta_b) + V_b \sin(-\theta_b + \frac{2\pi}{3}) + V_c \sin(-\theta_b + \frac{4\pi}{3}) \right]$$

(10)

If the values of practice θ_b=0 and ω_b=0, they are called *stator coordinate* [1]. When the rotor is called *reference frame*, it rotates on an angle (θ_b - θ_{er}).

If three symmetric wires are used, the component of current on zero ordinate is zero. Thus the voltage *d-q* stator can be stated as follow

$$\begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(-\theta_b) & \cos\left(-\theta_b+\frac{2\pi}{3}\right) & \cos\left(-\theta_b+\frac{4\pi}{3}\right) \\ \sin(-\theta_b) & \sin\left(-\theta_b+\frac{2\pi}{3}\right) & \sin\left(-\theta_b+\frac{4\pi}{3}\right) \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{11}$$

3. CONTROLLER

Control methods are used to regulate the speed of motors, both a synchronized motor with Artificial Neural Network (ANN) based on back-propagation and the each motor with a fuzzy controller. The ANN input Controller includes output from the motor-1 and motor-2, the rotate position of the motors and the motor speed set-point. So when the two motors drive simultaneously to run the electric car the motors should have the same speed. Therefore, the motor speed control with fuzzy controller for each motor is used to improve the performance of this controller, which will be explained in the following sections.

3.1 Controller Coordination

Figure 4 illustrates the two systems of interaction used to facilitate the completion of the coordination of two or more motor control systems. Dynamical system is expressed as follows:

$S_1(U_1,Y_1,W_2)$= dan $S_2(U_2,Y_2,W_1)=0$ (12)

With : $Ui \in R^{n_i}$ (Riil), $Wi \in R^{m_i}$ (Riil) and $Yi \in R^{p_i}$ (Riil), for $i = 1,2$.

With the number of dynamic system output vector $p = p_1 + p_2$, the two dynamic system control signal vector $n = n_1 + n_2$ and the loads of interacting vector $m = m_1 + m_2$.

With p_1, n_1, m_1: vector on motor-1 (S1); p_2, n_2, m_2: vector on motor-2 (S2).

Constraints are expressed by :

$$S_0 = \{(U,Y,W): S_1 = 0, S_2 = 0\} \tag{13}$$

By : $U = \left[U_1^T, U_2^T\right]^T \in R^n$ additional control vector, $Y = \left[Y_1^T, Y_2^T\right]^T \in R^p$ is an additional system output vector, $W = \left[W_1^T, W_2^T\right]^T \in R^m$ is the vector that describes the load interaction between the two systems.

Typically, cost functions of multiple systems are the sum of the cost function of all system components:

$$J(U,Y,W) \equiv J_1(U_1,Y_1,W_2) + J_2(U_2,Y_2,W_1) \tag{14}$$

Coordination can be applied to multiply the systems in an optimization problem: to obtain the value of cost function J, the minimum value is referred to the constraint S0. There is no common approach to solve the problem; therefore, the multiple systems are complex, but some of the concepts and basic principles of coordination can be shown in a model of coordination. In this method, the problem is divided into two levels of optimization problems. First, estimating the interaction of W is fixed at Z. Then calculating the value of:

$$H(z), H(Z) = \min[\, J(U,Y,Z)] \tag{15}$$

for $(U,Y,Z) \in S_0$

H (Z) is then solved by making interaction until the desired performance is achieved.

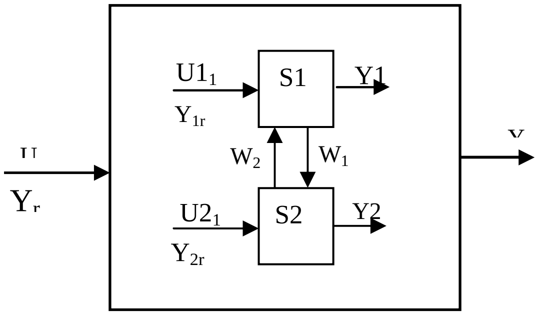


Figure 2 Interactions of two systems [3]

The basic principle of coordination for the interaction prediction is set in this modeling. Supposed $\hat{W} = \left[\hat{W}_1^T, \hat{W}_2^T\right]^T$ IS THE load interaction prediction and $W = \left[W_1^T, W_2^T\right]^T$ IS the actual load interaction under the control signal U, all the optimum conditions will be achieved if the predictions give the same value. From the condition above, the solution of the optimization problem depends on the knowledge of the structure and dynamic parameters of the lowest level subsystems (S_1 as the motor 1 and S_2 as the motor 2 do not interact) and how each subsystem interacts IS expressed mathematically. In a hierarchical system, AS expected, the addition of the coordinator should not affect the internal structure or parameters at lowest level subsystems. The coordinator should only give orders to the appropriate coordination of subsystems, so that each subsystem can be designed independently from the other subsystems. The higher its level is, the better the results are obtained.

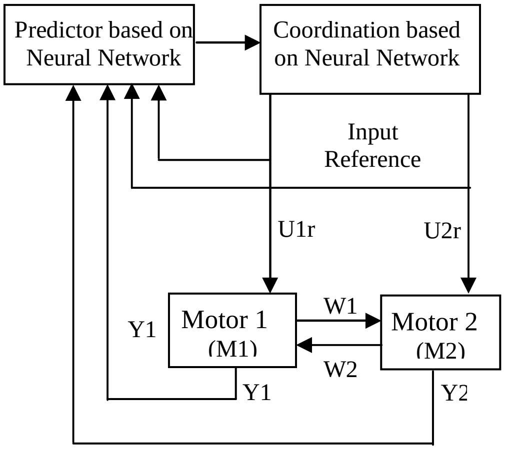


Figure 3 Coordination system block diagram

In a hierarchical structure, each sub-system is indicated by the mapping of the reference input to output. Controllers of each sub-system are designed separately and do not depend on each other. In order not to disturb the internal structure or sub-system parameters, the only control variable is referred as the input of the sub-system.

The purpose of coordination is to select the reference input vector resulting the error minimized occurrences. Estimating the prediction of the main output is related to each reference output option and constraints are expressed by the establishment of generated rules. Then, within a certain sampling interval, the desired performance can be provided by the experiments in the interaction of different load inputs and setting them according to the predictions of the main output.

Coordinating the preparation of controller algorithms:

- Developing sub-system coordination is shown in Figure 4.

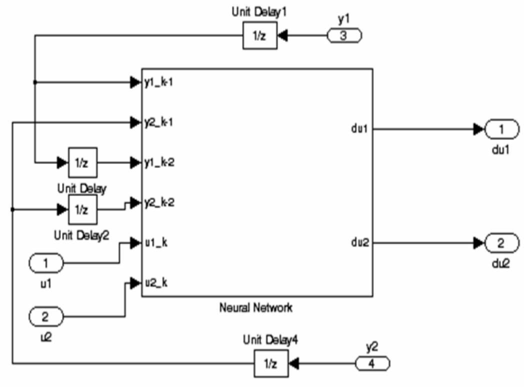


Figure 4 Coordination system for synchronizing the speed of two motors

- Designing Neural Network controller coordination is executed in the following steps:

Find out weighted value V (from the input layer to hidden layer), W (from the hidden layer to output layer), b1 as index of refraction (refractive index of the input layer to hidden layer) and b2 (refractive index of the hidden layer to output layer), through the back propagation method such as follows:

- The data measurement for various different loads carried out by Simulink is stored in the form mat.file.
- Because matlab works in the workspace, a simulation model is then created to transform data from mat.file to the workspace.
- The data are needed to find out the weighting value in the matrix (600 x 6), and they are created / compiled in matlab program. The data are converted from one column to 600 rows by 6 columns sequentially.
- The data are already in the form of matrix, file names are then given to them for input and output patterns desired. The data are executed in the program back propagation. The data obtained are in the raw form which is still used in the learning process. On the other hand, the bias of the system is processed on Neural Networks, and the data must be in the same range of activation functions, which normally lie between 0 and 1. It is therefore necessary to process the raw data by:

$$d_n = \frac{d_x - d_{\min}}{d_{\max} - d_{\min}} \tag{16}$$

Note: d_n - The normalized data

d_x - Raw data

$d_{\max}$ - Maximum value of the raw data

$d_{\min}$ - Minimum value of the raw data

- The back propagation program is processed to get the weighted value of interaction desired, that is, the smallest error value.
- Once the weighted inputs and bias index are obtained, they are delivered into the simulation model, Neural Network controller.
- A simulation model is performed by the coordination of multiple (two induction) motors and the Neural Network controller with continuous and changing loads.

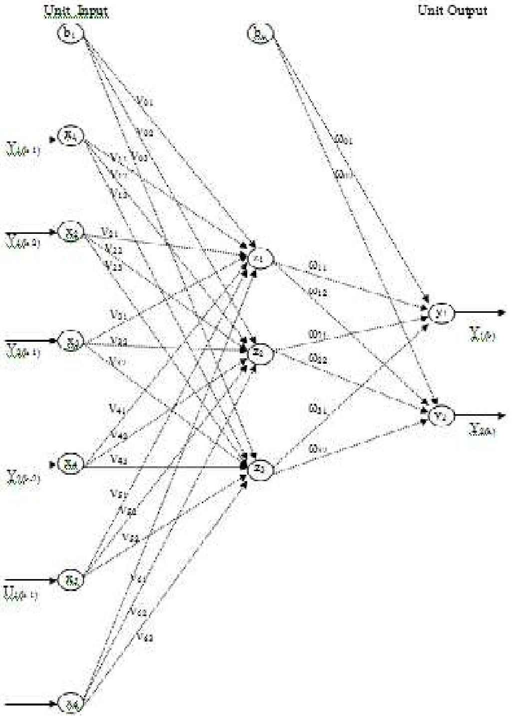


Figure 5 Neural Network Architecture Coordination system

3.2 Fuzzy controller on each motor

A controller using fuzzy is attached to each motor. The controller output is determined by using the method of fuzzy controller for each motor to find out both the error and delta error. The fuzzy controller algorithm formulation is as follows:

- Preparation of the membership function.
- Membership function includes both input and output data. The input is the data for Error and Delta Error from motor speed and the output is as a control signal source for the dc voltage inverter.
- Preparation of the Rule base.
- Rule base is a group of fuzzy rules related to the state of the input and output signals. Rule base is the basis for making decision or reasoning which is processed to do the control for the signal output from an input condition that has an error and delta error based on the set up rules. Inference process produces an output signal that is still in the form of fuzzy numbers showing a degree of membership of the control signal. In this case the fuzzy control system uses the error and delta error as a feedback input, and the output as the control for signal (voltage). Therefore, there is only one group of rule base, using a seven-level quantization in the form of linguistic variables NB, NS, Z, PS, PB.
- Preparation of defuzzification process.
- To obtain the output action of a condition input is done by following predefined rules called inference or reasoning (decision making). Decisions resulting from this reasoning process are still in the form of fuzzy, a degree of membership of output. These results must be converted back into non-fuzzy numerical variables through defuzzification process. The method used is defuzzification Centre of Area (COA), and the method is defined as follows:

(1 $$v_0 = \frac{\sum_{k=1}^{m} V_k \mu_v(V_k)}{\sum_{k=1}^{m} \mu_v(V_k)}$$

4. SIMULATION AND ANALYSIS TESTING

To run two motors with the coordination system should be done to obtain the magnitude of weighting parameters Neural Network controller. To get the weighting parameter, simulating the system without coordination with various loads is done and the results of all data obtained and sequenced are used as input controller Neural Network. The controller uses six inputs, two outputs with three layers and two bias indexes. Neural Network Controller uses a back propagation method. Simulation results in the matrix (23). Having obtained the value weighting, simulations are done on the model coordinate system fixed to the load, as shown in figure 4 for different loads.

$$V = \begin{pmatrix} -0{,}4326 & 0{,}4808 & 0{,}4447 \\ 0{,}2864 & -0{,}3216 & 0{,}2153 \\ -3{,}0146 & -1{,}2035 & 26{,}5787 \\ -16{,}4788 & 3{,}2536 & -150{,}0732 \\ 0{,}3026 & -3{,}9398 & 39{,}3867 \\ -15{,}9298 & -0{,}7232 & -130{,}8195 \\ 30{,}9913 & -1{,}1697 & 217{,}5605 \end{pmatrix} \quad (18)$$

$$W = \begin{pmatrix} -0{,}7597 & -0{,}7597 \\ -14{,}7654 & -14{,}7654 \\ -38{,}7494 & -38{,}7494 \\ 39{,}5229 & 39{,}5229 \end{pmatrix} \quad (19)$$

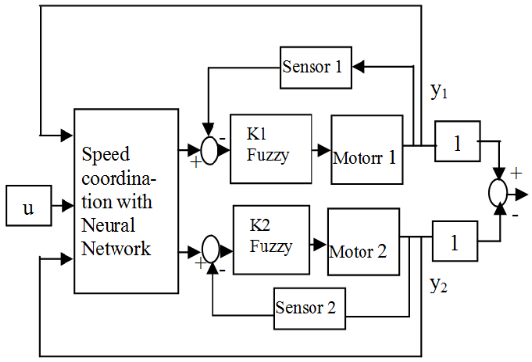


Figure 6 Block diagram of the synchronization system of two-speed motors

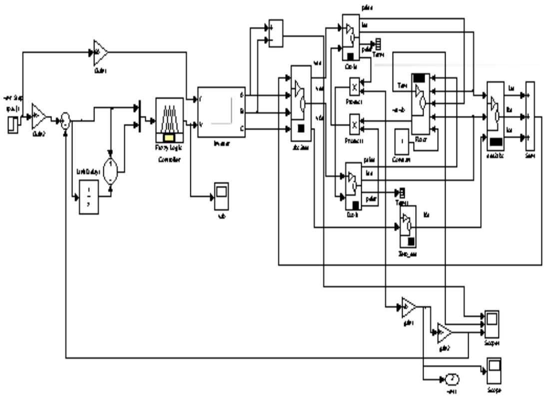


Figure 7 Simulation of a motor speed control with Fuzzy Controller

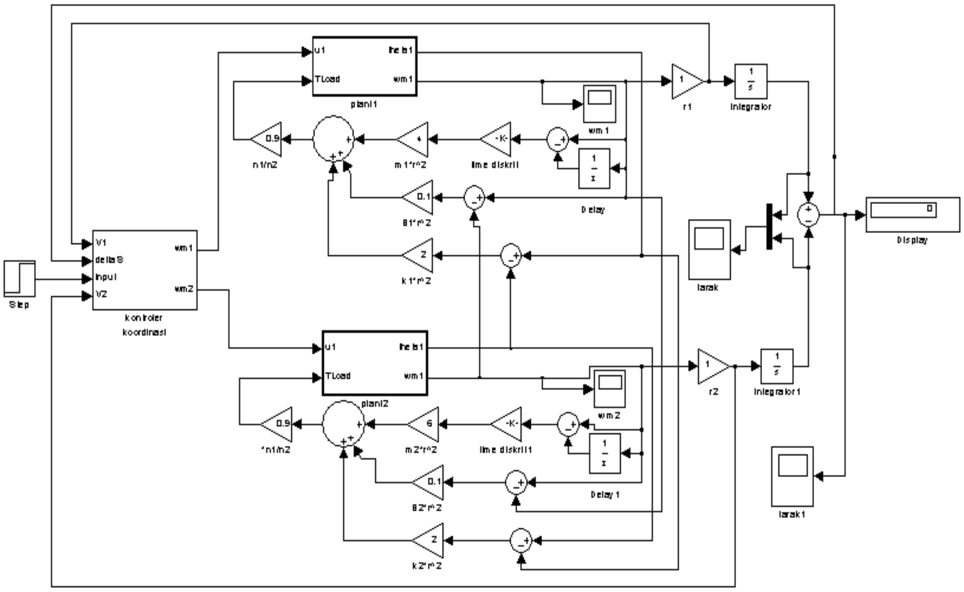
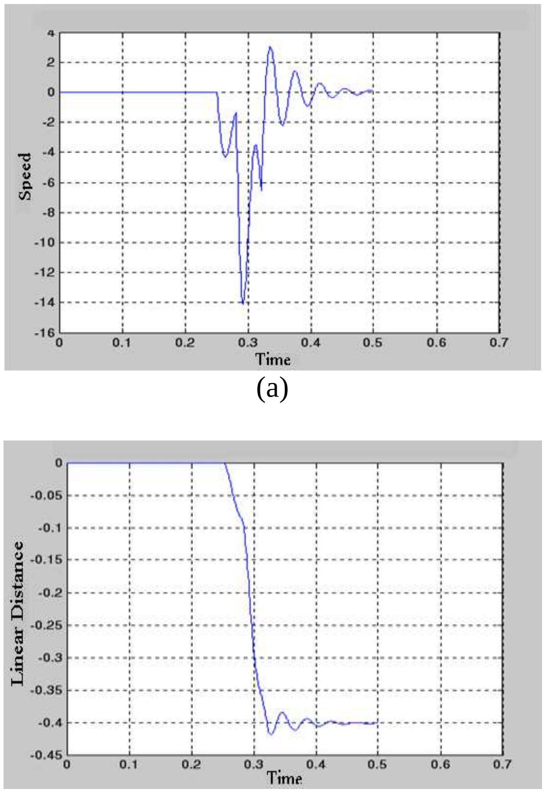


Figure 8 Simulation synchronization speed of two motors with a Neural Network Controller



(a)

(b)

Figure 9 Simulation synchronization speed of two motors

(a) Response difference in speed of two motors during load changes

(b) Linear distance from both the speed of the motor and the load changes

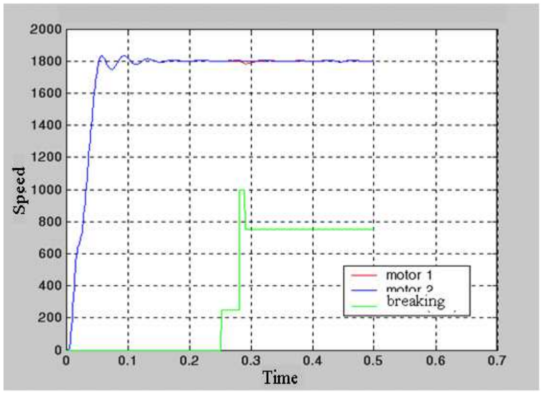


Figure 10 The response speed of two motors in the event of braking.

5. CONCLUSION

From the results of simulation using *Simulink*, a summary can be presented as follows:

- The simulation of single motor using fuzzy controller does not show overshot results obtained so the conditions are like on a first-order system.
- If the motor 2 is given a different load without changing the coordination of the motor 1, but the coordination is provided by the neural network controller, there is a little difference in speed; therefore, the difference in distance traveled by each car is small.
- If there is a decrease in one of the driving speed because of the additional load on the motor, the need for additional control signals is injected into the inverter output signal from the controller coordination.
- Without coordination, the output speed of the motor does not show overshoot. This is caused of the fuzzy controller on each motor that can control any load change.
- The coordination system of steady state conditions is achieved much faster (at t = 0.05 second) than without coordination of steady state (at t = 0.2 second).
- Constraints from the results of this study are still linear in distance of any difference for both the motor speed of 0.4 cm (shown in Figure 9b). Therefore, subsequent research needs to be developed in response to improve the speed of both motor speed settings. Besides, this motor improvement is intended to increase smoothness for both motor speeds which may give comfort on the car drivers, especially when the car is driven on high speed.

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