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MATHEMATICAL MODEL OF RESISTOR EFFECT ON THE SYNCHRONIZATION SYSTEMS

ALI S. AKAYLEH

Electrical Engineering Department
Faculty of Engineering
Tafila Technical University
P. O. Box 66, Tafila 66110, Jordan
e-mail: akayleh_em@yahoo.com

Abstract

In this paper, a new mathematical model is built using the electrical working shaft as a speed synchronization system with additional resistor in the common rotor circuit. Effective role of additional resistor on the synchronous capability and recovery time of the system is studied by using simple overhead crane. The calculated and experimental results show that the relationship between the necessary for synchronization additional resistor and the system's synchronous capability depends basically on the position of crane hoist (load distribution on the shafts). It is found also that increasing the additional resistor value gives a great capability of synchronization. Simultaneously proportional lead to a drop in the system efficiency. To overcome this drawback, a controller block is added to determine the optimal value of the additional resistor according to the hoist position or to the difference of loads on the motors shafts.

1. Introduction

Synchronization systems are defined as the systems work of which depend on the equality of the speeds for all the systems' motors despite of the differences in the

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loads and the direction of motion. The most traditional synchronization system with common rotor as a speed synchronization control element is the synchronous drive with electrical shaft system. This system consists of two or more identical three phase wound rotor induction motors connected together by the same alternating current supply and common additional resistor in the rotor's circuit, where the electromotive forces, generated in these coils as shown in Figure 1 move towards the additional resistor [1, 10].

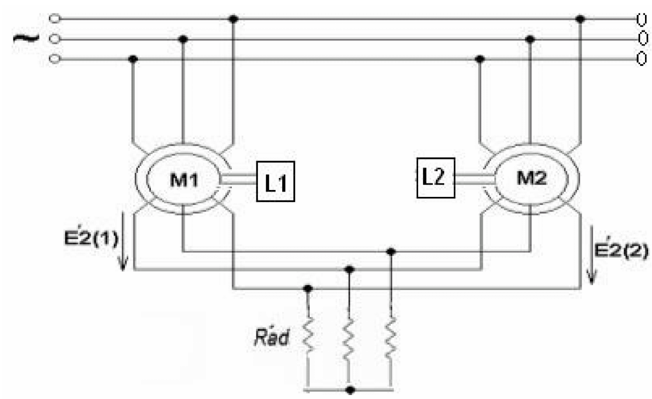

Figure 1. Electrical shaft system.

Such systems are characterized by simplicity in constants of design and operation, especially if the main following problems are solved, (i) Mechanical vibrations that appear at each starting process, especially if the hoist of the crane is outside of the center. These vibrations are due to the high starting current of the rotor. It is not considered as a major one because it occurs – as mentioned earlier – only at starting and can readily solved by equalizing the motor's loads or centralizing the crane hoist, (ii) Low system efficiency, related to the additional resistor located in the common rotor circuit, so as the additional resistor plays a great role in determining the required synchronous capability and recovery time (Increasing additional resistor gives a better synchronous capability and results in an increase of rotor losses and consequently a decrease in system efficiency) [3, 4]. Using a Matlab mathematical model this paper deals with solving the problem of system efficiency by adjusting additional resistor value according to the required synchronous capability or difference in loads on motor shafts [5]. The proposed mathematical model represents a synchronization system with electrical shaft system, where the main control element – employed for adjusting the system's synchronization – is the common additional resistor element.

2. System Equivalent Circuit and Equations

To derive the control equations for the synchronization system with electrical shaft, the system's simplified equivalent circuit shown in Figure 2 is utilized.

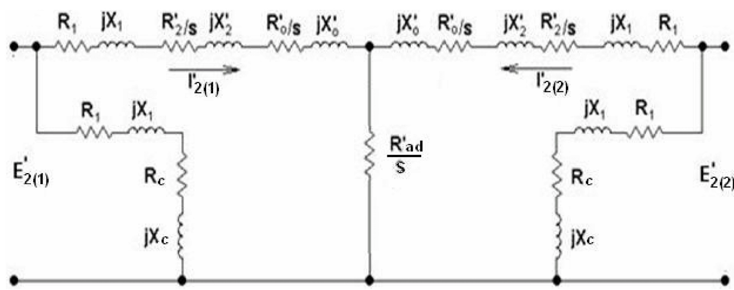

Figure 2. System equivalent circuit.

Here:

R_1, X_1 : Stator resistance and inductive reactance of first and second motors.

R_2', X_2' : Rotor resistance and inductive reactance of first and second motors.

R_c, X_m : Resistance and inductive reactance of magnetization circuit of the motors.

$E_{2(1)}', E_{2(2)}'$: Rotor phase voltage in the first and the second motors.

$I_{2(1)}', I_{2(2)}'$: Rotor current of the first and the second motors.

S : Slip.

To simplify the mathematical model it is assumed that the main power supply of the motors is coming from the rotor circuit not from the stator. The balance equations for the rotor voltage can be calculated as follows [15]:

$$E_{2(1)}' = I_{2(1)}'\left[Z_d + \frac{R_{ad}'}{S}\right] + I_{2(2)}'\frac{R_{ad}'}{S}, \quad (1)$$

$$E_{2(2)}' = I_{2(2)}'\left[Z_d + \frac{R_{ad}'}{S}\right] + I_{2(1)}'\frac{R_{ad}'}{S}, \quad (2)$$

where

$$Z_d = \left(R_1 + \frac{R_2'}{S}\right) + J(X_1 + X_2').$$

According to [2, 6, 7, 13] the currents and torques in the common rotor circuit can be determined as:

$$I'_{2(1)} = \frac{1}{2}\left[\frac{E'_{2(1)} + E'_{2(2)}}{Z_d + 2R'_{ad}/S} + \frac{E'_{2(1)} - E'_{2(2)}}{Z_d}\right] \tag{3}$$

$$I'_{2(2)} = \frac{1}{2}\left[\frac{E'_{2(1)} + E'_{2(2)}}{Z_d + 2R'_{ad}/S} + \frac{E'_{2(2)} - E'_{2(1)}}{Z_d}\right] \tag{4}$$

$$T_{1,2} = \frac{mE_2'^2}{2\omega_0}[T_A \pm T_S \text{ Sin } \Delta\alpha], \tag{5}$$

where α_1, α_2 are phase angles between the stator and rotor windings, ω_0 is no load speed, and *m* is the number of phase.

T_A - Asynchronous part of the motor torque:

$$T_A = \left(\frac{\left(R_1 + \frac{R'_2}{S_1}\right)(1 - \cos\Delta\alpha)}{\left(R_1 + \frac{R'_2}{S_1}\right)^2 + (X_1 + X'_2)^2} + \frac{\left(R_1 + \frac{R'_2}{S_1} + \frac{2R'_{ad}}{S_1}\right)(1 + \cos\Delta\alpha)}{\left(R_1 + \frac{R'_2}{S_1} + \frac{2R'_{ad}}{S_1}\right)^2 + (X_1 + X'_2)^2}\right).$$

T_S - Synchronous part of the motor torque:

$$T_S = \left(\frac{(X_1 + X'_2)\sin\Delta\alpha}{\left(R_1 + \frac{R'_2}{S_1} + \frac{2R'_{ad}}{S_1}\right)^2 + (X_1 + X'_2)^2} - \frac{(X_1 + X'_2)\sin\Delta\alpha}{\left(R_1 + \frac{R'_2}{S_1}\right)^2 + (X_1 + X'_2)^2}\right).$$

3. System Block Diagram

Based on the system's equivalent circuit, rotor current, electromagnetic and dynamic torque equations and angular speed equations, the mathematical model of the electromagnetic working shaft system (by simulink Matlab) have been built [8, 9]. This model which is shown in Figure 3 consists of three blocks, each of them has a specific function.

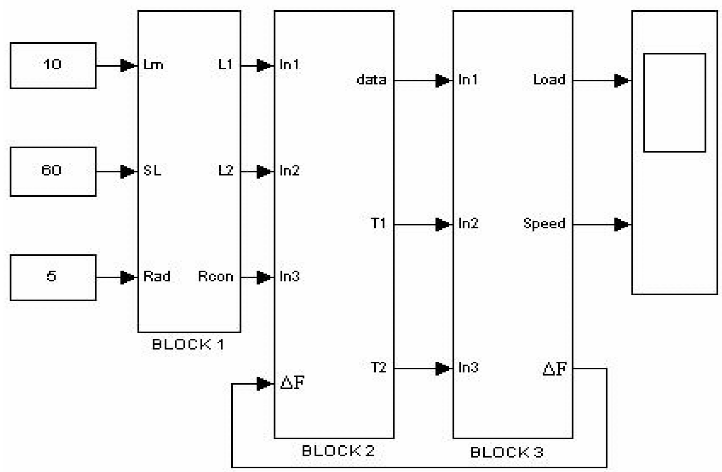

Figure 3. System block diagram.

Block 1 (Main distribution block)

Main distribution block, shown in Figure 4 consists of two subsystems. The first one is responsible for the load distribution on the shafts of motors without exceeding a maximum predetermined value, and the second subsystem determines the necessary additional resistor value which should be automatically added to the common rotor circuit of the system depending on the hoist moving direction or difference of loads [12, 14].

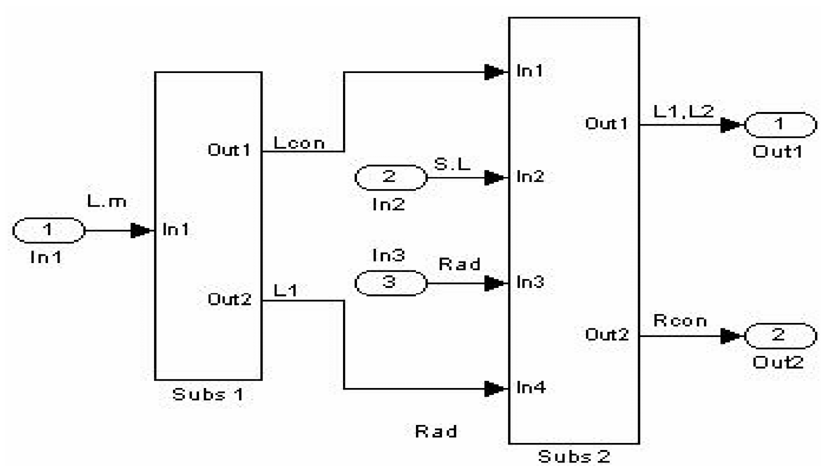

Figure 4. Load and additional resistor controller.

Block 2 (General data block)

This block encompasses the most important for the system parameters including the motors (two identical induction motors 5 hp, 4 pole, 50 Hz, 380 Line voltage, $R_1 = 1.118\,\Omega$, $R'_2 = 1.083\,\Omega$, $X_1 = X'_2 = 2.25\,\Omega$, $X_m = 76.8\,\Omega$) and reference (R'_M, SL, L_1, L_2) parameters. These parameters are responsible for building and determination the electromagnetic torque equations [11, 15].

Block 3 (Error calculation block)

In this block by using the dynamic torque $(T_d = T_{in} - T_L)$ and electromagnetic torque equations, angular position and angular speed relationships, difference of phase angle, and slip equations $(\omega_1, \omega_2, S_1\ S_2, \Delta\alpha)$ the synchronous capability and recovery time of the system are calculated. The above mentioned output value of this block are represented as the main system response (speed response) and as the package of feedback signals (ΔF) which goes to the first block of the system.

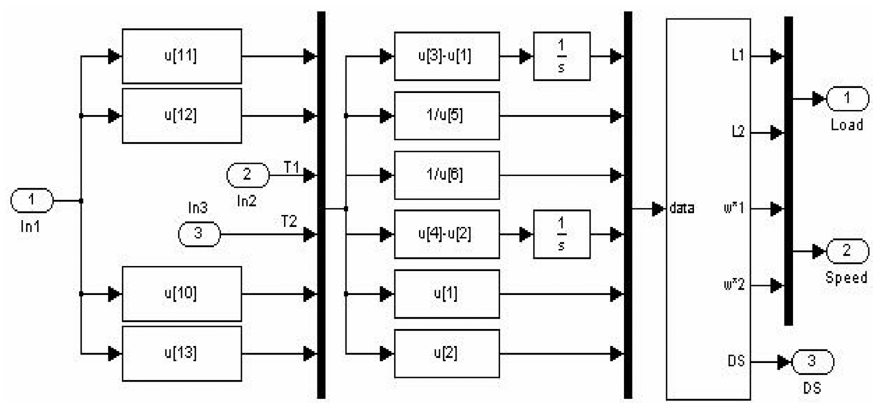

Figure 5. System main equations block.

4. System Operation and Test

The suggested model was verified experimentally using an overhead crane with moving hoist. This system consist of two identical induction motors, where the total load is distributed on the shafts depending on the hoist position. When the hoist is located in the center of crane, the load on the shafts are equal and the motors operate with the same speed. Changing the location of hoist to the left or to the right of the center will give different loads and the motors will operate with the different speeds.

In this case the motors (consequently the whole system) will be outside of synchronization. Additional resistor in the rotor common circuit plays most important role in determination of the synchronous capability and recovery time of the system, this was tested as shown in Figure 6 with various loads and additional resistor values. It shows that if the system operates without additional resistor with equal loads (Figure 6a) or no equal loads (Figure 6b), there is no connection between the motors and the motors operate as individual induction motors.

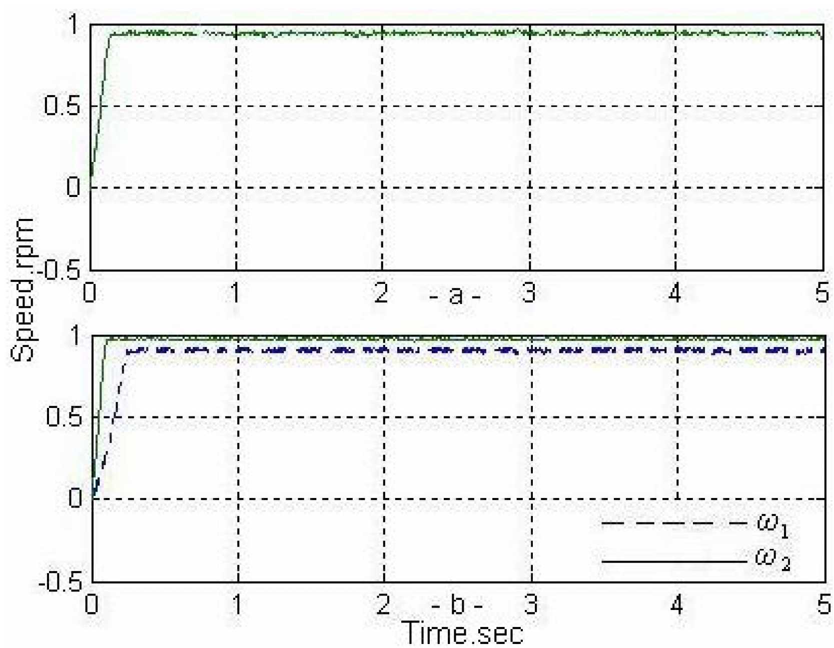

Figure 6. Speed response without additional resistor, (a) $L_1 = L_2$, (b) $L_1 \neq L_2$.

Figure 7 shows the speed response of the system when the additional resistor is not equal to zero and the load on the shafts are equal (hoist in the center of crane). In this case, the electromotive forces generated in rotor's coils will be equal in magnitude and opposite in direction. Therefore, the motors will also operate with the same speeds as individual induction motors.

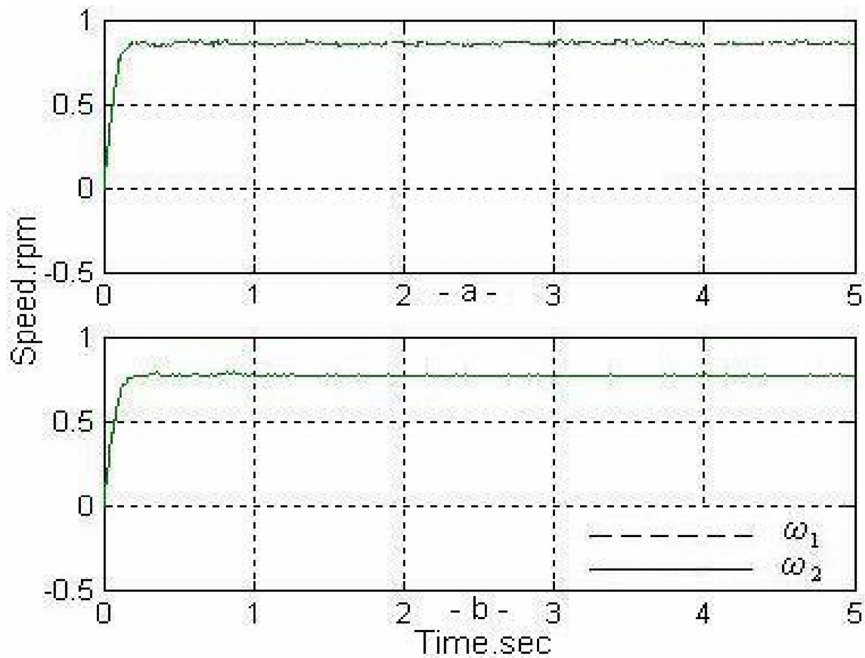

Figure 7. Speed response $(L_1 = L_2)$, (a) Rad $= 0.8R_2$, (b) Rad $= 1.6R_2$.

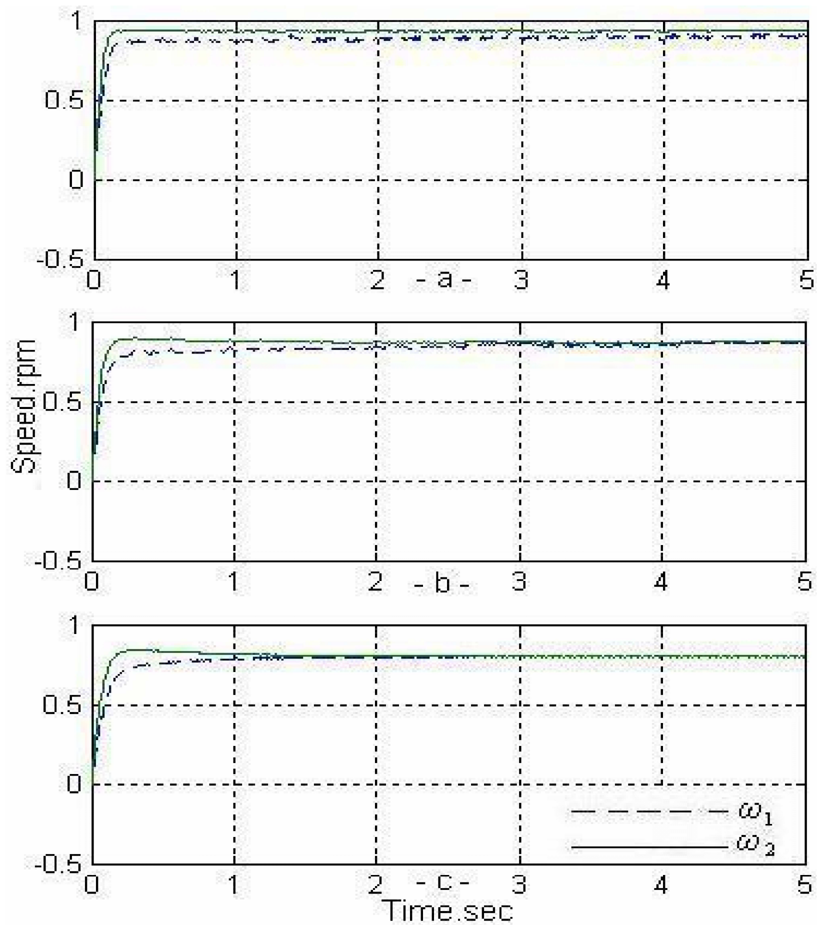

Figure 8. Speed response $(L_1 = 2L_2)$, (a) $\text{Rad} = 0.8R_2$, (b) $\text{Rad} = 1.6R_2$, (c) $\text{Rad} = 2.4R_2$.

For the next stage, we will define the system's behavior with difference in the distributed loads, in particular, when moving the hoist from the far left end of the crane until center. In this case, the electromotive forces generated in rotor's coils will not be equal in magnitude and opposite in direction. This will produce excess energy in the common rotor circuit. This energy leads to increase in the speed of the highest load motor and decrease in the speed of the lowest load motor until the equality of both motors speeds. To let the system work properly without any interference from an operator, a controller is designed to select the appropriate value of additional resistor depending on the hoist position (load distribution).

Every time the hoist position is outside the center, the value of additional of resistor automatically increases and when the load is distributed equally (hoist in the center) the value of additional of resistor will be zero. Figure 9 shows the speed response of the system with and without additional resistor controller. Including controller (Figure 9c) shows importance of additional resistor for improving the system synchronous capability, system response and consequently the system efficiency.

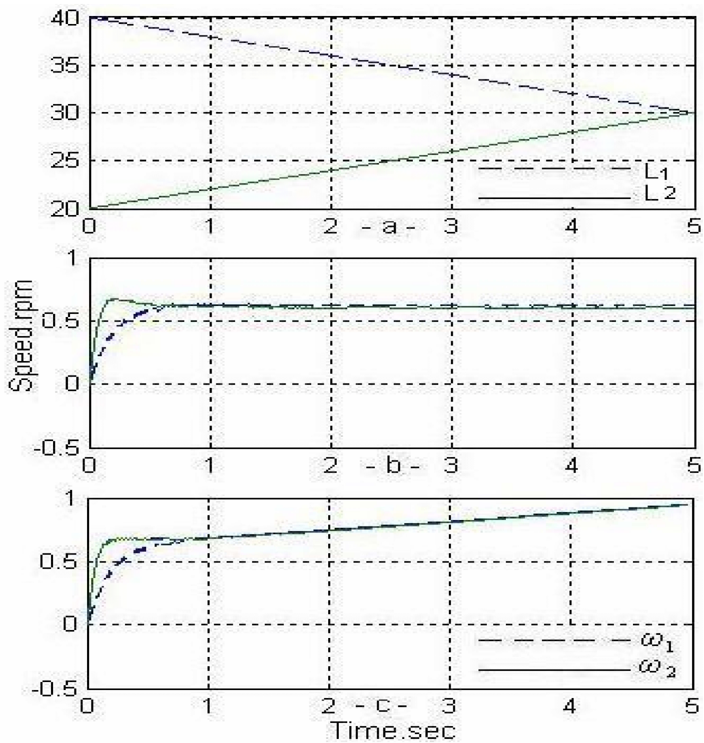

Figure 9. Speed response when Rad = $2.4R_2$, (a) system load distribution, (b) response without controller, (c) response with controller.

Figure 10 shows the complete operation of the system, where the hoist of the crane is moved as a forward and backward from left end to the right, and from the right end to the center of the crane. The results show that the loads redistribution effect on the system efficiency will be minimum. This is due to adjusting the additional resistor through the controller block that can be shown by comparing Figures 9, 10 with Figure 8.

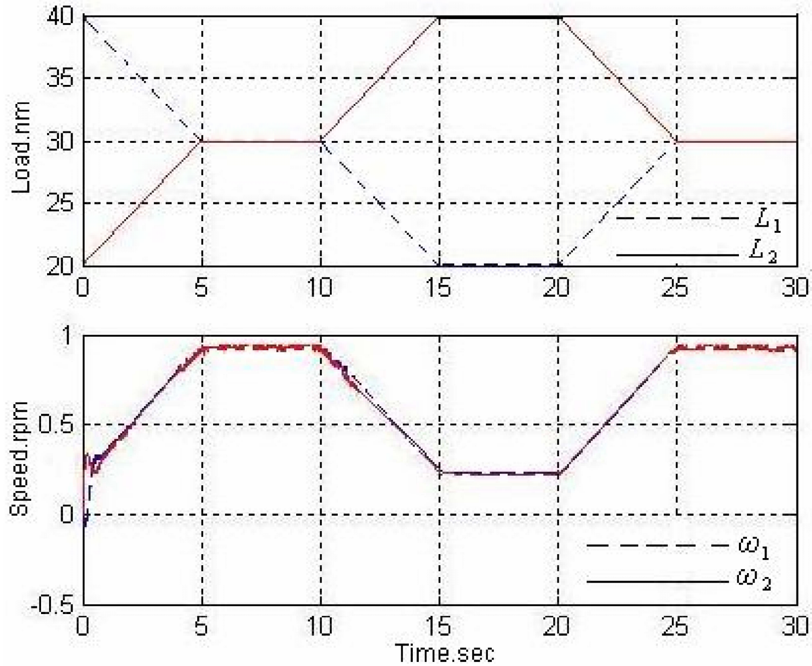

Figure 10. Speed response for complete system operation, with $\text{Rad} = 4.8R_2$.

5. Conclusions

The main fetchers of the proposed system are that it is simple and easy to implement, capable of dealing with any type of systems which requires speed synchronization. The control system is capable of reaching the synchronization speed even when the load distribution is very wide, and this is due to the additional resistor, the main role of which occurred only when there is a difference of loads allocated on the motors shaft. It was found that when the additional resistor was increased, the electromotive force increased too and consequently, the system synchronous capability increased. But a decrease in the system efficiency was noticed. Exceeding the value of additional resistor decreased the system efficiency which is the most important disadvantage. The system efficiency can be enhanced by adjusting the value of additional resistor – using the proposed control block – according to the required synchronous capability and recovery time of the system. Practically the performance and efficiency of electrical shaft system as a synchronization system will be surpass than the calculated results, this is related with real moving of crane (moving through gear box), where the real effective controlled speeds of the system are reduced to the tenth of the real speeds of the motors.

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