Synchronous Braking of Electromagnetic Working Shaft Systems

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Abstract **- A new synchronous system with electromagnetic working shaft was evolved by replacing the inductive rheostat element with a capacitor-inductive rheostat element. Effective role of additional capacitor element on the synchronous capability and recovery time of the system at start-up and braking is studied. The control strategy is to give maximum synchronous capability, minimum recovery time and speed synchronization at braking process. Mathematical model representing the evolved system is suggested and carried out using MATLAB/ SMULINK, where the simulated results confirm the validity of the proposed approach. It was found that the synchronous capability and the recovery time improvement could be enhanced about 40%.**

Keywords - Synchronous capability, dynamic braking, capacitor effect, recovery time.

I. INTRODUCTION

Synchronization systems are basically designed to adjust the speed of two or more motors with the existence of load differences allocated on their shafts. The most popular synchronization systems are the synchronization systems with auxiliary machines, synchronization systems with electrical shaft and synchronization systems with electromagnetic working shaft systems [3,14,15]. Applications of electromagnetic working shaft system as a speed synchronization control system can be found in papers regarding machines, offset printing, textiles and differential drives [8,9]. Performance of synchronization systems depends on speed synchronization with maximum loads difference (synchronous capability) and required synchronization time (recovery time). Synchronous capability of the system also depends on the type of synchronization systems, rotor shafts connection (mechanical or non mechanical connection) and type of synchronous controller [7, 16, 11].

The synchronization systems with electromagnetic working shaft is the most recently applicable compared to other synchronization systems. It consists of two identical wound rotor induction motors connected together to the same alternating current supply and each motor is connected to a wounded coil on steel cylinder (inductive rheostat element) which is very similar to the transformer connections as shown in Fig.1.However, this system suffers from a low synchronous capability, consequently low ability to operate at the same speed with a largest possible load difference [5]. The most important problems is the adjustment of synchronous capability at braking stage. Therefore it is necessary to develop and to explore methods of braking. Braking at different loads leads to difference braking torques and the develop and to explore methods of braking. Braking at different loads leads to difference braking torques and the motors will stop at different position angles. Selecting this torques can change many additional parameters [4,9,10].

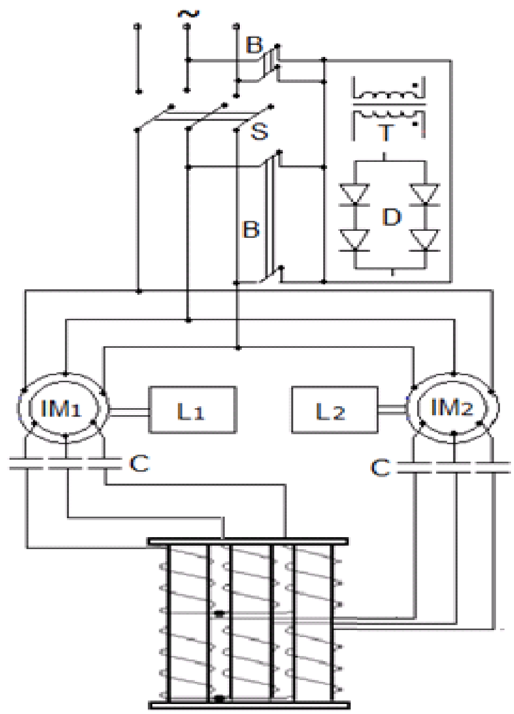

Figure.1. Electromagnetic working shaft system

In this paper a proposed design of electromagnetic working shaft braking will be investigated using dynamic braking technique [17].

II. EQUIVALENT CIRCUIT

The main equations of the electromagnetic working shaft system with additional inductive-capacitor element can be found using simplified equivalent circuit shown in Fig.2.

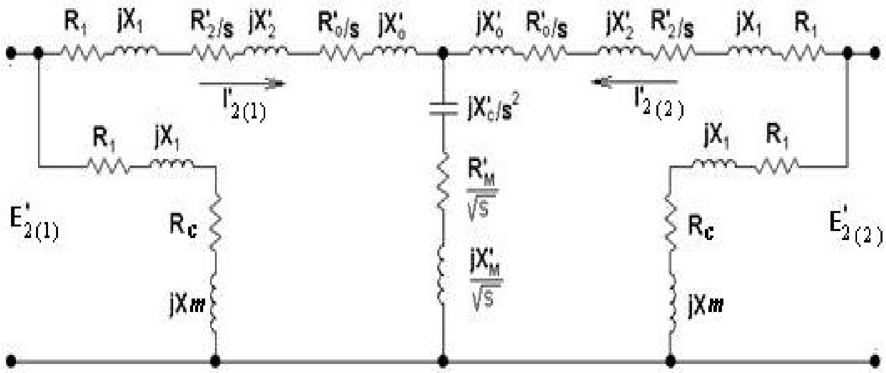

Figure 2. Simplified equivalent circuit of the system.

Where:

R_1, X_1: Stator resistance and inductive reactance.
R_2, X_2: Rotor resistance and inductive reactance.
R_M, X_M: Resistance and inductive reactance of magnetization circuit of inductive rheostat element
Ro, Xo: Resistance and inductive reactance of inductive rheostat element.
$E_{2(1)}$,$E_{2(2)}$: Rotor phase voltage of the motors
$I_{2\,(1)}$,$I_{2(2)}$: Rotor current of the motors.
X_C: Additional capacitive reactance.
S: Slip.

To simplify the mathematical model of the system it was assumed that the reference voltage value is the rotor's voltage [7]. From the equivalent circuit the rotor current at dynamic braking mode can be calculated as follows:

$$I_{1(2)} = \frac{I_o\ X\mu}{2}\left(\frac{\left(1-\ell^{\Delta\alpha}\right)}{\left(R_1+\frac{R_2'+R_o'}{S_1}\right)^2+J\left(X_k+X_o'+X\mu\right)^2}+\frac{\left(1+\ell^{\Delta\alpha}\right)}{\left(R_1+\frac{R_2'+R_o'}{S_1}+\frac{2R_M'}{\sqrt{S_1}}\right)^2+J\left(X_k+X_o'+X\mu+\frac{2X_M'}{\sqrt{S_1}}-\frac{2X_C'}{S_1^{\,2}}\right)^2}\right) \qquad (1)$$

$$I_{2(2)} = \frac{I_o\ X\mu}{2}\left(\frac{\left(1-\ell^{-\Delta\alpha}\right)}{\left(R_1+\frac{R_2'+R_o'}{S_1}\right)^2+J\left(X_k+X_o'+X\mu\right)^2}+\frac{\left(1+\ell^{-\Delta\alpha}\right)}{\left(R_1+\frac{R_2'+R_o'}{S_1}+\frac{2R_M'}{\sqrt{S_1}}\right)^2+J\left(X_k+X_o'+X\mu+\frac{2X_M'}{\sqrt{S_1}}-\frac{2X_C'}{S_1^{\,2}}\right)^2}\right) \qquad (2)$$

If the first motor is determined as a master motor of the system so ($E'_{2(1)} = I_o X_\mu$), ($E'_{2(2)} = I_o X_\mu e^{j\Delta\alpha}$), ($S_1 = S_b$) and ($\Delta\alpha = \alpha_1 - \alpha_2$). If the second motor is determined as a master motor of the system so ($E'_{2(2)} = I_o X_\mu$), ($E'_{2(1)} = I_o X_\mu e^{j\Delta\alpha}$), ($S_2 = S_b$) and ($\Delta\alpha = \alpha_2 - \alpha_1$), then the first and the second motor torques at dynamic braking mode can be find as [6,7].

$$T_{1(2)} = \frac{2.91\ I_o'^{\,2}\,\Sigma R_2'}{\omega_o S_{1(2)}} \qquad (3)$$

Where: $\Sigma R_2'$-Sum of resistances in the common rotor circuit, ω_o - no load speed.

Accoding to relationships between inductive rheostat parameters and the magnetization resistance [5,7], after some transformations the torque equations at dynamic braking will be:

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$$T_{1(2)}=\frac{1.46 I_o^{2} X^{2}_{\mu}}{\omega_o}\left[\left(\frac{\left(R_1+\frac{R'_2+R'_o}{S_b}\right)(1-\cos\Delta\alpha)}{\left(R_1+\frac{R'_2+R'_o}{S_b}\right)^2+\left(X_k+X'_o+X\mu\right)^2}+\frac{\left(R_1+\frac{R'_2+R'_o}{S_b}+\frac{2R'_M}{\sqrt{S_b}}\right)(1+\cos\Delta\alpha)}{\left(R_1+\frac{R'_2+R'_o}{S_b}+\frac{2R'_M}{\sqrt{S_b}}\right)^2+\left(X_k+X'_o+X\mu+\frac{2X'_M}{\sqrt{S_b}}-\frac{2X'_C}{S_b^{\,2}}\right)^2}\right)\pm\left(\frac{\left(X_k+X'_o+X\mu+\frac{2X'_M}{\sqrt{S_1}}-\frac{2X'_C}{S_1^{\,2}}\right)\sin\Delta\alpha}{\left(R_1+\frac{R'_2+R'_o}{S_b}+\frac{2R'_M}{\sqrt{S_b}}\right)^2+\left(X_k+X'_o+X\mu+\frac{2X'_M}{\sqrt{S_b}}-\frac{2X'_C}{S_b^{\,2}}\right)^2}-\frac{\left(X_k+X'_o+X\mu\right)\sin\Delta\alpha}{\left(R_1+\frac{R'_2+R'_o}{S_b}\right)^2+\left(X_k+X'_o+X\mu\right)^2}\right)\right] \quad (4)$$

III. SYSTEM MODELING

Mathematical model of the system has been built using MATLAB-SIMULINK [1,2,12] and the results achieved by varying current, dynamic torque, angular speed and angular positions equations [13,18]. As shown in Fig.3,the system model consists of two blocks each of them has a specific function. Block1 consists of the main basic data, such as induction motors parameters: 1.5kw, 50Hz, 4Pole, Vph=220v, Io=3.56 A, ,$X\mu$= 118Ω, R_1=4.25 Ω, R_2=4.26Ω, X_1=4.82Ω, X_2=7.425Ω, additional parameters in rotor common circuit :, R_M,X_M, X_C and feedback signals:Δα,S_1,S_2 [2,5].

Block2 consists of four blocks, each of them contains the mathematical equations that are responsible of dynamic torque calculations of the motors and correction elements responsible of synchronization process between the motors. Mainly inductive reactance parameters and dimensions can be calculate depending on the difference loads and rated power of motors [12].

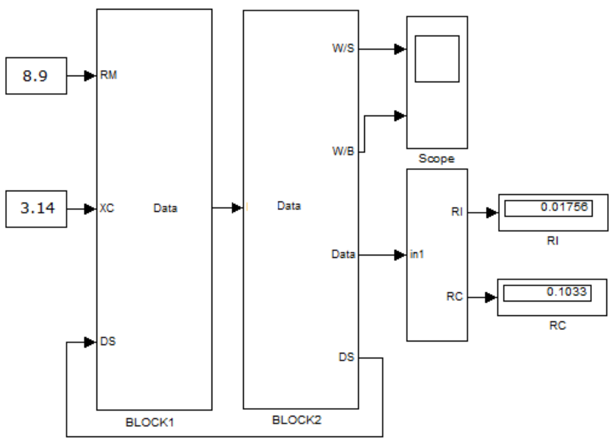

Figure 3. System block diagram..

If the loads are equal so as the rotor currents moving inside inductive reactance are equal and the electromagnetic fields generated in those rotors are equal in magnitude and opposite in direction, there is no connection between the rotors and the motors are operating as a separately induction motors. If the loads are not equal then the rotor currents and the electromagnetic fields are not equal and this leads to electromagnetic transformation of energy among the inductive element, those wasted energy lead to increase in speed of the highest load motor and decrease in speed of the lowest load motor. Investigations and laboratory tests show that the main effective of parameters on the synchronous capability and recovery time are (R_M, X_C). To simplified the system modeling and investigation we can consider a new parameters such as :(R_I) - relative resistance of inductive resistors parameter and (R_C)- relative resistance of capacitor parameter.

Where:

$$R_I=\frac{X'_M}{X_K+X_\mu},\quad R_C=\frac{X'_C}{X_K+X_\mu},\quad X_K=X_1+X_2$$

Figure.4A shows the effect of relative inductive reactance resistance (R_M*) on the synchronous capability and recovery time at constant difference in loads (L_1=1.25L_2). Comparing the speed system response we can see the real role of (R_M*) on the synchronization process of the system and the best synchronous capability and recovery time can be found at rated value of (R_M*), the worst synchronous capability and recovery time was at (R_M*=2) with some vibrations at start-up. Figure. 4B shows the effect of load difference on the synchronization process at constant (R_M*) it shows that increasing the load difference leads to decreasing the synchronous capability and recovery time. The best synchronous capability and recovery time was found at (L_1=1.25L_2), and the worst synchronous capability and recovery time was at (L_1=3L_2). So to work with perfect synchronous capability and recovery time, firstly we need to determine the required synchronous capability and after that we can select the required (R_M*) value.

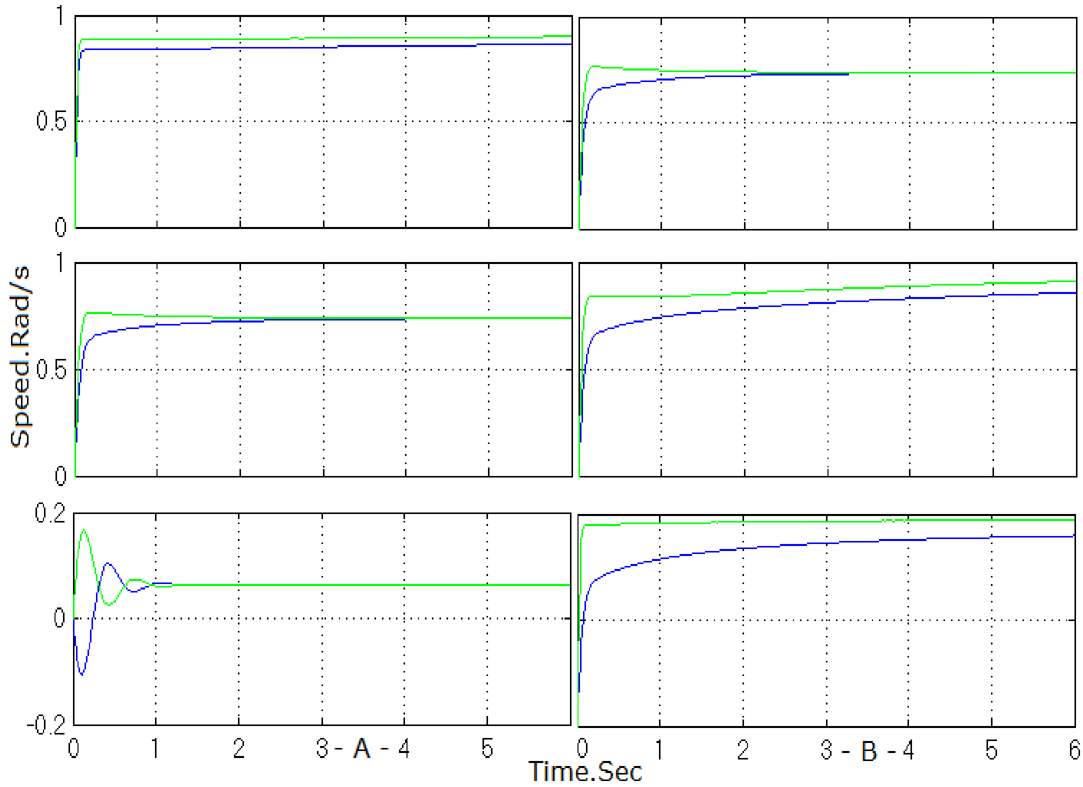

Figure 4. Speed response at start-up mode. A- L_1=1.25L_2, R_M*=0.5/1/2, B- R_M*=1, L_1=(1.25/1.5/3)L_2

Maximum synchronous capability can be found as a maximum difference of induced torques in the system [5]. $T_{asy} = T_{1(2)} - T_{2(2)}$.

Figure.5 shows the effect of varying (R_C*) on the maximum synchronous capability at different (R_I*) and difference loads. It shows that increasing in (R_C*) to (R_C*=2.5) leads to an increase in the maximum synchronous capability of the system at all variations of (R_I*). At (R_C*<0.5) the synchronous capability will be very small and the system does not have a coordinated braking.

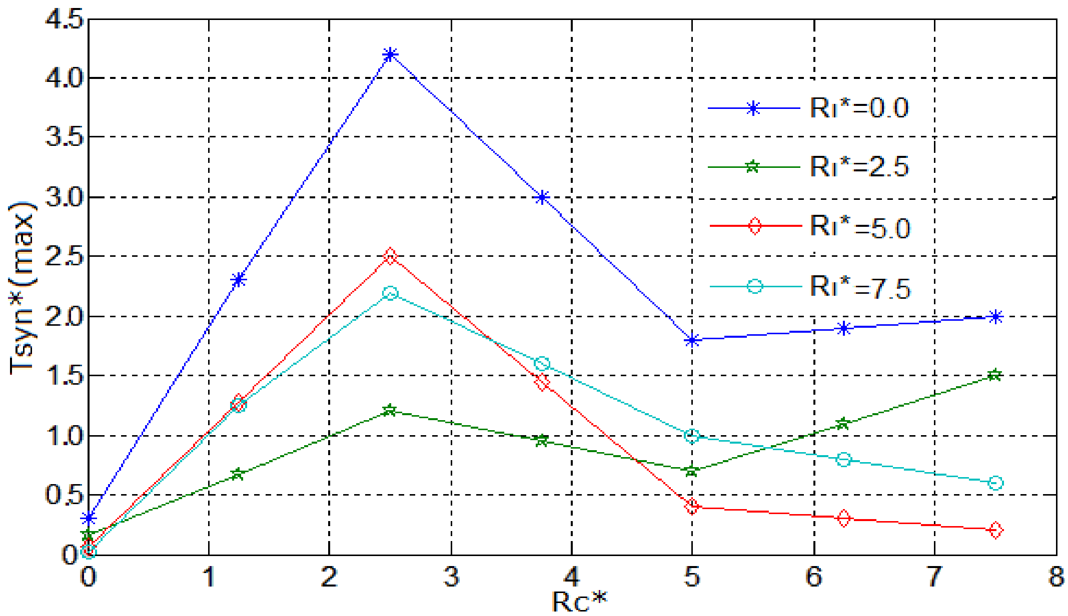

Figure 5. Maximum synchronous capability at different loads.

Figure.6 shows the effect of varying (R_C*) on the maximum dynamic braking torque at different (R_I*) and the effect of varying (R_I*) on the maximum dynamic braking torque at different (R_C*). The Figure shows that increasing (R_C*) to (R_C*=2.5) leads to an increase in the maximum dynamic braking torque, which leads to an increase in synchronous capability and a decrease in recovery time of the system. Increasing in (R_I*) at different (R_C*) has a regulated and controlled effect on the maximum dynamic braking torque only at (R_I*>5), which leads to an increase in synchronous capability and a decrease in recovery time of the system.

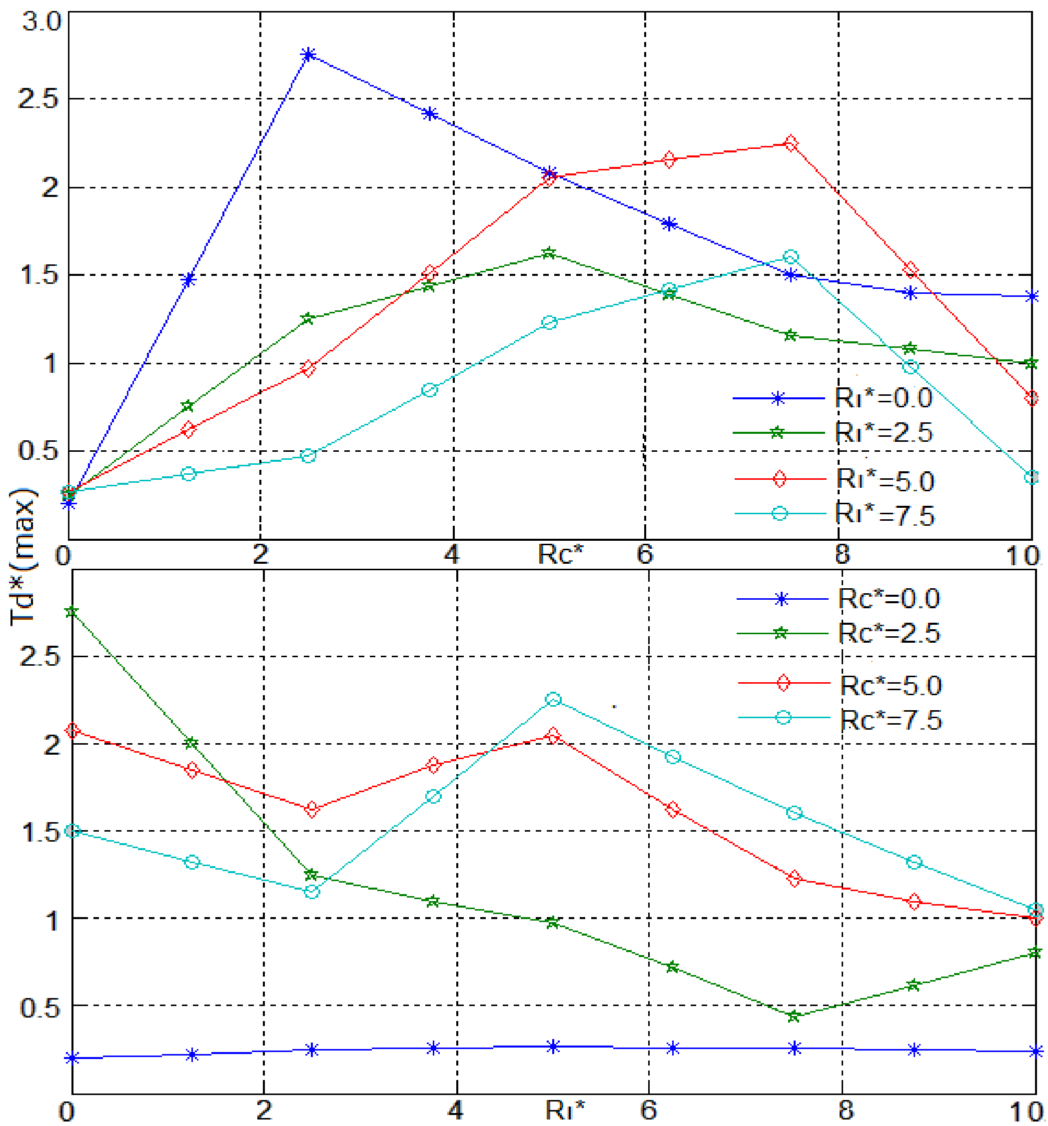

Figure 6. Maximum dynamic braking torque at equal loads..

IV. CONCLUSION

In this paper a new synchronous module is proposed that creates a sufficient braking torque and leads to a smooth braking and minimum mechanical vibrations. Depending on loads difference we can select the values of the resisters (RC*, RI*), that gives the required synchronous capability and recovery time. Increasing (RI*) value when (RC*) is negligible leads to appearance of a small dynamic braking torque, consequently to a small synchronous barking. Decreasing (RC*) value leads to increasing the capacitor volume, therefore proposed model can work perfectly in the systems that does not require great technical characteristics of synchronous capability and recovery time. In our case desirable values of (RC*, RI*) should be considered between 1.5> RC* <2.5 and 6> RI* <8.

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