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Braking of Three Phase Induction Motorsby Controlling Applied Voltage and Frequency Based on Particle Swarm Optimization Technique

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ABSTRACT

Braking of three phase induction motors is required in many industrial applications. This paper introduces braking of three phase induction motors using particle swarm optimization (PSO) technique. The objective is to determine the optimum values of the applied voltage and frequency during braking to stop the motor in a certain time with minimum braking energy losses to limit any excessive thermal heating. The proposed technique is important and more useful in applications of repeated braking cycles. The results are compared with that obtained using plugging braking method and it's found that the proposed technique gives lower braking energy and shorter braking time. The braking energy losses with the proposed method are about 20% of the plugging braking energy losses with the same braking time. The proposed method determines the variation of optimal values of applied voltage and frequency to have a certain braking time of three phase induction motor at a certain load torque with minimum braking energy losses. The characteristics of the motor are simulated using SIMULINK/MATLAB.

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1. INTRODUCTION

Braking of three phase induction motors is an important issue especially in industrial applications that require multi stop in a definite time. Braking can be mechanical through friction or electrical. Mechanical braking results in waste of rotor stored kinetic energy and excessive heat. Electrical braking has many methods such as plugging, regenerative and dynamic braking. Plugging depends on reversing the direction of the rotating field by changing the supply phase sequence, this results in an opposing torque that stops the motor. Plugging results in high currents, serious overheating and the motor must be disconnected when the speed reaches zero otherwise it will revolve in the opposite direction. If the motor speed is greater than synchronous speed, the slip is negative. In this case the motor acts as a generator retuning the energy to supply, this is called regenerative braking. Dynamic braking is achieved by disconnecting the supply and connecting external resistances across motor terminals, in this case rotor kinetic energy is converted into heat losses. Other braking methods can also be used such as DC injection, zero sequence, magnetic and capacitor self-excitation braking.

The issue of induction motor braking is discussed in literature, for example [1] deals with sensorless vector control of pulse width-modulated inverter-fed induction motor drivesequipped with a three-phase diode rectifier. An electronically controlled braking resistor across the dc link is not used, but instead, the power regenerated during braking is dissipated in the motor. In [2] braking of three phase induction motor is done using combination of two or more conventional methods, it is found that effective braking is obtained by applying different methods at different speed ranges, but this will result in complex circuit for braking. Braking torque in non-regenerative AC drives without the need of additional power circuits is discussed in [3]. In [4] conventional methods of braking, branch elimination method in conjunction with conventional tensor technique is used to establish a digital computer program to simulate the system. In [5, 6] two braking methods are examined to reduce motor current, one based on the injection of an AC voltage to the rotor winding during braking. The injected voltage must have the same frequency, same phase shift and opposite in direction to the rotor induced voltage. The second method depends on discrete variable frequency control using three phase inverter, AC thyristors monitored by a microcontroller PIC. Reducing energy loss during braking is examined by using direct torque control in [7], the method is investigated with constant and traction load toques.

Optimization of braking energy is a nonlinear problem; it is suitable to examine heuristic optimization techniques to solve this problem. PSO is used extensively to design, control and operate three phase induction motor [8-11]. The rule of the PSO in this paper is to find the suitable variation of voltage and frequency during a certain braking period to minimize energy losses in the motor, this will result in less heat and allow for frequent braking in a certain time.

2. MATHEMATICAL MODEL

The voltage equations of three phase squirrel cage induction motor in d-q frame are [12]:

$$u_{Sd} = i_{Sd}R_s + \frac{d}{dt}\lambda_{Sd} - \dot{\theta}_S\lambda_{Sq} \tag{1}$$

$$u_{Sq} = i_{Sq}R_s + \frac{d}{dt}\lambda_{Sq} + \dot{\theta}_S\lambda_{Sd} \tag{2}$$

$$0 = i_{Rd}R_R + \frac{d}{dt}\lambda_{Rd} - \dot{\theta}_R\lambda_{Rq} \tag{3}$$

$$0 = i_{Rq}R_R + \frac{d}{dt}\lambda_{Rq} + \dot{\theta}_R\lambda_{Rd} \tag{4}$$

Where:
u_{Sd} : d-axis stator voltage.
u_{Sq} : q-axis stator voltage.
i_{Sd} : d-axis stator current.
i_{Sq} : q-axis stator current.
i_{Rd} : d-axis rotor current.
i_{Rq} : q-axis rotor current.
λ_{Sd} : d-axis component of stator flux linkage.
λ_{Sq} : q-axis component of stator flux linkage.
λ_{Rd} : d-axis component of rotor flux linkage.
λ_{Rq} : q-axis component of rotor flux linkage.
R_S : Resistance of stator winding.
R_R : Resistance of rotor winding referred to stator.

The flux linkages are defined by:

$$\lambda_{Sd} = L_S i_{Sd} + M i_{Rd} \tag{5}$$

$$\lambda_{Sq} = L_S i_{Sq} + M i_{Rq} \tag{6}$$

$$\lambda_{Rd} = L_R i_{Rd} + M i_{Sd} \tag{7}$$

$$\lambda_{Rq} = L_R i_{Rq} + M i_{Sq} \tag{8}$$

Where:
L_S : Self inductance of stator winding.
L_R : Self inductance of rotor winding.
M : Mutual inductance between stator and rotor windings.

The electromagnetic torque equation is:

$$T_e = \frac{3}{2}\frac{p}{2}\frac{M}{L_R}(i_{Sq}\lambda_{Rd} - i_{Sd}\lambda_{Rq}) \quad (9)$$

The mechanical equation is:

$$T_e - T_L = J\frac{d\dot{\theta}}{dt} + B\dot{\theta} \quad (10)$$

Where;

θ : Rotor displacement

T_L : Load torque .

J : Moment of inertia Kg.m^2

B : Rotor friction.

p : Number of poles.

The model of three phase squirrel cage induction motor is developed by SIMULINK /MATLAB to solve the above nonlinear equations and to study the dynamic performance characteristics of the motor. The SIMULINK dynamic model of the motor is shown in Figure 1.

Energy lost in the motor is defined as:

$$w = \int_0^t (p_{cu} + p_{iron})\, dt \quad (11)$$

$$p_{cu} = 3I_S^2 R_S + 3I_R^2 R_R \quad (12)$$

$$p_{iron} = \frac{3V^2}{R_C} \quad (13)$$

Where;

p_{cu} : Motor copper losses.

p_{iron} : Motor iron losses.

I_S : Stator phase current.

I_R : Rotor phase current referred to stator.

V : Stator phase voltage.

R_C : Core loss resistance.

The ratio of voltage to frequency K_V must be limited to prevent motor saturation.

Figure 2 shows the SIMULINK model with these variable voltage and frequency.

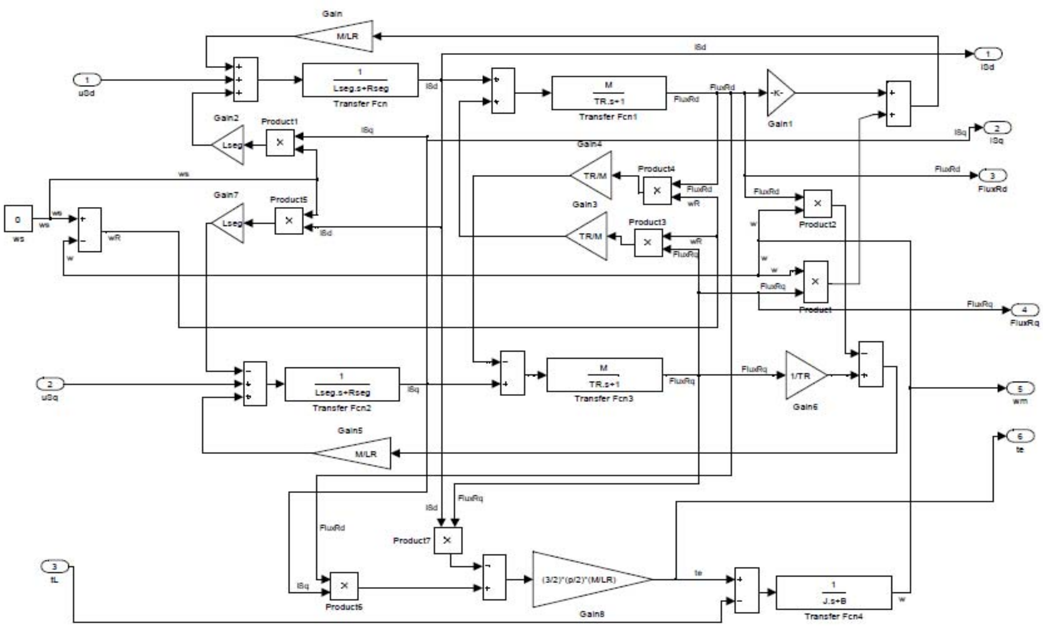

Figure 1. Simulink Model of three phase induction motor

The proposed method to optimize braking energy losses depends on changing motor input voltage and frequency according to the equations:

$$f = K_{f2} - K_{f1}t \tag{14}$$

$$V = K_V f \tag{15}$$

Where; K_{f1}, K_{f2} and K_v are constants.

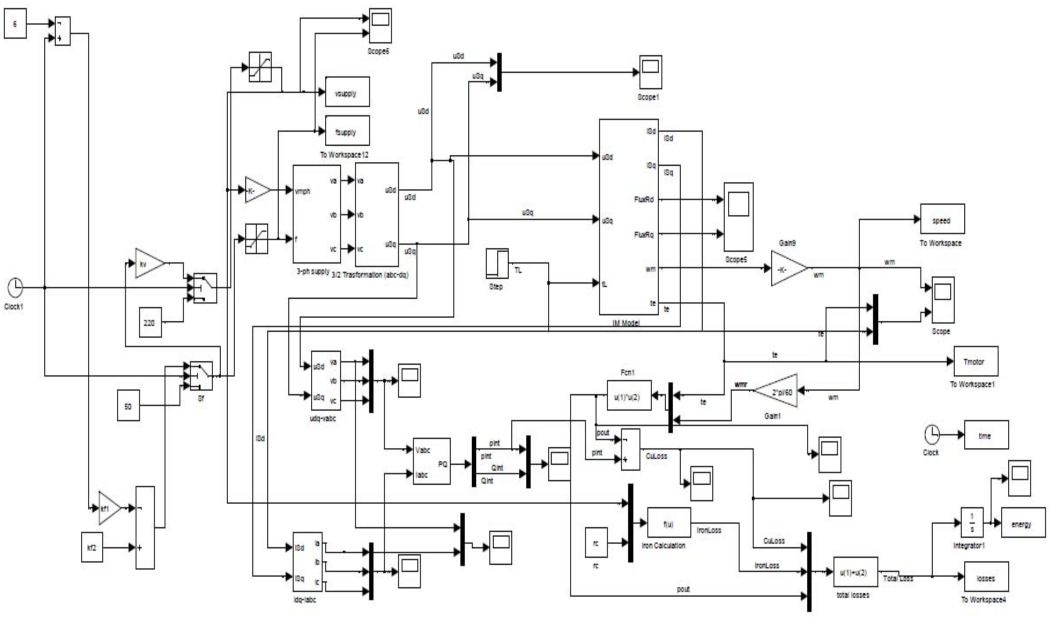

Figure 2. SIMULINK system scheme

3- OPTIMUM VOLTAGE AND FREQUENCY VARIATION USING PSO

In this part PSO is used to determine the constants K_v, K_{f1} and K_{f2} in Equation (14) and (15). The objective function is to minimize Equation (11) at certain braking time with the following inequality constraint to prevent saturation in the motor:

$$\frac{V}{F} < 5$$

Figure 3 shows the flow chart of PSO operation, for a certain load torque a swarm of 24 agents is initialized, for each agent the motor dynamic model is operated, and the objective function is evaluated. Agents are moved to their new position according to their velocities, their best position and the best position of the swarm. Agents velocity in swarm is updated according to the equation [13]:

$$v_i^{k+1} = wv_i^k + c_1 rand_1 \times \left(pbest_i - s_i^k\right) + c_2 rand_2 \times \left(gbest - s_i^k\right) \tag{16}$$

Where v_i^k is velocity of agent i at iteration k, w is weighting function, c_j is weighting coefficients, rand is random number between 0 and 1, s_i^k is current position of agent i at iteration k, $pbest_i$ is best position of agent i, and gbest is best position of the swarm. The weighting function w is given by:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \tag{17}$$

Where w_{max} is initial weight, w_{min} is final weight, $iter_{max}$ is maximum iteration number, and iter is current iteration number. According to Shi and Eberhart [14], [15], the following parameters are appropriate and the values do not depend on problems:

$$c_i = 2,\ w_{max} = 0.9 \text{ and } w_{min} = 0.4 \tag{18}$$

Maximum number of iteration is $iter_{max}$ = 50. This process is repeated for a braking time of 4, 4.5 and 5 sec at load torque of 0.5 N.m.

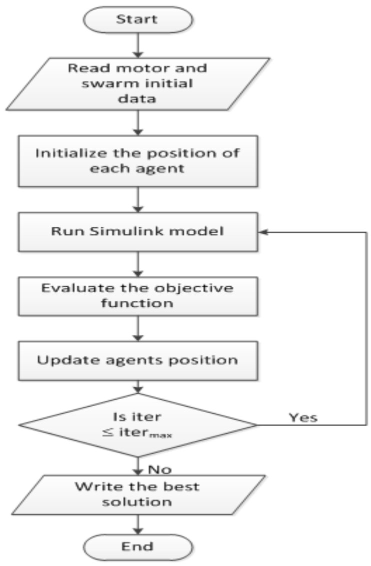

Figure 3. Flow Chart of PSO

4. RESULTS AND DISCSSION

Simulation has been carried out using SIMULINK/MATLAB for 220/380 V, 1.1 kW, 50 Hz three phase induction motor having the following parameters:

R_S = 5.15 Ω	R_R = 3.75 Ω
L_S =0.5887 H	L_R =0.5887 H
M=0.5568 H	p =2

In this section two groups of results are presented, the first one is the performance characteristics of the motor which is braked using conventional plugging method, by reversing two phases of the motor. In the second case the motor is braked with the proposed method by controlling the applied voltage and frequency to stop the motor within certain time with minimum energy losses.

All results are taken at load torque of 0.5 N.m and the motor runs in motoring mode with rated voltage and frequency from 0 sec to 6 sec, after that the motor is in braking mode.

4.1. Plugging Method

The braking time with plugging is 5 sec as shown in Figure 4. The developed torque is reversed during plugging and reducing the motor speed in the same direction of load torque as shown in Figure 5. Therefore, the speed is decreased from load speed to zero and to prevent rotation in reverse direction the applied voltage is removed.

The motor current during plugging is higher than the starting current as shown in Figure 6 because the motor slip during plugging is higher than 1 and hence the motor impedance is lower than that during stating. So the motor losses during plugging are higher than that during starting as shown in Figure 7.

Figure 8 shows the variation of input and output powers with time. The motor draws power from supply during motoring and plugging modes. The output power during plugging is reversed due to the reverse of torque direction. During motoring mode the difference between input and output powers is converted into losses but during plugging both of input power and output power are converted into losses. Therefore the plugging losses are high.

Figure 9 shows the variation of energy losses during one cycle of operation of starting, running and braking. The energy losses during braking with plugging are 14548 Joule within braking time of 5 sec and this energy losses are converted into heat.

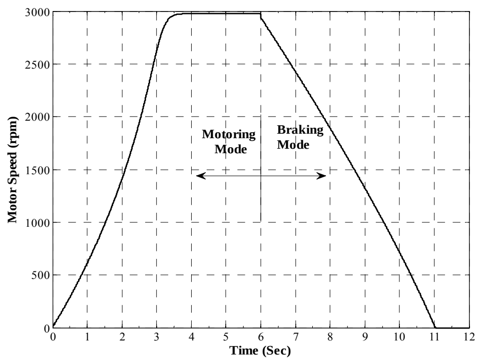

Figure 4. Variation of motor speed with time (plugging method)

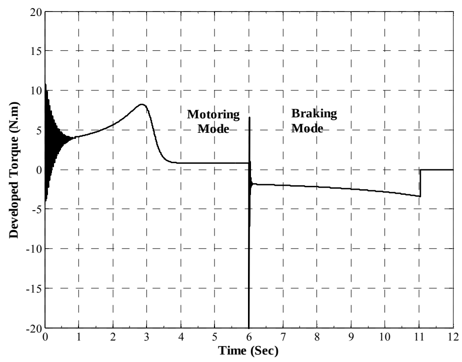

Figure 5. Variation of developed torque with time (plugging method)

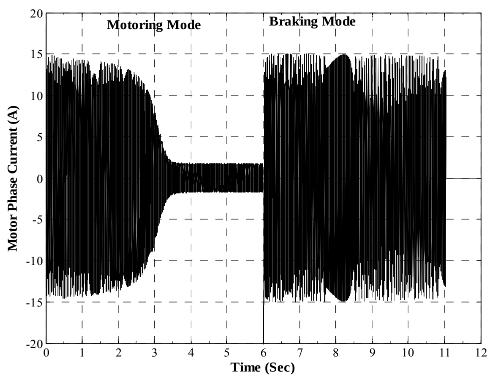

Figure 6. Variation of motor phase current with time (plugging method)

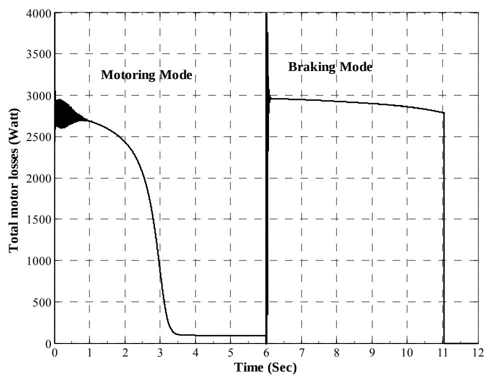

Figure 7. Variation of total motor losses with time (plugging method)

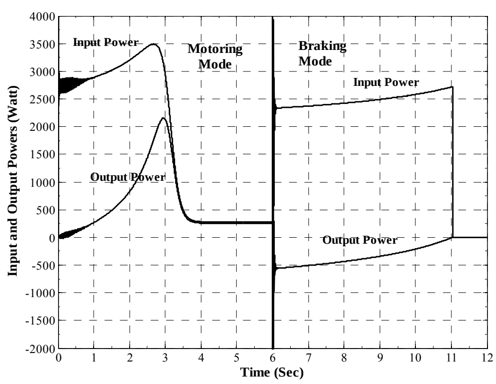

Figure 8. Variation of input and output powers with time (plugging method)

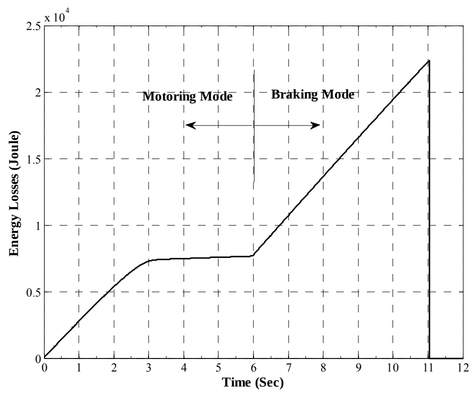

Figure 9. Variation of energy losses with time (plugging method)

4.2. Proposed Method

The performance characteristics of three phase induction motor with the proposed method of controlling both applied voltage and frequency to have minimum braking energy losses at certain braking time with PSO are shown in Figure 10 to 17. Figure 10 shows the variation of motor speed with time at different braking time of 4, 4.5 and 5 sec using the proposed method. The braking developed torque with lower braking time is higher than that of higher braking time as shown in Figure 11. Motor current in braking mode is lower than starting current and also lower than plugging braking current as shown in Figure 12. Therefore, the motor losses and energy losses are reduced compared with of plugging method as shown in Figure 13 and Figure 14. The braking energy losses are 2884 Joule with braking time of 5 sec, 2734 Joule with braking time of 4.5 sec and 2944 Joule with braking time of 4 sec.

With the same braking time of 5 sec, the braking energy losses with the proposed method are about 19.8 % of braking energy losses with plugging method. Therefore, the proposed method is more useful method to save energy for multi-braking applications.With the proposed method, the motor can be braked with time shorter than plugging braking time with lower braking energy losses. In Figure 15, the input power is the electrical power from supply and output power is the mechanical power. The output power is reversed in braking mode because the developed torque reversed.

The input power during braking with the proposed method is returned to supply from motor during a part of braking period.The optimum values of applied voltage and frequency to have certain braking time with minimum braking energy losses are obtained using PSO technique. The results and are shown in Figure 16 and Figure 17.

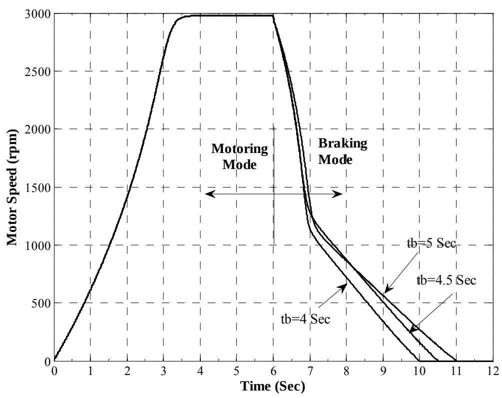

Figure 10. Variation of motor speed with time (Proposed method)

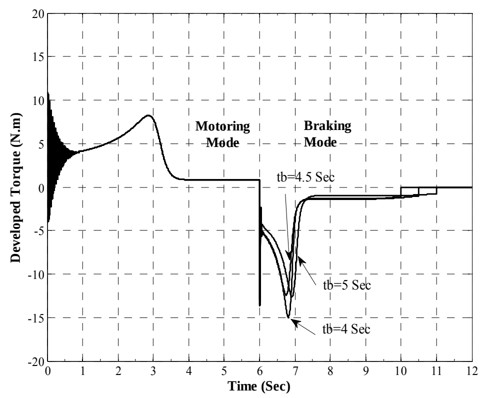

Figure 11. Variation of developed torque with time (Proposed method)

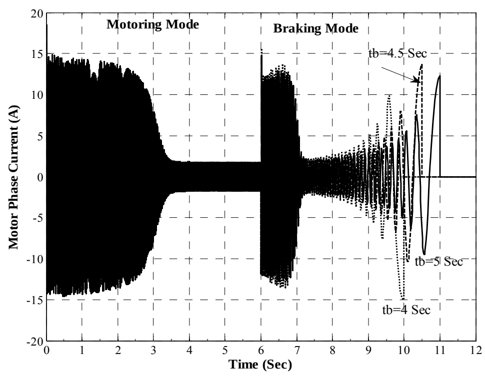

Figure 12. Variation of motor phase current with time (Proposed method)

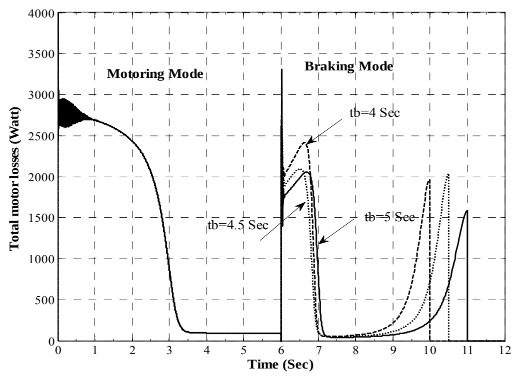

Figure 13. Variation of total motor losses with time (Proposed method)

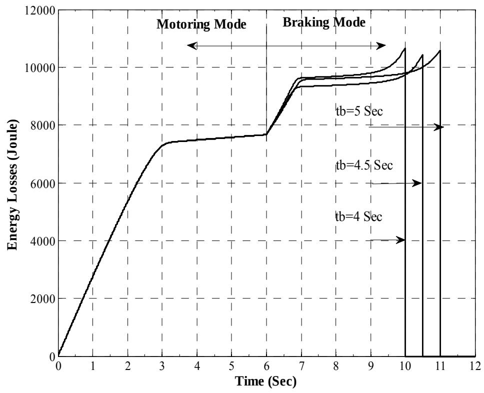

Figure 14. Variation of energy losses with time (Proposed method)

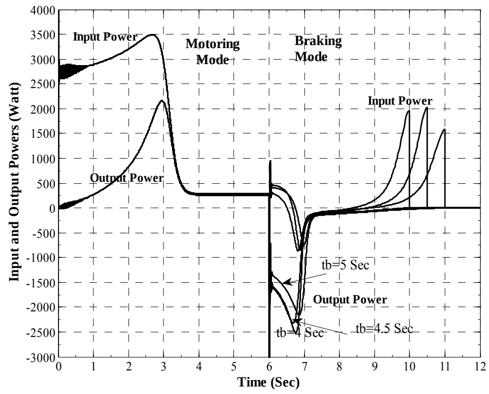

Figure 15. Variation of input and output powers with time (Proposed method)

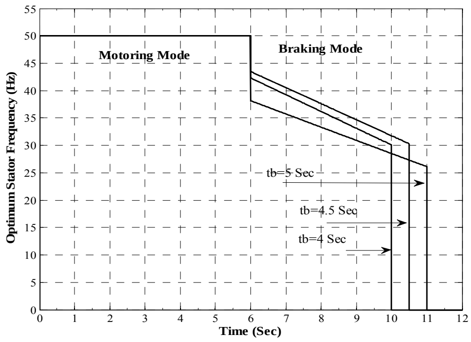

Figure 16. Variation of optimum values of stator frequency with time (Proposed method)

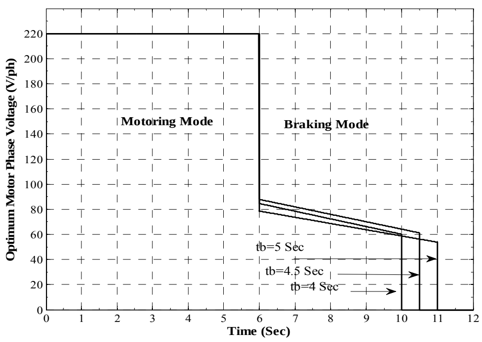

Figure 17. Variation of optimum values of motor phase voltage with time (Proposed method)

5. CONCLUSION

Using the proposed braking method, three phase induction motors can be braked at a given braking time with minimum braking energy losses. The proposed method determines the optimum values of applied voltage and frequency to stop the motor within certain time with minimum braking energy losses by particle swarm optimization technique. The braking energy losses with the proposed method are about 20 % of plugging braking energy so that the proposed method is more useful for multi braking applications without any excessive overheating for the motor.

REFERENCES

[1] Marko Hinkkanen, JormaLuomi. Braking Scheme for Vector-Controlled Induction Motor Drives Equipped With Diode Rectifier Without Braking Resistor. *IEEE Transactions on Industry Applications*. 2006; 42(5): 1257-1263.

[2] PL Rongmei, Shimi SL, Dr S Chatterji, Vinod K Sharma. A Novel Fast Braking System for Induction Motor. *International Journal of Engineering and Innovative Technology (IJEIT)*. 2012; 1(6): 65-69.

[3] MukulRastogi, Peter W Hammond. Dual-Frequency Braking in AC Drives. *IEEE Transactions on Power Electronics*. 2002; 17(6): 1032-1040.

[4] Bilal Abdullah Nasir. Braking Methods of Induction Motor Fed From A Current- Source Inverter. *Elsevier, Energy Procedia.* 2012; *14:* 1819-1824.

[5] Hairik, HA Thejel, RH Kadhem WA. Proposed scheme for plugging three-phase induction motor. *MELECON 2010 15th IEEE Mediterranean Electrotechnical Conference*, Valletta. 2010; 1-5.

[6] Laabidi M Rebhi, B Kourda, F Elleuch, M Ghodbani L. Braking of induction motor with the technique of discrete frequency control. *Systems Signals and Devices (SSD), 7th International Multi-Conference*. Amman. 2010; 1-6.

[7] Sowilam GMA, Korfly MI, Hassan AA. Braking methods of induction motor using direct torque control. *Power Systems Conference, MEPCON 2006, Eleventh International Middle East*. 2006; 1: 35-40.

[8] Amin AMA, El Korfally MI, Sayed AA, Hegazy OTM. Efficiency Optimization of Two-Asymmetrical-Winding Induction Motor Based on Swarm Intelligence. *Energy Conversion, IEEE Transactions*. 200924(1): 12-20.
[9] Ping Guo, Dagui Huang, Daiwei Feng, Wenzheng Yu and Hailong Zhang. Optimized design of induction motor parameters based on PSO (Particle Swarm Optimization). *Mechatronics and Automation (ICMA), International Conference*, Chengdu. 2012; 837-842.
[10] Tofighi EM, Mahdizadeh A, Feyzi MR. Online estimation of induction motor parameters using a modified particle swarm optimization technique. *Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE*. 2013; 3645-3650.
[11] Wei Hu, Gui Liu, Li Fu, Hongmei Zhang. Research of motor fault diagnosis based on PSO algorithm. Control and Decision Conference (CCDC), 2013 25th Chinese, Guiyang. 2013.
[12] John Chiasson. Modelling and high performance control of electric machine. John Wiley & Sons, Inc., 2005.
[13] Xin She Yang. Natural Inspired Metaheuristic algorithm, Luniver Press, University of Cambrodge, United Kingdom, second edition. 2010.
[14] Shi Y, Eberhart R. ***A modified particle swarm optimizer.*** Proceedings of IEEE International Conference on Evolutionary Computation (ICEC'98), Anchorage, IEEE Press. 1998: 69–73.
[15] Shi Y, Eberhart R. ***Parameter selection in particle swarm optimization.*** Proceedings of the 1998 Annual Conference on Evolutionary Programming, San Diego, MIT Press, 1998.

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