International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 7, No. 4, December 2016, pp. 1038~1048
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v7i4.pp1038-1048

Minimization of Starting Energy Loss of Three Phase Induction Motors based on Particle Swarm Optimization and Neuro Fuzzy Network

Mahmoud M. Elkholy, Mohamed A. Elhameed
Electrical Power and Machines Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt

Article Info

Article history:

Received May 18, 2016
Revised Oct 24, 2016
Accepted Nov 5, 2016

Keyword:

Induction motor
Neuro-fuzzy network
Particle swarm optimization
Starting energy losses

ABSTRACT

The purpose of this paper is to minimize energy losses consumed by three phase induction motors during starting with wide range of load torque from no load to full load. This will limit the temperature rise and allows for more numbers of starting during a definite time. Starting energy losses minimization is achieved by controlling the rate of increasing voltage and frequency to start induction motor under certain load torque within a definite starting time. Optimal voltage and frequency are obtained by particle swarm optimization (PSO) tool according to load torque. Then, outputs of the PSO are used to design a neuro-fuzzy controller to control the output voltage and frequency of the inverter during starting for each load torque. The starting characteristics using proposed method are compared to that of direct on line and V/F methods. A complete model of the system is developed using SIMULINK/MATLAB.

Corresponding Author:

Mahmoud M. Elkholy,
Electrical Power and Machines Department, Faculty of Engineering,
Zagazig University, P.O. Box 44519 Zagazig, Al Bahr Street, Zagazig, Egypt.
Email: melkholy71@yahoo.com

1. INTRODUCTION

Three phase induction motors are used extensively in industry due to rigidness, less maintenance and fault tolerant. When these motors are connected directly to supply, they draw large currents and dissipate large amount of energy. This results in more voltage drop across the network elements and more heat for the motor itself especially in multi-start operations [1].

Many researches discussed the problem of motor starting [2-8], some of which discussed soft starting to produce less currents and no sudden torques [9, 10], soft starting may enhance starting energy, but the save is not optimum. For example, in [11] the save is not more than 4 % at light load and there is a negative save with torques greater than 60 % of full load torque. In [12], a neuro-fuzzy soft starter is used to reduce energy losses by adjusting the firing angles of the thyristors of an AC voltage controller, but optimal conditions and effect of frequency variation are not discussed. In [13], genetic algorithm is used to optimize the energy of starting by defining the appropriate voltage ramp during starting, the save in energy reaches 20 %, but frequency variation is not investigated in the paper. Adaptive and optimal control of induction motor using PSO and neuro fuzzy controller is proposed in [14-16].

In this paper, particle swarm optimization method is used to obtain the rate of change of both voltage and frequency over the full range of load torques from no load to full load to have minimum starting energy losses. There are constraints such as both applied voltage and frequency must equal to the rated values at the end of starting period and the motor must be started within a certain specified time. The output of the optimization process is used to design a neuro-fuzzy controller to control the voltage and frequency during starting depending on load torque so that the proposed system is optimal and adaptive.

2. MATHEMATICAL MODEL

Using Laplace transformation the voltage equations of three phase squirrel cage induction motor in d-q frame are [17]:

$$I_{Sd}(s)(1+sT_\sigma)R_\sigma = V_{Sd}(s) + \psi_{Rd}(s)\frac{M}{T_R L_R} + \dot{\theta}(s)\psi_{Rq}(s)\frac{M}{L_R} + \dot{\theta}_S(s)I_{Sq}(s)L_\sigma \quad (1)$$

$$I_{Sq}(s)(1+sT_\sigma)R_\sigma = V_{Sq}(s) + \psi_{Rq}(s)\frac{M}{T_R L_R} - \dot{\theta}(s)\psi_{Rd}(s)\frac{M}{L_R} - \dot{\theta}_S(s)I_{Sd}(s)L_\sigma \quad (2)$$

$$\psi_{Rd}(s)(1+sT_R) = I_{Sd}(s)M + \dot{\theta}_R(s)T_R\,\psi_{Rq}(s) \quad (3)$$

$$\psi_{Rq}(s)(1+sT_R) = I_{Sq}(s)M - \dot{\theta}_R(s)T_R\,\psi_{Rd}(s) \quad (4)$$

Where$R_\sigma = R_S + \frac{M^2}{{L_R}^2}R_R$, $L_\sigma = L_S - \frac{M^2}{L_R}$, $T_R = \frac{L_R}{R_R}$ and $T_\sigma = \frac{L_\sigma}{R_\sigma}$

V_{Sd} is the d-axis stator voltage, V_{Sq} is the q-axis stator voltage, I_{Sd} is the d-axis stator current, I_{Sq} the q-axis stator current, I_{Rd} is d-axis referred rotor current, I_{Rq} is q-axis referred rotor current, L_S is the self inductance of stator phase winding, L_R is the self inductance of rotor phase winding and M is the mutual inductance between stator and rotor windings. Thed-q flux linkages of stator and rotor are defined by:

$$\psi_{Sd} = L_S I_{Sd} + M I_{Rd} \quad (5)$$

$$\psi_{Sd} = L_S I_{Sq} + M I_{Rq} \quad (6)$$

$$\psi_{Rd} = L_R I_{Rd} + M I_{Sd} \quad (7)$$

$$\psi_{Rq} = L_R I_{Rq} + M I_{Sq} \quad (8)$$

The electromagnetic torque equation is:

$$T_e = \frac{3}{2}\frac{p}{2}\frac{M}{L_R}\left(I_{Sq}\psi_{Rd} - I_{Sd}\psi_{Rq}\right) \quad (9)$$

The motor mechanical equation is:

$$T_e - T_L = (Js + B)\dot{\theta}(s) \quad (10)$$

Where;p is the number of poles, T_e is the electromagnetic torque of the motor, T_L is the load torque, J is the moment of inertia Kg.m^2 and B is the friction coefficienct. The model of three phase squirrel cage induction motor is developed using SIMULINK /MATLAB to solve above nonlinear equations and to study the dynamic performance characteristics of the motor during starting. The SIMULINK dynamic model of the motor is shown in Figure 1.a. The starting energy losses (w), stator copper losses (p_{cu}) and iron losses (p_{iron})of the motor are defined as:

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

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

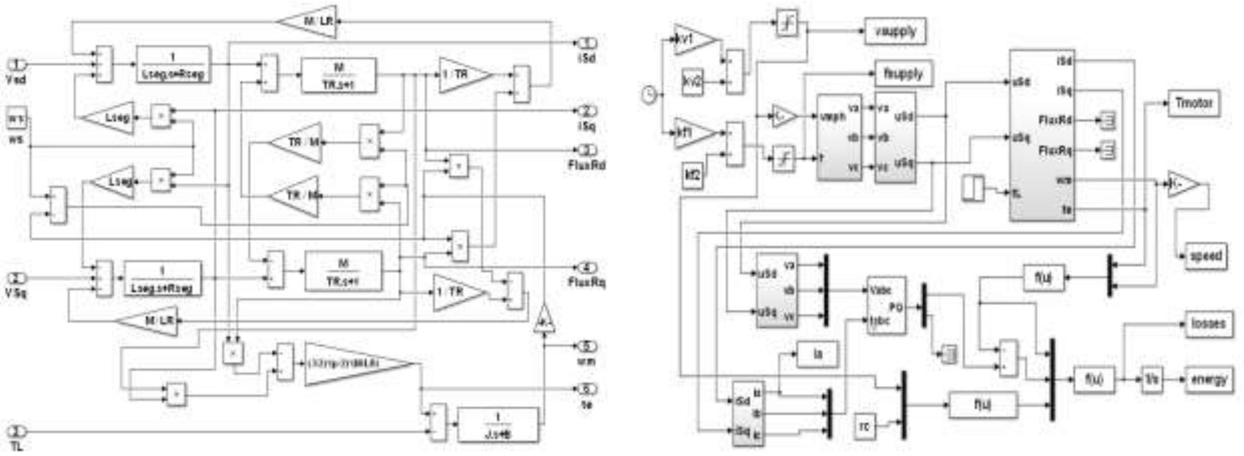
$$p_{iron} = \frac{3\,V^2}{R_C} \quad (13)$$

Where; I_S is the stator phase current, I_R is the referred rotor phase current, V is the stator phase voltage, R_S is the resistance of stator phase winding, R_R is the referred resistance of rotor phase winding and R_C is the core loss resistance. Motor voltage and frequency are changed during starting according to the equations:

$$V = K_{V1}t + K_{V2} \quad (14)$$

$$f = K_{f1}t + K_{f2} \quad (15)$$

Where; K_{V1}, K_{V2}, K_{f1} and K_{f2} are constants.
The maximum values of voltage and frequency are the rated values of the motor. The ratio of voltage to frequency must be limited to the ratio of rated voltage and frequency to prevent motor saturation and overheating. Figure 1.b shows the SIMULINK model with these variable voltage and frequency.



a. SIMULINK Model of Three Phase Induction Motor b. SIMULINK System Scheme

Figure 1. Developed SIMULINK Model

3. OPTIMUM VOLTAGE AND FREQUENCY VARIABLES USING PSO

In this part PSO method is used to determine the constants K_{v1}, K_{v2}, K_{f1} and K_{f2} in Equations (14) and (15). The objective function is Equation (11) of starting energy losses with the inequality constraints of:

a. Starting time ≤ 10 s.
b. Motor voltage and frequency must equal rated values at the end of starting time.

Figure 2 shows the flow chart of the 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. New position of Agents is determined according to their velocities, their best position and the best position of the swarm. Agent's velocity in swarm is updated according to Equation (16):

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

where v_i^k is velocity of agent i at iteration k, w is weighting function, c_i is weighting coefficients, $rand$: is random number between 0 and 1, s_i^k is the 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:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (17)$$

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 [18, 19], the following parameters are appropriate and do not depend on optimization problems:

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

Simulation has been carried out by using SIMULINK/MATLAB for 220/380 V, 1.1 kW, 50 Hz three phase induction motor having: 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 and J=0.05 kg.m^2. PSO are used to obtain the optimum voltage and frequency variables, maximum number of iterations is $iter_{max}$ = 50. The process is repeated for a load torque range from 0.2 to 3 N.m in a step of 0.2 N.m. For each load torque, PSO is run for five times and the best solution is recorded. The optimal values of K_{V1}, K_{V2}, K_{f1} and K_{f2} are listed in Table 1. Figure 3 and Figure 4 show the PSO fitness function results at load torque of 1 and 2 N.m respectively. The optimum values of motor voltage and frequency obtained by PSO are shown in Figure 5 and Figure 6. The optimum values of voltage and frequency are varied with different values of load torque, therefore a neuro-fuzzy technique is used to adapt theseoptimum with load torque.

Table 1. Optimal Motor Voltage and Frequency Parameters

TL(N.m)	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
K_{V1}	16.153	15.873	15.06	14.574	14.1776	14.123	13.98	13.827	13.483	13.173	12.517	12.279	11.407	11.274	11.266
K_{V2}	58.702	61.595	69.627	75.411	79.806	83.253	87.311	91.556	92.11	96.958	100.368	107.552	114.336	115.359	120.034
K_{f1}	5.232	5.015	4.854	4.69	4.49	4.333	4.17	4.019	3.808	3.645	3.416	3.281	3.041	2.884	2.735
K_{f2}	11.741	12.32	13.925	15.082	15.961	16.651	17.47	18.317	18.423	19.392	20.135	21.513	22.898	23.095	24.035

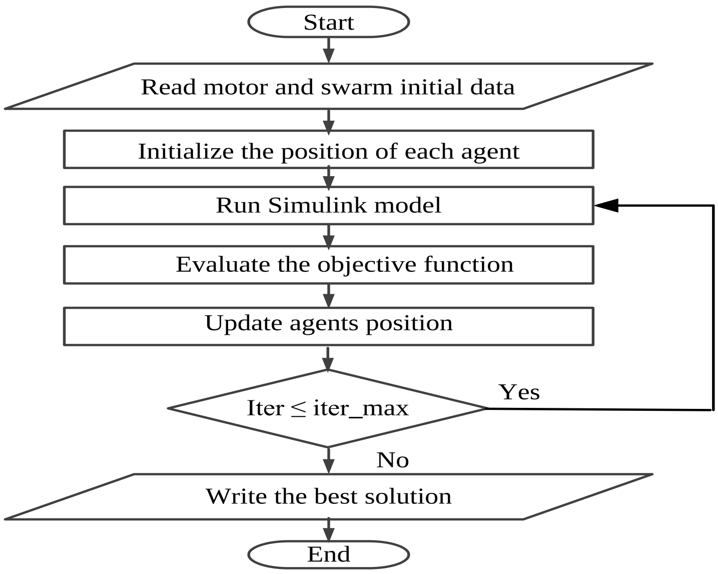


Figure 2. Flow Chart of the PSO Method

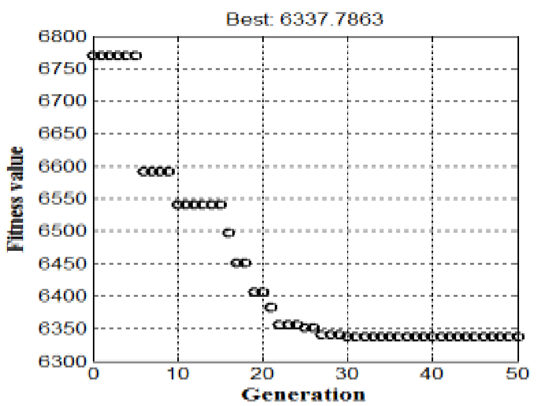


Figure 3. Variation of PSO Fitness Value with Generation at Load Torque 1 N.m

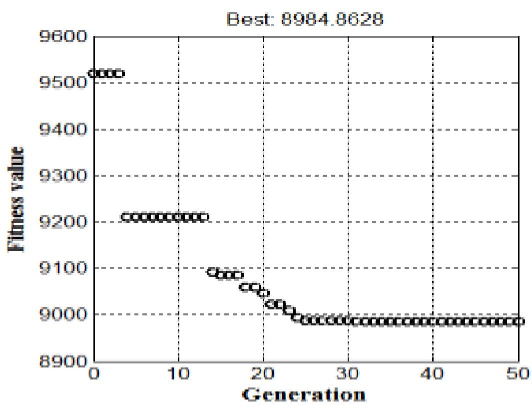


Figure 4. Variation of PSO Fitness Value with Generation at Load Torque 2 N.m

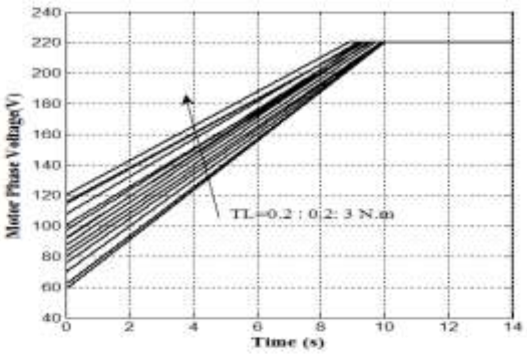


Figure 5. Variation of Motor Phase Voltage with Time at Different Load Torques

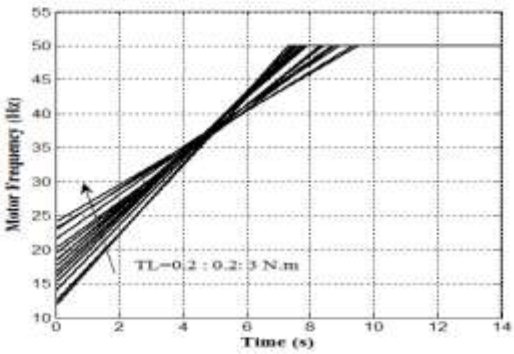


Figure 6. Variation of Motor Frequency with Time at Different Load Torques

4. ADAPTIVE NEURO-FUZZY CONTROLLER FOR MOTOR INVERTER

Sugeno fuzzy system [20], is more compact than Mamdani system and is used for adaptive techniques for constructing fuzzy models. These adaptive techniques can be used to customize the membership functions so that the fuzzy system best models the data. The concept of adaptive neuro-fuzzy inference system ANFIS is used to obtain the required voltage and frequency values. The optimal values of voltage and frequency depend on the load torque. A neuro-fuzzy network is trained to perform this adaptation. The input to this network is load torque, and the outputs are the four constants of voltage and frequency equations. An ANFIS is built for each constant in the voltage and frequency equations, i.eK_{V1}, K_{V2}, K_{f1} and K_{f2}. The four networks have the same structure of a hidden layer with 6 neurons and are trained for 1000 epochs, Table 2 shows the training statistics for these networks. Figure 7 shows the training pattern for the networks. The output of the ANFIS is compared with the output in the training set and is shown in Figure 8. A Gaussian membership functions are used to fuzzy input data and a linear function is used for the output data. A back propagation algorithm is used to adapt membership functions so that the error goal between targets and outputs of ANFIS is achieved. Complete Simulink model of the system with neuro-fuzzy controller is shown in Figure 9.

Table 2. Training Statistics of ANFIS Networks

Parameter	Max. error	Mean error	Standard Deviation
K_{v1}	3.1422×10^{-4}	4.9687×10^{-6}	1.6883×10^{-4}
K_{v2}	3.4055×10^{-4}	1.4188×10^{-5}	1.7557×10^{-4}
K_{f1}	2×10^{-3}	1.6843×10^{-6}	1.3×10^{-3}
K_{f2}	8.0540×10^{-5}	2.8264×10^{-6}	3.5745×10^{-5}

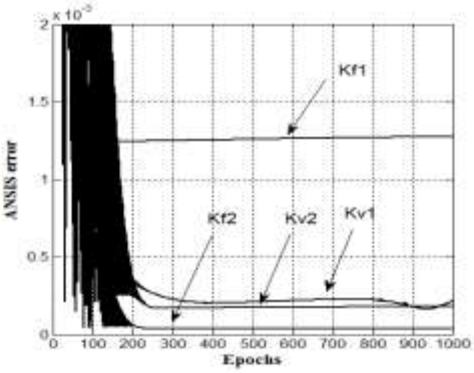


Figure 7. Variation of K_{V1}, K_{V2}, K_{f1} and K_{f2} ANFIS Error with Training Epochs

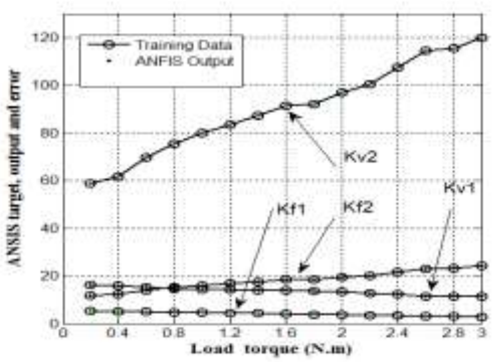


Figure 8. Variation of K_{V1}, K_{V2}, K_{f1} and K_{f2} ANFIS Output, target

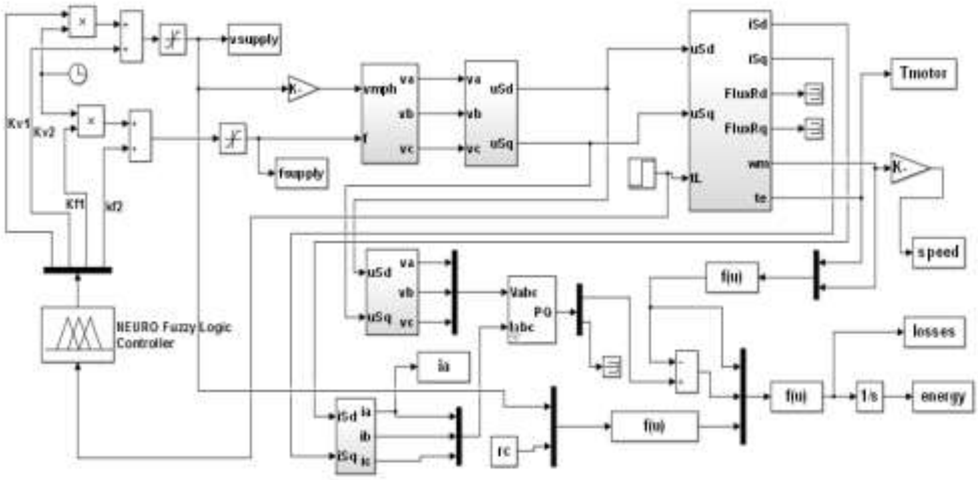


Figure 9. SIMULINK Model of the System with Neuro-Fuzzy Controller

5. RESULTS AND DISCUSSION

Simulation has been carried out by using SIMULINK/MATLAB for two different motors. Motor A is a 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 and J=0.05 kg.m^2. Motor B is a 220/380 V, 2 hp, 50 Hz three phase induction motor having the following parameters: R_S = 5.6 Ω, R_R= 4.965 Ω, L_S =0.0.2611 H, L_R=0.2611 H, M=0.2445 H, p =4 and J=0.2 kg.m^2.

5.1. Results of Motor A

In this section three groups of results are presented for motor A. The first group represents results when the motor is started by the proposed method where voltage and frequency are changed as given in Equations (14) and (15) with constants K_{V1}, K_{V2}, K_{f1} and K_{f2} as listed in Table 2. The second group represents results of DOL method. The third group represents results when the motor is started with V/F method where frequency is increased with ramp rate from 0 Hz to rated frequency of 50 Hz in 10 s (this is the factory setting of EUROTHERM DRIVES 605 Series Frequency Inverter) and voltage is given as:

$$V = \frac{Rated\ Voltage}{Rated\ Frequency} \times 5\ t = 4.4 \times 5\ t = 22\ t \qquad (19)$$

Figure 10.a shows the variation of motor energy losses with the three starting methods at different load torques ranges from 0.2 N.m to 3 N.m with a step of 0.2 N.m. It's shown that the proposed technique reduces starting energy losses much more than DOL and V/F starting. This reduction in starting energy losses leads to energy saving especially in multi-starting application.

The variation of motor speed and developed torque with time at different load torques are shown in Figures 10.b and 10.c respectively. In case of V/F starting method with high load torques, and at low frequency the developed torque is lower than load torque so that the motor failed to start and motor starts when the frequency reaches its rated value.

The variation of stator current with time at load toque of 0.2 N.m in case of the three methods of starting is shown in Figure 10.d. The starting current in case of V/F method is lower than that of the proposed and DOL methods but the starting time is the highest. Starting energy losses with proposed method are the lowest one at all range of load torques as shown in Figure 11. The percentage saving in starting energy losses of proposed method compared to other methods are shown in Table 3 and calculated as:

$$\%\ \text{Saving in Starting Energy losses compared to DOL} = \frac{Saving\ in\ Starting\ Energy\ losses}{DOL\ Starting\ Energy\ Losses} \times 100 \qquad (20)$$

% Saving in Starting Energy losses compared to (21)

$$\frac{V}{F} = \frac{Saving\ in\ Starting\ Energy\ losses}{V/F\ Starting\ Energy\ Losses} \times 100$$

% Saving in Starting Energy losses compared to modefied

$$\frac{V}{F} = \frac{Saving\ in\ Starting\ Energy\ losses}{modefied\ \frac{V}{F} Starting\ Energy\ Losses} \times 100 \tag{22}$$

In modified V/F method the voltage and frequency are boosted by 10 % at starting to improve the starting torque as:

$$f = 5 + \frac{(50-5)}{10} \times\ t = 5 + 4.5\ t\ ,\ \ V = 22 + \frac{(220-22)}{10} \times\ t = 22 + 19.8\ t \tag{23}$$

Table 3. % Saving in Starting Energy Losses of Motor a of Proposed Method Compared to DOL and V/F Methods

Load Torque (N.m)	% Saving in Starting Energy losses compared to DOL	% Saving in Starting Energy losses compared to V/F	% Saving in Starting Energy losses compared to modified V/F
0.2	34.9014	34.7008	22.4533
0.4	33.4208	41.0692	23.0389
0.6	32.1303	47.3993	28.6780
0.8	30.6508	53.1449	36.1000
1.0	29.6767	53.2691	44.4024
1.2	28.5710	51.6331	52.3407
1.4	27.6932	50.0330	54.3077
1.6	26.9064	48.4016	52.8746
1.8	27.7919	47.8792	52.3544
2.0	27.7643	46.6350	51.0622
2.2	28.5335	45.9077	50.1629
2.4	29.0182	44.8966	48.9659
2.6	30.4330	44.5331	48.3310
2.8	34.4472	46.2188	49.5671
3.0	38.8202	48.1995	51.0327

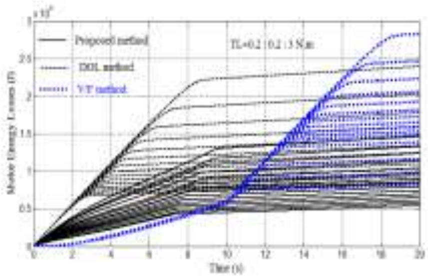


Figure 10.a Variation of Motor Energy Losses with Time at Different Load Torques (motor A)

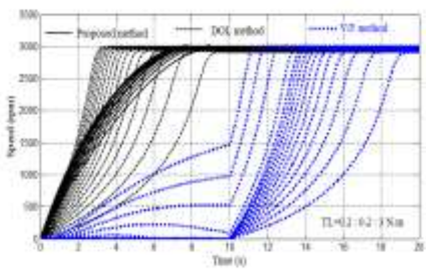


Figure 10.b. Variation of Speed with Time at Different Load Torques (motor A)

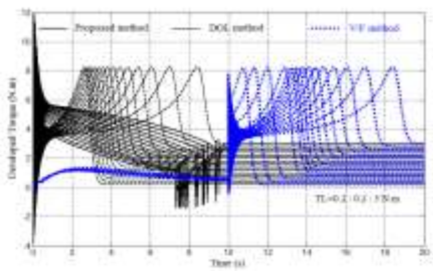


Figure 10.c Variation of Developed Torque with Time at Different Load Torques (motor A)

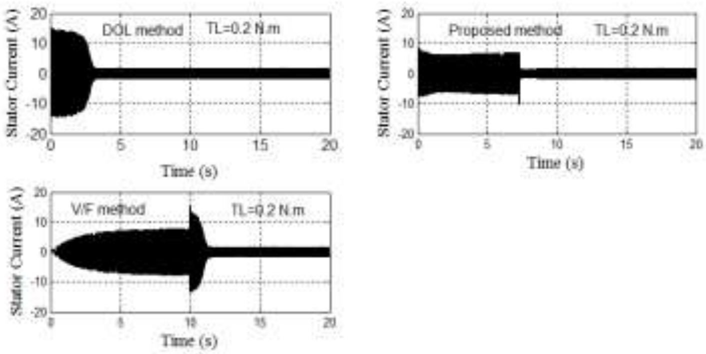


Figure 10.d Variation of Stator Phase Current with Time at Load Torque of 0.2 N.m (motor A)

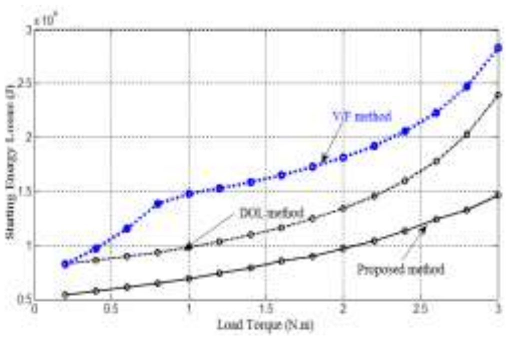


Figure 11. Variation of Starting Energy Losses with Time at Different Load Torques (motor A)

5.2. Results of Motor B

In this section the same results are repeated for motor B. The variation of motor energy losses, speed and motor torque are shown in Figures 12.a to 12.c respectively. It's shown that the motor energy losses of proposed method are the smallest. In V/F method, the motor fails to start when loaded by a load torque equals or greater than 5 N.m which is 50% full load up to the motor voltage and frequency are increased to rated values. Therefore, the motor energy losses of V/F method are the highest.The variation of motor current with time at no load torque is shown in Figure 12.d. The starting current of V/F method is the lowest one but the developed torque is small so that the motor starting time is high and the corresponding energy losses is the highest one as shown in Figure 13. The optimal values of constants K_{V1}, K_{V2}, K_{f1} and K_{f2} of this motor from the PSO as listed in Table 4. The percentage saving in starting energy losses of motor B of proposed method compared to other methods are shown in Table 5.

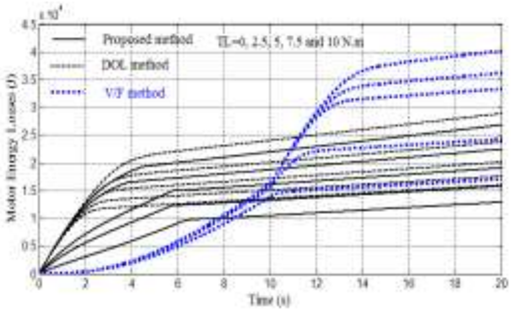


Figure 12.a. Variation of Motor Energy Losses with Time at Different Load Torques (motor B)

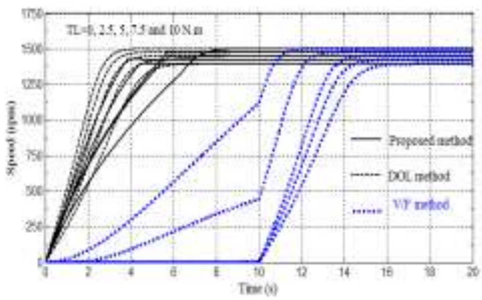


Figure 12.b. Variation of Speed with Time at Different Load Torques (motor B)

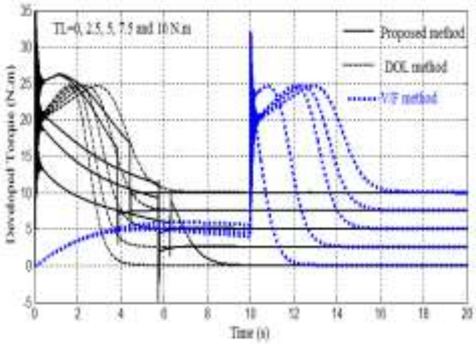


Figure 12.c. Variation of Developed Torque with Time at Different Load Torques (motor B)

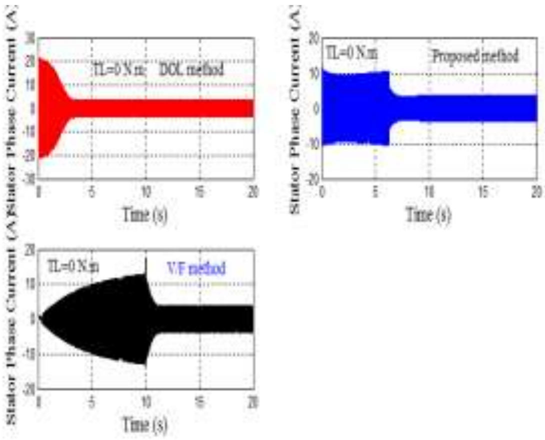


Figure 12.d. Variation of Stator Phase Current with Time at No Load torque (motor B)

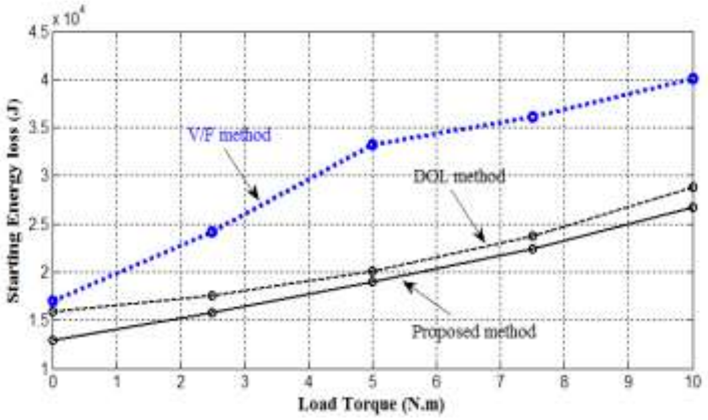


Figure 13. Variation of Starting Energy Losses with Time at Different Load Torques (motor B)

Table 4. Optimal Motor Voltage and Frequency Parameters of Motor B

TL(N.m)	0	2.5	5	7.5	10
K_{V1}	13.573	10.1234	8.0915	9.9001	9.3768
K_{V2}	84.271	128.0304	148.0665	208.2964	208.7867
K_{f1}	5.2718	4.2573	3.5152	2.1579	1.8459
K_{f2}	16.8559	25.6061	29.7303	41.6615	41.7989

Table 5. % Saving in Starting Energy Losses of Motor B of Proposed Method Compared to DOL and V/F Methods

Load Torque (N.m)	% Saving in Starting Energy losses compared to DOL	% Saving in Starting Energy losses compared to V/F	% Saving in Starting Energy losses compared to modified V/F
0	19.2462	24.3329	21.2729
2.5	10.2553	34.8480	29.0131
5	5.1893	42.7697	44.1758
7.5	5.4848	37.9954	43.3044
10	7.2202	33.3063	38.4952

6. CONCLUSIONS

In this paper minimization of starting energy losses of three phase squirrel cage induction motor is achieved by controlling the rate of change of applied voltage and frequency during starting. The optimum values of voltage and frequency rates are obtained by particle swarm optimization (PSO) to have minimum starting energy losses with constraints of keeping the rated V/F ratio, reaching rated voltage and frequency at steady state and limiting starting time to 10 sec. The suitable values of voltage and frequency are varied according to load torque during starting. Therefore, optimum values are obtained over a wide range of load torque from no-load to full load, a neuro-fuzzy controller is designed to adapt the rate of change of voltage and frequency. To validate the proposed method, it is applied to two three phase induction motors, starting energy losses in both cases are lower than that of direct on line method and conventional V/F method at different load torques.

REFERENCES

[1] M. Mohammadi, A. Mohammadi Rozbahani, S. Abasi Garavand, M. Montazeri, H. Memarinezhad. Fuzzy Bang-Bang Control Scheme of USSC for Voltage Sag Mitigation due to Short Circuits and Induction Motor Starting in Distribution System. *International Journal of Power Electronics and Drive System (IJPEDS).* 2014; 4(4): 451-460

[2] Zhou Jing-hua, Chen Cheng, Zhang Xiao-wei and Chen Ya-ai. *Reducing Voltage Energy-saving Control Method of Induction Motor*. International Conference on Electrical Machines and Systems, Busan, Korea, 2013; 2159-2162.

[3] Alexei V. Udovichenko. *New Energy Saving Multizone Alternating-Voltage Soft Starters of Induction Machines*. Micro/Nanotechnologies and Electron Devices (EDM), 2011 International Conference and Seminar of Young Specialists, Erlagol; 2011: 415-419.

[4] Nafeesa K and Saly George. Optimization of Starting Performance of Thyristorized Static Switch Fed Three Phase Induction Motor. Power Electronics, *Drives and Energy Systems (PEDES) & 2010 Power India, 2010 Joint International Conference*; 2010: 1-5.

[5] Vlad, I. Campeanu, A. Enache, S. Enache and M.A. Energy. *Aspects and monitoring of asynchronous motors starting*.Optimization of Electrical and Electronic Equipment (OPTIM) 2014 International Conference, Bran; 2014: 306-31.

[6] Rusnok, S. Sobota, P. Mach, V. Kacor, and P. Misak. Possibilities of program EMTP - ATP to analyze the starting current of induction motor in frequent switching.*Electric Power Engineering (EPE), 16th International Scientific Conference*, Koutynad Desnou; 2015: 614 – 619.

[7] Danang Wijaya, F. Kusumawan and S.A. Prabowo, H. Reducing induction motor starting current using magnetic energy recovery switch (MERS).*Information Technology and Electrical Engineering (ICITEE), 2014 6th International Conference,* Yogyakarta; 2014: 1 – 6.

[8] Piao Run-hao, Zhao Haisen, Zhang Dongdong and Li Jiaxuan. *Analytical method for starting performance calculation of induction motors considering skin effect and leakage flux saturation*. Electrical Machines and Systems (ICEMS), 17th International Conference, Hangzhou; 2014: 135 – 138.

[9] Li Shue and Fue Chao. *Design and Simulation of Three Phase AC Motor Soft Starter*. Intelligent System Design and Engineering Applications (ISDEA), 3rd International Conference on Intelligent System Design and Engineering Applications; 2013: 554-557.

[10] Li Kai, Chen Xing Lin and Tang Qiang. *Dynamic Identification and Control of IM Soft- Start Using ANN*. Industrial Technology, 2008. ICIT 2008. IEEE International Conference; 2008: 1-6.

[11] Frede Blaabjerge, Johne K. Pederson, Soren Rise and Hans Henrik Hansen. *A Comparative Study of Energy Saving Benefits in Soft starters for Three Phase Induction Motors.* Industry Applications Conference, 1995. Thirtieth IAS Annual Meeting, IAS '95, Conference Record of the 1995 IEEE; 1995: 367-374.

[12] Syed Abdul Rahman Kashifa and Muhammad Asghar Saqiba. A Neuro Fuzzy Application: Soft Starting of Induction Motors with Reduced Energy Losses. *Electric Power Components and Systems*. 2012; 40 (12): 1339-1350.

[13] I. Ya. Braslavsky, A.V. Kostylev and D.P. Stepanuk.Energy consumption optimization during starting of thyristor voltage converter induction motor system. *International Symposium on Power Electronics, Electrical Drives, Automation and Motion, SPEEDAM*.2006: 11- 14.

[14] Sakuntala Mahapatra, Raju Daniel, Deep Narayan Dey and Santanu Kumar Nayak.*Induction motor control using PSO-ANFIS.* International Conference on Computer, Communication and Convergence (ICCC 2015). 2015: 753–768.

[15] Xin She Yang. Natural Inspired Metaheuristic algorithm. Luniver Press, University of Cambrodge, United Kingdom, second edition, 2010.

[16] Mahmoud M. Elkholy, Mohammed A. Elhameed. Braking of Three Phase Induction Motors by Controlling Applied Voltage and Frequency Based on Particle Swarm Optimization Technique. *International Journal of Power Electronics and DriveSystem (IJPEDS)*. 2015; 5(4): 520-528.

[17] John Chiasson. Modelling and high performance control of electric machines. John Wiley & Sons, Inc., 2005

[18] Shi Y and Eberhart R. A *modified particle swarm optimizer*. Proceedings of IEEE International Conference on Evolutionary Computation (ICEC'98), Anchorage, IEEE Press. 1998: 69–73.

[19] Shi Y and Eberhart R. *Parameter selection in particle swarm optimization.* Proceedings of the 1998 Annual Conference on Evolutionary Programming, San Diego, MIT Press, 1998.

[20] Jang, J.S.R. ANFIS: Adaptive-Network-based Fuzzy Inference Systems. *IEEE Transactions on Systems*, Man and Cybernetics. 1993; 23(3): 665-685.

BIOGRAPHIES OF AUTHORS

Mahmoud M. Elkholy received Bachelor of Engineering (B.E) degree (with honor) from Zagazig University, Egypt in 1994 under the specialization of Electrical Machines and Power Engineering, Master of Science degree from Zagazig University, Egypt 1998 under the specialization of Electrical Machines and Doctor of Philosophy (Ph.d) in the year 2001 from Zagazig University, Egypt in the Dept. of Electrical power and Machines Engineering. He has 18 years of experience in academia and research at different positions. Currently he is an Assistant Professor, Faculty of Engineering, Zagazig University, Egypt. His interest includes control the steady state and dynamic performance of electrical machines, artificial intelligence and renewable energy

Mohamed A. Elhameed received the B.E. degree (with honors) from Zagazig University-faculty of Engineering, Zagazig, Egypt in electrical power and machines engineering in 1996, Master degree in 2000 in the field of electrical power system from the same institute, and the Ph. D. degree from Zagazig University, Egypt, in 2004, in the field of electrical power system. He has been assistant professor, Faculty of Engineering, Zagazig University, Egypt. His current interest includes electrical machines modeling and control, artifitial intelligence, renewable energy, optimization and FACTS devices.