LIMITING STATOR CURRENT FOR THREE-PHASE INDUCTION DRIVE MOTOR USING PULSE WIDTH MODULATION SYSTEM

Nwosu A. W.
Department of Electrical Engineering,
Chukwuemeka Odimegwu Ojukwu University, Uli,
Anambra State.

Asiwe, M. U.
Delta State Polytechnic, Oghara
Email: asiweuc@gmail.com

ABSTRACT

Induction motor is the most widely used electromechanical machine due to its low cost and minimum maintenance. It has more losses, less efficiency and high power consumption when working at variable speed. The influence of these motors (in term of energy consumption) in energy intensive industries is significant in total input cost. This research presents a development of optimal control system for induction motor drives using pulse width modulation system leading to optimization of the stator current to its least possible value for a given output torque and energy saving. The stator voltage values of the induction motor was varied by varying the modulation index (M_a) using the principle of constant flux. The classical optimal control system which uses information on torque of the motor was used to generate the appropriate voltage amplitude that minimized the induction motor stator current. The constant optimal stator current controller models were configured and built for a set of experimental data using MATLAB computer program. The models were validated by simulation using a typical three-phase induction motor of 4000kw, 400V at a nominal frequency of 50Hz drive model implemented with MATLAB/Simulink toolbox. The results show that at minimum torque, the initial current needed to operate the induction motor at nominal frequency using the open loop system was 3.6A but using the classical control, 1.6A was needed to operate the induction motor saving 2.0A. The results show greater stator current minimization when implementing classical optimal control system.

KEYWORDS: Stator Current, Induction Motor, Torque and Modulation Index.

1.0 INTRODUCTION

Induction motor is the most widely used electromechanical machine due to its low cost and minimum maintenance. When managed directly from the line voltage, the motor operates at an approximate constant speed. It is then required to modify both the line voltage and frequency to obtain speed and torque variations. Following this was the realization that the ratio of the voltage and frequency should be approximately constant (Gnacinski, 2007). The induction motor has the disadvantage that it has more loss and less efficiency when it works at variable speeds. The need of efficient drive systems was achieved by special controllers that not only modify losses and efficiency, but also searching for the optimal values of stator current to reduce power consumption from the source to be minimum (Palit, 1989).

The trends of developing optimal controllers were developed due to the increase in power consumption, which represents the most important problem due to the decrease in power resources. Studies prove that it is possible to decrease the power consumption and increase the efficiency in the induction motor. The control system which achieves all of these is called the Drive System Optimization (Bhim and Singh, 1993). One of the important parameters that require optimization is the stator current. This is because the source voltage and current are applied to the stator winding terminals and this lead to development of magnetic field in the winding and in turn induce an electromagnetic field in the rotor bar thereby producing current in the rotor bar. This value should be minimized, and to achieve this, the method of optimizing adopted was the Classical Optimal Stator Current Control System. (Boukhelife,et al 2004).

The induction motor is made up of the stator, or stationary windings, and the rotor. The stator consists of a series of wire windings of very low resistance permanently attached to the motor frame. As a voltage and a current is applied to the stator winding terminals a magnetic field is developed in the windings. By the way the stator windings are arranged, the magnetic field appears to synchronously rotate electrically around the inside of the motor housing. (Bimal, 2007). The rotor is comprised of a number of thin bars, usually aluminum, mounted in a laminated cylinder. The bars are arranged horizontally and almost parallel to the rotor shaft. At the ends of the rotor, the bars are connected together with a "shorting ring." The rotor and stator are separated by an air gap which allows free rotation of the rotor and the magnetic field generated in the stator induces an EMF in the rotor bars. In turn, a current is produced in the rotor bars and shorting ring and another magnetic field is induced in the rotor with an opposite polarity of that in the stator. The magnetic field, revolving in the stator, will then produce the torque which will "pull" on the field in the rotor and establish rotor rotation.

2.0 ANALYSIS OF MODELING

The stator voltage values of the three-phase induction motor can be varied by varying the modulation index (M_a) using the principle of constant volt/hertz, to maintain an approximately constant flux. The study and analysis of modeling and simulation of open loop ac drive system using am embedded MATLAB model gives identical responses under the same operating conditions (Rateb, 2006). In this work, the open loop ac drive system components was modeled using embedded MATLAB/ Simulink models.

4.0KW 400V 50Hz 1430rpm three phase induction motor was used. The ratings and parameters of the motor are listed in table 1:

Table 1: Rating Parameters of the Three Phase Induction Motor.

Three-Phase Squirrel Cage Induction Motor Rating Parameters	
Number of poles	4
Rated power	4[KW]
Rated voltage	400[V]
Rated frequency	50 [Hz]
Stator resistance	1.405 [Ω]

Rotor resistance	1.395 [Ω]
Stator inductance	0.005839 [H]
Rotor inductance	0.005839 [H]
Air gap inductance	0.1722 [H]
Inertia	0.0131 [$Kg.m^2$]
Nominal speed	1430 [rpm]

For a 4KW (4000W) nominal power, the nominal output torque is given as

$T_n = P / \omega = (30 \times 4000)/(\pi \times 1430) = 26Nm$ (Sim Power Systems Version 4).

For a 400V nominal phase to phase voltage, the DC voltage at the output of a rectifier circuit will be $V_d = (400 \times 2^{0.5}) = 565.7V$. Hence, the DC supply voltage to the inverter is chosen to be 566V at 50Hz. The MOSFET has an ON state resistance of $1 \times 10^{-3}\Omega$

- For a 4KW, 400V, 50Hz nominal output power in a discretized model in Simulink, the snubber capacitance of the MOSFET is
  $C_s = 4000/(1000 \times 2\pi \times 50 \times 400) = 32 \times 10^{-6}$ farad (Sim Power Systems Version 4)
- The snubber resistance of the MOSFET $R_s = (2 \times T_s)/C_s = 309.84$ ohms,
  Where $Ts = 2 \times 10^{-6}$ is the discrete time step. (Sim PowerSystems Version 4)

The discrete SV PWM block is an inbuilt three phase pulse generator in Simulink that generates three phase pulses to the three phase inverter according to the constant volt/hertz principle, using space vector pulse width modulation technique.

- The constant volt/hertz (V_{rms}/f) ratio here is 400/50 = 8.
- The rms voltage at the output of the inverter is given by
- $V_{rms} = (m \times V_d)/2^{0.5}$, (1)
  Where:
  m is the modulation index.
- The current values and corresponding voltages at different load torques can be obtained by varying the stator voltage throughout the modulation index variation , ($0 < m < 1$). The results obtained were presented in table 2 below:

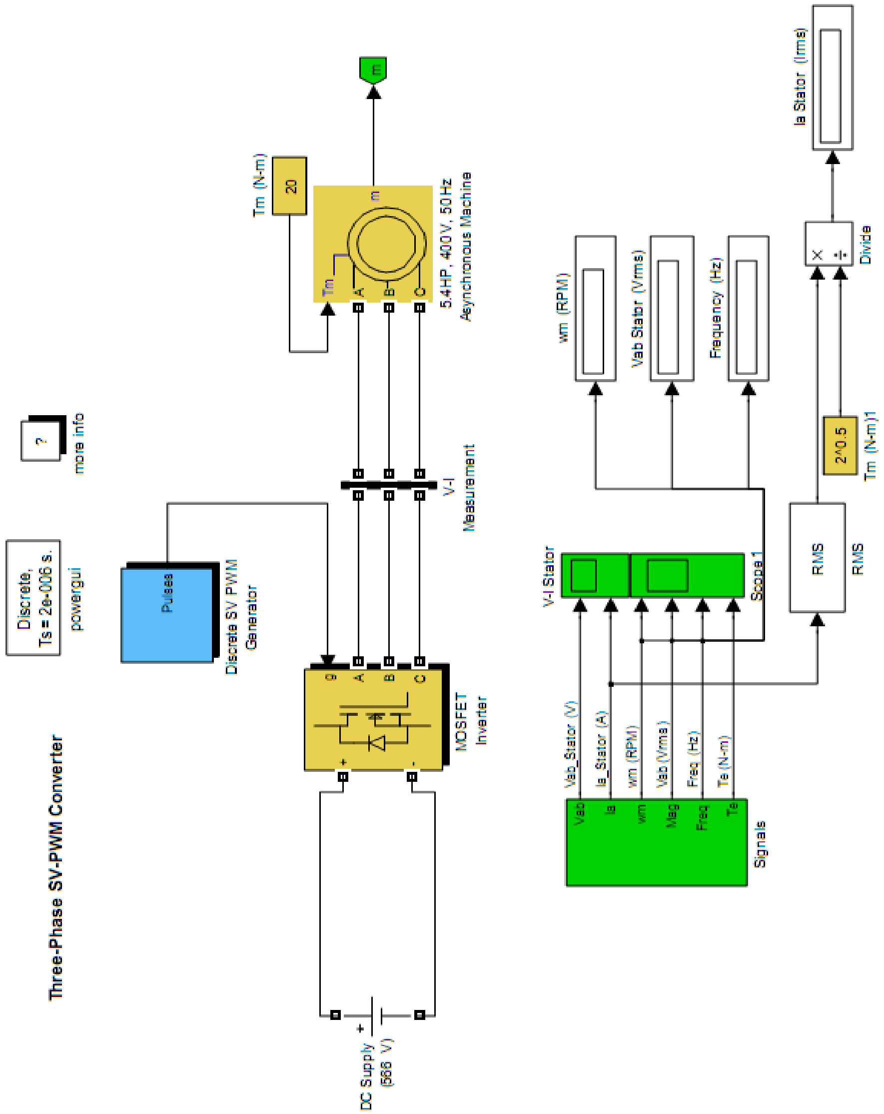

Figure 1: Open-loop speed control model of an induction motor using constant V/Hz principle and a space vector (SV) PWM technique in MATLAB/Simulink

Table 2: Stator Current Value and Corresponding Voltages obtained by varying the Modulation index at different Load Torques at 50Hz.

M	V_{l-l} /V	V_p/V	T=2, I_s/A	T=3, I_s/A	T=4, I_s/A	T=5, I_s/A	T=6, I_s/A	T=7, I_s/A	T=8, I_s/A	T=9, I_s/A	T=10, I_s/A	T=11, I_s/A	T=12, I_s/A	T=13, Is/A	T=20, I_s/A
0.1	40	23.09	-	-	-	-	-	-	-	-	-	-	-	-	-
0.15	59	34.64	-	-	-	-	-	-	-	-	-	-	-	-	-
0.2	80	46.18	3.68	-	-	-	-	-	-	-	-	-	-	-	-
0.25	100	57.73	2.35	3.23	-	-	-	-	-	-	-	-	-	-	-
0.3	120	69.28	2.13	2.71	3.41	4.24	-	-	-	-	-	-	-	-	-
0.35	140	80.83	2.07	2.5	2.99	3.56	4.30	-	-	-	-	-	-	-	-
0.4	160	92.37	2.03	2.53	2.92	3.35	3.66	4.34	4.92	5.56	6.14	-	-	-	-
0.45	180	103.92	2.25	2.52	2.84	3.18	3.55	3.95	4.38	4.84	5.35	5.91	6.52	7.11	-
0.5	199	115.47	2.31	2.56	2.83	3.12	3.42	3.75	4.09	4.46	4.85	5.27	5.72	6.20	-
0.55	219	127.02	2.41	2.73	2.96	3.21	3.47	3.74	4.03	4.34	4.66	4.99	5.35	5.72	-
0.6	240	138.56	2.5	2.88	3.09	3.31	3.53	3.77	4.02	4.28	4.55	4.83	5.12	5.43	8.04
0.65	260	150.11	2.73	2.94	3.12	3.32	3.52	3.73	3.95	4.17	4.41	4.65	4.90	5.16	7.30
0.7	280	161.65	2.84	3.01	3.18	3.35	3.53	3.72	3.91	4.11	4.32	4.53	4.75	4.97	6.78
0.75	300	173.20	2.93	3.22	3.37	3.53	3.70	3.87	4.04	4.22	4.40	4.59	4.79	4.99	6.56
0.8	320	184.75	3.09	3.27	3.41	3.56	3.71	3.86	4.02	4.19	4.35	4.52	4.70	4.88	6.27
0.85	340	196.29	3.36	3.38	3.52	3.65	3.79	3.94	4.09	4.24	4.39	4.55	4.71	4.87	6.12
0.9	360	207.84	3.44	3.57	3.70	3.83	3.96	34.09	4.23	4.37	4.51	4.65	4.80	4.95	6.08
0.95	380	219.39	3.54	3.77	3.88	4.00	4.13	4.25	4.38	4.51	4.64	4.77	4.91	5.05	6.09
1.0	400	230.94	3.7	3.93	4.04	4.15	4.27	4.39	4.50	4.63	4.75	4.87	5.00	5.13	6.09

Where:

- m is the modulation index, V_{l-l} is the phase to phase rms stator voltage in volts

V_p is the per phase rms stator voltage in volts, I_s is the per phase rms stator current in amperes and T is the output torque in Nm.

3.0 DESIGN OF CLASSICAL OPTIMAL STATOR CURRENT CONTROLLER

The optimal current values and corresponding voltages at different load torques can be obtained by varying the stator voltage throughout the modulation index variation. The minimum current points for different load torques were calculated and pointed out on V-I curve of the induction motor, as shown in figures 2 below.

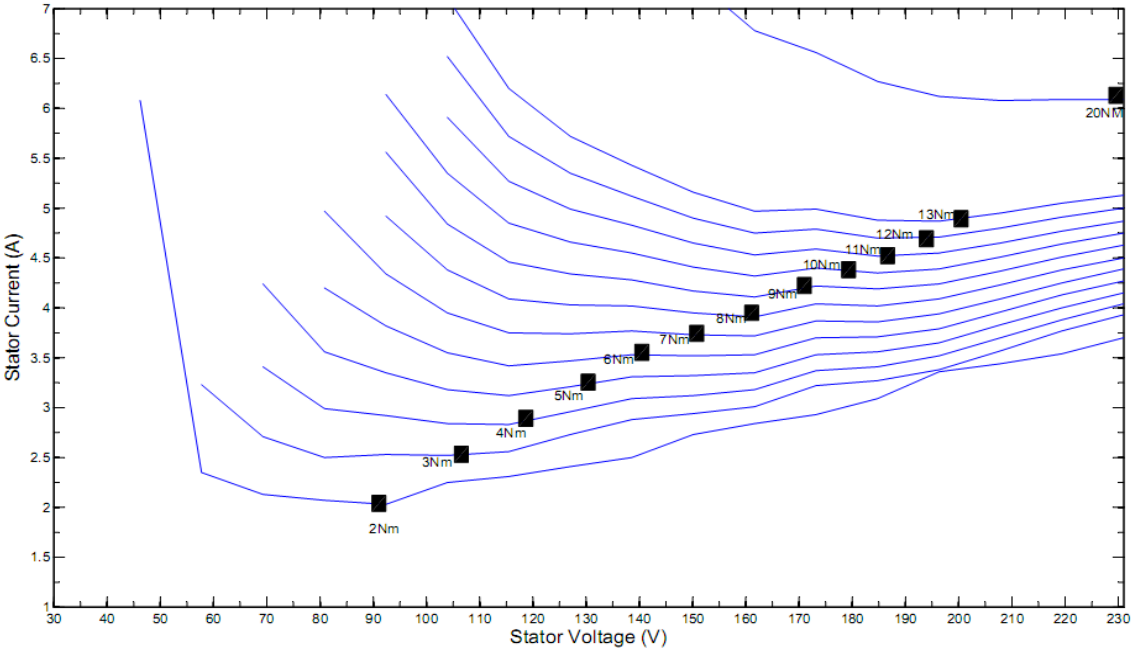

Figure 2: Stator current vs. per phase rms stator voltage at different load torques at 50Hz

The resultant minimum points obtained by fitting V_p vs I_s curve represent the optimal voltages (V_{opt}) and the optimal currents (I_{opt}) values for different load torques at the specified frequencies, and satisfy the best performance for motor operation .These values are shown in the tables 3.

Table 3: Optimal Voltages and Currents of Variant Load Torques at 50Hz.

T [N.m]	**V_{opt} [V]**	**I_{opt} [A]**
2	92.0591	2.1982
3	104.9087	2.6392
4	116.4275	3.0237
6	150.5038	3.6373
8	168.681	4.179
10	181.6806	4.6372
12	201.736	5.0644
13	210.139	5.1987
20	230	6.578

The relationship between the stator voltage and the stator current at different load torques at each frequency can be obtained by using MATLAB Curve Fitting Toolbox, the graph of figure 3 was obtained.

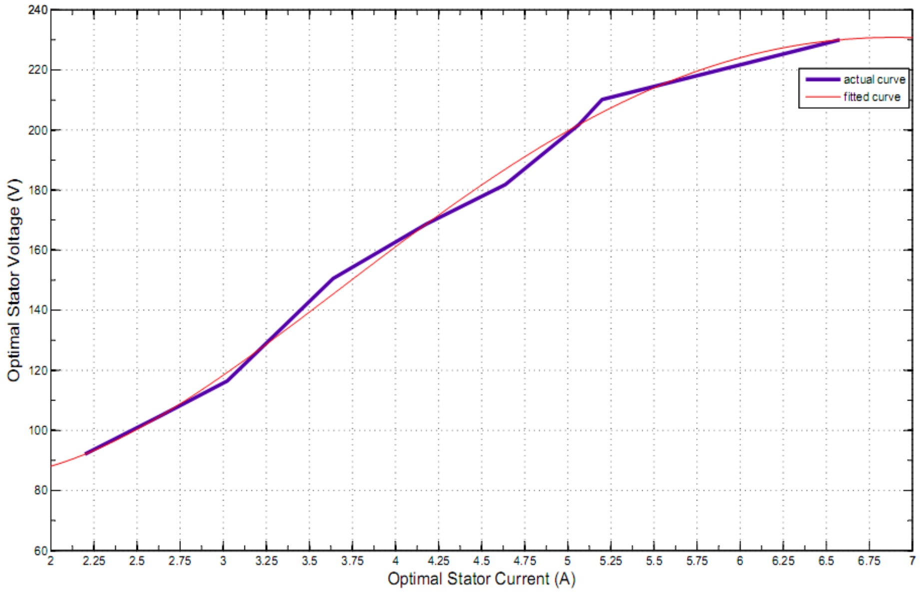

Figure 3: Optimal stator voltage vs stator current fitting curve at 50Hz

The optimal current controller's equation at nominal frequency at 50Hz in figure 3 is given by

$$V_p = a_1 I_s^4 + a_2 I_s^3 + a_3 I_s^2 + a_4 I_s + a_5 \qquad (2)$$

Where; $a_1 = 0.2746$

$a_2 = -6.617$

$a_3 = 50.68$

$a_4 = -115.2$

$a_5 = 164.4$

V_p is the per phase stator voltage, Is is the stator current.,

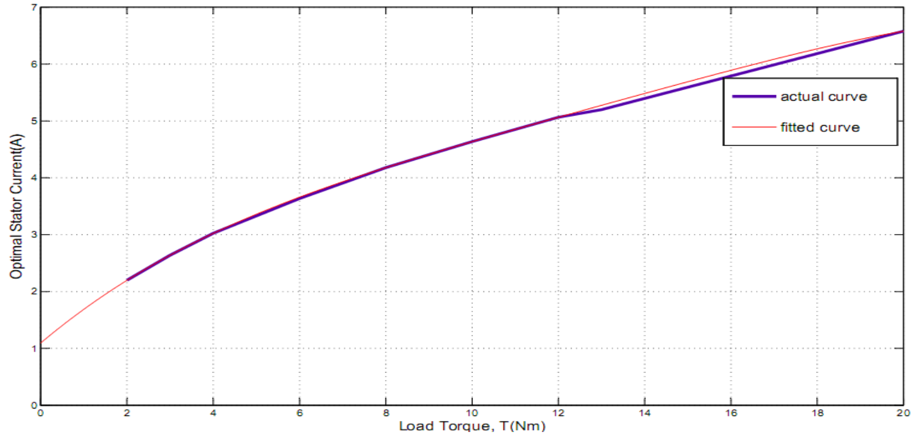

Figure 4: Optimal stator current vs load torque fitting curve at 50Hz

The equation relating optimal current and load torque at 50Hz in figure 4 is given by

$$I_s = b_1 T^2 + b_2 T + b_3 \qquad (3)$$

Where; $b_1 = -0.005522$

$b_2 = 0.3564, \quad b_3 = 1.613$

4.0 MODELING OF CLASSICAL OPTIMAL STATOR CURRENT CONTROLLER

Figures 3 and 4 shows the models of optimal stator current controller at nominal frequency 50Hz. This model was derived using equations (i) and (ii). From MATLAB/Simulink toolbox.

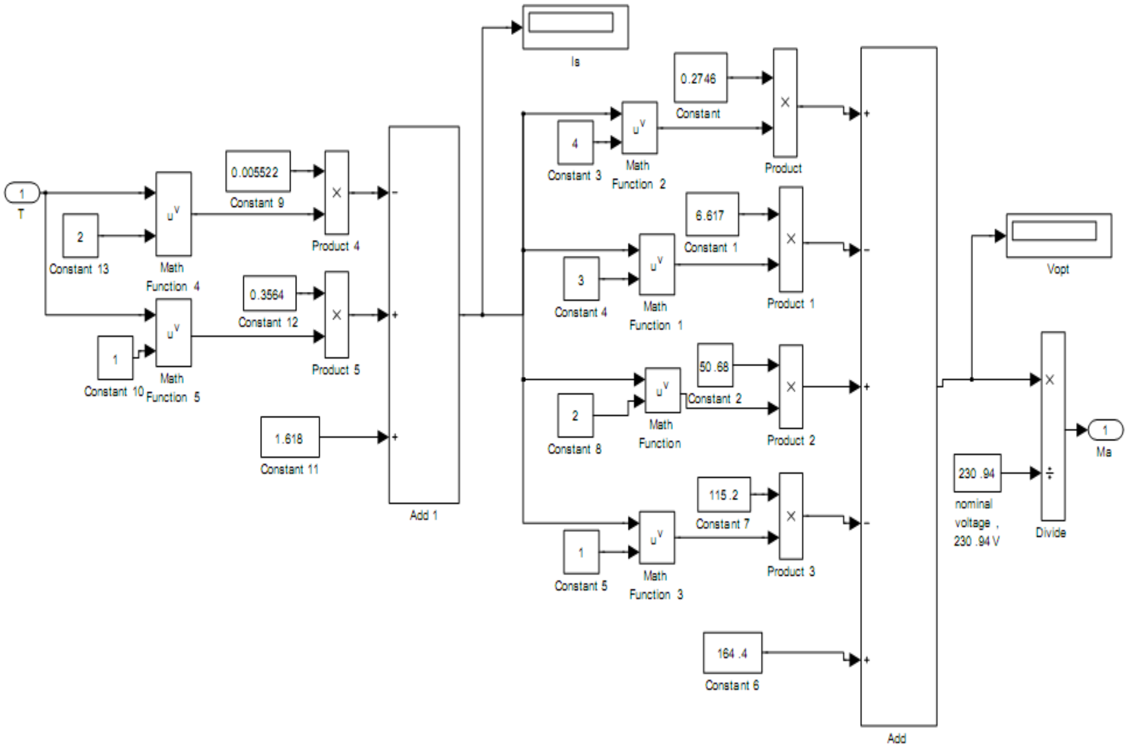

Figure 5: Model of optimal current controller at nominal frequency (50Hz)

According to frequency applied, an automatic switch can select proper controller, which applies the suitable modulation index (M_a) as a control signal to control the value of applied voltage on the stator. The automatic switch has four input ports, one port for each controller. This switch uses control signal (CS) to determine the required input port (suitable controller), the control signal computed by the following relationship:

$$CS = -0.1f + 6 \qquad (4)$$

Where : f is the frequency.

If the control input is not an integer value, the block first truncates the value to an integer by rounding to floor.

The model of classical optimal stator current controller is shown in figure 5.

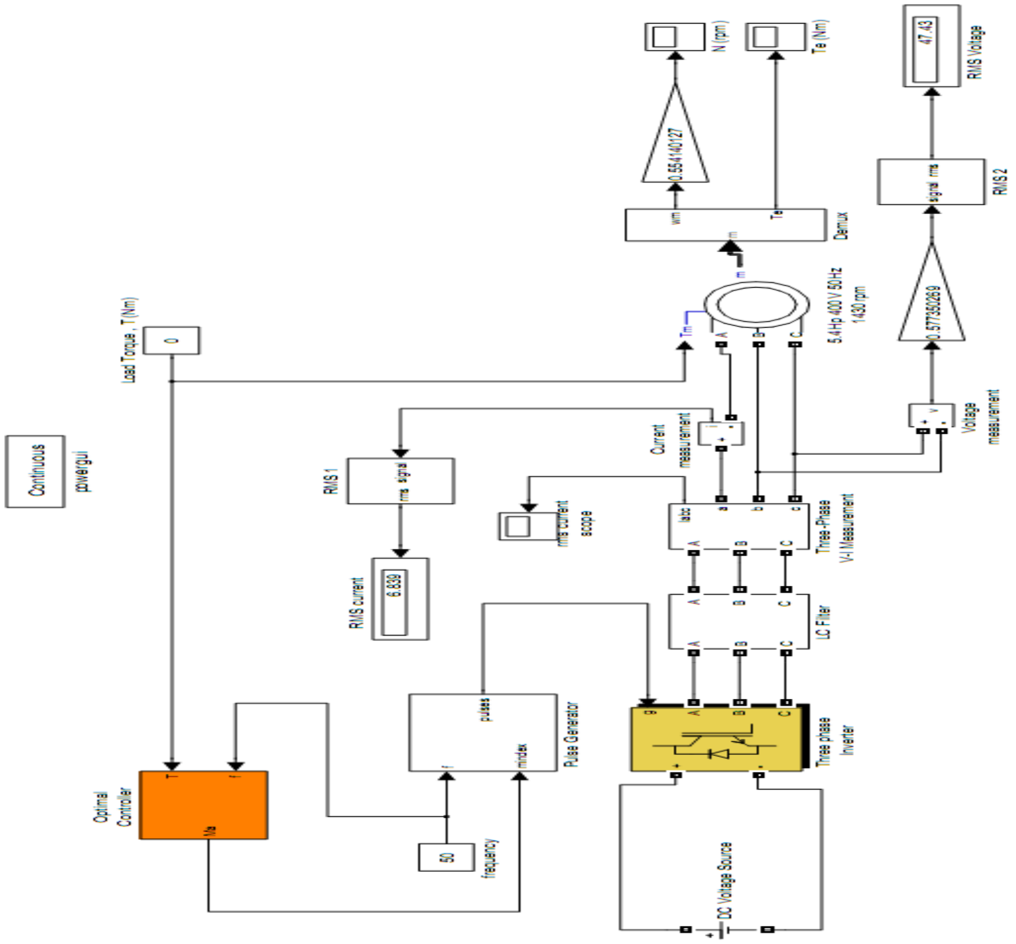

Figure 6: Model of classical optimal stator current control system

5.0 ANALYSIS OF RESULTS

The simulation results of open-loop ac drive system, and classical optimal control system are presented. All these results are supported by figures that compare the open loop system and the classical optimal control system. Figures 4 represents stator current versus load torques relationship at nominal frequencies for open loop and classical optimal control system. These figures show an improvement of stator current minimization, leading to energy saving which is the aim of this research.

Current Comparison Between the Open-loop ac Drive System, and Classical Optimal Control System at nominal frequency (50Hz).

The figure 7 shows at minimum torque, the initial current needed to operate the induction motor at nominal frequency using the open loop system was 3.6A but using the classical control, 1.6A was needed to operate the induction motor saving 2.0A.

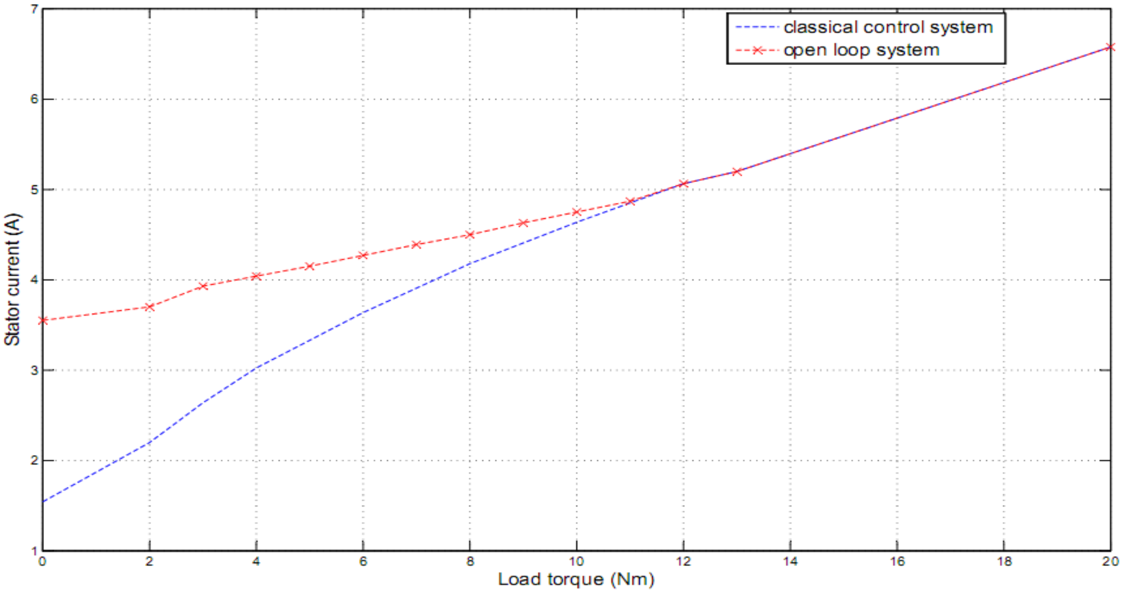

Figure 7: Stator current comparisons at nominal frequency (50Hz)

CONCLUSION

It is obvious that classical control system provides very good opportunity to saving energy**,** reduce operating costs and increase profit as a result of prolong life of the induction machine . Optimal stator current controller model developed can be used in industrial drive systems under different loading conditions will give significant energy saving (reduction of power consumption) by minimizing stator current consumption and minimizing input power consumption. It have also help to improve the efficiency of the induction motor. And finally, operating the induction motor at the minimized stator current will help prolonging the life span of the induction motor by reducing the vibration, heat and noise generated.

REFERENCES

Bhim, S. and Singh, B. N. (1993): *Experience In The Design Optimization Of A Voltage Source Inverter Fed Squirrel Cage Induction Motor*, Electric Power Systems Research, Vol. 26, Pp. 155-161.

Boukhelifa, A., Kherbouch, M., Ibtiouen, R. and Touhami, O. (2004): *Stator Current Minimization By Field Optimization In Induction Machine*, International Review of Electrical Engineering, (ICEE), Vol. 1, Issue 4, Pp. 510.

Gnacinski, P. (2007): *Energy Saving Work Of Frequency Controlled Induction Cage Machine*, Energy Conversion and Management, Vol. 48, Pp. 919-926.

Palit, B. B. (1989): *Energy Saving Operation At Induction Motors By Voltage Reduction At No-And Low Partial Load*, in Proc. Institute of Electrical and Electronics Engineer (IEEE) Ind. Appl. Annual Meeting, Vol. 21., Pp. 147-151.

Rateb, I. H. (1997): *The Effect of Non-Nominal Voltage on Indices of AC Drive Systems*, Journal of Engineering Studies & Research, Baghdad, Vol.2, No.1, Pp. 4 – 16.

Rateb, I. and Hussein, S. (2006): *Improving Mechanical Characteristics of Inverter-Induction Motor Drive System*, American Journal of Applied Sciences, Vol.3, No.8, Pp.155-168.

Sim Power Systems (2001): *Modeling, Simulation, Implementation*, User's Guide Version 4, Pp. 12-15.