Implementation of Vector Control Algorithms for Optimization of the Induction Motor Dynamics

[1]Chibueze C, [1]Akpado, K.A,[2]Obayi.I A.A, [3]F.N.Ugwoke,[4]Okafor, K.C

[1]Dept. of Electronics and Computer Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[2]Dept. of Computer Science, University of Nigeria, Nsukka, Nigeria
[3]Department of Computer Science, Michael Opara University of Agriculture, Umudike, Umuahia
[4]Dept. of Electrical Electronics Engineering, Federal University of Technology, Owerri, FUTO, Nigeria

Abstract

Induction motors are well suited for industrial drives since they are rugged in their construction, simple, robust, reliable, have maintenance free and relatively low cost. Though they are reliable; they are subjected to some undesirable stresses, causing faults resulting in failure. Monitoring of an IM for speed control and energy efficiency optimization is a new research area which helps in avoiding unexpected failure of an industrial process control. This paper presents a vector control algorithm for optimization of the IM dynamics aimed at improving the speed and torque response. This was implemented using PLC-PI Vector Control Model. In our model, an Insulated Gate Bipolar Transistor (IGBT) was be used to control the motor rotation direction and rotation speed of the induction motor as well as utilizing the snubber network to regulate back electromagnetic flux. We showed that on starting the drive, steady state voltage/current waveforms, speed regulation dynamics/performance and drive efficiency responses gave optimal responses. From the simulation design results, other various characteristics such as torque, vector control speed, feedback gain, saturation effects, hysteresis, and noise cancellation were computed and plotted with MATLAB R2011.

I. INTRODUCTION

Induction motor is a high efficiency electrical machine when working closed to its rated torque and speed [1]. However, at light loads, no balance in between copper and iron losses, results considerable reduction in the efficiency. The part load efficiency and power factor can be improved by making the motor excitation adjustment in accordance with load and speed. To implement the above goal, the induction motor should either be fed through an inverter or redesigned with optimization algorithms. The optimization of induction motor design with AI and NIA has received considerable attention recently [1].

In the context of energy efficiency, since it has been estimated that about 50% of the world electric energy generated is consumed by electric machines [2], this is a problem for several reasons. First, inefficient electric motors waste electrical energy, thereby increasing electrical demand and associated electricity costs required to power motors. Second, electrical energy losses from inefficient motors waste precious natural resources, causing increased emissions of greenhouse gases, and increase operating costs (i.e. increases utility bills). Third, waste heat from inefficient motors increases maintenance and decreases the life of the motor.

For these reasons, there are compelling economic and environmental needs to optimize the energy efficiency in electric drives [3], [4].Though induction motors have a high efficiency at rated speed and torque, at light loads, motor efficiency decreases dramatically due to an imbalance between the copper and the core losses. Hence, energy saving can be achieved by proper selection of the flux level in the motor [5], [6].

To improve the motor efficiency, the flux must be reduced, obtaining a balance between copper and core losses. Induction motor drive can be controlled according to a number of performance functions, such as input power, speed, torque, air gap flux, power factor, stator current, stator voltage, and overall efficiency [7], [8].

As the conventional speed control approaches require a complex mathematical model of the motor to develop controllers for IM quantities such as speed, torque, and position. Recently, to avoid the inherent undesirable characteristics of conventional control approaches, PLC-PI is considered a better alternative for IM performance enhancement.

For a three phase squirrel cage induction motor which is widely used for industral automation, because of its constant speed characteristics, to continuously have a reliable operation, its parameters must be optimized and performance must be monitored continuously.

In this paper, the implementation of optimization scheme for monitoring and controlling induction motor based on variation in load torque and speed reference (Nola's theory) using PLC-PI is demonstrated to show an enhanced performance with low latency and as such characterized and validated with MATLAB Simulink R2011.

1.1. Research Contributions

This work seeks to develop and demonstrate a complete PLC-PI drive response for IM speed, torque and energy efficiency. Using a proposed PLC-PI vector control dynamics, this will scale gracefully while enhancing the speed performance of an IM. Also, this paper modelled the dynamics of 3phase IM while developing a steady state IM direct torque control with enhanced space vector modulation (DTC-SVM). This will minimize the ripples of an electromagnetic load torque and flux linkage.

II. RELATED RESEARCH EFFORTS

The paper in [9] presented an optimal design method to optimize three-phase induction motor in manufacturing process. The work used Genetic Algorithm for optimization while considering three objective functions namely torque, efficiency, and cost are considered. The optimally designed motor was compared with an existing motor having the same ratings. The work showed computer simulation results illustrating the effectiveness of the proposed design process. The paper in [10] emphasized the need for energy conservation as a requirement for saving the electrical energy and then developed an optimized and efficient of electrical drive systems under certain operating conditions.

The paper in [11] introduced a smart speed control system for induction motor using fuzzy logic controller. In their work, two speed control techniques, Scalar Control and Indirect Field Oriented Control are used to compare the performance of the control system with fuzzy logic controller. The work showed that the indirect field oriented control technique with fuzzy logic controller provides better speed control of induction motor especially with high dynamic disturbances.

The work in [12] presented a design and implementation of a monitoring and control system for the three-phase induction motor based on programmable logic controller (PLC) technology. It focused on the implementation of the hardware and software for speed control and protection with the results obtained from tests on induction motor performance is provided. Several works were reviewed with the outlined limitations below.

2.1. Limitations of Existing 3Phase IM designs and Models

In this research, the identified speed control schemes as well as dynamic performance schemes in literature include:

- Field flux variation, Speed control by connecting a resistance in series with armature,
- Current /voltage control across the armature terminals
- Indirect vector controlled using artificial intelligent controller viz: Adaptive Control techniques such as model reference adaptive control, sliding mode control, variable structure control, and self-tuning PI controllers
- Direct torque control with space vector modulation (DTC-SVM)
- Discrete space vector modulation (DSVM)
- Space vector pulse width modulation (SVPWM)

The identified limitations of these schemes vis-à-vis their controllers are as follows:-

i. The overall efficiency of the system is low as much of the input energy is dissipated in the controller as heat, (lossy and inefficient)
ii. The speed may vary largely with variation of load.
iii. The effects of saturation in IM at various operating condition is very significant.
iv. Lack of effective cost optimization algorithms (The controller has relatively high cost.)
v. In most systems, high speed computation, hence fast switching frequency often leads to high output oscillation.

In this work, though several induction motor efficiency optimization methods have been proposed in the literature, however only few of them are based on offline analysis and use look up tables for online control. These methods present some restrictions because of the practical limited size of lookup table. The proposed scheme in this work achieves steady state response under all load conditions. With this scheme, there is reduction in losses as the torque load on an IM is varied. Also, the model has the capacity to handle flux, current and frequency calculation for optimum motor efficiency at different operating points. The proposed technique is convenient for online and real-time control.

III. METHODOLOGY

Using system characterization, functional vector control algorithm for PLC-PI system with torque and speed references utilizing high speed PWM inverter for optimizing the design gap in the IM complex dynamics and high nonlinearity model was developed. We used MATLAB simulation software for its realization. A study IM system efficiency assessment will be discussed below.

3.1. Testbed Characterization/ Description

We characterized, configured and used the CK 6132 CNC Lathe machine system installed in a mechanical and workshop department of NASENI hall to carry out a study on efficiency in an induction motor based VAC system while maintaining the temperature between 20^0C-75^oC . At full load, the air-cooled 3phase induction with 1420 R.P.M, 4-pole, a voltage of 220v/50Hz at 4Amp in the CNC lathe was studied. The IM is rugged and has a low maintenance squirrel-cage rotors. A fan for providing forced ventilation is mounted axially on the rear side of the motor. The air flow direction is as standard from the motor shaft (DE) to the rear of the motor (NDE) in order to keep the motor heat loss away from the machine. The reverse direction of air flow can be ordered as an option.

The motors are equipped with an integrated encoder system for sensing the motor speed and indirect position. For machine tools, the encoder system is capable of C-axis operation as standard - i.e. an additional encoder is not required for C-axis operation. The induction motor drives the cutting fluid coolant chamber which under regulated pressure pumps this fluid into the milling chamber. Figures 1a, 1b and figure 1c shows a part of the field testbed used for our investigations. In our testbed, the properties sought after in a good cutting fluid are the ability to:

- Keep the work piece at a stable temperature (critical when working to close tolerances). Very warm is satisfactory, but extremely hot or alternating hot-and-cold is to be avoided.
- Maximize the life of the cutting tip by lubricating the working edge and reducing tip welding.
- Ensure safety for the people handling it (toxicity, bacteria, fungi) and for the environment upon disposal.
- Prevent rust on machine parts and cutters.

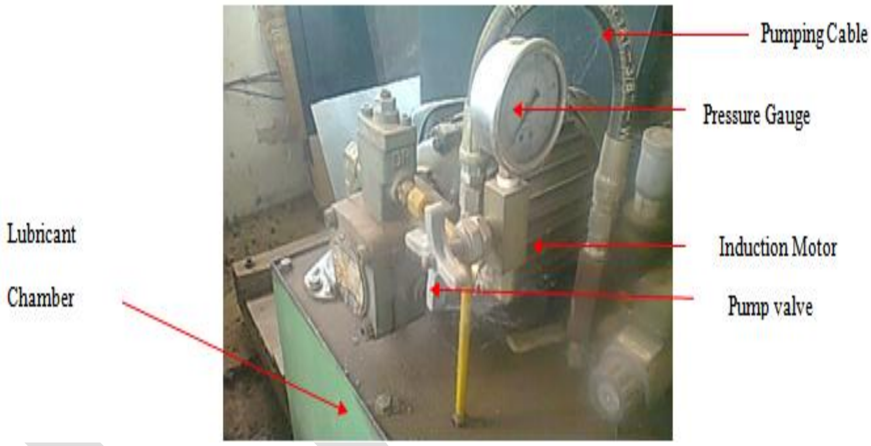

Figure 1a: Testbed CNC Induction Motor drive (Source: NASENI Abuja, 2013)

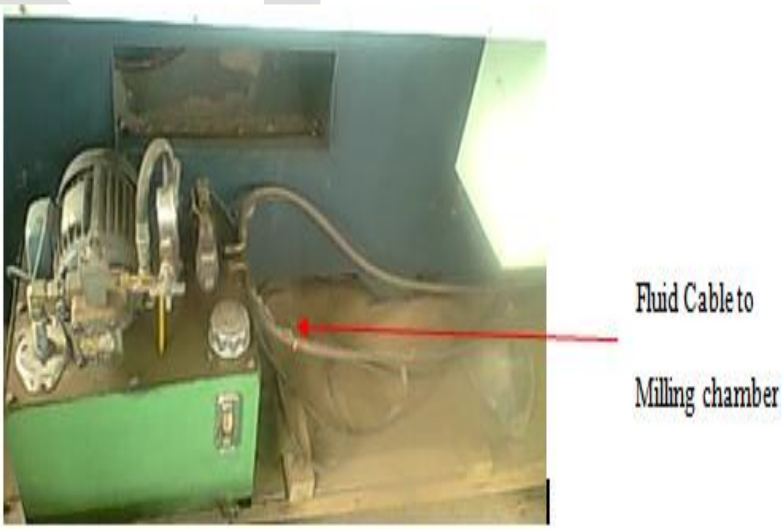

Figure 1b: CNC Induction Motor drive with cooling chamber (Source: NASENI Abuja, 2013)

Figure 1c: CNC Lathe with readout control panel and Milling dashboard (Source: NASENI Abuja, 2013)

As shown in the setup of figure 1a and figure 1b, the cooling chamber stores the cutting fluid or coolant for use in the VAC milling dashboard. This is a type of coolant and lubricant designed specifically for metalworking and machining processes. In the CNC machine, most metalworking and machining processes benefit from the use of cutting fluid, depending on work piece material. On fixing the load torque, a high-pressure, high-volume pumping via the IM drive forces a stream of oil-water emulsion directly into the tool-chip interface, with walls around the machine to contain the splatter and a sump to catch at a very high speed (see figure 1c). Since figure 1a,1c and 1c lacks a functional vector control system, the algorithm below was developed for its process dynamics where there no PLC-PI vector control.

A. *CNC Lathe Machine ALGORITHIM I*

Algorithm I: **Process Model Dynamics of No PLC-PI vector Control System**

I: ***Begin ( )***

1. *INPUT: Space vector Parameters = 0; Ref Speed= 1=1:N; Tm< = 300;*
   IM parameters = Default
2. *OUTPUT: Rotor Speed R_S, 3Ø Tm,Vab,Iac*
3. *Begin Procedure:{}*

Begin
4 Check start Button
If (Start button = = ON)
Then
Wait = = 5sec;
Else 1;
Check the VAC (Coolant Level) Status
If (the VAC pump tank is Filled (Normal))
Then Initiate Space Vector PWM
Activate the Clocks && Drive 3Ø IM
Monitor all Inputs (1) && Keep Checking VAC Level
Else return I;
If (Speed Rs, Efficiency Optimization Controls = = 1)
For (t = 0;; t ++)
Out ← Te, 3Ø IM, Vab,Iab,UD,Rs
Return I.

The three-phase power supply is connected to a three-phase main switch and then to 3 pole MCB which provides protection against current overloads. This is then connected to variable frequency drives (VFD) direct torque which controls the speed of motor and we change direction of motor through a direct torque scheme. At low scale varying load torques, the efficiency values are computed taking cognizance of the speed variations.

The technical IM specifications are summarized in Table 1. Other testbed parameters are as well noted in our simulation details.

Table 1: IM Specifications

	Selected Specifications	**Values**
1	CNC Machine Model	CK 6132
2	Induction Motor type	Delta
3 4	Input Voltage Input Current	350-415V AC 4 AMP, 3Phase,
5 6	Rated Power Input Frequency	0.75KW 50Hz
7	Number of pole Rated Speed	4 1420 R.P.M
9	Power factor	0.8

B. Deductions

1. The Efficiency index of a direct torque control is practically lower and needs to be improved.
2. The losses in an inefficient and unmodulated control system (direct control torque) is relatively higher in the context of speed control as shown in the hysteresis analysis later in this work.
3. The direct torque vector control is highly inflexible and needs to be improved.
4. Large scale integrations and interoperability is observed to be lacking in direct vector control scheme.

3.2. Proposed Model for IM Speed and Efficiency Optimization

In this research, the PLC- PI PWM vector control scheme is proposed for speed and energy optimization for IMs. It considered optimal control through a vector Pulse Width Modulation Scheme (PWM). Also, it uses a variable frequency drive as an actuator targeted for VAC systems.

Considering figure 2, in the model, we have the PWM Dc voltage source [V], IGBT gate *(G)*, phase current, Phase voltage, mechanical torque, 3Phase IM with speed reference, scope and sink. The signal applied to the gate of the PWM switch *G* is a pulse train with constant frequency *f* (and constant period *T*), but with varying pulse width. The amplitude of the signal applied to the gate will cause switch transition between cutoff and saturation with very short rise and fall times. The snubber network has capacitance *C* and inductance *L* that can suppress back *Emf* oscillation at power down. The relative values of *C* and *R* are selected such that the time constant = *C/R* is at least 10 times the period *T* of the pulse train applied to the gate *G*. The long *C/R* time constant will have a low-pass filtering effect on the chopped output of the switch G, and will effectively smooth the current into DC with very little AC component. The vector PWM consequently drives the 3phase IM based on the reference speed and mechanical torque. The following configurations were setup in figure 2 viz:

- A closed-loop control system for constant speed operation, configured with speed feedback and load current feedback. The induction motor drives a variable load, is fed by a PWM inverter gate *G*, and the PLC-PI controls the inverter V/f output.
- For standard variable speed operation, the IM reference speed is set while firing the PWM IGBT gate. In this case, the induction motor drives a variable load and is fed by a constant voltage-constant frequency standard three-phase supply.
- An open-loop configuration can be obtained from the closed-loop configuration by removing the speed and load feedback.

Essentially, the proposed system in figure 2 is advantageous over other system in the following ways:-

1. It provides smooth control of speed over a wide range in both directions. Here instead of adding IM, an optimal control speed can be set by the PLC-PI gain factor. The PLC-PI vector control supplies control signals to a PWM inverter switch.

2. These control signals have variable duty cycle that depends on the speed required (IM speed reference).That is the PLC correlates and controls the operational parameters to the speed set point requested by the user. However, depending on the duty cycle, the IM gets the average voltage and accordingly speed varies. Figure 2 shows the conceptual system model/architecture developed in this research for the IM optimization.

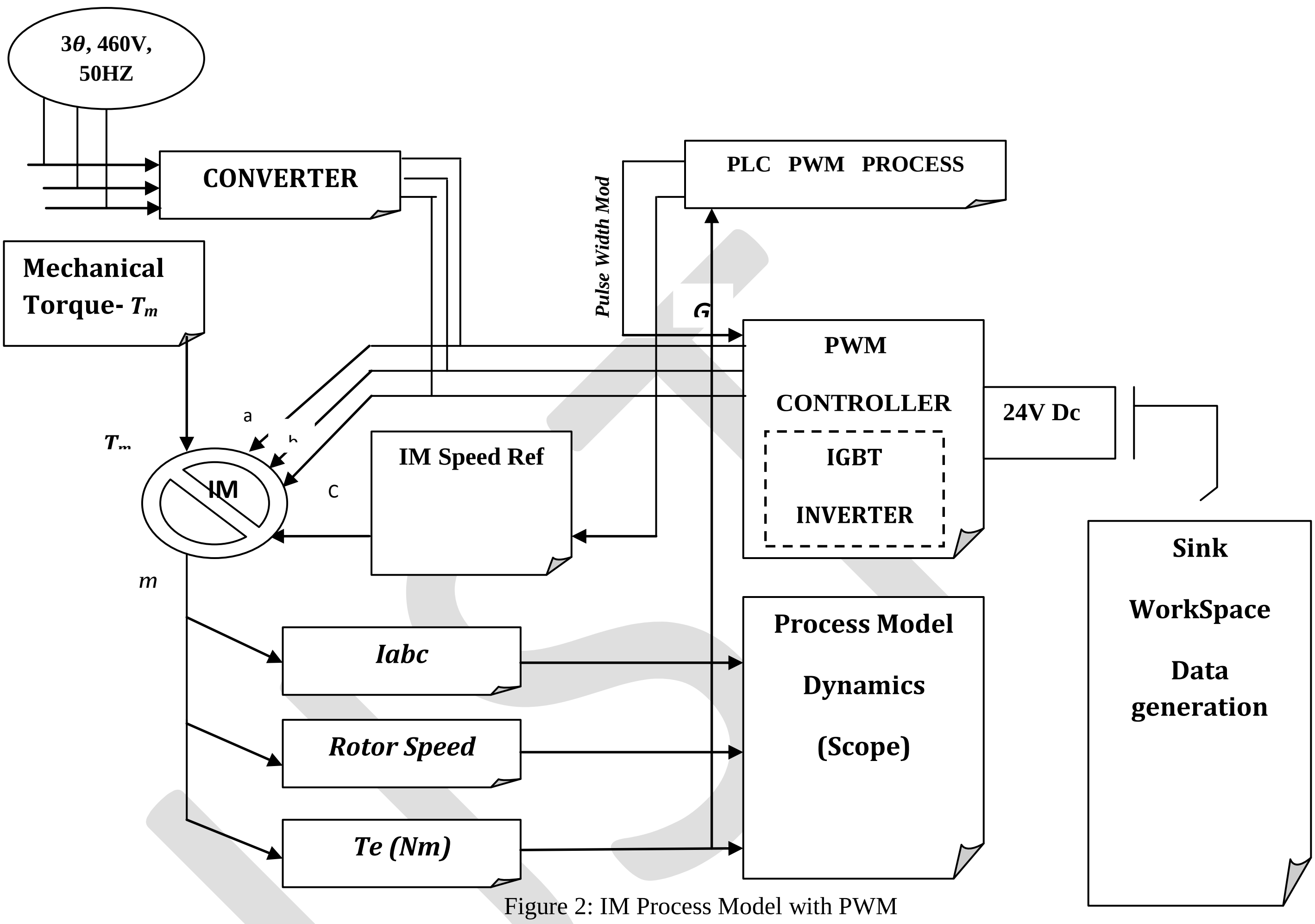

Figure 2: IM Process Model with PWM

In this research, the PLC- PI PWM vector control scheme is proposed for IM optimization as shown in figure 2. A contribution in the optimum design of a three phase induction motor in a manufacturing process using three objective functions, namely: Torque (T), Speed(S) and Efficiency (E) is analyzed. Considering figure 1 and figure 2, this work targets the PLC-PI PWM design for all VAC systems where its presence makes significant impact compared with other schemes.

Firstly, the design architecture is presented as a new proposal following the challenges with direct torque control with space vector modulation (DTC-SVM), discrete space vector modulation (DSVM), Space vector pulse width modulation (SVPWM). The IM internal architecture is extended from related works in literature with the various model characterizations.

IV. SIMULATION DESIGN

Simulation studies are performed to validate a theoretical development. The main tool used in this research is Simulink-MATLAB software version, R2011 [95]. The design Model was used in an efficiency controller which is incorporated in the model of IM drive. In the first scenario, the simulation was run to a steady state value. Power losses from hysteresis and drive performances were tested with efficiency controller (i.e. With PLC PI vector control PWM) and compared with the case when efficiency controller is not included in a drive model (i.e. No PLC PI vector control PWM). In all cases, various data were obtained and was used to plot the corresponding graphs as shown in figures x to xx.

A. Configurations

In Simulation model this work used a 3Phase, 50Hz, 460V IM modeled in a selectable *dq* reference frame of rotor type (i.e. Squirrel -caged), whose mechanical input, Load torque *Tm* is varied for various efficiencies. **T**his work will implement and show the PLC internal architecture. The dynamic model comprises of digital gain isolator (PLC speed controller), clock synchronizer, phase current converter, current regulator and flux converter for all I/Os. The values where configured based on the field specifications only. The PLC speed controller is based on PI regulator implemented to generate a pulse that fires and drives the induction motor via the PWM inverter. We used the design as shown in figure 3 as a test case for figure 2. In this case, for speed control, we fired the gate of the DTC-PWM inverter for effective current drive via the I/O. This facilitates optimal performance in the system as shown in figure 3 using the parameters stated below.

B. IM Parameters

1. Nominal Power, Voltage (line-line), and frequency [Pn(VA),Vn(Vrms),fn(Hz)]:=[50*746,460, 60]
2. Stator resistance and inductance [Rs (ohm) Lls(H)] := [0.087 0.8e-3]
3. Rotor resistance and inductance [Rr'(ohm) Llr'(H)]:= [0.228 0.8e-3]
4. Mutual inductance Lm (H): =34.7e-3
5. Inertia, friction factor and pole pairs [J(kg.m^2) F(N.m.s) p()]:= [1.662 0.1 2]
6. Initial conditions: =[1, 0 , 0 , 0 , 0 , 0 , 0 , 0]
7. Discrete solver model: = Trapezoidal.
8. Damping factor [N.rad/Sec]:=0.002

C. Design of DTC-PWM (IGBT INVERTER)

A. PARAMETERS

1. Number of bridge arms:=3 ie A,B,C
2. Snubber resistance Rs (Ohms):= 1000
3. Snubber capacitance Cs (F) :=Inf
4. Ron (Ohms):= 1e-3
5. Forward voltages [Device Vf(V) , Diode Vfd(V)]:= [0.8 0.8]
6. [Tf (s) , Tt (s)] = [1e-6 , 2e-6]

All the simulation descriptions, designs as well as the parameter configurations are shown in Figure 4.6 depicting the PLC-PI vector dynamics while the developed PLC-PI Vector Control Algorithm is shown below.

Algorithm II: Optimization procedure➔ discrete solver model

1. ***Begin:***
2. *Set performance Specifications*
3. *Initial IM design variables*
4. *Design Calculations of the Stator layout*
5. *Design Calculations of the rotor layout*
6. *Set the Optimization Engine (Discrete solver model)*
7. *Perform Calculation by Setting Objective Functions && Constraints*
8. *Test for Complete Convergence, Speed, Load Torque &&Efficiency*
9. *Update design variables*
10. *Check if Optimum design is achieved*
11. *If No, then* ***Return*** *➔ 2,* ***Else***
12. *Execute Performance Analysis*
13. *End.*

Algorithm III: **Process Model Dynamics of PLC-PI vector Control System**

I: ***Begin ( )***
2. *INPUT: Space vector Parameters = 0; Ref Speed= 1=1:N; Tm< = 300;*
IM parameters = Default
3. OUTPUT: Rotor Speed R_S, 3∅ Tm,Vab,Iac
4. *Begin Procedure:{}*
Begin
Start Simulation
Check the PLC-PI vector control Status
If (Satisfactory)

Then Initiate Space Vector PWM
Activate the Clocks && Drive 3∅ IM
Monitor all Inputs (1) && Keep Checking PLC-PI sequence
Else return I;
For i=1 to n+1
If (Speed Rs, Efficiency Optimization Controls = = 1)
Out ← Te, 3∅ IM, Vab, Iab, UD, Rs
For (i = n+1;i ++)
Return I.

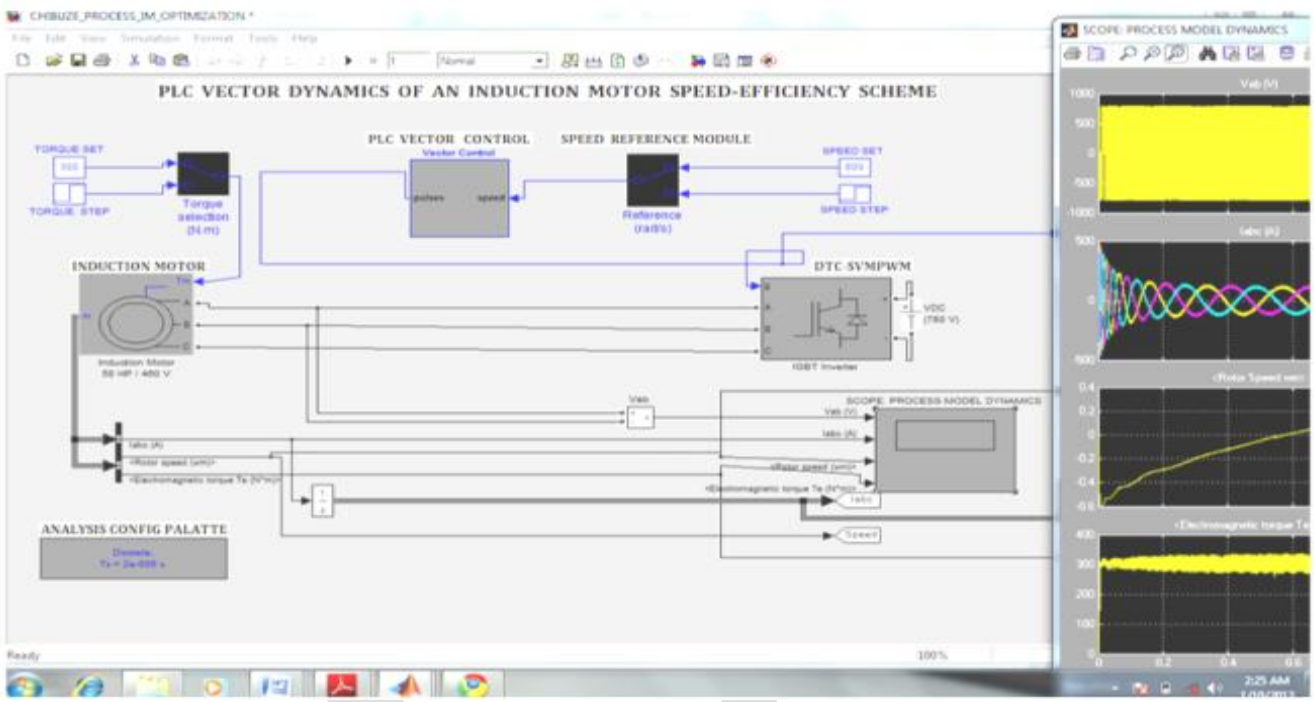

Figure 3: Design of PLC-PI Vector Control dynamics

V. PERFORMANCE EVALUATIONS

In this work, Algorithms I and II were employed in figure 3 to realize figures 4 to figure 16 whose evaluations are discussed below, viz:

5.1. Speed-Torque Linear Characteristics

Figure 4, shows the speed-torque characteristics of an induction motor started at full voltage and operated on utility power. In the PLC-PI vector control scheme, the maximum threshold achieved for the Torque is 300N.m which yielded a speed range of 1700rad/sec. A shown in the plot, the speed-torque curve for the 3Phase IM in the case application of VAC system, the load-torque requirement is set at 300N.m for conservative purposes.

Essentially, when this motor is started across-the-line by the PLC-PI PWM pulses, the IM develops approximately 50% of full-load torque for starting and then accelerates along the speed-torque curve through the pull-up torque point of 300N.m, and finally operates in this full-load torque point, depending on the set gate firing drive requirements as shown in figure4. As the load-torque requirement exceeds the maximum torque capability of the IM, the motor will maintain its steady state speed while utilizing its available torque to accelerate and drive its load. For instance, if the load line required more torque than the motor could produce at the pull-up torque point (for example, 160% load torque versus 140% pull-up torque te), the motor would not increase in speed past the pull-up torque speed, but will maintain a steady state speed threshold that will sufficiently the load. Though this could cause the motor to overheat, and/or overload devices to trip. The implication is that it is very important to insure that the IM has adequate accelerating torque to reach full speed. This creates a linear relationship as shown in figure 4.

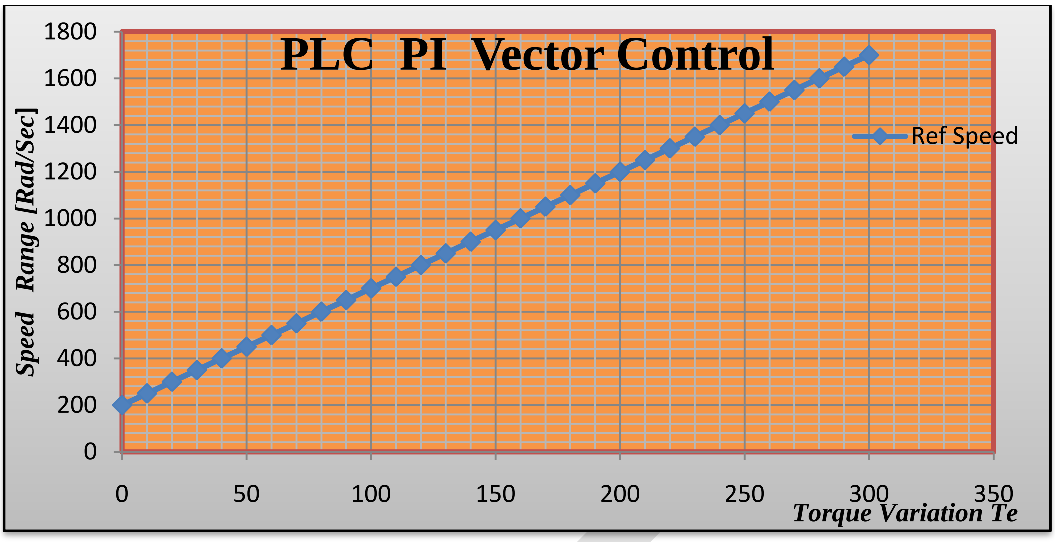

Figure 4: A plot of PLC-PI Vector Control Speed against *Te*

5.2. Feedback Gain Effects

From figure 3, the combination of proportional and integral terms in the PLC-PI as shown in figures 5 and figures 6 is important to increase the speed response and also to eliminate the steady state errors in the model. This work observes that as K_i increasing, the response reaches the steady state faster with steady state error approaching to zero. The result obviously shows with PLC-PI controller, it's feasible able to eliminate the steady state error in the IM VAC system.

From Figure 5, following the line PID control law in the PLC-PI vector control, the closed-loop system in t-domain with gain values tracks the error between the reference signal and the system output which fires the gate using the PWM. The *kp*, *ki*, and *kd* are the proportional integral and derivative feedback gains, respectively. However setting *kd* parameter is equal to zero, this yields a proportional-integral (PI) controller which causes system output y(t) to tracks the reference signals r(t) as the speed approaches infinity. This then makes for perfect tracking and enhanced speed control as shown in figure 5. As the gain is varied, the motor speed follows a proportional linear trend. This is considered as an enhancement to the system in general. Figure 6 shows the effects of closed-loop response as we vary the integral PLC-PI gain in relation to torque *Te*. The feedback gain has a linearized effect on the Torque.

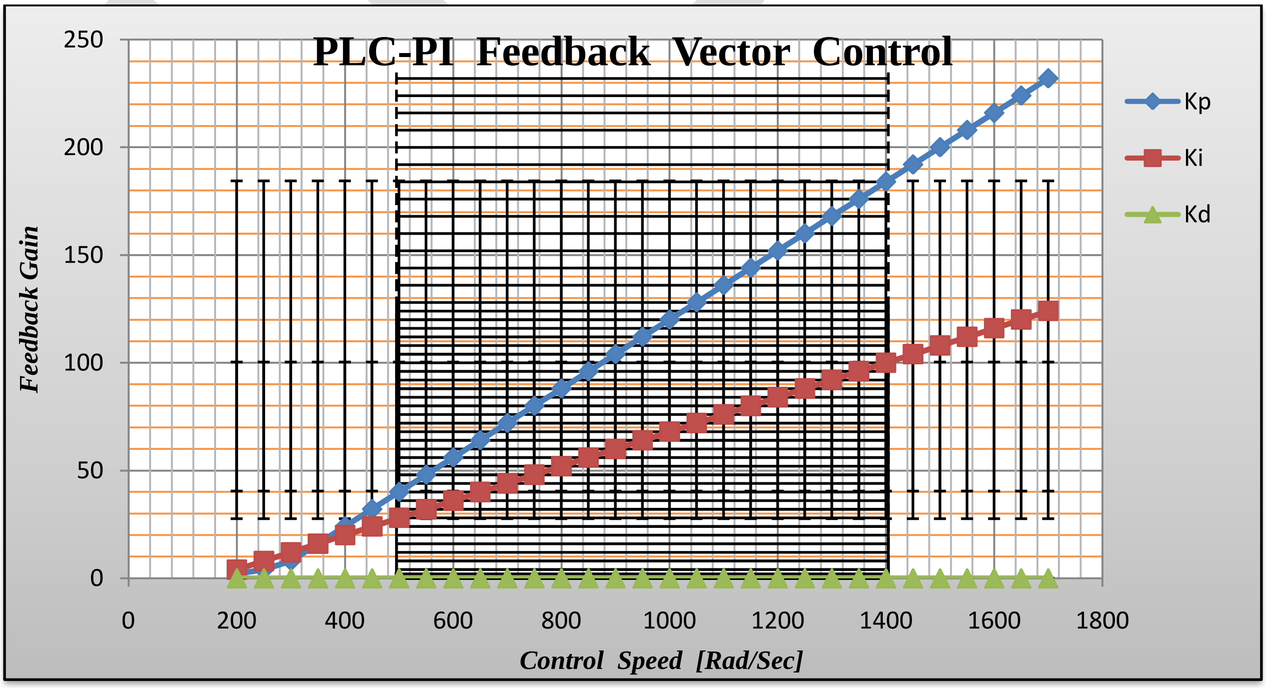

Figure 5: A plot of PLC-PID feedback PWM Against Control Speed

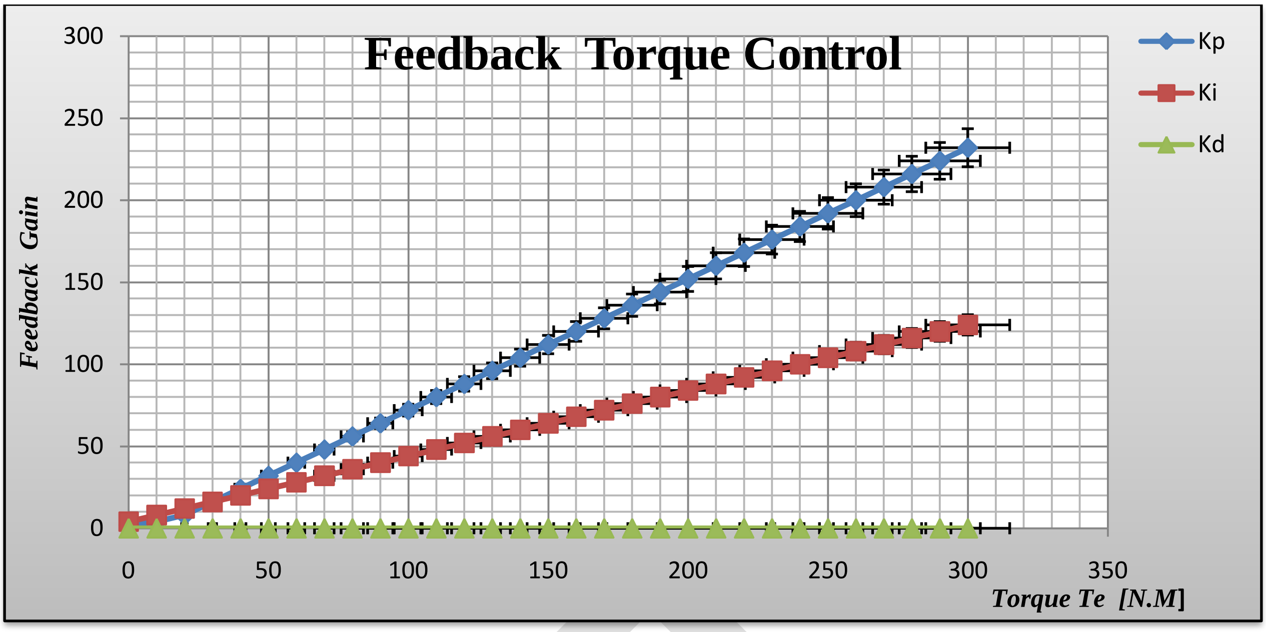

Figure 6: A Plot of PLC-PID feedback Gain against Te.

5.3. Efficiency Comparisons

From figure 7, using the PLC-PI vector control scheme for induction motor drive leads to energy saving compared to the case with No PLC-PI vector control considering the results of the testbed as earlier discussed. The proposed scheme uses information on speed and torque of the IM to generate the appropriate voltage amplitude that saves the energy. As depicted in the plot, the implementation of PLC-PI vector control strategy alongside with its algorithm for efficiency improvement results in the following with respect to the *Te* variations:

- Less torque ripple with flux changes
- Less drive sensitivity to load perturbations
- Electromagnetic torque margin is controlled so better control characteristics are obtained.
- Total power losses are reduced especially when motor works with light loads.

As depicted in figure 7, the efficiency is about 90% compared with the second case with about 80%. Several factors contributes to the efficiency of the PLC-PI vector control strategy such as the optimization, snubber network, PI feedback gains and IM matching design parameters.

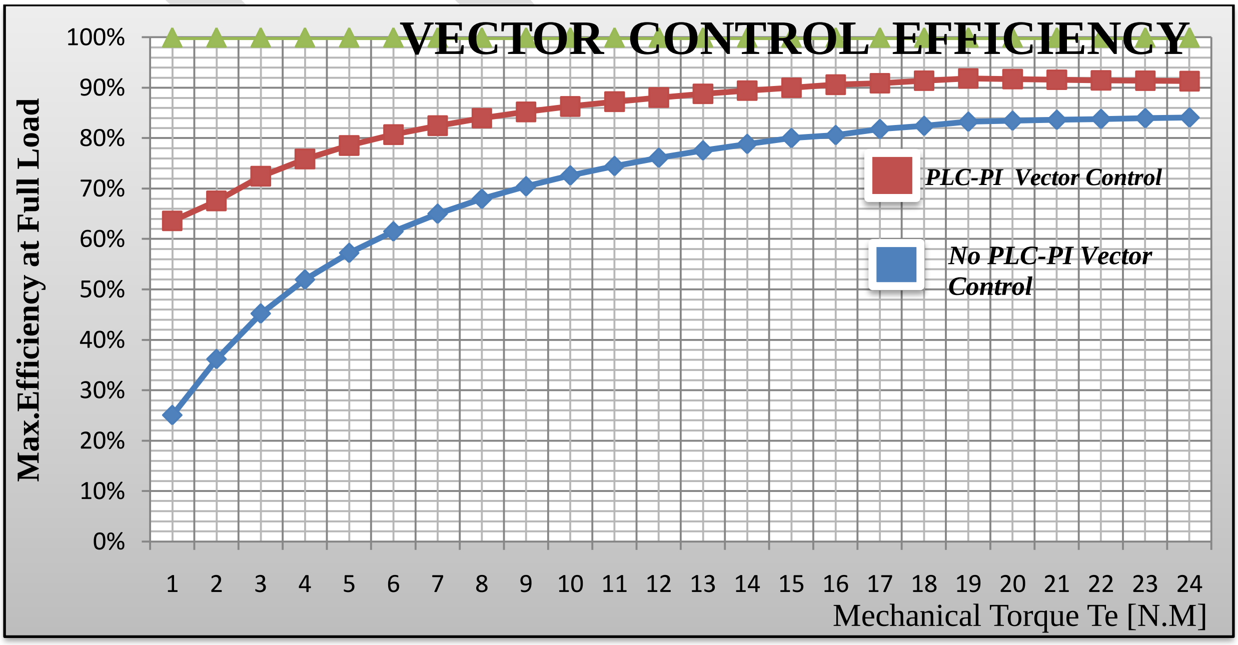

Figure 7: A Plot of PLC-PI Vector Control efficiency against *Te*

5.4. Hysteresis Effects

IM VAC systems experience hysteresis which is the dependence of the system not only on its current environment but also on its past environment. This dependence arises because the system can be in more than one internal state. To predict its future development, either its internal state or its history must be known. The rotation of the rotor which alternately increases and decreases forms an output loop as shown in figure 12. However, loops may also occur because of a dynamic lag between input and output often, rate-dependent hysteresis. This effect disappears as the input changes more slowly. From figure 4, voltage Source Inverter which is used to regulate the speed of three-phase squirrel cage motors by changing the frequency and voltage consist of input rectifier (PWM), snubber network, and output converter.

The PLC-PI speed control loop which uses a proportional-integral controller to produce the flux and torque references for the space vector block. The PLC-PI space vector block computes the IM torque and flux estimates and compares them to their respective reference. The comparators outputs are then used by an optimal switching table which generates the inverter switching pulses. That drives the IM to generate a significant degree of hysteresis shown in figures 8 and figure 9.

As shown in figure 8, the hysteresis band with PLC-PI vector control block is smaller compared with figure 9. This implies that losses will be minimal compared with figure 9 which has a wider hysteresis band. For the VAC systems, lower hysteresis loop is required for better efficiency.

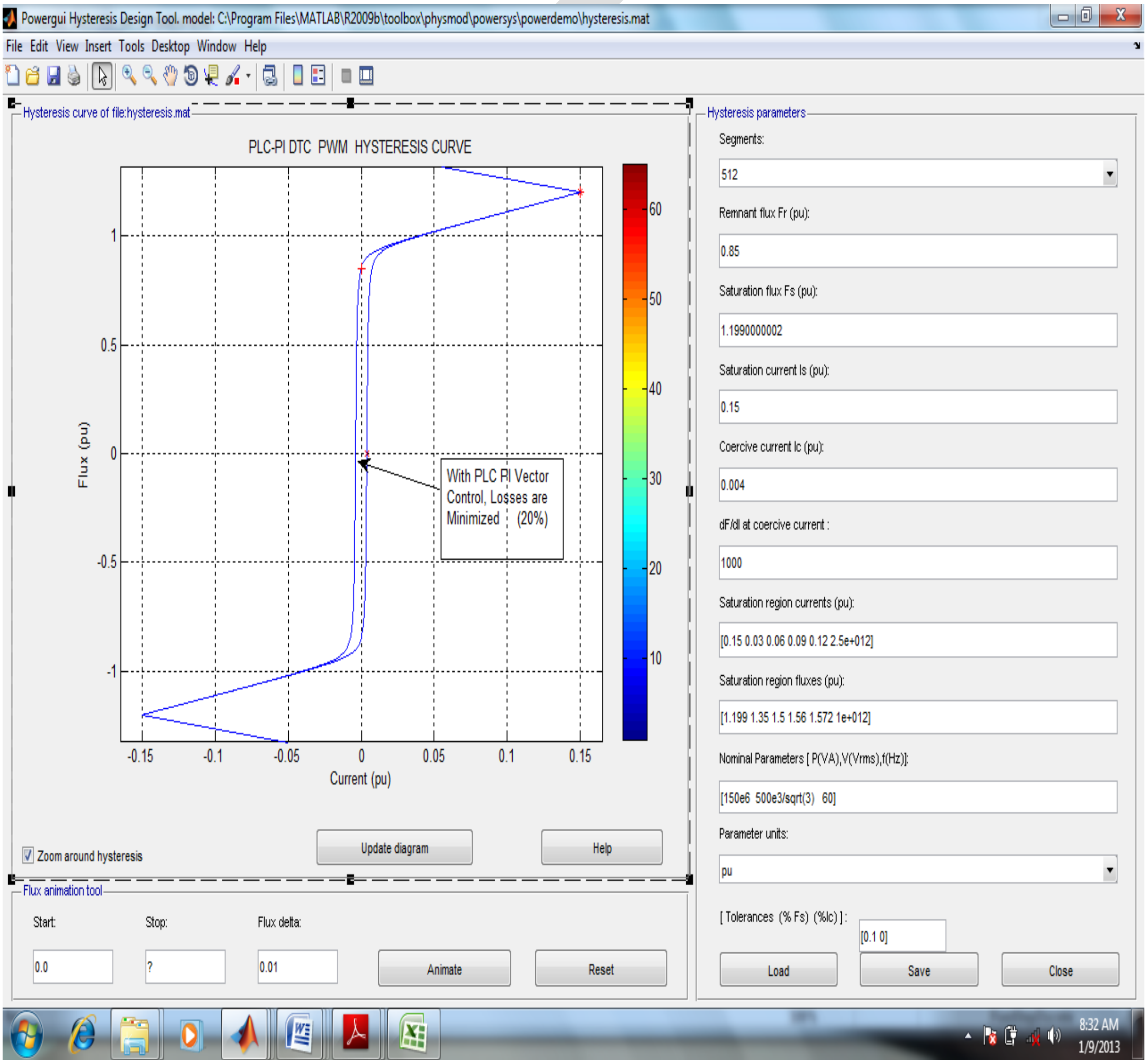

Figure 8: A Plot of Hysteresis Curve for PLC-PI Vector Control

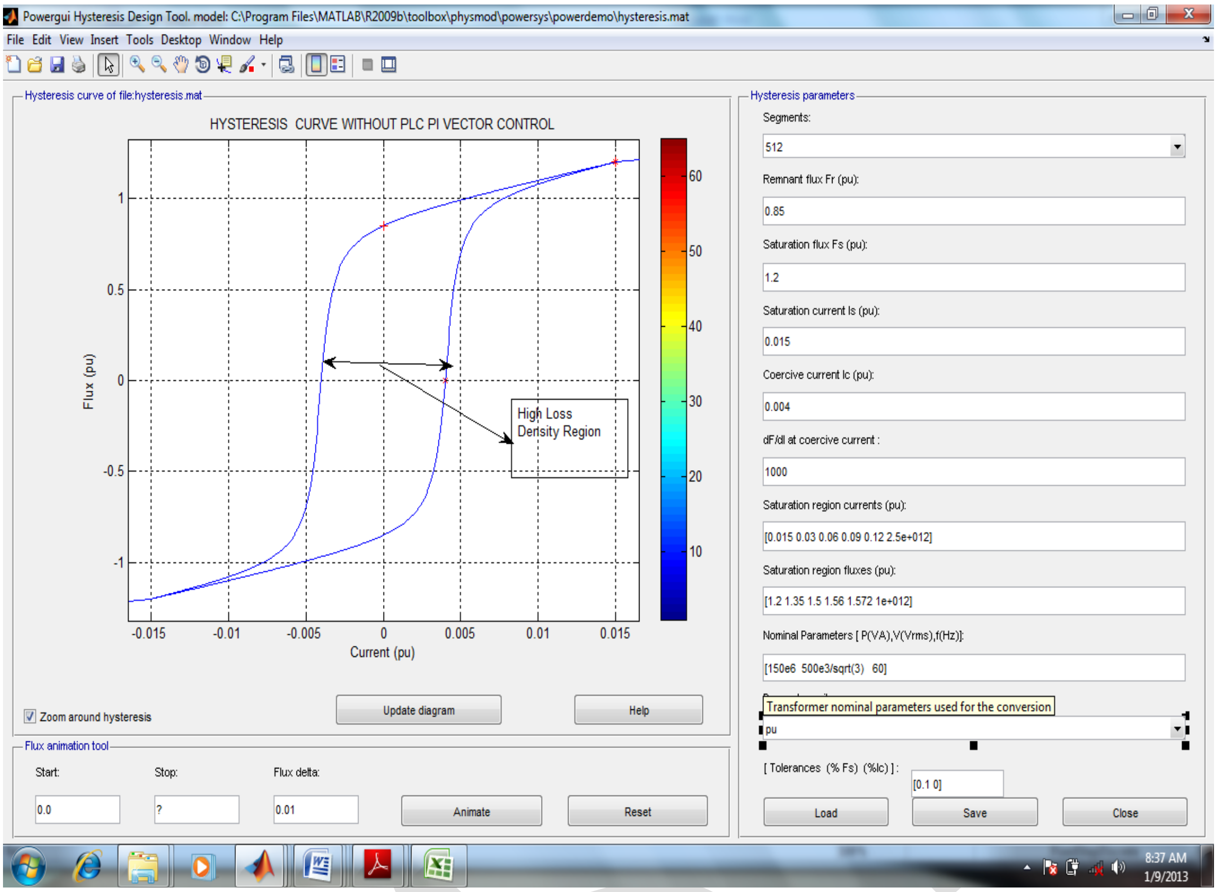

Figure 9: A Plot of Hysteresis Curve for No PLC-PI Vector Control.

5.5. Noise Oscillation Damping Effect

Figure 10 shows visible noise oscillation in the speed resulting from its initial machine inertia in the rotor and stator of the IM but was normalized after 0.25secs. The normalization results from the process regulation in the IM design parameters for its speed torque characteristics.

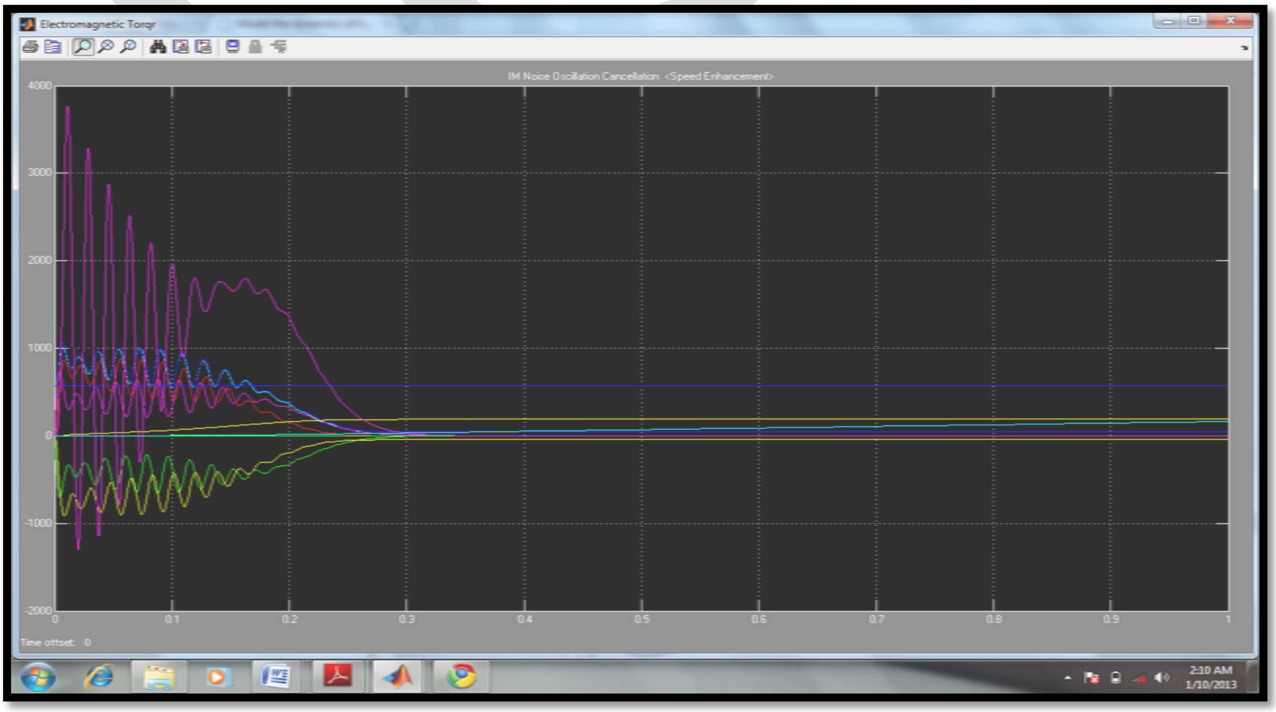

Figure 10: A Plot of IM Noise Oscillation Cancellation

5.6. Rotor Speed Effects At Steady State Condition

Figure 11 shows the rotor speed characteristics from figure 4 under controlled gain of the PLC-PI vector controller.

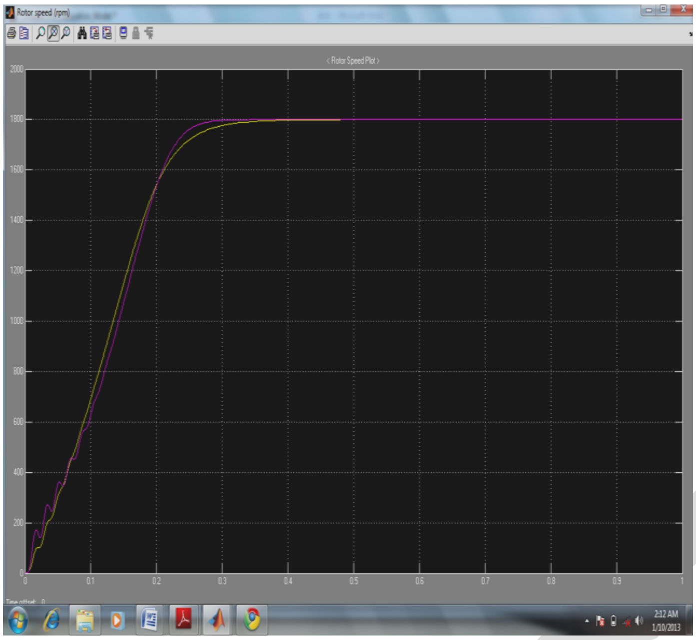

Figure 11: A Plot of Rotor Speed characteristics

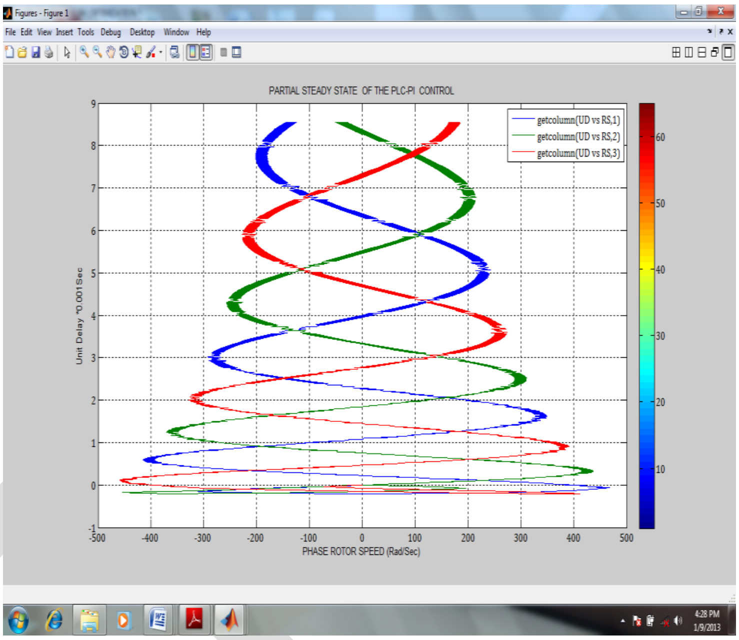

Figure 12: Partial Steady State Response of PLC-PI vector control

5.7. Speed Enhancement Responses

In this research, speed enhancement is the central objective which is achieved by the PLC-PI controller PWM. The graphs in figure 13, figure 14, figure 15, and figure 16 as shown in the simulation model of figure 4 comprises of in the Phase voltage V_{ABC}, Phase current I_{ABC} Rotor Speed R_S , Electromagnetic Torque T_e.

The responses were obtained by the variation of the PLC-PI feedback gain at varied Mechanical torque and Reference speed. Though, a small relative tolerance is required because of the high switching rate of the inverter, the steady state operation of the above components signifies an effective system for the VACs except figure 16 showing a Plot of No PLC-PI Vector Control at Steady State.

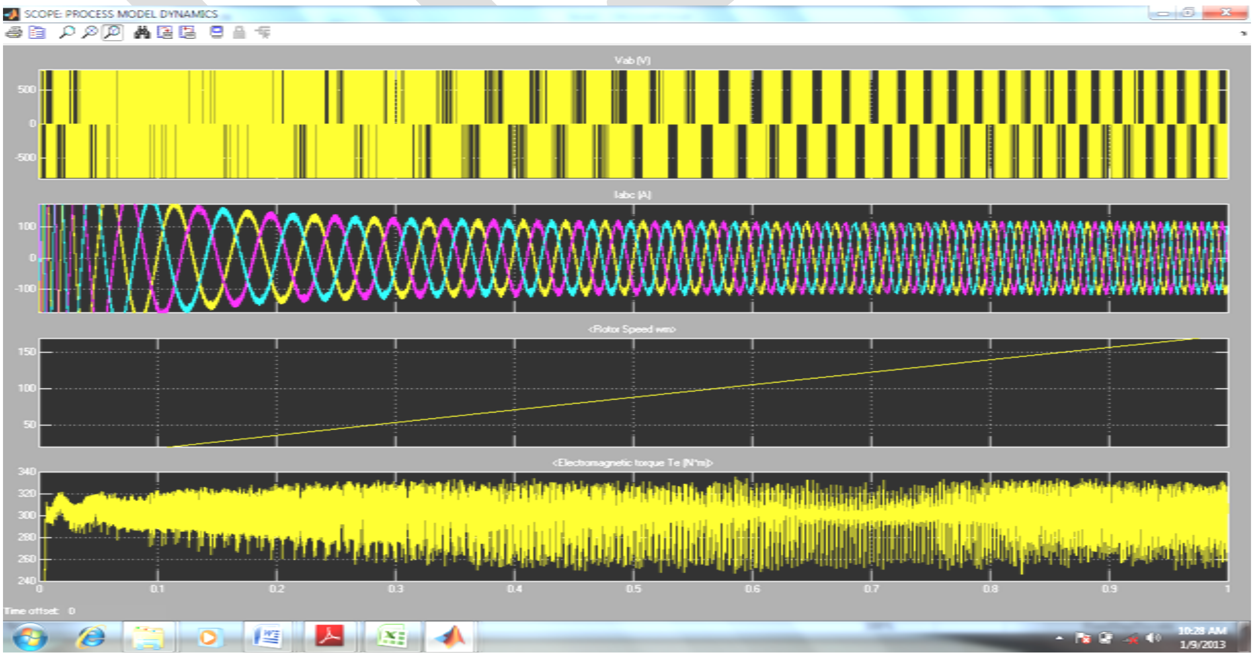

Figure 13: A plot of Enhance Speed at Tm= 0, Ref =200

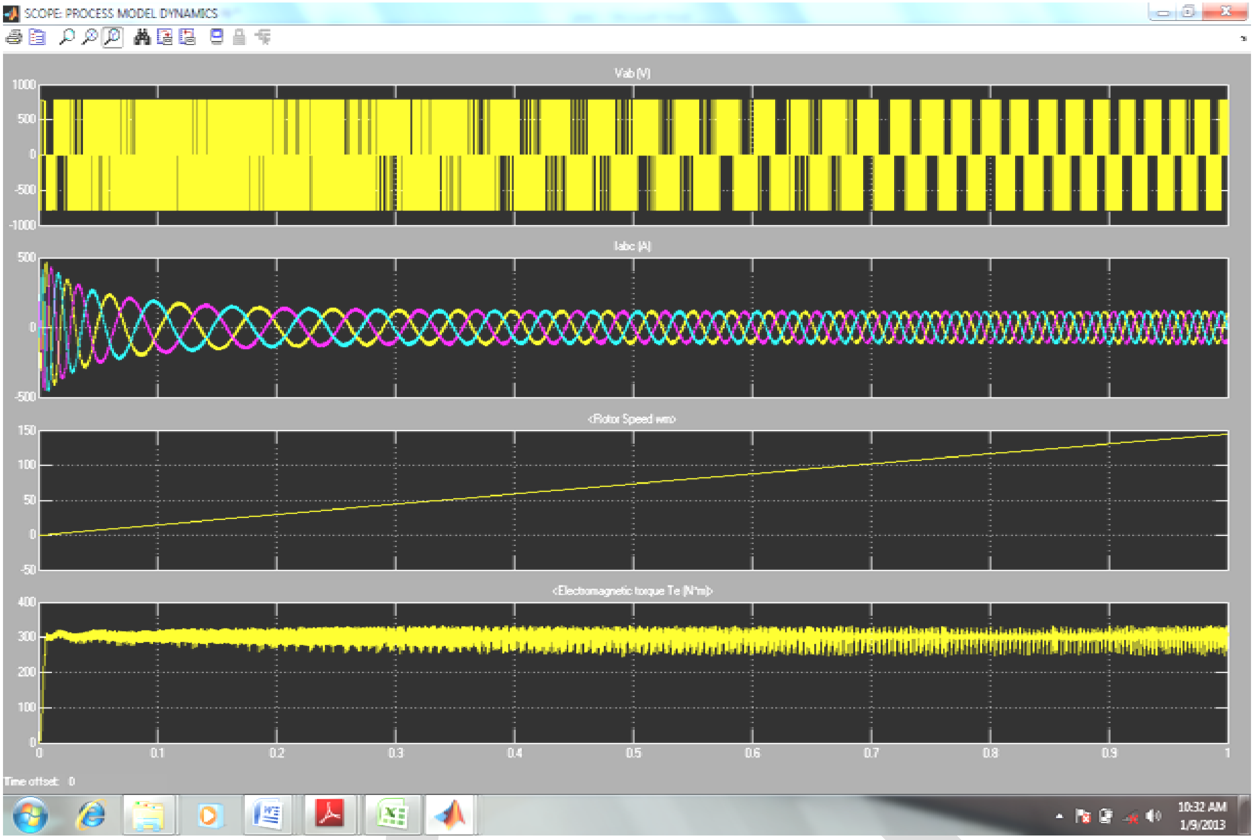

Figure 14: A plot of Enhance Speed at Tm=50, Ref = 450

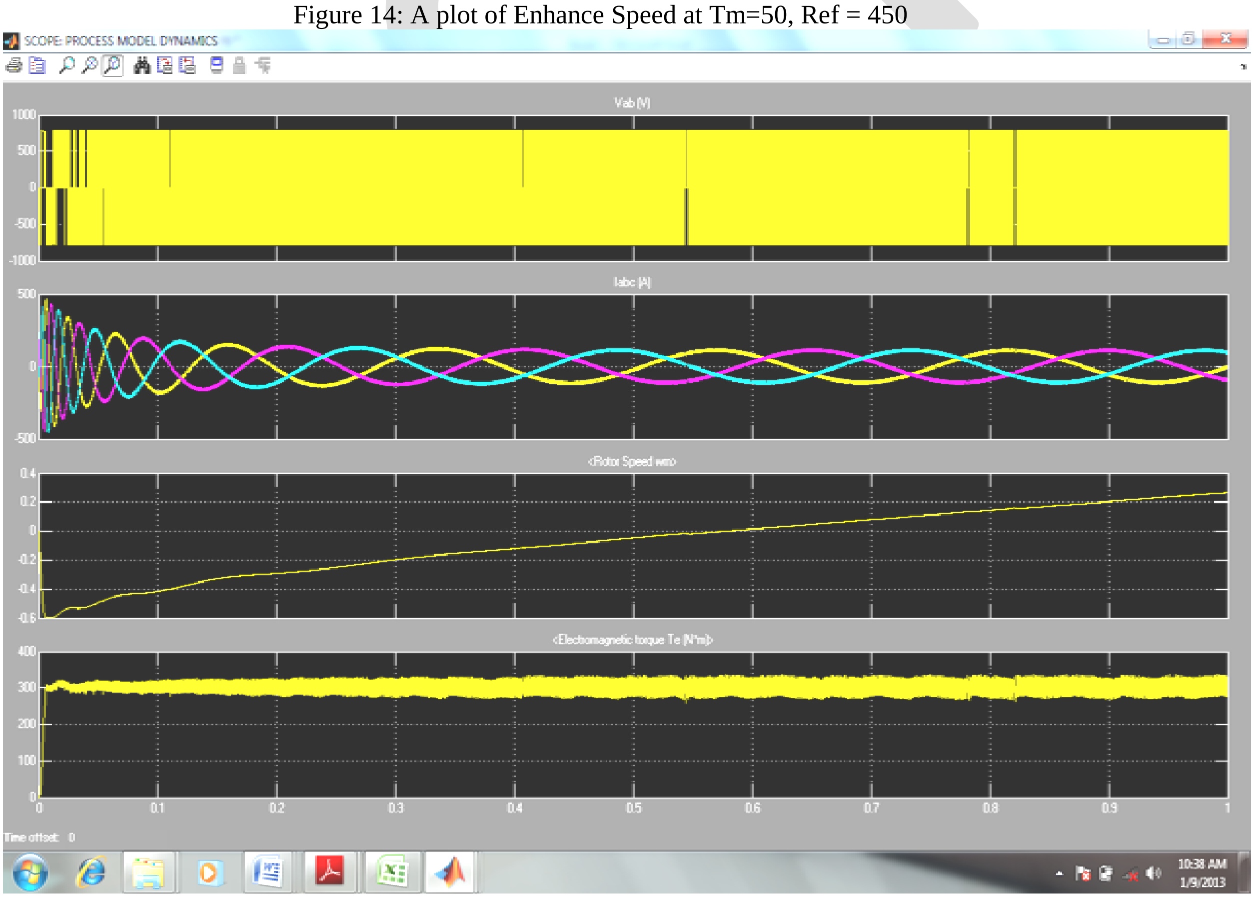

Figure 15: A plot of Enhance Speed at Tm=300, Ref=800

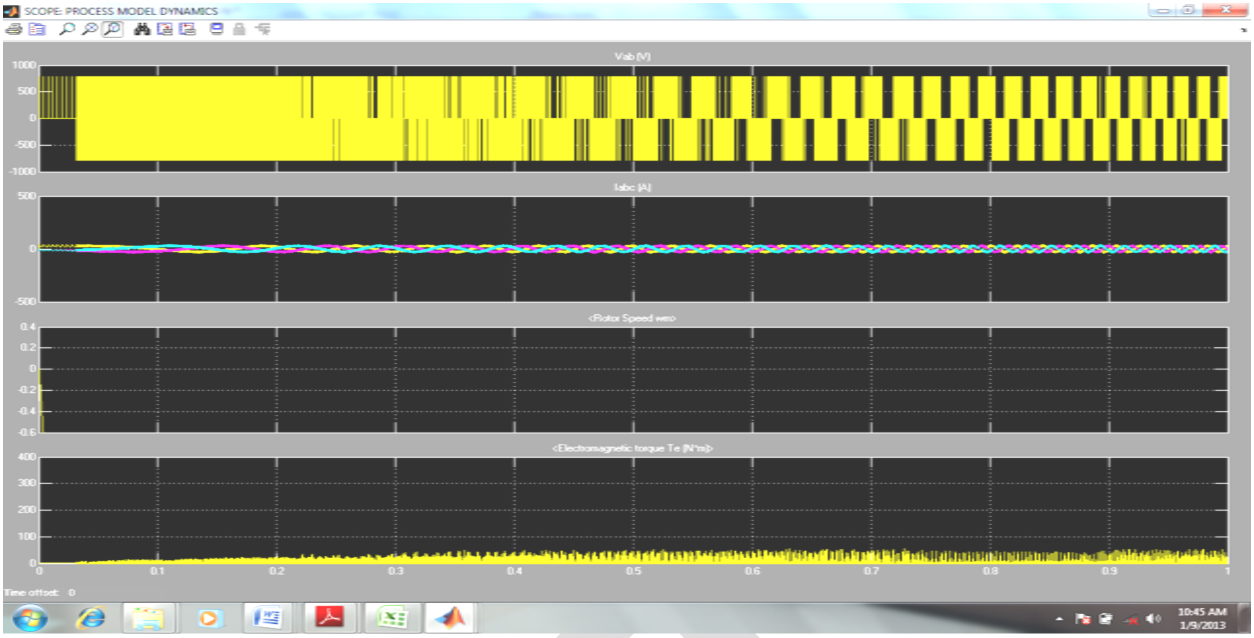

Figure 16: A Plot of No PLC-PI Vector Control at Steady State

VI. CONCLUSION

For a three Phase squirrel cage induction motor which is widely used for industrial automation, because of its characteristics (steady state speed, *Te*), to continuously have a reliable operation under steady state, its performance must be monitored continuously. In this research, a 3Phase IM with a PLC-PI Vector Control PWM was modeled to improve the efficicency and speed of VAC systems.The implementation results shows less torque ripple with flux changes, less drive sensitivity to load perturbations, better torque margin for IM characteristics, good efficiency and better hysteresis, leading to reduction in power losses especially when motor works with light loads.

Also, a dynamic model of the IM was simulated for saturation stator current behaviour under its nominal voltage considerations showing a better current response under saturation magnetizing effect. The results also shows that the speed of an IM to be optimized as well as the energy efficiency with optimized designed parameters while efficiently eliminating ripples and dead zone back electromagnetic flux in the VAC system.

This work used the real life testbed parameters to carry out the simulation design of the Non vector controlled embedded system automation.

From the simulation results, we obtained and confirm that the PLC-PI PWM scheme has a very good dynamic performance and robustness during the transient period and during the sudden loads (steady state conditions). It is concluded that the proposed PWM vector controller has superior performance than the earlier proposed schemes.

Furthermore, it was observed that in a carefully designed VAC system, energy optimization strategies will adversely save cost for an automation industry while improving the speed of the IM. This is the converse with systems that regulates IM without PLC-PI vector control. This work could be adopted in the wider industries to minimize energy losses, save cost, improve performance and the quality of production

Future work will focus on improving the snubber network parameters will enhance better effectiveness.

Also, the PLC-PI vector control will be used for further analysis of impedance/frequency measurement, RLC line parameters and load/machine initialization.

References

1. C. Thanga Raj,S. P. Srivastava, and Pramod Agarwal, “Energy Efficient Control of Three-Phase Induction Motor - A Review”, International Journal of Computer and Electrical Engineering, Vol. 1, No. 1, April 2009. Pp.61-70.
2. Hussein Sarhan, “Energy Efficient Control of Three-Phase Induction Motor Drive” Energy and Power Engineering, 2011, 3, 107-112 Doi:10.4236/epe.2011.32014 Published Online May 2011 (http://www.SciRP.org/journal/epe).
3. W. Leonhard, “Controlled AC Drives, a Successful Transfer from Ideas to Industrial Practice,” *Control Engineering Practice*, Vol. 4, No. 7, 1996, pp. 897-908. doi:10.1016/0967-0661(96)00087-1

4. G. C. D. Sousa, B. K. Bose and J. G. Cleland, "Fuzzy Logic Based on-Line Efficiency Optimization Control of an Indirect Vector-Controlled Induction Motor Drive," *IEEE Transactions on Industrial Electronics*, Vol. 42, No. 2, 1995, pp. 192-198. doi:10.1109/41.370386
5. H. R. Andersen, C. B. Rasmussen, E. Ritchie and J. K. Pedersen, "Efficiency Comparison of Electrical Motors for Energy Optimized Variable Speed Low Power and Low Cost Household Equipment," 6th European Conference on Power Electronics and Applications, Seville, 1995, pp. 3381-3386.
6. F. C. Lin and S. M. Yang, "On-Line Tuning of an Efficiency-Optimized Vector Controlled Induction Motor Drive," Tamkang Journal of Science and *Engineering*, Vol. 6, No. 2, 2003, pp. 103-110.
7. I. Kioskeridis and N. Margaris, "Loss Minimization in Scalar-Controlled Induction Motor Drives with Search Controllers," *IEEE Transactions on Power Electronics*, Vol. 11, No. 2, 1996, pp. 213-220. doi:10.1109/63.486168.
8. A. K. Sharma, R. A. Gupta and Laxmi Srivastava. "Implementation of Neural Network in Energy Saving of Induction Motor Drives with Indirect Vector Control," Journal of Theoritical and Applied Information Technology, Vol. 5, 2008, pp. 774-779.
9. Mehmet Çunkas, and Ramazan Akkaya, "Design Optimization Of Induction Motor By Genetic Algorithm And Comparison With Existing Motor", Mathematical and Computational Applications, Vol. 11, No. 3, pp.193-203, 2006.
10. Hussein Sarhan, "Energy Efficient Control of Three-Phase Induction Motor Drive" Energy and Power Engineering, 2011, No.3, 107-112 doi:10.4236/epe.2011.32014, Published Online May 2011 (http://www.SciRP.org/journal/epe)
11. D. Archana, Kotyada. Kalyani, B. Shankar Prasad, "Efficiency Optimization Control of Induction Motor Using Fuzzy Logic", International Journal of Soft Computing and Engineering (IJSCE) ISSN: 2231-2307, Volume-2, Issue-3, July 2012 327.
12. Yasar Birbir*, H.Selcuk Nogay,"Design and Implementation of PLC-Based Monitoring Control System for Three-Phase Induction Motors Fed by PWM Inverter", International Journal Of Systems Applications, Engineering & Development Issue 3, Volume 2, 2008.