International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 5, Number 4 (2012), pp. 437-447
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Energy Saving Scheme for Induction Motor Drives

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Abstract

The speculation of energy saving is an attention grabber when the savings and reduction in running cost are promising. This paper presents an efficient Neural Network (NN) based energy-saving scheme for three phase induction motors. The proposed scheme is based on the variable voltage control employing Space Vector Modulation (SVM). Voltage control is required to meet the variation in the input voltage and to regulate the output of the inverter. From the simulation studies, it is observed that, SVM gives better harmonic response and higher efficiency compared to other Pulse Width Modulation (PWM) techniques and it is used in the present work. The three phase induction motor is modeled based on the Krause's theory. Error back propagation algorithm is used to train the neural network to estimate the required voltage at various load conditions. The NN based energy-saving scheme incorporating SVM technique has been developed and it elucidates that considerable energy can be saved with this scheme, when the three phase induction motors operate at no load or light load.

Keywords: Energy saving, Error back propagation, Voltage Control, Space Vector Modulation, Three Phase Induction Motor

Introduction

The influence of induction motors in energy intensive industries is significant in total input cost. Although, induction motor is a high efficiency electrical machine, there is considerable reduction in efficiency when working close to its rated torque and speed, at light loads. When the motor excitation is adjusted with respect to load and speed, efficiency can be improved at light loads [1]. Partial load efficiency can be ascended by using a power controller (such as an inverter) between the supply and the motor. The energy saving is calculated from the losses with and without reduced excitation at partial load. For this, the induction motor is modeled using Krause's Model [2].

Voltage controllers are increasingly used as energy savers, reducing the flux level in the connected induction motor in accordance with the load [3]. The use of Space Vector Modulated (SVM) inverter eliminates the drawback of SCR voltage controllers partially. SVM technique has several advantages [4], [5] such as lower torque ripple, lower THD in the AC motor current, lower switching loss, and easier to implement in the digital systems [6].Voltage control of three phase induction motors is done and the results indicate the merit of voltage control [7].

Traditionally, PI controllers are used in inverters. They suffer from certain disadvantages. Recent development in artificial neural network (ANN) technology has made it possible to train neural networks for non linear loads. A neural network has the advantage of very fast implementation of an SVM algorithm that can increase the converter switching frequency [8]. Since, ANN are highly parallel and distributed networks, they are extremely fault tolerant and insensitive to noise.

Manufacturing industries can consider the NN based Energy Saving Scheme to make their final product more competitive in this globalizing and competitive environment. Proper energy conservation technique of these motors will go a long way in improving the energy scenario, since "Energy Saved is Energy Generated".

Block Diagram of the NN based Energy Saver

The block diagrammatic representation of the intelligent based energy saver for three phase induction motor drive is shown in Fig.1.

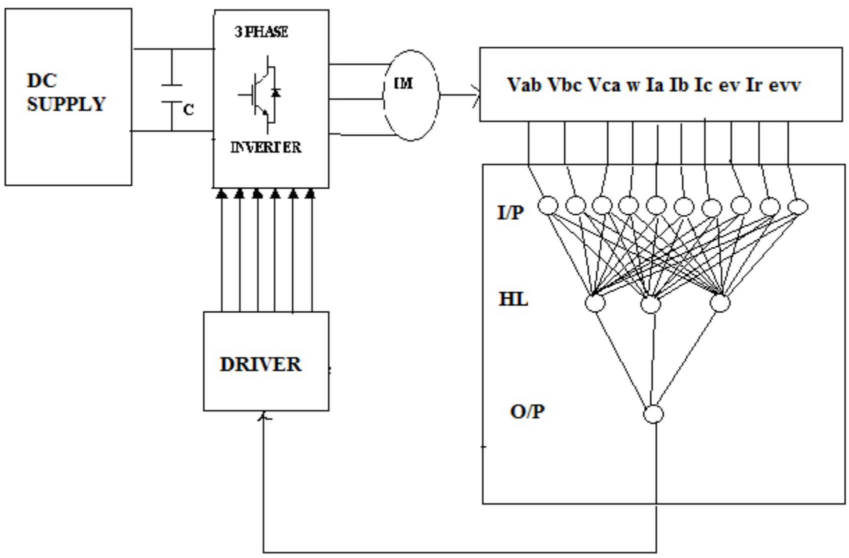


Figure 1: Block diagram of the Intelligent based Energy Saver

The fixed DC supply voltage is converted into variable three phase ac voltage by an inverter and is fed to the motor. Various parameters such as line voltages (Vab, Vbc, Vca), speed (w), stator currents (Ia, Ib, Ic), rotor current (Ir), error in voltage (ev) and PI output (evv) are measured and neural network is trained. With the trained output, driver produces the driving pulses for the six switches in the inverter.

Driver holds the Space Vector Modulation (SVM) technique. With this technique, the driving pulses are produced and at each time, the weights and biases of the NN are updated using the back propagation algorithm [9].SVM technique approximates the reference voltage by a combination of the eight switching patterns. With the values of V_d, V_q, V_{ref} and sector the gate timing is generated. Finally, gate pulses are obtained by comparing them with triangular wave. Thus, the driving pulses are fed to the inverter switches.

Modeling of Three Phase Induction Motor

The SIMULINK model [10] of a three phase induction motor is shown in Fig. 2. The induction motor is modeled using Krause's theory.

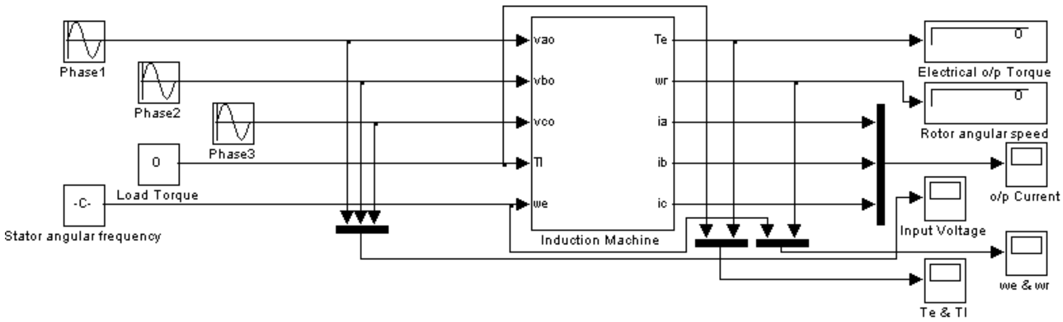


Figure 2: Model of Three Phase Induction Motor

The inputs to the induction machine are the three-phase voltages, fundamental frequency and the load torque. The outputs are the three phase currents, the electrical torque and the rotor speed. The model is obtained based on the flux linkage equations developed with Krause's theory and is shown in Fig.3.

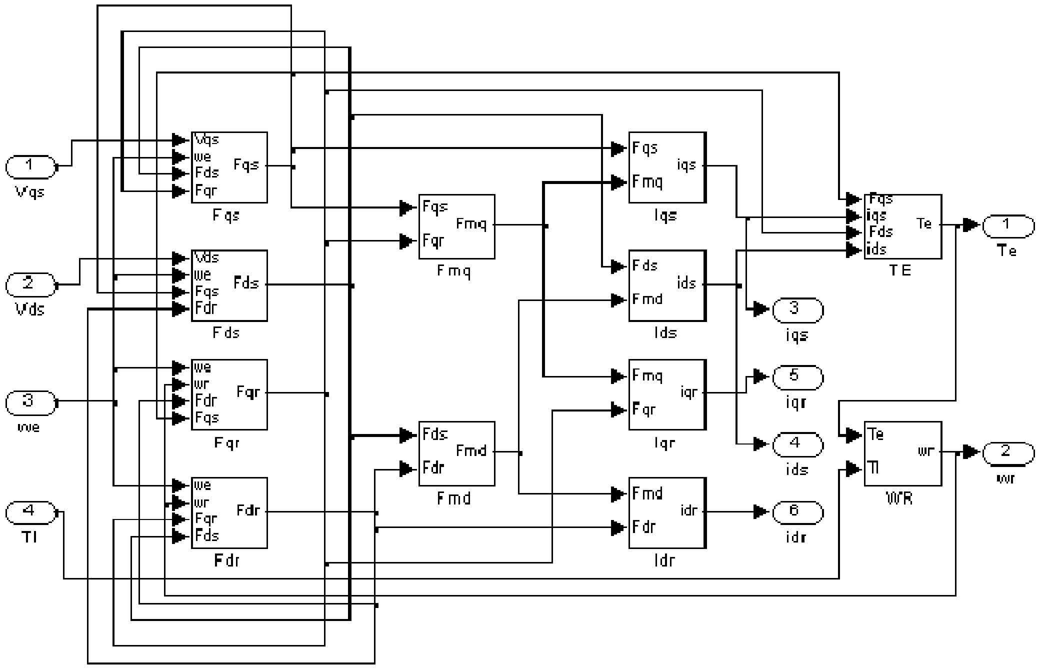


Figure 3: Flux Linkage Model of the Three Phase Induction Motor

The harmonic analysis is performed on line inverter, PWM inverter and SVM inverter fed induction motor drives. The FFT analysis for SVM inverter fed induction motor drive is shown in Fig.4.

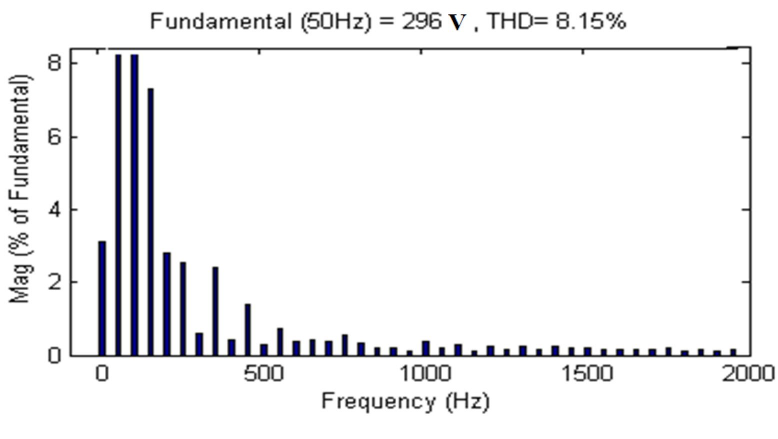


Figure 4: Harmonic Spectrum of Output Voltage of SVM Inverter fed Induction Motor

From the analysis, various parameters like THD and fundamental component are observed and the same is given in Table-1.

Table I: Comparison between PWM and SVM Inverter Fed Induction Motor Drive Systems

Parameters	PWM	SVM
V01	284V	296V
THD	16.63%	8.15%

From the Table-1, it is inferred that SVM technique provides better THD, increased fundamental component.

Energy Conservation

With projecting problems of environment protection and energy shorting, people pay more attention on energy saving. In modem cities, motor drive systems can consume over half of all electricity. Furthermore, those systems can consume over 75% of all electricity in an industrial plant. In the present scenario, the demand increases in the range of 9-10% and the generation increases in the range of 5-6%.Thus, the gap between the two, is in the range of 3-4%.

Induction motor drives are most popular with real applications and are applied in industries. But, it consumes more electricity. The rated efficiency of an induction motor is high when it runs under the full load. In general, the rated efficiency is larger than 75%. However, the operating efficiency of the induction motor drive system will be low if an induction motor is not selected correctly or does not match its load appropriately. Therefore, even a modest improvement in the energy efficiency of induction motor drives can imply huge energy-savings. One unit of energy saved is equivalent to two units of energy generated.

In the industries like, drilling, punching press, etc., the motors are usually operated at light loads. The energy consumed by the motor is much larger than the energy required by the motor. The excrescent energy causes jouncing, heating, noising and core losses. So, the running-efficiency and power factor are very low. Moreover, the life-span of the motor will be reduced. Thus, it is very important to study energy saving of induction motor as the motor is the main equipment that consumes energy in an industry. There are two technical approaches for energy saving of the motor. One is from the motor itself to improve structural design, and new material and so on. Another is from the running condition of the motor by controlling the supply voltage and frequency according to the load torque and speed. The second approach is considered here for the energy saving of induction motor.

Open Loop Control Scheme

In open loop control, input voltage is applied to the motor and the corresponding parameters are noted. The SIMULINK model for open loop control of induction motor is shown in Fig.5.

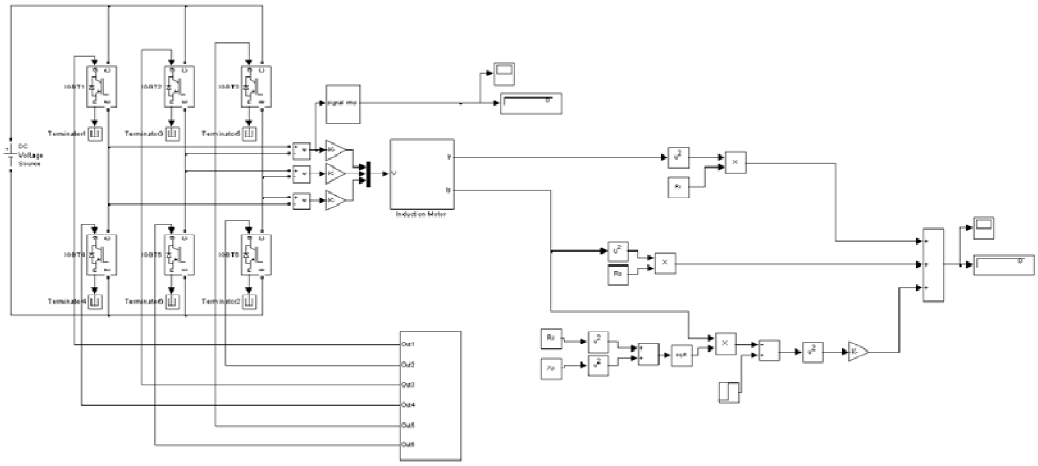


Figure 5: Open Loop Control of Induction Motor

At no-load, the voltage to the induction motor is changed, in steps, from 20% to 100% of the rated voltage. At each voltage step, the motor is allowed to run for 15 minutes and various parameters, losses, power factor, speed and slip are measured. Based on the losses, the energy saving is calculated with equation (1). In this, the output voltage remains unregulated. In order to regulate the output voltage, closed loop control is adopted.

Energy saving = (Losses at full load –Losses at partial load)
* 100 / Total losses at full load (1)

The same experiment has been conducted for partial load conditions also. From the simulation, it is observed that the energy can be saved during no load and partial load conditions by reducing the stator voltage.

Artificial Neural Networks

Neural networks are simply a class of mathematical algorithms, since a network can be regarded as a graphic notation for a large class of algorithms. It consists of an input layer, a hidden layer and an output layer, where each layer has a specific function. The input accepts an input data and distributes it to all the neurons in the hidden layer. The input layer is usually passive and does not alter the input data. The neurons in the hidden layer act as feature detectors. They encode in their weights a representation of the features present in the input patterns. The output layer accepts a stimulus pattern from the middle layer and passes the result to a transfer function block, which constructs the output response pattern of the network. The neural network system to estimate the driving pulses of an inverter fed three phase induction motor is shown in Fig.6.

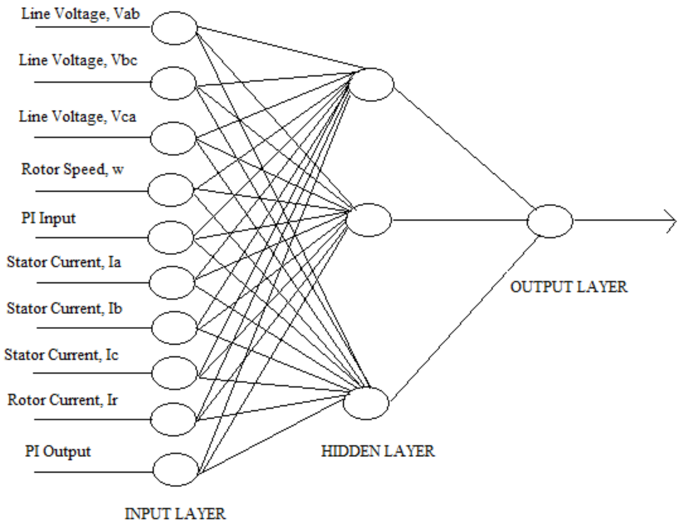


Figure 6: Neural Network System to estimate the Driving Pulses of an Inverter

The number of hidden layers and the number of neurons in each hidden layer depend on the network design consideration [11]. The hidden layer transfer function is log-sigmoid or tan-sigmoid and the output transfer function is usually linear [12]. Equations (2) and (3) show the transfer functions, where X is the input vector, Y and O are the output vectors of the hidden layer and output layer respectively. V_{ji}, W_{kj} are the weight matrices, and B_1 and B_2 are the bias vectors.

$$Y = \frac{1}{\left(1 + e^{-(V_{ji}.X + B_1)}\right)} \tag{2}$$

$$O = W_{kj}.Y + B_2 \tag{3}$$

The algorithm of the back propagation of the error is the most well-known algorithm for the training of the multi-layer networks. To provide the required data to train the neural network, a simulation program is written. Using this program, 1, 00, 000 sets of training pattern are obtained. These patterns are used for training the neural network using error back propagation algorithm. After training the neural network successfully, the program is replaced by neural network controller and the simulation is performed. Output of the neural network controller is used to generate the driving pulses of the SVM inverter.

Closed Loop Control Scheme

In the closed loop, the load on the motor is sensed continuously. Based on the load, the voltage applied to the induction motor is varied. Non-linear load is developed using the MATLAB coding and the same is given below.

```
function out=par(a)
x=a(1);
```

```
if(a>=230)
out(1)=11;
elseif(a<=184)
out(1)=2.2;
else(a<=46)
out(1)=0;
end
```

At full load, rated voltage is applied to the induction motor and at reduced load conditions partial voltage is applied. The neural network based closed loop control of a three phase induction motor system is shown in Fig.7.

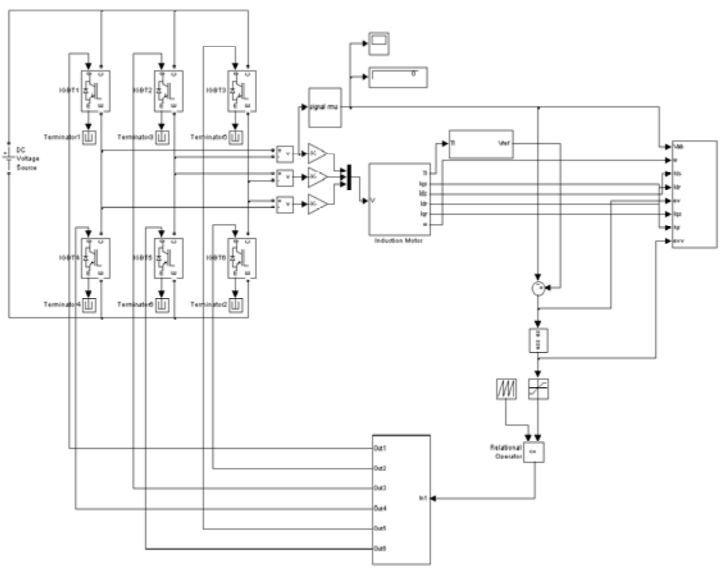


Figure 7: Closed Loop Control of Induction Motor

The power circuit used to generate the SVM voltage is modeled and simulated. SVM voltage is applied to the three phase induction motor. Initially, PI controllers are used to control the voltage applied to the three phase induction motor. Using Nichols and Zeiger rules, the values of K_p and K_i are tuned for various load conditions. For each load, the PI controller is tuned and parameters like line voltages, stator current, rotor current, speed of the machine, error in voltage and PI output are estimated [13]. Around 1,00,000 sets of training patterns are obtained. These patterns are used for training the neural network, using the error back propagation algorithm. The subsystem of the closed loop scheme holding the neural network controller is shown in Fig.8.

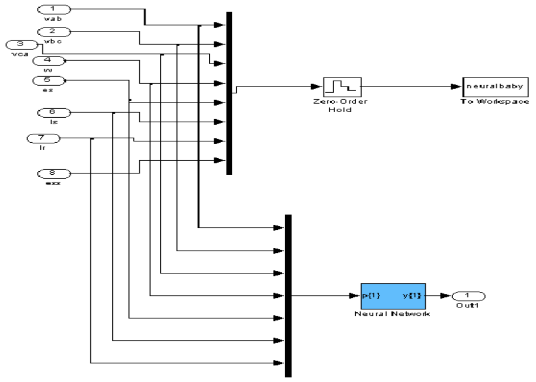


Figure 8: Subsystem with Neural Network Controller

Results and Discussions

From the simulation study of open loop control of induction motor, it is observed that, the no-load and partial load operation at the reduced voltage yields energy saving in induction motor. At no-load, 49% of energy can be saved. In addition to the energy saving, the power factor improves from 0.32 to 0.77. The compromise has to be made with motor speed. The motor speed falls from 1497rpm at rated voltage to 1297rpm at 20% of the rated voltage. Based on the parameters measured, various performance characteristics have been plotted and the same is shown in Fig.9.

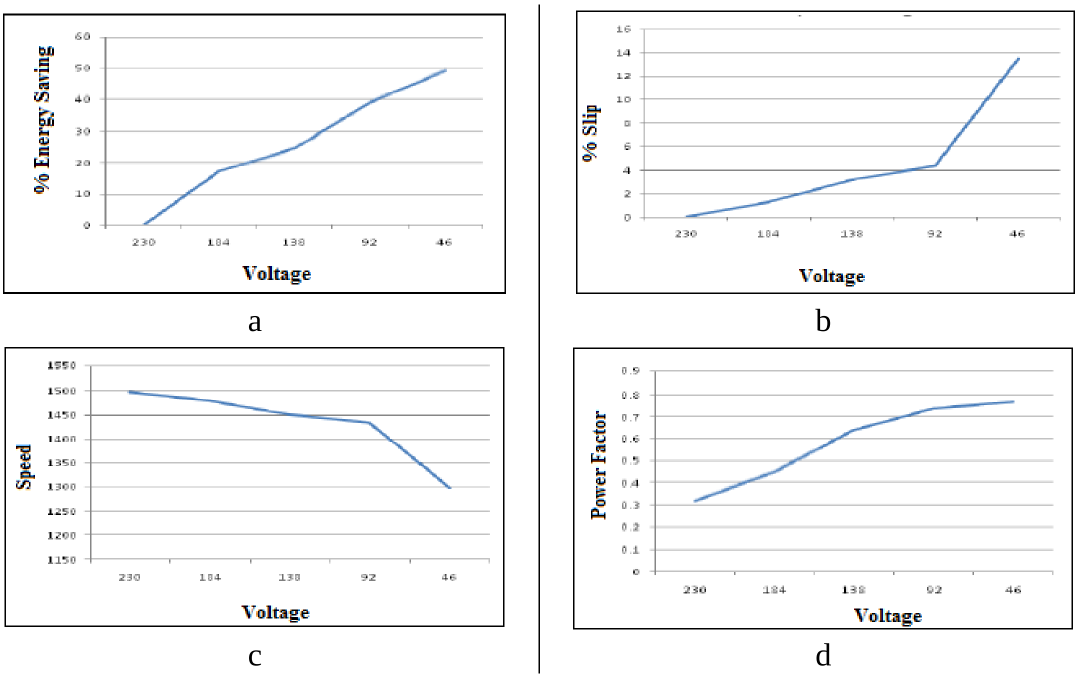
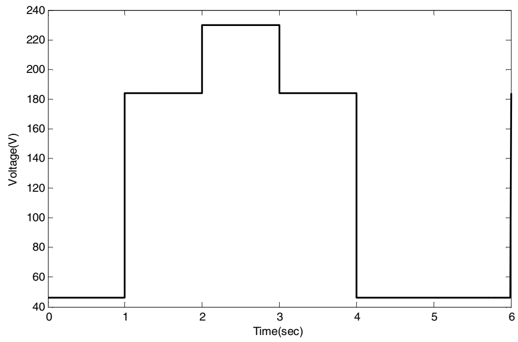
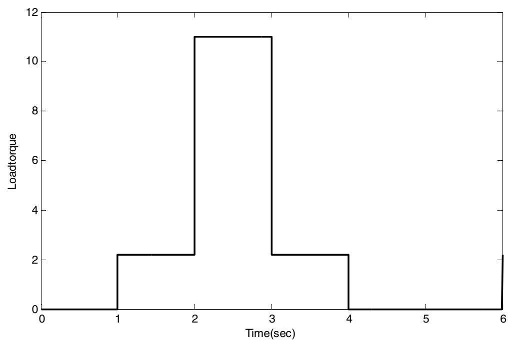


Figure 9: Performance Characteristics (a)Energy Saving vs Voltage (b)Slip vs Voltage (c) Speed vs Voltage (d) Power factor vs Voltage

In closed loop control, load on induction motor and the voltage applied on the stator terminals of the motor are sensed continuously. Based on the results, saving in energy is calculated. The variations are shown in Fig.10.



a



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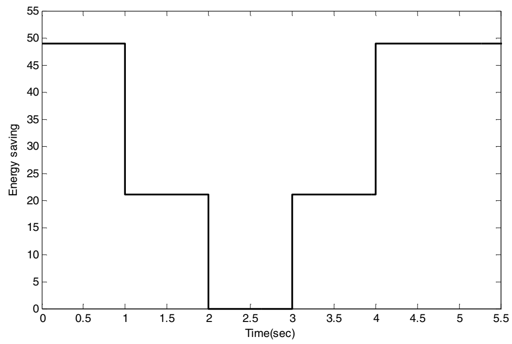

c

Figure 10: Graphs (a) Voltage vs Time (b) Load torque vs Time (c) Energy saving vs Time

From Fig.10, we infer that, at no load and 20% 0f the rated load, 49% and 21% of energy can be saved respectively. Thus, the saving in energy increases with decrease in the load. Thus, energy can be effectively saved with the Intelligent Energy Saver.

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