# Energy Saving Algorithm on Induction Motors controlled by a 68HC11 Microcontroller System using Fuzzy Logic Approaching

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*Abstract*-- The potential of energy saving in induction motors is in lightly loaded. This research has overcome these situations, by sensing the load and controlling the motor terminal voltages to meet the load requirement using a microcontroller system. The program in this microcontroller system can detect the motor load indirectly using $\beta$ angle. Base on this angle we predict notch angle ($\gamma$) using fuzzy logic algorithm. The experiment results on a squirrel cage three phase induction motor, 1.5 KW, 380/220 V, Y connected, shows that the biggest energy saved when motor on no load condition, is about 58 %. Energy saving is started at about 60% of rated load. There is no saved energy at full load condition. Fuzzy logic algorithm does work well on slow changing of loads.

***Index Terms*--induction motor, energy saving, microcontroller, fuzzy logic**

## I. INTRODUCTION

The potential of energy saving in partly loaded induction motors, has been known since more then ten years ago [2]. The analysis of motor model in d-q axis has been developed by Lipo [3], Based on this model, performance motor can be investigated theoretically. The general configuration of this controller is using three coupled thyristors inserted in between energy sources and the motors, shown in figure 1. A microcontroller is used as a smart controller to fire the thyristors according load conditions [4].

It is not difficult to find partly loaded induction motors in industrial application. Firstly, it is impossible to meet the rated motors as required in design, usually the applied rated motors are larger than the rated load. Secondly, several industry load characteristics are time variant such as in lift, escalator, conveyer, pump etc [1]. These conditions make motor are not fully loaded, and tend to reduce the motor performances such as motor power factor and efficiency and so the overall electrical system.

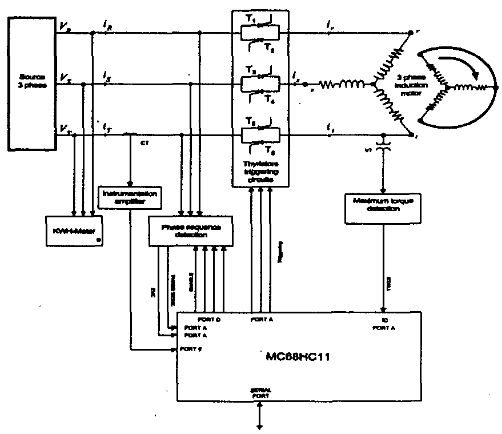


Fig. 1 Thyristor controlled inducion motor system

This research has overcome these situations, by sensing the load and controlling motor terminal voltages to meet the load requirement using a microcontroller system. The system can detect the phase sequence, electrical frequency systems, motor stalling conditions, zero crossing voltages, and ceasing current angle $\beta$. By measuring the source voltage phase sequence and frequency, this controller can be plug in every system automatically. By knowing the zero crossing and ceasing current we can controlled power input to the motor to meet the load requirement by adjusting the thyristor firing angle.

Motor terminal voltages and currents are shown in figure 2.

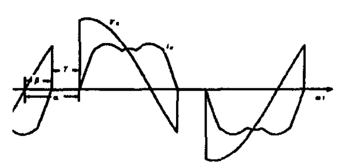

Fig. 2. Motor terminal voltage and phase current waveforms. $\beta$ is determined by motor parameters and loads. $\gamma$ is the hold off angle and $\alpha$ is the firing angle. These angles follow the formula:

$$\alpha = \beta + \gamma$$

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In steady state operation we keep the angle γ constant by controlling the firing angle α follows the load changing. Using γ as controller, theoretically gives a stable controller [4].

During starting condition, the measured β is minimum at a specific load. When the load is constant, energy saving algorithm try to keep β as close as possible to β minimum by controlling hold off angle γ while the motor is running. Fuzzy logic algorithm is used to control this angle (γ) by sensing the ceasing current angle β at any time. By measuring β in every cycle we can calculate the errors and error rates of changing β, these are the input of the fuzzy system. This algorithm is written on machine language. It is not easy to get relation formula for β and γ. The empirical result for specified motor at no load condition is shown in figure 3.

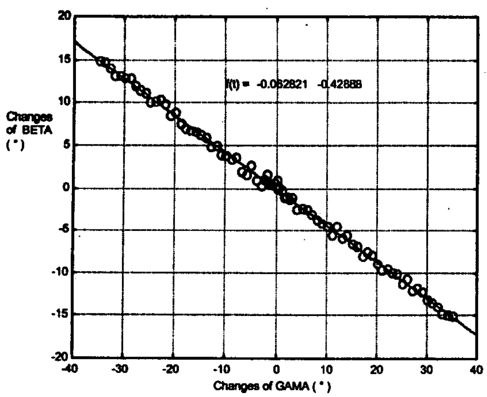


Figure 3. Changes of β Vs changes of γ

## II. THEORETICAL BACKGROUND

An induction motor can be analyzed using one phase equivalent circuit as shown in figure 3

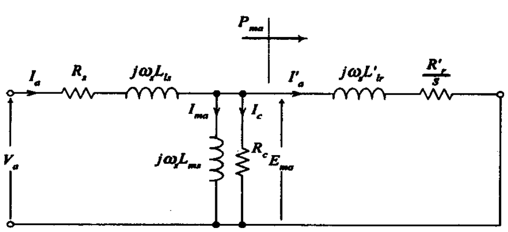

Figure 4. One phase equivalent circuit

Based on figure 4, motor mechanical power can be analyzed using formula :

$$P_{mech} = \frac{3(1-s)}{s} R'_r \, (I'_a)^2 \quad \text{Watt} \quad .... \quad (1)$$

$$\text{Torque :} \quad T = \frac{P_{mech}}{\omega_m} \quad \text{N.m} \quad .... \quad (2)$$

$s$ : motor slip, $\omega_m$ : rotor angular mechanical speed.

Equation (1) shows that reducing the motor voltage, and so the motor current will reduced the motor power. Equation (2) shows that the motor will deliver a constant torque in reduced voltage, if the rotor speed is also reduced. Decreasing the slip is possible until the maximum slip value at which the maximum torque condition. The motor will at the stalling condition if the slip is reduced further and the motor current will increase and so the power. The motor must be hold at the maximum slip that give maximum torque in order to work at the minimum input power. The saving algorithm maintains the motor work at this point at all load condition, by adjusting the motor voltages automatically.

## III. HARDWARE DEVELOPMENT

Microcontroller is a powerful tool for any real time control application. The microcontroller has got five I/O ports : A,B,C,D,and E. It is also contained on ADC (Analog to Digital Converter) and two 16 bit timers. The hardware development involved two tasks. Firstly is designing electronic circuits to interface the 8 bit microcontroller to the motor for specific application and secondly is writing the software in machine language. The maximum torque is detected by interrupt capture input of port A. This pin detects the motor back emf at specified phase. ADC is used to measure the motor phase current and the microcontroller keep to fire thyristors in order the current does not exceed the rated value. The program in microcontroller does the soft-starter and protection on any motor malfunctions. The flow chart of the software controlling motor operation is shown in figure 6. Motor operation can fit any phase sequences and source frequency systems. It can control the motor either in energy-saving algorithm or with minimum hold off angle (γ).

## IV. FUZZY LOGIC ALGORITHM

The fuzzy logic algorithm has improved the implementation on real time systems. The sequential procedure lies on finding out error and change of error of the feedback variables (beta and change of beta) and fuzzyfying them with three triangular membership functions with a finite overlap. The fuzzified output is processed through min-max method. Finally the defuzzification is performed with the center of gravity method on singleton membership functions output. The output of defuzzification determine the value of gamma (γ). On machine language all the value of membership functions (inputs and output) are given on look-up tables placed in an EPROM.

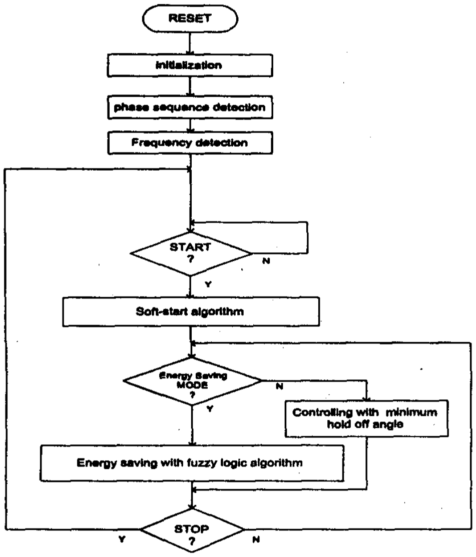


Figure 6. Flow chart of motor controlling software

## V. EXPERIMENT RESULTS

The results of the experiment on three phase, 220/380, 1.5 kW, induction motor are sohwn in figure 7 and 8.

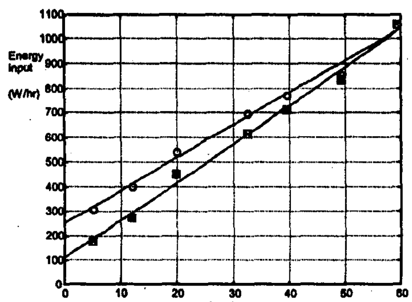


Figure 7. Energy input vs Load

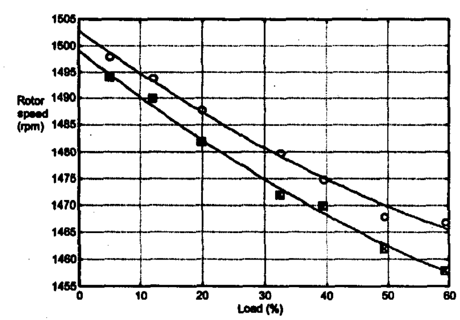


Figure 8. Rotor speed vs load

Figure 7 shows that on 5 % load, there is an energy saving at about 42%. There is less energy saved as load increased. When the load is about 60% there is no more saved energy. The saving energy algorithm makes the motor running at speed lower than normal speed (figure 8), its 0.5% at 60% load, and 0.27% at no load. From these results, we conclude that energy saving algorithm should be only used on a system that the speed is not necessary constant, and the load is variable. This algorithm is very useful when the motors are under-loaded, or most of the times are unloaded.

## VI. CONCLUSION

The results of this experiment agree with the theoritical results from the d-q axis three phases motor model which has been developed based on Matlab programming language. The experiment results on a squirrel cage three phase induction motor, 1.5 KW, 380/220 V, Y connected is shown in figure 7 & 8. These figure show that the biggest energy saved when motor on no load condition, is about 58 %. Energy saving is started at about 60% of rated load. There is no saved energy at full load condition. There is a reduced motor speed when motor operates on energy saving mode. Fuzzy logic algorithm can be used as control algorithm in real time systems to overcome system parameters that always changing because of the load characteristics.

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