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Maximizing the Efficiency of 3-Phase Induction Motors (Squirrel Cage Motor)

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Abstract: Induction motors are used for many industrial purposes. They can act as electrical drives for many processes in many production processes. This paper will focus on how to improve the efficiency of these motors- 3 phase squirrel cage induction motor (SCIM) in order to save electrical energy. This is because it has been experimentally observed that the efficiency of the induction motors is poor with low load conditions, hence more energy is wasted. We will be looking at the various losses in the induction motor. Also the paper will sample some methods like the conventional methods and the fuzzy logic approach as used in maximizing/optimizing the efficiency of the induction motors. We shall also sample results from simulations that prove show how the efficiency is maximized by adjusting the input voltage.
Keywords: Induction Motor, Input power, Output power, Motor Losses, Efficiency,

I. INTRODUCTION

The induction motor is a 3 phase AC electrical driving device. It is widely used in different countries at an industrial scale. The squirrel cage is the most common type found. They are always rated according to the power input which is the power supplied to it at maximum load. The output power is measured as a mechanical power from the shaft rotation. The efficiency of these motors is of great importance, and a slight increase in this efficiency has been found to save a significant amount of electrical energy [1][2]. This paper will suggest some methods that can be followed to maximize the efficiency of these important machines. In this paper, section 2 will talk about the input and output power, and also the types of losses [1] [2] obtainable in the SCIM. Also section 2 will dwell on optimizing the efficiency of the SCIM using the conventional methods and also the fuzzy logic [3]. Section 3 will be on the results and graphs from and simulations [3] [4] [5], section 4 will be our conclusion[2].

II. METHODOLOGY

A. *Squirrel Cage Induction Motor (SCIM) Input and Output power, Losses and efficiency*.

Input power is the amount of electrical power supplied at the input at full load. The input power at most times is not fully utilized by the motor due to losses in the motor which result chiefly from using the motor at low load. The output power is the mechanical power delivered by the shaft. We can calculate the efficiency of the motor if we can find the losses in the motor.

Total electrical energy in= Mechanical energy out + Motor losses.

$$efficiency = \frac{mechanical\ energy\ out}{electrical\ energy\ in} \times 100\%$$

Losses in the motor come from stator windings (primary copper loss), rotor windings (secondary copper loss) magnetic flux in the iron core (iron loss), mechanical losses and stray losses.[1] [2]
Total Loss = Copper loss + Iron loss + Mechanical loss + Stray loss
Copper loss: Copper loss varies as a function of load current. Whenever load is applied to the motor copper loss also will change. Copper loss comprise of stator and rotor copper losses. Stator losses are proportional to current in the stator windings. Rotor losses are proportional to current flowing in the rotor.
Stator loss is given by; $P_s = I_s^2 R_s$
Rotor loss is given by; $P_r = I_r^2 R_r$
Total copper loss $P_{cu} = I_{rms}^2 R = P_s + P_r$

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Where $R = \frac{N \cdot l_w}{\sigma \cdot A_w / N}$ and therefore, $P_{cl} = (NI_{rms})^2 \frac{l_w}{\sigma \cdot A_w}$

Iron loss: is a constant loss, i.e. It will not change when the load is changing. The core loss of motor is directly proportional to supply voltage. This is can be reduced by reducing the supply voltage. Iron loss or core loss is the losses due to eddy currents and hysteresis.

Mechanical loss: this is as a result of friction in the bearings and opposition of wind to the rotor windings.

Stray losses: The stray losses are mainly attributed to the rotor current. Since the rotor current in SCIM cannot be measurable, stray losses are expressed as a function of the stator current.

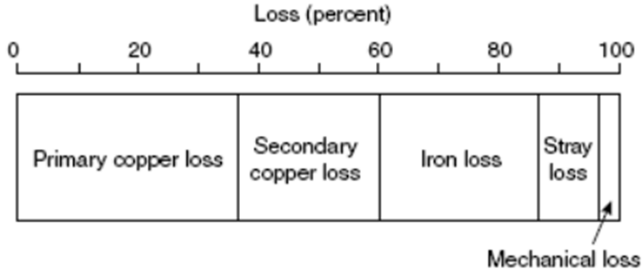

Figure 1. Diagram showing the component of energy loss in SCIM

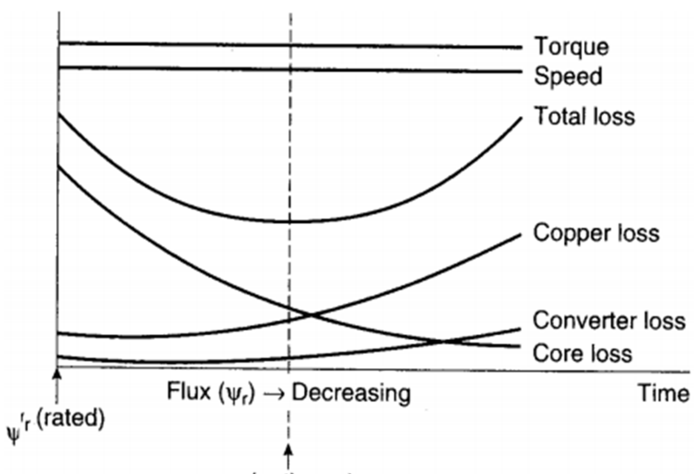

Figure 2. Loss characteristics in an SCIM

B. Maximizing Efficiency

We shall apply two approaches:

1) *The Conventional method:* The copper losses and the core losses form major part of the losses of the SCIM during low load conditions. Thus it has been observed that less input voltage result in less core losses and less current in rotor and stator windings results in lower copper losses. It is also observed that at maximum efficiency copper loss equals core loss. So the system has to adopt a voltage regulating scheme. Three methods can be used to achieve the voltage regulating scheme.

The first approach is called simple state control which utilizes the fact that in operation with optimal efficiency, certain motor quantities are easily defined. The control circuit kept the identified quantity to it value throughout the operation regardless the load torque and speed. This method requires knowledge of both motor parameters and speed. The second approach is known as model-based control or also called loss model controller (LMC). The method is based on the properly modeling the motor and the losses to derive an expression that associated with minimum losses or maximum efficiency. Then the controller is built based on this expression. The approach requires the knowledge of stator voltage, current and phase shift angle. The third approach is called search control (SC). The principle of SC is to keep the output power of the motor constant and finding the operating point where the input power is minimum. The minimum power is found by exact measurement of the input power, and iteratively changing the flux level in small steps until the input minimum power is detected. The main advantage of SC is that the point of optimal efficiency is found without knowing the motor or converter parameters.

2) *The fuzzy logic approach:* The classical approach deals with problems that assume only two states e.g. true or false. Fuzzy logic is based on a series of "If-Then" rules. IF there is a given input, THEN the fuzzy controller will take a particular action as based on a rule set. These rules assign each input in membership sets. The membership sets are not crisp like in classical theory, rather they overlap each other. There are three main parts in the fuzzy inference system: the fuzzification, the fuzzy inference and the defuzzification.

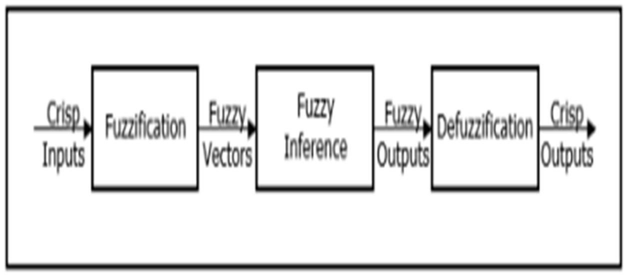

Figure 3. Parts of a fuzzy controller

Fuzzification is changing crisp sets (inputs) into fuzzy membership sets. The fuzzy inference is the part where the "IF-THEN" decision making is done based on the rules. Here the fuzzy input is matched with its corresponding output fuzzy set. Defuzzification is the process of converting the fuzzy output to crisp output.

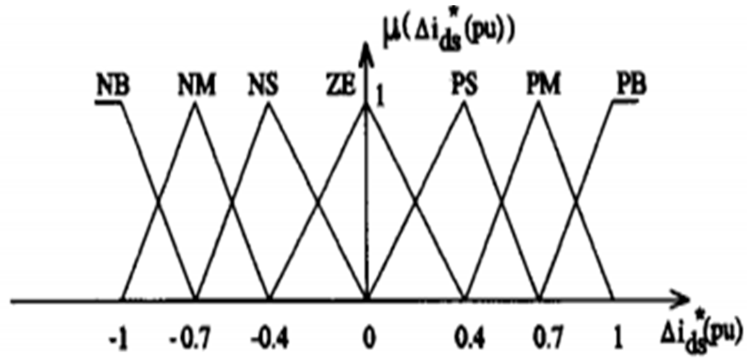

Figure 4. Example of a fuzzy membership function.

By virtue of its adaptability, it can be applied to problems whose non-linearity and dynamic nature has made them intractable to solution via classical control methods. Fuzzy logic is based on a set of rules or a rule table designed to accommodate different conditions or values of its fuzzy set.

Three interactive efficiency-optimizing (input power minimizing) controllers have been developed for ASDs that control the frequency and voltage supplied to a motor by maintaining a ratio of voltage to frequency that is the same as the ratio at the motor's rated conditions- voltage/frequency ASD(e.g., 220V at 50 Hz, 110V at 60 Hz). These controllers are voltage perturbation for input power minimization, speed correction and slip compensation.

The voltage perturbation is focused on the input voltage and the stator voltage because input power minimization is the aim. So fuzzy logic has been associated with voltage perturbation and the fuzzy logic membership functions for input and output are divided into five fuzzy sets namely; Negative Medium (NM), Negative Small (NS), Zero(ZE), Positive Small (PS), Positive Medium (PM). These membership functions are used to represent the input and output values of the ASD. The input variables are ΔV_{Sold} and Δ_{Pin} and the output variable is $\Delta V_{Snew.}$ The fuzzy sets that are to be applied for both input and output should be triangular, but the output must be isosceles in order to simplify defuzzification.

The figure below shows the table of rules for the application of fuzzy sets to the input and output variables.

ΔP_{in} \ $\Delta V_{s\,old}$	NM	NS	ZE	PS	PM
NM	NM	NS	ZE	PS	PM
NS	NS	NS	ZE	PS	PM
ZE	ZE	ZE	ZE	ZE	ZE
PS	PS	PS	ZE	NS	NS
PM	PM	PS	ZE	NS	NM

Figure 5. Example of fuzzy rule table

An example is when the ΔV_{Sold} is positive small (PS) and the ΔP_{in} is positive medium (PM) then the ΔV_{Snew} is negative small (NS). (Hint: we use this table like our elementary children's' times table).

The speed correction control is of importance because the voltage perturbation changes the motor speed and hence the output. But our aim was to minimize input at a constant output. Speed corrector controller has been designed to correct the speed alteration with voltage perturbation. The fuzzy speed controller uses parameters such as voltage, commanded speed, measured speed, and output voltage to estimate the optimum frequency setting.

The slip of a motor is given as Rotor speed/Frequency. Usually when frequency is set, a rotor speed higher than desired is gotten and this results in using of more power. Therefore slip compensation control is used to estimate the slip which will result when the frequency is set to a certain frequency and estimates an optimum frequency for the desired percent speed.

III. RESULTS AND ANALYSIS

Figure is a captured screen from a real-time demonstration of the optimizing and speed controllers for the ASD. The motor load being measured and controlled simulates a pump or fan running at 90% of rated speed and 81% of rated torque. At each step, a speed correcting controller compensates for changes in speed with changes in input frequency. Ultimately, the input power is reduced from about 81 to about 78% of rated input power. The speed controller has been shown to hold speed during efficiency optimization to within 0.5%.

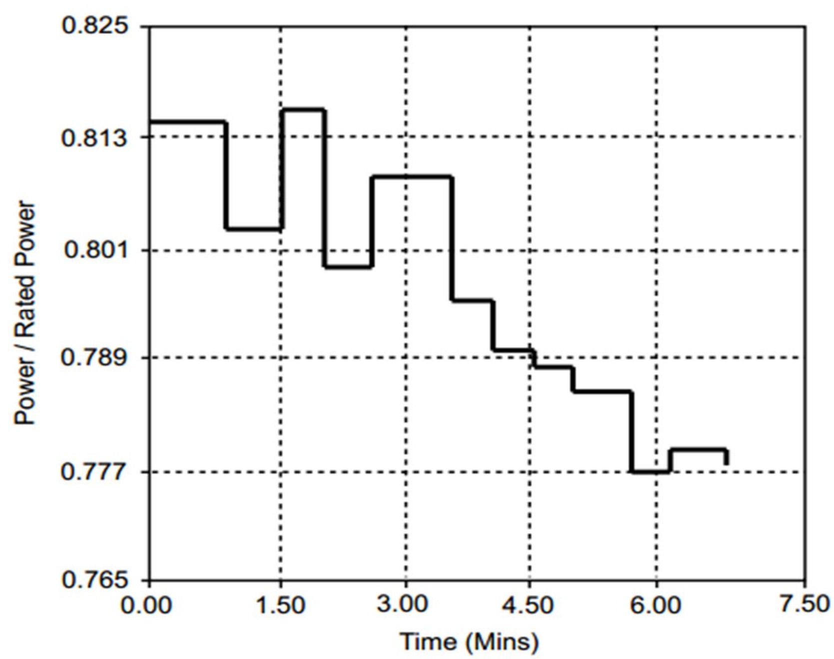

Figure 6. Efficiency optimization results for 90% speed and 81% torque

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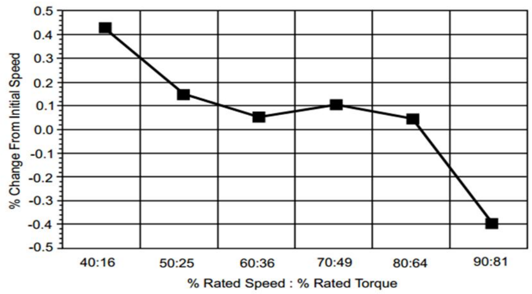

Figure 7. Percent change in motor speed from initial motor speed, without slip compensation.

Figure illustrates controller behavior over several pump-fan load conditions tested in the laboratory. Slip compensation was not active in these tests.
Typical power savings due to slip compensation for a 10 hp motor are shown in Figure. A total of 1-2% of rated power is saved.

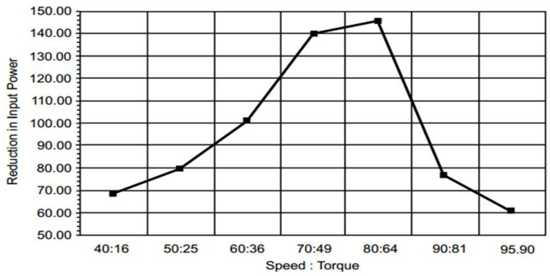

Figure 8. Power reduction in watts due to slip compensation (rated input power = 8477W).

For the ASD, it is seen that Motor A exhibits less gain from efficiency optimization in the 50 to 60% speed range than at the highest and lowest output powers. The test data also show that, in this operating range, voltage perturbation for optimization reverses its direction; i.e., at the higher speed/torque combinations, voltage perturbation results in voltage increases until Pin is minimized. At lower speed/torque combinations, voltage decreases to optimize. Motor B results are more common during efficiency optimization, with almost no improvement at rated conditions (100:100). Motor A behavior suggests that the optimum slip of a motor does not necessarily occur at rated conditions. The finding is significant because it implies that, for some motors, input power can be reduced significantly near rated output power operation.

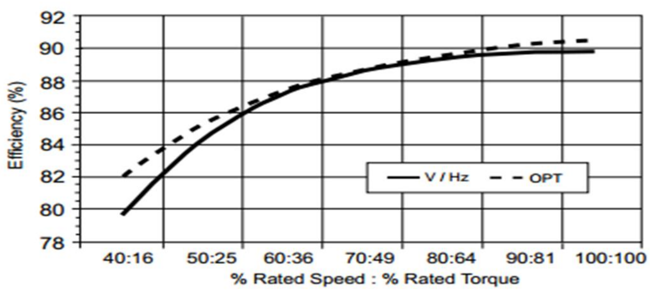

Figure 9. V/Hz and optimum efficiencies--Motor A

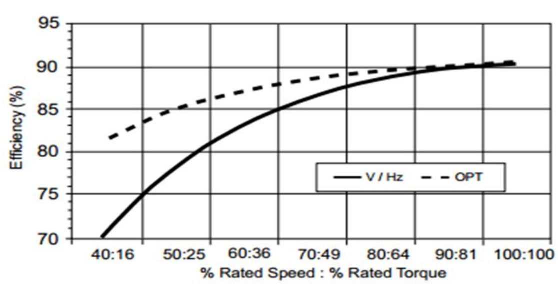

Figure 10. V/Hz and optimum efficiencies--Motor B.

IV. CONCLUSION

Conventional methods aid in reducing losses in an induction motor, thereby increasing the efficiency but the fuzzy logic approach presents a more suitable and convenient mode of optimizing. The amplitude of the input voltage can easily be reduced by at low load by implementing the rules of a fuzzy controller thereby reducing the energy wasted.

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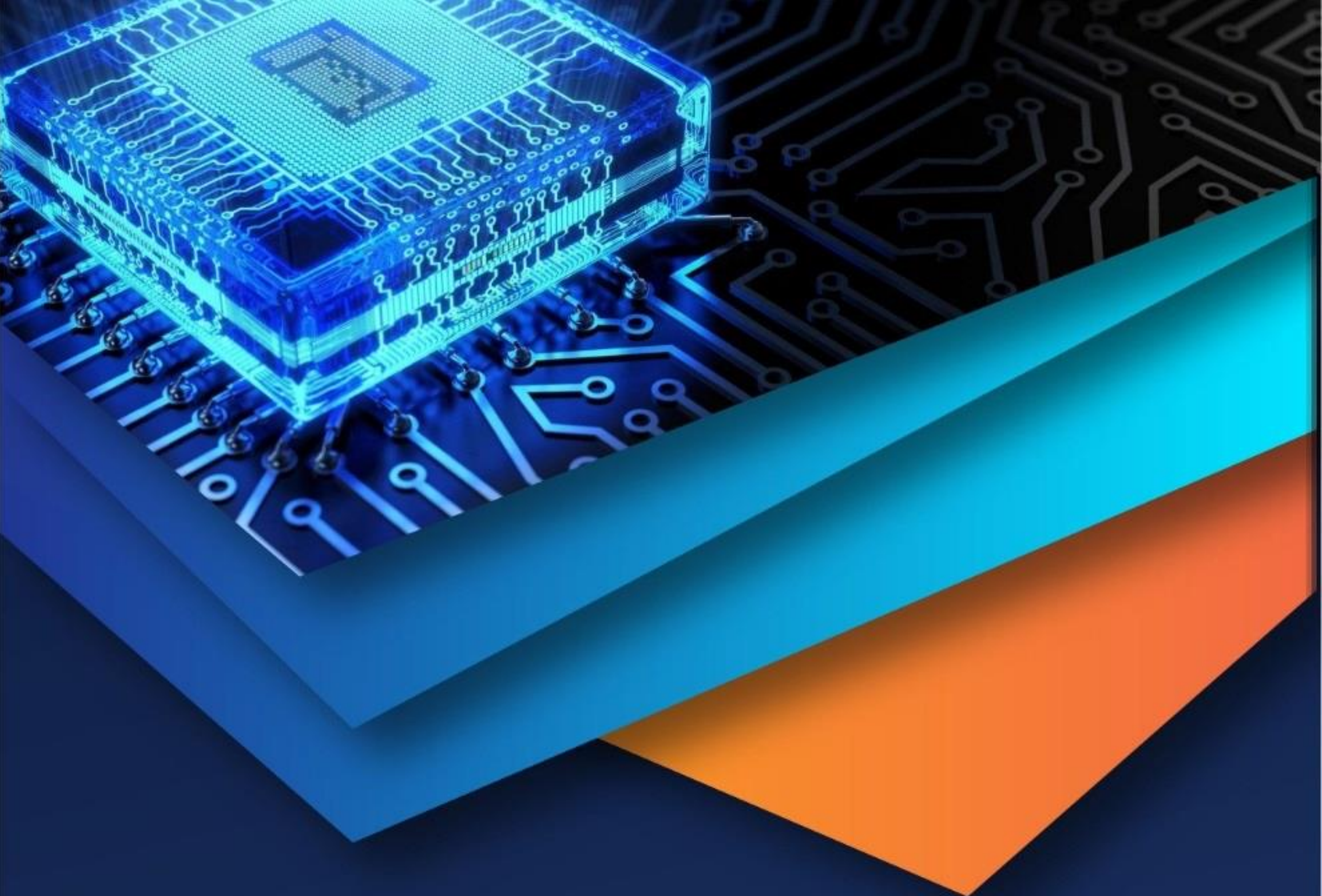

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