EFFICIENT APPLICATION OF 3 — PHASE INDUCTION MOTORS

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SUMMARY

The operating efficiency of three phase induction motors depends on the load driven and the input conditions as well as their design, and on the loading cycle in variable load systems. Information useful for the Energy Manager in his Energy Audits is provided together with a discussion on possible ways of achieving higher efficiencies.

INTRODUCTION

Industry in Sri Lanka consumes over 45% of the total electricity sold (1) and an estimated 60% of this Energy is converted to motive power using three phase induction motors. These motors in a plant need to be carefully considered by the Energy Manager in the plant design stage, in purchasing and in subsequent Energy Audits. Efficiency of three phase induction motors is high in comparison with other types of motors; but the full benefits of this high efficiency can be enjoyed only if they are properly utilised.

The low efficiency of partly loaded and overloaded motors is a well known feature. Difficulties encountered in the evaluation of the operating efficiency, together with other plant operational and maintenance requirements, often prevent them from being considered as potential means of achieving substantial Energy savings. An average of 1 percentage point increase in the operating efficiency of three phase induction motors can save the Industry over Rs. 1 million a month.

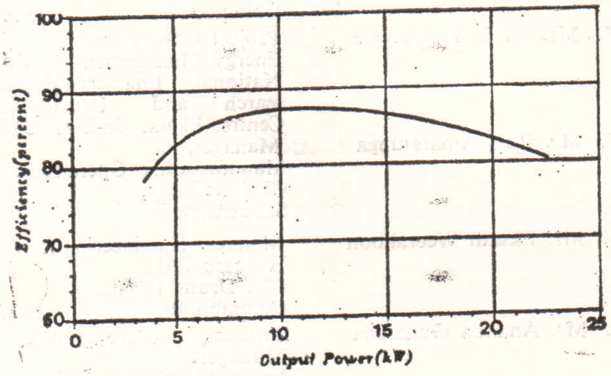

Fig. - Efficiency - Load characteristics of a 18.5 kw motor

EVALUATION OF EFFICIENCY

$$\text{Efficiency} = \frac{\text{Useful mechanical output}}{\text{Electrical power input}} \times 100\%$$

Fig. 1 shows the efficiency-Load characteristics of a 440v, 18.5 kW, 1500 rpm squirrel cage induction motor under normal operating conditions. The maximum efficiency of 87.4% occurs at an output of 12 kW. The full load efficiency is 84.3% while the efficiency at an output of 4.5 kW is 81.0%.

Different types of losses and their relative magnitudes for the same motor at full load are shown in Fig. 2. The total losses amount to 3.43 kW.

Figures 1 and 2 are based on information in reference (2).

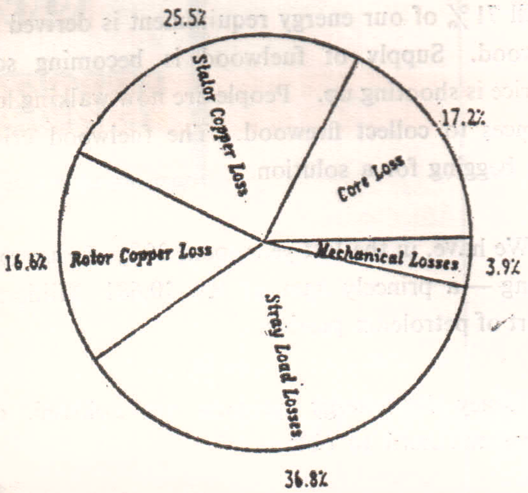

Fig. 2 - Types of losses and their relative magnitudes for a 185 kw motor at full load

Core loss :—Consists of eddy current loss and hysteresis loss and is nearly independent of the output power under normal operation. This quantity affects motor efficiency at light loads.

Copper losses :— Losses in stator and rotor windings. These increase with load and are partly the reason for lower efficiency at higher loads.

Mechanical losses :— These occur in bearings and due to windage and are nearly constant under normal operation.

Stray load losses :— Additional losses caused by non uniform current distribution and current distortions and increase with load and are partly the reason for lower efficiency at higher loads.

SELECTION OF A MOTOR

In the selection of a new motor for a specific steady load, it is the normal practice to aquire a motor rated at about 25% above the required output and this agrees favourably with efficiency considerations, especially in the case of medium sized motors. The Energy Manager needs to request information on efficiency from the motor manufacturer and compare the Energy performance of the different types and sizes of motors suitable for his requirement.

In the absence of manufacturers specifications, characteristics on Fig. 1 can be used to estimate these for medium sized motors (10 to 100 kW).

Comparing two suitable motors A and B to drive a steady load of L kW,

Difference in annual Energy costs,

$$C_1 = K \times h \times L \times \left(\frac{1}{E_A} - \frac{1}{E_B} \right) \times 100$$

where,

K = cost of electricity Rs/kWh
n = hours of operation per year
E_A = percentage efficiency of motor A at load L
E_B = percentage efficiency of motor B at load L

Difference in annual demand costs,

$$C_2 = D \times L \times \left(\frac{1}{E_A} - \frac{1}{E_B} \right) \times 100 - 12$$

(if dynamic power factor correction is already available)

where, D = cost/kWh. month

If the life span of both motors A and B is y years, Present value of the difference in operating costs,

$$C = (C_1 \times C_2) \times yd$$

where yd is the annuity factor at selected discount rate. If,

$C_B - C_A < C$, motor B is to be preferred to A.

C_A = Initial cost of motor A
C_B = Initial cost of motor B

EXISTING MOTORS: Estimation of efficiency

It is often a problem for the Energy Manager to estimate the operating efficiency of currently available motors in his plant, especially in the absence of manufacturer's specifications on efficiency. Comprehensive tests on motors are difficult to undertake in a medium scale industrial environment. However, off line electrical measurements of voltage, current, input power and power factor are conveniently made at motor terminals and offer the best alternative method for estimating efficiency. Figures 3 and 4 can be used for this purpose, for medium sized motors. As all types of losses depend on the type of motor, no universal relationships can be given for efficiency.

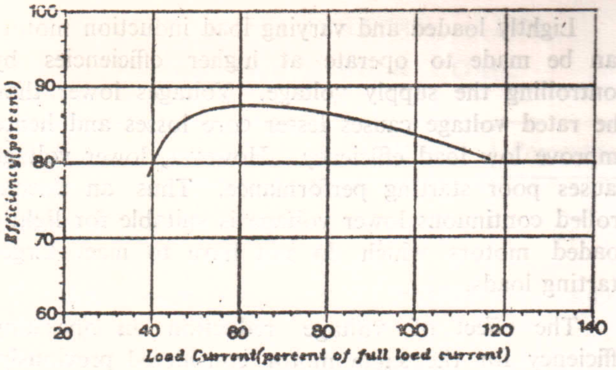

Fig. 3 - Efficiency - Load characteristics of a 18.5 kw motor

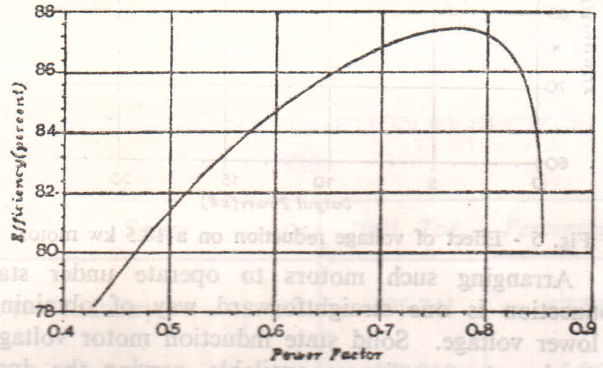

Fig 4 - Efficiency - Power Factor Characteristics, 18.5 kw motor

Motors drawing currents between 40% and 110% of their rated full load current are generally within 5 percentage points below the optimum efficiency.

EXISTING MOTORS: Replacement Decision

An economic analysis similar to that for a new motor can be carried out to consider replacement of motor that are identified to be operating at low efficiencies. These are likely to be lightly loaded motors. However, replacement based purely on the grounds of low efficiency is unlikely to be an attractive investment, especially if no beneficial application can be found for the existing motor. However, the plant Energy Manager could,

(*a*) look for possibilities of interchanging motors between different drives to attain the best possible overall efficiency, and

(*b*) consider replacement of motors for best efficiency during regular and breakdown maintenance work.

VOLTAGE REDUCTION

Lightly loaded and varying load induction motors can be made to operate at higher efficiencies by controlling the supply voltage. Voltages lower than the rated voltage causes lesser core losses and hence improve low load efficiency. However, lower voltage causes poor starting performance. Thus an uncontrolled continuous lower voltage is suitable for lightly loaded motors which do not have to meet larger starting loads.

The effect of voltage reduction on operating efficiency for the same motor considered previously, is shown in Fig. 5.

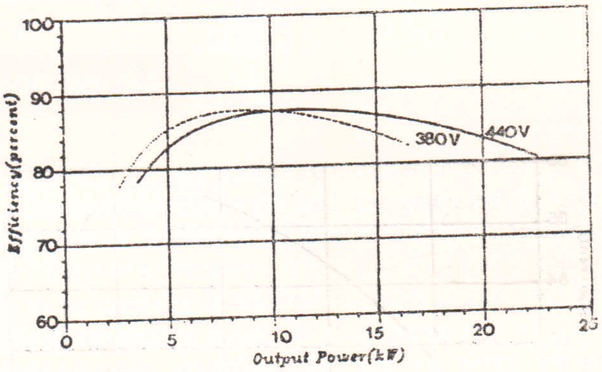

Fig. 5 - Effect of voltage reduction on a 18.5 kw motor

Arranging such motors to operate under star connection is one straightforward way of obtaining a lower voltage. Solid state induction motor voltage control systems are now available, serving the dual purposes of speed and Energy control for certain applications, such as in fan and pump motors (3). With the expected further reduction of cost of these systems in the future, continuous voltage control would also be a popular means of motor efficiency control.

CYCLIC LOADING

Certain motors in a plant would be subjected to cyclic variations of load. These systems have to be examined in order to,

(*a*) establish their operating load levels at different stages of the cycle,

(*b*) identify any periods of overloading or idling, and

(*c*) to consider intermittent operation if long idling periods are identified.

A motor running idle during a considerable proportion of its load cycle can be stopped and restarted. The possible frequency of starts is however limited by the thermal capabilities of the motor, and thereby the starting load. The breakeven times between successive starts against different starting load levels are given below, which can be used as general guidelines to consider stop-start operation for motors.

Load (per cent)	*No load running time before shutdown*
25	0.5 min
50	2.5 min
75	3.5 min
100	6.0 min

BEARINGS

These need to be maintained in a healthy condition in order to avoid additional direct losses as well as secondary electrical losses which may occur due to shaft eccentricity and imbalance.

CONCLUSIONS

The manner in which a three phase induction motor is put into service, affects its Energy performance. The factory Energy Manager should investigate all new and existing motors and drives, with special attention to the following.

(*a*) The loading and loading cycle of the motors. Can motors be grouped to replace several small lightly loaded motors, with a medium sized motor, well matched with the load?

(*b*) For steadily loaded motors, do the motor ratings correspond to optimum efficiency?

(*c*) Could a control system be installed for terminal voltage control?

(*d*) Would it be possible to stop and start motors idling for considerable periods of time?

(*e*) Is the efficiency specified when ordering new motors?

REFERENCES

(1) Statistical Digest 1983, Ceylon Electricity Board.

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