Induction Motor Efficiency Improvement Trends in Industry

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Abstract: A very large portion of the produced electricity gets consumed by induction motor applications like pumps, fans, and compressors. A major portion of this produced electrical energy can be saved by proper speed control methods, but even with the large savings obtained these approaches, still it is essential and possible to optimize the control technique used in variable speed drives to optimize the induction motor operations. In an experiment made on 1 kW induction motor (used in variable speed pump system) with energy optimal control, it was found that 10% of the consumed energy can be typically be saved in comparison of constant V/Hz (rated flux) control. This paper produces a review of various possible approaches for operating an induction motor at optimal condition for a particular application. It also gives a brief idea of various software/hardware tools which are being used in industry.

Keywords: Induction motor, efficiency, Optimal flux, Fan, Pump

Introduction

Induction motor is a large consumer of electrical energy in the industries and its influence is more in energy intensive industries like cement and steel industries particularly in fan, pump and compressor applications. Its efficiency is high when working close to its rated torque and speed. However, the influence of many factors like partial load, over-sizing, poor power quality, and voltage unbalance, results in considerable reduction in the efficiency. Among all these factors affecting motor efficiency, partial loading occurs more frequently and is the main potential for energy conservation. A minute enhancement in the efficiency of these induction motors results in substantial savings in the long duration of its operation. The partial loading condition efficiency and the power factor of the induction motor can be improved by adapting air gap flux level in accordance with load and speed. After exhaustive review of the existing literature in the area of optimal flux control of induction motor, it is found that extensive efforts are being made to improve the performance of these motors, particularly for industrial motors where partial loading occur. HVAC applications in the cement industry and steel industry are identified to have partially loaded motors which suffer from poor efficiency and higher operating cost; especially process fan, compressor and pump motors. These are low dynamic applications and potential efficiency improvement margins are there at partial load and steady-state.

Variable Frequency Drive

Installation of variable frequency drives (VFDs) in electric motor-powered systems (EMDS) such as fans, blowers, pumps and compressors are common practices. This is done for improving the efficiency of EMDS and lesser consumption of electrical energy. These installations have resulted in tremendous energy savings (ranging from 10-60%) in the past [1, 2], triggered a revolution in industrial automation and leading to higher performance and efficiency. VFDs are better suited to load requirements and thus ensure better use of motor
energy for a particular application by achieving high output and torque current ratio. The nominal electromagnetic torque at all frequencies can be generated at the rated flux [3]. However, at partial mechanical loading condition the motor flux produced may be larger than the amount necessary for development of the load torque. In this situation, the motor losses (core and copper losses) get increased dramatically, resulting in a high total loss and a dramatic drop in productivity [4 – 6]. In the conventional VFDs motor input power does not get reduced to minimum possible level for any given speed and load torque, especially in applications with wider speed range. The traditional way is to implement a pre-set V/Hz-ratio variable torque curve that depends on speed. Because the similar flux is used, no matter how the load is variable, it is necessary to make the flux reduction quite conservative for stability, and hence it does not provide complete minimization of drive losses. Variable voltage variable frequency control is a more complex approach, where both load and speed depend on the V/Hz ratio [7].

In partial load conditions, minimizing losses is of great importance [8 – 10]. Generally, the industrial motors are designed to run at a rated condition of load (50-100%). For the rated load torque and rpm, the induction motor efficiency is very high when operated at the rated flux. However, the rated flux operation causes excessive core loss under partial load conditions and thus impairs the efficiency of the drive\(^1\). The motor flux is more than necessary in this situation as it would be necessary to develop the needed torque. Therefore, the induction motor air gap flux level must be decreased to improve the induction motor performance.

**Optimal Flux Operation**

The control technique for reducing motor drive losses by changing the motor flux to appropriate level as per the load requirements of the motor is called optimum flux operation. The optimum operating point is obtained by reducing the amount of motor cumulative losses [7, 10 - 12]. Losses are generally categorized into five components: stator copper losses, copper losses from rotor, the core losses, friction and windage losses and stray losses. As per Nola theory, there is always a pre-defined flux value for a given load condition (torque and speed) at which the maximum efficiency condition gets produced; where the loss components (copper and core) is essentially equal, i.e. an appropriate balance between the loss components of motor. The optimum flux usually occurs below the rated flux. The two critical losses are copper losses and core losses, contributing about 70% of the total losses occurring in the motor. An analysis of components of copper and core losses shows that they disagree with their patterns. These losses can be regulated as they depend on the machine's magnetic and electrical load. While operating at rated flux the magnetic losses become more as compared to electric losses in partial load conditions, i.e. the core losses are 2–3 times smaller than the copper losses in normal conditions, but they represent the cumulative loss component in the case of partially loaded motors. The reverse occurs when the machine operates at a higher value than the rated flux. Flux control means direct control of magnetic losses. Change in magnetic losses, change their corresponding electrical losses. Hence, without disturbing the developed torque, reduction in core losses occurs while decreasing the flux. Due to the

\(^1\)As the load get reduced on the motor, the magnitude of the active current reduces. However, the magnetizing current does not have a corresponding reduction, which is proportional to the voltage supply. This results in reduction of motor power factor, with a reduction in applied load.
optimal distribution of the copper and core loss, the maximum efficiency is offered at any given load torque and speed conditions. [13 – 15].

Methods of Optimal Flux Operation
Motor magnetizing flux is varied in order to reduce losses in real-time systems, and can be achieved in two ways: (a) loss model control (LMC) and (b) search control (SC). In the first approach, by using the motor loss model we determine the optimum air gap flux. The losses of stray load are represented on the stator side by an equivalent resistance. This is a method of feed-forward approach. By implementing optimization principles in the model of motor loss, the optimal flux value is estimated. Usually the objective function is an analytical expression representing either the loss, the efficiency or the total input power. Minimizing the total loss value during the optimization process is the desired objective. Through applying tools and techniques for classical or modern optimization, optimum flux value is derived. The internal control loop may be scalar control loop or vector control loop, but it may be more appropriate in second loop i.e. vector control loop (also called field-oriented control (FOC)), because optimal flux can be implemented in a very short span, while search control regularly varies the level of flux which causes electromagnetic torque oscillations. Inverter loss is also sometimes included in the expression of loss.

This LMC method is quick but suffers a drawback of parameter variation due to rise in temperature, flux saturation in magnetic circuit and skin effect in the running conditions, thus imposing the need for detailed data on the function parameters of the motor loss. If they are not estimated online, a sub-optimal solution may be offered by LMC. It is important to take care of the parameter variation i.e. sensitivity in the loss model operation. The accuracy also depends on the extent to which the motor drive and losses are correctly modelled, but it is very cumbersome as the losses (stray load loss and mechanical loss) are not constant. Therefore, there is always a trade-off between accuracy and complexity while developing the motor or drive loss model. Some sudden flux shift can also cause unacceptable pulsations of torque.

On the other hand, SC seeks maximum efficiency by search technique, i.e. online searching for optimal flux. The controller continuously tests the drive's DC input energy at fixed intervals and searches for maximum flux or excitation current. Because input power is a parabolic flux variable, the air gap flux is decreased stepwise until the input power gets lowered to the minimum level while maintaining constant output power. This method does not require the knowledge of the loss model and is completely insensitive to variations in motor parameters, but suffers from a slow convergence problem and can never reach the optimum point. Due to the oscillations in the flux, the torque ripples are always present in SC. Often known as the on-line performance optimization controller because it involves the minimum input energy monitoring.

There are also the hybrid techniques that combine the good features of the two strategies for optimization, i.e. SC and LMC use both motor parameter information and feedback to provide a more accurate solution for induction motor drive efficiency optimization. This seems to be an attentive approach for maximizing the output of the induction motor drives. It is possible to take care of both steady-state and dynamic outputs. It is
also possible to achieve accelerated convergence along with eliminating other drawbacks. One of the hybrid method approaches is to first estimate the current flux or flux element from the loss model and then change the flux using the search technique. In various literatures, the use of artificial intelligence (AI) techniques are also seen. Determination of optimum flux value both of the forms (in offline and online) are seen in various literatures. These controllers can achieve rapid convergence.

**Energy - Efficiency Software and Other Tools**

Computerized load and output calculation techniques include many advanced motor efficiency assessment methods. There are three categories: (a) special devices, (b) methods of software, and (c) methods of analysis. The special devices package in a portable box containing all or most of the necessary instrumentation. To measure volts, amps, resistance, speed, watts and vars etc., software and analytical methods need various generic portable instruments. The Washington State University Cooperative Extension Energy Program (WSUCEEP) recently performed lab testing of several performance assessment approaches in collaboration with the Oregon State University Motor Systems Resource Facility (OSUMSRF). These include three special devices: Vogelsang Motor-Check and Benning, ECNZ Vectron Motor Monitor, and MAS-1000 Niagara Instruments.

ORMEL96 (Oak Ridge Motor Efficiency and Load, 1996) was developed by the Oak Ridge National Laboratory, a software setup that used an analogous circuit theory approach to measure an in-service motor’s load and efficiency. The calculation of both the motor - efficiency and the load - factor requires only machine name-plate data and a measurement mechanism of the motor speed. The software also allows user to enter the sensed data optionally. Free software tools, such as Motor Decisions MatterSM Easy Saving Map and MDM MotorSlide Calculator, are designed to quickly identify potential savings for motor performance upgrades. These methods include the three most common performance classes: below the rate of EPAct, EPAct and NEMA Premium efficiency. A side-by-side comparison of annual energy costs and annual energy savings is provided after entering hours of operation and electricity costs in this table. The software is available at www.motorsmatter.org. MotorMaster+ is published by the U.S. Department of Energy (DOE). CanMost, likewise, is the Canadian Engine Selection Tool. Another is LEAP (Long-range Energy Alternatives Planning System) which is a commonly used and effective software tool for evaluating energy policy, energy planning and mitigating climate change.

**Conclusion**

Induction motor is a large consumer of electrical energy in the industries and its influence is more in energy intensive industries. In these motors partial loading occurs frequently and here is the main potential for energy conservation. This paper presented an overview of trends for doing efficiency optimization for the aforesaid situations. It also briefed about the various software/ hardware tools which are being used in industry nowadays.
Bibliography


