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Induction Motor Efficiency Improvement Trends: A Review

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Abstract:

Induction motor is a large consumer of electrical energy in the industries and its influence is more in energy intensive industries and applications like cement, steel manufacturing, fan, pump and compressor applications. It has sufficientely high efficiency when working close to its rated load. However, the influence of many factors like partial load, over-sizing, poor power quality, and voltage unbalance, results in considerable reduction in the efficiency (see details in appendices). Among all these factors affecting motor efficiency, partial loading occurs frequently and is the main potential for energy conservation. A small increment in the efficiency of these motors can result in substantial savings in the long period. This paper presents an overview of trends for doing efficiency optimization for the aforesaid situations. It also gives a brief idea of various software/ hardware tools which are being used in industry.

Keywords: Optimization, VFD, Fan, Pump, Efficiency, Induction Motor

Introduction

In many industrial applications such as in the textile industry (spinning drive), hoist drive, pumps in all kinds of process industries, fans, compressors, etc., the part-load

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operation of induction motors can not be avoided. By adapting the magnetizing level (Optimal flux) in the motor according to load and speed, the part load efficiency and power factor of the induction motor can be improved. After a thorough review of the existing literature in the area of induction motor optimum flux control, it is found that extensive efforts are being made to improve the performance of these motors, especially for industrial motors where partial loading takes place. HVAC applications in the industry are identified to have partially loaded motors which suffer from poor efficiency and higher operating cost in the plant; 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) or variable speed drives (VSDs) in electric motor powered systems (EMDS) such as crushers, grinders, mixers, fans, blowers, pumps and compressors are common practices for improving the efficiency of electrical energy. These VFD installations have resulted in tremendous energy savings of 10-60% in the past along with other benefits [1, 2], triggering a revolution in industrial automation leading to higher performance and efficiency in specific industrial applications and home appliances. VFDs are better suited to load requirements and thus ensure better use of motor energy for a particular application [3]. The operation of the induction motor at the optimized flux provides better use of the motor iron in terms of efficiency, thereby achieving high output and torque current ratio. The nominal electromagnetic torque at all frequencies can be generated at the rated flux. Nonetheless, the motor flux generated at partial mechanical load can exceed the amount really necessary to develop the load torque. In this case, there is a dramatic increase in motor iron and copper losses, resulting in a high total loss and a dramatic decrease in productivity [4-6].

Conventional VFDs do not reduce motor input power at any given motor speed and load torque, especially in applications with wider speed range. The traditional way is to use a predefined V / Hz-ratio variable torque curve that depends on speed. Because the same V / Hz is used at a given speed, no matter how the load changes, it is necessary to make the flux reduction quite conservative to avoid instability, and it does

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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 speaking, motors are designed to run at a rated load of 50-100 percent. For rated load and rpm, the induction motor efficiency is high when worked 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 motor air gap flux must be reduced in order to enhance the induction motor performance.

Meaning and Methods of Optimal Flux Operation

The control technique for reducing losses of motor drive by changing the rate of motor flux to the load of the motor is called optimum energy management. This method is also referred to as regulation of performance enhancement or minimization of losses. The optimum operating point is obtained by reducing the amount of motor cumulative losses [7, 10 - 12]. Losses from these motors are usually divided into five components: copper losses from stator, copper losses from rotor, losses from iron, mechanical losses and stray losses. There is always a defined flux value for any given load condition (torque and speed) which produces maximum efficiency condition where the loss of copper and core is essentially equal, i.e. an appropriate balance between loss of copper and iron. The optimum flux usually occurs below the rated flux. The two critical losses are copper losses and core losses, contributing about 70% of the machine's total losses. 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

[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.

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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 optimal distribution of the copper and core loss, the maximum efficiency is offered at any given load torque and speed conditions. In optimal flux operation there is an appropriate balance between constant and variable losses. The reduction of flux at partial loads also results in less acoustic noise from the converter and the system [13 – 15].

Motor magnetizing flux is varied in order to reduce losses in real-time systems, and this is achieved using two methods: (a) loss model based control (LMC) and (b) search based control (SC). Using the motor loss model, the LMC method determines the optimum air gap flux. The losses of stray load are represented on the stator side by the equivalent resistance. This is a method of feed-forward and analysis. 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 part of the control principle can be achieved in simple scalar control loop or in vector control loop, but it may be more appropriate in field-oriented control (FOC) i.e. vector control because optimal flux values can be implemented in a short interval, while search control regularly varies the flux that produces electromagnetic torque oscillations. Inverter loss is also sometimes included in the expression of loss.

This LMC method is quick but suffers a drawback due to parameter variation due to temperature rise, magnetic circuit saturation, skin effect at run-time 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 sensitivity of loss model operation for parametric variations. The accuracy also depends on the extent to which the motor drive and losses are correctly modeled, but it is very complicated as the stray load loss and mechanical loss are not strictly constant. Therefore, there is always a trade-off

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between accuracy and complexity in the development of the loss model. Some sudden flux shift can also cause unacceptable pulsations of torque.

Most of the model-based loss model techniques (LMTs) are feasible for steady mode applications where the motor operating points; thus, the parameters rarely change. They can be used also for applications which require very fast update of the control variable, e.g., electricity operated vehicles or hybrid electric vehicles (i.e. EVs and HEVs). But these controllers may cause higher pulsations in torque and flux during load transitions. The previous work on LMC method shows that the biggest advantage of this method is simplicity, hence very less hardware complexities.

On the other hand, SC or self-optimizing method or physics–based control system, the second method is of a feedback nature which 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 hunts for appropriate flux or flux component of current (excitation current). This method is of a nature of feedback that finds maximum efficiency by adopting search technique, i.e. searching for optimum point of operation. Because input power is a parabolic flux variable, the flux is decreased in steps. The process is continued until the calculated input power gets down to the minimal value while maintaining constant output power. The SC approach does not require the informations from the loss model (parameters) of motor and is completely insensitive to variations in motor parameters, but suffers from a slow convergence problem and can never reach the optimum point and specifications for precise power measurements. Due to the oscillations in the flux, the torque ripples are always present in SC. The benefir of a loss model controller is delay does npt occur in determining optimum flux and drive output, but the delay occurs due to the search in the case of search command. Often known as the on-line performance optimization controller because it involves the minimum input energy monitoring.

There are also hybrid methods that combine the good characteristics of 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 motor drives of the induction. It is possible to take care of both steady-state and dynamic outputs. It

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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. The inner control method an be of scalar or in the field (vector) control mode. The scalar control method is based on the motor's steady-state model and may show weak dynamic performance, while the flux vector control scheme allows the torque and flux to be controlled decoupled, resulting in better results.

In various literatures, the application of artificial intelligence (AI) techniques as an example; artificial neural network (ANN), fuzzy logic, nature-inspired (NIA), genetic (GA) and differential evolution (DE) algorithms are also seen in optimization. Determination of optimum flux value both of the forms (in offline and online) are seen in various literatures. These controllers can achieve rapid convergence. NIA is a relatively new addition to stochastic search strategies focused on the self-organizing group activity based on the category of population. Some common NIA include GA, PSO, Evolutionary Algorithm (EA), Simulated Annealing (SA), and Strategy for Evolution (ES), etc. [16 – 25].

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 require 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.

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ORMEL96 (Oak Ridge Motor Efficiency and Load, 1996) was developed by the Oak Ridge National Laboratory, a software that used an analogous circuit theory method 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 rotor speed. The software also allows the user to enter the measured 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. A small increment in the efficiency of these motors can result in substantial savings in the long period. 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.

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References

[1] E. Worrell, and C. Galitsky, “Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making,” https://www.energystar.gov/ia/business/industry/LBNL-54036.pdf, 2008.

[1] R. Kajaste, and M. Hurme, “Cement Industry Greenhouse Gas Emissions–Management Options and Abatement Cost,” Journal of Cleaner Production. 112: 4041-4052. 2016.

[3] E. Worrell, N. Martin, and L. Price, “Potentials for Energy Efficiency Improvement in the US Cement Industry,” Energy. 25(12): 1189-1214, 2000.

[4] C.T. Raj, S.P. Srivastava, and P. Agarwal, “Differential Evolution Based Optimal Control of Induction Motor Serving to Textile Industry,” International Journal of Computer Science. 35(2): 201-208, 2008.

[5] N. Kumar, T. R. Chelliah, and S. P. Srivastava, “Adaptive Control Schemes for Improving Dynamic Performance of Efficiency-Optimized Induction Motor Drives,” ISA transactions. 57: 301-310, 2015.

[6] D. de Almeida Souza, W.C. de Aragao Filho, and G. C. D. Sousa, “Adaptive Fuzzy Controller for Efficiency Optimization of Induction Motors,” IEEE Trans. Ind. Electron., 54(4): 2157-2164, 2007.

[7] F. Abrahamsen, F. Blaabjerg, and J. K. Pedersen, “Efficiency Improvement of Variable Speed Electrical Drives for HVAC Applications,”Energy Efficiency Improvements in Electronic Motors and Drives. 130-135, 2000.

[8] M.W. Turner, V.E. McCormick, and J. G. Cleland, “Efficiency Optimization Control of AC Induction Motors: Initial Laboratory Results,” US Environmental Protection Agency. https://permanent.access.gpo.gov/websites/epagov/www.epa.gov/ORD/WebPubs/projsum/600sr96008.pdf, 1996.

[9] J. G. Cleland, V. E. McCormick, and M. W. Turner, “Design of an Efficiency Optimization Controller for Inverter-fed AC Induction Motors,” Industry Applications Conference. 30th IAS Annual Meeting. Orlando, FL, USA 16-21, 1995.

[10] C. Chakraborty, and Y. Hori, “Fast Efficiency Optimization Techniques for The Indirect Vector-Controlled Induction Motor Drives,” IEEE Trans. Ind. Appl. 39(4): 1070-1076, 2003.

[11] G.C. Sousa, B.K. Bose, and J.G. Cleland, “Fuzzy Logic Based On-Line Efficiency Optimization Control of an Indirect Vector-Controlled Induction Motor Drive,” IEEE Trans. Ind. Electron., 42(2): 192-198, 1995.

[12] G. O. Garcia, J. C. M. Luis, R. M. Stephan, and E. H. Watanabe, “An Efficient Controller for an Adjustable Speed Induction Motor Drive,” IEEE Trans. Ind. Electron. 41(5): 533–539, 1994.

[13] C. Chakraborty, M. C. Ta, T. Uchida, and Y. Hori, “Fast Search Controllers for Efficiency Maximization of Induction Motor Drives Based on DC Link Power Measurement,” Power Conversion Conference. (PCC-Osaka 2002), Japan: 402-408, 2002.

[14] C. Ta, C. Chakraborty, and Y. Hori, “Efficiency Maximization of Induction Motor Drives for Electric Vehicles Based on Actual Measurement of Input Power”. IECON’O1: The 27th Annual Conference of the IEEE Ind. Electron. Soc., Hyatt Regency Tech Center, Denver, Colorado, USA. 1692-1697, 2001.

[15] G. O. Garcia, J.C. Mendes Luis, R. M. Stephan, and E. N. Watanabe, “Fast Efficiency Maximizer for Adjustable Speed Induction Motor Drive,” International Conference in Industrial Electronics, Control, Instrumentation and Automation, Argentina: 37-42, 1992.

[16] S.N. Vukosavic, and E. Levi, “Robust DSP-Based Efficiency Optimization of A Variable Speed Induction Motor Drive,” IEEE Trans. Ind. Electron. 50(3): 560-570, 2003.

ISSN:0971-1260
Vol-22-Issue-34-December -2019

[17] L. Kawecki, and T. Niewlerowicz, “Bi-Criterial Optimization in Induction Motors Speed Control taking into Consideration the Electromagnetic Transients,” In Proceedings of IEEE International Symposium on Industrial Electronics. 2: 935–939, 1996.

[18] G. Mirzaeva, and L. Sazdanoff, “The Effect of Flux Optimization on Energy Efficiency of Induction Motors in Fan and Pump Applications,” Power Engineering Conference (AUPEC), Australia: 1-6, 2015.

[19] T. Ahonen, J. Tamminen, J. Viholainen, and J. Koponen, “Energy Efficiency Optimizing Speed Control Method for Reservoir Pumping Applications,” Energy Efficiency. 8(1): 117-128, 2015.

[20] F. Xie, and Q. Wang, “FOC for Loss Minimization of Induction Motor using SVM.,” Metallurgical and Mining Industry. 4:79-84, 2015.

[21] M.M. Kuriakose, A. Sukeshkumar, and M.W. Beevi, “Efficiency Optimization of Vector Controlled Induction Motor Drives,” 10th National Conference on Technological Trends (NCTT09), 74-79, 2010.

[22] J.F. Stumper, A. Dotlinger, and R. Kennel, “Loss Minimization of Induction Machines in Dynamic Operation,” IEEE Trans. Energy Convers., 28(3): 726-735, 2013.

[23] B.K. Bose, N.R. Patel, and K. Rajashekara, “A Neuro-Fuzzy-Based On-Line Efficiency Optimization Control of A Stator Flux-Oriented Direct Vector-Controlled Induction Motor Drive,” IEEE Transactions on Industrial Electronics. 44(2): 270-273, 1997.

[24] B. Pryymak, J.M. Moreno-Eguilaz, and J. Peracaula, “Neural Network Flux Optimization using A Model of Losses in Induction Motor Drives,” Mathematics and Computers in Simulation. 71(4): 290-298, 2006.

[25] O.S. Ebrahim, M.A. Badr, A.S. Elgendy, and P.K. Jain, “ANN-Based Optimal Energy Control of Induction Motor Drive in Pumping Application,” IEEE trans. Energy Conver. 25(3): 652-660, 2010.