International Journal on Emerging Technologies **2**(1): 45-49(2011) **ISSN : 0975-8364**

Performance Optimization of Asynchronous Machine Using Fuzzy Voltage Controller

A.A. Ansari* and D.M. Deshpande*

**Department of Electrical Engineering, MANIT, Bhopal, (MP)*

(Received Accepted)

ABSTRACT : Induction motors are, without any doubt, the most used in industry. Motor drive efficiency optimization is important for two reasons: economic saving and reduction of environmental pollution. In this paper, advantages of using fuzzy logic in steady-state efficiency optimization for induction motor drives are described. Simulated results of a fuzzy logic based optimum search controller are presented. Many optimization techniques are discussed. Efficiency optimization of induction motor using fuzzy logic controller is carried out using Matlab/ simulink.

Keywords : Fuzzy controller, Energy efficiency; Induction motor; Power electronics.

I. INTRODUCTION

The induction motor is without doubt the most used electrical motor and a great energy consumer. Three phase induction motors consume 60% of industrial electricity and it takes considerable efforts to improve their efficiency. Most of the motors operate at constant speed although the market for variable speed is expanding. Moreover, induction drive is often used in servo drive applications. Three strategies are used in efficiency optimization of induction motor drive e.g. Simple State Control, Model Based Control and Search Control. Search strategy methods have an important advantage compared to other strategies. It is completely insensitive to parameter changes while effects of the parameter variations caused by temperature and saturation are very expressed in two other strategy. The on-line efficiency optimization control on the basis of search , where the flux is decremented in steps until the measured input power settles down to the lowest value is very attractive. The control does not require the knowledge of motor parameters and the algorithm is applicable universally to any motor. Problems related to the efficiency optimization and search controller design are discussed in the paper. Simulation results are given

MODELING OF INDUCTION MOTOR

The induction motor model can be developed from its fundamental electrical and mechanical equations. In stationary reference frame the voltage equations are given by

$$V_{ds} = R_s i_{ds} + p\lambda_{ds}$$

$$V_{qs} = R_s i_{qs} + p\lambda_{qs}$$

$$0 = R_r i_{dr} + \omega_r \lambda_{qr} + p\lambda_{dr}$$

$$0 = R_r i_{qr} - \omega_r \lambda_{dr} + p\lambda_{qr}$$

where p indicates the differential operator (d/dt).

The stator and rotor flux linkages are defined using their respective self leakage inductances and mutual inductance as given below

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr}$$

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr}$$

$$\lambda_{dr} = L_r i_{dr} + L_m i_{ds}$$

$$\lambda_{qr} = L_r i_{qr} + L_m i_{qs}$$

The electromagnetic torque in the stationary reference frame is given as

$$T = (3/2)\,(P/2)\,(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds})$$

III. EQUIVALENT CIRCUIT OF AN INDUCTION MOTOR

An induction motor is essentially a transformer. In the transformer the load on the secondary is electrical where as in case of induction motor the load is mechanical which can be replaced by an equivalent electrical load of load resistance R_L given by $R_L = R_2/K^2\ (1/s - 1)$ where R_2 is the rotor phase resistance and K is the turn-ratio of rotor to stator. The simplified equivalent circuit of an induction motor is shown in Fig.1.

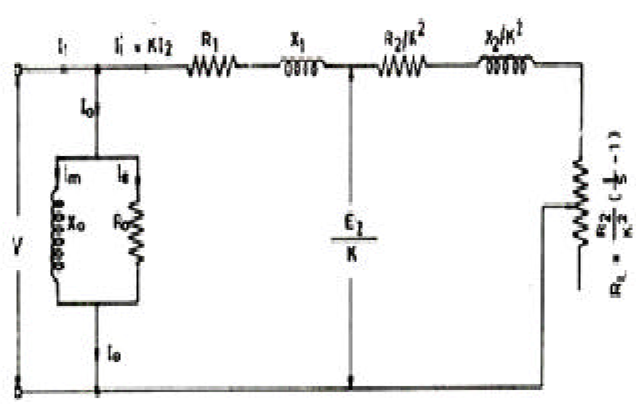

Fig. 1.

IV. LOSS REDUCTION AND CONTROL TECHNIQUES

Losses in an IM constitute copper loss and core loss in stator and rotor, mechanical loss, and stray load loss. Core loss and copper loss depend on the magnetic and electric loading of the machine and, therefore, are controllable. The stray load loss depends mainly on the construction of the motor (type of stator and rotor slots, length of overhang, etc.) and also on the harmonics in the supply voltage [8]. Usually, for a given motor and specified load, the sum of stray load loss and the mechanical loss do not exceed 30% of the total losses and may be assumed to remain constant. Thus, the motivation of loss minimization is to look for an optimum balance of the variable losses to make the total loss minimum. So far, efforts on loss minimization are put into three major directions: (1) through improved design of the motor and converter; (2) by better management to operate a group of motors in a more efficient way; and (3) by introducing better control techniques. Therefore, investigation is focused on better control techniques to yield loss minimization

V. PERFORMANCE OPTIMIZATION TECHNIQUES

The induction machine should operate with the rated flux for the rated value of load torque, where as for load torque less than rated, the reduction of flux causes a reduction in iron losses and magnetizing current, thereby improving efficiency and power factor For a very low load torque (up to about 15% of the rated value), energy saving work can reduce considerable power loss. Following section, discuss different types of controllers which are used to operate the motor with reduced operating energy cost at partial load. These are as follows [9].

A. Operate the Motor at Star Mode

Induction motors operate at light load, require less torque. Keep the motor connection in star results reduced power consumption. When the motor run in star mode, the voltage applied to stator phase winding is reduced by the factor ?3. Since the torque developed in the motor is directly proportional to square of the voltage, the developed torque in star mode is also reduced by the factor 3. Therefore, the motor can be operated in star mode up to 0.33 p.u loads. This method is not suitable for wide range of partial loads.

B. Variable Voltage Fixed frequency (VVFF) Control

Instead of starting induction motor with full voltage soft starter can be used to start the motor which offers low starting current. The job of soft starter is to apply a voltage to the motor, which is gradually increased in a ramp wise manner, thus enabling the motor to start. Three-phase voltage controller is used which consists of two thyristors per phase in anti parallel connection, where the input is connected to the respective phase of the mains supply and the output to each motor phase. Soft starter is aimed at the application of a reduced voltage to the motor for its start and reduction of voltage at motor is low load. In this case the iron losses are decreased and energy conservation is achieved. Optimum performance of the motor can be achieved by adjusting voltage This is scalor control of induction motor.

C. Displacement power Factor Control

If slip varying in induction motor, the motor terminal impedance and hence power factor, current and efficiency all vary. When maintain constant optimal slip by using voltage controller the terminal impedance and hence power factor and efficiency remain constant at optimal values irrespective of load [9].

D. Rotor Slip Frequency Control

In this control, optimum rotor slip frequency is calculated to wide range of speed and torque of given motor and constructed a look up table. The objective function shown in may be maximum power factor or efficiency. The optimal efficiency slip can be calculated by using the equivalent circuit parameters of an induction motor. Since the presence of harmonics in inverter supply optimal slip calculation may not be accurate. The optimal slip frequency can also be calculated from the measurement of input power, output power of the motor, inverter frequency and slip frequency.

E. Loss Model Controller

The loss model controller measures the speed and stator current and through the motor loss model and determines the optimal air-gap flux [8]. The main problem of this approach is that it requires the exact values of machine parameters which include core losses and main inductance flux saturation [4]. The inner part control algorithm may be in scalar or vector.

F. Search Controller for Minimum Input Power

This controller measures the input power of the machine drive regularly at fixed intervals and searches for the flux value which results in minimum power input for given values of speed and torque.This technique is slow for reaching the optimum value and a ripple in steady state torque is always present.

VI. STATOR VOLTAGE CONTROL FOR OPTIMUM EFFICIENCY OPERATION OF MOTOR

Induction Motors are highly efficient at rated load and have efficiencies in the range 85%-95%. Motor losses consist of three main components: (1) Friction and Windage Losses (2) Iron Losses (3) Copper Losses. Friction and Windage Losses are insensitive to load changes, as speed is essentially constant.

Iron losses consist of hysterisis losses and eddy current losses. At constant frequency, hysterisis loss is proportional to B1.6 and the eddy current loss is proportional to B2 where B is the maximum flux density in the air gap. The maximum flux density remains constant if the applied voltage is kept constant. Thus, as load is decreased, voltage remaining constant, the iron loss constitutes a greater percentage of the output. This results in poor efficiency at part loads.

Part load efficiency can be improved by reducing the applied voltage to the motor. The motor has to be a standard squirrel cage motor optimized for full load running. In the case of such a motor the running slip will be around 0.04 pu and hence its torque-slip curve will be steep around zero slip. When the applied voltage is reduced, the load torque intersects the motor curve at a new point on the new torque-slip curve. However due to the steepness of T-S curves, the speed of machine will not vary much though it will decrease a little. Hence as a first approximation it may be assumed that the motor speed does not change when voltage across an under loaded motor is varied. If the speed does not change the load torque and mechanical power output will not change and since voltage has come down the motor will draw an increased active current component to supply the same output. The reactive current component is predominantly magnetizing in nature and it will come down since applied voltage has come down.

The total stator current which is constituted by active and reactive components can increase or decrease depending on the amount of voltage reduction. Thus when the voltage across an under loaded motor is gradually reduced its stator current decreases first, reaches a minimum at a particular voltage and increases with further reduction in voltage. The value of minimum current will depend on the exact load on the motor. Coming to the loss variations, with reduction in voltage the iron loss comes down and initially the currents and hence copper losses also come down.

When the voltage is reduced to sufficiently low level, the consequent increase in copper losses will at some point turn the total losses away from its decreasing trend i.e. there will be one particular voltage at which the total losses in the motor will be a minimum. This voltage value will not coincide with the voltage value at which the current is minimum at the same loading level but it will be close.

With the assumption that the speed of the motor does not vary with reduction in voltage the minimum current point will coincide with maximum power factor (or minimum phase angle) condition. Similarly the minimum loss point (i.e. maximum efficiency point) will coincide with minimum power input point. Minimum current point does not correspond to maximum efficiency point as already mentioned; but they are close. But if the small variation in motor speed and consequent changes in output power are also considered, the optimum voltage point for a particular load condition in the four cases i.e. the minimum current point, the minimum power factor angle point, the minimum power input point and the minimum loss (maximum efficiency) point, will be different.

The minimum loss point is difficult to monitor electronically; though that is what we want to do. However, the other three conditions can be monitored electronically by sensing motor voltage and current and using some form of a minimum search algorithm implemented either digitally or in analog circuits. Of course, the loss reduction achieved will be less than optimal. Minimum power condition is the closest to maximum efficiency condition followed closely by current minimum condition. It is easier to process the current minimum search and hence it is current minimum search that is employed in most of the Smart Motor Controllers available in the market.

The six-thyristor scheme is used in all SMCs. The SMCs also take care of the control of starting and stopping of the motor. Essentially, they start up the motor and apply full voltage first. Then, the current is sampled and a search routine is initiated.

The voltage is decreased slightly and the change in current is noted. If the current decreases the voltage is further reduced in steps till the current shows a tendency to turn back i.e. to increase. If, in the first voltage reduction step the current increased, then the voltage is taken up in steps till the current reaches a minimum. This procedure is repeated in a periodic manner to fine-tune the applied voltage against load variations.

VII. OPTIMAL CONTROL OF INDUCTION MOTOR THROUGH SEARCH CONTROL

Search control (SC) does not require the knowledge of the motor loss model for implementing optimization controllers. This controller measures the input power of the machine drive regularly at fixed interval and searches optimal flux value which results in minimum power input or stator current for the given values of speed and torque. Torque ripple always presents in SC due to the oscillations in the air gap flux.

Induction motor performance optimization through search control was successfully carried out in matlab/simulink The advantages of SC control in induction motor efficiency optimization are as follows

1. If the power input is measured on the source side of the rectifier, the minimization is not restricted to the motors but affects the entire system and thus reduces the total amount of energy consumed.

2. Since the source voltage and current waveforms have a much smaller harmonic content than the corresponding motor waveforms, the power measurement is more accurate and easier to obtain.

3. Insensitive to parameter variation in the motor due to thermal and core saturation effects.

4. Simulink is an environment for multi domain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that enables to design, simulate, implement, and test a variety of time-varying systems, including power system , electrical machines, communications, controls, signal processing, video processing, and image processing.

VIII. MODEL IN SIMULINK

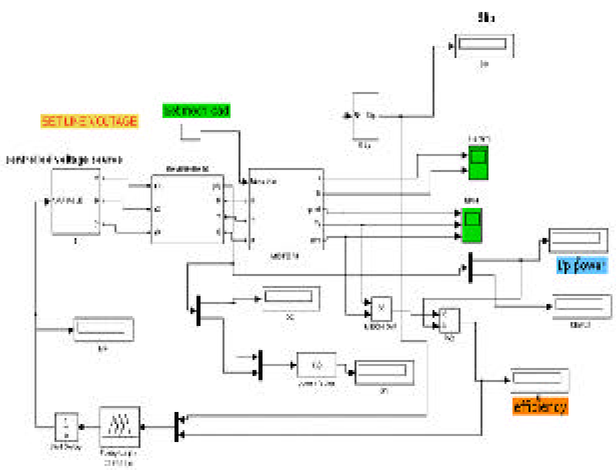

Fig 2. Simulink Model.

A three-phase motor rated 3 HP, 220 V, 1725 rpm induction motor is fed by a sinusoidal controlled voltage source. The model is built entirely with standard Simulink blocks. Generators output goes through Controlled Voltage Source blocks before being applied to the Asynchronous Machine block's stator windings. The machine's rotor is short-circuited. The load torque applied to the machine's shaft is variable and set to any value between 0 to11.9 NM .The motor is started from stall. The synchronous speed set point is 1.0 pu, or 1800 rpm. This speed is reached after 0.9 s.

IX. FUZZY LOGIC APPROACH

The fuzzy logic is an aggregation of rules, based on the input state variables condition with a corresponding desired output. A mechanism must exist to decide on which output, or combination of different outputs, will be used since each rule could conceivably result in a different output action. Fuzzy logic provides machinery for carrying out approximate reasoning processes when the available information is uncertain, incomplete or vague. The success of this methodology has been demonstrated in a variety of fields. A fuzzy logic controller essentially embeds the experience and intuition of a human plant operator, and sometimes those of the designer of the plant

X. IMPLEMENTATION OF FUZZY LOGIC CONTROLLER

To obtain fuzzy based model of the motor, the training system derives information from two main sources,

a. The efficiency curves of the motor, which provides important information about the appropriate voltage to be applied

b. The dynamic real time operating waveforms of the motor, which can include real-time operating effects,

During the training phase, each input-output data pair, which consists of a crisp numerical value of measured quantities, is used to generate the fuzzy rules.

To determine a fuzzy rule from each input-output data pair, the first step is to find the degree of each data value in every membership region of its corresponding fuzzy domain. The variable is then assigned to the region with the maximum degree.

When each new rule is generated from the input-output data pairs, a rule degree or truth is assigned to that rule, where this rule degree is defined as the degree of confidence in the developed method a degree is assigned which is the product of the membership function degree of each variable in its respective region.

Every training data set produces a corresponding fuzzy rule that is stored in the fuzzy rule base. Therefore, as each input output data pair is processed, rules are generated. A fuzzy rule or knowledge base is in the form of two dimensional tables, which can be looked up by the fuzzy reasoning mechanism. Speed/slip error is calculated with comparison between reference speed/slip and speed/slip signal feedback. Speed/slip error and speed/slip error changing are fuzzy controller inputs. A fuzzy logic controller operation is based on the rules formed.

Simulation studies are performed to validate a theoretical development. Simulation model was made in Simulink-Matlab software. Power losses and drive performances were veteran with efficiency controller and compared with the case when efficiency controller is not included in a drive model.

XI. RESULTS AND DISCUSSION

Model of efficiency controller is incorporated in the model of motor drive. Simulation results show that the efficiency and power factor of induction motor Performance of induction machine can be improved under the different operating conditions especially in light load region. Simulation results are compared with those obtained with the conventional method. By comparison it is observed that performance is improved using fuzzy logic controller.

S. No.	Mech Load (NM)	Fuzzy Efficiency (PU)	Without Fuzzy Efficiency (PU)	Fuzzy Slip (PU)	Without Fuzzy Slip (PU)	Fuzzy Speed (RPM)	Without Fuzzy Speed (RPM)	PF Fuzzy (PU)	PF (PU)
1.	0.5	0.8405	0.775	0.0012	0.0001	1798	1799	0.1016	0.0713
2.	1	0.9068	0.8682	0.004	0.0019	1793	1796	0.1834	0.1244
3.	1.5	0.9388	0.9039	0.0096	0.0037	1783	1793	0.3343	0.1769
4.	2	0.9439	0.9217	0.0135	0.0055	1776	1709	0.4225	0.2277
5.	2.5	0.9371	0.9319	0.1547	0.0073	1772	1787	0.4635	0.2761
6.	3	0.9447	0.938	0.0155	0.0092	1772	1783	0.4657	0.3254
7.	3.5	0.9444	0.9414	0.0184	0.011	1767	1780	0.5176	0.3681
8.	4	0.9431	0.9434	0.0214	0.0129	1762	1777	0.5653	0.4099
9.	4.5	0.9411	0.9444	0.0243	0.0147	1756	1773	0.607	0.449
10.	5	0.9387	0.9447	0.272	0.1654	1751	1770	0.6433	0.4854
11.	5.5	0.9357	0.9444	0.0303	0.0184	1745	1768	0.675	0.519
12.	6	0.9325	0.9436	0.0334	0.0203	1740	1763	0.7023	0.55
13.	6.5	0.929	0.9426	0.0365	0.0222	1734	1760	0.726	0.5785
14.	7	0.9253	0.9414	0.0397	0.0241	1729	1756	0.7466	0.6046
15.	7.5	0.9215	0.9398	0.0429	0.026	1723	1753	0.7643	0.6283

XII. CONCLUSION

Squirrel cage induction motors are very popular in variable-speed drives due to simple, ruggedness and inexpensive too. These are available at all power ratings. In earlier days DC motors were preferred to induction machine. With development in power electronics and microelectronics now induction motors are used in high performance drives. The effect of electrical torque, speed, current due to change in applied voltage for induction machines are analyzed. Artificial intelligent has found high application in most nonlinear systems same as motors drive because it has intelligence like human but there are no sentimental against human like angriness. Artificial intelligent techniques can use as controller for any system without requirement to system mathematical model; it has been used in electrical drive control. With this manner, efficiency and reliability of drives increase and volume, weight and cost of them decrease. A fuzzy based scheme for induction motor drive is presented .It leads to energy saving. The proposed scheme is used to generate the appropriate voltage based on speed and torque of the motor and hence saves the energy. This analysis is carried through matlab/simulink software environment.

REFERENCES

[1] Ta, C. M. and Hori, Y., "Convergence Improvement of Efficiency-Optimization Control of Induction Motor Drives," *IEEE Transactions on Industry Applications,* Vol. **37**, pp. 1746-1753 (2001).

[2] Bose, B. K., Patel, N. R. and Rajashekara, K., "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,* Vol. **44**, pp. 270-273 (1997).

[3] Sousa, G. C. D., Bose, B. K. and Cleland J. G., "Fuzzy Logic Based On-Line Efficiency Optimization Control of an Indirect Vector-Controlled Induction Motor Drive,"*IEEE Transactions on Industrial electronics,* Vol. **42**, pp. 192-198 (1995).

[4] A. K. Sharma, R. A. Gupta, and Laxmi Srivastava., " A new technique for energy reduction in induction motor drives using artificial neural network" 2005.

[5] Pragasen Pillay, Senior Member, IEEE, Peter Hofmann, and Marubini Manyage "Derating of Induction Motors Operating With a Combination of Unbalanced Voltages and Over or Undervoltages ieee transactions on energy conversion, vol. **17**, no. 4, December 2002.

[6] Feng-Chieh Lin and Sheng-Ming Yang.,"On-line Tuning of an Efficiency-Optimized Vector ControlledInduction Motor Drive" 2003.

[7] G. Zenginobuz, et al., "Performance optimization of induction motors during voltage -controlled soft starting, "*IEEE Trans. Energy Conv.,* vol. **19**, no. 2, 2004, pp. 278-288.

[8] S. Ghozzi , K. Jelassi, X. Roboam, "Energy optimization of induction motor drives, " in *Proc. IEEE Conf.Industrial Technology* (ICIT), 2004, pp. 602-610.

[9] C. Thanga Raj, S. P. Srivastava, and Pramod Agarwal. "Particle Swarm and Fuzzy Logic Based Optimal Energy Control of Induction Motor for a Mine Hoist Load Diagram." *IAENG International Journal of Computer Science,* 36:1, IJCS_36_1 Feb 2009.