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LOSS MINIMIZATION IN AN INDUCTION MOTOR BASED ON TRUE PARAMETRIC MODEL

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ABSTRACT This paper describes a new approach to power loss minimization in a three-phase induction motor. The method employs the motor's parametric model of which parameters resulted from identification. In this work, genetic algorithm is employed to identify the motor's model. The approach of loss minimization is suitable for use with variable load situation. Its usefulness and limitation are illustrated via simulation results.

1. INTRODUCTION

Most industries employ both synchronous and asynchronous types of electrical machines that consume a fair amount of energy. Electrical engineers have attempted several methods to cut the energy bills. For instance, design energy efficient machines, and utilize electronic technology to save energy for drive systems. One efficient method to achieve energy savings in existing electrical machines is to cut the power losses in machines as much as possible. This topic is the main interest of this work, particularly addressed to induction machines that are asynchronous type.

The idea of loss minimization in machines is not new. Some researchers [1] attempted to find stator exciting frequency to minimize losses in ac machines. They assumed constant motor's parameters through its operating range. Realistically, those parameters are not constant. They also assumed equal rotor and stator frequencies. This condition is true only when the slip is equal to 1. Insertion of external impedance method was proposed in [2] for slip-ring rotor type of induction motors. This complicated method requires sophisticated and high cost electronics for realization. Moreover, it causes harmonics to the system. The work in [3] attempted to find optimum input voltage and frequency that minimized the total motor losses. Core saturation, skin effect, and source harmonics were taken into account. These factors are very difficult to be determined in practice. Optimum air gap flux to minimize losses was introduced in [4]. Harmonic and stray losses were taken into account by the work in [5] to achieve better description for losses in the motor model. The central idea of the work described herein is similar to [6] that uses an equivalent circuit of a motor. For motors of less than 10 kW, the converter loss is negligible when it is compared with the motor power losses. The work presented herein considers nonlinearity of the motor. It will be shown later that the motor losses are expressed as the function of torque, speed, voltage, and frequency. Thus, this approach is realistic in terms of motor performance, true motor parameters, and is easy to apply.

Section 2 of this paper describes the motor equivalent circuit, and the identification of its parameters. The loss expression and how to minimize the losses are discussed in section 3. In section 4, simulation results are presented and limitation of the method discussed. Section 5 provides conclusions.

2. MOTOR EQUIVALENT CIRCUIT AND PARAMETERS

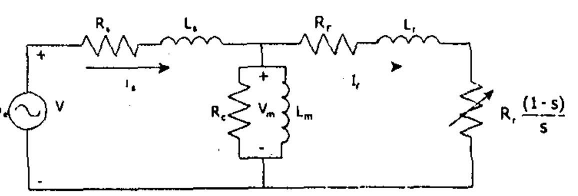


Fig.1 Equivalent circuit of an induction motor

It is commonly known that most portions of power losses in motor arise during steady-state operation. Thus an equivalent circuit of an induction motor plays an important role in loss minimization [5,7]. Fig. 1 shows the motor equivalent circuit. Conventionally, the parameters of the equivalent circuit are obtained from no-load and block-rotor tests. In practice, the motor impedances vary because of temperature, saturation characteristic, skin effect, and harmonic [6,8]. Using constant R's and L's values could lead to an erroneous treatment of loss minimization. However, R_c and L_m are practically constant. Their values (R_c=3.3114 kΩ, and L_m=0.5098 H) are quite large and can be acceptably obtained from the conventional tests.

This work is interested in variable load condition of the motor operation. The load ranges from 0-100 %. To assess the R's and L's values of the motor as a function of multi-variables mentioned above is very difficult, perhaps not possible. In order to keep the problem tractable, these values are viewed as a function of rms voltages fed to the motor. This approach leads to simple modelling and identification, as well as simple future implementation of an energy saving controller for the motor. Fig. 2 depicts the experimental set up to measure the motor speed-torque characteristics. Referring to fig. 2, the pendulum machine and its control unit act

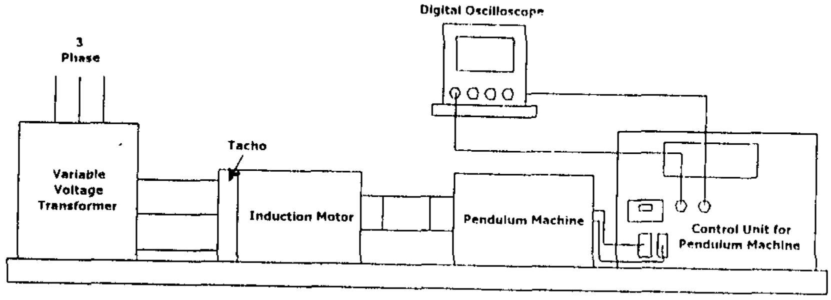


Fig.2 Experimental set up for identification of motor parameters

as a torque measuring instrument. Input voltages of various rms values were fed to the motor and the characteristics recorded. Some of the test results are illustrated in fig. 3. An off-line identification based

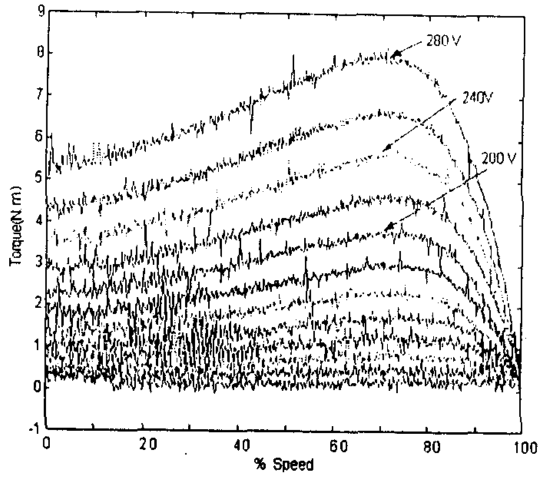
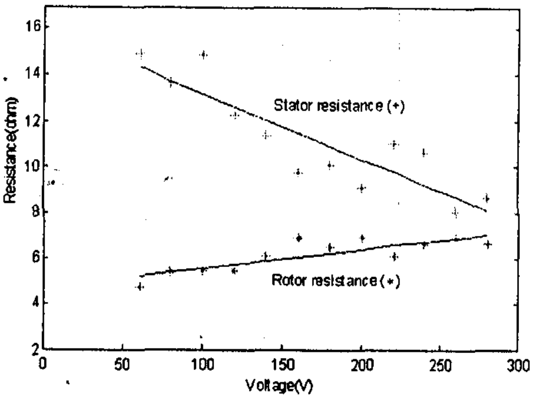
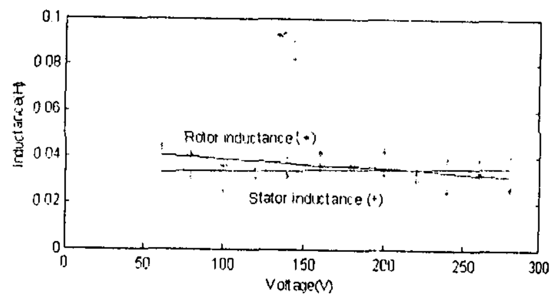


Fig.3 Motor characteristics obtained from the tests.

on genetic algorithm (GA) was employed to extract the motor parameters as the function of rms input voltages. The readers can find an informative review of GA in [9]. The results obtained from the GA identification are illustrated in fig. 4. Fig. 4(a) depicts the stator and rotor resistances, while the inductances in fig. 4(b). The corresponding numerical data is compiled in table 1. Applying the linear regression, one can obtain the equations (1-a)-(1-d) describing these parameters as the function of the exciting rms voltage.



(a)



(b)

Fig.4 Identified values of R's and L's (a) stator and rotor resistances, (b) inductances

Voltage (V)	$R_s(\Omega)$	$R_r(\Omega)$	$L_s(H)$	$L_r(H)$
60	14.8863	4.7375	0.0428	0.0441
100	14.8182	5.4533	0.0248	0.0359
140	11.4050	6.1207	0.0396	0.0317
180	10.1102	6.4891	0.0356	0.0357
220	11.0193	6.1219	0.0328	0.0298
280	8.6603	6.6382	0.0402	0.0265

Table 1. Numerical data obtained from GA identification

$$R_s = -0.028006 \times V + 15.961169 \quad (1\text{-a})$$
$$L_s = 6.292346e-006 \times V + 0.033130 \quad (1\text{-b})$$
$$R_r = 0.008418 \times V + 4.716302 \quad (1\text{-c})$$
$$L_r = -4.222108e-005 \times V + 0.043419 \quad (1\text{-d})$$

Next section discusses the role of these parameters in loss minimization.

3. LOSS TERMS AND APPROACH TO MINIMIZATION

The total power losses of the motor can be expressed as

$P_{loss,\,total}$ = stator copper loss+rotor copper loss +core losses.

Losses in switching devices are lumped into the stator loss, while stray loss, friction and windage loss are negligible. Hence,

$$P_{loss,\,total} = |I_s|^2 R_s + |I_r|^2 R_r + \frac{|V_m|^2}{R_c} = V^2\left[\left|\frac{Z_2 + Z_m}{Z_T}\right|^2 R_s + \left|\frac{Z_m}{Z_T}\right|^2 R_r + \left|\frac{Z_2 Z_m}{Z_T}\right|^2 / R_c\right] \quad (2)$$

where

$$Z_1 = R_s + j2\pi f L_s \quad (3)$$

$$Z_2 = \frac{R_r}{s} + j2\pi sf L_r \quad (4)$$

$$Z_m = \frac{R_c j2\pi f L_m}{R_c + j2\pi f L_m} \quad (5)$$

$$Z_T = Z_1Z_2 + Z_1Z_m + Z_2Z_m \quad (6), \text{and}$$

$$\text{slip } s = \frac{N_s - N_m}{N_s} \quad (7)$$

From the motor torque equation (8)

$$T = \frac{P_{ag}}{\omega_s} = V^2\left|\frac{Z_m}{Z_T}\right|^2 \frac{R_r}{s} \cdot \frac{1}{\omega_s} \quad (8)$$

, one can realize that

$$P_{loss,\,total} = T \cdot \omega_s \cdot \frac{s}{R_r}\left[\left|\frac{Z_2 + Z_m}{Z_m}\right|^2 R_s + R_r + \frac{|Z_2|^2}{R_c}\right] \quad (9)$$

Equation (9) is in a useful form for the implementation of loss minimization in an induction motor. Regarding this, the load torque T is known from measurement or estimation; the rpm required is known from the speed command; and the rms voltage is known from measurement. Some computational results for the total power losses are illustrated in fig. 5. Referring to fig. 5, the negative power loss means generating mode. Only the positive power loss (motoring mode) is considered

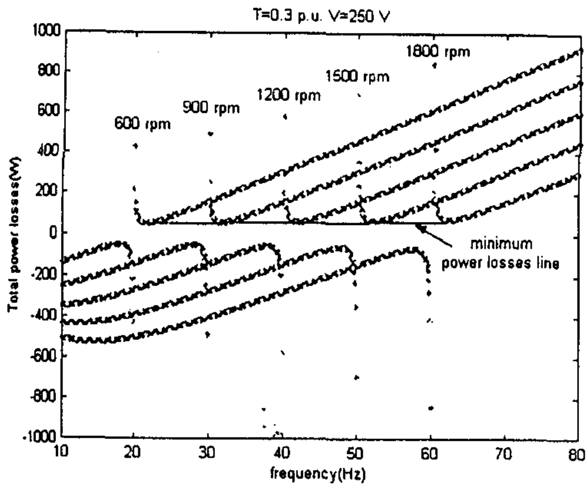


Fig.5

herein. The minimum power loss line can be found for the whole speed range. For other values of torque and rms voltage fed to the motor, the shape of the curves looks similar.

In terms of implementation, real-time computing and searching for a corresponding frequency for the motor to run on minimum power loss are possibly executed by a fast processor. With a low clock rate processor, a lookup table is a suitable approach. The method of loss minimization can be viewed as an adaptive algorithm of energy saving controller for an ac drive.

4. SIMULATION RESULTS

Simulation has been brought into action to assess the usefulness of limitation of the proposed method. Fig. 6

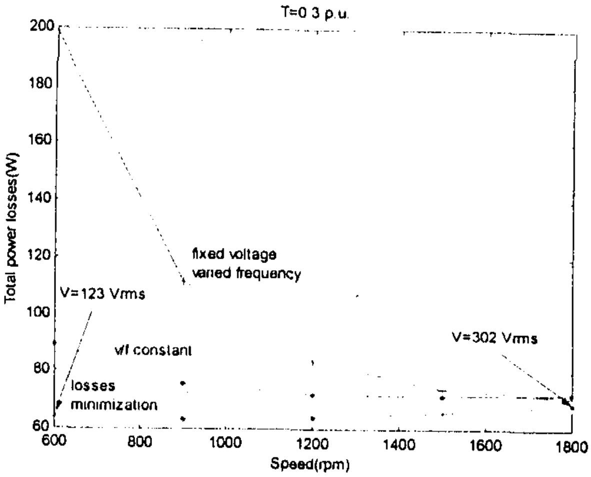


Fig. 6 Simulation results when load torque is 0.3 p.u.

shows that the proposed method is the most efficient way to minimize losses in induction motors when the load torque is low. The results are compared with those of the v/f constant and the fixed voltage with varied frequency methods, respectively. When the load torque is up to about half rated, the proposed method is still efficient as can be seen from the fig. 7. When the load

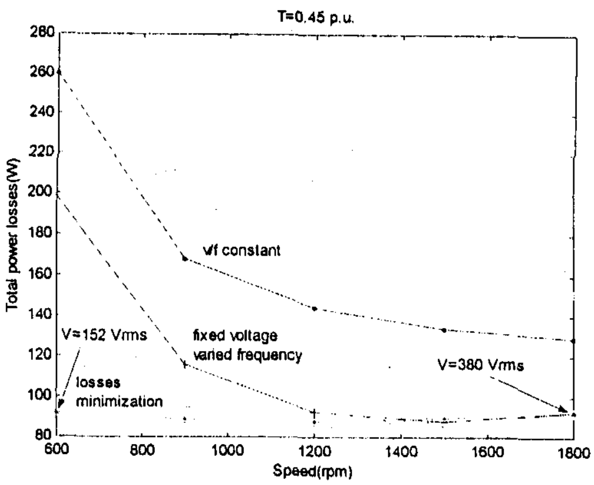


Fig. 7 Simulation results when load torque is 0.45 p.u.

torque is high, the proposed method is not attractive *because an excessive voltage must be applied to the* motor. However, it is still efficient in a low speed range as illustrated in fig. 8. Under such circumstances, the fixed voltage with varied frequency method becomes more attractive for loss minimization in induction motors.

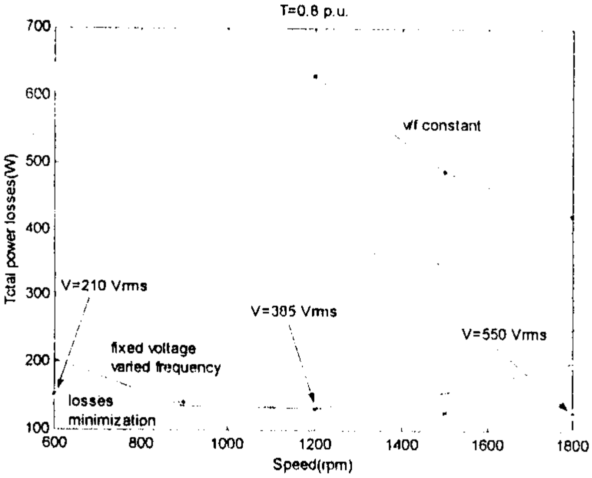


Fig. 8 Simulation results when load torque is 0.8 p.u.

5. CONCLUSIONS

This article has described a new approach to minimize power losses in induction motors. The proposed method is based on the true parametric model of the motor. The parameters are obtained from identification. The simulation results show that the method is very efficient when the load torque ranges from 0 to half rated. Above half rated load, the method is still attractive in a low speed range. Implementation of the method as adaptive algorithm for energy savings in ac drives is not complicated using either real-time computing or lookup table approach. Design and implementation of an ac drive with energy saving schemes to cover the whole load range is now undergoing at the Control and Automation Research Group, Suranaree University of Technology. The project is supported by the Nation Board of Energy Policy.

6. ACKNOWLEDGMENT

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LIST OF NOTATIONS

V = supply voltage (Vrms)
ω_e = supply radian frequency (rad)
R_s = stator resistance (Ω)
R_r = rotor resistance (Ω)
L_s = stator inductance (H)
L_r = rotor inductance (H)
R_c = core resistance (Ω)
L_m = core inductance (H)
V_m = air-gap voltage (Vrms)
I_s = stator current (A)
I_r = rotor current (A)
s = slip
f = stator frequency (Hz)
N_s = synchronous speed (rpm)
N_m = motor speed (rpm)
ω_s = synchronous speed (rad/s)
T = load torque (N.m.)
P_{ag} = air-gap power loss (W)

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Kongpol Areerak was born in 1979, Pichit, Thailand. He received his BEng (EE) in 1999 from Suranaree University of Technology. He is working on his thesis towards a master's degree in electrical engineering. His research interest is control and drive.

He wishes that Asia will seriously implement all kinds of technologies to save energy, resources, and environment in the years to come.