THE USE OF FIELD TEST COUPLED WITH GENETIC ALGORITHM FOR ESTIMATION OF INDUCTION MOTOR PARAMETERS

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ABSTRACT

This paper proposed a technique for estimating the parameters of three-phase induction motor in order to conduct on-site energy audits of existing motors, which are then used to project a cost savings. This proposed technique uses only a few sets of data (voltage, current, speed, power factor or torque if possible) from the field test of motor (on-site), instead of the no-load and blocked rotor tests, coupled with the genetic algorithm for evaluating the equivalent circuit parameters. Once these parameters are known it is possible to obtain the operating performances (50-100%) of the motor such as efficiency, current, torque. This technique could be suitable for the general purpose drive applications when the motor cannot operate at no-load since its shaft is permanently connected to its load. To illustrate how well the performances of the estimated model match that of the actual motor obtained from load test, the results of estimated operating performances of 3HP and 5HP induction motor, that is, efficiency, input current, torque and power factor, were compared to those obtained from load tests. The results show that the estimated operating performances using six-impedance equivalent circuit compared to those obtained from load test are acceptable.
Keywords: *Genetic algorithms, equivalent circuits, induction motors, optimization methods, parameter estimation.*

INTRODUCTION

The industry is becoming increasingly concerned about the ability of motors to ride through power system disturbances. The majority of motors in the field are induction motors and there are many methods pertinent to field efficiency evaluation in the literature and new methods are appearing every year (Hsu and Scoggins, 1995; Bonnett, 1994). There may be various reasons for the desire of testing an induction motor in the field, such as consideration of exchanging out of date or worn motors with new, or checking the efficiency after rewinding. Determination of efficiency is essentially a simple procedure. However, depending on the required degree of accuracy in the field, it may be an involved process. Particularly the output power is hard to detect, one of the established procedures (IEEE Standard 112-1996) is therefore to calculate the efficiency according to indirect methods by measuring the losses and subtract them from the input to find the output.

The methods for determination of field efficiency of induction motor can be summarized as follows (Hsu et al, 1998) nameplate method, slip method, equivalent circuit method, segregated loss method, and shaft torque method. On field test one may estimate the efficiency based on information from the nameplate which a few problems may occur. First, the nameplate efficiencies of a given motor can be evaluated according to different standards. Second, some manufacturers and vendors which gives an approximation of motor efficiency, based on motor nameplate information. Third, the motor may have been rewound. The limitations of the slip method are that it does not recognize actual current losses which vary at loaded and no-load conditions, and the calculations rely upon the value indicated on the motor nameplate for speed (rpm) at tested by the manufacturer. The advantage of equivalent circuit method is that the performance of a motor can be predicted at any load when the impedance values are known. There are different approaches for obtaining the impedance values, which is the purpose of this paper. The segregated loss method estimates the magnitudes of the fives losses, namely: stator copper loss, rotor copper loss, core loss, stray load loss, and friction and windage loss.

The most straightforward method is to measure the output power directly from the shaft without any need to calculate losses. The shaft torque method offers the most accurate field efficiency evaluation method. However, it is also high intrusive. In order to conduct on-site energy audits or assessments of existing motors, which are then used to project a cost savings, the operating performances of these motor must be known. Comparison of actual motor efficiencies is certainly a valid tool to justify the use of one motor over another. An energy audit is a complex and costly activity. Proper testing method is absolute essentials and practically impossible to accurately accomplish while the motor is in service. The conventional technique for identification of an induction motor equivalent circuit parameters are based on the no-load and blocked rotor tests, which is undoubtedly a tedious and time consuming task if the motor is already coupled to driven equipment in the process. The calculations of the operating performances in this present work are based on the equivalent circuits in which their parameters are estimated by using only a few sets of data (3 sets) from the field test (on-site) instead of the no-load and the blocked rotor tests coupled with the genetic algorithm. This technique is suited to general purpose drive applications when the motor cannot operate at no-load since its shaft is permanently connected to its load. This paper aimed at proposing a technique for estimating the parameters of three-phase induction motor in order to conduct on-site energy audits of existing motors, which are then used to minimize the cost of a project.

MATERIALS AND METHODS

The block scheme of the experimental equipment is given in Fig. 3. All motors are tested in the laboratory form light load to full load (load test). The electrical input (voltage, current, power factor) and mechanical output (speed, shaft torque) under load test are measured. Then only 3 data sets of input voltage, current power factor and speed (need not be close to no-load or full-load) are selected and then are evaluated in the optimization process. The results of estimated equivalent circuit parameters (using six-impedance and approximate) of each motor obtained from the proposed technique are illustrated on Tables.

Estimation of Induction Motor Parameters: The data needed for calculating the performance of an induction motor under load operation can be obtained from the equivalent circuit which is the results of a no load test, a blocked rotor test, and measurements of the dc resistances of the stator winding. In order to perform these tests in the field, two difficulties are faced; first, it is difficult to block the rotor when the motor is incorporated inside the system. Second, the no-load test is typically hard to perform in practice, because the machine cannot rotate without load (fan, gear). Many computer programs are designed to estimate these parameters of the motor equivalent circuit (Along, Ippolito, Ferrante and Raimondi, 1998; Gastli, 1999).

Genetic Algorithm: The genetic algorithm is optimization methods (Michalewicz, 1996) which may be used to solve a system of nonlinear equation. It uses objective functions based on some performance criterion to calculate an error. However, the genetic algorithm is based on natural selection and natural genetics using random numbers, and does not require a good initial estimate. The mechanics of the genetic algorithm are elementary, involving nothing more than copying stings, random number generation, and swapping partial strings. It composes of three operators, i.e. reproduction, crossover, and mutation.

Reproduction is the process in which individual strings are selected according to their fitness. The fitness is determined by calculating how well each string fits an objective function. Copying strings according to their fitness value implies that strings which fit the objective function well have a higher probability of contributing one or more offspring in the next generation. Crossover is a genetic step in which all the members of the population obtained after the reproduction process are randomly mated. Each pair mutually interchanges a randomly selected portion of bits to produce variety. Thus, new strings are generated in the new population. After crossover, the entire population passes through another genetic step called mutation. In this process, randomly selected bits of a randomly selected string are changed from a 1 to a 0 and vice versa in order to prevent the algorithm losing potentially useful information. The probability of mutation is set beforehand in the program, which is compared with a randomly generated number. The probability for mutation to occur is usually very small, roughly one mutation per thousand bit transfers.

The important advantages of this algorithm over other optimization methods are that it is able to find the global minimum instead of a local minimum and that the initial estimate need not be close to the actual values. Moreover, it does not require the use of the derivative of the function.

Equivalent Circuit: The equivalent circuits as in Fig. 1 can be represented the steady state behavior of a three-phase induction motor.

Where

R_1: stator resistance,

R_2: core loss resistance,

R_2: rotor resistance referred to stator,

X_1: stator leakage reactance,

X_2: rotor leakage reactance referred to stator,

X_m: magnetizing reactance,

X_{eq}: equivalent leakage reactance ($X_1 + X_2$),

s: slip

From the six-impedance and approximate equivalent circuits, the equations of stator current (I_1) and power factor (PF) can be expressed as in equation 1 and 2 respectively.

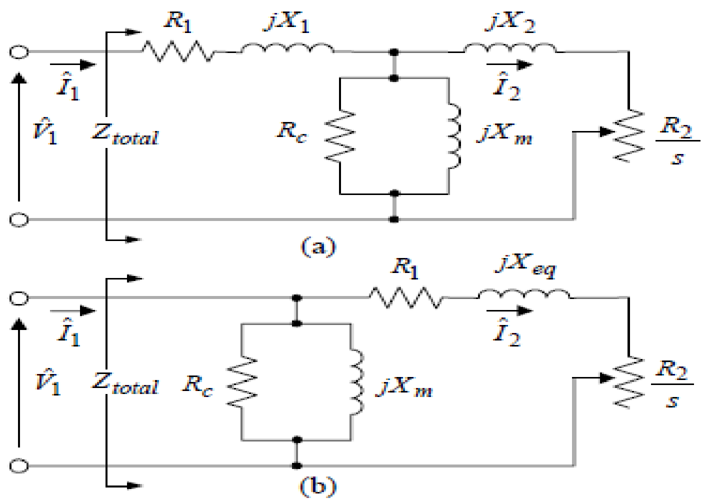

Fig. 1: Equivalent circuits of three-phase induction motor
a) Six-impedance b) approximate

$$\tilde{I}_1 = \frac{\tilde{V}_1}{Z_{total}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$PF = cos\left[tan^{-1}\frac{|Im\,Z_{total}|}{|ReZ_{total}|}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Parameter Estimation from Field Test: The equivalent circuit parameters can be estimated by using the field test coupled with genetic algorithm. The flow chart of the proposed technique is shown in Fig. 2. The technique for estimating the equivalent circuit parameters proceeds as follows. From the field test of motor (on-site), only 3 sets of data of motor input voltage, current, power factor (or torque if possible) and speed, which need not be close to no-load or full-load values, are directly measured while the motor is in service. The stator winding resistance R_1 which is obtained from resistance measurements is also included. However, it remains inconvenient to measure the shaft torque in the field.

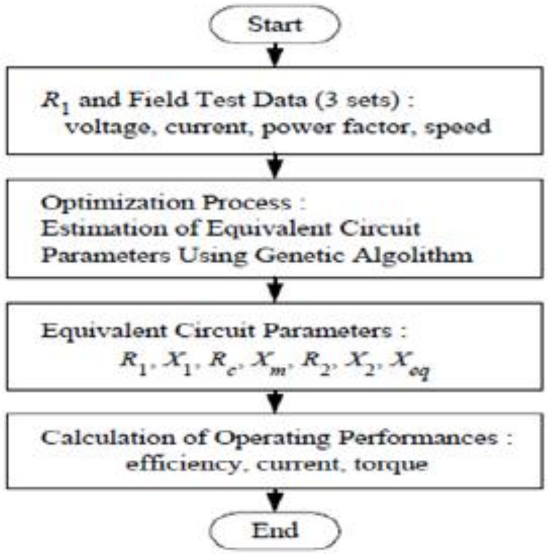

Fig. 2: Flow chart of proposed technique

$$F_{objective} = \sum_{i=1}^{3}\left|\frac{PF_{i,cal}}{PF_{i,data}} - 1\right|^2 + \sum_{i=1}^{3}\left|\frac{I_{1i,cal}}{I_{1i,data}} - 1\right|^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

$$Fitness = \frac{1}{1 + F_{objective}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where $I_{1i,cal}$ and $PF_{i,cal}$ are the calculated values using (1) and (2) respectively, $I_{i,data}$ and $PF_{i,data}$ are obtained from the field test measurement.

For this reason, the motor input power factor data is then proposed in this technique. Then these test data sets are determined in the optimization process. The aim of genetic algorithm (binary or floating point implementation) is to minimize the error of equation 3, or to maximize the fitness of equation 4. After optimization process, the parameters of equivalent circuit can be obtained and finally, the operating performances (50-100%) of an actual induction motor can be predicted.

RESULTS AND DISCUSSION

The results show that both binary and floating point implementation can be used in the genetic algorithm. Only one drawback of using the binary implementation is time consumption. Nothing that the accurate values Rc and Xm will be obtained if a set of data at light load is provided. The results of estimated operating performances of 3HP and 5HP induction motor,that is, efficiency, input current, torque and power factor, are compared to those obtained from load tests and illustrated as shown in Fig. 1 to Fig. 8. The average errors of estimated operating performances are also presented on Table 2. The results show that the estimated operating performances using six-impedance equivalent circuit compared to those obtained from load test are acceptable. The errors of estimated efficiency, input current and torque vary only slightly (5%) over the actual motors operating at range of half load to full load. For approximate equivalent circuit, the considerable errors are produced for the input current value (over 20%) which occurs from using the approximation of Z value in equation 1. This version would be unacceptable. However, Table 2 shows that these errors do not affect the estimated efficiency, torque and power factor significantly.

The proposed technique for estimating equivalent circuit parameters of induction motor in the field (on-site) focuses on the operating efficiency and motor load in order to identify energy efficiency gains and possible reliability improvements. Based on the findings of this study, the most straightforward method is to measure the output power directly from the shaft torque which offers the most accurate field efficiency evaluation method. However, it is also high intrusive since it remains inconvenient to measure the shaft torque in the field if the motor is already coupled to driven equipment in the process industry. The equivalent circuit method which is based on the IEEE standard 112 (1997) is also not a useful field test for efficiency. Simplified methods without conducting no-load and blocked rotor tests are possible.

Thus, the technique of using a few sets of electrical input data (voltage, current, power factor) and speed of actual motors in the field is then suggested for estimating the impedance values of equivalent circuit. Two cases (motor 3 HP and 5 HP) are performed to illustrate how well the estimated models match that of the actual motors. The results show that the acceptable estimated operating performances (efficiency, input current, torque, power factor) of motors using six-impedance equivalent circuit compared to those form load test are obtainable (average errors about 5%). However, it was found that the estimated input currents obtained from the version of using approximate equivalent circuit would be unacceptable, thus this version is not suggested.

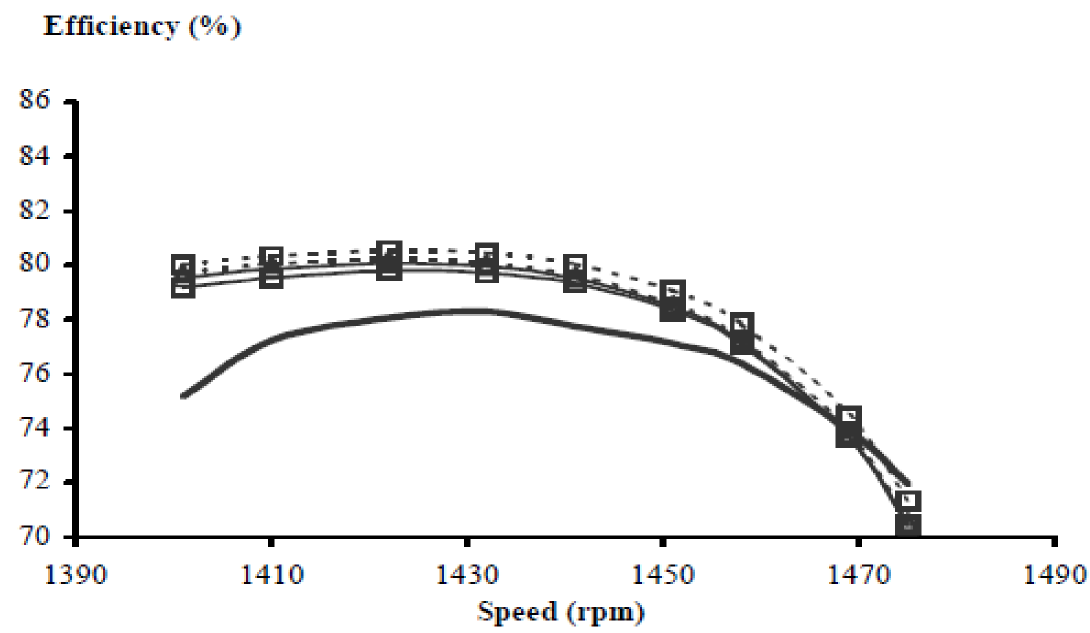

Fig.3: Operating performance of motor 5HP with load test efficiency as function of speed

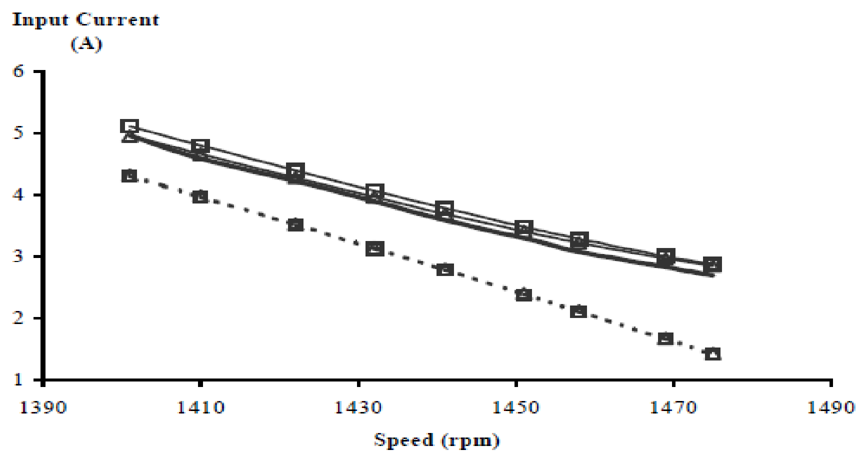

Fig. 4: Operating performance of motor 5HP with load test input current as function of speed

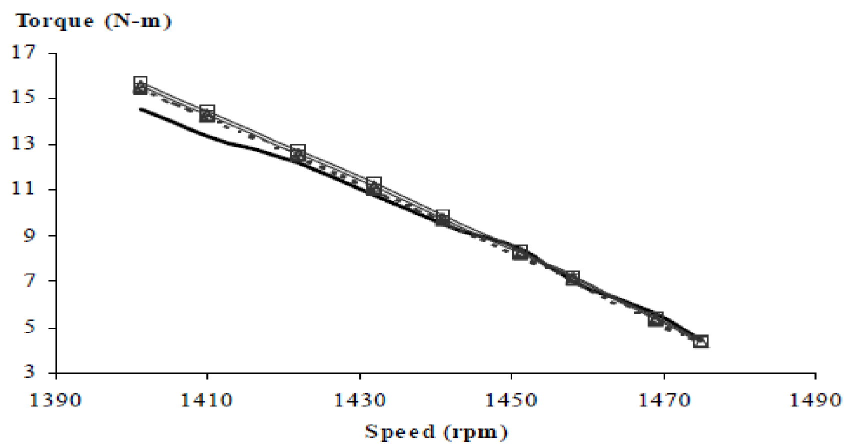

Fig.5: Operating performance of motor 5HP with load test torque as function of speed

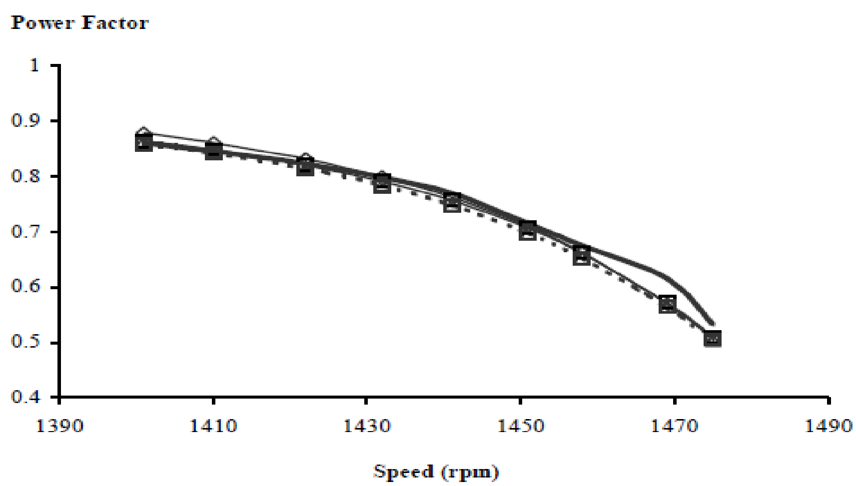

Fig. 6: Operating performances of motor 5HP with load test power factor as function of speed

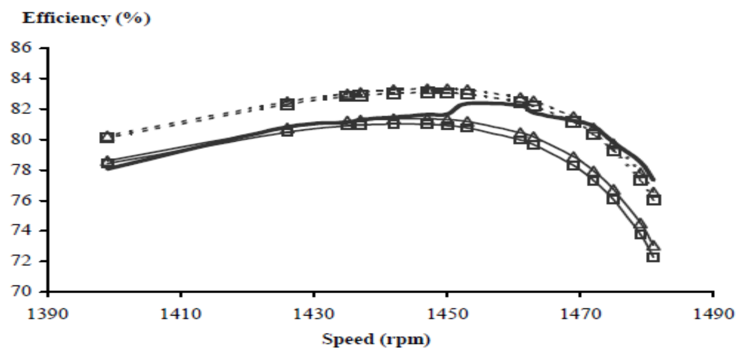

Fig.7: Operating performance of motor 3HP with load test efficiency as function of speed

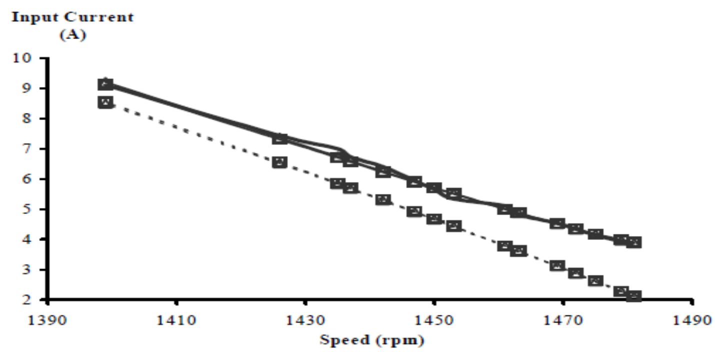

Fig. 8: Operating performance of motor 3HP with load test input current as function of speed

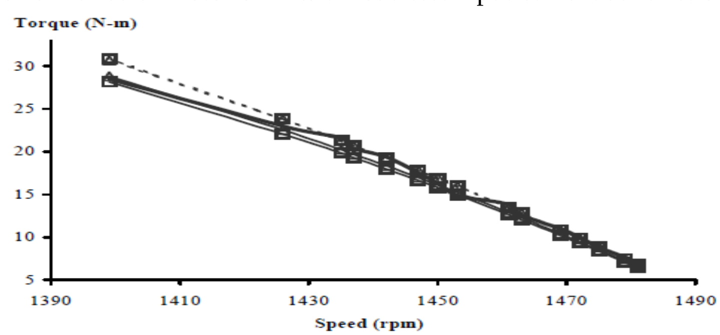

Fig.9: Operating performance of motor 3HP with load test torque as function of speed

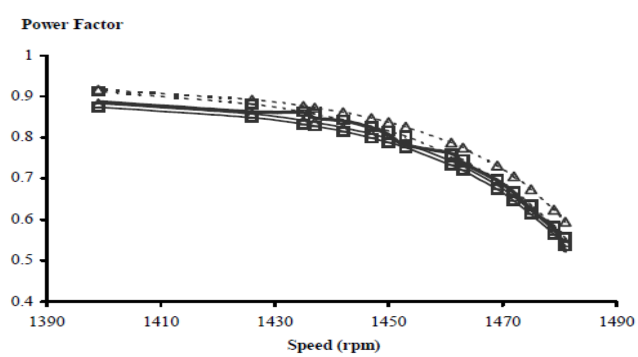

Fig.10: Operating performance of motor 3HP with load test power factor as function of speed

Table 1: Results of estimated equivalent circuit parameters of Motors using field test coupled with genetic algorithm

	No. 1 3HP, 380V, 50Hz, 4-pole, 5.0A, 1420rpm			
	Six-impedance (Ω)		Approximate (Ω)	
	Binary	Floating	Binary	Floating
R_1	3.50	3.50	3.50	3.50
R_2	3.16	3.31	3.46	3.45
R_c	701	731	593	569
X_m	83.8	85.3	91.5	90.0
X_1	2.17	1.00	-	-
X_2	2.14	1.00	-	-
X_{eq}	-	-	2.36	1.00

	No. 2 5HP, 380V, 50Hz, 4-pole, 7.9A, 1420rpm			
	Six-impedance (Ω)		Approximate (Ω)	
	Binary	Floating	Binary	Floating
R_1	2.50	2.50	2.50	2.50
R_2	1.59	1.53	1.65	1.65
R_c	489	499	483	500
X_m	62.4	62.2	70.3	68.7
X_1	3.22	3.34	-	-
X_2	2.35	1.78	-	-
X_{eq}	-	-	2.31	3.00

Table 2: Average Error of Estimated Operating Performances of Motors Using Field Test Coupled With Genetic Algorithm

	No. 1 3HP, 380V, 50Hz, 4-pole, 5.0A, 1420rpm			
	Six-impedance (%)		Aproximate (%)	
	Binary	Floating	Binary	Floating
Efficiency	2.2	2.4	2.8	2.5
Input current	5.3	3.0	26.1	25.5
Torque	3.4	3.7	3.6	3.5
Power factor	2.0	2.3	2.8	2.4

	No. 2 5HP, 380V, 50Hz, 4-pole, 5.0A, 1420rpm			
	Six-impedance (%)		Aproximate (%)	
	Binary	Floating	Binary	Floating
Efficiency	2.5	1.9	1.3	1.3
Input current	1.8	1.6	23.7	24.1
Torque	5.0	3.6	2.8	2.4

The proposed technique is applied to three-phase induction motors which have the following ratings:

No.1: 3 HP(2.2kw), 380V, 50 HZ, 4-pole, 5.0 A, 1420 rpm.

No.2: 5 HP(3.7kw), 380V, 50 HZ, 4-pole, 7.9 A, 1420 rpm.

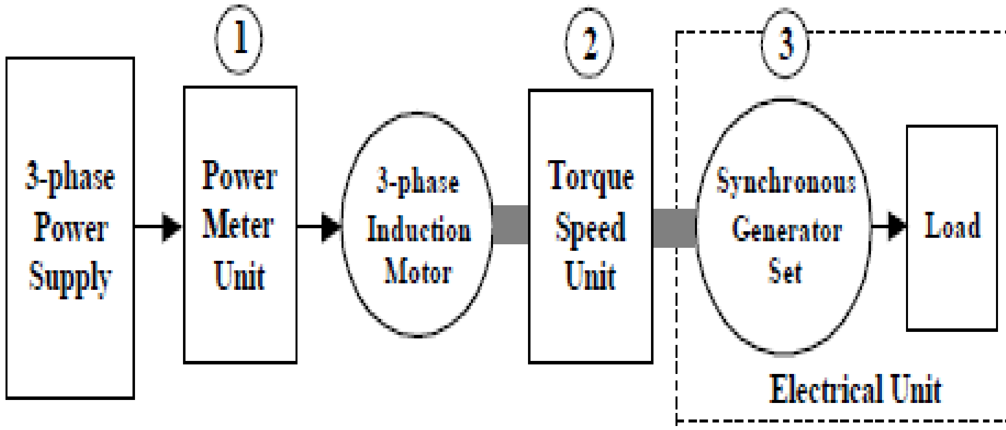

Fig. 3: Basic scheme of experimental equipment.
1: Digital power meter, Yokogawa WT 1030.
2: Measurement and analyzing unit, Siemens 2GA 3377-18
3: Machine set, Siemens type G-G 180/4-1,400/420V, 10kw, 26.5A, 1500-300rpm, U2 310V,0.7A.

CONCLUDING REMARK

It is worth noting that this proposed technique could be suitable of conducting on-site energy audits of existing motors, which are then used to project a cost savings and payback in order to support a decision to replace operating motors with a higher-efficiency model. Finally, the definition of efficiency is simple and precise, however, if the method used to determine either the mechanical output or electrical input is only an approximation, the resulting efficiency then becomes an approximation too.

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