EXECUTIVE SUMMARY OF THE PROJECT

Title of the project

ACHIEVING ENERGY EFFICIENCY IN THREE PHASE INDUCTION MOTORS: NON-DESTRUCTIVE WINDING QUALITY ASSURANCE APPROACH

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Energy efficiency and renewable energy are said to be the “twin pillars” of a sustainable energy policy. Both strategies must be developed concurrently in order to stabilize and reduce carbon dioxide emission in our lifetime.

In India, promotion of energy efficiency and energy conservation, which is found to be the least cost option to augment the gap between demand and supply, is a part of the strategy developed to make power available to all by 2012. Nearly 25,000 MW of capacity creation through energy efficiency in the electricity sector alone has been estimated.

Energy conservation measures are of significance not only to developing countries like India, but for developed countries also.

Electric motor systems account for roughly 70% of industrial and 35% of tertiary sector electricity demand worldwide. The energy efficiency of motor systems typically can be improved by 20 to 30% of the losses. Thus, they represent a huge, untapped potential for cost-effective energy savings and are a major driver for reduction of electricity demand and associated local pollutant and greenhouse gas emissions from power plants.

1.2 MOTIVATION FOR THE PROJECT

Central Electricity Authority, India (CEA) (2007) shows that in India, during 2003-04, the amount of electricity consumed in industry and agriculture was 154 TWh and 114 TWh respectively, out of a total of 524 TWh. Both are expected to increase substantially, with consumption forecast to be 318 TWh and 187 TWh for 2011-2012 in these sectors respectively.

Bonnett (1993) illustrated that the ability to increase generating capacity is a very difficult and slow process. It is estimated that a typical electric power plant will cost $3-4 billion and will require 12 to 15 years to implement. Hence, he opined that even if the cost of energy can be controlled, the need for additional capacity will continue to drive the need for conservation and more efficient products at an accelerated pace during the next decade. Even today, the time for building up a generating capacity remains almost the same and the amount of money to be spent to develop a new generating capacity is still higher. Thus, in order to cater to growing demand, there exists a need for conservation and more efficient products.

Energy Asia (2006) provides the statistics that in the Indian agricultural sector, energy is consumed mainly for pumping water. Mathur (2007) provides the statistics that in India, about 12 million electrical pump-sets used in agriculture consume 28% of its electricity. And in Indian industry, about 70 % of the total electricity demand is in electric drive systems. Hence, motors are the largest single consumers of electricity in both these sectors.

Even a small improvement in the operating-efficiency or avoidance of unwarranted energy consumption by quality assurance of motors, which form the major component of the motor-drives or pump systems, will significantly contribute towards energy efficiency improvement of the system, to enormous energy conservation and can lead to reduction of green house gas emissions. This thesis analyses possible ways of unwarranted efficiency reduction in electric motor, which forms the major component of the electric drive system as well as the basic machine common to all manufacturing processes today. It proposes a few non-traditional approaches for operating- efficiency improvement in them to achieve the original operating-efficiency level achieved through the original design or, in certain possible cases, a higher operating-efficiency level.

A few of the possible means of efficiency reduction, life-time reduction and undesirable performance change occur in the three phase squirrel cage induction motors due to improper windings. They are:

- Three phase squirrel cage induction motors in manufacturing line
- Rewound three phase squirrel cage induction motors operating at end-user’s site.

Before, proceeding to discuss further, it is better to review the relationship that exists between motor winding variables and performance of the motor. These are some of the fundamentals necessary for the measures dealt with in this thesis to avoid unwarranted energy consumption, to achieve efficiency improvement by making the motor attain the original operating- efficiency level arrived at through design or by achieving operating-efficiency levels higher than the Standard efficiency design level (prescribed by BIS or IEC Standards) in three phase squirrel cage induction motors.

1.3 RELATIONSHIP BETWEEN MOTOR WINDING VARIABLES AND PERFORMANCE

Hasuike (1983) describes 12 variable elements, which affect the improvement in Efficiency of a 3.7 kW, three phase cage induction motor. “The variable elements are: stator bore, length of the stack, air gap length, diameter of the stator conductors, number of stator conductors per slot, size of the stator slot, material of the rotor bar, size of the rotor bar, length of stator coil end-connection, size of the end ring, the grade of electrical steel sheets, the friction and windage losses”.

If the motor was designed according to an efficiency level (such as Standard efficiency or High efficiency) at the design stage, the designer has already specified all the variables. A change in the specified value of winding variable in the form of diameter of the stator conductor, number of stator conductors per slot, number of parallel circuits in each phase may occur when proper managerial procedures are not followed during manufacture or rewind.

Umans (1989) explains the fact that: “Induction motor design is an integrated process and that it is not in general possible to adjust one motor design parameter (such as the winding turns distribution) without changing a number of performance parameters (Torque, Efficiency, etc.)".

Hasuike (1983) has studied, by design computations, the effect of change in the winding variables individually from the original design and its effect on the performance of the motor of 3.7 kW rating. The graphs provided by Hasuike (1983) depicts that a decrease in the stator conductor size will result in decrease in efficiency, space factor, locked rotor current and starting torque; whereas increased heating occurs; while power factor remains almost constant. A decrease in the number of stator conductors per slot will result in a decrease in power factor, efficiency and stator conductor's space factor. It could also be deciphered that there is an increase in the locked rotor current, starting torque and operating temperature, when there is a reduction in the number of stator conductors in each slot than the original design.

Umans (1989) elaborates that "…if the motor was not designed for optimal efficiency, increase in conductor area during a rewind may, in fact, improve the efficiency. This will result from well understood phenomenon. Perhaps, the motor has been rewound with the same turns distribution, but, with larger wire size (resulting in lower winding resistance and hence lower ohmic losses). In this case, the result will simply be an improvement in efficiency…".

1.5 PERFORMANCE REDUCTION DUE TO IMPROPER WINDING

1.5.1 Performance Reduction in Manufactured Motors

While manufacturing motors of regular designs, the stators in the manufacturing line are compared with a standard stator, during Surge Comparison Test (SCT), to check that the winding in the manufactured stator is exactly the same as the winding present in the standard stator. The other routine tests carried out on the stator under test will, then, assure that the stator produced will have the same winding parameters as per the designer's specification to the winder. The surge comparison test needs a standard stator as a pre-requisite for comparison. However, in a custom-designed motor, this is not possible. Hence, the quality of stator winding of a custom-designed motor cannot be assured thoroughly.

Further, the research scholar could not find a method in the reported literature to select a standard stator from among a consignment of stators in the manufacturing line. Such a method would be of much significance when winding work is sub-contracted and when preference for low winding cost is dominant in the market. Hence, as of now, SCT on custom-designed motors will be useful only to detect any winding dissymmetry. It will not be able to ensure that the stator winding adheres to designer's specification.

Actually, there might have been a deviation in the winding configuration from the value of winding variable arrived at by the designer, which might have led to performance reduction. Even after contemporary end-of-line manufacturing test, a motor with a value of winding variable different from the designer-specified value may pass unnoticed. In fact, the efficiency and life achieved could be better in a motor with proper winding than that obtained in a motor with improper winding.

It may be thought that the manufacturer can develop a model motor, test it and then start the manufacture of custom-designed motors. However, this will take a lead time. Further, it is not possible to have a benchmark motor, especially, when winding is sub-contracted by the manufacturer with the intent of reducing overheads.

Hence, it is good to discuss the need for regulatory compliance tests in custom-designed three phase cage induction motors to assure their quality. It may be found from the personal communication with the Senior Design Manager, Large Machines division, Kirloskar Electric Company Limited that such a method will be of value when custom-designed motors are manufactured (Prakash 2009a).

1.5.2 Operating-Efficiency Reduction in Rewound Motors

One of the items in the SEEEM (2006) list of potential energy efficiency improvements refers to poor rewinding practices.

Darby (1986) discusses why efficiency reduction occurs during rewind of motors including conductor size reduction and drop in number of turns. He reports that “there are several ways to reduce the time required for winding which reduces the cost of rewinding for those who only look at the price of a rewind. If a smaller diameter wire is used, the wires can be inserted in the slots much more easily and quickly, but this is a very detrimental practice and should not be permitted. And as the cross-sectional area of the conductor is reduced, the resistance will go up and the I^2R losses will go up. It raises stator losses with no corresponding beneficial effect. Another bad winding practice is to drop turns. This makes winding easier and faster, and it is true that it reduces winding resistance, but it increases the starting current, starting torque and full-load torque and will increase stator core loss due to increased flux densities”.

Darby (1986) shares his experience that “the original winding was usually duplicated until we began to look more closely at motor efficiency. The practice of verifying the winding data in each motor that were rewound started several years ago. The verification is done by calculating the flux densities in the iron at the tooth, the air gap and the back iron. The circular mills per ampere of the winding, the slot space available and the slot space required are calculated. The present data was also compared with the master file of the original winding data, which we receive from Electrical Apparatus Service Association, which is our trade association...”.

However, the Indian scenario even today is quite different. No such practice of verifying the winding data in each motor that is rewound exists with most of the rewinders even today.

Energy Asia (2006) estimates that 50% of the operational motors in Indian industry are Rewound motors. The agricultural power tariff is highly subsidised and in certain states of India, it is free of charge. Hence, farmers find little incentive for efficient use of electricity. Sant and Dixit (1996) report that the end-use efficiency of agricultural pump-sets is dismally low in India. Normally, in Indian small and medium scale industries as well as agriculture, rewinding is done by winders who are not well-informed about the significance of various winding variables. They normally rewind as per the winding that was present in the ‘burnt’ motor. The commercially available motors of Standard efficiency designs (not of Energy-efficient design) are as per design for lower capital cost and not for lower life cycle costs. Moreover, many Rewound motors of Standard efficiency design operate with windings, which do not even stick to the winding as per design that minimised capital cost, let alone the winding design that would lower life-cycle cost. Further, preference for low cost is dominant in the market, while opting for rewinding. Hence, rewinders make compromises in the quality of rewinding. Typically, either the conductor cross-sectional area is less or the number of turns fewer than required by the original design. Such deviation in winding data from its designer’s specifications will result in performance reduction, which includes efficiency reduction. Thus, there is an unnecessary increase in the Consumption of Energy. Hence, there is a significant potential for operating-efficiency improvement in rewound motors by rectifying such improper winding.

The above discussions on improper rewinding will be applicable to motors with three phase windings irrespective of their original design. Hence, such reductions take place in Rewound motors of both Standard efficiency and Energy-efficient designs.

1.6 NECESSITY OF NON-DESTRUCTIVE APPROACHES

Two possible means of operating-efficiency reduction in three phase squirrel cage induction motor were detailed in the earlier section. Rectification to avoid the efficiency and life-time reductions that occur in the motors requires:

- The value of winding variables in the Custom-designed motors need be ensured in the manufacturing line to be as per the designer’s winding specification.
- The winding data in a Rewound motor operating at the end-user’s premises need be non-destructively determined.

The winding variables / winding data that have to be ascertained include: (i) Type of the winding, (ii) Number of Layers, (iii) Coil Span, (iv) Number of parallel circuits in each phase, (v) Number of turns per coil and (vi) Conductor cross-sectional area.

Of the above-said winding parameters, Type of winding, Number of layers, and Coil span can be ascertained by observing the winding overhang.

Conventional Quality assurance tests employed by motor manufacturers include High potential test, Surge comparison test and Resistance measurement test.

High potential test is useful to determine the insulation strength of the winding.

Moses and Harter (1957) describe how Surge test can compare the adjacent phases of motor windings. Zotos (1994) discusses about an electronic and portable device "Surge Tester" used to locate insulation faults and winding dissymmetry. It discusses about motor failures due to steep fronted switching surges, and the need for surge protection.

Surge Comparison Test (SCT) cannot give any quantitative information and at its best, it can only indicate whether the phases compared are similar or not. The pre-requirement for the test to be carried out, in the manufacturing line, on a stator to assure the quality of its winding is a standard stator with winding variables as per design specifications. The criterion to assure the quality is that the stator under test be identical to the standard stator. However, in the two cases under consideration in this thesis, it is difficult, if not possible, to have a standard stator.

IEEE Standard 118 (1978) presents methods of measuring electrical resistance that are commonly used to determine the characteristics of electric machinery and equipment. Resistance per phase of the winding depends upon Number of turns per coil, Number of parallel paths, Number of in-hands and

Conductor cross-sectional area. However, simple resistance determination will not be sufficient to determine each of these winding data.

The inductance measurement on a wound stator cannot be performed, as there is no accepted Standard for inductance measurement of wound machines. Personal correspondence by the research scholar with Technical support specialist of Electrical Apparatus Service Association (EASA) puts forth the fact (Prakash 2009b).

Visual inspection alone cannot accurately determine the conductor cross-sectional area present in the winding.

Combined resistance measurement and visual inspection is also not enough to determine the unknown winding data under consideration in an induction motor stator, whose winding configuration may have Number of parallel circuits in each phase more than one.

Reduction in performance, which includes efficiency, due to improper winding can, then, be detected only by performing end-of-line tests carried out by machine manufacturers. IEEE Standard 112 (2004) covers instructions for conducting and reporting the more generally applicable and acceptable tests of poly phase induction motors. The end-of-line tests recommended are load test on low horse power motors and pre-determination tests on motors of large power ratings. However, these tests can be performed only after the entire machine is assembled.

The other possible option for determination of the above said winding data is by physical examination involving destruction. Such invasive procedure can only be adopted by rewinders to determine the winding data of a ‘burnt’ motor. However, this procedure is not advisable for the applications considered in this thesis, and hence, cannot be adopted.

Hence, by conventional practice and from literature, as far as the knowledge of the research scholar, a way to determine non-destructively the Number of Turns per Coil, Conductor cross-sectional area and Number of parallel circuits in each phase is not available.

Walters (1999a) describes that, in typical 1.5 kW and 15 kW motors, copper loss (and particularly the stator copper loss) dominates.

Therefore, it is imperative to develop Non-destructive methods to assure the quality of Custom-designed motors, as well as to ascertain the actual Number of Turns per coil (NTPC), Conductor Cross-sectional area (CA) and Number of parallel circuits in each phase (NPCP) of stator winding of Rewound low horse power three phase squirrel cage induction motors.

1.7 PROBLEM STATEMENT

This project, based primarily on experimental work, aims to avoid unwarranted Energy consumption and performance deterioration caused by improper windings, which may ensue during manufacture, in low horse power three phase squirrel cage induction motors.

CHAPTER 2

OBJECTIVES

1) To develop non-destructive instrumentation system to detect winding configuration of a wound stator, which can be implemented on the field (Production-line testing)

2) To make the instrumentation system accurate and reliable

3) To put to use the instrumentation system and demonstrate that energy efficiency could be improved by quality assuring the winding present in wound stators.

METHODOLOGY

- The experiments to be performed on a wound stator core to determine its winding data would be a proposed EMF method and Resistance Measurement Method.
- Using the relationship developed between the EMF induced in the whole winding and the EMF induced in a search probe, experiments have to be carried out on wound stators of various stator bores to validate the theoretically developed relationship
- The stator cores that have large deviation in winding data from the designer specified winding data need to be identified experimentally on Stator cores from the field. On finding such deviations, the energy efficiency in motors with windings that have deviation in winding data is possible by adopting suitable corrective measures. The corrective measures will ensure that correct winding is employed for the motor of that particular rating. The efficiency improvement will be quantified.
- Documentation and publication of the result obtained.

CHAPTER 3

WORK DONE

- Testing of stator cores of various dimensions and with varied winding configuration by the proposed EMF method and resistance measurement method completed. Sample results have been provided.

Table1: EMF Test and Resistance Test results on Motor A

EMF TEST

Motor A: Slots – 36, Poles – 6, Coil Span – 5(1-6), T_C = 80, SWG– 22, Star Connected

S.No	f (Hz)	V_L (V)	E_P (mV)	T_C
1	50.88	17.427	4.91	88.79
2	50.72	25.286	7.15	88.49
3	50.72	36.833	10.44	88.56

RESISTANCE MEASUREMENT METHOD

R_{L-L} = 19.962 ohms

Table2: EMF Test and Resistance Test results on Motor B

Motor B: Slots – 24, Poles – 4, Coil Span – 6(1-7), T_C = 50, SWG - 21, Delta Connected

S.No	f (Hz)	V_L (V)	E_P (mV)	T_C
1	50.68	5.359	3.45	54.92
2	50.61	9.219	6.00	54.75
3	50.4	12.96	8.58	54.76

RESISTANCE MEASUREMENT METHOD

R_{L-L} = 4.29 ohms

Table 3: Consolidation of results of the Winding Quality Assurance Approach

S. No	Details of the Stator Core	Actual T_C	T_C calculated by EMF Method	R_L by Resistance Method	T_C calculated by Resistance Measurement Method
1	**Motor A:** 36 Slots, 6 pole, Single Layer, (1-6) Coil Span -5, SWG - 22	80	88.49	19.962 Ω	80
2	**Motor B:** 36 Slots, 4 pole, Double Layer, (1-7) Coil Span -6, SWG - 21	50	54.76	4.29 Ω	50
3	**Motor C:** 36 Slots, 4 pole, Concentric, (1-8, 1-10, 1-12) Coil Span – 7, 9, 11, SWG - 20	70	79.16	4.81Ω	70

- Procurement of Electromagnetic field theory software completed.
  ANSYS Electromagnetic Bundle Version - 18

- Validation of the experimental results with the simulation using software is completed.

CHAPTER 4

FUTURE SCOPE

- Automation of the EMF method and resistance measurement method used for finding the winding details and thereby developing an instrument using Virtual Instrumentation System.

- Checking the motor stators with correct and incorrect winding configuration using the automated instrument.

CHAPTER 5
CONCLUSION

When there is no reliable energy savings, additional responsibilities will rely on motor manufacturers. Therefore, in production line quality assurance measures becomes more important.

So far, there is no Non-Destructive test in field for determining the winding data. In order to implement the research level methods in field, an inventory is necessary. Hence this research method involves inventory management and therefore, it will not be practically feasible.

However, the proposed approach can be adopted in the field during process line test itself. Hence, this Instrumentation system will be useful in quality assurance of windings in three phase induction motors.

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