

ANALYSIS AND DESIGN OPTIMIZATION OF IRRIGATION PUMP MOTORS

by

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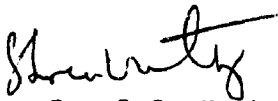
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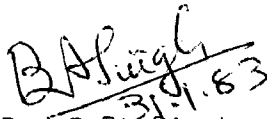
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CERTIFICATE

Certified that the thesis entitled "Analysis and Design Optimization of Irrigation Pump Motors," which is being submitted by Mr. Bhim Singh, in partial fulfilment for the award of the Degree of Doctor of Philosophy in the Centre of Energy Studies of the Indian Institute of Technology, Delhi, is a record of student's own work carried out by him under our joint supervision and guidance. The matter embodied in this thesis has not been submitted for the award of any other degree or diploma.



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SUMMARY

Electrical energy in rural and low load density areas is primarily consumed by irrigation pump motors. These pump sets are mostly driven by squirrel cage induction motors on account of its lower cost, physical ruggedness and maintenance free operation. The investigation reported in this thesis deals with various aspects of analysis and design of such pump motors under realistic power supply situations encountered in practice. Some of the special features relating to such a study are as follows.

A. Analysis

(i) In India and other developing countries, a wide fluctuations in supply voltage in rural areas have been observed contributing to the overall heating and/or consequent derating of motors.

(ii) Irrigation pump motors in low load density areas may have to operate on a single-phase supply system. It has been found technically feasible and economically advantageous to install initially a single wire earth return (SWER) system and/or single-phase two conductor system for rural electrification in remote and hilly regions. As the load demand increases, the SWER system can be converted to a regular three-phase power system. The irrigation pump sets in such situations may use either a single-phase motor or a three-phase motor with suitable phase convertors. The latter having the advantage that it can be used directly when a three-phase supply is installed later.

B. Design

(i) With the increasing cost of electrical energy, it has now become imperative to attempt the minimization of overall cost instead of optimizing only the cost of material. For this, the design optimization could be carried out in terms of more than one objective functions from which a suitable design for the given application can be selected. In addition to cost minimization, the design optimization can also be attempted with a view to providing higher performance of the motor in terms of higher efficiency and/or higher power-factor. Thus, sometimes one may aim at designing a high performance motor rather than a low cost motor.

(ii) For design optimization of an induction motor, a large number of variables are available from physical consideration. However, all of them do not satisfy the requirements of basic variables and hence attempt should be made to identify a set of basic variables having significant bearing on the cost and/or the performance of the machine. In this context, it also becomes desirable to impose suitable constraints on the design to meet the thermal, starting and other operational requirements of the machine.

(iii) Considering the highly nonlinear nature of the design optimization problem, various methods of direct search and sequential unconstrained minimization techniques (SUMT) could be employed with different objective functions.

In the first part of this investigation, studies are made on the steady-state performance of a three-phase induction motor when it is fed from a balanced three-phase source or a single-phase (SWER) system using suitable phase converters. For the motor operation with single-phase supply, two different types of converters viz. one element (capacitor) type and two element (Inductor-capacitor) type have been considered. Both starting as well as run up operation have been studied by considering two set of values for the converter elements. These values are chosen to yield minimum unbalance at starting and run up conditions, respectively. Starting performance of the motor under the balanced case is compared with that of single-phase using static phase converters in terms of torque, supply and winding currents, voltage across the converter elements, unbalance factor and various starting qualities such as torque per input ampere, torque per input ampere squared and torque for stator watt-loss. In addition to the starting performances, the study presents the effect of voltage fluctuations on various performance factors such as supply and winding currents, power-factor, efficiency and losses of the motor for an assumed constant pump load. Motor operation under balanced as well as single-phase supply with suitable converter has been considered. It has been shown that the voltage fluctuation, in general, leads to substantially higher losses for a given output and if it is desired to limit the temperature rise within a safe limit then the output of the motor will have to be considerably reduced. This has been given in terms of derating factors of the motor for different levels of supply voltages.

The steady-state analysis is followed by the transient analysis of pump motors both under three-phase and single-phase systems. The performance of the motor under transient conditions is also of interest as the knowledge of transient winding currents and instantaneous torque is required in assessing the suitability of the windings and shaft dimensions. Further, transient voltage across the phase converter elements should be known for specifying its voltage ratings. Thus, in the present investigation, the transient analysis of the run up performance has been carried out using the theory of instantaneous symmetrical components and its associated operational equivalent circuit. For the motor fed from a single-phase supply, the transient analysis takes into account two values of phase converters corresponding to the values that cause minimum unbalance at starting and running conditions, respectively. The digital simulation of the run up transients has been done in which the change over from the starting value of the converter to its running value is logically selected at the appropriate speed. The dynamic model is shown to be simple and versatile as it uses directly measurable quantities, takes nonlinearity into account and is applicable to any type of symmetrical or asymmetrical connection of the motor. The flow chart for digital simulation is presented. The simulated run up transient patterns for currents, instantaneous torque, and speed for different modes of starting are presented and critically discussed.

Extensive tests have been carried out in the laboratory to provide correlation with simulated results.

The last part of the investigation deals with the design optimization of induction motor used in irrigation pump applications. The design optimization of cage motors has so far been reported with only manufacturing cost as an objective function using various optimization techniques. However, with the increasing cost of electrical energy, the operating cost and/or certain performance indices play a significant role in the overall system economy in addition to its efficient operation. Therefore, in this investigation, six objective functions, namely, the cost of active material, the cost of annual energy consumed, the overall cost as a proper combination of these two, the full load power-factor, the annual operating cost based on kVAh input and the mixed cost (the sum of annual kVAh input cost and certain part of active material cost) are considered in the design optimization of these motors. A set of nine basic variables is identified with their lower and upper bounds in order to provide a feasible design. Along with these implicit constraints, other suitable explicit constraints are also imposed to meet the thermal starting and other performance requirements of the machine. The optimization is achieved through various techniques of direct search and indirect search, namely, univariate method, Rosenbrock's method, Box's complex method and Sequential Unconstrained Minimization Techniques (SUMT) in conjunction with direct search method. The algorithm with program description and flow chart summary are given for all the methods used in this investigation. Optimized design results for a typical 3.7 kW, 400 V, 50 Hz, 4 Pole squirrel

cage induction motor are presented for all the objective functions. This has been used to compare the efficacy of various optimization techniques. Selection of an appropriate design for irrigation pump applications has been discussed.

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