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An Innovative Approach for Energy Conservation in Induction Motor

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Abstract- **Three phase Induction motors are mainly employed in Textile mills, Agriculture and almost in all the machine tools. About 65% to 70 % of electrical energy generated is being utilized by three phase induction motors because of their robust construction and easy operation. Hence, a small improvement in the design of induction motor for energy conservation and increased efficiency is cost effective. Conventional induction motor consists of a three phase distributed winding in the stator and short circuited squirrel cage rotor. Generally, to have standard dimensions, induction motors are designed for standard output ratings. To have factor of safety, the ratings of the motor are generally chosen on higher side. Due to said reasons over rated motors are normally used. To improve the efficiency of the motor operation and to have sufficient energy conservation, a novel design and operation of Double Winding Induction Motor (DWIM) is suggested in this paper. This motor consists of two windings on the same stator core and conventional squirrel cage rotor. Out of two stator windings, one winding is used to meet the mechanical load. A three phase EMF is developed in other winding, works as an induction alternator. Both mechanical and electrical loading can be controlled by a PIC Microcontroller for its maximum efficiency and power balancing modes of operation.**

Keywords: **Double winding Induction motor, Induction alternator, Maximum efficiency mode, Power balancing mode**.

I. INTRODUCTION

Electrical demand of a country is the index of its growth. One way of energy conservation is the effective usage of available resources. Due to simplicity and rugged construction induction motors are widely used in almost all the manufacturing sectors. The efficiency and power factor this motor depends on the load available on the shaft. Since there is only one mechanical output is possible in the conventional induction motor, its power factor and efficiency is limited. Hence, a double winding induction motor is presented in this paper.

Introduction of double winding induction machine was suggested and implemented in the year 1930 for turbine alternators. When one of the windings is energized by a three phase supply, a revolving magnetic field is developed in the air gap. This magnet field is utilized by both the windings for developing two different outputs [1]. Energy conserving induction motor with field control method was introduced with different levels of stator excitation with multiple tapings in the stator. Instant motor loading is sensed as a change of power factor or sub synchronous slip speed and the tapped stator windings are excited accordingly [2]. Energy conservation can be obtained through adaptive variations of the supply voltage. The desired voltage variation for minimum energy consumption at varying loads is obtained by control circuitry designed with mathematical modeling. Two stator windings are wound for dissimilar number of poles designed to produce two independent torques that can be controlled to obtain desirable torques. The machine can be controlled by V/f and sensor less control [3]. In double winding induction machine, one of the stator windings acts as a generator. By controlling the applied voltage to the secondary or the generator winding, the rotor speed can be controlled [4]. The stator of double winding induction motor may be connected in star or delta. The active resistance decreases to considerable value and hence copper losses are decreased [5].

Multiphase machines have degree of freedom to improve overall performance of the system. By the usage of space voltage vector, the adjustment of torque and flux become flexible [6]. The energy efficient induction motor now become popular and replaces the conventional induction motors. The efficiency of the induction is improved by providing premium steel and copper rotor cage have been used instead of standard steel and aluminum [7]. The stator windings of double winding induction motor can be arranged with different shift angles. In double winding induction motor, shift angle of 60 degrees or zero degrees the best choice [8]. The implementation of double winding induction motor can be carried out in during the rewinding process of conventional induction, which reduces the cost of the machine and simplifies the production procedure. The optimized design of induction motor using Rosen Brock's method is carried out with the objective of minimizing the cost of active materials, the cost of annual energy consumed and the annual cost [9]

By synthetic loading technique, induction motor can be loaded to its rated capacity without connecting actual loading of the machine [10]. Conventional brake drum testing is adopted for testing of proposed model. The simulated annealing algorithm for the optimization of induction motor with non-linear multi variable programming can be used for the design [11].

In the general rewinding process, rewinding practice is adopted with reduction in either winding conductor size or reduction in number of turns. Because of this practice, efficiency reduces by 5 points. The torque per ampere is decreased and also causes rise in temperature machine.

A method has been proposed to measure the frequency in improvement in improperly rewound motors with that of standard energy efficient motor [12]. Efficiency of the induction motor can be optimized even at lightly loaded condition by means of TRIAC fed drive. More than 10% efficiency improvement is possible even at one fourth of the full load [13].

II. MACHINE MODEL

A. Representation of the Proposed Scheme

The representation of DWIM is shown in Figure.1 One of the stator windings is connected to a three phase supply, electrical load is connected to the second stator winding. The principle of operation of a Double Winding Induction Motor depends on that when one of the windings is connected to a three phase supply, a revolving magnetic filed of constant magnitude is developed in the air gap. The same filed is utilized by both the stator windings to work as induction motor to meet mechanical load while, a three phase EMF is induced in the second winding, works as an Induction alternator to meet electrical load. In the proposed model both the windings are placed with zero degree phase angle displacement between the windings for optimum utilization.

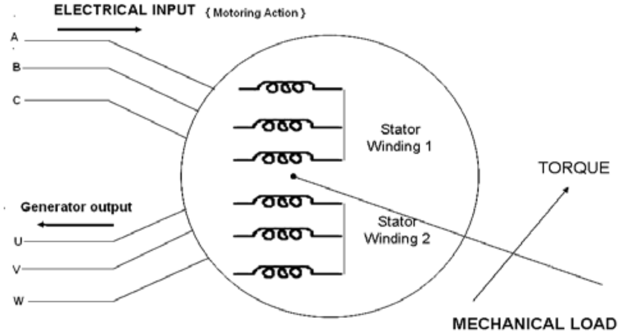

Fig. 1. Double Winding Induction motor

As a proof for the discussion, a 3 kW, 415 V, 4 pole, 3-phase Squirrel Cage Double Winding Induction Motor has been designed, fabricated and tested.

B. Design Considerations

The design of the double winding induction motor is affected by various constraints such as thermal limit, overload capacity and utility of stator slots. The energy conserving double winding induction motor is ideal to be used for low power operations due to the limitation in thermal insulation value. The value of air gap flux density is large which determines large overload capacity. The use of semi-enclosed slots results in silent operation. Slot utility factor for the designed DWIM motor is about 43.3% where as for conventional induction motor, the slot utility factor is about 25%.

C. Design of DWIM machine

Number of poles = 4,
Synchronous speed = 1500 rpm
Diameter of the core = 0.139 m
Length of the core = 0.11m
Number of turns per phase =240 with cross sectional area of 36 SWG.
Both the stator windings are of identical nature. Current density chosen is 7.5 A/mm^2
Electrical loading = 21000A/ m^2
Magnetic loading = 0.44 wb/m^2

III. EXPERIMENTAL INVESTIGATIONS

To evaluate the performance characteristics, a series of testing has been carried out. Experimental set up for conducting the experiment is shown in theFig2.

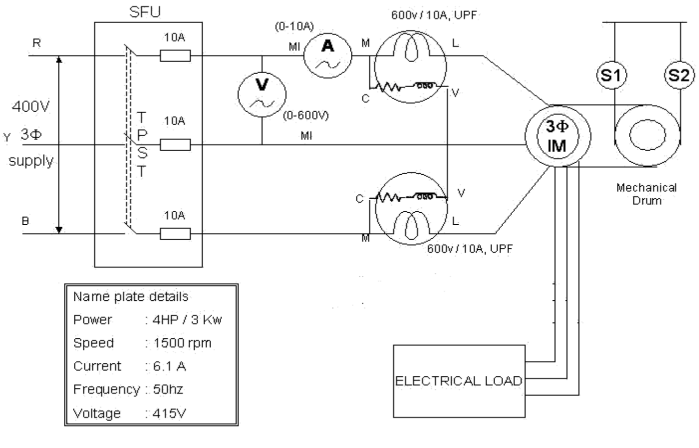

Fig. 2. Experimental Setup

The following testing arrangements are used for testing the DWIM.

1. **Conventional Mechanical load test**: Using brake drum arrangement, load test has been carried out in both the windings considering each winding separately to analyze the performance of the machine.
2. **Mechanical and Electrical load test:** One of the stator winding is connected to a three phase supply and a

three phase loading rheostat is connected in the second winding. By means of brake drum arrangement, mechanical load is applied and electrical load is applied using three phase loading rheostat.

The following tables, Table.I and Table.II shows the reading observed during the conventional loading with mechanical load on the shaft. Table.2 shows the observation of reading taken with mechanical and electrical loads. Electrical load 2 A is connected to the second stator winding. However, rated load current of 6.1A is maintained by adjusting the mechanical load.

TABLE I
BRAKE TEST ON DWIM WITH MECHANICAL LOAD

S. N O	V VOLTS	A AMPS	W1 (X4) WATTS	W2 (X4) WATTS	S1	S2	N RPM	T	I/P WATTS	O/P WATTS	%n	COS Φ	% SLIP
1.	415	2.5	120	0	0	0	1466	0	480	0	0	0	0.99
2.	415	3	180	0	0.5	4	1458	3.60	720	549.37	76.3	0.25	1.48
3.	415	3.5	260	50	1	7.2	1448	6.386	1240	967.84	78.05	0.384	2.162
4.	415	4	320	100	1.2	10	1442	9.064	1680	1368.03	81.42	0.4758	2.567
5.	415	4.5	360	150	3	14	1438	11.330	2040	1705.28	83.59	0.527	2.837
6.	415	5	440	200	3.8	15.6	1426	12.154	2250	1814.26	81.62	0.504	3.648
7.	415	5.5	490	230	4.4	19.6	1416	15.656	2880	2320.34	80.56	0.586	4.324
8.	415	6	560	280	5.4	23	1408	18.128	3360	2671.53	79.50	0.619	4.864
9.	415	6.5	590	320	6.4	25	1398	19.158	3640	2803.27	77.01	0.599	5.540

TABLE II
MECHANICAL LOAD WITH 2A ELECTRICAL LOAD

S.NO	V	I	W1 X4	W2 X4	S1	S2	N	T	I/P	O/P+ 1416	%n	COSQ	%SLIP
1.	415	3	330	100	0	0	1470	0	1720	1416	0	0.79	2
2.	415	3.5	390	180	3	0	1458	2.943	2280	1865.3	81.8	0.90	2.8
3.	415	4	420	210	5.8	0.2	1450	5.4936	2520	2250	89.2	0.97	3.3
4.	415	4.5	490	270	8.6	0.4	1446	8.0442	3040	2694	88.64	0.93	3.6
5.	415	5	540	320	11.4	1.2	1430	10.006	3440	2984	86.7	0.95	4.6
6.	415	5.5	590	360	15.4	2.6	1426	12.556	3800	3290	86.5	0.96	4.9
7.	415	6.1	650	420	18.8	3.4	1420	15.100	4280	3661	85.5	0.97	5.3

The efficiency characteristic of DWIM for conventional mechanical loading is shown in the fig 3.

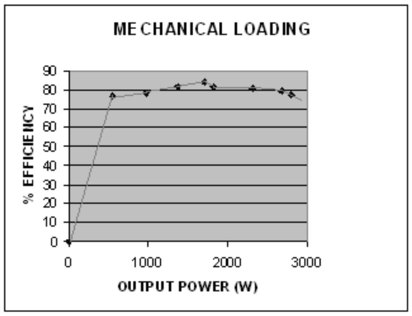

Fig. 3. Output Power Vs Percentage Efficiency

The efficiency characteristics of DWIM for conventional mechanical loading along with different level of electrical loadings are shown in the following fig. 4 – 8.

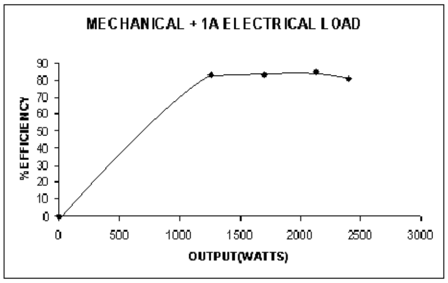

Fig. 4. Output Power Vs Percentage Efficiency

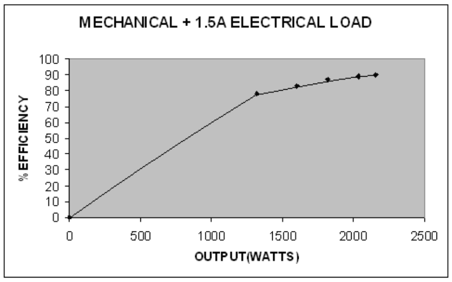

Fig. 5. Output Power Vs Percentage Efficiency

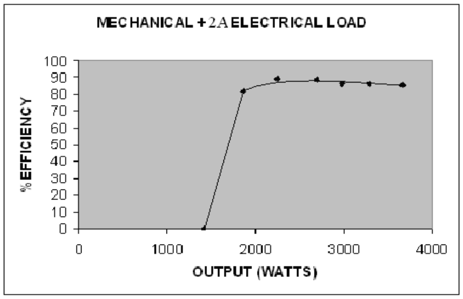

Fig. 6. Output Power Vs Percentage Efficiency

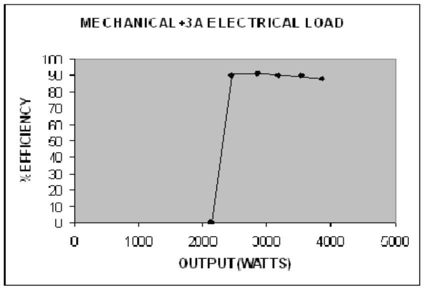

Fig. 7. Output Power Vs Percentage Efficiency

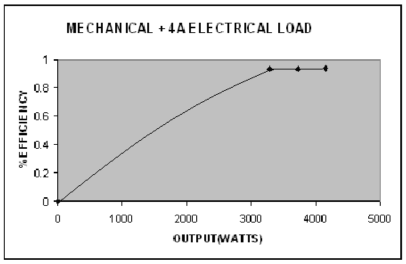

Fig. 8. Output Power Vs Percentage Efficiency

A. Predetermination of performance of DWIM

Apart from the conventional loading of DWIM, the performance can be predetermined by using its equivalent circuit. Equivalent circuit can be obtained by conducting no load and blocked rotor tests. Equivalent circuit of Double winding induction motor is shown in Fig.9.

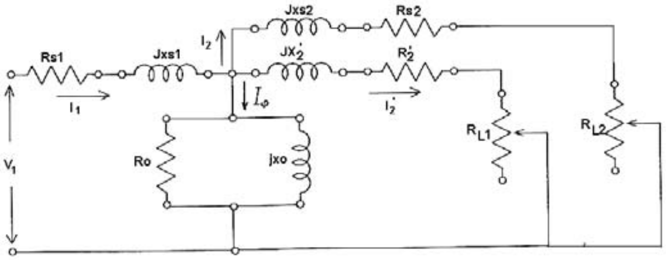

Fig. 9. Equivalent circuit of DWIM

B. Analysis of equivalent circuit

The coupling component of equivalent circuit R_0 and X_0 are responsible for the core losses. The stator current I_1 has three components namely current responsible for core losses (I_μ), current flows through the rotor circuit (I_2') and current delivered to the electrical output through the second stator winding (I_2). The voltage across the rotor circuit and second stator winding are given by the following equations:

$$V_2 = V_1 - I_{1s}(r_{1s} + jX_{1s}) \quad (1)$$

$$I_2' = V_2 / (r_2' + r_L' + jX_2') \quad (2)$$

$$I_{2s} = V_2 / (r_{2s} + r_{Ls} + j X_{2s}) \quad (3)$$

$$I_{1s} = \overline{I_0} + \overline{I_{2s}} + \overline{I_2}' \quad (4)$$

Performance prediction

Electrical input = $3\ V\ I\ \text{Cos}\Phi$
Stator copper loss = $3(I_{1s}^2 + I_2'^2)$
Iron losses = $3\ V\ I_0\ \text{Cos}\Phi_0$
Rotor copper loss = $3\ I_2'^2\ r_2'$
Mechanical output = $3\ I_2'^2\ r_L'$
Electrical output = $3\ I_{2s}^2\ r_{Ls}$

C. Determination of Equivalent load resistance of second winding

For conventional induction motor, electrical equivalent of mechanical output can be determined from the no load and blocked rotor tests. Similarly, electrical equivalent load of second winding can be predetermined. From the various mechanical and electrical load combinations on the each winding equivalent resistance is determ.8(od)-2(is 3)3.9((is 3 er)-9.6)-5.1

A. Flow Chart

The operation of DWIM with PIC controller and contactor can be explained with a flow chart as shown in the Figure.10

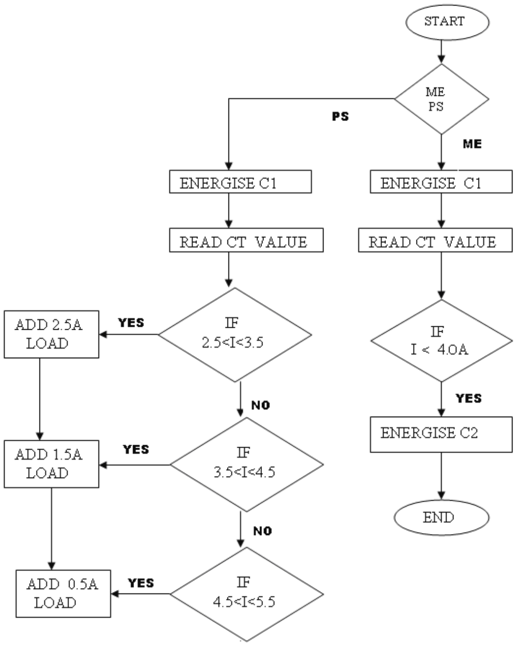

Fig. 10. Flowchart of Machine operation

B. Mode I . Maximum efficiency Mode

The control circuit diagram for mode I operation is shown in Figure.11. PIC controller senses the mechanical and electrical load on the machine. PIC controller switches on the external electrical load in the second winding in order to maintain 4.5 A depends on the mechanical load**.**

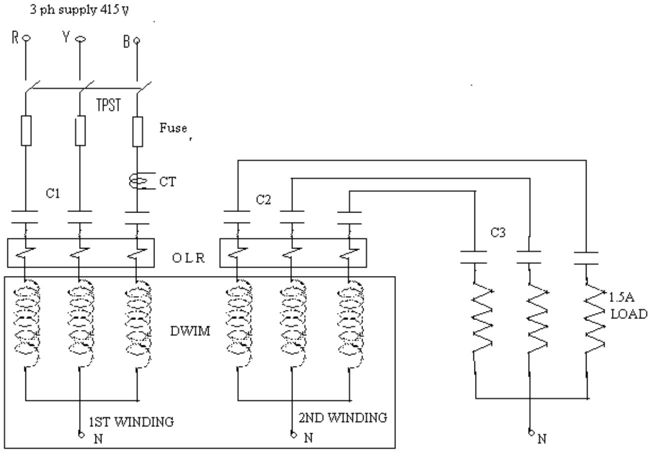

Fig. 11 Control Circuit for Mode I operation Mode II Power Balancing Mode

In power balancing mode, motor is operated to its rated capacity. The control circuit for Mode II operation is shown in Figure.12. The current transformer is coupled with controller through a precision rectifier. Depending upon the load current in the first winding, the controller switch on the external electrical loads through contactors C1, C2 and C3 in different combination. In this mode, controller is programmed such a way that the machine runs at its rated capacity. The contactor operation for different loading condition is shown in the Table.IV.

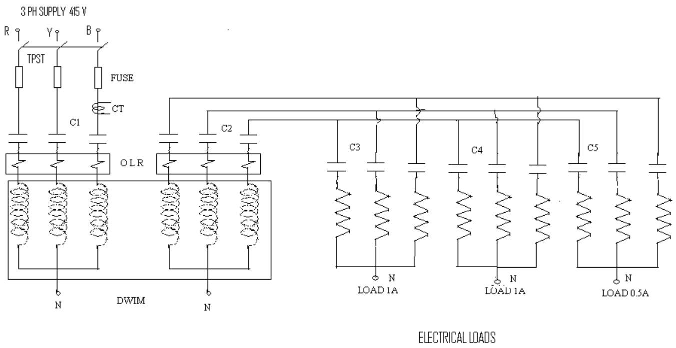

Fig. 12. Control Circuit for Mode II Operation

C. Operation of contactors

Depends on the machine operation whether the machine is operated in Mode I or Mode II, the contactors are operated appropriately. Initially, the mode of operation is selected. Based on the selection, relay coils receives the signals from the controller and energizes the corresponding contactors. For an example, the following Table. IV shows the operation of contactor C3 for different load current.

TABLE IV
CONTACTOR C3 OPERATION

Load current in the first winding	Contactor C3 (1A load)	Contactor C3 (1 A load)	Contactor C3 (0.5A load)
2.0<I<3.5	ON	ON	ON
3.5< I <4.5	OFF	ON	ON
4.5< I <5.5	OFF	OFF	ON

D. Energy Conservation

During the selection of motors, for the factor of safety slightly over rated machines are considered. However, using DWIM, it is possible to make of additional power that can be developed in the second stator winding is used to meet the electrical loads, which are in turn need not depends on separate supply. Consider the following load test details as an example for energy conservation.

Supply voltage : 415 V
Load current : 5.0 A (Mechanical)
Input power : 3000 w
Output power : 1511w (Mechanical)
Output voltage : 405 V
Load current : 1.9 A
Output power : 1280 w (Electrical)

In the above test results, electrical power of 1280 watts has been tapped from the second winding. If the machine is operated for 16 hours a day, then monthly energy saving will be 1.28 X 16 X 30 = 614.4 kWhrs

V. CONCLUSION

A 3kW, 3 phase, 4 pole, 1440 rpm, 415V double winding induction motor has been designed and successfully tested. The experimental results illustrate the improvement of efficiency over the conventional induction motors. By utilizing this electrical output from the motor to supply the lighting loads, the industry's concern dependency on separate supply to the lighting loads is reduced. The double winding induction motor can be employed, where the induction motors run continuously all the day like textile industries and any manufacturing units using induction motors. The out put power from the second winding can be used for charging the UPS system, supply lighting loads.

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