

Design and Development of Three Stator Winding Induction Motor

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Abstract

Three phase induction motors are employed in almost all the industries because of its simple construction and easy operation. Efficiency of the induction motor is affected by its fixed losses and variable losses which mainly depend on the input supply voltage and load current respectively. An attempt is made to minimize the iron losses by controlling the supply voltage. A new Three Winding Induction Motor (TWIM) is proposed in this paper in which stator consists of three windings accommodated in the same core. Stator coils are designed to be operated at 415 V, 350 V and 200 V respectively. Shaft loads are categorized as low medium and high, Stator coils are energized through a controller based on the load demand. In this study, it is suggested to operate the machine with flat efficiency characteristics, irrespective of shaft load. When compared to conventional induction motor slot utility is improved from 29% to 55%. Another approach of this machine is that while one of the windings is considered to meet the mechanical load, as an Induction Alternator (IA) a three phase out put with two different voltage levels are induced in the other two windings. If 415 V winding is considered to meet the mechanical load, a three phase voltage of 350 V and 200 V is induced in the other two windings. These outputs can be used directly or with converters to feed electrical loads or to charge batteries to obtain uninterruptible power supply. Thus, TWIM is operated to its rated capacity and energy conservation is achieved by connecting additional loads in the other two windings. Experiment result ensures the considerable increase in the efficiency and power factor.

Keywords: Three Winding Induction Motor (TWIM), Induction Alternator (IA), Control circuit for Optimum utilization.

Introduction

Induction motors are employed in Textile mills, Agriculture and almost all the manufacturing industries to drive the loads because of its rugged construction and ease operation. The major limitation of induction motor is its efficiency and power factor. These two parameters depend on the shaft load. In conventional induction motor, only mechanical output is available and hence, its power factor and efficiency is limited. Dual stator winding induction motor would be the better choice to overcome these limitations. Dual stator induction motor became popular since 1930. When a three phase supply is applied to one of the stator windings, a revolving magnetic field of constant magnitude is developed in the air gap and this field is shared by both the windings [1]. The various possibilities in the design modification, speed control, efficiency, power factor improvement of induction motor and double winding induction motors are discussed below. Dual stator induction motor stator with two separate windings wound for a dissimilar number of poles is fed from an independent variable-frequency variable-voltage inverter. This drive offers advantages as speed sensor less operation, Zero speed operation is achieved by independently controlling the two sets of stator current and hence, maintaining a minimum electrical frequency independent of mechanical speed. This drive is suited for either constant volts per hertz or field oriented operation. Circulating harmonics currents are eliminated by the dissimilar number of poles [2]. Three-phase induction motors are designed to meet high starting torque, good operating efficiency and power factor. Optimization design of three-phase induction motor is formulated as a nonlinear multivariable programming problem to meet the above requirements. The simulated annealing algorithm was used to obtain an optimum design [3]. Any significant improvement in the operating efficiency of induction motor will be effort at energy conservation. The optimized design of induction motor can be obtained using Rosenbrock's method to minimize the cost of active materials, the annual energy consumed and the total annual cost [4]. The stator of a double winding induction motor can be connected in star and delta, thereby active resistance by 11% and inductance by 13% can be reduced. The active resistance decreases to considerable value and hence copper losses are decreased. DWIM has increase of output power and torque of 10% and starting torque reduced by 3.5% [5]. A 3.7 kW three phase induction motors are widely used in agriculture and industries. During rewinding process, efficiency get reduced by five percentage points due to improper rewinding process in which the winding conductor size is reduced by 1 SWG or by reducing number of turns from the winding specification. This improper rewinding practice results in reduction of torque per ampere and increase in winding temperature for the given load. [6]. Efficiency of the induction motor can be optimized even at lightly loaded condition by means of TRIAC fed drive. Input voltage is adjusted based on the optimal- efficiency and power factor. More than 10% efficiency improvement is possible even at one fourth of the full load [7]. Dual stator induction motor suggested for energy conservation consists of two sets of RUN windings. The main RUN winding is energized to have sufficient MMF in order to produce sufficient magnetic flux and to operate the motor at light loads with good power factor. In this machine reduced power is applied to the second set of RUN winding and hence, the

power consumed due to eddy currents, copper losses and poor power factor are considerably reduced [11]. The efficiency of an induction motors ranges between 0.75 and 22 kW can be improved by means of die cast copper instead of aluminium cage rotor with premium steel core [12]. In multflux level of a three-phase squirrel-cage induction motor, the efficiency and power factor can be both maximized as a function of load. The stator winding with two sets of turns, shares the same positions in the stator slots. Among all the possible stator winding connections, six modes were selected and analyzed [15]. Efficiency of an induction motor can be improved by cutting the predefined arc-section of the rotor. Air gap over a periphery will not be uniform and causes edge effect. The redesign is focused on construction of the rotor with novel windings configurations [16]. Optimal values of induction motor design parameters can be determined using Particle Swarm based approach to three-phase Induction Motor based on particle-swarm-optimization (PSO) technique. This method shows improvement in efficiency, active material cost, and performance under starting and full load conditions [17]. Dual stator induction motor can be operated in power balancing mode and maximum efficiency mode for effective utilization of the machine. Second set of stator winding can feed electrical loads, thereby power factor and efficiency is improved [18].

Machine Model

Representation of the Proposed Scheme

The TWIM consists of three stator windings designed to operate at three different voltage levels. The windings are arranged in the same stator core. The principle of operation of a Three Winding Induction Motor depends on one set of winding which is connected across a three phase supply and revolving magnetic filed of constant magnitude is developed in the air gap. The same is utilized by the stator winding to work as an induction motor to meet mechanical load while, a three phase EMF is induced in the other two sets of winding to which electrical load can be connected that works as an Induction Alternator. The 415 V winding is connected across the supply till the rated speed is attained. Then based on the shaft load, the respective coils are energized. The stator windings of three winding induction motor can be arranged with different shift angles. In double winding induction motor, shift angle of 60 degrees or zero degrees are predicted as the best choice [8]. A controller circuit continuously monitors the shaft load. If the load is one third of the rated current, 200 V winding is energized through the controller and when the load is two third of the rated current, 350 V winding is energized. Rated voltage is applied when the machine is started and when the machine is operated above the two third capacity of the rated current. Double Winding Induction Motor is used for a wide range of speed control applications. By controlling the voltage applied to the secondary winding, the rotor speed can be controlled. The machine has a similar speed control charatertics to that of a slip ring induction motor [9].The pictorial representation of three stator winding induction motor (TWIM) is shown in the Figure.1.The terminal box consists of three sets of six terminals of three stator windings. While one set of winding is energized, three phases out put can be tapped in other two sets of winding.



Figure 1: Three Stator Winding Induction motor.

Design Considerations

The design of the three stator three winding induction motor is affected by various constraints such as thermal limit, overload capacity and utility of stator slots. The energy conserving three stator 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 proposed model uses semi-enclosed deeper slots. The stator of TWIM consists of three set of stator windings placed in the same slot and therefore slot utility is increased. Slot utility factor for the designed TWIM motor is about 55%, where as for conventional induction motor, it is about 29%. 2.2 kW and 3.7 kW capacity induction motors are generally used in most of the small applications. The suggested design is suitable only for small capacity induction motors. Since deeper slots are preferred for the design, the reactance offered will be considerable.

Design Description of the proposed TWIM

2.2 kW and 3.7 kW three phase induction motors are widely used in agriculture and industries. As a proof for the discussion, a 2.2 kW, 415 V, 4- pole, 3-phase Squirrel Cage Three Stator Winding Induction motor has been designed, fabricated and tested. M45 silicon alloy steel stampings are used for stator core. Stator coils are insulated with F-Class insulation. The technical details of TWIM are given below:

Number of stator slots	= 36
Number of rotor slots	= 44
Diameter of the bore	= 150 mm
Length of the bore	= 120 mm
Magnetic loading	= 0.44 Wb/m ²
Electrical loading	= 21000 ac/m
Turns per phase of 200 V winding	= 144
Turns per phase of 350 V winding	= 250
Turns per phase of 415 V winding	= 298
Slot area	= 130.5 mm ²

Conductor area = 72.5 mm²

Experimental Investigations

In order to evaluate the performance of a three phase induction machine, there are various indirect and direct methods that are available. Rapid full load efficiency evaluation of three phase induction motors is using the synthetic loading technique with the help of a digital signal processor (DSP) controlled high switching frequency power electronic inverter synthetically loading the induction machine without the need to connect a load to the machine's drive shaft. This method considerably reduces the testing time compared with conventional methods of efficiency measurement and the accuracy of the result is maintained. This method can also directly quantify rotational losses of the induction motor under test [10]. The various direct and indirect methods of testing of induction motor that are available. By using Artificial Intelligence (AI) techniques such as artificial neural network (ANN), fuzzy logic, expert systems and nature inspired (NIA), Genetic algorithm and differential evaluation, energy optimization and design modification of induction motor is possible [13]. One of the methods to improve the Power Factor of three phase induction motor is through Power Factor Controller (PFC) with Programmable Logic Controller (PLC) in which the voltage to frequency ratio is maintained constant in order to obtain a maximum torque. To minimize the pseudo oscillation and harmonics, Zero voltage switching of static switches is allocated in the control algorithm [14].

In order to evaluate the performance characteristics of a designed TWIM, a series of testing has been carried out. Experimental set up with both electrical and mechanical loading is shown in Figure.2

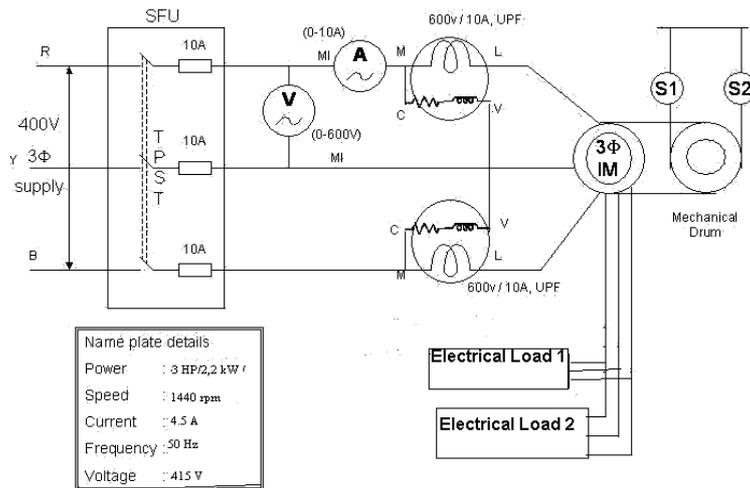


Figure 2: Experimental Setup.

Testing of TWIM

The following tests are carried out in TWIM:

Conventional Mechanical load test: Since the machine is designed for a rated voltage of 415 V, initially, a load test is carried out considering 415 V winding alone, keeping other two windings un loaded. The efficiency and power factor characteristics for this voltage are shown in Figures 7 and 8.

Load test on 350 V winding: In order to analyze the performance of induction motor for 350 V, a load test is carried out considering this winding alone and other two windings are kept unloaded. The efficiency and power factor characteristics for this voltage are shown in Figures 5 and 6.

Load test on 200 V winding: In order to analyze the performance of induction motor for 230 V, a load test is carried out considering this winding alone and other two windings are kept unloaded. The efficiency and power factor characteristics for this voltage are shown in Figures 3 and 4.

The performance of the three winding induction motor is studied for different operating voltages. The current corresponds to the maximum efficiency was identified for each voltage of operation. Control circuit has been designed based on these load currents.

Table.1 shows the reading observed during 415V winding is considered. Table.2 shows the observation of reading taken with 350V winding is considered. Table.3 shows the observation of reading taken with 200 V winding.

Table 1: Loading of Twim with 415 V Supply.

S.No	Input Voltage	Line Current	Input power	Speed	Torque in Nm	Output power	Slip	Efficiency	Power factor
1	415	1.2	240	1490	0	0	0.66	0	0.28
2	415	1.5	680	1480	2.3	352	1.33	51.7	0.64
3	415	3.0	2000	1421	7.8	1165	5.26	58.3	0.93
4	415	4.0	2660	1410	12.6	1856	6.0	68.8	0.93
5	412	4.5	3000	1392	16.0	2328	7.2	77.6	0.93
6	410	5.0	3100	1356	17.5	2486	9.6	80.2	0.87

Table 2: Loading of Twim with 200 V Supply.

S.No	Input Voltage	Line Current	Input power	Speed	Torque in Nm	Output power	Slip	Efficiency	Power factor
1	200	2.0	280	1480	0	0	1.33	0	0.4
2	200	2.3	600	1472	3.1	476	1.87	79.4	0.77
3	200	2.5	760	1460	3.9	598	2.67	78.7	0.88

Table 3: Loading of Twim with 350 V Supply.

S.No	Input Voltage	Line Current	Input power	Speed	Torque in Nm	Output power	Slip	Efficiency	Power factor
1	350	1.1	240	1488	0	0	0.8	0	0.36
2	350	1.5	720	1474	2.68	413	1.73	57.4	0.79
3	350	2.2	1200	1462	4.74	726	2.53	60.5	0.90
4	350	2.7	1520	1444	8.80	1028	3.73	67.7	0.93
5	350	3.2	1680	1424	9.06	1352	5.06	71.9	0.97
6	350	3.6	2160	1410	10.92	1812	6.0	74.5	0.98

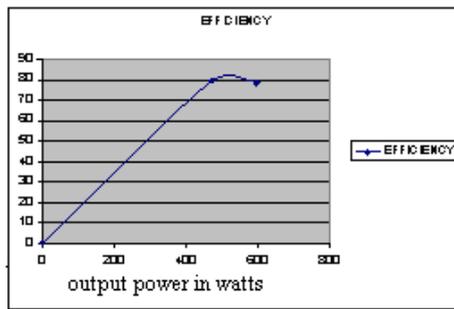


Figure.3: Efficiency Characteristics with 200 V supply.

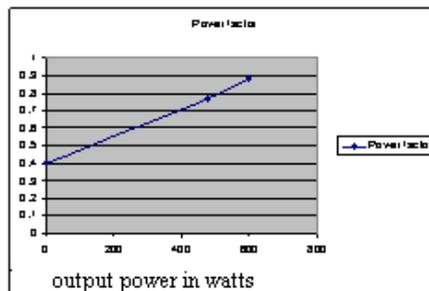


Figure.4: Power Factor Characteristics with 200 V supply.

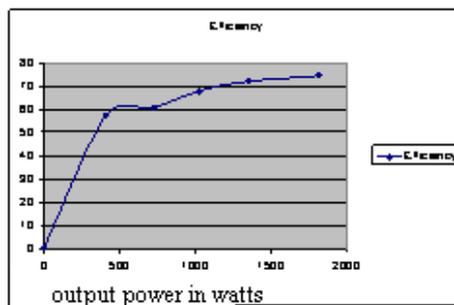


Figure.5: Efficiency Characteristics with 350 V supply.

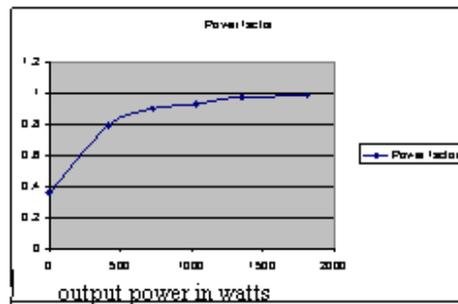


Figure 6: Power Factor Characteristics with 350 V supply.

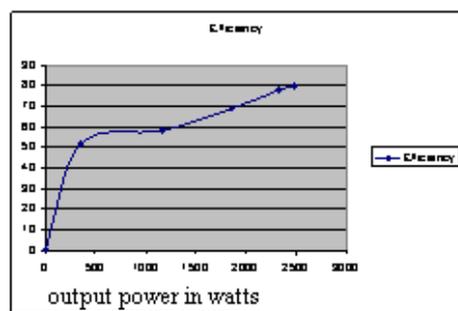


Figure 7: Efficiency Characteristics with 415 V supply.

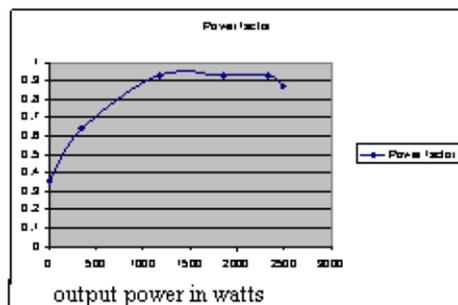


Figure 8: Power Factor Characteristics with 415 V supply.

Flow Chart

The flow chart shown in Figure 9 explains the operation of controller circuit of TWIM. Initially the stator winding is energized with 415 V so as to meet the starting current. Once the rotor attains the rated speed, the controller start sensing the load current continuously. When the shaft load is up to one third of the rated capacity, 200 V stator winding is energized and when the load is up to two-third of the rated capacity, 350 V stator winding is energized. When the motor is operated above the two-third capacity 415 V stator winding is energized. The main objective of the switching is to limit the iron losses. Also, from the various testings, for the given load

for the given voltage the efficiency and power factor are maximum. From the controller circuit corresponding voltages are identified the respective stator coils are energized.

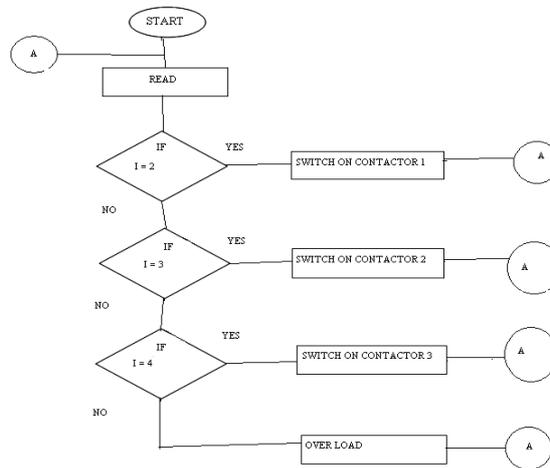


Figure 9: Flow Chart for operation of TWIM.

The block diagram of controller circuit is shown in Figure 10. AC voltage controllers are designed to convert the given three phase supply voltage to the required level of stator voltages. Three relay coils are energized through PIC microcontroller which receives the signals based the shaft load. When the load is up to one-third of rated capacity 200 V stator winding is energized.

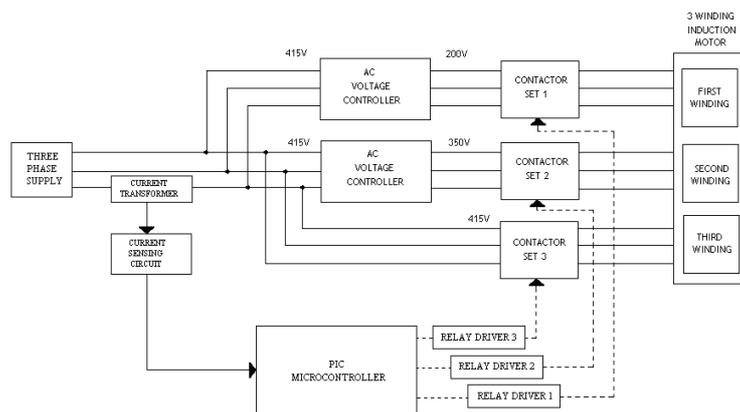


Figure 10: Block diagram of Control Circuit of TWIM.

Optimum utilization of the TWIM

Though the machine is designed with controller circuit to obtain near about flat efficiency characteristics, another mode of operation of the machine is also possible.

If 415 V stator winding is energized, the machine can be loaded to its rated capacity of 4.5 A. A three phase EMF of 350 V and 200 V is generated in the other two windings, to which external electrical load can be connected. Further these voltage outputs can be further converted to charge the battery through which interruptible power can be tapped.

Conclusion

A 2.2 kW, 3-phase, 4-pole, 1440 rpm, TWIM has been designed, fabricated and tested successfully. The experimental results illustrate the improvement of efficiency and power factor over the conventional induction motors. When the load current is about 2.6 A, and the machine operated with 415 V supply. the corresponding power factor is less than 0.7 and the efficiency is less than 58%, where as for the same load, when the stator is fed from 200 V supply, the efficiency is 79% and the power factor is 0.88. Similarly, when the load current is 3.6 A, the efficiency is 75%, where as efficiency is 70% when the supply is 415 V. From the other mode of operation, by utilizing the electrical output from the remaining two windings to feed electrical loads, the industry's dependency on separate supply to the loads is reduced. The three winding induction motor can be employed, where the induction motor runs continuously for a longer period of time like textile industries and manufacturing units. The out put power from the other two windings can be used for charging the batteries, there by allowing the UPS system to supply lighting loads.

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