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# Dual Winding Concurrent Machine: Performance and Parametric Analysis

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ABSTRACT

Synchro machines are generally employed for constant speed applications. An attempt is made in this project to improve the efficiency and power factor of synchronous machine and also to conserve energy. A 3kw, 415V, 1500 rpm Double winding synchronous machine (DWsyM) has been designed, fabricated and tested. The stator consists of two sets of 3 phase winding in the same core. Since the machine always runs at synchronous speed the terminal voltage at the secondary winding is always maintained constant. A separate DC source is required to excite field winding of synchronous machine. There are various methods exciting the field winding. In double winding synchronous machine excitation process become simple compared to any other methods. One of the 3 phase stator winding is energized by a 3 phase supply. Separate DC source is not required for field winding. Load tests with various combinations of electrical and mechanical loads have been conducted. Experiment results prove improvement in the efficiency and power factor to great extent compared to induction and reluctance motor. Since the load connected to second set of winding is not dependent on separate supply, the power tapped from this winding is considered as energy conservation. This type of machine can be employed where the machine is expected to run continuously. In addition to performance improvement, energy conservation is also obtained.

Keywords: DW Synchronous machine, Power factor and Efficiency.

## 1. INTRODUCTION

Conventional induction motor consists of only one set of winding in its stator and DWIM consists of two sets of windings in the same stator. A three phase supply is applied to one of the stator windings, a revolving magnetic field is developed in the air gap and this field is shared by both windings. Two separate windings with displaced angle between them are provided in the same stator for the improvement in efficiency. The behavior of an alternator with two three phase stator windings displaced by an angle is analyzed by means of an orthogonal transformation (Fuchs1974). Weber (1992) represented a dual stator induction motor for energy conservation which consists of two sets of RUN windings. Out of two sets of windings, one set of RUN winding is energized to have sufficient MMF to meet the reduced mechanical load, thereby the flux density in stator core reduces, reduced eddy current losses and copper losses. Depending on the shaft load of the machine, second set of RUN winding is excited through a power source.

## 2. DESIGN OF DOUBLE WINDING INDUCTION MOTOR

In a double winding induction motor, when one of the windings is connected to a three phase supply, a revolving magnetic field of constant magnitude is developed in the air gap. This 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 set of winding to which electrical load can be connected to work as an Induction alternator.

## 3. REPRESENTATION OF DWIM

Razik (2006) explained that the stator windings of double winding induction motor can be arranged with different shift angles .In DWIM, shift angle of 60 degrees or zero degrees are the best choice. In the proposed model, to obtain optimum utilization, both the windings are placed with zero degree phase angle displacement between them and the representation of proposed DWIM is shown in Figure3.1.

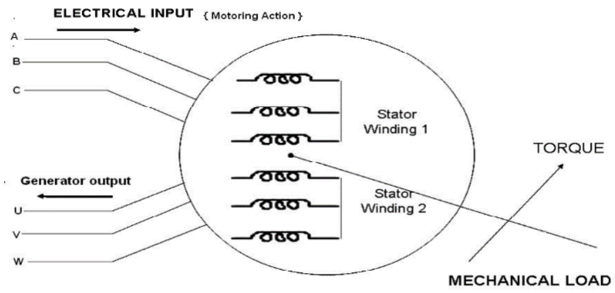



Figure.3.1 Double Winding Induction Motor

***Design Considerations***

Design of the double winding induction motor is affected by various constraints such as thermal limit, over load capacity and utility of stator slots. 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 overloadcapacity.Useofsemi-enclosedslotsresultsinsilentoperation.The stator of DWIM consists of two sets of stator windings placed in the same slot and therefore slot utility is increased. Slot utility factor for designed DWIM is 43.3%whereas for a conventional induction motor, it is about 29%.

***Design of stator***

Design procedure is presented for a 3kW, 415V, 50Hz, Double Winding Induction Motor. Electrical loading, magnetic loading, efficiency and power factor of the machine are chosen as given below:

Flux density in the stator core Bav = 0.44Wb/m2

Electrical loading = 18000ac/m

Efficiency = 80% Power factor = 0.85

Winding factor Kw = 0.9

Output Co-efficient C0= 11xBav x Kw xacx10-3 = 11x 0.44x0.9x18 = 83.2

kVA output of the motor Q = 3/ 0.8x0.85 = 4.41kVA

***The product of the diameter and the length of the core***

D2L = Q/C0  x ns = 4.41/83.2x25 = 2.12x10 3m3

For good overall design ratio

Length of core L = 0.785D

Diameter of the core = 0.139m

Length of the core = 0.11m

DWIM presented here consists of two sets of identical coils in the same stator core. Hence the design of one set is similar to the other.

Stator voltage per phase Vph = 240V

Flux per pole m = (BaxDxL)/ P = 5.28mWb

Turns per phase Tph = Vph/(4.44x50x 5.28x 10-3x0.9) = 228turns

Slot per pole per phase =3

Number of stator slots =36

Slot pitch =D/Ss = x0.139x103/36 = 12mm

Total stator conductors for each winding = 3x2x228 = 1368conductors

Conductors per slot for each winding = 1368/36 = 38

Stator current per phase is = 3x103/3x240x0.8x0.85 = 6.1A

18SWGenameledcoppercoilischosenforthewinding

Diameter of the conductor=1.22mm

Area of Stator conductor=1.17mm2

Current density = 6.1/1.17 = 5.21A/mm2

Area of conductors per slot = 1.17x76 = 88.92 mm2

Area of each slot = 205mm2

Space factor=88.92/205 = 0.433

## 4. PERFORMANCE OF DWIM

One stator acts as a motor and the other as a generator. By controlling the voltage supplied to the generator winding, the rotor speed can be adjusted. One of the stator winding of DWIM is connected to a three phase supply; a revolving magnetic field is developed in the air gap. With respect to first winding, this field interacts with rotor conductors and develops torque to meet mechanical load, where as a three phase EMF is developed in second set of winding to which an additional electrical load can be connected. The main scope of concept is energy conservation, efficiency and power factor improvement at reduced mechanical load of DWIM.

***Load test with Electrical and Mechanical loads***

In the proposed DWIM, both stator windings are of identical nature. In order to obtain performance characteristics as conventional induction motor, one of the windings is connected to a three phase supply and other set of winding is left free .Load test has been carried out with brake drum arrangement and electrical load on second set off winding to study the performance of machine. Experimental set up with both electrical and mechanical loading is shown in Figure 4.1.Table 4.1shows the reading observed considering one set of winding to operate the machine as induction motor to meet the mechanical load and the second set of winding is unloaded. Efficiency and power factor characteristics are shown in Figure4.2. The maximum efficiency of the machine is 83.6% and the corresponding power factor is 0.63.

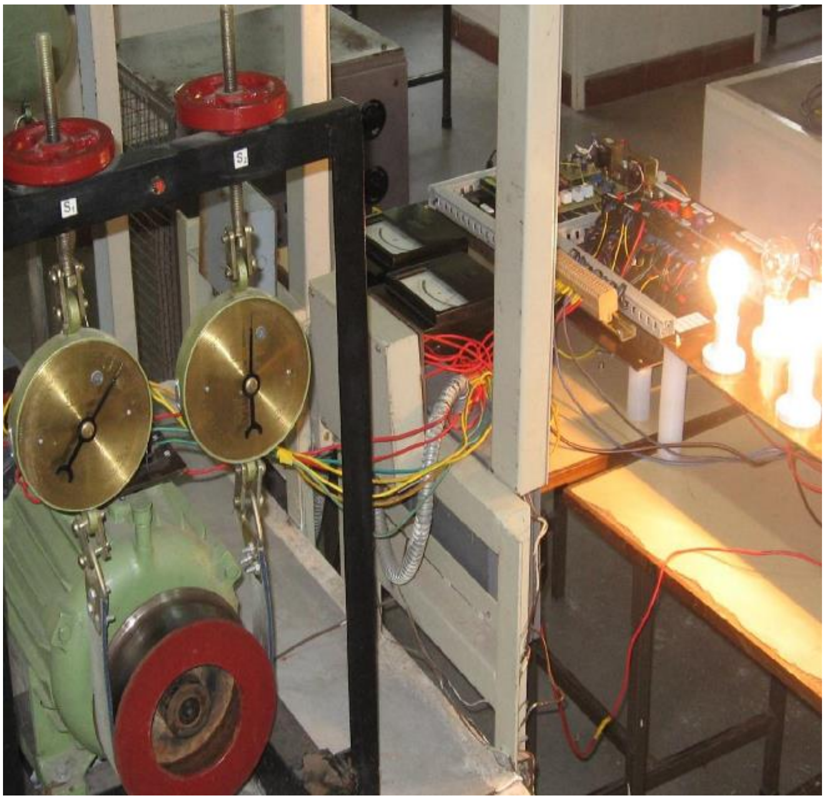


Figure 4.1 Experimental Setup

Table 4.1 Conventional load test

| Input voltage | Line current | Input power(W) | Speed in rpm | Torque in Nm | Output power (W) | %Efficiency | Power factor | %Slip |
|---|---|---|---|---|---|---|---|---|
| 415 | 2.5 | 480 | 1466 | 0 | 0 | 0 | 0.27 | 2.3 |
| 415 | 3.0 | 720 | 1458 | 3.6 | 549 | 76.3 | 0.33 | 2.8 |
| 415 | 3.5 | 1240 | 1448 | 6.4 | 968 | 78.1 | 0.49 | 3.5 |
| 415 | 4.0 | 1680 | 1442 | 9.1 | 1368 | 81.4 | 0.58 | 3.9 |
| 415 | 4.5 | 2040 | 1438 | 11.3 | 1705 | 83.6 | 0.63 | 4.1 |
| 415 | 5.0 | 2250 | 1426 | 12.2 | 1814 | 81.6 | 0.63 | 4.9 |
| 415 | 5.5 | 2880 | 1416 | 15.7 | 2320 | 80.6 | 0.73 | 5.6 |
| 415 | 6.0 | 3360 | 1408 | 18.1 | 2672 | 79.5 | 0.78 | 6.1 |

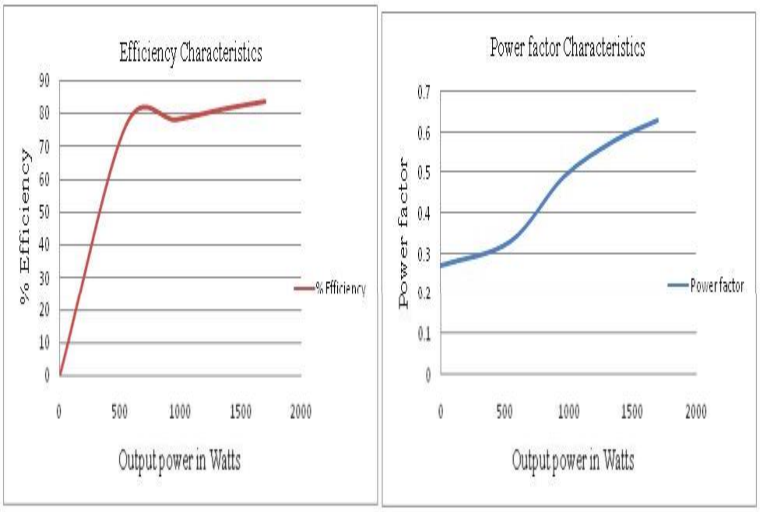
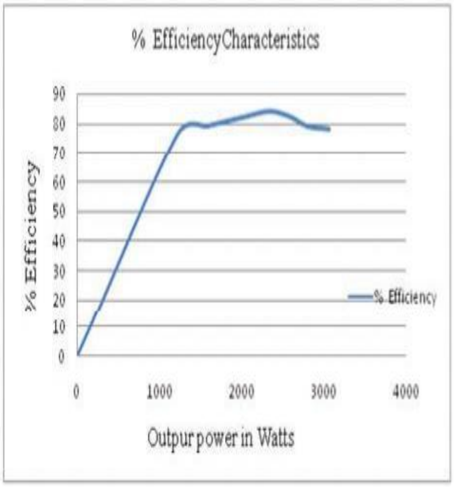
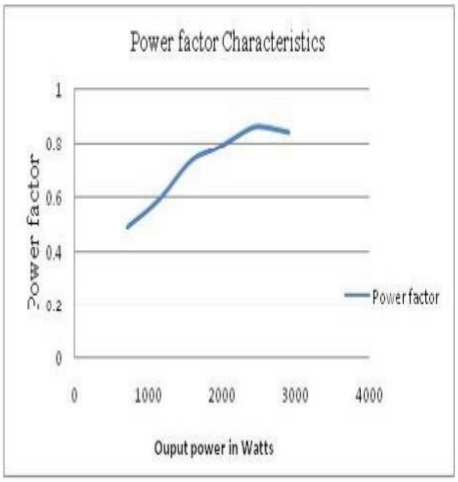



Figure 4.2 Efficiency and power factor Characteristics (DWIM)

| Voltage(V) | Line current(A) | Input power(W) | Speed(rpm) | Torque(Nm) | Mechanical output (W) | Electrical output(W) | Total output(W) | %Efficiency | Power factor | %Slip |
|---|---|---|---|---|---|---|---|---|---|---|
| 415 | 2.4 | 840 | 1480 | 0 | 0 | 720 | 720 | 85 | 0.49 | 0.93 |
| 415 | 3.0 | 1380 | 1470 | 2.3 | 354 | 720 | 1074 | 78 | 0.64 | 1.60 |
| 415 | 3.5 | 1840 | 1468 | 5.6 | 859 | 720 | 1579 | 86 | 0.73 | 2.13 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 415 | 4.0 | 2240 | 1458 | 8.0 | 1220 | 720 | 1940 | 86 | 0.78 | 2.80 |
| 415 | 4.5 | 2760 | 1452 | 10.8 | 1640 | 720 | 2360 | 85 | 0.85 | 3.20 |
| 415 | 5.0 | 3080 | 1444 | 12.0 | 1810 | 720 | 2530 | 82 | 0.86 | 3.73 |
| 415 | 6.0 | 3640 | 1420 | 14.7 | 2185 | 720 | 2905 | 80 | 0.84 | 4.93 |




Test performance have been compared with IEC60034-30, it is observed that the standard efficiency for 3kW, 4-pole induction motor is

81.5%, but in tested machine efficiency is 79.9%.DWIM consists of two identical windings, when a three phase 415V supply is applied to one winding, the same magnitude of 415V is induced in second winding .A lamp load is used to test the machine whose power factor is unity. Table 4.2 shows the reading observed with1A electrical load on second set of winding in addition to the mechanical load. Efficiency and power factor characteristic are shown in Figure4.3.The maximum efficiency of the machine is 86% and the corresponding power factor is 0.78.

Table 4.2 Mechanical load with1A Electrical Load

| Voltage(V) | Line current(A) | Input power(W) | Speed(rpm) | Torque(Nm) | Mechanical output (W) | Electrical output(W) | Total output(W) | %Efficiency | Power factor | %Slip |
|---|---|---|---|---|---|---|---|---|---|---|
| 415 | 2.4 | 840 | 1480 | 0 | 0 | 720 | 720 | 85 | 0.49 | 0.93 |
| 415 | 3.0 | 1380 | 1470 | 2.3 | 354 | 720 | 1074 | 78 | 0.64 | 1.60 |
| 415 | 3.5 | 1840 | 1468 | 5.6 | 859 | 720 | 1579 | 86 | 0.73 | 2.13 |
| 415 | 4.0 | 2240 | 1458 | 8.0 | 1220 | 720 | 1940 | 86 | 0.78 | 2.80 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 415 | 4.5 | 2760 | 1452 | 10.8 | 1640 | 720 | 2360 | 85 | 0.85 | 3.20 |
| 415 | 5.0 | 3080 | 1444 | 12.0 | 1810 | 720 | 2530 | 82 | 0.86 | 3.73 |
| 415 | 6.0 | 3640 | 1420 | 14.7 | 2185 | 720 | 2905 | 80 | 0.84 | 4.93 |

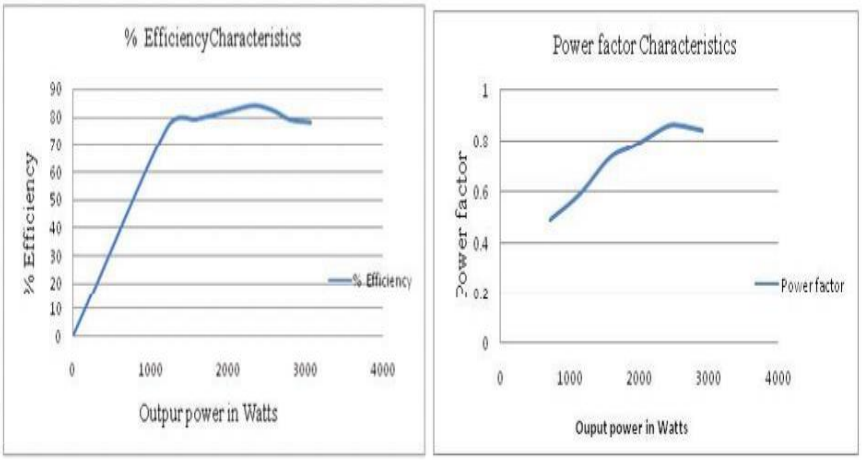



Figure 4.3 Efficiency and power factor with 1A Electrical load (DWIM)

Table 4.3 shows the reading observed with 1A electrical load with capacitor across the load and efficiency and power factor characteristics is shown in Figure 4.4.When a capacitor of 20µF is included across the load, the maximum efficiency increased to 85.8% and the corresponding power factor is improved to 0.94.

Table 4.3 Mechanical load with 1A Electrical Load and Capacitance

| Input Voltage | Line Current(A) | Input Power(W) | Speed in rpm | Torque Nm | Mechanical Output(W) | Electrical Output(W) | Total Output(W) | %Efficiency | Power Factor |
|---|---|---|---|---|---|---|---|---|---|
| 415 | 2.7 | 1800 | 1440 | 6.6 | 994 | 480 | 1474 | 81.8 | 0.93 |
| 415 | 3.1 | 2080 | 1435 | 8.0 | 1207 | 520 | 1727 | 83.0 | 0.93 |
| 415 | 3.6 | 2440 | 1435 | 10.5 | 1573 | 520 | 2093 | 85.8 | 0.94 |
| 415 | 4.1 | 2780 | 1420 | 12.4 | 1838 | 520 | 2358 | 84.8 | 0.94 |
| 415 | 4.7 | 3160 | 1410 | 14.2 | 2097 | 520 | 2617 | 82.8 | 0.94 |
| 415 | 5.4 | 3660 | 1400 | 16.7 | 2446 | 520 | 2966 | 81.1 | 0.94 |

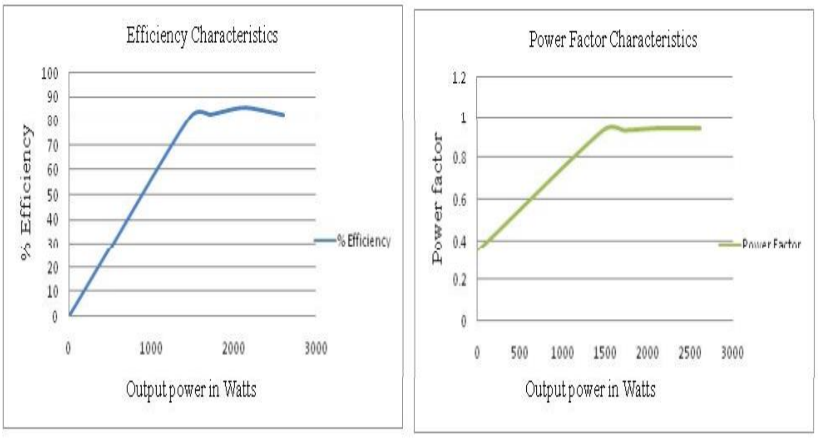



Figure 4.4 Efficiency and power factor with 1A load and capacitor (DWIM)

Table 4.4 shows the reading observed with 2Aelectrical load on the second set of winding in addition to the mechanical load and the corresponding performance characteristics is shown in Figure 4.5.The maximum efficiency of the machine is84% and the corresponding power factor is 0.85.

Table 4.4 Mechanical Load with 2A Electrical Load

| Input Voltage | Line Current(A) | Input Power(W) | Speed in rpm | Torque in Nm | Mechanical Output (W) | Electrical Output(W) | Total Output(W) | %Efficiency | Power Factor |
|---|---|---|---|---|---|---|---|---|---|
| 415 | 3.0 | 1560 | 1488 | 0 | 0 | 1200 | 1200 | 77 | 0.72 |
| 415 | 4.0 | 2360 | 1472 | 4.9 | 756 | 1200 | 1956 | 83 | 0.82 |
| 415 | 4.5 | 2680 | 1464 | 7.9 | 1203 | 1200 | 2403 | 90 | 0.83 |
| 415 | 5.0 | 3040 | 1452 | 8.8 | 1342 | 1200 | 2542 | 84 | 0.85 |
| 415 | 5.5 | 3440 | 1438 | 10.8 | 1624 | 1200 | 2824 | 82 | 0.87 |

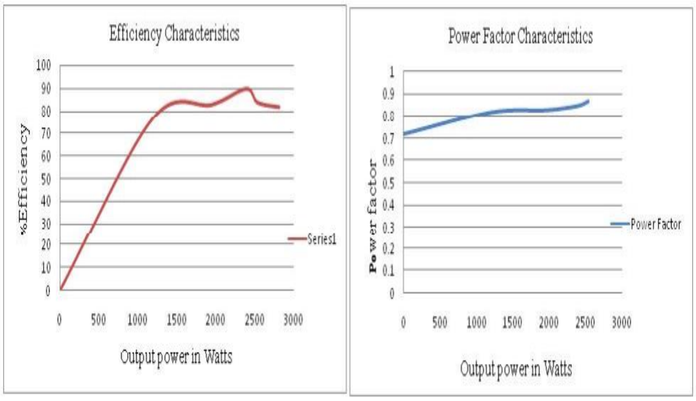



Figure 4.5 Efficiency and power factor with 2A Electrical load (DWIM)

Table 4.5 shows the reading observed with 3Aelectrical load on the second set of winding in addition to the mechanical load and the corresponding performance characteristics is shown in Figure 4.6.The maximum efficiency of the machine is 92% and the corresponding power factor is 0.91.

Table 4.5 Mechanical load with 3A Electrical Load

| Input Voltage | Line Current(A) | Input Power(W) | Speed in rpm | Torque Nm | Mechanical Output(W) | Electrical Output(W) | Total Output(W) | %Efficiency | Power Factor | %Slip |
|---|---|---|---|---|---|---|---|---|---|---|
| 415 | 3.7 | 2480 | 1474 | 0 | 0 | 2125 | 2125 | 86 | 0.93 | 1.7 |
| 415 | 4.0 | 2640 | 1460 | 2.0 | 301 | 2125 | 2426 | 92 | 0.91 | 2.7 |
| 415 | 4.5 | 3120 | 1452 | 3.7 | 715 | 2125 | 2840 | 91 | 0.96 | 3.2 |
| 415 | 5.0 | 3480 | 1440 | 6.6 | 1035 | 2125 | 3160 | 90 | 0.97 | 4.0 |
| 415 | 5.5 | 3920 | 1430 | 9.4 | 1410 | 2125 | 3535 | 90 | 0.99 | 4.7 |
| 415 | 6.1 | 4360 | 1426 | 11.6 | 1728 | 2125 | 3853 | 88 | 099 | 4.9 |

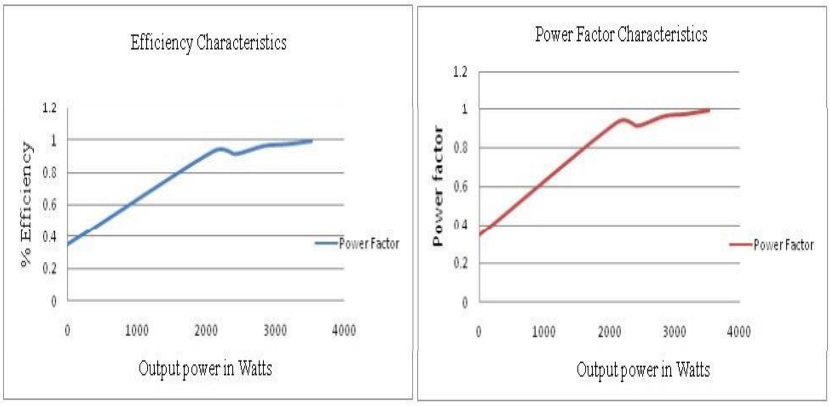



Figure 4.6 Efficiency and power factor with 3A Electrical load (DWIM)

Table 4.4 corresponds to the reading with 2Aelectrical load in the second winding and Table 4.5 shows the reading with 3A electrical loading the second winding. The efficiency and power comparison is shown in Figure 4.7. Main focus of this concept is to improve efficiency and power factor when the machine is lightly loaded with mechanical output. When operated as a conventional induction motor for a load current of 3A, efficiency is 76.3% and power factor 0.33.For the same load current, electrical load of 720W is added in the second winding and hence efficiency is improved to 78% and power factor to 0.64.With a capacitor of 20μF across the load, efficiency is improved to 83% and power factor to 0.93.

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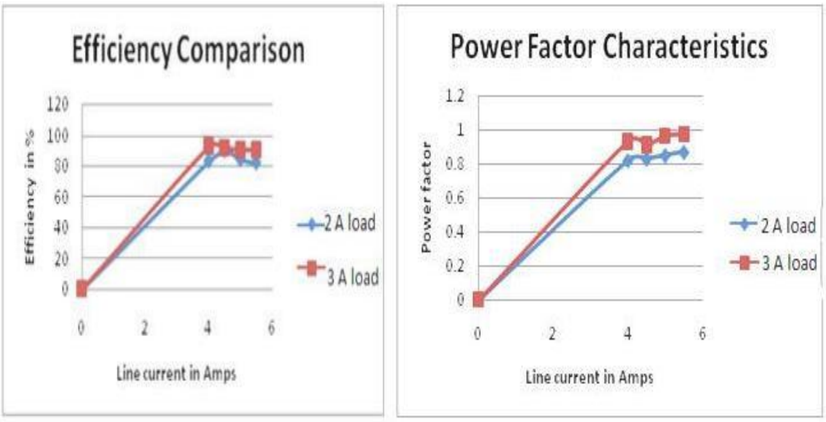


Figure 4.7 Efficiency and power factor comparison for 2A and 3A (DWIM)

## 5. CONCLUSION AND FUTURE WORKS

A 3 kW, 3- phase, 4- pole, 1500 rpm, 415 V Double Winding Induction motor has been tested. When the machine is operated as conventional induction motor, the maximum efficiency and power factor are 76.33% and 0.33. When an electrical load is connected in the second winding, the efficiency and power factor are improved to 83% and 0.93. By utilizing the electrical output from the second set of winding, dependency on separate supply to the connected load to this winding is reduced. The Double Winding Induction Motor can be employed, where the induction motors run continuously like in textile industries and manufacturing units. As a future scope, a DC shunt motor is coupled with this double winding induction motor to act as a dual alternator machine to find out regulation and embedded control systems drives are to be used. The output power from the machine can be used for charging the light loads and power loads.

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