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RESEARCH ARTICLE

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DESIGN AND DEVELOPMENT OF MULTI-FLUX INDUCTION MOTOR FOR HIGHER EFFICIENCY IN PART-LOAD CONDITIONS

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ABSTRACT

Three-phase Squirrel Cage Induction Motors (SCIMs) are widely used in industrial and domestic applications hence minimization of electrical energy consumption through a better motor design becomes a major concern. In multiflux winding induction machine (MFIM), motor performance can be maximized in terms of both efficiency and power factor by properly regulated magnetizing flux as a function of load. A 3Hp MFIM is developed which consists of a standard squirrel-cage rotor and a stator with two separate identical coils sharing same position in stator slots wound for a similar number of poles. Multiflux winding can be connected either in series or in parallel which give rise to Multi-flux, the stator current distribution will be simultaneously coupled with the rotor to produce the desired torque. Multi-flux level motor is proposed with different possible winding connections, which allow the magnetizing flux to be regulated, among all the possible stator winding connections, six modes were selected and analyzed.

The developed MFIM is tested under all loading condition and the results are compared with standard 3Hp SCIM. From the comparison it is observed that under all loading conditions MFIM show a better efficiency and power factor then SCIM thereby it improves the performance of induction machine.

Keywords : Multiflux induction motor, Delta Parallel, Star Series, Efficiency ,Power factor.

1.INTRODUCTION

Large part of electrical energy is used in industries, transforms mechanical energy by the electric drives of various machines. Among all electrical machines, Squirrel Cage Induction motors (SCIM) are most commonly used in industry due to their simplicity, rugged structure, cheapness and easy maintainability but, over sized SCIMs operate with low efficiency and power factor, which causes a much higher power consumption in manufacturing sector.

An attempt to improve the efficiency even by a small amount will lead to a large economic gain. Adjustable flux motors, with multiple winding connections, can be a solution in variable and fixed load applications to improve efficiency. The objective of this work is to explore the possibility of improving the performance of induction motor by means of power factor and efficiency under all loading conditions.

It is observed that Stator winding consist of two set of coils with star-star / Delta connection change , it is established that there exists a significant possibility for energy saving, on the basis of application of induction motors with star-star/Delta connection change, especially for power up to 30 kW motor (by Miloje c and Jovan c).

In Delta connection, total losses and reactive loads are reduced up to 75-85%. Benefits of such motors would be significant because more than 80% induction motors are light loaded (70% of load). In such manner, motor with two characteristics is attained, it is sufficient to choose one of two possible connections, YY (”double star”) connection or D (”delta”) connection, on the basis of load. Even, with connection change it is possible to adjust to load changes in future.

It is also observed that part load efficiency improvement by controlling stator voltage can be effectively examined by considering slip as the controlled quantity .The linear machine serves as an important initial case and verifies that best efficiency is maintained by keeping slip constant (D.N.Novotny and T.A.Lipo).

A new type of dual stator winding induction machine has been presented, DSIM has a standard squirrel-cage rotor and two stator windings wound for a dissimilar number of poles. The main advantage of the drive is its improved capability to operate at low and zero speeds, maintaining relatively high stator frequencies. This feature is particularly useful for implementation of speed sensor less schemes and it adds a new degree of flexibility to standard control methods currently used in ac drives (Alfredo R Munoz and Thomas A Lipo).

By regulating stator winding voltage magnetizing flux depending upon the load, maximum efficiency could be achieved. To regulate stator winding voltage or flux, multiple winding in stator can be used. By providing this, maximum efficiency could be achieved even at low load conditions by regulating flux (Fernando .J.T.E.Ferreria

2.ANALYSIS OF STATOR WINDING CONNECTIONS

2.1Theoretical Analysis of Stator Winding Connections

MFIM machine with 36 stator slots, with three-phase winding configuration with a double-layer, lap type winding. These coils would be separated into two groups per phase, each consisting of coils (that can be connected in series or parallel) sharing the same position in the stator slots. This would form the six coils A1-A2, A11-A22, B1-B2, B11-B22, C1-C2, C11-C2 (instead of three coils A1-A2, B1-B2, C1-C2 in conventional three phase IM) depicted in the connection of 400V line-line arrangement.

As discussed in the previous chapter, Considering a stator winding with two sets of turns (or groups, which can be connected either in series or in parallel) sharing the same positions in the stator slots, several connection combinations are possible, depending on the current and voltage requirements these arrangements are namely :

- Delta-Parallel (DP)
- Star-Parallel (YP)
- Delta-Series (DS)
- Star-Series (YS)
- Star-Delta (YD)

The entire connection diagram for the above said connections are shown below. In the figure the set of turns is represented in triangle and the direction of flux is represented by an arrow inside. R, Y, B represent (3 phase supply) R-phase, Y-phase and B-phase respectively. Line voltage is represented as V_{LL} and winding voltage as V_w, I_w denotes per unit winding current, I_L denotes line current (all being rms).

Even though same line voltage is applied to all arrangements, each arrangement differ by its own winding voltage Vw and flux generated. The voltages between the terminals of each set of turns (or group) of the same phase have the same phase angles, because they share the same flux path in the stator core. In the line-to-line voltage estimation for each connection mode, it was assumed nominal magnetizing flux and winding symmetry (same number of turns for all groups). In Table, the calculation of the resultant line-to-line voltage and change in flux for the six selected connections is shown.

Assuming a symmetrical voltage supply system with constant frequency and without distortion, and neglecting the stator winding leakage inductance and resistance, the average fundamental magnetizing flux per pole and phase φ of an induction motor under no-load operation is approximately given by

$$\Phi \; \alpha \; V_w$$

2.2 Delta-Parallel

The first connection to be analysed is Delta-parallel, this is chosen as reference connection. DP connection is said to be delta connection with two set of turns connected in parallel as shown in figure.2.1 Another reason for considering DP as a reference connection is the line voltage V_{LL} and winding voltage V_w are equal.

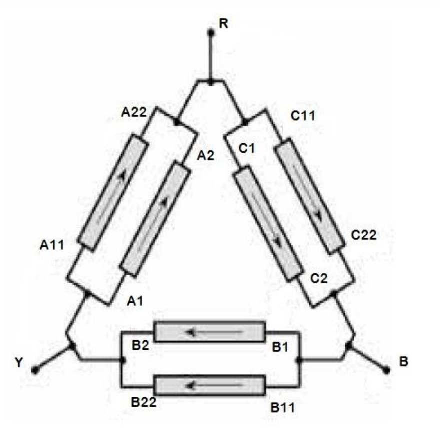

Figure.1.1 Delta parallel

In three phase delta connection phase line voltage is equal to phase voltage. In parallel circuit voltage remains same. Since the coils are identical (equal resistance) the voltage drop in the both coils are equal. Hence the line voltage V_{LL} is equal to the voltage between the coils (winding voltage)

$V_{LL} \quad = \quad V_w$

$V_w \quad = \quad 400V$

Flux value of delta parallel connection

$\Phi_{DP} \quad = \quad 400 / (4.44f\, T_{ph}\, k_w)$

$\Phi_{DP} \quad = \quad 7.54$ mWb

Three phase delta connection line current is equal to root three times of phase current. In parallel circuit current divides so, the line current I_L divides into two components I_{W1} and I_{W2} Since the coils are identical (equal resistance) the current in the both coils are equal. Therefore the winding current is equal to

For Δ connection,

$I_{L\,(max)} \quad = \quad \sqrt{3} I_w \quad$ (i.e., $I_w = I_{ph}$)

$I_{L\,(max)} \quad = \quad \sqrt{3}\,(I_{W1} + I_{W2})$

$\quad = \quad \sqrt{3} \times 2\, I_{W\,(max)}$

$I_{L\,(max)} \quad = \quad 3.46\, I_{W\,(max)}$

$I_{w\,(max)} \quad = \quad 1.3$ A

2.3 Star-Parallel

SP connection is said to be star connection with two set of turns connected in parallel as shown in figure 2.2

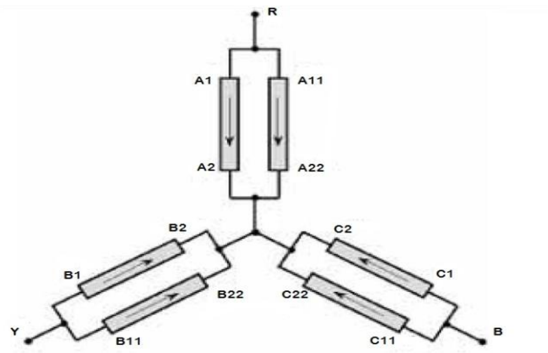

Figure 1.2.Star parallel:

In three phase star connection line voltage is equal to root three times of phase voltage. In parallel circuit voltage remains same. Since the coils are identical (equal resistance) the voltage drop in the both coils are equal. Hence the winding voltage V_W is equal to the voltage between the coils (winding voltage)

$V_{LL} \quad = \quad \sqrt{3} V_w$

$V_w \quad = \quad 231$ V

Flux value of star parallel connection

$\Phi_{SP} \quad = \quad 231 / (4.44f\, T_{ph}\, k_w)$

$\Phi_{SP} \quad = \quad 4.35$ mWb

Three phase star connection phase current is equal to line current. In parallel circuit current divides so, the line current I_L divides into two components I_{W1} and I_{W2} Since the coils are identical (equal resistance) the current in the both coils are equal. Therefore the winding current is equal to

For Y connection,

$I_{L\,(max)} = I_{w\,(max)} \quad$ (i.e., $I_w = I_{ph}$)

$I_{L\,(max)} = (I_{W1} + I_{W2})$

$I_{L\,(max)} \quad = 2\, I_{W\,(max)}$

$I_{w\,(max)} = 2.25$ A

2.4 Delta-Series

DS connection is said to be delta connection with two set of turns connected in series as shown in figure.2.3

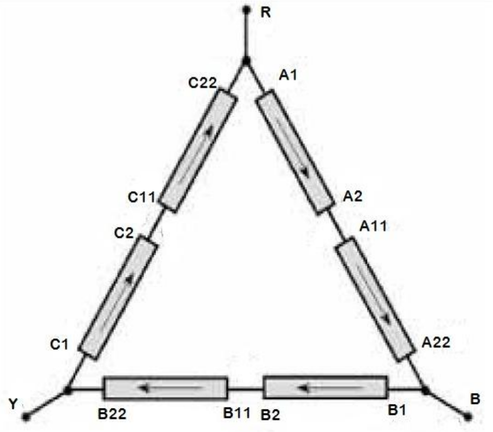

Figure1.3. Delta series:

In three phase delta connection line voltage is equal to phase voltage. In series circuit voltage divides so, the line voltage V_{LL} divides into two components V_{W1} and V_{W2} Since the coils are identical (equal resistance) the voltage drop in the both coils are equal. Therefore the winding voltage is equal to

$V_{LL} = (V_{W1} + V_{W2})$

$V_L = 2\,V_W$

$V_w = 200$ V

Flux value of delta series connection

$\Phi_{DS} = 200 / (4.44f\,T_{ph}\,k_w)$

$\Phi_{DS} = 4.33$ mWb

Three phase delta connection line current is equal to root three times of phase current. In series circuit current remains same. Since the coils are identical (equal resistance) the current in the both coils are equal. Hence the line current I_L is equal to the current in the coils (winding current)

For Δ connection,

$I_{L\,(max)} = \sqrt{3} I_{w\,(max)}$ (i.e., $I_w = I_{ph}$)

$I_L = 1.73 I_{W\,(max)}$

$I_{w\,(max)} = 3.46$ A

2.5 Star-Series

SS1 connection is said to be star connection with two set of turns connected in series as shown in figure 2.4

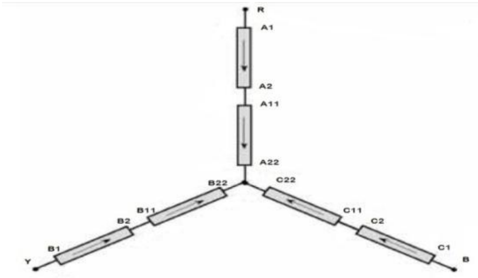

Figure.1.4. Star series

In three phase star connection line voltage is equal to root three times of phase voltage. In series circuit voltage divides so, the line voltage V_{LL} divides into two components V_{W1} and V_{W2} Since the coils are identical (equal resistance) the voltage drop in the both coils are equal. Therefore the winding voltage is equal to

$V_{LL} = \sqrt{3} V_W$

$V_{LL} = \sqrt{3}\,(V_{W1} + V_{W2})$

$V_L = 2\sqrt{3}\,V_W$

$V_W = 115.6$ V

Flux value of star series connection

$\Phi_{SS} = 115.64 / (4.44f\,T_{ph}\,k_w)$

$\Phi_{SS} = 2.18$ mWb

Three phase star connection phase current is equal to line current. In series circuit current remains same. Since the coils are identical (equal resistance) the current in the both coils are equal. Hence the line current I_L is equal to the current in the coils (winding current)

For Y, connection,

$I_{L\,(max)} = I_{w\,(max)}$ (i.e., $I_w = I_{ph}$)

$I_{w\,(max)} = 4.5$ A

2.6 Star-Delta

SD connection is said to be star connection with two set of turns connected in series as shown in figure 2.5

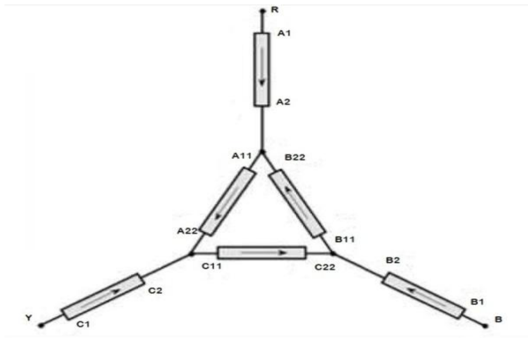

Figure.1.5.Star delta

In three phase star connection line voltage is equal to root three times of phase voltage. Three phase delta connection line voltage is equal to phase voltage

V_L = √7 V_W

V_W = 170 V

Flux value of star delta connection

Φ_{SD} = 170 / (4.44f T_{ph} k_w)

Φ_{SD} = 3.2 mWb

Three phase star connection phase current is equal to line current

For Y, connection,

I_L = I_w (i.e., $I_w = I_{ph}$)

$I_{w\,(max)}$ = 4.5 A

Considering a per-group winding current limit I_w max, which leads to nominal stator Joule losses, the line current limit I_L max can be established, which is presented. Due to line current limits as well as the expected higher stator Joule losses for the same per-phase current few connections are rejected and alternative connections can be selected.

Among all the five selected connections, depending on the motor load profile, some connections can be neglected due to higher losses and their proximity in terms of flux level to the nearest connection modes. For example, the YP connection can be neglected due to its proximity to the DS connections. Delta Series, Star Series and Star Delta are selected, leading to a practical three-flux level motor.

Table 1.1. Maximum Efficiency and Power factor

MFIM connection	Maximum efficiency (%)	Power factor at maximum efficiency
Star series	87	0.78
Delta series	89	0.79
Star delta	89	0.61

In testing of MFIM, electrical parameters such as current, voltage and input power are measured using analog ammeter, voltmeter, and watt meter respectively. Mechanical parameters like load (in kg) and speed are measured using analog spring balance and tachometer respectively. Finally, output power, torque, slip, efficiency where calculated and presented. From above Maximum efficiency and power factor of different connections at is tabulated.

3. Characteristics of MFIM

3.1 Efficiency Characteristics

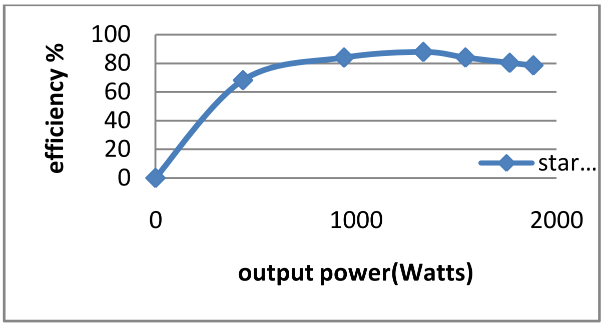

Figure.3.1. Efficiency as a Function of Output Power – Star Series

Star series:

Maximum efficiency of about 87 % is observed around 60% of load. From 45 to 68 % of load, around 85 % efficiency is obtained. Efficiency decreases beyond 70% of load, Full load efficiency 78 %.

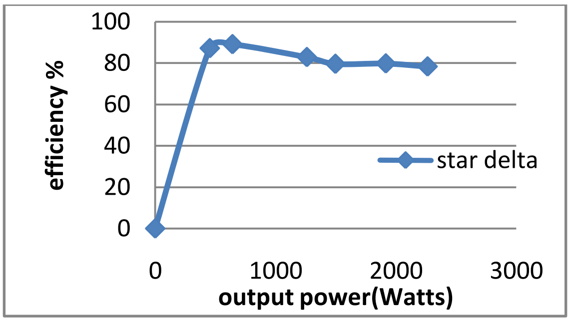

Figure.3.2. Efficiency as a Function of Output Power – Star delta

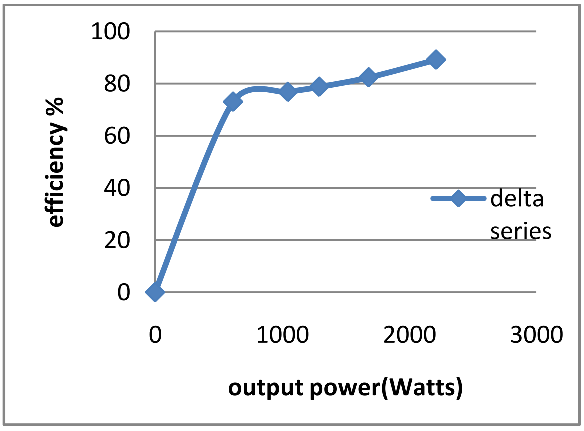

Figure.3.3. Efficiency as a Function of Output Power – Delta Series

Star delta:

Maximum efficiency of about 89 % is observed around 25% of load. From 20 to 60 % of load, around 85 % efficiency is obtained. Efficiency decreases beyond 60% of load, Full load efficiency 78 %.

Delta series:

Maximum efficiency of about 89 % is observed around 100% of load. From 80 to 100 % of load, around 85 % efficiency is obtained.

3.2 Power Factor Characteristics

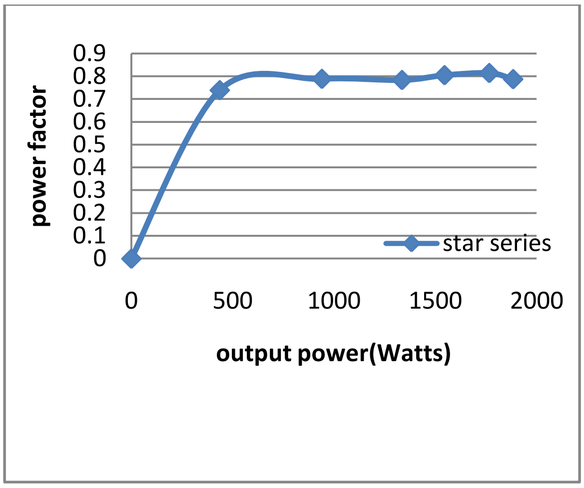

Figure.3.4.Power Factor as a Function of Output Power – Star Series

Star series:

At 80% of load, Maximum power factor of 0.81 is observed. From 60 to full load, power factor around 0.8 is observed.

Delta series:

Power factor linearly increases from on load to full load, at 100% of load, Maximum power factor of 0.79 is observed. From 60 to full load, power factor around 0.75 is observed.

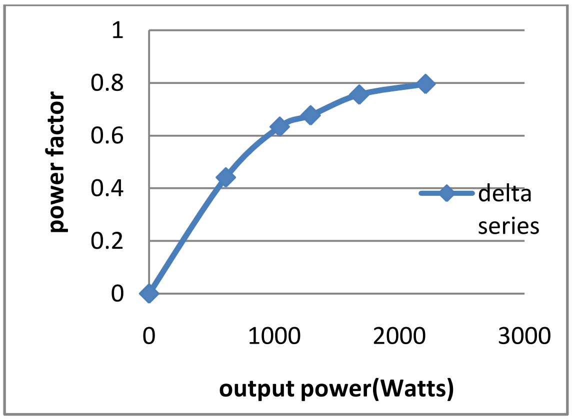

Figure.3.5.Power factor as a function of output power – Delta series

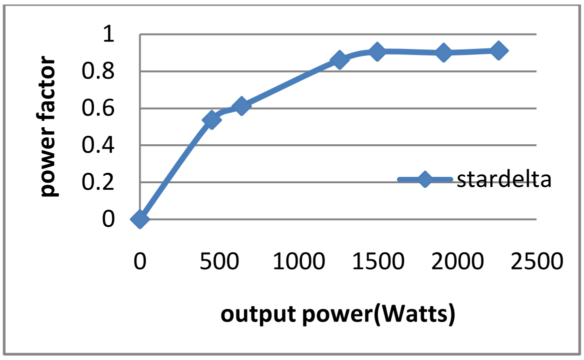

Figure.3.6.Power Factor as a Function of Output Power – Star delta

Star delta:

Power factor linearly increases from on load and become steady near full load, at 70 % of load, Maximum power factor of 0.9 is observed. From 60 to full load, power factor around 0.87 is observed.

3.3 Torque Slip Characteristics

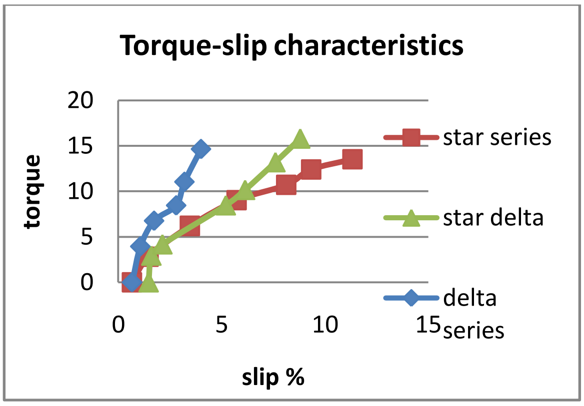

Figure.3.7. Torque Slip Characteristics – MFIM

Star series1:

Maximum slip of this connection is 11.33 at full load and maximum torque of 13.58 N/m at full load is observed. With increase in slip value torque increases proportionally

Delta series:

With slight increase in slip value torque increases rapidly, compared to other connections. At the same time it has the minimum slip value than other connections under full load

Star delta:

It shows intermediate behaviour, Maximum value of slip 8 at full load, Maximum torque 15.79 N/m.

Further analysis of MFIM efficiency characteristics is presented in next chapter.

4. Performance Characteristics

From load test output power, slip, efficiency, power factor are calculated and to know about the performance characteristic of the SCIM, efficiency and power factor is plotted against output power.

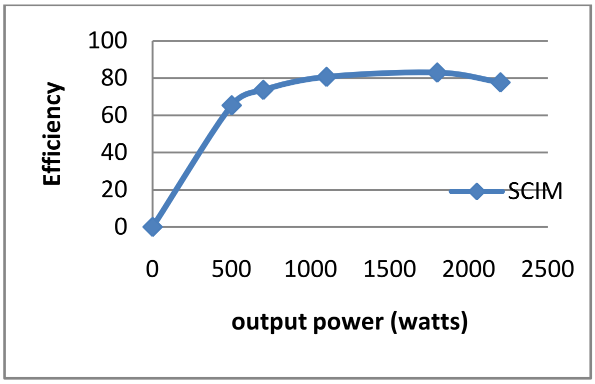

Figure.4.1 Efficiency Vs Output Power – SCIM

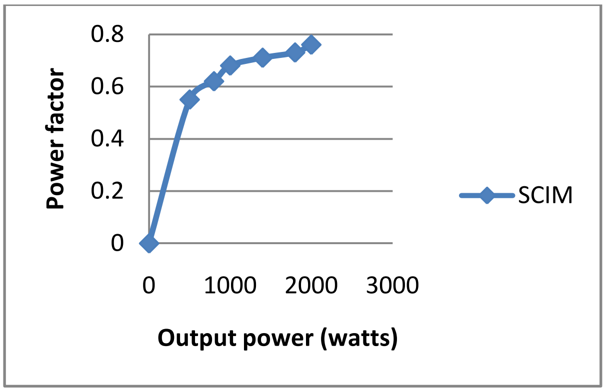

Figure.4.2 Power Factor Vs Output Power – SCIM

5. CHARACTERISTICS COMPARISON

To evaluate the performance of MFIM, efficiency and power factor is compared with the performance of conventional SCIM.

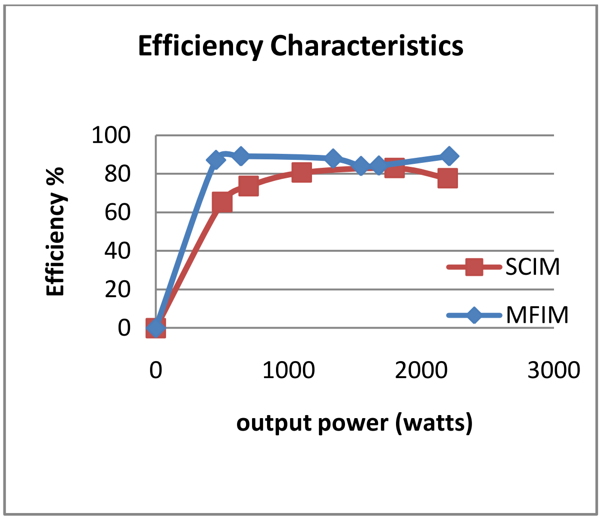

Figure 5.1 Efficiency Comparison

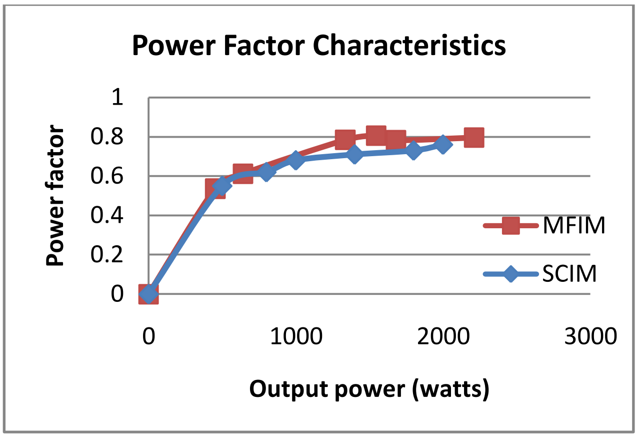

Figure 5.2. Power Factor Comparisons

From the efficiency comparison characteristics, it is clear that starting from no load to full load condition MFIM shows better efficiency than SCIM and it is important to know that at part load condition (below 50% of load) SCIM shows poor efficiency (below 60%) whereas in MFIM show above 80%.

From the power factor comparison characteristics, it is observed that over all power factor of MFIM is a little better than conventional SCIM. Overall in all aspects MFIM show a better performance.

6.CONCLUSION

In this project, the design for a multiflux induction machine was developed. The main aim of this design was in order to improve the reliability of the motor under variable loading conditions. The design maintains the same structure / core for both conventional and the multiflux operations. Thus, by reconnecting the coils available at the terminals, multiflux level operations could be achieved.

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