FABRICATION OF 3-PHASE TO 5-PHASE CONVERSION AND ANALYSIS OF LABORATORY FIVE PHASE INDUCTION DRIVE

B.JYOTHI[1]
Asst. Professor, EEE Department
KL University, Green fields
Vaddeswaram, Guntur (Dist), AP, India
09959209040,jyo9290@gmail.com

DR.M.VENU GOPALA RAO[2]
Professor& Head, EEE Department
PVP Siddhartha Institute of Technology
Vijayawada, AP, India
venumannam@gmail.com

Abstract: *This paper aims at the fabrication of five phase induction drive for laboratory purpose from three phase to five phase transformer connection. Here, five phase drive is proposed rather than conventional three phase drive because by increasing the number of phases torque ripples are reduced hence amplitude of the current is reduced without increasing the voltage per phase therefore it increases the reliability of the system. In five phase drive, failure of one phase, the performance does not degrade to that extent in the three phase drive. Considering these advantages than conventional three phase drive fabricated the induction motor. To facilitate five phase supply, obtained from the transformer setup it takes three phase supply as input and five phase supply as obtained as an output by properly connecting the secondary windings of the transformer. Experimental Results are analyzed both three phase to five phase transformer connection scheme and five phase induction motor drive.*

Key words: *Five Phase Induction Motor Drive (FPIMD), Thee phase to five phase transformer(3Ph-5Ph),Turns Ratio, Phase loss, Unbalanced.*

1. Introduction

The feasibility of a phase order is higher than three, grown in the area of multi-phase machine for high power applications, which are both rugged and energy-efficient. Increased phase number drive acquire a number of advantages than conventional three-phase drives such as: falling the amplitude and rising the frequency of torque pulsation, without raising the voltage per phase, lowering the rotor harmonic currents, current per phase and dc link current harmonics, higher reliability and higher power in the same structure. Hence multi phase induction drives are employed where reliability is required with the great extent such as Electric ship propulsion and hybrid electric vehicles, Air craft's etc.

The research has been in progress for the last two decades only look into the different problems which are associated to utilize the multi-phase machine drives are possible choice by the existing three-phase machine.

The Science and Engineering Research Board (**SERB-DST**) sanctioned a grant for this project(SB/EMEQ-320/2014).

On behalf of multiphase motor drives are concerned, the first proposal was given by Ward and Harrer way back in 1969[1] and since then, the research was slow and steady until the end of the last century. Among the accessible multiphase machines, five-phase induction machines are most likely considered multiphase machine drive in recent research. Here, examine the odd phase drive than even phase. If deal with even phase (i.e. 6, 12, 24….etc), they are likely to be multiples of 3, and operates like a double cage three phase drive. So as to avoid this problem consider only odd number of phases. However, increasing the number of phases certainly increases the difficulty of the system. [2]-[3].

In a squirrel cage induction motor the stator is excited by source and the rotor bars are short circuited. So there is a flexibility of increasing the number of phases in the stator side. Which can be done through three phase to five phase transformer connection scheme. The rotor phases get automatically adjusted.

The proposed block diagram is shown in Fig.1. This paper, elaborates how the conventional three phase transformer provides the output five phase supplies and fabrication of five phase induction motor by traditional three phase induction machine.

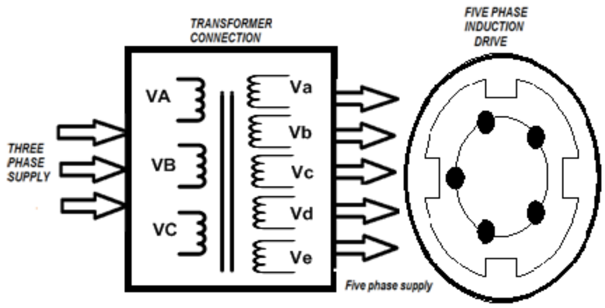


Fig.1.Block Diagram of the Proposed Drive.

2. Fabrication of Laboratory Three Phase To Five Phase Transformer

The transformer primary three phases and secondary five phases can be connected in four different ways**.**

A. Star- Star

B. Star- Polygon

C. Delta- Star

D. Delta-Polygon

The phase difference between the two consecutive phases is 72° and this exact phase difference obtained by properly selecting the turn's ratio [1]. Here conversion is done by considering three multi-winding transformers T-I,T-II,T-III. Each primary winding of three multi-winding transformer has only one winding. Secondary side of T-II and T-III transformers are have three windings and T-I transformer has two windings in case of star connection and three windings in case of polygon connection. The phases are labeled **"A"**, **"B"**, **"C"** of the input supply and **"a"**, **"b"**, **"c"**, **"d"**, **"e"** are the phases of output supply respectively. Balanced three phase supply is given to the input terminals as designated as A, B, and C.V_A, V_B, V_C are the phase to neutral voltages. V_a , V_b, V_c,V_d, V_e are the output phase voltages to neutral. [1]

A. Star-star

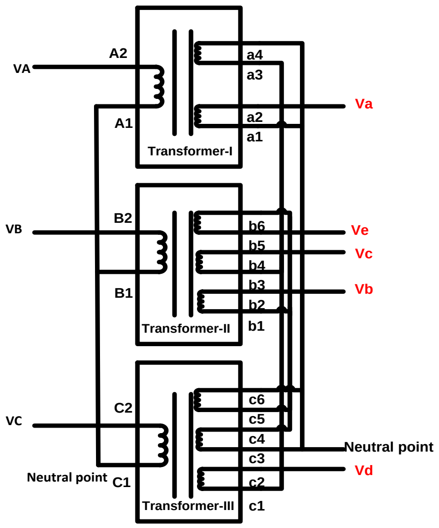


Fig.2.Connection scheme of Transformer in Star-Star mode

In this type of transformer connection scheme, input and output windings are connected in Star-Star fashion, Primary winding of each transformer consists of two terminals, overall Six terminals of primaries and similarly the sixteen terminals of secondary's are connected in star. This scheme of connection is shown in Fig.2.

Phase "A" of the input and phase "a" of the output are in same phase. Phase "b" of the output, obtained from the phasor sum of winding voltage "c_6 c_5" and "b_1 b_2".Similarly "c" , "d" ,"e" output phases are obtained from phasor sum of "a_4 a_3" and "b_4 b_3", "a_4 a_3" and "c_1 c_2", "c_4 c_3" and "b_5 b_6"respectively [1]. By proper connection winding terminals the five phase output would be obtained.

Now, developed the laboratory experimental setup of three phase to five phase transformer with power rating as 2 KVA in star-star mode only by using the connection scheme shown in Fig.2.Dimensions are considered to fabricate 3ph-5Ph transformer shown in Fig.3.Also E&I laminations are shown in Fig.4.Complete experimental setup of 3ph-5Ph transformer shown in Fig.5.

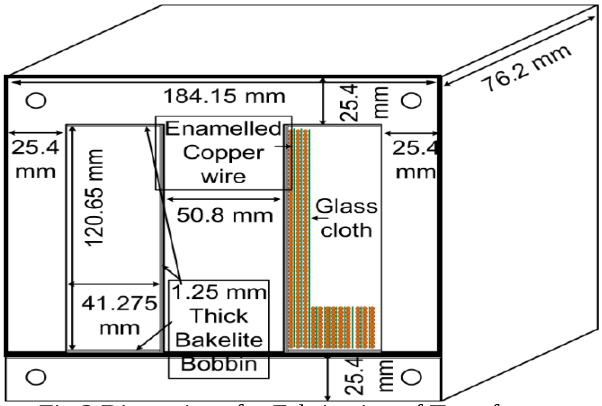


Fig.3.Dimensions for Fabrication of Transformer

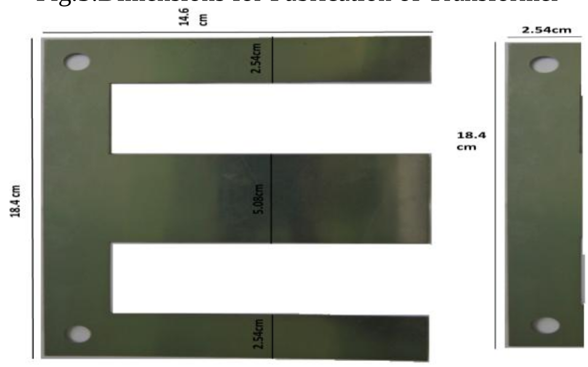


Fig.4.E & I lamination Dimensions used for Fabrication of Transformer

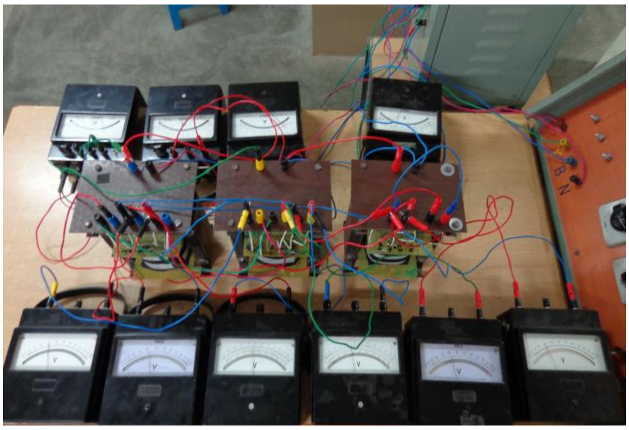


Fig.5.Experimental Setup of Five Phase Transformer

Table I
Turns Ratio's For All Four Types of Transformer Connection Schemes

Primary	Star-Star Secondary	Turns Ratio(N_s/N_p)	Star-Polygon Secondary	Turns Ratio(N_s/N_p)	Delta –Star Secondary	Turns Ratio(N_s/N_p)	Delta-Polygon Secondary	Turns Ratio(N_s/N_p)
Phase – A	$a_1\,a_2$	1	$a_1\,a_2$	1	$a_1\,a_2$	1	$a_1\,a_2$	1
			$a_3\,a_4$	0.47	$a_4\,a_3$	0.47	$a_3\,a_4$	0.47
	$a_3\,a_4$	0.47	a_5a_6	0.47			a_5a_6	0.47
Phase – B	$b_1\,b_2$	0.24	$b_1\,b_2$	0.24	$b_1\,b_2$	0.24	$b_1\,b_2$	0.24
	$b_3\,b_4$	0.68	b_3b_4	0.68	$b_4\,b_3$	0.68	b_3b_4	0.68
	$b_5\,b_6$	0.858	b_5b_6	0.858	$b_5\,b_6$	0.858	$b_5\,b_6$	0.858
Phase – C	$c_1\,c_2$	0.68	$c_1\,c_2$	0.68	$c_1\,c_2$	0.68	$c_1\,c_2$	0.68
	$c_3\,c_4$	0.24	c_3c_4	0.24	$c_4\,c_3$	0.24	c_3c_4	0.24
	c_3,c_5	0.858	$c_5\,c_6$	0.858	$c_5\,c_6$	0.858	$c_5\,c_6$	0.858

B. Star-Polygon

Here supply voltage will be in phase with the primary winding and secondary connected as polygon, phase to phase voltage will appear across the secondary terminals, the output voltage 54° lagging from the primary as well as the supply voltage.

C. Delta-Star

Here, the supply voltage will lead the voltage across the primary winding by 30°.Secondary winding phase-a will be in phase with the primary winding phase-A. As a result the secondary voltage will be lag behind the supply voltage by 30°.

D. Delta-Polygon

Here, Primary winding voltage lags behind the supply voltage by 30° and secondary winding voltage lags behind the primary by 54°. There by a total of 84° phase shift is observed from supply to the secondary side.

Experimental setup of fabricated five phase transformer under rated load in star-star mode shown in Fig.6.Further the 3ph to 5ph transformer fed to five phase induction motor drive.

Fig .6.Experimental Setup of Fabricated Five Phase Transformer under Rated Load Testing.

3. Fabrication of Five Phase Induction Drive

Before going to the fabrication of the drive, modeling the drive by using simulink library, in which the mathematical equations are modeled and used for computations of various inputs. In real time it is difficult for a designer to directly make computations on hardware for required output parameters. So mathematical modeling of the machine helps the designer to observe the output responses for different inputs. Therefore modeling of machines has become such an important tool for machines [4]-[10].

After simulation, Hardware setup of induction motor designed by existing conventional three phase motor to desired phase output by rearranging the copper winding in slots, here the slots are only the multiples of five earlier designed the slots only multiples of three in case of conventional three phase motors.

Fig.7.Stator and Rotor of Three phase induction drive

Fig 7.Shows the squirrel cage rotor and 24 slots,4 -pole stator of three phase induction motor.

By using this motor drive fabricate the five phase induction drive. Here five phase stator core slots are multiple five, so possibility to fabricate 2-pole machine instead of 4-poles. Slots are becomes reduced as 20 for five phases. Four slots are leaving with no winding.

Fig 8.shows the two pole, 20 slots five phase induction drive. Even there is four slots deficiency the drive runs very smoothly. Fig .8.represents the five phase stator with five phase terminals a, b, c, d and e.

Fig8.Slots with copper windings of five phase induction drive

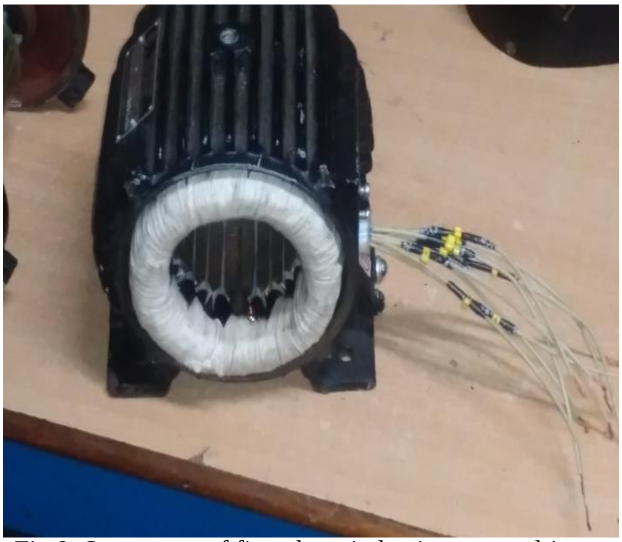


Fig.9. Stator core of five phase induction motor drive

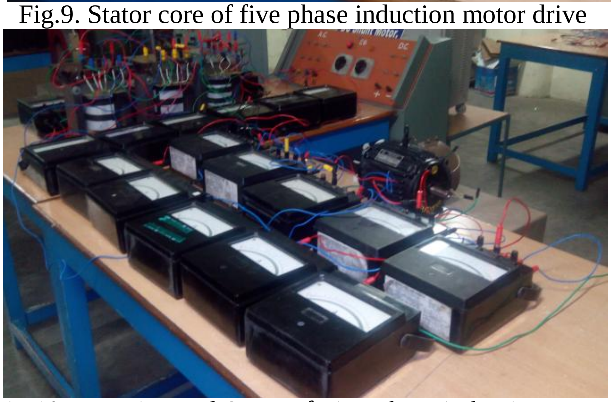


Fig.10. Experimental Setup of Five Phase induction motor drive

4. Results

The proposed work simulated first by using star-star connection of the five phase transformer fed to five phase induction motor drive. Next, the laboratory experimental setup was developed. Both the results are analyzed and shown below under steady state condition and unbalanced condition or phase loss condition.

- Simulation Results of 3ph -5ph Transformer

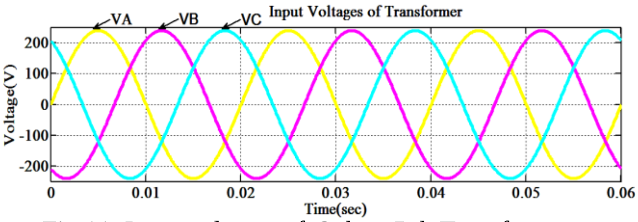


Fig.11. Input voltages of 3ph to 5ph Transformer

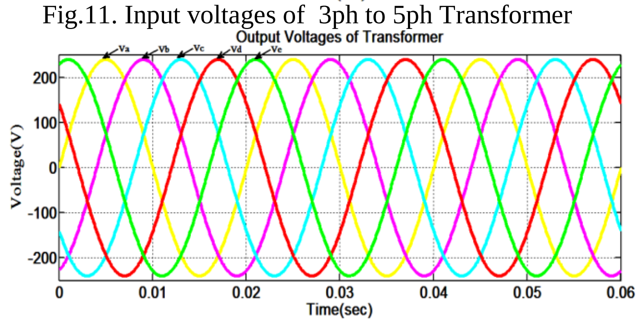


Fig.12. Output voltages of 3ph to 5ph Transformer

Observe the Fig.11 and 12 the phase voltages of input and output voltages are same in star-star scheme of connection i.e.240V/ph.

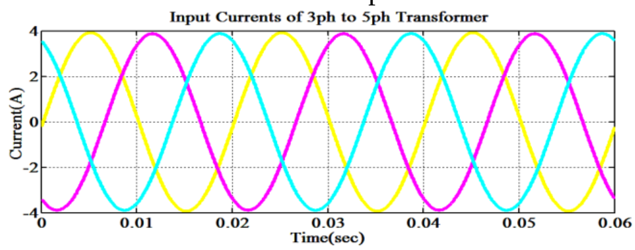


Fig.13. Input currents of 3ph to 5ph Transformer

3ph to 5ph Transformer input currents observed from Fig.13 as 4A.Input no load currents are 3 to 5% of the full load current of the primary. Transformer operated without induction motor drive, hence the output currents are zero.

- Experimental Results of 3ph to 5ph Transformer

Table. II Turns Ratio's of Star-Star Connection

Primary	Secondary	Turns Ratio(N_s/N_p)	
		Theoretical	Practical
Phase –A	a_1 a_2	1	1
	a_3 a_4	0.47	0.47
	b_1 b_2	0.24	0.237
Phase –B	b_3 b_4	0.68	0.669
	b_5 b_6	0.858	0.856
	c_1 c_2	0.68	0.688
Phase –C	c_3 c_4	0.24	0.237
	c_3,c_5	0.858	0.883

Table. III Transformer on No- Load

(a)Input and Output voltages

3-Phase Input Voltages(V)			5-Phase Output Voltages(V)				
V_{AN}	V_{BN}	V_{CN}	V_{an}	V_{bn}	V_{cn}	V_{dn}	V_{en}
240	240	240	240	240	240	240	240

(b)Currents and Power

3-Phase Input Currents(A)			No Load Primary Current(A)			No-Load Power(W)
I_A	I_B	I_C	I_{A0}	I_{B0}	I_{C0}	W_0
4	4	4	0.38	0.36	0.4	116

Table. IV Transformer with Resistive Load

(a)Input and Output voltages

3-Phase Input Voltages(V)			5-Phase Output Voltages(V)				
V_{AB}	V_{BC}	V_{CA}	V_{ab}	V_{bc}	V_{cd}	V_{de}	V_{ea}
415	415	415	282	284	286	285	282
415	415	415	272	276	278	278	276
415	415	415	240	250	264	240	248
415	415	415	222	232	244	222	232

(b)Input and Output Currents

3-Phase Input Currents(A)			5-Phase Output Currents(A)				
I_A	I_B	I_C	I_a	I_b	I_c	I_d	I_e
0.38	0.36	0.4	0	0	0	0	0
6	5.4	5.6	3.3	3.5	3.1	3.5	3.3
10.8	10.3	10.4	6.2	6.6	6.6	6.2	6.5
12.8	12.2	12.2	7.3	7.7	7.6	7.3	7.6

(c)Input, Output and Total power

Total input Powe (W)	5-Phase Output Power (W)					Total Output Power(V
W_i	W_{AN}	W_{BN}	W_{CN}	W_{DN}	W_{EN}	W_0
116	0	0	0	0	0	0
4040	720	760	680	640	720	3520
7680	1220	1360	1340	1200	1340	6460
9120	1400	1520	1480	1360	1488	7248

- Simulation Results Of 3ph -5ph Transformer With Five Phase Induction Motor Drive

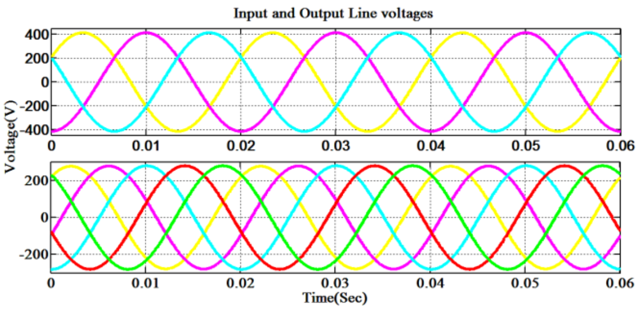


Fig.14. Input and Output Line voltages of 3ph - 5ph Transformer with FPIMD

Observe the Fig.14 the line voltages of input are 415V and output voltages are 283 V for star-star scheme of connection of 3ph to 5ph Transformer with FPIMD.

Table. V Transformer on Load (FPIMD)

(a)Input and Output Line Voltages

3-Phase Input Voltages(V)			5-Phase Output Voltages(V)				
V_{AB}	V_{BC}	V_{CA}	V_{ab}	V_{bc}	V_{cd}	V_{de}	V_{ea}
415	415	415	282	284	286	282	282

(b)Input and Output Currents

3-Phase Input Currents(A)			5-Phase Output Currents(A)				
I_A	I_B	I_C	I_a	I_b	I_c	I_d	I_e
3.1	3.2	3.1	1.8	2.1	1.9	1.9	2

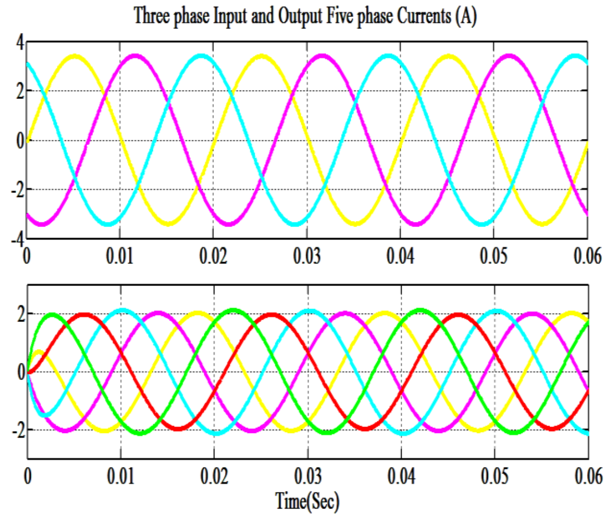


Fig.15. Input and Output currents of 3ph to 5ph Transformer with FPIMD

Observe the Fig.15 the three phase input currents are 3.2A and output five phase currents are 2A for star-star scheme of connection of 3ph to 5ph Transformer with FPIMD.

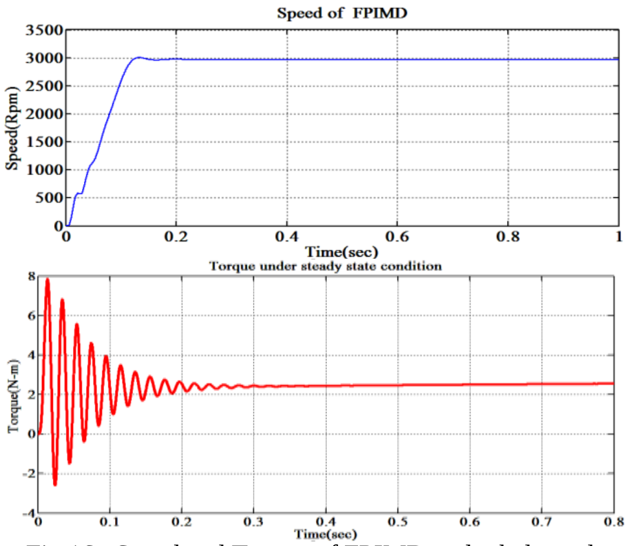


Fig.16. Speed and Torque of FPIMD under balanced condition.

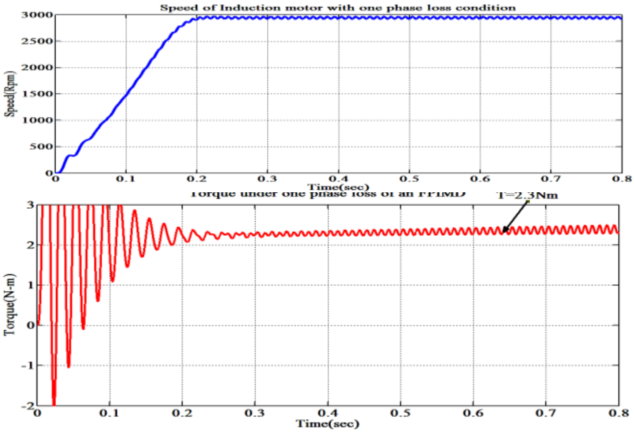
Observe the Fig.16 the rotor speed and no load Torque of the FPIMD are 2985 Rpm as 2.2Nm respectively. The laboratory experimental values are also tabulated in Table.VI and shown below. The settling time of the torque will be o.3Sec.

Table. VI FPIMD Input and Output Powers, Speed and Torque

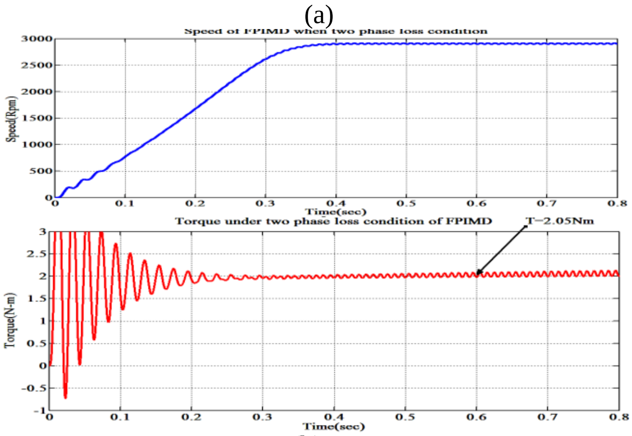
Total input power(W)	Total output power(W)	Speed(Rpm)	Torque(Nm)
920	760	2984	2.43

- FPIMD when phase loss condition

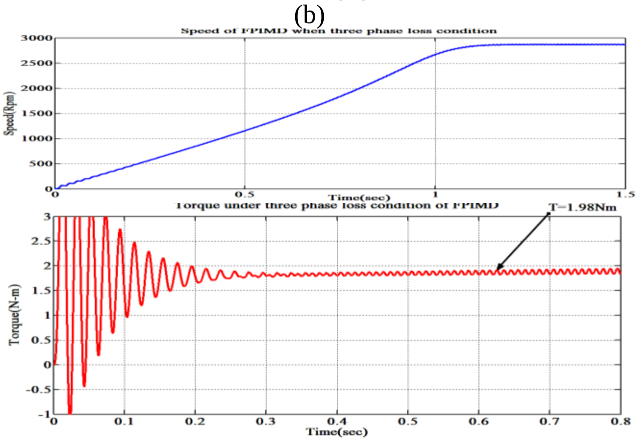
The input and output voltages of FPIMD are same when phase loss condition. Speed and torque are changed slightly, the results are shown both simulated using MATLAB and through experimental setup. Also practical values are tabulated.



(a)



(b)



(c)

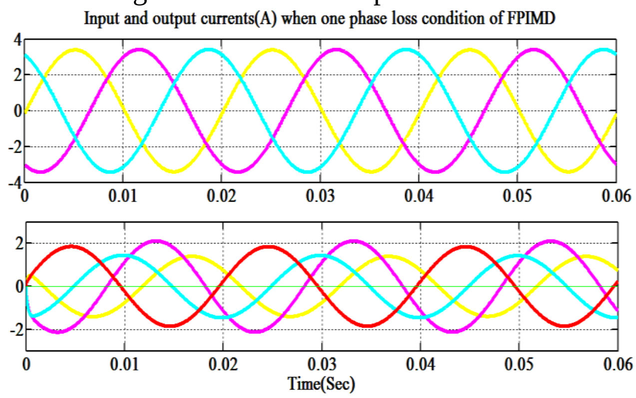
Fig.19. Speed and Torque of FPIMD under (a) one phase (b) two phase (c) three phase loss condition.

Observe the Fig.19 of speed and torque under phase loss condition; there is no much difference even at phase loss of FPIMD. Experimental values are also tabulated in Table VIII. Torque ripple content also reduced by using proposed induction motor drive.

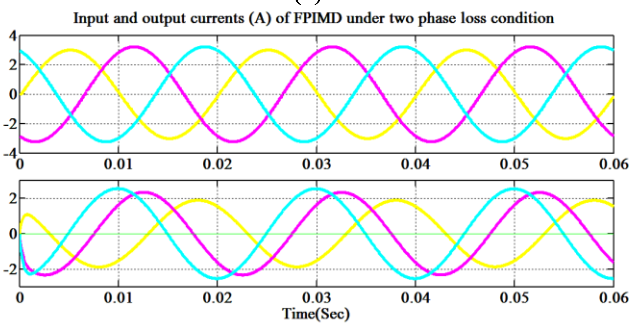
Table. VII FPIMD Speed and Torque under phase loss condition

No. of phase loss	Speed(Rpm)	Torque(Nm)	%Torque
1	2980	2.3	95
2	2972	2.05	84.36
3	2944	1.98	81.48

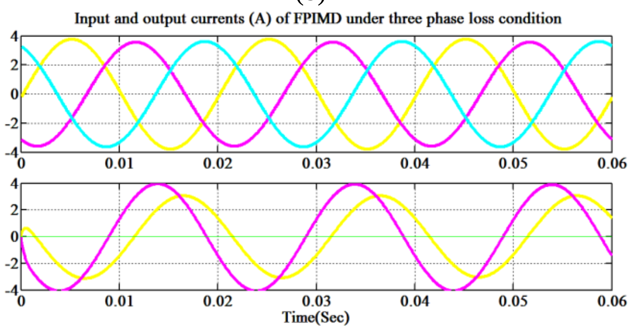
Similarly the input and output currents are also shown below in Fig.20 under different phase loss conditions.



(a).



(b)



(c)

Fig.20 .Input and Output of FPIMD under (a) one phase (b) two phase (c) three phase loss condition.

Observe Fig.20 the input currents are changed slightly but the output currents are increased, without increasing the voltage under phase loss condition; Experimental values are also tabulated in Table VIII.

Table.VIII Input and output currents when FPIMD phase loss condition

No. of phase loss	3-Phase Input Currents(A)			5-Phase Output Currents(A)				
	I_A	I_B	I_C	I_a	I_b	I_c	I_d	I_e
1	3.5	3.6	3.5	1.8	2.2	1.9	2	0
2	2.9	3.4	3.5	2.2	3.2	3.1	0	0
3	3.8	3.8	3.7	3.6	3.4	0	0	0

Observe the Fig.20 of input and output currents under phase loss condition; the performance of FPIMD does not degrade much. Compare Table. III and VIII, the stator currents are increased when phase loss condition. Therefore the advantages of the proposed drive, without increasing the voltage, the stator currents are increased with minimum torque ripple in the drive. Hence the reliability of the drive, get enhanced.

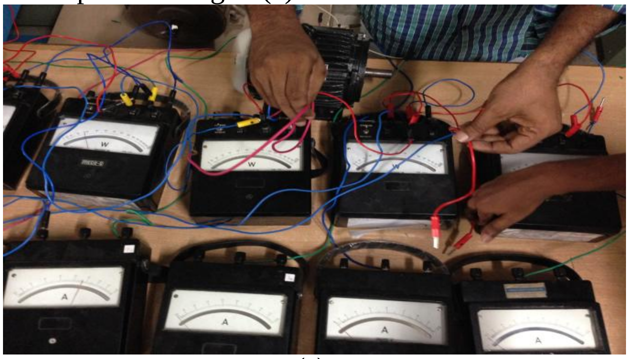
The efficiency and no load power factor (p.f) of same IM with 3 phases and in 5 phase connection are shown in Table IX.

Table.IX Comparison 3ph and 5 Ph Induction Machine Drive Efficiency, No Load Power Factor under Phase Loss Condition

No. of phase loss	3-Phase Induction Machine		5-Phase Induction Machine	
	Efficiency (%)	No-Load p.f.	Efficiency (%)	No-Load p.f.
1	85	0.125	83	0.24
2	--	--	81	0.17
3	--	--	78	0.14

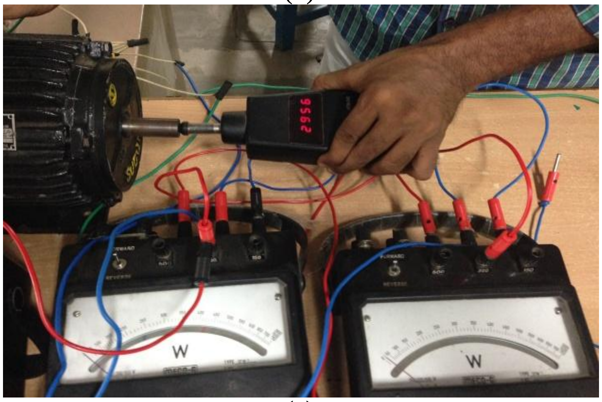
The proposed drive valid under faulty condition i.e. even at failure of phases the performance of the does not degrade. This condition also verified experimental laboratory setup. Different phase loss cases are shown in Fig.21.

Phase a, b, c and d (i.e. lose of phase 'e') are producing a toque pulsations nearly at 2.3Nm and observations are conveniently shown in Fig.21 (a) in zoom mode. After loss of two adjacent'd', 'e' phases, toque pulsations are nearly equal to 2.05Nm and depicted in Fig.21 (b). Later, loss of adjacent phases 'c','d', 'e' toque pulsations nearly at 1.98Nm and depicted in Fig.21(c).



(a)

(b)



(c)

Fig.21 .Laboratory Experimental setup of FPIMD under (a) one phase (b) two phase (c) three phase loss condition.

5. Conclusion

Laboratory type five phase transformer successfully fabricated and tested. Phase and line voltages under no load and load are accurately verified with respect to theoretical calculation done in this paper. Five phase induction motor effectively run at rated speed with input fed from five phase transformer. From results obtained, torque attained by five phase induction motor is superior to conventional three phase induction motor. Also 95% torque if one phase loss, 84% toque at two phases loss and 81% torque even if three phase loss. Also observed, five phase induction motor effectively run at rated speed even if three phases are loss. The compared results from both the simulation and fabricated experimental setup and observe that both are in the significant region.

Appendix

FIVE PHASE INDUCTION MOTOR DRIVE	
power	1HP
Frequency	50 Hz
Line to line voltage	415V
Stator resistance	0.56 ohm
Stator inductance	0.0342 H
Rotor resistance	0.6 ohm
Rotor inductance	0.0342 H
Mutual inductance	0.0298 H
Inertia	0.0345 kg.m^2
Friction	0.0043 N.m.s
Number of poles	2

References

1. Atif Iqbal, Shaik Moinuddin, M. Rizwan Khan, Sk. Moin Ahmed, and Haithen Abu - Rub, "*A Novel Three - Phase to Five - Phase Transformation using a special transformer connection*" IEEE Transactions on power delivering, vol. 25, no. 3, JULY 2010, p. no: 1637 – 1644.

2. E. Levi; Bojoi I.R.; F. Profumo; H.A. Toliyat; S. Williamson "*Multiphase induction motor drives- a technology status review*". (2007).In: IET Electric Power Applications, vol. 1 n. 4, pp. 489-516.- ISSN 1751-8660

3. Emil Levi, Senior Member, IEEE, Martin Jones, Slobodan N. Vukosavic, Member, IEEE, and Hamid A. Toliyat, Senior Member, IEEE"*A Novel Concept of a Multiphase, Multimotor Vector Controlled Drive System Supplied From a Single Voltage Source Inverter*" IEEE Transactions On Power Electronics, Vol. 19, No. 2, March 2004 P. No: 320 – 335.

4. J.MarcelIonel,Mihail-Florin Stan, Elena-OtiliaVirjoghe, "Current Trends on Command, Control, Modeling and Simulation of the Induction Machines," WSEAS Transactions on Systems And Control., Issue 2, Vol. 5,pp.91-101,February 2010.

5. PalakG.Sharma, S. Rangari "*Simulation of Inverter Fed Five Phase Induction Motor*". International Journal of Science and Research (IJSR), India Online ISSN: 2319-7064.

6. Hamid A.Toliyat, *Senior Member*, "*Analysis and Simulation of Five-Phase Variable-Speed Induction Motor Drives under Asymmetrical Connections*" IEEE Transactions On Power Electronics, Vol. 13, No. 4, July 1998.

7. Atif Iqbal, Shaik Moinuddin, M. Rizwan Khan, Sk. Moin Ahmed, and Haithen Abu – Rub "*Modeling, simulation and implementation of a five-phase induction motor drive system*" Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India, 2010 Joint International Conference on 20-23 Dec. 2010 , published in IEEE digital library

8. B. jyothi "*Comparison between specially connected transformer scheme and five leg inverter*",Dec 16-18, INDICON 2011, published in IEEEdigital library.

9. "*Induction Motor Modelling for Vector Control Purposes*", Helsinki University of Technology, Laboratory of Electro mechanics, Report, Espoo 2000, 144 p.

10. P.C.Krause, "*Analysis of electric machinery*" Newyork: Mc. Graw-Hill, 1986. ISBN-13: 978-0070354364.

11. Fatiha Zidani and Rachid Nait Said, "Direct Torque Control of Induction Motor with Fuzzy Minimization Torque Ripple", Journal of Electrical Engineering,Vol.56, No.7-8, pp.183-188, 2005.