Chapter 6

Details of motors, Experimental setup and Voltage waveforms

6.1 INTRODUCTION

Five motors were tested. Out of these five four motors were design and manufactured under the supervision of the author whereas one motor was design and manufactured by other.

The four motors manufactured are having following details.

(1) First motor was design and manufactured for 415 V supply. The rating of this motor is as below: Frame 63, 3-phase, 415 V, 470 W, 1.3 A, 50 Hz, 2-Pole, Class F, Continuous duty Induction motor.

(2) Second motor was design and manufactured for 380 V supply. The rating of this motor is as below: Frame 63, 3-phase, 380 V, 470 W, 1.4 A, 50 Hz, 2-Pole, Class F, Continuous duty Induction motor.

Both above motors are now being used by ABB ltd. in their Isolator operating mechanism drive [72].

(3) Third motor was design and manufactured for 2- pole constructions. The rating of this motor is as below: Frame 71, 3-phase, 415 V, 300 W, 50 Hz, 2-Pole, Class F, Continuous duty Induction motor.

(4) Forth motor was design and manufactured for 4- pole constructions. The rating of this motor is as below: Frame 71, 3-phase, 415 V, 300 W, 50 Hz, 4-Pole, Class F, Continuous duty Induction motor.

Both above motors are now being used by Delmer Products ltd. in their magnetic polisher.

Fifth motor was having following rating: 3-phase, 380 V, 1250 W, 50 Hz, 4-Pole, Class F, Continuous duty Induction motor.

6.2 STAMPING

Motors were manufactured from CRNGO stamping of Grade 47A, having thickness 0.5 mm and maximum core loss of 6.98 W/Kg. at 1.5 tesla. The stampings were manufactured by Steel Authority of India ltd., Rourkela Steel Plant, Rourkela- 769011 –Orissia.

[1],[2] The stamping size for first and second motor was as below:

Frame 63 (IS-1231)

Stator OD = 87 mm

Stator ID = 48 mm

Rotor OD =47.5 mm

Rotor ID = 15 mm

Core Length = 70 mm

Stator slots/Rotor slots = 24/18

[3] The stamping size for third (two pole) motor was as below:

Frame 71 (IS-1231)

Stator OD = 105 mm

Stator ID = 58 mm

Rotor OD = 57.5 mm

Rotor ID = 20 mm

Core Length = 60 mm

Stator slots/Rotor slots = 24/18

[4] The stamping size for fourth (four pole) motor was as below:

Frame 71 (IS-1231)

Stator OD = 105 mm

Stator ID = 63 mm

Rotor OD = 62.5 mm

Rotor ID = 20 mm

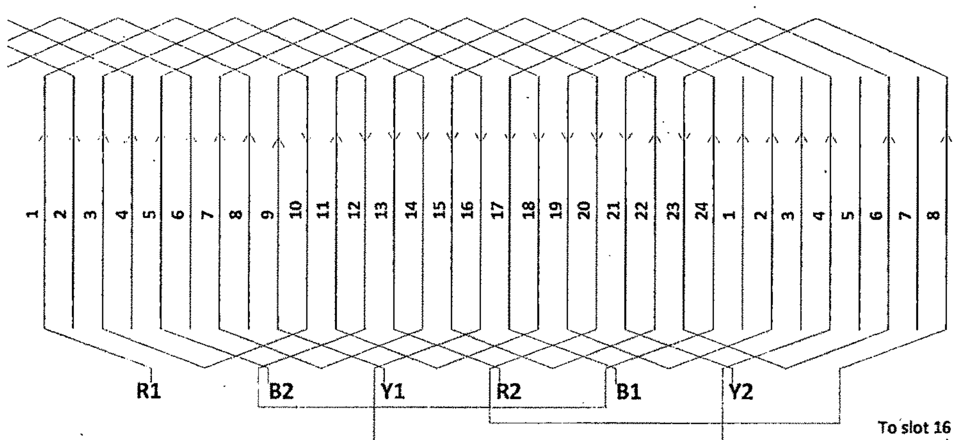
Core Length = 60 mm

Stator slots/Rotor slots = 24/18

6.3 WINDING DETAIL

Stator of first and second motor was wound as per detail given in diagram W – 3. The number of turns per coil was 120 for motor number 3 and 110 for motor number 4. There were four coils in series per phase for all three phases. Two terminals per phase were taken out. The coils were made from dual coated hermetic grade super enameled copper wire of 27 swg. This wire is having fine covering of enamel. The diameter for 27 swg wire is 0.417 mm and with enamel covering diameter is 0.467 mm. The diameter for 28 swg wire is 0.376 mm and with enamel covering diameter is 0.425 mm.

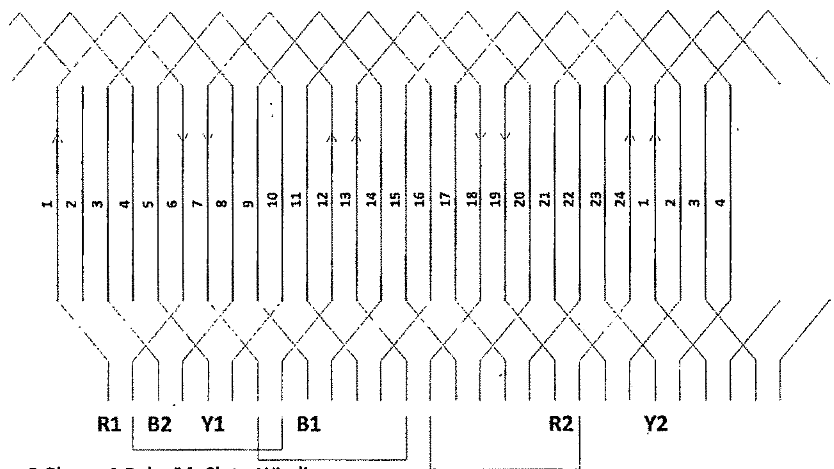
Stator of third (2-pole) motor was wound as per detail given in diagram W – 3. The number of turns per coil was 130. There were four coils in series per phase for all three phases. The terminal at the end of each coil is taken out for the purpose of measuring voltage. Accordingly each phase winding is having five terminals as shown in figure 6.1. The coils were made from dual coated hermetic grade super enameled copper wire of 27 swg. This wire is having fine covering of enamel.



3-Phase, 2-Pole, 24- Slots, Winding
Starts R1 slot 1, Y1 slot 9, B1 slot 17
Ends R2 slot 13, Y2 slot 21, B2 slot 5

Pitch 1 to 10
group is of two coils

Drg. No. W-3



3-Phase, 4-Pole, 24- Slots, Winding
Starts R1 slot 1, Y1 slot 5, B1 slot 9
Ends R2 slot 19, Y2 slot 23, B2 slot 3

Drg. No. W-4

Stator of Fourth (4-pole) motor was wound as per detail given in diagram W – 4. The number of turns per coil was 130. There were four coils in series per phase for all three phases. The terminal at the end of each coil is taken out for the purpose of measuring voltage. Accordingly each phase winding is having five terminals as shown in figure 6.1. The coils were made from dual coated hermetic grade super enameled copper wire of 28 swg. This wire is having fine covering of enamel.

6.4 SLOT INSULATION

Polyester paper of 0.17 mm thickness was used as slot insulation and coil top insulation. There were only one coil side in slot hence coil side separating insulation was not required. Press phan paper of 0.13 mm thickness was used as phase separator on overhang of the coils.

6.5 TERMINAL INSULATION SLEEVE

To protect the winding from voltage surges and to enhance the insulation level near joints of enamel wire and terminal PVC wire, mica sleeve were used. Length of the sleeve was such that it can cover minimum three inch length of enamel wire and two inch length of PVC wire.

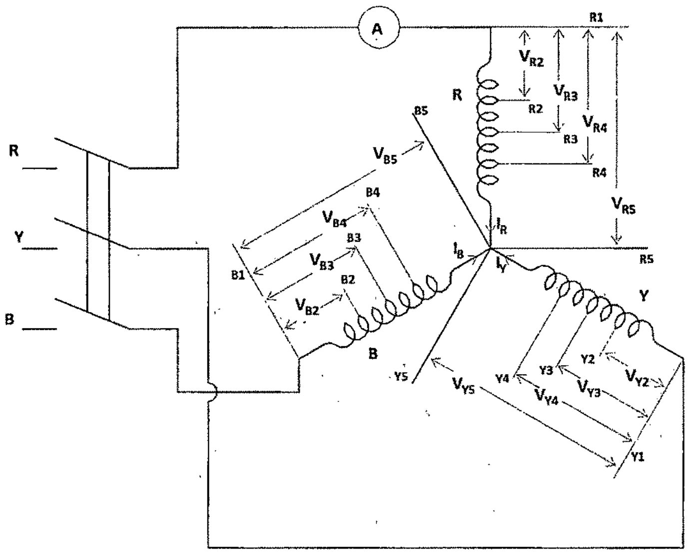


Fig. 6.1 Measurement of voltage waveform

6.6 VARNISHING

Varnish Elmo 65 E/R of Dr. back and co. was used. Elmo 65 E/R is an alkyd-phenolic resin based, baking impregnating varnish of temperature index 130 (Thermal Class B) The stator was pre heated in oven at 80^0 C for 2 hours and then varnish was poured on the winding from one end. Pouring was stopped when varnish was reached to the second end. Now the winding was heated to 120^0 C for four hrs. and then varnished was applied as per above procedure. Final curing was done at 120^0 C for eight hrs.

6.7 TESTING OF MOTORS

6.7.1 MOTOR NO.1

Frame 63, 3-phase, 415 V, 470 W, 50 Hz, 2-Pole, Class F, Continuous duty Induction motor.

6.7.1.1 RESISTANCE MEASUREMENT:

Resistance of each phase was measured with Ohm meter of Agronic Electronics, Ghatkopar, Mumbai. Instrument Model No. is Agronic-65.

Table 6.1 Resistance of Frame 63, 3-phase, 415 V, 470 W, 1.3 A, 50 Hz, 2-Pole, I.M.				
Sr. No.	R-Phase	Y-Phase	B-Phase	Avg. DC Resistance
1	20.90 ohm	20.95 ohm	21.00 ohm	20.95 ohm

6.7.1.2 NO LOAD TEST:

Table 6.2 No Load test, Frame 63, 3-phase, 415 V, 470 W, 1.3 A, 50 Hz, 2-Pole, I.M.				
Sr. No.	Voltage(L-L)	Line Current	Power(Total)	Speed
	(V_0) Volts	(I_0) mA	(P_0) Watts	(N_0) RPM
1	425	744.00	58.2	2980
2	415	640.00	50.0	2980
3	400	552.00	45.4	2980
4	380	488.00	38.2	2980
5	350	382.00	34.1	2970
6	320	328.00	30.9	2970
7	280	308.00	24.8	2966
8	200	252.00	21.8	2966
9	150	240.00	19.0	2966
10	100	200.00	17.0	2966

From curve between no load power and voltage it was estimated that friction and windage loss is 15 W.

6.7.1.3 BLOCKED ROTOR TEST

Table 6.3 Blocked Rotor test, Frame 63, 3-phase, 415 V, 470 W, 1.3 A 50 Hz, 2-Pole, I.M.			
Sr. No.	Voltage(L-L)	Line Current	Power(Total)
	(V_b) Volt	(I_b) Amp.	(P_b) Watts
1	200.0	1.30	165.0

6.7.1.4 EQUIVALENT CIRCUIT PARAMETERS

The equivalent circuit parameters calculated by Program B1 using results of above three test and resistance value corrected to 95^0 C as mentioned in IEEE-112 for class B insulation are as below

Table 6.4 Equivalent Circuit Parameters Frame 63, 3-phase, 415 V, 470 W, 1.3 A 50 Hz, 2-Pole, I.M.					
R_s	X_s	R_{fe}	X_m	R_r	X_r
Ohm	Ohm	Ohm	Ohm	Ohm	Ohm
25.9025	41.3231	4258.64	376.6067	14.3353	41.3231

6.7.1.5 PERFORMANCE OF THE MOTOR FROM EQUIVALENT CIRCUIT

The performances of the motor using above parameters in MATLAB program B9 are as below.

Table 6.5 Performance of Frame 63, 3-phase, 415 V, 470 W, 1.3 A, 50 Hz, 2-Pole, I.M. obtained using MATLAB program B9

Sr. No.	Output Power	Input Power	Input Current	PF	Speed	Torque	Efficiency
	(W)	(W)	(A)		(RPM)	(Nm)	(%)
1	197.82	265.20	0.7951	0.4821	2941	0.6422	74.59
2	290.94	372.90	0.8809	0.5888	2910	0.9546	78.02
3	371.36	472.47	1.0099	0.6508	2879	1.2319	78.60
4	390.66	497.51	1.0451	0.6622	2870	1.2967	78.52
5	448.75	576.47	1.1633	0.6893	2842	1.5077	77.84
6	469.99	606.92	1.2117	0.6968	2830	1.5857	77.43
7	531.47	702.46	1.3744	0.7110	2790	1.8192	75.65
8	580.38	791.47	1.5430	0.7135	2744	2.019	73.32

6.7.1. PERFORMANCE OF THE MOTOR FROM ACTUAL LOAD TEST

The motor was tested for different load. The loading set up is shown in Fig. 6.2 and 6.3 6.4. The reduction gear ratio was 30. The weight requires to be coupled with gear box shaft of ratio 30 for producing necessary torque at motor shaft is as below:

For ex T Nm at motor shaft corresponds to T*30 Nm at gear shaft ≡ (T*30*1000)/9.81 Kgmm or is equal to (0.6*30*1000)/(9.81*52) Kg. wt at 104 mm pulley.

Table 6.6 The weight requires to be coupled with gear box shaft of ratio 30 for producing necessary torque at motor shaft.

Torque at motor Shaft Nm	0.60	0.90	1.00	1.25	1.50	1.75	2.00
Approx. Weight required at GB shaft (Kg.) pulley dia. 104 mm	35.0	52.92	58.8	73.51	88.21	102.91	117.6

Figure 6.2 Experimental setup for loading the motor.

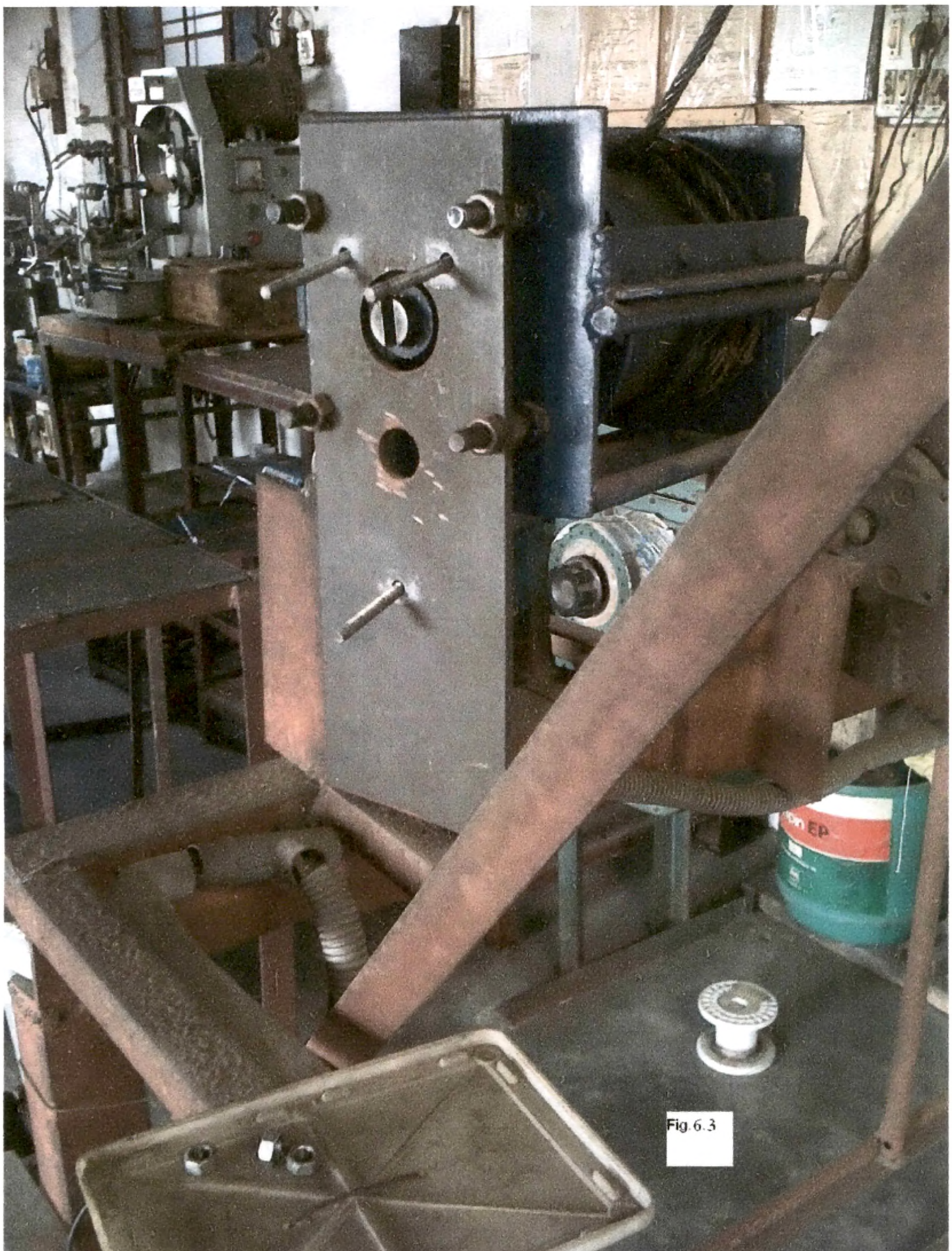


Figure 6.3 Experimental setup for loading the motor.

Figure 6.4 Measuring instruments

Figure 6.5 Dynamometer for loading the motor.

Figure 6.6 Dynamometer for loading the motor.

The motor was operated with above weight successfully. The distance to be travelled by loading trolley was 12 ft. With pulley diameter of 104 mm observations were to be noted in around 6.722 seconds. (i.e. Peripheral speed = π*D*(N/60) = 3.14*104*3000/60 = 544.2 mm/sec. and distance to be travelled 12*12*25.4 = 3657.6 mm). As this time was very small, the observations are taken with dynamometer directly coupled with motor shaft.

Table 6.7 Observations Table of Load Test of Frame 63, 3-phase, 415 V, 470 W, 1.3 A 50 Hz, 2-Pole, I.M.

Sr. No.	Voltage	Current	Input Power	Motor Speed	Weight At 150 mm
	(Volts)	(A)	(Watts)	(RPM)	(Kg)
1	415	0.95	322.20	2898	0.443
2	415	1.05	424.40	2884	0.655
3	415	1.15	520.60	2870	0.841
4	415	1.20	545.20	2868	0.884
5	415	1.30	626.00	2860	1.019
6	415	1.35	653.40	2856	1.068
7	415	1.50	745.20	2841	1.214
8	415	1.60	813.40	2830	1.330

Performances calculated from above observations are as below.

Table 6.8 Performance of Frame 63, 3-phase, 415 V, 470 W, 1.3 A 50 Hz, 2-Pole, I.M. from Load test

Sr. No.	Output Power	Efficiency 1	Power Factor	Torque
	(W)			(Nm)
1	197.83	61.40	0.4718	0.6518
2	291.00	68.59	0.5623.	0.9938
3	371.93	71.44	0.6297	1.2375
4	391.12	71.74	0.6320	1.3023
5	449.00	71.74	0.6699	1.4995
6	470.00	71.93	0.6733	1.5716
7	531.47	71.32	0.6911	1.7864
8	580.00	71.31	0.7072	1.9571

When the equivalent circuit parameters are presented to NR method algorithm discuss in chapter 5, following parameters are obtained.

Table 6.9 Equivalent Circuit Modified Parameters Frame 63, 3-phase, 415 V, 470 W, 1.3 A 50 Hz, 2-Pole, I.M.					
R_s	X_s	R_{fe}	X_m	R_r	X_r
Ohm	Ohm	Ohm	Ohm	Ohm	Ohm
25.90	41.695	4458.63	376.60	15.96	41.695

The performance of motor with modified parameters and taking in to account stray load loss as 1.85% as per IEEE 112 is being shown in table 6.10

Table 6.10 Performance of Frame 63, 3-phase, 415 V, 470 W, 1.3 A 50 Hz, 2-Pole, I.M. based on modified Parameters				
Sr. No.	Output Power	Efficiency	Power Factor	Torque
	(W)			(Nm)
1	197.95	78.72	0.4644	0.6437
2	291.00	80.86	0.5786	0.9573
3	371.37	80.25	0.6448	1.2366
4	390.79	79.98	0.6570	1.3056
5	448.74	78.78	0.6859	1.5163
6	470.03	78.18	0.6938	1.5958
7	531.39	75.86	0.7087	1.8350
8	580.00	72.95	0.7107	2.0433

6.7.2 MOTOR NO.2

Frame 63, 3-phase, 380 V, 470 W, 1.4 A, 50 Hz, 2-Pole, Class F, Continuous duty Induction motor.

6.7.2.1 RESISTANCE MEASUREMENT:

Table 6.11 Resistance of Frame 63, 3-phase, 380 V, 470 W, 1.4 A, 50 Hz, 2-Pole, I.M.				
Sr. No.	R-Phase	Y-Phase	B-Phase	Avg. DC Resistance
1	19.00 ohm	19.10 ohm	18.90 ohm	19.00 ohm

6.7.2.2 NO LOAD TEST:

Table 6.12 No Load test, Frame 63, 3-phase, 380 V, 470 W, 1.4 A, 50 Hz, 2-Pole, I.M.				
Sr. No.	Voltage(L-L)	Line Current	Power(Total)	Speed
	(V_0) Volts	(I_0) mA.	(P_0) Watts	(N_0) RPM
1	415	692.00	62.2	2980
2	400	604.00	57.8	2980
3	380	625.00	52.2	2980
4	350	312.00	44.2	2980

From curve between no load power and voltage it was estimated that friction and windage loss is 15 W.

6.7.2.3 BLOCKED ROTOR TEST

Table 6.13 Blocked Rotor test, Frame 63, 3-phase, 380 V, 470 W, 1.4 A 50 Hz, 2-Pole, I.M.			
Sr. No.	Voltage(L-L)	Line Current	Power(Total)
	(V_b) Volt	(I_b) Amp.	(P_b) Watts
1	207.80	1.40	180.0

6.7.2.4 LOAD TEST

Table 6.14 Observations Table of Load Test of Frame 63, 3-phase, 380 V, 470 W, 1.4 A 50 Hz, 2-Pole, I.M.					
Sr. No.	Voltage	Current	Input Power	Motor Speed	Weight At 150 mm
	(Volts)	(A)	(Watts)	(RPM)	(Kg)
1	380	1.3	607.8	2816	0.993
2	380	1.35	662.2	2810	1.086
3	380	1.4	693.6	2800	1.134

Performance based on above test is as below.

Table 6.15 Performance of Frame 63, 3-phase, 380 V, 470 W, 1.4 A 50 Hz, 2-Pole, I.M. from Load test				
Sr. No.	Output Power	Efficiency	Power Factor	Torque
	(W)			(Nm)
1	430.89	70.89	0.7103	1.4612
2	470.24	71.01	0.7452	1.5980
3	489.28	70.54	0.7527	1.6687

6.7.2.5 EQUIVALENT CIRCUIT PARAMETERS

The equivalent circuit parameters calculated by Program B1 using results of above three test are as below

Table 6.16 Equivalent Circuit Parameters Frame 63, 3-phase, 380 V, 470 W, 1.4 A 50 Hz, 2-Pole, I.M.					
R_s	X_s	R_{fe}	X_m	R_r	X_r
Ohm	Ohm	Ohm	Ohm	Ohm	Ohm
23.4916	40.0205	3420.1264	353.8899	14.3574	40.0205

Motor performance from equivalent circuit is as below

Table 6.17 Performance of Frame 63, 3-phase, 380 V, 470 W, 1.4 A, 50 Hz, 2-Pole, I.M. obtained using MATLAB program B9							
Sr. No.	Output Power	Input Power	Input Current	PF	Speed	Torque	Efficiency
	(W)	(W)	(A)		(RPM)	(Nm)	(%)
1	430.82	568.00	1.2303	0.7014	2809	1.4647	75.84
2	470.15	630.62	1.3505	0.7095	2775	1.6174	74.55
3	489.15	663.82	1.4184	0.7110	2756	1.6946	73.68

When the equivalent circuit parameters are presented to NR method algorithm discuss in chapter 5, following parameters are obtained.

Table 6.18 Equivalent Circuit Modified Parameters Frame 63, 3-phase, 380 V, 470 W, 1.4 A 50 Hz, 2-Pole, I.M.					
R_s	X_s	R_{fe}	X_m	R_r	X_r
Ohm	Ohm	Ohm	Ohm	Ohm	Ohm
23.4916	43.1718	3580.74	442.01	15.9367	43.1718

The performance of motor with modified parameters and taking in to account stray load loss as 1.85% as per IEEE 112 is being shown in table

Table 6.19 Performance of Frame 63, 3-phase, 380 V, 470 W, 1.4 A 50 Hz, 2-Pole, I.M. based on modified Parameters				
Sr. No.	Output Power	Efficiency	Power Factor	Torque
	(W)			(Nm)
1	430.64	76.51	0.7410	1.4765
2	469.95	74.54	0.7415	1.6365
3	489.21	73.16	0.7381	1.7212

6.7.3 MOTOR NO.3

Frame 71, 3-phase, 415 V, 300 W, 50 Hz, 2-Pole, Class F, Continuous duty Induction motor.

6.7.3.1 RESISTANCE MEASUREMENT:

	Table 6.20A			
Sr. No.	R-Phase ohm			
	R_1- R_2	R_1- R_3	R_1- R_4	R_1-R_5
1	6.161	12.322	18.502	24.642

	Table 6.20B			
Sr. No.	Y-Phase Ohm			
	Y_1- Y_2	Y_1- Y_3	Y_1- Y_4	Y_1-Y_5
1	6.160	12.321	18.500	24.640

	Table 6.20C			
Sr. No.	B-Phase ohm			
	B_1-B_2	B_1- B_3	B_1- B_4	B_1-B_5
1	6.162	12.323	18.503	24.644

6.7.4 MOTOR NO.4

Frame 71, 3-phase, 415 V, 300 W, 50 Hz, 4-Pole, Class F, Continuous duty Induction motor.

6.7.4.1 RESISTANCE MEASUREMENT:

	Table 6.21A			
Sr. No.	R-Phase ohm			
	R_1- R_2	R_1- R_3	R_1- R_4	R_1-R_5
1	7.701	15.403	23.104	30.804

	Table 6.21B			
Sr. No.	Y-Phase Ohm			
	Y_1- Y_2	Y_1- Y_3	Y_1- Y_4	Y_1-Y_5
1	7.702	15.404	23.106	30.806

	Table 6.21C			
Sr. No.	B-Phase ohm			
	B_1-B_2	B_1- B_3	B_1- B_4	B_1-B_5
1	7.700	15.402	23.102	30.802

6.7.5 MOTOR NO.5

6.7.5.1 RESISTANCE MEASUREMENT:

Fifth motor (380V, 50 Hz, 1.2 KW, 4-Pole) was tested at ERDA

Stator resistance is obtained by DC test method. The value of resistance obtained is 5.568 Ω

6.7.5.2 NO LOAD TEST

Table No. 6.22	380 V, 50 Hz, 1.2 KW, 4-Pole IM				
	Voltage	Current	Power	PF	Speed
Practical	380	1.15	100	0.1321	1499
Simulation					

50 Hz	377.9	1.071	102.3	0.1459	1497.33
60 Hz	377.4	0.9061	101.7	0.1717	1799.2

6.7.5.3 BLOCKED ROTOR TEST

Table No. 6.23	380 V, 50 Hz, 1.2 KW, 4-Pole IM				
	Voltage	Current	Power	PF	Speed
Practical	99	2.8	230	0.479	0
Simulation					
50 Hz	98.57	2.847	240.7	0.4972	0
60 Hz	98.35	2.46	195.8	0.4672	0

Life of the motor means the period of time for which motor is available for doing specified work or is able to deliver the rated power starting from the time from where motor is put in to the service. Normally the life of the motor is decided by the healthiness of insulation system and bearing. This point is being discussed in chapter 2.

In this work stresses developed on winding insulation by the converter switching are investigated. For this purpose voltage wave forms at motor terminals and inside the winding are recorded. Experiments are being done on two pole and four pole winding as per details mentioned above are prepared. The photo graph of testing setup is shown in fig. 6.5 and 6.6

CRO of Yokogawa, Japan, Model No. DL 750 was used for the measurement purpose. Investigation was made for three different source of voltages (1) Sinusoidal utility 50 Hz supply (2) Filtered inverter supply taken from drive No. VDF007B43A of Delta (3). Unfiltered inverter supply taken from drive no. VFD004S43A of Delta. Experiments of wave forms measurement are being done on Motor No. 3 and 4. Around 600 waveforms are being recorded and investigated. The waveforms recorded are mentioned in table 6.20 and 6.21.

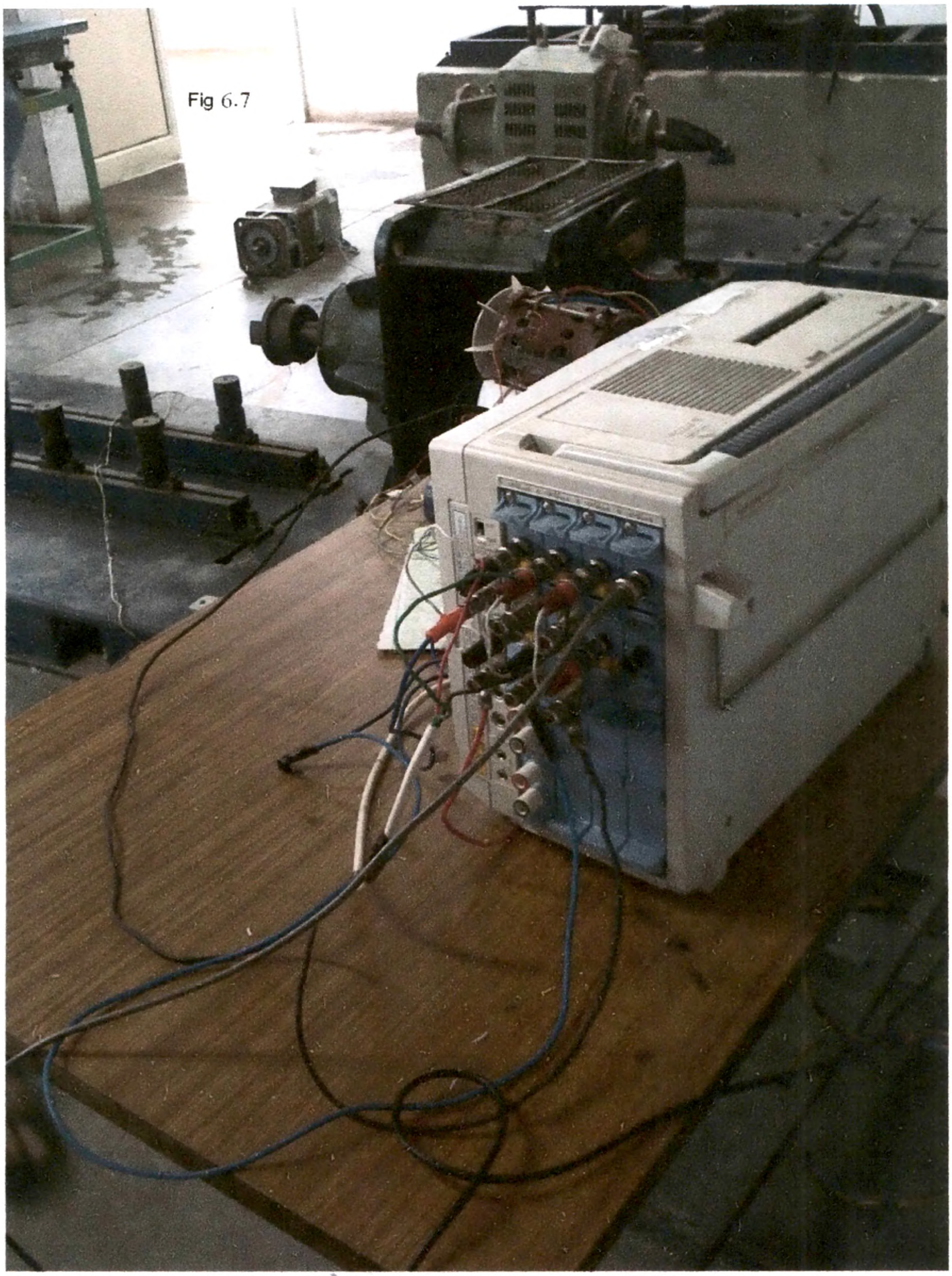


Figure 6.7 Waveform recording setup, ERDA

Figure 6.8 Waveform recording setup, ERDA

Table 6.24 List of waveforms for 2 P windings		
Sr.No.	Waveform No	Waveform Description
1	KRK0040	Phase voltage and Voltage across first coil, and line current of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.
2	KRK0041	Phase voltage and Voltage across second coil and line current of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.
3	KRK0042	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.
4	KRK0043	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.
5	KRK0022	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.
6	KRK0023	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.
7	KRK0028	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.
8	KRK0029	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.
9	KRK0021	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
10	KRK0024	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
11	KRK0027	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
12	KRK0030	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
13	KRK0020	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
14	KRK0025	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
15	KRK0026	Phase voltage and Voltage across third coil of 3-phase, 415

		V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
16	KRK0031	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
17	KRK0032	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 60 Hz.
18	KRK0035	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 60 Hz.
19	KRK0036	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 60 Hz.
20	KRK0039	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 60 Hz.
21	KRK0033	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 70 Hz.
22	KRK0034	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 70 Hz.
23	KRK0037	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 70 Hz.
24	KRK0038	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 70 Hz.
25	KRK0106	R-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 20 Hz.
26	KRK0121	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 20 Hz.
27	KRK0126	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 20 Hz.
28	KRK0107	R-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 30 Hz.
29	KRK0122	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 30 Hz.
30	KRK0127	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 30 Hz.

31	KRK0108	R-Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.
32	KRK0123	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.
33	KRK0128	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.
34	KRK0109	R-Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.
35	KRK0124	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.
36	KRK0129	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.
37	KRK0110	R-Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 60 Hz.
38	KRK0125	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 60 Hz.
39	KRK0130	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 60 Hz.

Table 6.25 List of waveforms for 4 P windings		
Sr.No.	Waveform No	Waveform Description
1	KRK0004	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 50 Hz, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply
2	KRK0005	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.
3	KRK0006	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.
4	KRK0007	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.
5	KRK0017	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.

6	KRK0016	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.
7	KRK0011	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.
8	KRK0010	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 25 Hz.
9	KRK0018	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
10	KRK0015	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
11	KRK0012	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
12	KRK0009	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 40 Hz.
13	KRK0019	Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
14	KRK0014	Phase voltage and Voltage across second coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
15	KRK0013	Phase voltage and Voltage across third coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
16	KRK0008	Phase voltage and Voltage across fourth coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with PWM inverter with frequency 50 Hz.
17	KRK0136	R-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 20 Hz.
18	KRK0146	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 20 Hz.
19	KRK0156	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 20 Hz.
20	KRK0137	R-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 30 Hz.
21	KRK0147	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied

		with PWM inverter with frequency 30 Hz.
22	KRK0157	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 30 Hz.
23	KRK0138	R-Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.
24	KRK0148	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.
25	KRK0158	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.
26	KRK0139	R-Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.
27	KRK0149	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.
28	KRK0159	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.
29	KRK0160	R-Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 60 Hz.
30	KRK0150	Y-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 60 Hz.
31	KRK0140	B-Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 60 Hz.

Waveforms for 2-Pole winding No. KRK0040, No. KRK0106, No. KRK0107, No. KRK0108, No. KRK0109, No. KRK0110 and for 4-Pole winding No. KRK0004, No. KRK0138, No. KRK0139 are shown here below.

Wave form No. KRK0040

Phase voltage and Voltage across first coil, and line current of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.

Fig. 0040A Normal View of wave forms

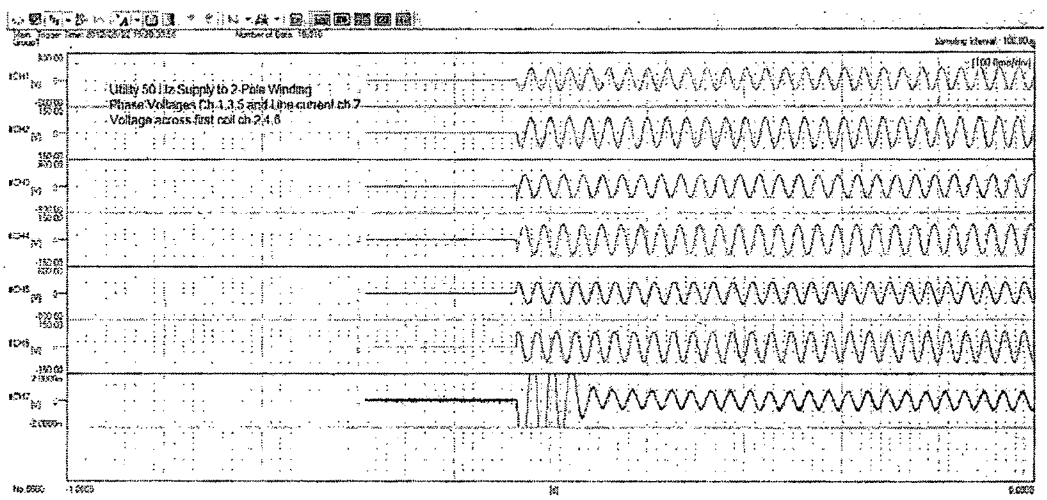
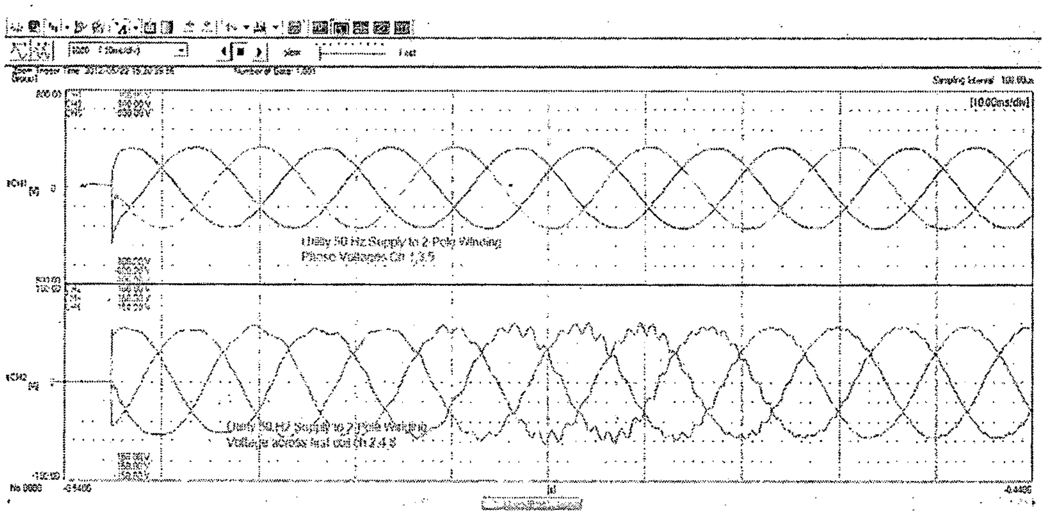


Fig. 0040B Enlarge View of wave forms



Wave form No. KRK0040

Fig. 0040C R-Phase

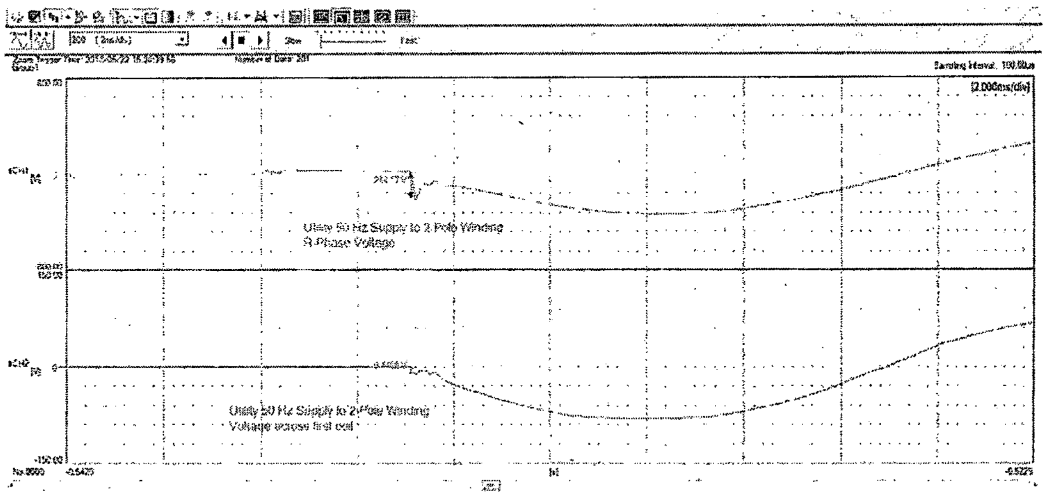
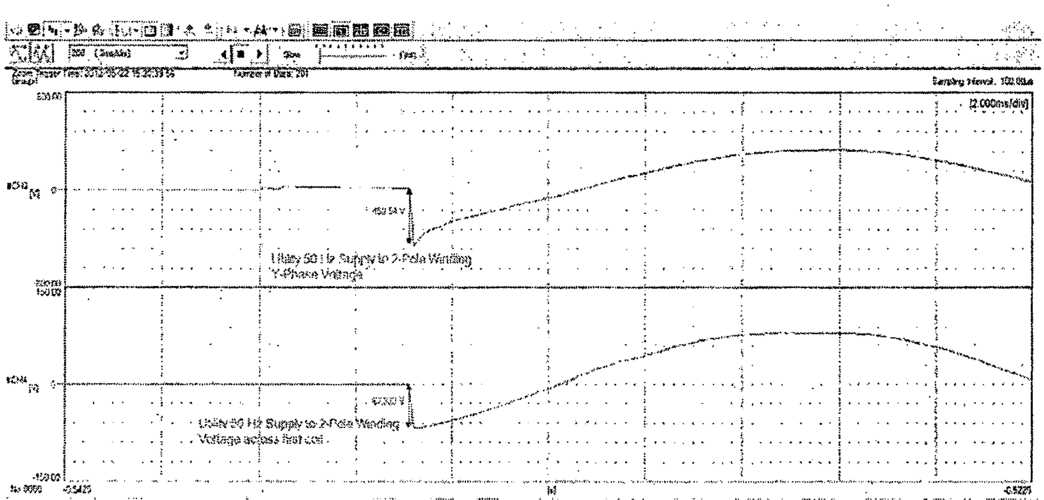
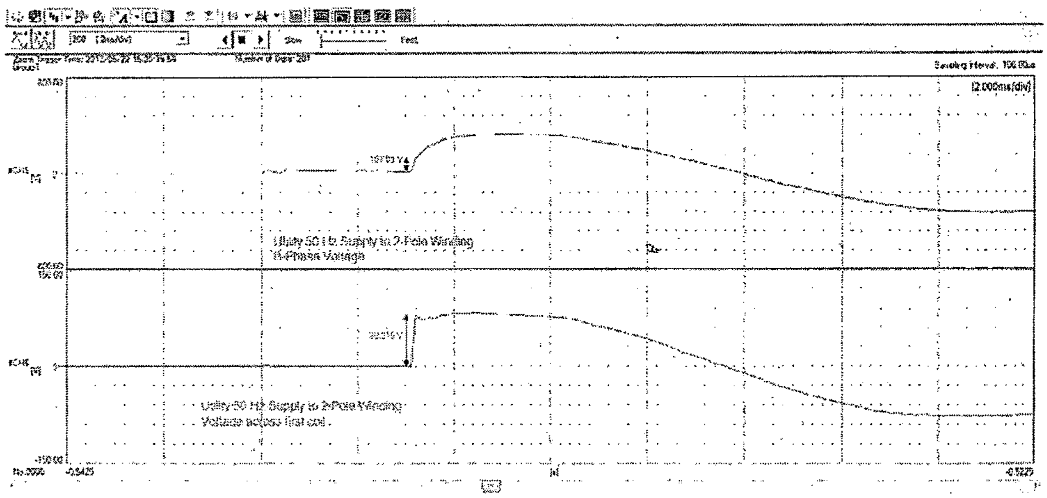


Fig. 0040D Y-Phase



Wave form No. KRK0040

Fig. 0040E B-Phase



Phase	Item	First Peak
R-Phase	Phase Voltage	214.17 V
	Voltage across coil	9.44 V
Y-Phase	Phase Voltage	453.54 V
	Voltage across coil	67.32 V
B-Phase	Phase Voltage	107.09 V
	Voltage across coil	80.31 V

Wave form No. KRK0106, Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 20 Hz.

R-phase Voltage

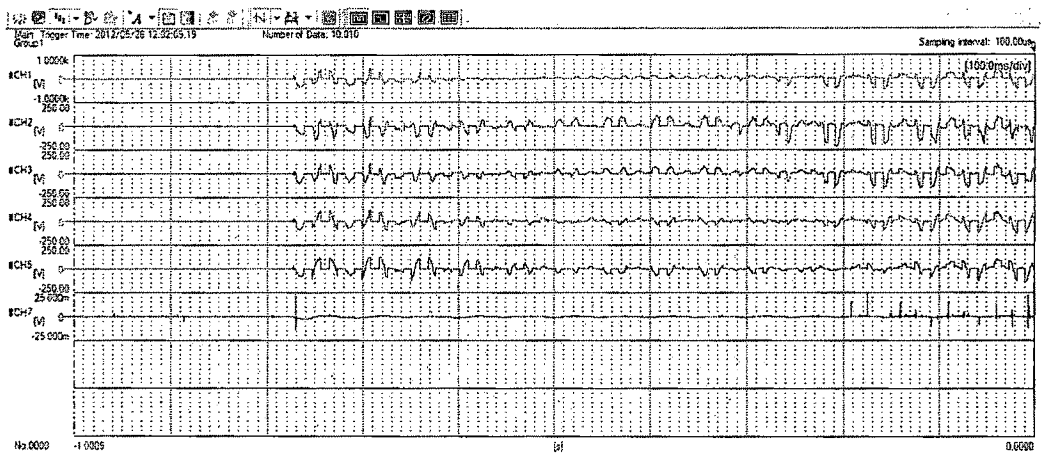


Diagram 1: Shows enlarge view of voltage wave forms across all four coils.

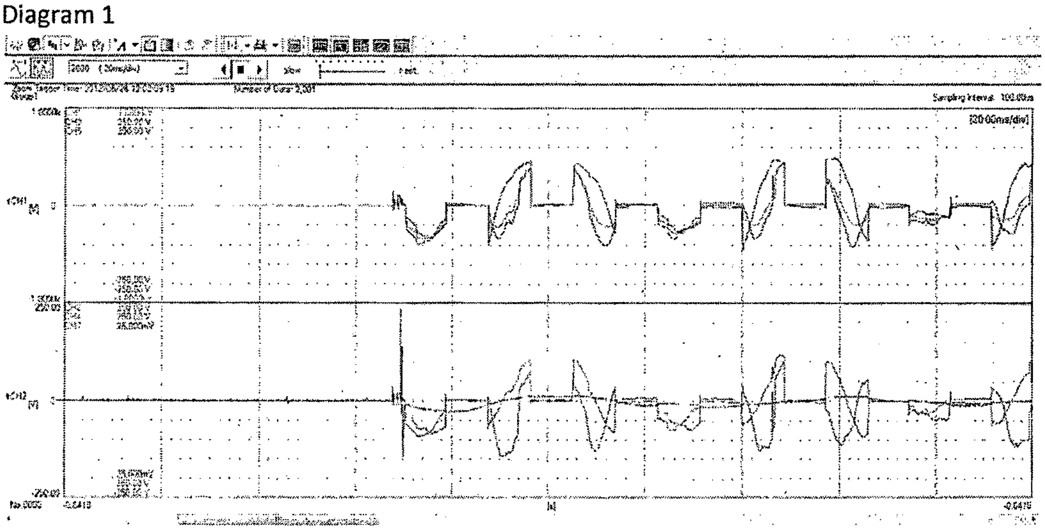
Diagram 2: Shows phase voltage wave form and voltage across first coil.

Diagram 3: Shows phase voltage wave form and voltage across second coil.

Diagram 4: Shows phase voltage wave form and voltage across third coil.

Diagram 5: Shows phase voltage wave form and voltage across fourth coil.

Diagram 1



Wave form No. KRK0106

Diagram 2

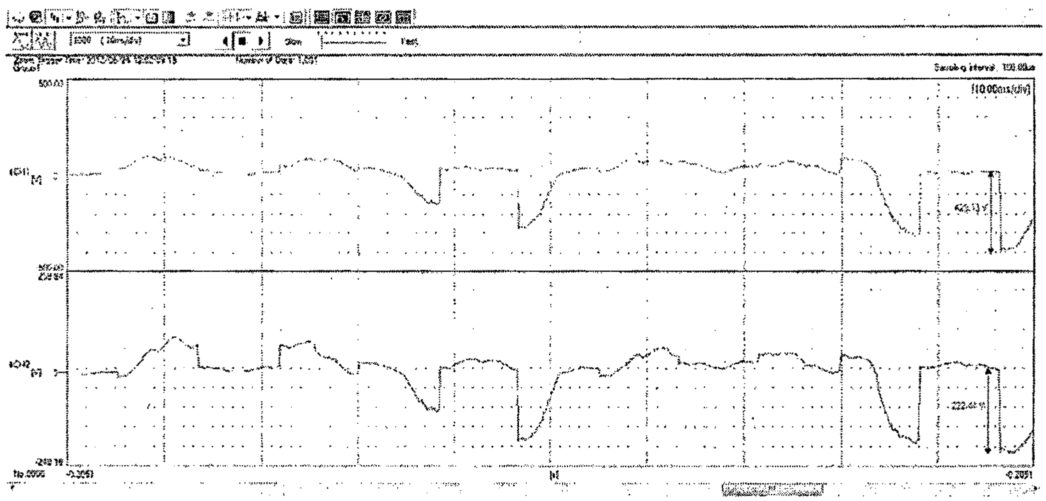
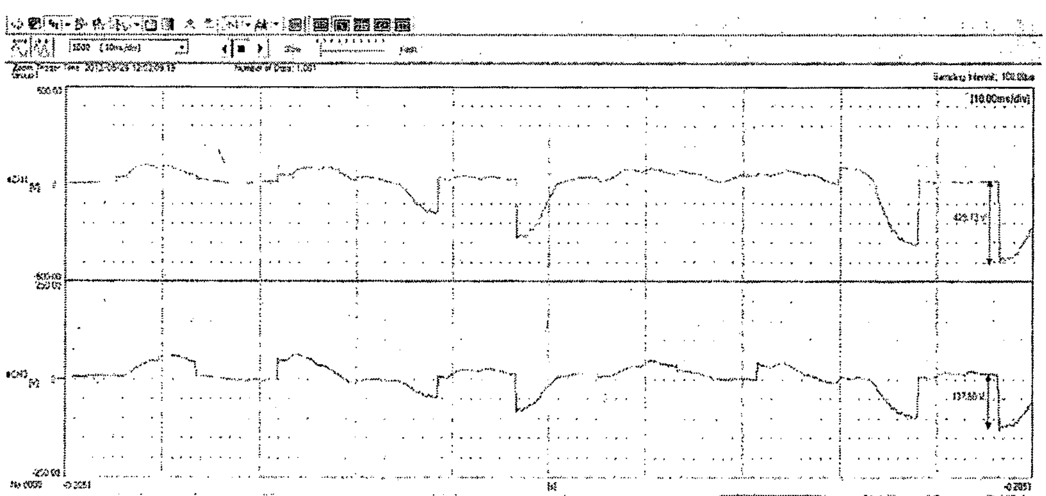


Diagram 3



Wave form No. KRK0106

Diagram 4

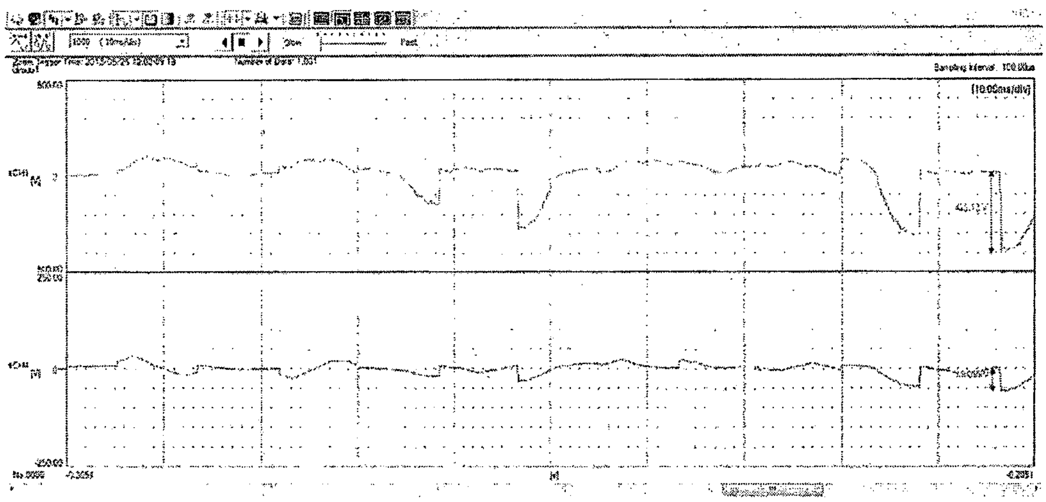
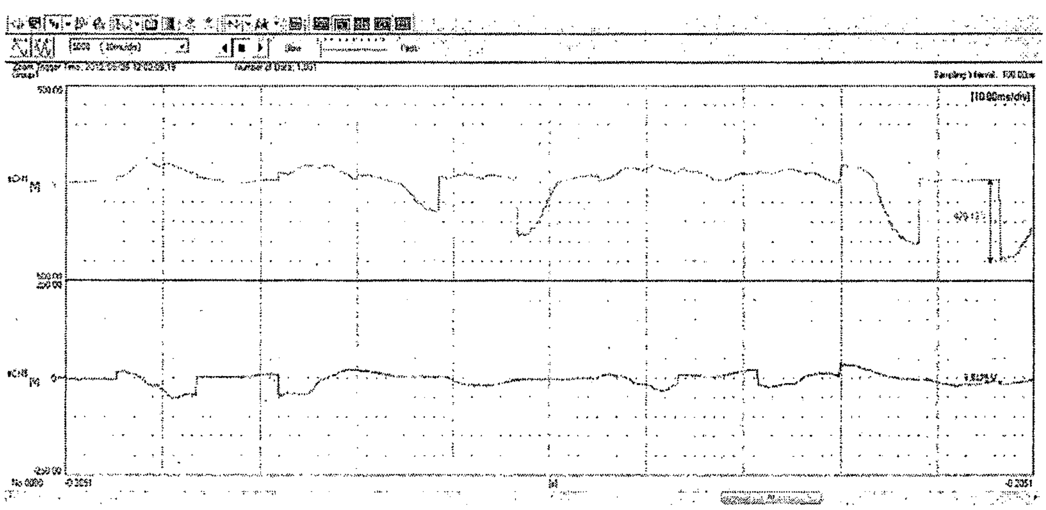


Diagram 5



Phase	Item	Voltage Variation
R-Phase	Phase Voltage V_{15}	429.43
	Voltage across first coil V_{12}	222.44
	Voltage across second coil V_{23}	137.80
	Voltage across third coil V_{34}	59.05
	Voltage across four coil V_{45}	9.84

Wave form No. KRK0107, Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 30 Hz.

R-phase Voltage

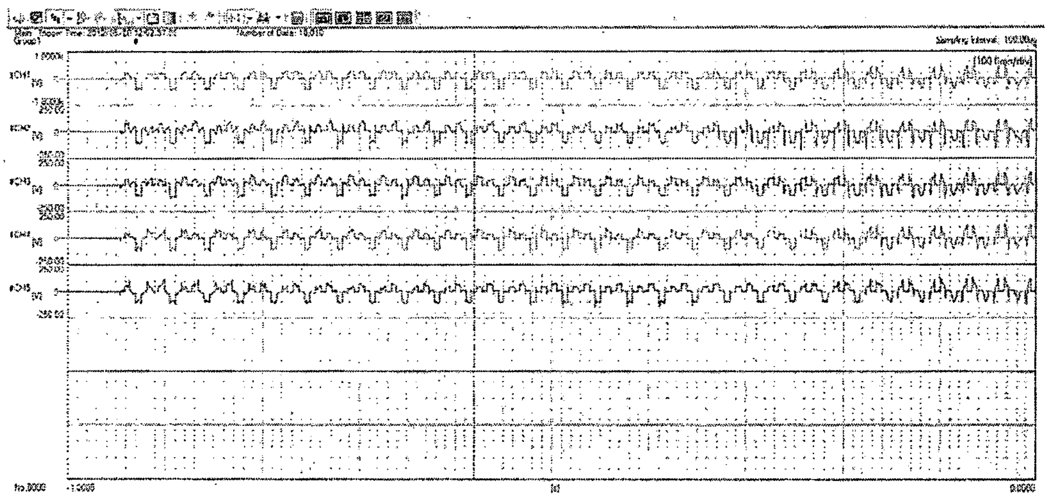
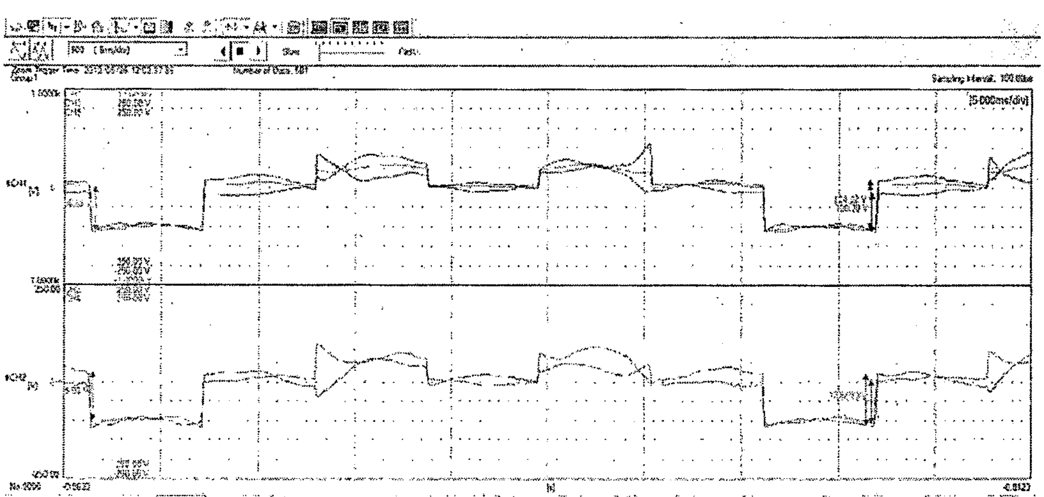


Diagram 1: Shows enlarge view of voltage wave forms across all four coils. Diagram 2: Shows phase voltage wave form and voltage across first coil. Diagram 3: Shows phase voltage wave form and voltage across second coil. Diagram 4: Shows phase voltage wave form and voltage across third coil. Diagram 5: Shows phase voltage wave form and voltage across fourth coil.

Diagram 1



Wave form No. KRK0107

Diagram 2

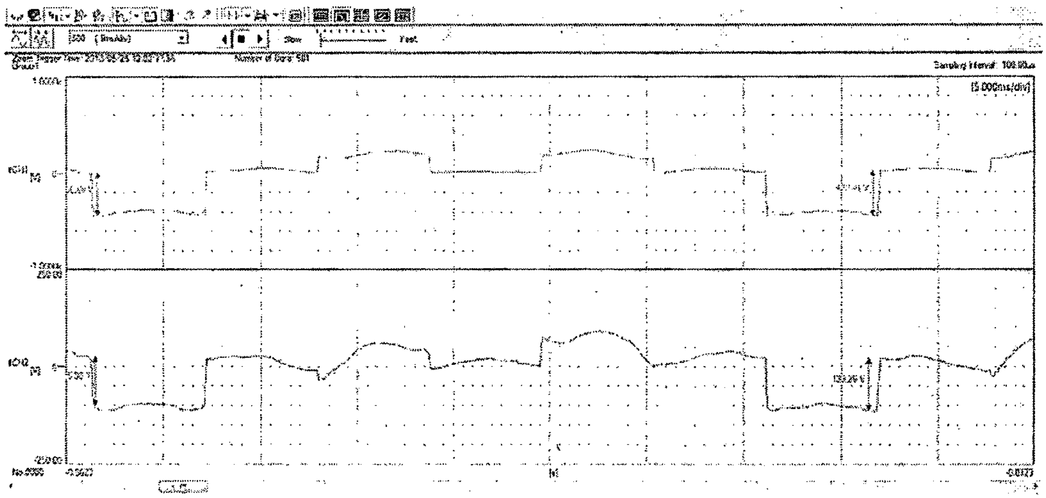
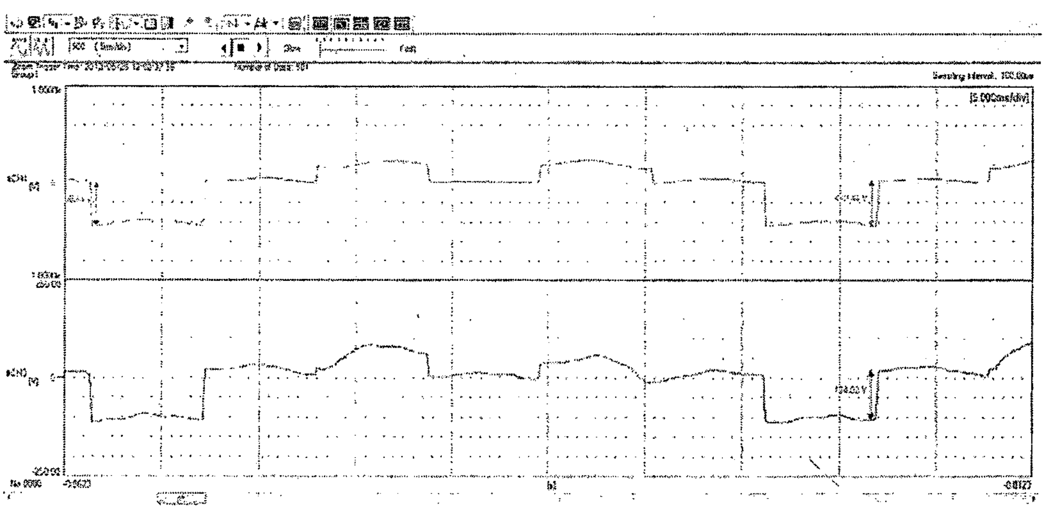


Diagram 3



Wave form No. KRK0107

Diagram 4

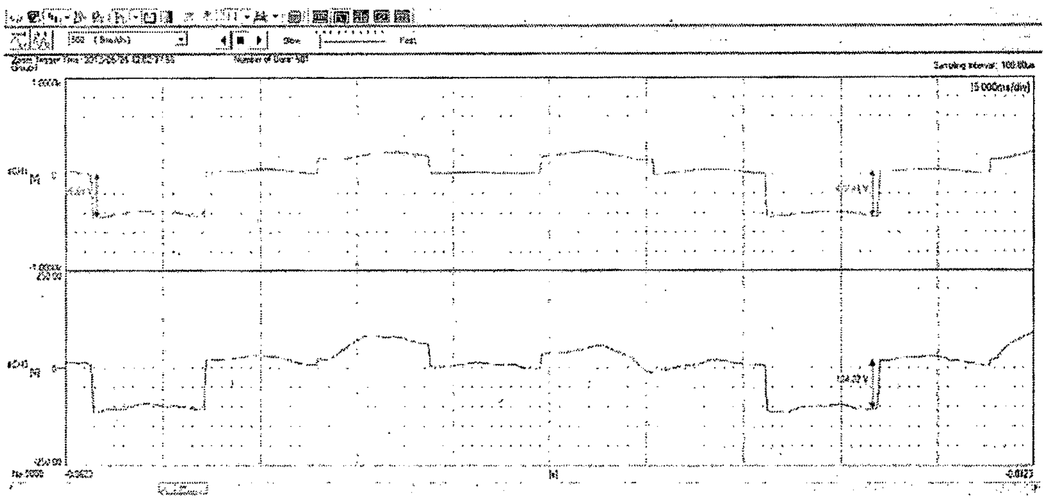
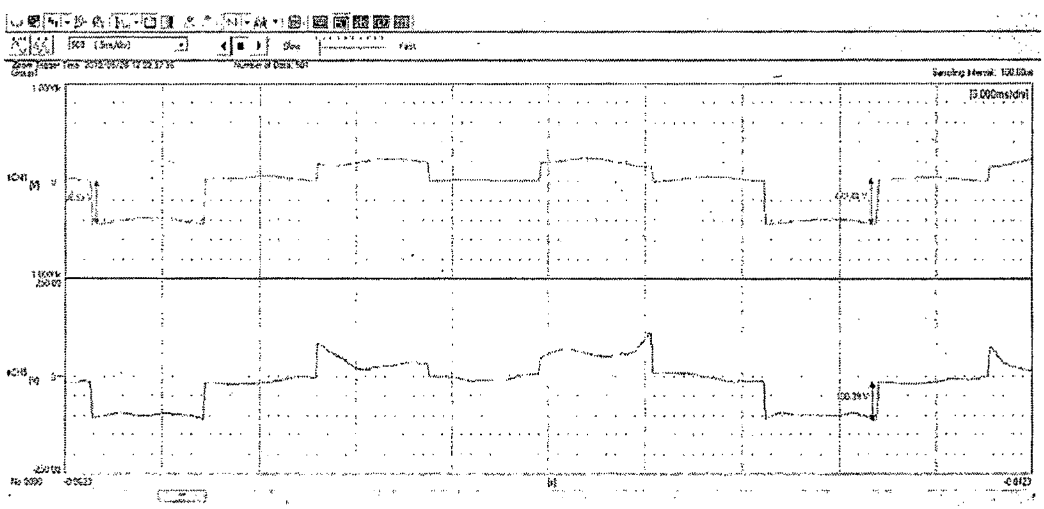


Diagram 5



Phase	Item	Voltage Variation
R-Phase	Phase Voltage V_{15}	472.44
	Voltage across first coil V_{12}	133.86
	Voltage across second coil V_{23}	124.02
	Voltage across third coil V_{34}	114.17
	Voltage across four coil V_{45}	100.39

Wave form No. KRK0108

Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.

R-phase Voltage

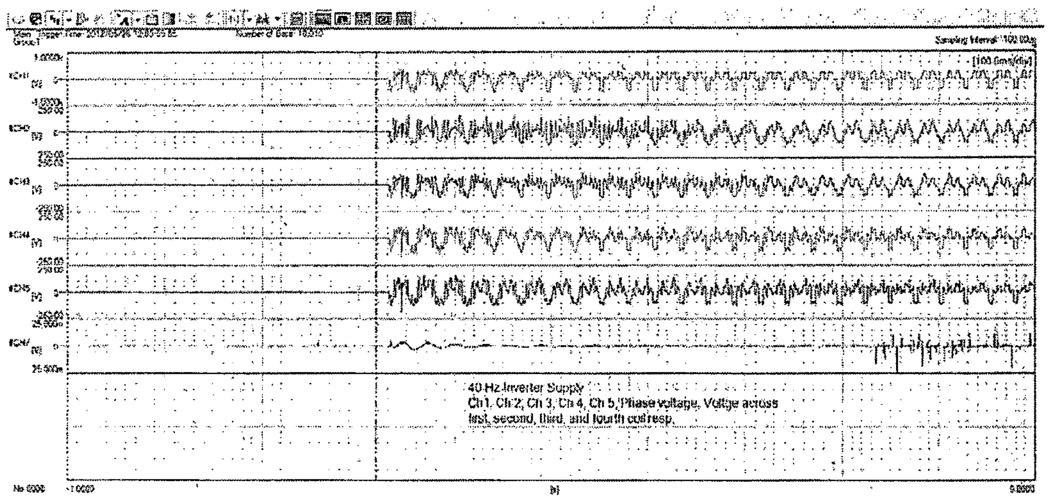
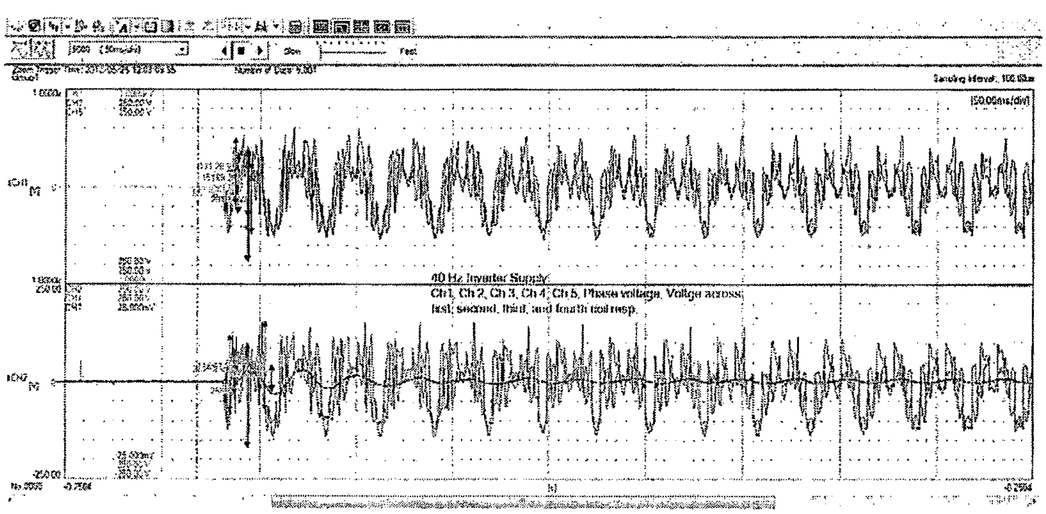


Diagram 1: Shows enlarge view of voltage wave forms across all four coils. Diagram 2: Shows phase voltage wave form and voltage across first coil. Diagram 3: Shows phase voltage wave form and voltage across second coil. Diagram 4: Shows phase voltage wave form and voltage across third coil. Diagram 5: Shows phase voltage wave form and voltage across fourth coil.

Diagram 1



Wave form No. KRK0108

Diagram 2

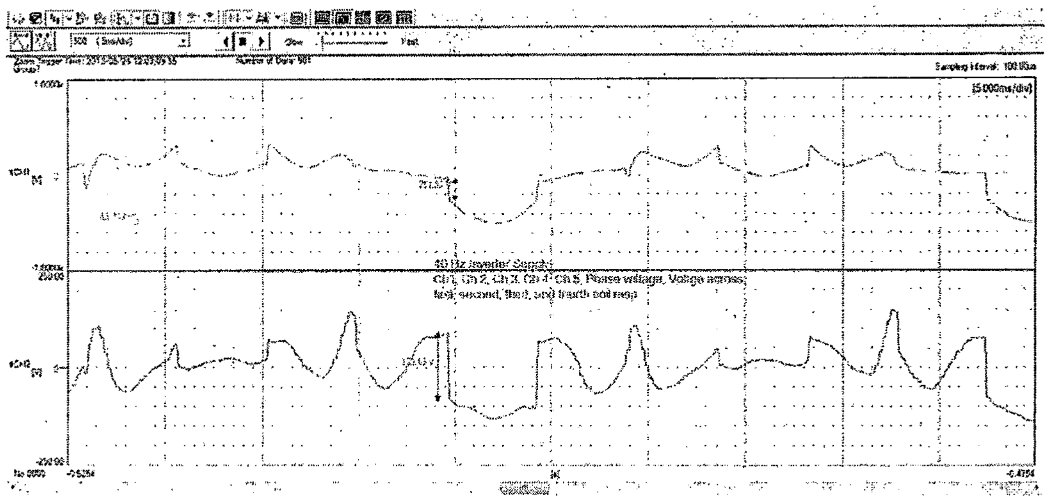
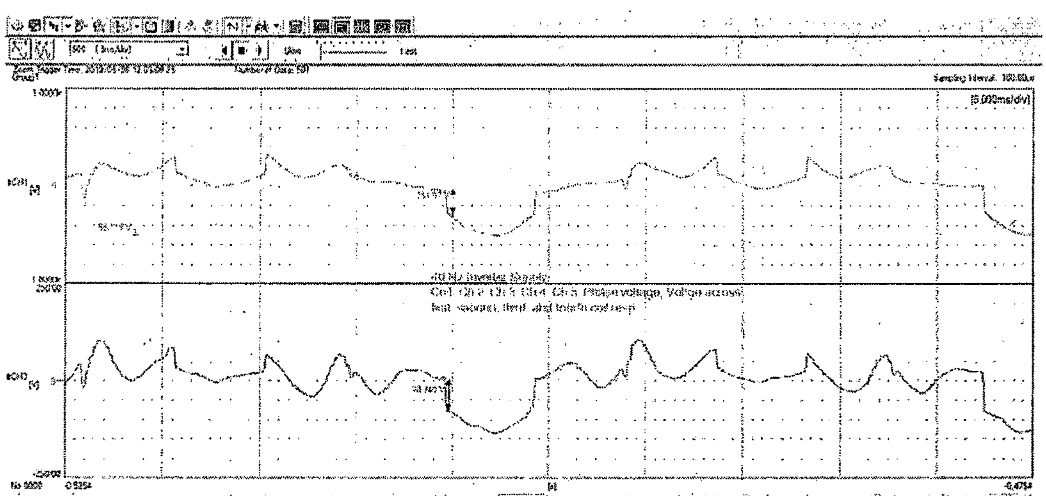


Diagram 3



Wave form No. KRK0108

Diagram 4

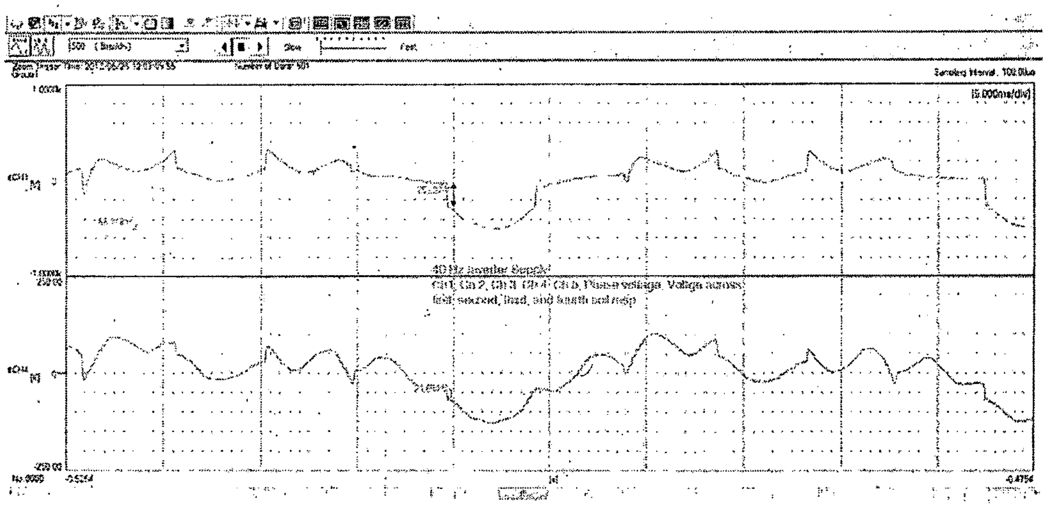
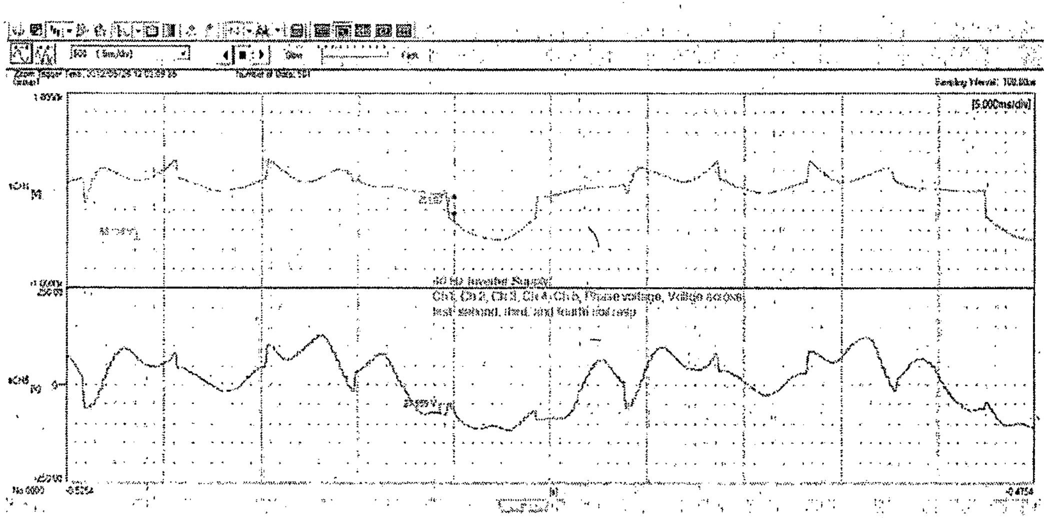


Diagram 5



Phase	Item	Voltage Variation
R-Phase	Phase Voltage V_{15}	251.97
	Voltage across first coil V_{12}	179.13
	Voltage across second coil V_{23}	78.74
	Voltage across third coil V_{34}	21.65
	Voltage across four coil V_{45}	-27.55

Wave form No. KRK0109

Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.

R-phase Voltage

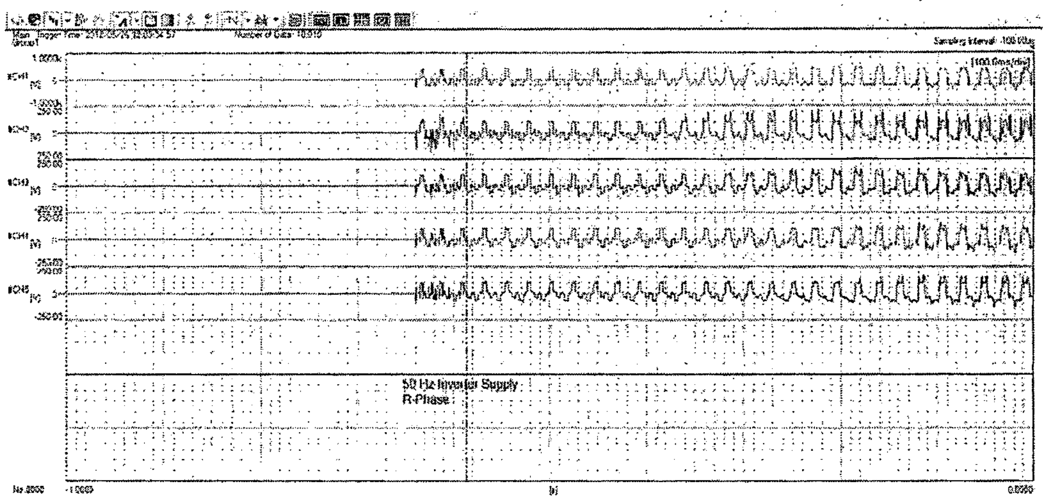
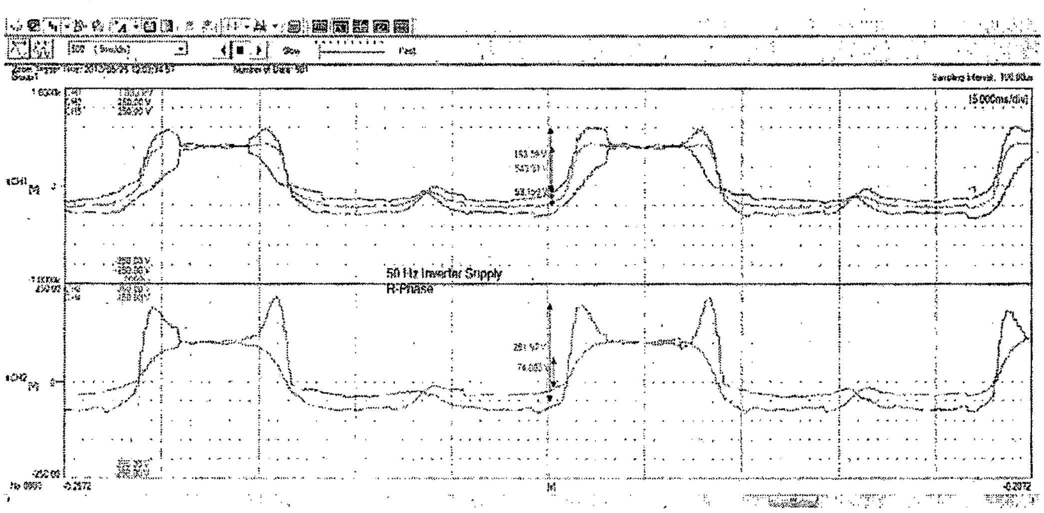


Diagram 1: Shows enlarge view of voltage wave forms across all four coils. Diagram 2: Shows phase voltage wave form and voltage across first coil. Diagram 3: Shows phase voltage wave form and voltage across second coil. Diagram 4: Shows phase voltage wave form and voltage across third coil. Diagram 5: Shows phase voltage wave form and voltage across fourth coil.

Diagram 1



Wave form No. KRK0109

Diagram 2

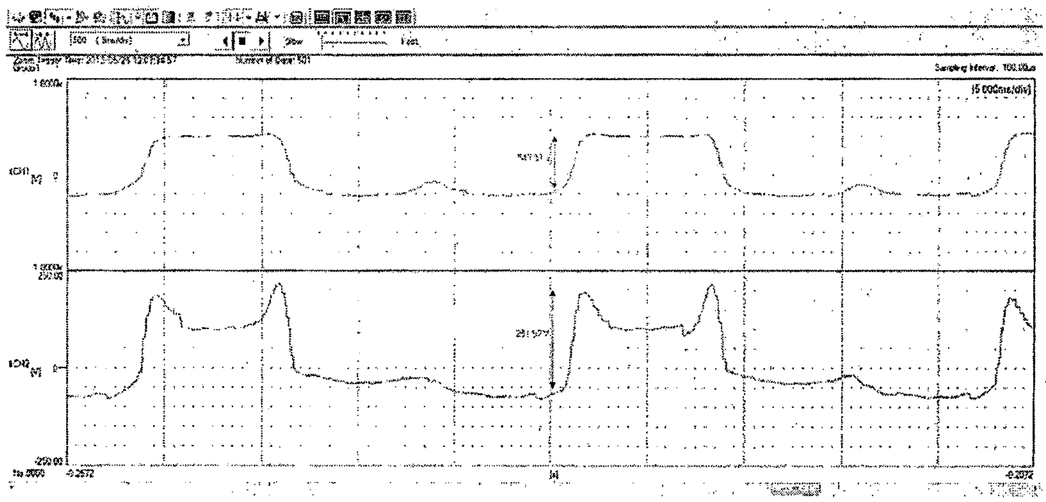
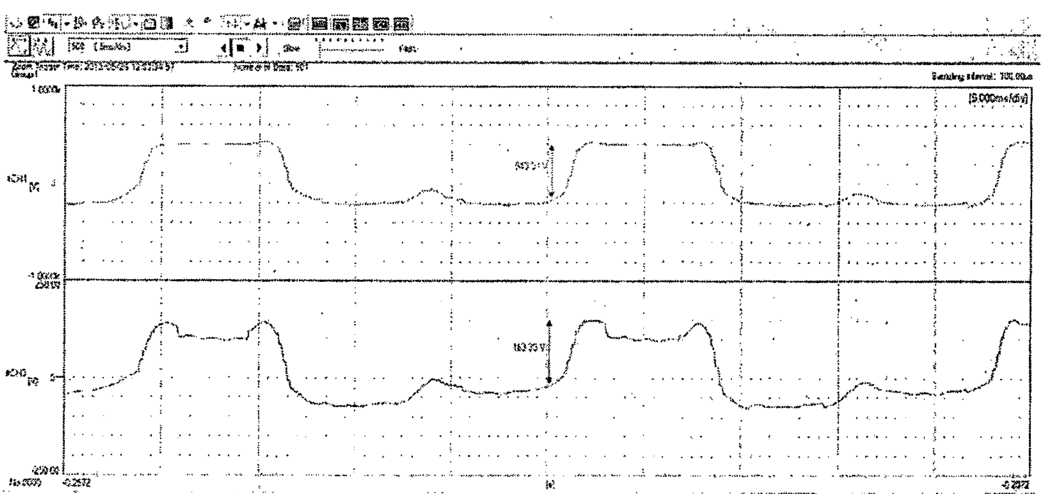


Diagram 3



Wave form No. KRK0109

Diagram 4

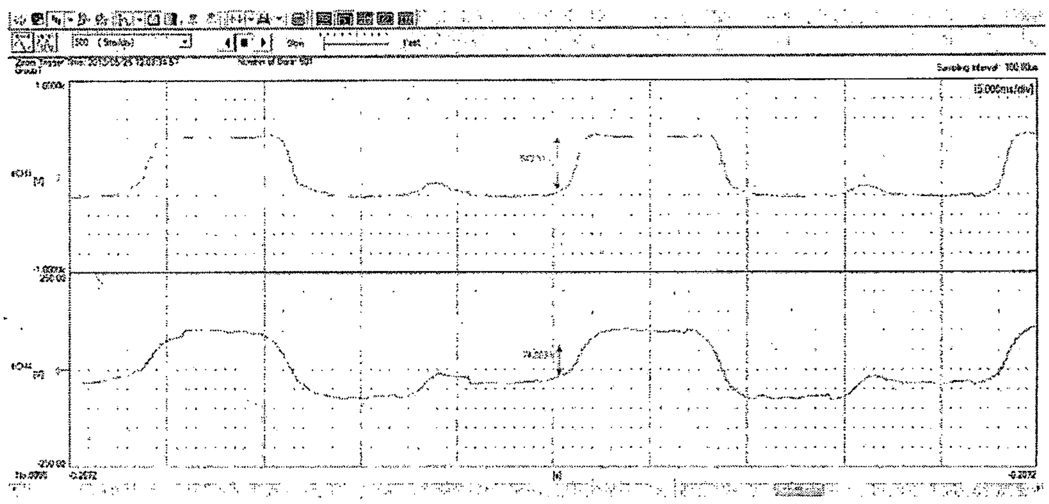
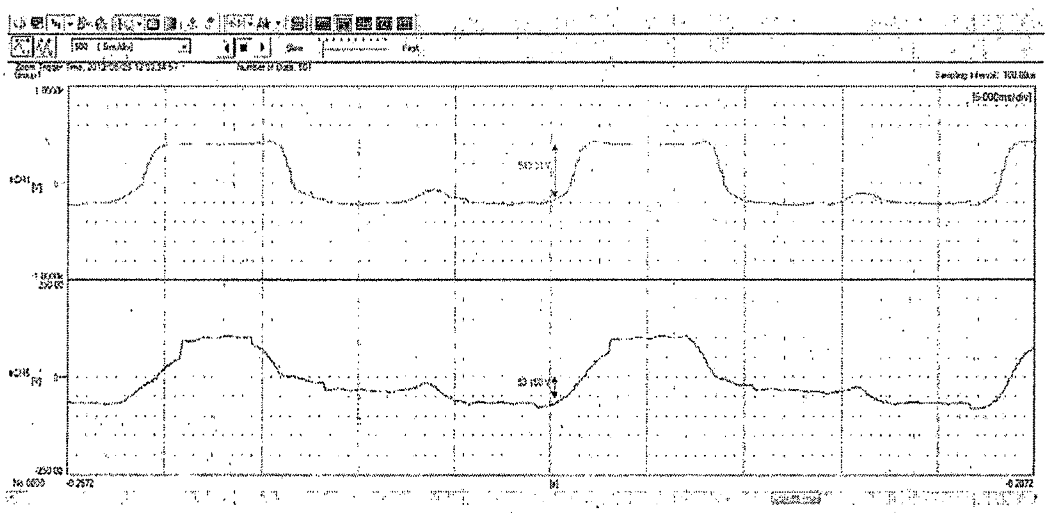


Diagram 5



Phase	Item	Voltage Variation
R-Phase	Phase Voltage V_{15}	543.31
	Voltage across first coil V_{12}	251.95
	Voltage across second coil V_{23}	163.39
	Voltage across third coil V_{34}	74.80
	Voltage across four coil V_{45}	53.15

Wave form No. KRK0110

Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 2-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 60 Hz.

R-phase Voltage

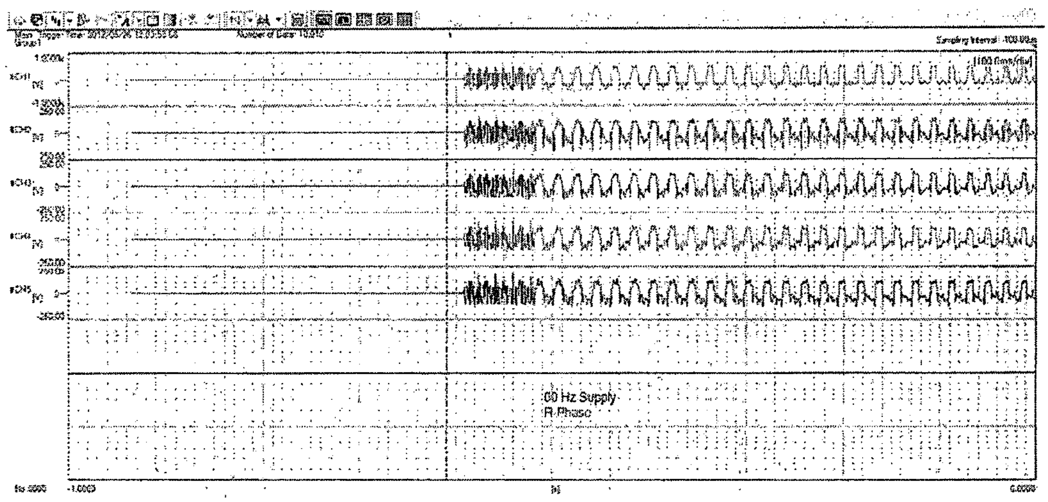
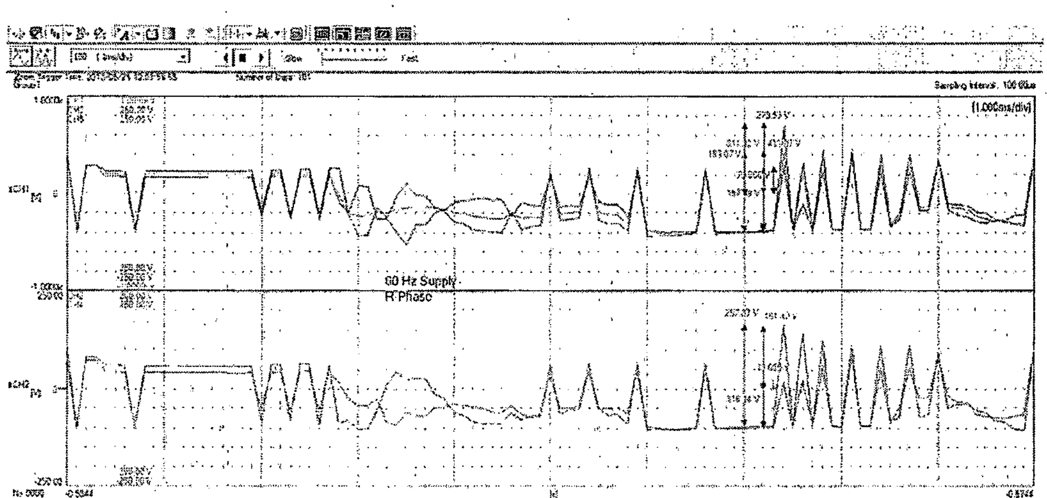


Diagram 1: Shows enlarge view of voltage wave forms across all four coils. Diagram 2: Shows phase voltage wave form and voltage across first coil. Diagram 3: Shows phase voltage wave form and voltage across second coil. Diagram 4: Shows phase voltage wave form and voltage across third coil. Diagram 5: Shows phase voltage wave form and voltage across fourth coil.

Diagram 1



Wave form No. KRK0110

Diagram 2

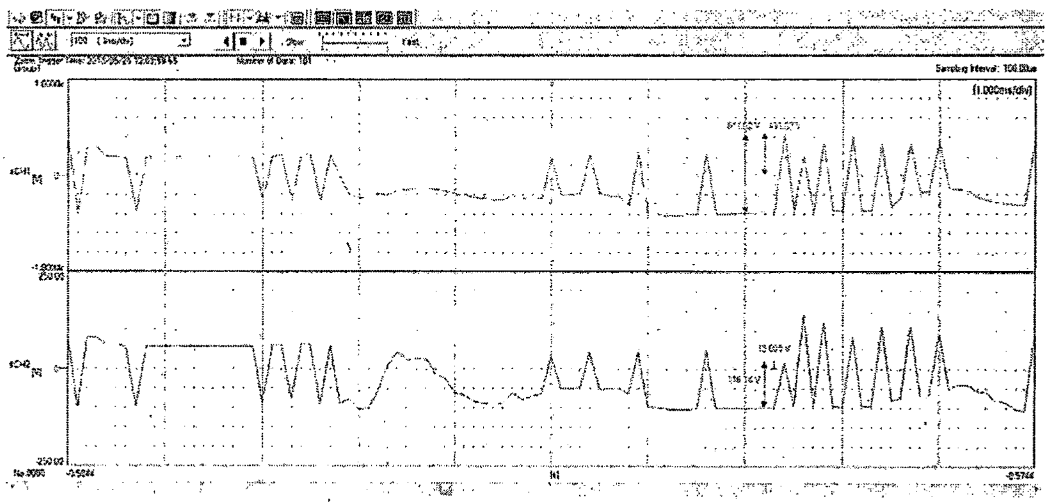
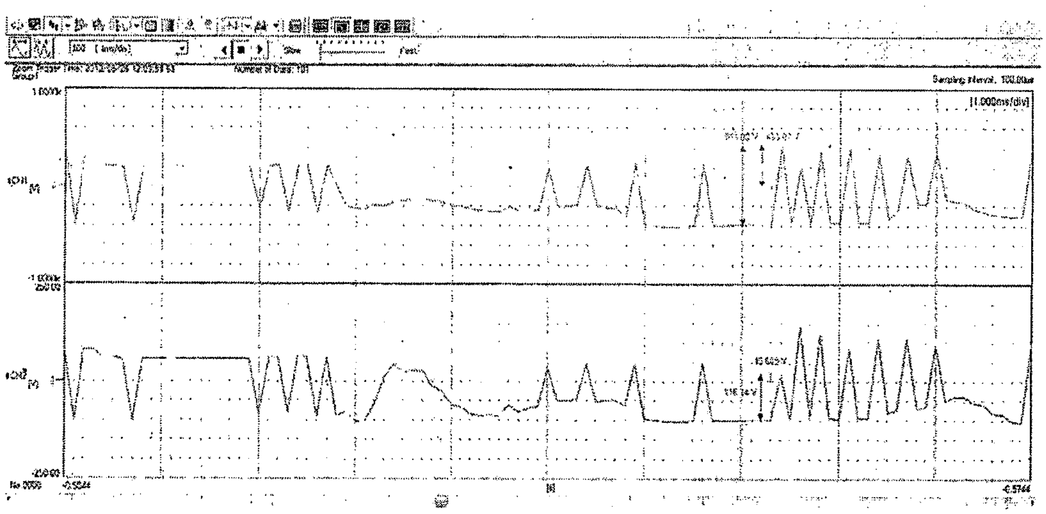


Diagram 3



Wave form No. KRK0110

Diagram 4

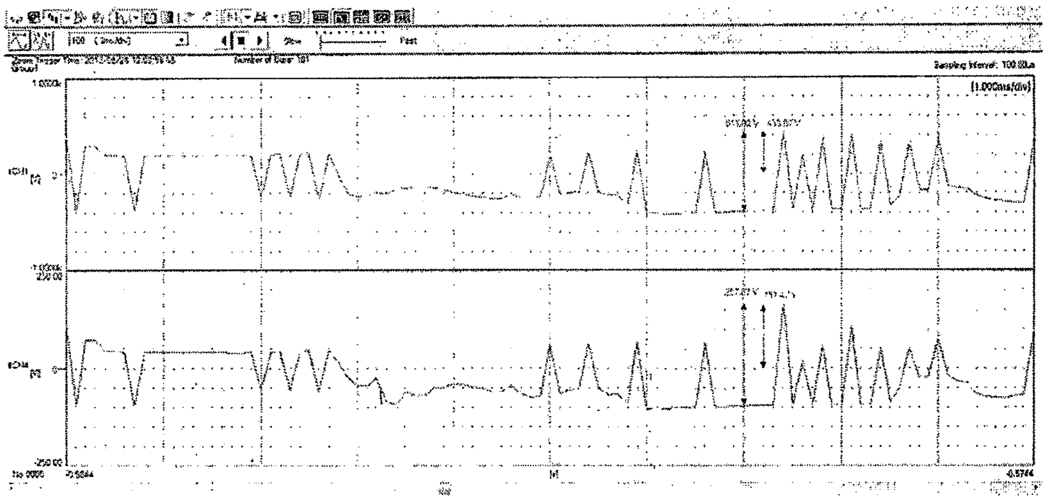
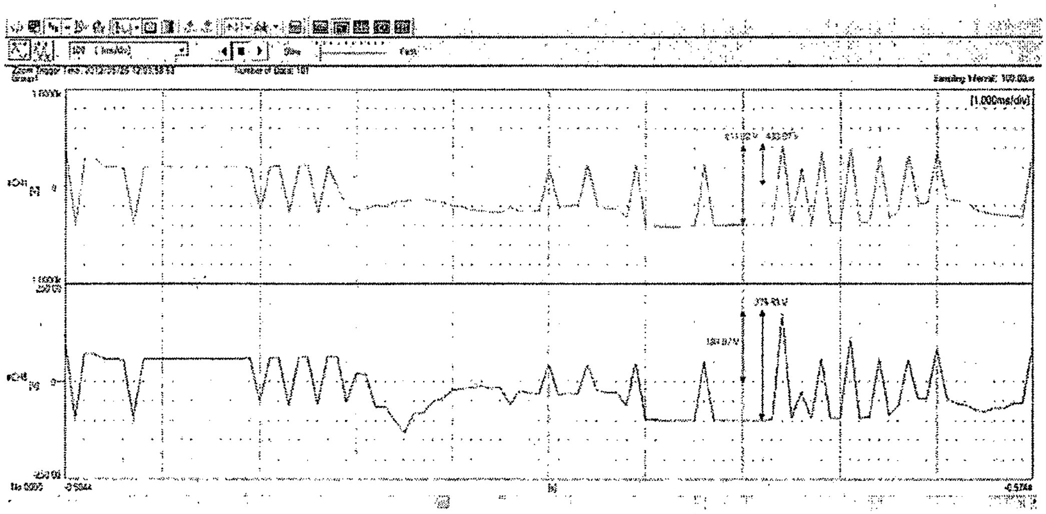


Diagram 5



Phase	Item	Change in 1 ms	Change in 0.5 ms
R-Phase	Phase Voltage V_{15}	811.02	433.07
	Voltage across first coil V_{12}	116.19	17.71
	Voltage across second coil V_{23}	157.48	70.86
	Voltage across third coil V_{34}	257.87	161.42
	Voltage across four coil V_{45}	279.53	183.07

Wave form No. KRK0004

Phase voltage and Voltage across first coil of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor on NO LOAD when supplied with sinusoidal supply-50 Hz.

Fig. 0004A Normal View of wave forms

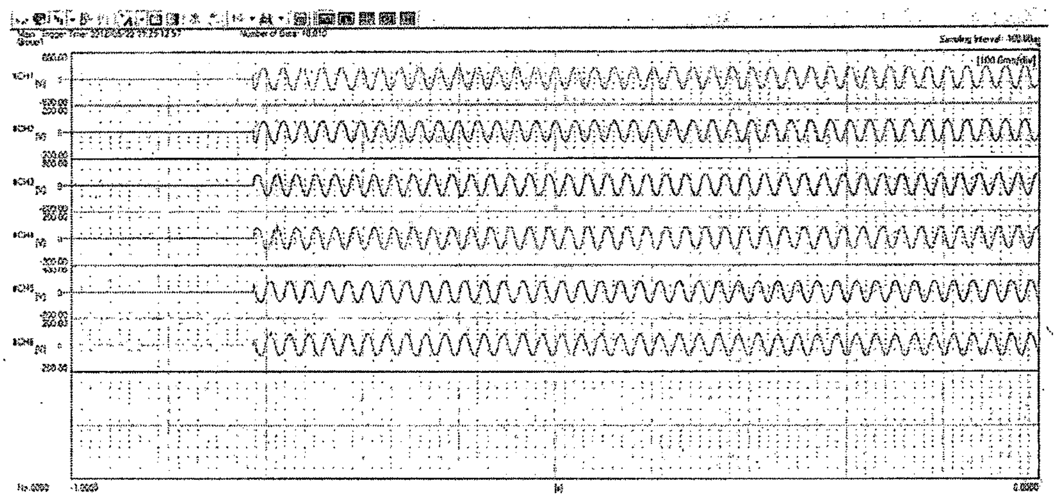
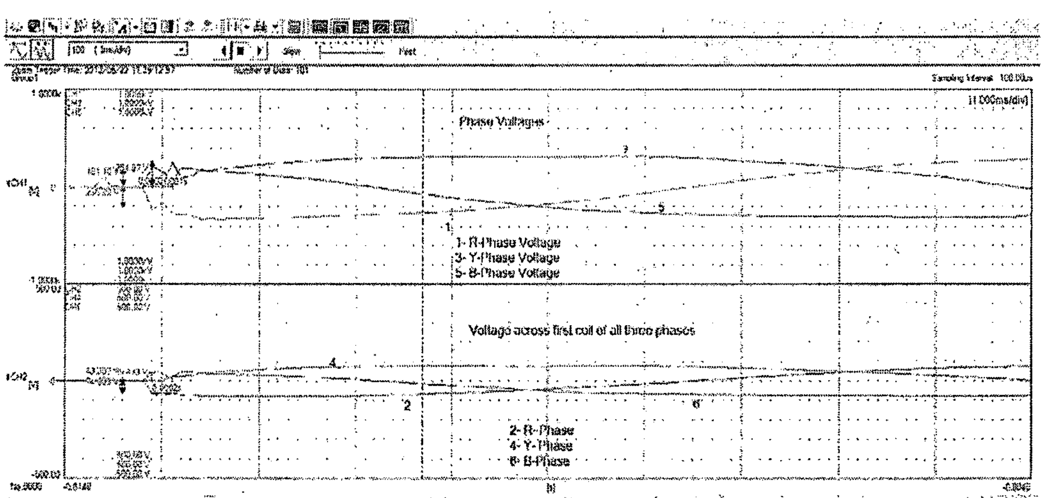


Fig. 0004B Enlarge View of wave forms



Wave form No. KRK0004

Fig. 0004C R-Phase

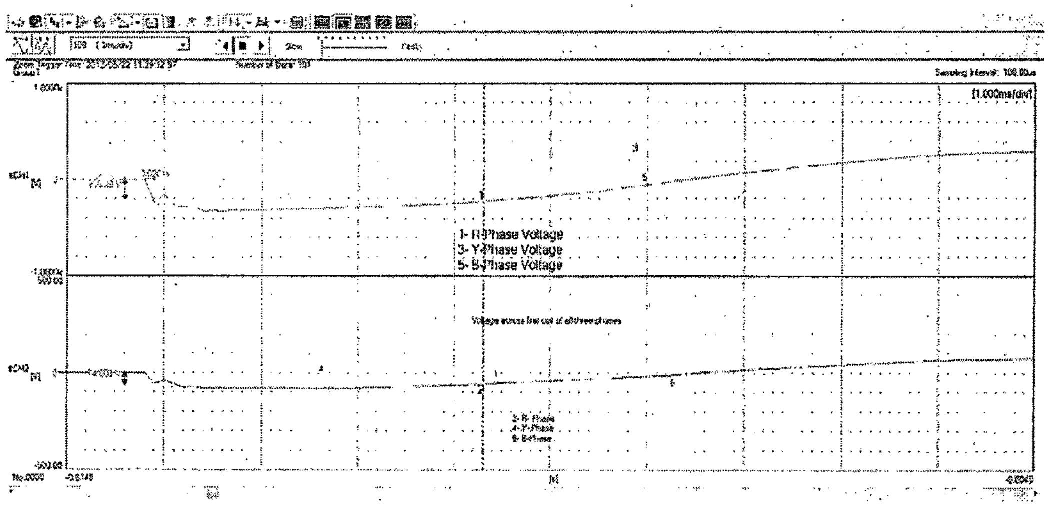
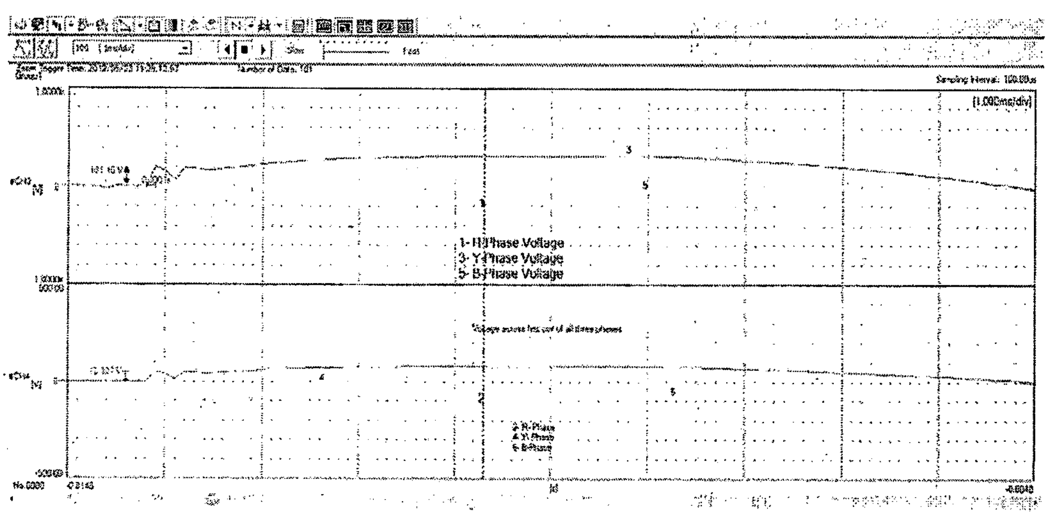
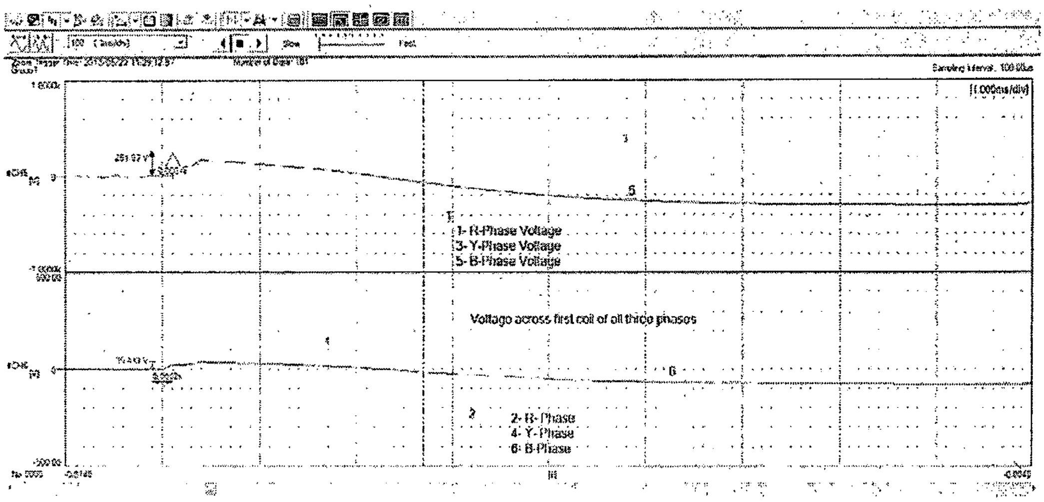


Fig. 0004D Y-Phase



Wave form No. KRK0004

Fig. 0004E B-Phase



Phase	Item	First Peak
R-Phase	Phase Voltage	236.22 V
	Voltage across coil	74.803 V
Y-Phase	Phase Voltage	181.10 V
	Voltage across coil	43.307 V
B-Phase	Phase Voltage	251.97 V
	Voltage across coil	35.433 V

Wave form No. KRK0138

Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 40 Hz.

R-phase Voltage

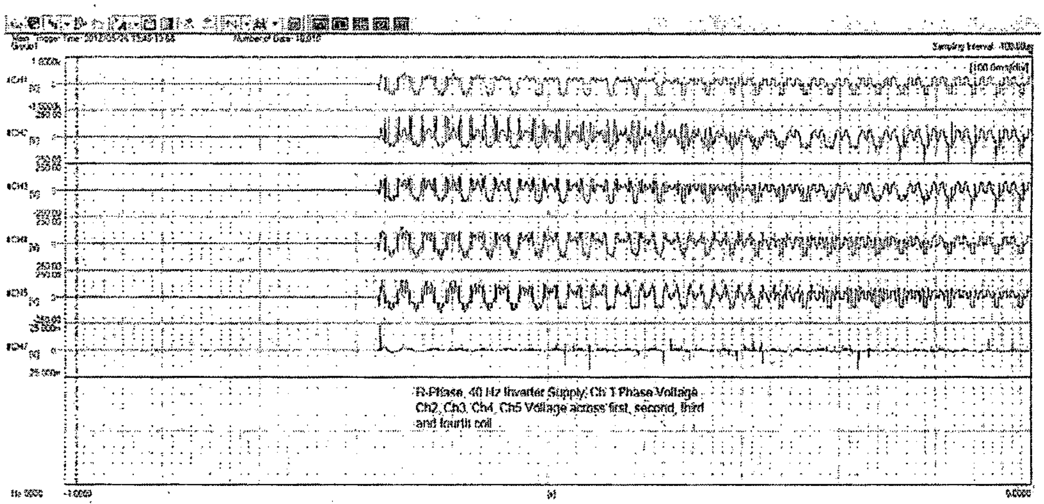
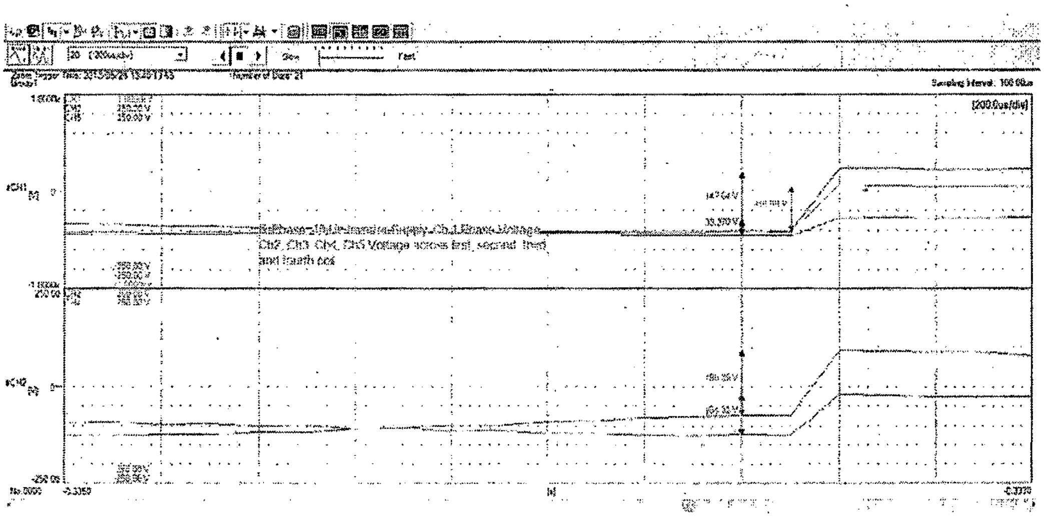


Diagram 1: Shows enlarge view of voltage wave forms across all four coils. Diagram 2: Shows phase voltage wave form and voltage across first coil. Diagram 3: Shows phase voltage wave form and voltage across second coil. Diagram 4: Shows phase voltage wave form and voltage across third coil. Diagram 5: Shows phase voltage wave form and voltage across fourth coil.

Diagram 1



Wave form No. KRK0138

Diagram 2

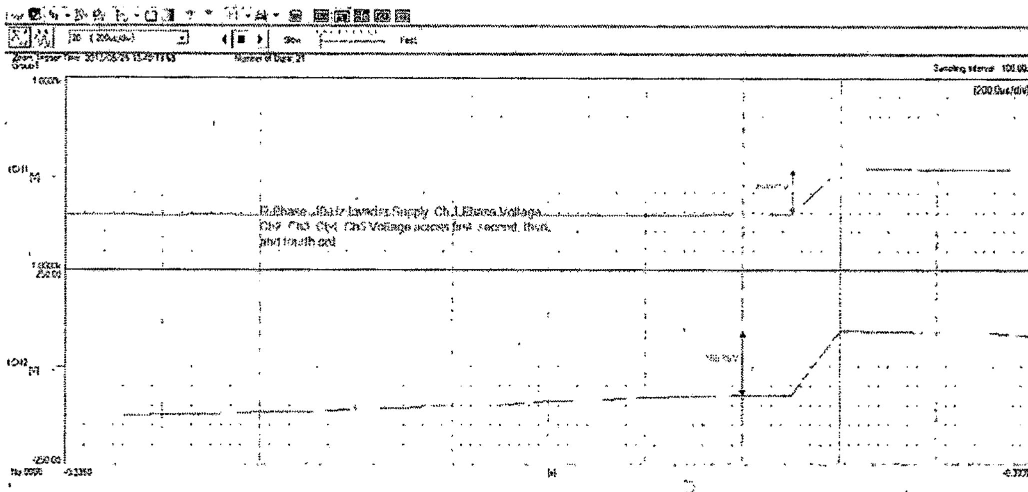
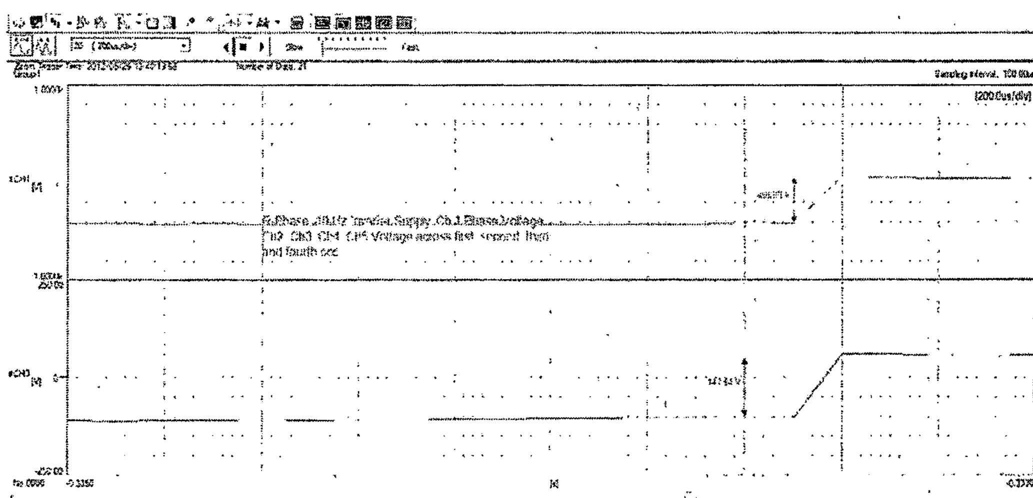


Diagram 3



Wave form No. KRK0138

Diagram 4

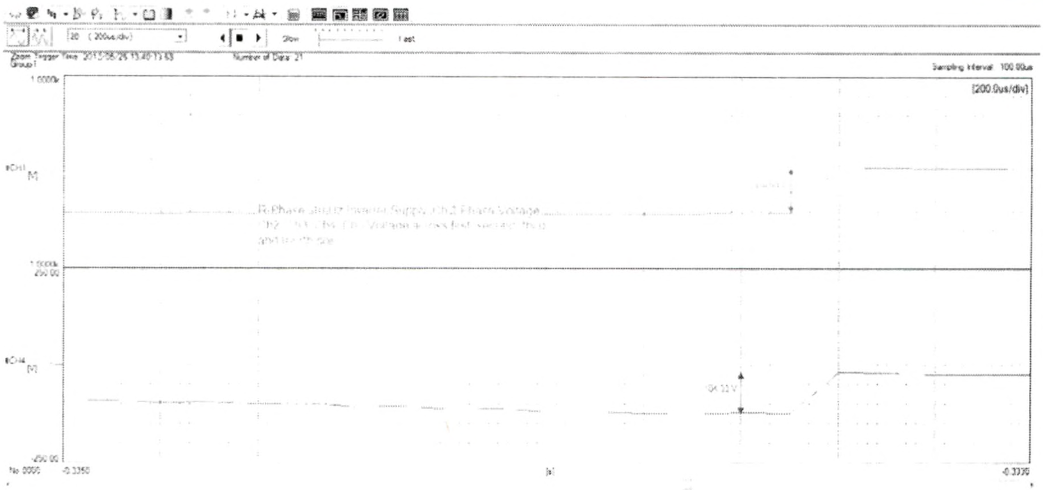
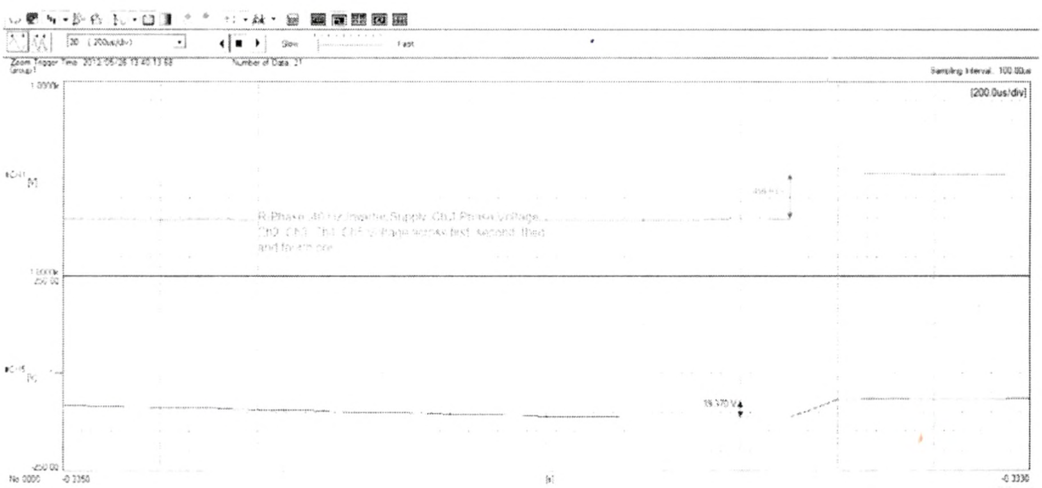


Diagram 5



Phase	Item	Voltage Variation
R-Phase	Phase Voltage V_{15}	456.69 V
	Voltage across first coil V_{12}	165.35
	Voltage across second coil V_{23}	147.64
	Voltage across third coil V_{34}	104.33
	Voltage across four coil V_{45}	39.37

Wave form No. KRK0139

Phase voltage and Voltage across all coils of 3-phase, 415 V, 250 W, 4-Pole Jewellery Polisher Motor when supplied with PWM inverter with frequency 50 Hz.

R-phase Voltage

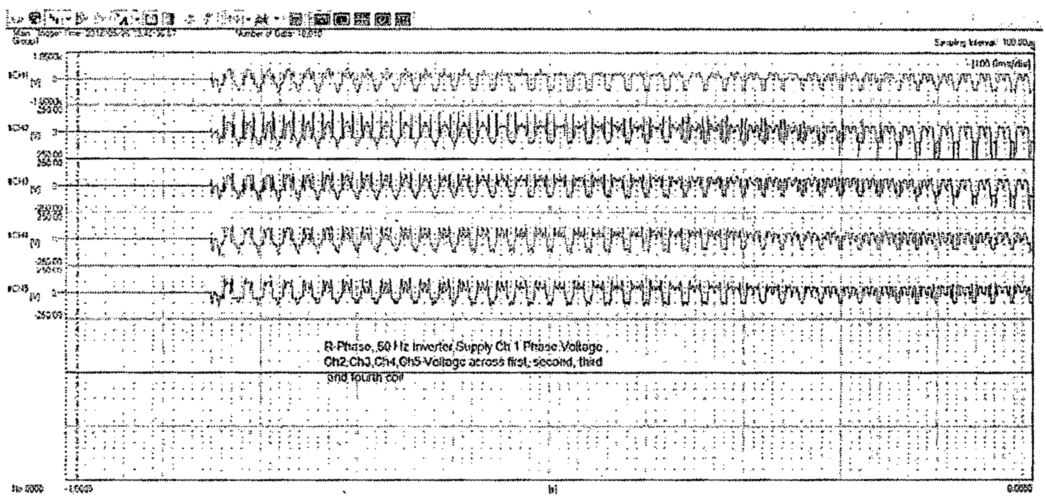
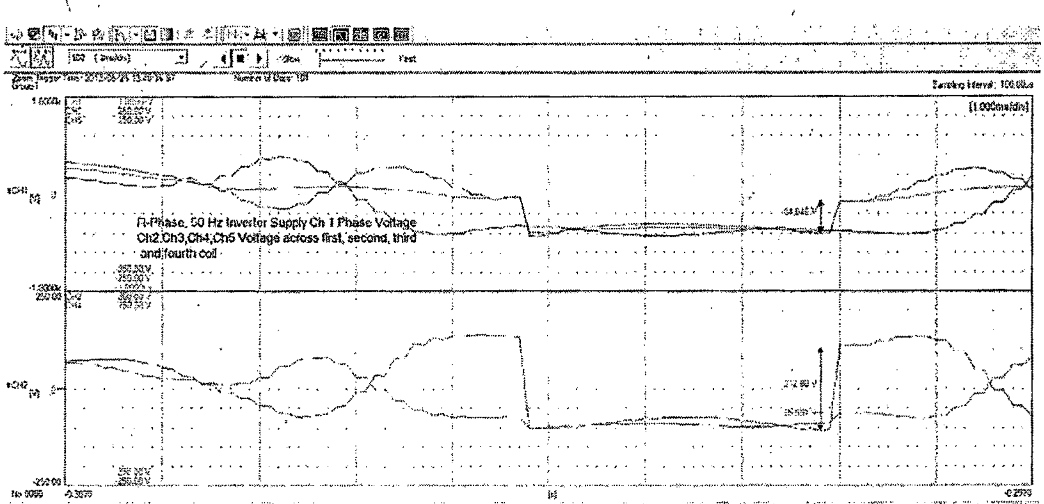


Diagram 1: Shows enlarge view of voltage wave forms across all four coils. Diagram 2: Shows phase voltage wave form and voltage across first coil. Diagram 3: Shows phase voltage wave form and voltage across second coil. Diagram 4: Shows phase voltage wave form and voltage across third coil. Diagram 5: Shows phase voltage wave form and voltage across fourth coil.

Diagram 1



Wave form No. KRK0139

Diagram 2

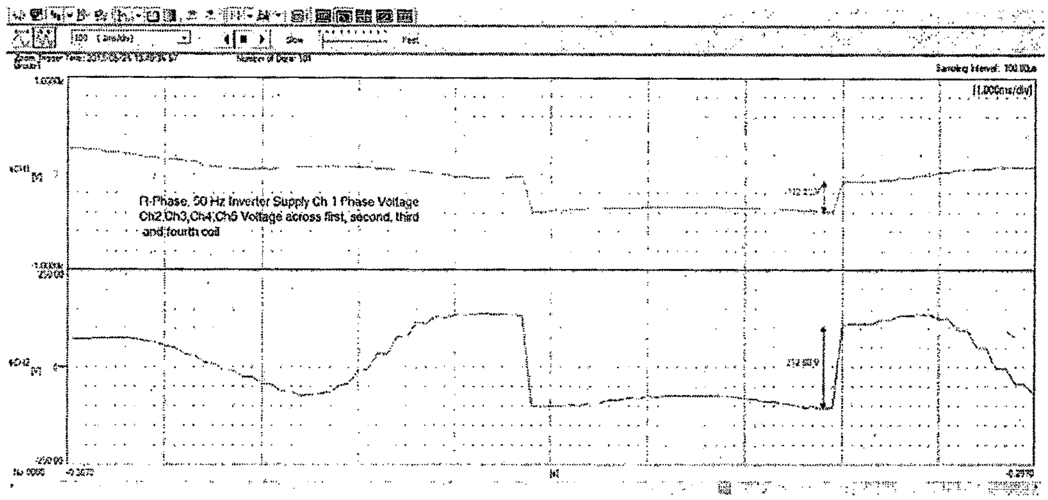
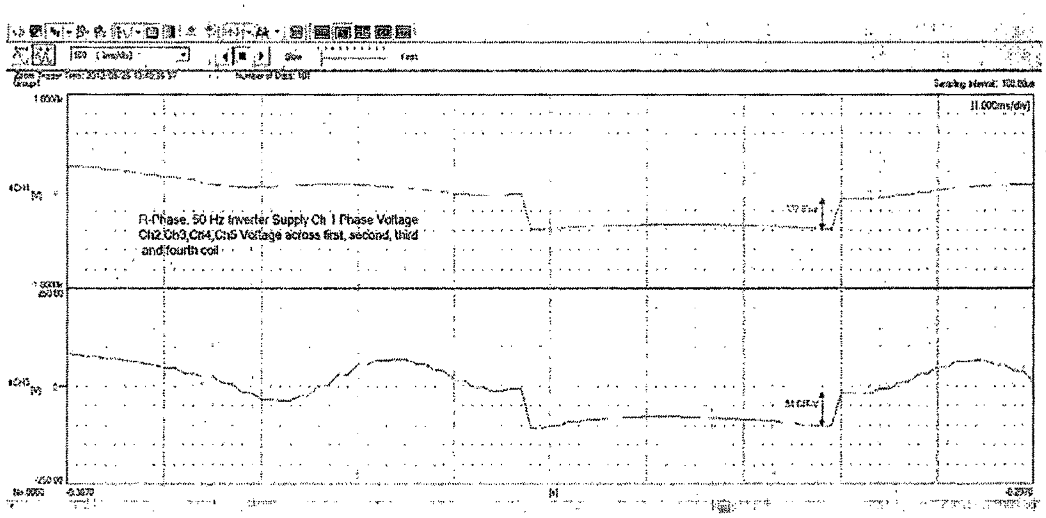


Diagram 3



Wave form No. KRK0139

Diagram 4

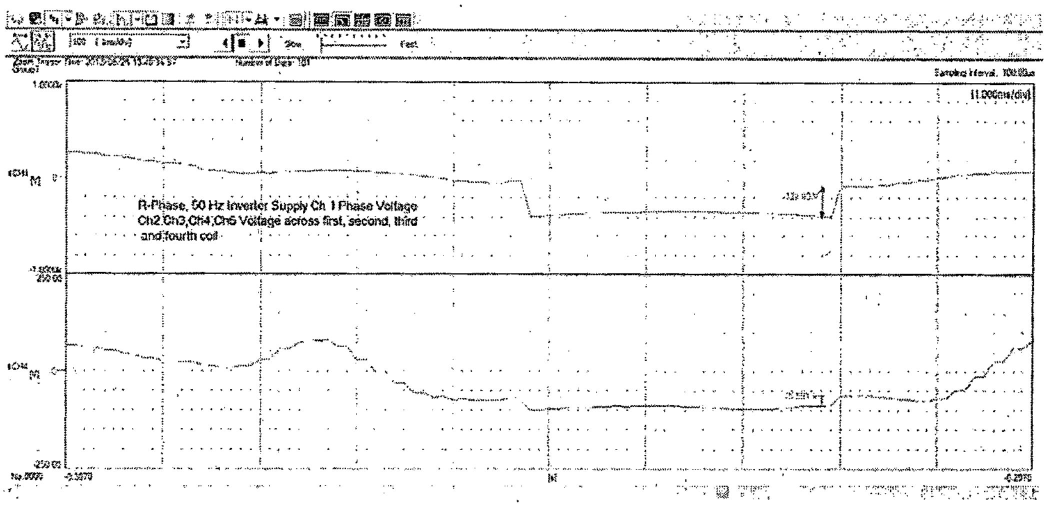
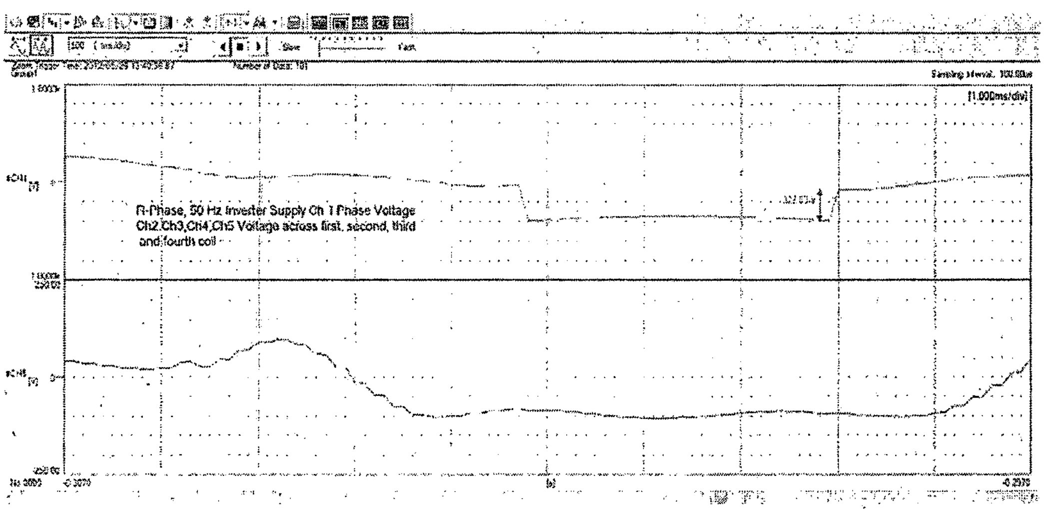


Diagram 5



Phase	Item	Voltage Variation
R-Phase	Phase Voltage V_{15}	322.83 V
	Voltage across first coil V_{12}	212.60
	Voltage across second coil V_{23}	84.64
	Voltage across third coil V_{34}	25.59
	Voltage across four coil V_{45}	0.0

Investigated waveforms are of coil voltages with respect to phase voltage and voltage of one coil with respect to voltage of second coil. When motor is operated on sinusoidal supply, then during switching period voltage across motor phase becomes equal to supply line voltage and the maximum voltage across any of the coil obtained is 80 V. Unexpected behaviour was observed in variation of coil voltage (harmonic voltage after few cycle from starting) with sinusoidal supply during starting, however this is not producing over voltages or high dv/dt. Voltage rise time when motor is supplied with converter is very small and is of the order of micro second. In some cases the peak voltage at motor terminals reaches to value which twice the value of dc link voltage. However for low voltage motor as peak is not reaches to large value coil manufactured with medium covering enamel wire and due care is taken to maintain the thickness around the conductor can withstand this voltages even though the variation of supply voltage is very peculiar particularly at low frequency.

The distribution of voltage during switching condition is not even among the coils of a winding and hence turns. The voltage drop in coils near terminal is more than that of in other coils. The measured voltage drop across first coil from terminal of winding of four coils in series is varying 30 to 56% of the phase voltage against 25% of the phase voltage. During the transition period voltage across first coil may be 70% of the total voltage. Comparison of wave forms for sinusoidal supply and inverter supply shows that distortions were very large with inverter supply which increases the losses and produces more stresses on the insulations.