Annexure III

PHASE SEQUENCE CALCULATION FOR INDUCTION MOTOR

Equivalent circuit for 10 kW, 50 Hz, 415 Volts, thee phase delta connected Induction motor is given below to calculate the effect of unbalance voltage on Induction motor. The value are obtained by conducting the No Load Test, Load Test & Block Rotor Test at ERDA Laboratory,

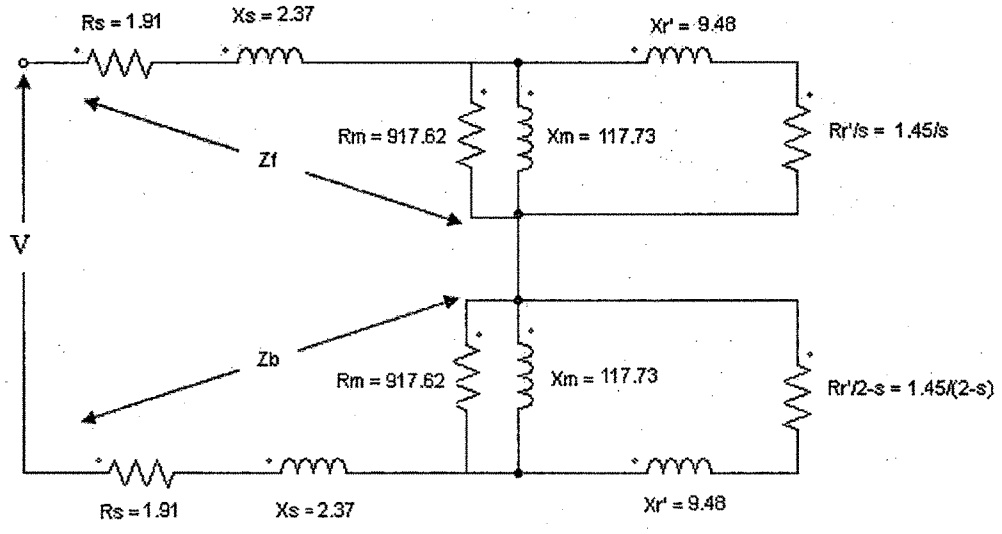

Figure AIII-1 Per phase equivalent circuit of Induction motor for calculation of speed torque characteristics under unbalance stator voltage condition.

The 10 kW motor performance characteristics was calculated with input rms voltage having unbalance as below in Table AIII-1:

Table AIII-1: table of unbalance voltage used for calculation

V_a	V_a angle	V_b	V_b angle	V_c	V_c angle
415.00	0.00	415.00	-120.00	215.00	120.00

Sequence voltage was calculated from the input voltage as mentioned in Table AIII-1 which is given below in Table AIII-2 for Zero Sequence, Positive Sequence and Negative Sequence voltage.

Table AIII-2: table of calculated sequence voltage & its percentage w.r.t positive sequence

V_o	V_+	V_-
33.33-57.73j	348.33-3.31E-14j	33.33+57.73j
V_{omag}	V_{+mag}	V_{-mag}
66.67	348.33	66.67
$\%V_o/V_p$		$\%V_n/V_p$
19.14		19.13875598

With sequence voltage & equivalent circuit of Induction motor for Positive Sequence, Negative Sequence & Zero Sequence which is given below, the speed torque characteristics of Induction Motor was obtained.

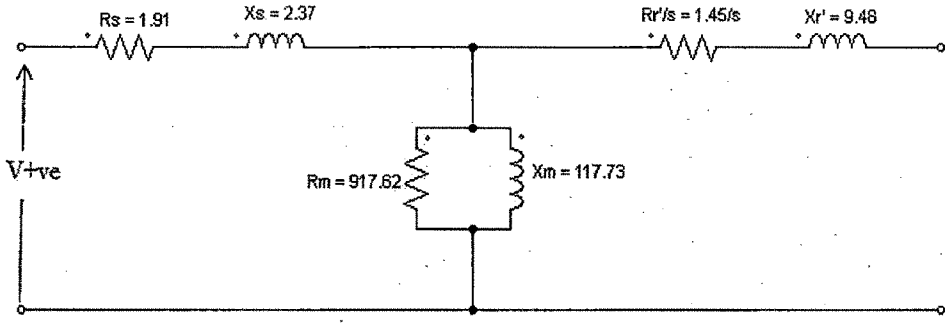

Figure III-2 Per phase equivalent circuit of Induction motor for calculation of speed torque characteristics under +ve sequence voltage.

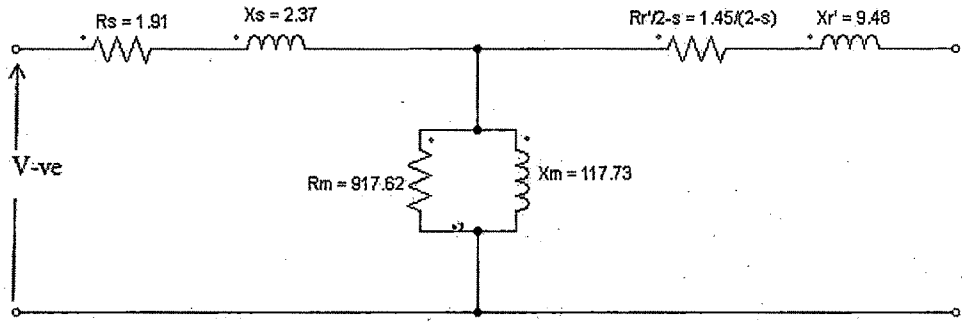

Figure III-3 Per phase equivalent circuit of Induction motor for calculation of speed torque characteristics under -ve sequence voltage.

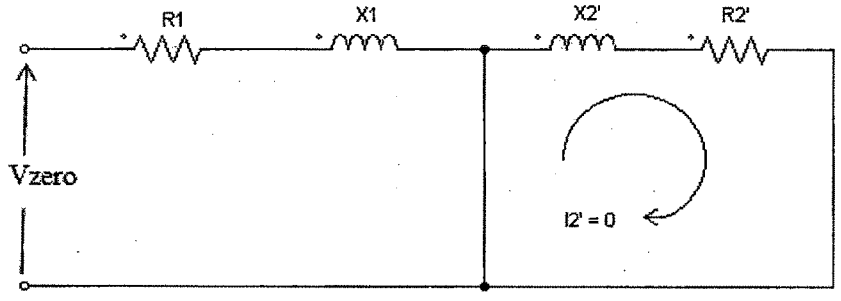

Figure III-4 Per phase equivalent circuit of Induction motor for calculation of speed torque characteristics under Zero sequence voltage.

The detail of calculation speed & torque at different slips with resolution of 0.005 are given below for balance voltage of 415 Volts

1	2	3	4		6	7	8	9	10	11	12	13	14	15	16	17
Voltage	Avg. Cur.	Input W	N50	Slip	Rotor output	Eff.	P.F.	Eff.*p.f.	Stator Cu. Loss	Rotor Cu loss	Rotor output	Stray loss	Losses	Wm	Shaft power	Shaft Torque (Balance voltage)
415.0	6.0	630.8	1499.9	0.000	22.7	3.6	0.1	0.5	69.4	0.0	22.7	31.5	100.9	157.1	22.7	0.1
415.0	6.8	2300.3	1492.5	0.005	1672.0	72.7	0.5	34.3	88.3	8.4	1672.0	31.5	128.2	156.3	1672.0	10.7
415.0	8.3	3958.8	1485.0	0.010	3269.7	82.6	0.7	54.9	131.8	33.0	3269.7	31.5	196.3	155.5	3269.7	21.0
415.0	10.2	5569.0	1477.5	0.015	4781.6	85.9	0.8	65.5	198.2	72.8	4781.6	31.5	302.5	154.7	4781.6	30.9
415.0	12.2	7118.7	1470.0	0.020	6198.4	87.1	0.8	70.7	285.5	126.5	6198.4	31.5	443.5	153.9	6198.4	40.3
415.0	14.3	8597.5	1462.5	0.025	7513.2	87.4	0.8	73.2	391.5	192.6	7513.2	31.5	615.6	153.2	7513.2	49.1
415.0	16.4	9997.3	1455.0	0.030	8721.9	87.2	0.9	74.2	513.8	269.7	8721.9	31.5	815.1	152.4	8721.9	57.2
415.0	**18.4**	**11312.4**	**1447.5**	**0.035**	**9822.3**	**86.8**	**0.9**	**74.3**	**650.2**	**356.2**	**9822.3**	**31.5**	**1037.9**	**151.6**	**9822.3**	**64.8**
415.0	**20.4**	**12539.0**	**1440.0**	**0.040**	**10814.7**	**86.2**	**0.9**	**73.8**	**798.2**	**450.6**	**10814.7**	**31.5**	**1280.3**	**150.8**	**10814.7**	**71.7**
415.0	32.2	18663.2	1387.5	0.075	15031.1	80.5	0.8	65.0	1988.6	1218.7	15031.1	31.5	3238.8	145.3	15031.1	103.4
415.0	38.4	20839.2	1350.0	0.100	15857.2	76.1	0.8	57.6	2822.6	1761.9	15857.2	31.5	4615.9	141.4	15857.2	112.2
415.0	**42.2**	**21694.5**	**1320.0**	**0.120**	**15752.6**	**72.6**	**0.7**	**52.0**	**3412.9**	**2148.1**	**15752.6**	**31.5**	**5592.5**	**138.2**	**15752.6**	**114.0**
415.0	51.3	21501.2	1200.0	0.200	12888.5	59.9	0.6	35.0	5045.5	3222.1	12888.5	31.5	8299.1	125.7	12888.5	102.6
415.0	56.2	19340.7	1050.0	0.300	9071.8	46.9	0.5	22.5	6050.0	3887.9	9071.8	31.5	9969.4	110.0	9071.8	82.5
415.0	58.5	17441.0	900.0	0.400	6335.9	36.3	0.4	15.1	6554.1	4223.9	6335.9	31.5	10809.5	94.2	6335.9	67.2
415.0	59.7	16000.8	750.0	0.500	4416.4	27.6	0.4	10.3	6841.6	4416.4	4416.4	31.5	11289.5	78.5	4416.4	56.2
415.0	60.5	14912.4	600.0	0.600	3025.3	20.3	0.3	7.0	7022.5	4538.0	3025.3	31.5	11592.0	62.8	3025.3	48.1
415.0	61.0	14072.7	450.0	0.700	1980.2	14.1	0.3	4.5	7144.9	4620.5	1980.2	31.5	11796.8	47.1	1980.2	42.0
415.0	61.4	13409.5	300.0	0.800	1169.9	8.7	0.3	2.7	7232.3	4679.6	1169.9	31.5	11943.3	31.4	1169.9	37.2
415.0	61.7	12874.3	150.0	0.900	524.9	4.1	0.3	1.2	7297.4	4723.7	524.9	31.5	12052.5	15.7	524.9	33.4
415.0	61.9	12434.3	0.0	1.000	0.0	0.0	0.3	0.0	7347.6	4757.7	0.0	31.5	12136.8	0.0	0.0	30.3

As mentioned above same calculation was done with unbalance voltage as mention in Table AIII-1. table of unbalance voltage used for calculation.

2			3	4	5.000	6	7	8	9	10	11	12	13	14	15	16	17
Current Pos Seq.	**Current Neg. Seq.**	**Current Zero Seq.**	**Input power**	**Speed**	**Slip**	**Rotor Output**	**eff.**	**P.F.**	**Eff.*p.f.**	**Stator Cu. Loss**	**Rotor Cu loss**	**Rotor output**	**Stray loss**	**Losses**	**Wm**	**Shaft power**	**Shaft Torque (unbalance voltage)**
5.1	10.1	37.9	3459.5	1499.9	0.000	-47.2	-1.4	0.3	-0.5	2992.3	126.3	-47.2	44.7	3163.3	157.0	-47.2	-0.3
5.7	10.1	37.9	4635.9	1492.5	0.005	1114.9	24.0	0.4	10.7	3005.6	132.2	1114.9	44.7	3182.5	156.3	1114.9	7.1
7.0	10.1	37.9	5804.4	1485.0	0.010	2240.8	38.6	0.5	19.6	3036.2	149.6	2240.8	44.7	3230.5	155.5	2240.8	14.4
8.5	10.1	37.9	6939.1	1477.5	0.015	3306.1	47.6	0.5	25.8	3083.0	177.6	3306.1	44.7	3305.3	154.7	3306.1	21.4
10.2	10.1	37.9	8031.0	1470.0	0.020	4304.4	53.6	0.6	29.9	3144.5	215.4	4304.4	44.7	3404.6	153.9	4304.4	28.0
12.0	10.1	37.9	9072.9	1462.5	0.025	5230.9	57.7	0.6	32.6	3219.1	262.0	5230.9	44.7	3525.8	153.2	5230.9	34.2
13.7	10.1	37.9	10059.3	1455.0	0.030	6082.5	60.5	0.6	34.5	3305.3	316.3	6082.5	44.7	3666.3	152.4	6082.5	39.9
15.5	**10.1**	**37.9**	**10986.0**	**1447.5**	**0.035**	**6858.0**	**62.4**	**0.6**	**35.7**	**3401.4**	**377.3**	**6858.0**	**44.7**	**3823.3**	**151.6**	**6858.0**	**45.2**
17.1	**10.1**	**37.9**	**11850.2**	**1440.0**	**0.040**	**7557.3**	**63.8**	**0.6**	**36.5**	**3505.6**	**443.7**	**7557.3**	**44.7**	**3994.0**	**150.8**	**7557.3**	**50.1**
27.0	10.1	37.9	16165.9	1387.5	0.075	10529.0	65.1	0.6	36.2	4344.2	984.8	10529.0	44.7	5373.7	145.3	10529.0	72.5
32.2	10.1	37.9	17699.7	1350.0	0.100	11112.0	62.8	0.5	33.9	4931.7	1367.5	11112.0	44.7	6343.8	141.4	11112.0	78.6
35.4	**10.1**	**37.9**	**18303.0**	**1320.0**	**0.120**	**11039.0**	**60.3**	**0.5**	**31.7**	**5347.6**	**1639.5**	**11039.0**	**44.7**	**7031.7**	**138.2**	**11039.0**	**79.9**
43.1	10.1	37.9	18169.5	1200.0	0.200	9024.2	49.7	0.5	24.0	6497.5	2396.0	9024.2	44.7	8938.2	125.7	9024.2	71.8
47.2	10.1	37.9	16651.0	1050.0	0.300	6339.5	38.1	0.4	17.1	7204.9	2864.9	6339.5	44.7	10114.4	110.0	6339.5	57.7
49.1	10.0	37.9	15316.7	900.0	0.400	4416.7	28.8	0.4	12.4	7559.6	3101.3	4416.7	44.7	10705.7	94.2	4416.7	46.9
50.1	10.0	37.9	14306.7	750.0	0.500	3069.7	21.5	0.4	8.9	7761.8	3236.7	3069.7	44.7	11043.2	78.5	3069.7	39.1
50.8	10.0	37.9	13545.1	600.0	0.600	2095.7	15.5	0.4	6.3	7888.8	3322.0	2095.7	44.7	11255.5	62.8	2095.7	33.4
51.2	10.0	37.9	12959.5	450.0	0.700	1366.4	10.5	0.4	4.2	7974.4	3379.7	1366.4	44.7	11398.8	47.1	1366.4	29.0
51.6	10.0	37.9	12499.2	300.0	0.800	803.5	6.4	0.4	2.6	8035.3	3420.9	803.5	44.7	11500.9	31.4	803.5	25.6
51.8	10.0	37.9	12130.2	150.0	0.900	358.5	3.0	0.4	1.2	8080.3	3451.4	358.5	44.7	11576.4	15.7	358.5	22.8
52.0	9.9	37.9	11829.7	0.0	1.000	0.0	0.0	0.4	0.0	8114.7	3474.7	0.0	44.7	11634.0	0.0	0.0	20.6

Speed v/s Torque curve for balance voltage & unbalance voltage is shown below

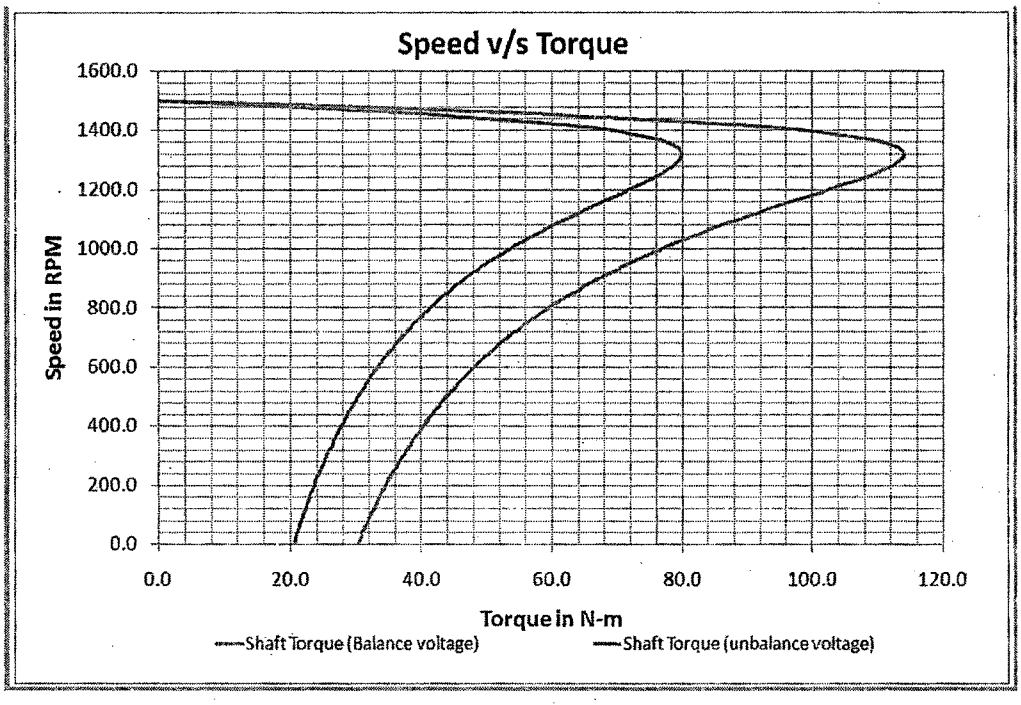

Figure III-5 Speed Torque Characteristics of Induction motor under balance voltage as well as unbalance voltage condition.

From above data it is clear that with unbalance voltages, losses in the motor are high as compared to if motor is supplied with balance voltage. For 10 kW, 4 poles, 3 phases, delta connected, 415 volts, three phase motor losses with balance voltage & unbalance voltage having negative sequence voltage of 20% & zero sequence voltage of 20 %, the losses calculated are as follows:

	Input power Watts	output Power Watts	Total Losses Watts	% Effi.	Total Saving Watts	% saving of input power
with balance voltage	11312	9822	1038	87	2785	28
with Unbalance voltage	10986	6858	3823	62		