EE234 Experiment 5: Speed Control of a Three-Phase Induction Motor

Inderjeet Nair, 170020013
Ayan Sharma, 170020023
Aaron John Sabu, 170070050

March 2019

1 Aim

This experiment aims to:

- study the behaviour of inverter-fed three-phase induction motor (IM)
- obtain the performance characteristics ($T - N_r$) of the induction motor (IM)

2 Theory and Circuit Diagrams

Given below is the equivalent circuit for the induction motor. R_s and X_{sl} represent stator winding resistance and stator leakage inductance respectively, whereas R_s' and X_{rl}' represent rotor winding resistance and rotor leakage inductance respectively. R_c is the core loss component and X_m is the magnetizing reactance.

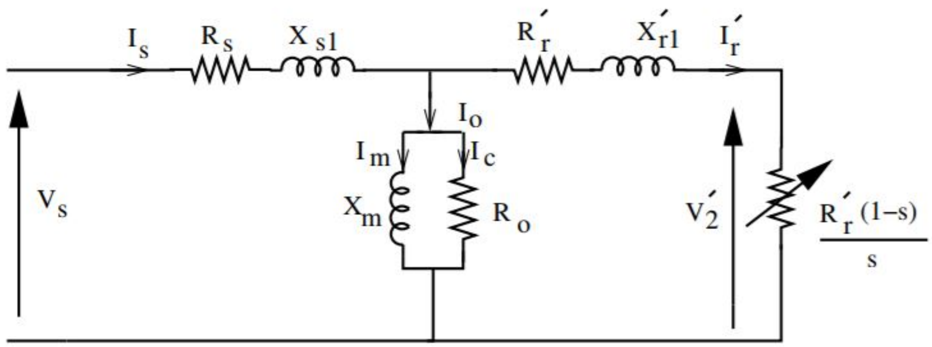

Figure 1: Equivalent Circuit of an Induction Motor

As a result of the transformation of the circuit from a solely electrical perspective to a total perspective including mechanical and electrical power, we can write $\frac{R_r'(1-s)}{s}$ as the electrical equivalent of the mechanical load.
Power developed by the motor is given by:

$$P_d = (I_r')^2 \frac{R_r'(1-s)}{s}$$

Rotor copper loss is given by

$$P_c = (I_r')^2 R_r'$$

Hence, the total power supplied across the airgap is given by the sum of the above:

$$P_a = P_d + P_c = (I_r')^2 \frac{R_r'}{s}$$

As a result, we see that:

$$P_a : P_d : P_c = 1 : (1-s) : s$$

The circuit we use in the lab is given below:

2.1 Part 1

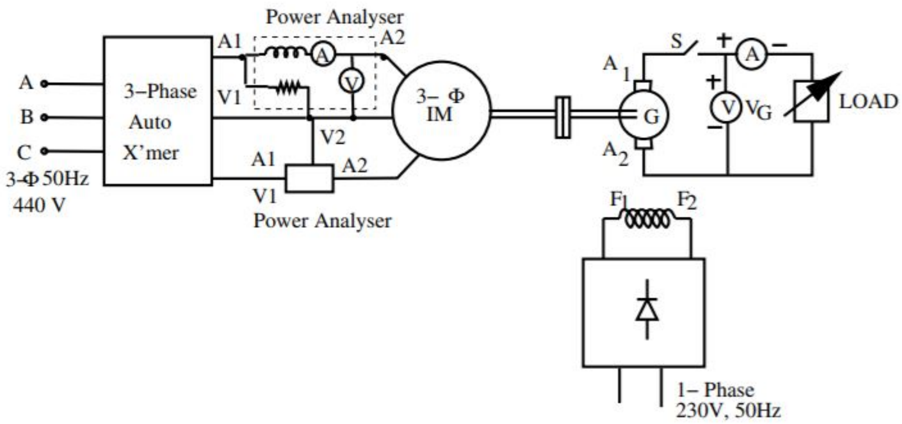

Figure 2: Part 1 Circuit

2.2 Part 2

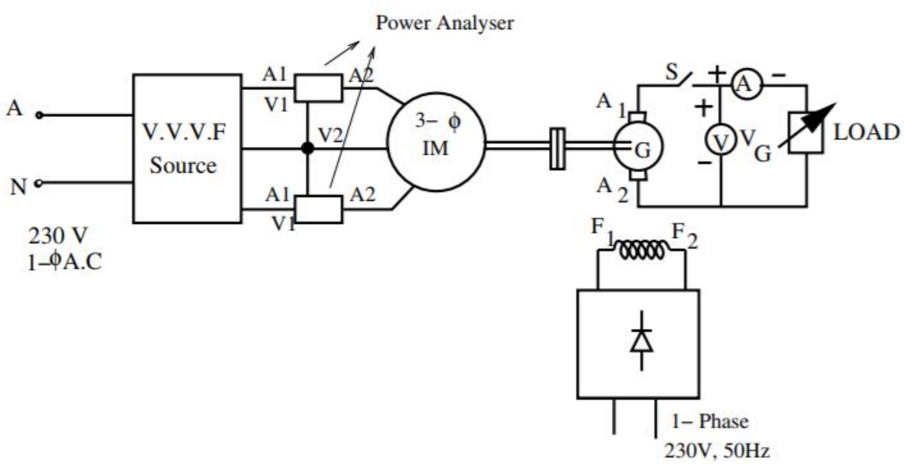

Figure 3: Part 2 Circuit

3 Observation Tables and comments

The specifications of induction motor on which the experiment was performed is as follows:

Voltage rating(V)	220
Current rating(A)	5.12
Rated speed(rpm)	1427

The following observation is obtained when the induction motor has no load speed of 1495rpm(The subscript 1 refers to W_1 readings and 2 refers to W_2 readings):

V_1	I_1	P_1	V_2	I_2	P_2	P_{total}	V_{ag}	I_{ag}	V_{fg}	I_{fg}	ω	Load
212.4	2.643	378.9	212.7	2.599	-134.85	244.05	158	0	187	0.42	1495	0
212.5	2.680	398.1	211.9	2.593	-120.31	277.79	155	0	187	0.42	1485	1
212.2	2.695	420.6	212	2.600	-82.87	337.73	154	0.5	188	0.42	1483	2
217.5	2.927	482.5	215.1	2.745	-95.08	387.42	152	0.9	187	0.4	1482	3
217.8	2.888	483.7	216.4	2.781	-73.04	410.66	151	1.1	187	0.41	1478	4
216.6	2.988	519.2	214.5	2.790	-60.16	459.04	149	1.3	187	0.40	1476	5
216.6	2.930	515.2	216.1	2.851	-23.97	491.23	149	1.5	187	0.40	1474	6
217.0	2.978	535.7	216.3	2.912	-5.90	529.8	148	1.8	187	0.40	1471	7
216.9	3.035	563.9	216.0	2.987	35.8	599.71	146	2.1	187	0.40	1468	8
216.6	3.105	591.5	215.9	3.071	63.84	655.34	145	2.4	187	0.40	1464	9
216.1	3.195	617.3	215.2	3.1487	88.5	705.8	144	2.8	187	0.40	1460	10
215.8	3.277	650.7	215.2	3.243	116.29	766.99	143	3.1	187	0.40	1456	11
215.4	3.338	664.4	214.7	3.298	132.26	796.66	142	3.3	187	0.40	1454	12

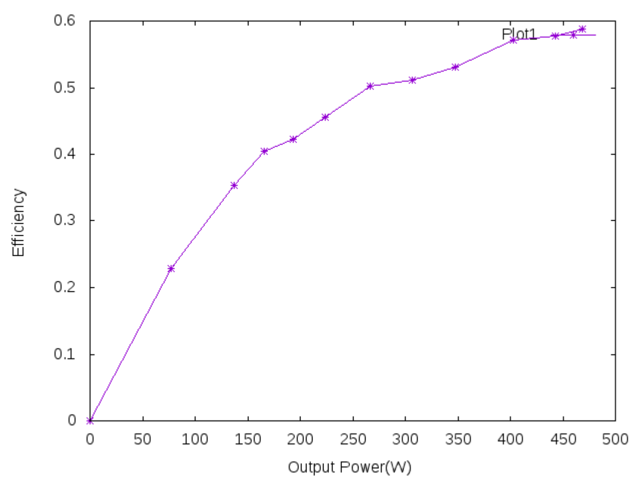

Figure 4: Plot for above data for efficiency v/s Output Power

The following readings are obtained when no load speed is 1485rpm

V_1	I_1	P_1	V_2	I_2	P_2	P_{total}	V_{ag}	I_{ag}	V_{fg}	I_{fg}	ω	Load
171.90	1.887	237.2	171.88	1.847	-49.55	187.65	155	0	186	0.40	1485	0
171.92	1.8935	248.2	171.2	1.873	-31.08	217.12	153	0	186	0.40	1482	1
171.90	1.9793	285.3	171.63	1.9433	-1.84	283.46	151	0.5	187	0.40	1476	2
171.80	2.038	297.3	171.17	1.986	14.234	311.534	150	0.7	188	0.40	1473	3
171.82	2.099	316.6	170.84	2.051	32.72	349.32	149	0.9	187	0.40	1469	4
171.44	2.162	335.2	170.4	2.181	60.61	395.81	147	1.3	188	0.40	1464	5
171.03	2.285	366.1	170.34	2.327	88.91	455.01	146	1.6	188	0.40	1458	6
170.63	2.420	396.1	170.11	2.478	111.75	507.85	145	1.9	187	0.40	1451	7
170.4	2.585	429.32	168.72	22.544	142.16	553.18	144	2.1	188	0.40	1447	8
170.44	2.667	441.3	170.16	2.699	152.17	593.47	143	2.3	188	0.40	1444	9
170.23	2.783	466.6	169.97	2.880	177.03	643.63	141	2.6	188	0.40	1437	10
170.00	2.971	502.3	169.35	3.071	201.6	706.9	140	2.9	188	0.40	1429	11
169.40	3.129	529.3	169.10	3.277	231.6	760.9	138	3.2	188	0.40	1422	12

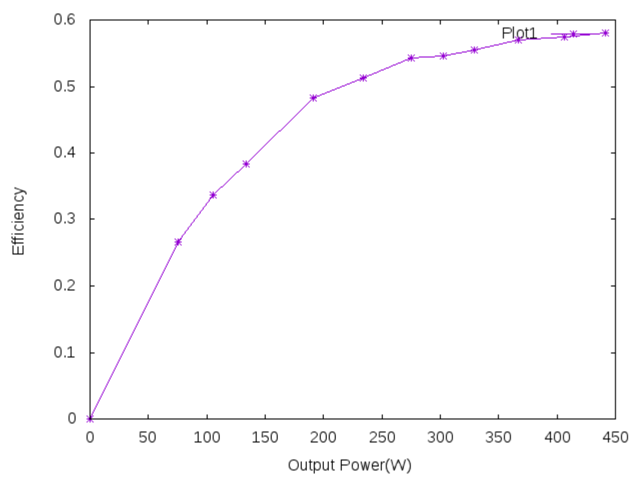

Figure 5: Plot for above data for efficiency v/s Output Power

The following data was obtained when the armature voltage was controlled using voltage drive. The following table was obtained when the frequency is set to 40Hz:

V_1	I_1	P_1	V_2	I_2	P_2	P_{total}	V_{ag}	I_{ag}	V_{fg}	I_{fg}	ω	Load
171.90	1.887	237.2	171.88	1.847	-49.55	187.65	155	0	186	0.40	1485	0
171.92	1.8935	248.2	171.2	1.873	-31.08	217.12	153	0	186	0.40	1482	1
171.90	1.9793	285.3	171.63	1.9433	-1.84	283.46	151	0.5	187	0.40	1476	2
171.80	2.038	297.3	171.17	1.986	14.234	311.534	150	0.7	188	0.40	1473	3
171.82	2.099	316.6	170.84	2.051	32.72	349.32	149	0.9	187	0.40	1469	4
171.44	2.162	335.2	170.4	2.181	60.61	395.81	147	1.3	188	0.40	1464	5
171.03	2.285	366.1	170.34	2.327	88.91	455.01	146	1.6	188	0.40	1458	6
170.63	2.420	396.1	170.11	2.478	111.75	507.85	145	1.9	187	0.40	1451	7
170.4	2.585	429.32	168.72	22.544	142.16	553.18	144	2.1	188	0.40	1447	8
170.44	2.667	441.3	170.16	2.699	152.17	593.47	143	2.3	188	0.40	1444	9
170.23	2.783	466.6	169.97	2.880	177.03	643.63	141	2.6	188	0.40	1437	10
170.00	2.971	502.3	169.35	3.071	201.6	706.9	140	2.9	188	0.40	1429	11
169.40	3.129	529.3	169.10	3.277	231.6	760.9	138	3.2	188	0.40	1422	12

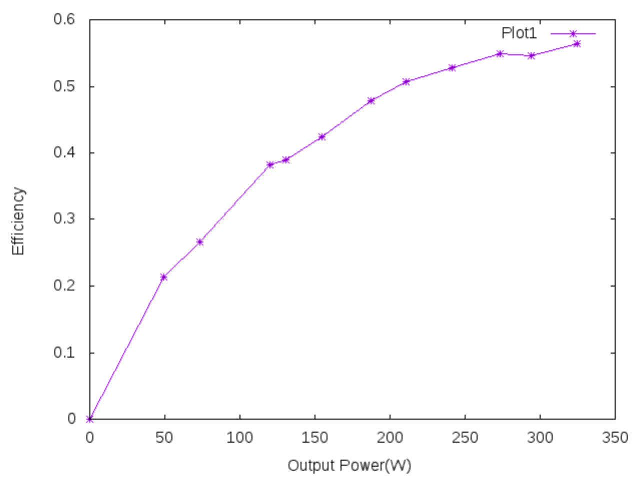

Figure 6: Plot for above data for efficiency v/s Output Power

The following data was obtained when the armature voltage was controlled using voltage drive. The following table was obtained when the frequency is set to 55Hz:

V_1	I_1	P_1	V_2	I_2	P_2	P_{total}	V_{ag}	I_{ag}	V_{fg}	I_{fg}	ω	Load
213.1	2.168	317.2	213.5	2.153	-83	234.2	170	0	190	0.40	1638	0
212.7	2.102	327.7	212.0	2.179	-50.9	276.8	168	0.3	189	0.40	1632	1
211.7	2.195	362	211.1	2.201	-30.3	331.7	167	0.6	189	0.40	1630	2
210.1	2.218	376.0	211.0	2.253	-5.674	370.326	166	0.8	188	0.4	1627	3
210.2	2.263	404.8	210.4	2.340	27.87	432.67	165	1.2	189	0.40	1621	4
209.9	2.346	426.4	210.5	2.443	55.23	481.63	163	1.5	189	0.40	1616	5
209.2	2.454	463.4	208.8	2.557	91.24	554.64	161	1.8	189	0.41	1611	6
208.0	2.561	485.1	207.6	2.643	113.94	599.04	160	2.0	189	0.40	1608	7
207.6	2.696	529.3	207.6	2.789	147.99	677.29	159	2.4	189	0.40	1602	8
207.2	2.770	541.8	207.6	2.882	168.10	709.9	158	2.6	189	0.40	1598	9
207.0	2.877	569.0	207.2	3.037	198.16	767.16	156	2.9	189	0.40	1593	10
206.5	3.041	605.2	206.4	3.213	228.1	833.3	154	3.2	189	0.40	1586	11
205.9	3.169	630.04	206.1	3.297	246.6	876.64	153	3.4	189	0.40	1582	12

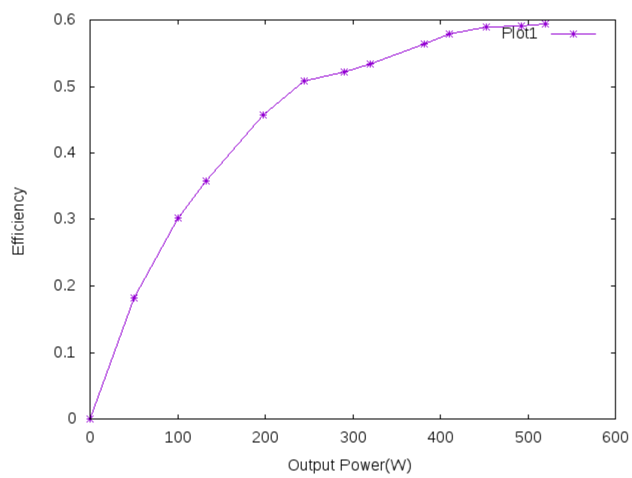

Figure 7: Plot for above data for efficiency v/s Output Power

4 Conclusion

1. At higher values of V/f, the torque speed characteristics of the motor intersects x-axis at higher values than in voltage controlled drive. In V/f case we can achieve an almost constant maximum torque. This property is used for obtaining higher starting torques in V/f controlled drives.

2. For voltage controlled drive, no load speed is same irrespective of the voltage making it difficult to achieve large variation in speed is difficult.

3. Parallel torque-speed $(T - \omega)$ characteristics are observed for V/f controlled drive. This is because of constant **sk** (slip speed) which leads to an inefficient control drive.

4. In this case, a decrease in output power leads to a reduction in input power and hence less copper losses compared to the voltage-controlled drive. Therefore this is more efficient than the purely voltage-controlled drive.

5 Answers

1. Due to the high initial current that exists momentarily when the motor is just switched on leads to temporary reduction in lamp intensity.

2. The three phase winding produces rotating magnetic field which in-turn rotates the motor. Interchanging two of the stator fields reverses the direction of rotation of magnetic field and thus the motor's rotation direction.

3. A high current will be produced if two phases of the DC motor were swapped. First the direction of magnetic field reverses and then the sense of rotation of motor. This can damage the circuit. Therefore the interchanging of phases is done at lower speed to avoid damage to the motor.

4. Motor for ceiling fan is a single phase induction motor.
   A universal motor for mixer.
   Universal motor for suction for a vacuum cleaner.

5. Firstly, power requirement of an induction motor is less than the DC motor. There is more wear and tear in a DC motor than in an induction motor due to the presence of carbon brushes in the DC motor. Also, an induction motor requires less maintenance in contrast to its counterpart.

6. The rotating magnetic produced due to the stator currents moves the rotor. If rotor moves at the same speed as that of magnetic field there won't be a relative motion and hence speed of rotor will decrease because of frictional losses. So, rotor won't be able to attend speed of rotating field. As the motor always runs at a different speed it is called as asynchronous motor.