Chapter 7

Discussion and Analysis of Experiment Results

7.1 COMPARISON OF PERFORMANCE

The performance obtained for Frame 63, 3-phase, 415 V, 470 W, 1.3 A, 50 Hz, 2-Pole, Induction Motor from actual load test, from equivalent circuit and from modified equivalent circuit is as shown in following table:

Table 7.1 Comparison of performance of Frame 63, 3-phase, 415 V, 470 W, 1.3 A, 50 Hz, 2-Pole, I.M.

Sr. No.	Method	Output Power	Power Factor	Torque	Efficiency
		(W)		(Nm)	(%)
1	Actual Test	197.83	0.4718	0.6518	61.40
	Equiv. ckt	197.82	0.4821	0.6422	74.59
	Modified Par.	197.95	0.4644	0.6437	78.72
2	Actual Test	291.00	0.5623	0.9938	68.59
	Equiv. ckt	290.94	0.5888	0.6596	78.02
	Modified Par.	291.00	0.5786	0.9573	80.86
3	Actual Test	371.93	0.6297	1.2375	71.44
	Equiv. ckt	371.36	0.6508	1.2319	78.60
	Modified Par.	371.37	0.6448	1.2366	80.25
4	Actual Test	391.12	0.6320	1.3023	71.74
	Equiv. ckt	390.66	0.6622	1.2967	78.52
	Modified Par.	370.79	0.6570	1.3056	79.98
5	Actual Test	449.00	0.6699	1.4995	71.74
	Equiv. ckt	448.75	0.6893	1.5077	77.84
	Modified Par.	448.74	0.6859	1.5163	78.78
6	Actual Test	470.00	0.6733	1.5716	71.93
	Equiv. ckt	469.99	0.6968	1.5857	77.43
	Modified Par.	470.03	0.6938	1.5958	78.18
7	Actual Test	531.47	0.6911	1.7864	71.32
	Equiv. ckt	531.47	0.7110	1.8192	75.65

	Modified Par.	531.39	0.7087	1.8350	75.86
8	Actual Test	580.00	0.7072	1.9571	71.31
	Equiv. ckt	580.38	0.7135	2.019	73.32
	Modified Par.	580.00	0.7107	2.0433	72.95

Comparison of power factor obtained from equivalent circuit and modified equivalent circuit revel that power factor calculated from modified equivalent circuit gives somewhat more nearer value to the actual value.

The torque obtained from modified equivalent circuit gives somewhat higher value than the value calculated from equivalent circuit however the deviation from actual value is very small.

The efficiency obtained from modified equivalent circuit gives higher value than the value calculated from equivalent circuit and obtained from actual test however the difference decreases as the load increases. The main advantage with modified parameters is this, it eliminates the calculation of friction and windage losses and hence running of motor at different voltages.

The relation between performance values obtained from modified equivalent circuit and actual test at full load are as below

$$PF_m = 1.00072 * PF_a \_\_(7.1)$$

$$T_m = 1.01598 * T_a \_\_(7.2)$$

$$Eff_m = 1.0869 * Eff_a \_\_(7.3)$$

Where suffix 'm' stand for modified circuit parameters and 'a' stands for actual test.

The performance obtained for Frame 63, 3-phase, 380 V, 470 W, 1.4 A, 50 Hz, 2-Pole, Induction Motor from actual load test, from equivalent circuit and from modified equivalent circuit is as shown in following table:

Table 7.2 Comparison of performance of Frame 63, 3-phase, 380 V, 470 W, 1.4 A, 50 Hz, 2-Pole, I.M.

Sr. No.	Method	Output Power	Power Factor	Torque	Efficiency
		(W)		(Nm)	(%)
1	Actual Test	430.89	0.7103	1.4612	70.89
	Equiv. ckt	430.82	0.7014	1.4647	75.84
	Modified Par.	430.64	0.7410	1.4765	75.51

2	Actual Test	470.24	0.7452	1.5980	71.01
	Equiv. ckt	470.15	0.7095	1.6174	74.55
	Modified Par.	469.95	0.7415	1.6365	74.54
3	Actual Test	489.28	0.7527	1.6687	70.54
	Equiv. ckt	489.15	0.7110	1.6946	73.68
	Modified Par.	489.21	0.7381	1.7212	73.16

The power factor at 90 % of full load (i.e. 430 W) obtained from modified circuit parameters is slightly higher than actual test but at full load it is almost same as actual. The power factor at 104 % of full load (i.e. 489 W) obtained from modified circuit parameters is lower than actual test but still gives better idea about the power factor. However it can be used to estimate the power factor without the knowledge of friction and windage loss.

The torque for the entire load range obtained from modified circuit parameters is slightly higher than actual test. Same is the case for efficiency.

The relation between performance values obtained from modified equivalent circuit and actual test at full load are as below

$$PF_m = 1.0049 * PF_a \_\_(7.4)$$

$$T_m = 1.024 * T_a \_\_(7.5)$$

$$Eff_m = 1.049 * Eff_a \_\_(7.6)$$

7.2 MAXIMUM VOLTAGE TO WINDING

Numbers of wave forms are recorded for 2-Pole winding and 4-Pole winding. The motor operating voltage was 415 V (L-L). 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

When motor is operated on utility supply at 50 Hz, maximum voltage recorded during switching is 453.54 V (Wave form No. KRK040) and hence the ratio of voltage across the phase to L-L voltage is 1.09.

When motor was supplied with inverter supply at 25 Hz, the maximum voltage recorded across the phase is 1014.1 V with dc link voltage 466.14 V (KRK0023). The ratio of voltage across the phase to dc link voltage is 2.17 and the ratio of voltage across the phase to rated L-L voltage is 2.44.

When motor was supplied with inverter supply at 40 Hz, the maximum voltage recorded across the phase is 982.68 V with dc link voltage 478.74 V (KRK0026). The ratio of voltage across the phase to dc link voltage is 2.05 and the ratio of voltage across the phase to rated L-L voltage is 2.38.

When motor was supplied with inverter supply at 50 Hz, the maximum voltage recorded across the phase is 800 V with dc link voltage 466.14 V (KRK0023). The ratio of voltage across the phase to dc link voltage is 1.67 and the ratio of voltage across the phase to rated L-L voltage is 1.93.

When motor was supplied with inverter supply at 60 Hz, the maximum voltage recorded across the phase is 653.54 V with dc link voltage 590.55 V (KRK0035). The ratio of voltage across the phase to dc link voltage is 1.06 and the ratio of voltage across the phase to rated L-L voltage is 1.57.

When motor was supplied with inverter supply at 70 Hz, the maximum voltage recorded across the phase is 1133.9 V with dc link voltage 590.55 V (KRK0033). The ratio of voltage across the phase to dc link voltage is 1.92 and the ratio of voltage across the phase to rated L-L voltage is 2.73.

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 more than twice the value of dc link voltage and rated line to line voltage of the motor. 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 with stand this voltages even though the variation of supply voltage is very peculiar particularly at low frequency.

7.3 VARIATION OF PHASE VOLTAGE AND VARIATION OF VOLTAGE IN COIL NEAR TERMINALS

The variation of phase voltage and variation of voltage across coils are recorded for different frequencies. 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. The results are shown in following tables.

Table 7.3	Item	Voltage Variation
R-Phase-30 Hz	Phase Voltage V_{15}	472.44
KRK0107	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

Table 7.4	Item	
Y-Phase-30 Hz	Phase Voltage V_{15}	196.85
KRK0122	Voltage across first coil V_{12}	104.33
	Voltage across second coil V_{23}	53.15
	Voltage across third coil V_{34}	17.71
	Voltage across four coil V_{45}	21.66

Table 7.5	Item	Voltage Variation
B-Phase, 30 Hz	Phase Voltage V_{15}	440.94
KRK0127	Voltage across first coil V_{12}	139.76
	Voltage across second coil V_{23}	118.11
	Voltage across third coil V_{34}	98.42
	Voltage across four coil V_{45}	78.74

Table 7.6	Item	Voltage Variation
R-Phase, 40 Hz	Phase Voltage V_{15}	251.97
KRK0108	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

Table 7.7	Item	Voltage Variation
Y-Phase, 40 Hz	Phase Voltage V_{15}	338.58
KRK0123	Voltage across first coil V_{12}	100.39
	Voltage across second coil V_{23}	82.67
	Voltage across third coil V_{34}	72.83
	Voltage across four coil V_{45}	82.67

Table 7.8	Item	Voltage variation
B-Phase 40 Hz KRK0128	Phase Voltage V_{15}	649.61
	Voltage across first coil V_{12}	116.14
	Voltage across second coil V_{23}	153.54
	Voltage across third coil V_{34}	175.20
	Voltage across four coil V_{45}	204.72

Table 7.9	Item	Voltage Variation
R-Phase 50 Hz KRK0109	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

Table 7.10	Item	Voltage Variation
Y-Phase, 50 Hz KRK 0124	Phase Voltage V_{15}	314.96
	Voltage across first coil V_{12}	185.04
	Voltage across second coil V_{23}	90.55
	Voltage across third coil V_{34}	39.37
	Voltage across four coil V_{45}	0.0

Table 7.11	Item	Voltage Variation
B-Phase 50 HZ KRK0129	Phase Voltage V_{15}	393.70
	Voltage across first coil V_{12}	200.79
	Voltage across second coil V_{23}	122.05
	Voltage across third coil V_{34}	57.08
	Voltage across four coil V_{45}	13.70

Table 7.12	Item	Change in 1 ms	Change in 0.5 ms
R-Phase, 60 Hz KRK0110	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

Table 7.13	Item	Change in 1 ms
Y-Phase, 60 Hz KRK0125	Phase Voltage V_{15}	480.31
	Voltage across first coil V_{12}	283.46
	Voltage across second coil V_{23}	169.29
	Voltage across third coil V_{34}	27.56
	Voltage across four coil V_{45}	-15.74

Table 7.14	Item	Change in 1 ms	Change in 0.5 ms
B-Phase 60 Hz	Phase Voltage V_{15}	889.76	480.31

KRK0130	Voltage across first coil V_{12}	131.89	29.52
	Voltage across second coil V_{23}	185.04	78.74
	Voltage across third coil V_{34}	267.72	165.35
	Voltage across four coil V_{45}	305.12	198.82

During the experimentation no abnormal behavior of insulation was observed. This is due to the low system voltage, however if we select higher system voltage then we may come across partial discharges and premature insulation failure. Hence following precaution will help in avoiding the undesirable situation.

7.4 AVOIDING LIFE REDUCTION DUE TO PARTIAL DISCHARGES

The methods of avoiding reduced life in motors from partial discharges fall into two categories:

A. Keep voltage at the motor below the starting voltage levels for partial discharge by:
   - Using a very low system voltage (Like 230 Volts),
   - Using a longer rise time ASD,
   - Keeping cable lengths between motor and ASD very short,
   - Using filters between the motor and the ASD to either clip the voltage at a low value or increase the rise time of the voltage wave,
   - Using a form coil motor,
   - Using a special random wound motor construction

   Or

B. Design a special motor insulation that has adequate life in the presence of partial discharges.

7.4.1 USE A LOW VOLTAGE SYSTEM

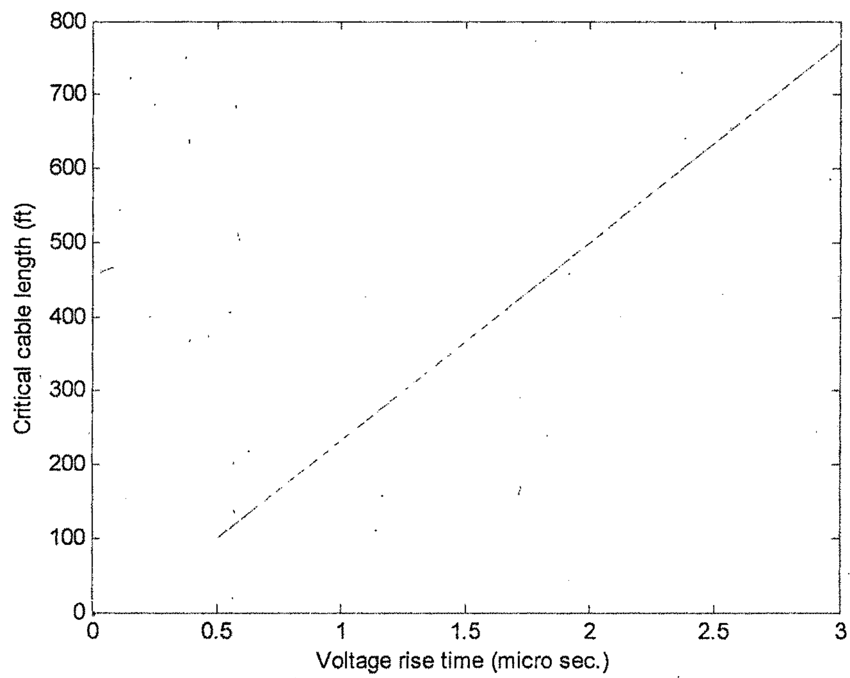
Utilizing 208 or 230 Volt systems is often not possible but should be considered if available

7.4.2 USING A LONGER RISE TIME ASD

While theoretically nice, these are not presently available, and for good reasons. The fast device turn-on times that result in the fast rise times allows higher ASD efficiencies, less effect on motor noise, and less effect on motor temperature rise. Because of these benefits, methods must be developed to achieve acceptable motor life in their presence.

7.4.3 KEEPING CABLE LENGTHS SHORT

Figure 7.1 shows [73] that "short" is defined by the rise time of the ASDs switches. With today's ASDS having rise times measured in tenths of microseconds, critical cable length (the distance at which theoretical voltage doubling occurs) is happening at distances shorter than is used in most industrial applications. Where possible, shortening the cable length to less than critical length is desirable. Where not practical, one of the other alternatives must be used.



Critical cable length vs rise time
Fig.7.1

7.4.4 USING FILTERS

Several types of filters are commercially available to either increase rise times or to clip the voltage at a certain value with the same rise time [74]. There is great value in using these filters to minimize spare motors. Engineers are always interested in using standard motors on ASDs. The reasoning in this strategy is that somewhere between 10% and 20% of he motors in a typical plant today are used on ASDs, while the remaining 80% to 90% are used o utility power. If a special motor is used for ASD applications, then either spares are required for both the standard and ASD motors of the same rating, or the extra cost of the ASD rating motors must be absorbed in all motors in the plant so that only one spare per rating is required. Using properly designed filters can allow standard motors to be used in these situations.

7.4.5 USING FORM COIL MOTORS

This solution is expensive and often not available in lower horsepower ratings. Certainly, though, when available and if affordable, it is a good solution. A motor built with an insulation system designed for medium-voltage supplies and applied on low voltage usually works well with today's low voltage IGBT ASDs.

7.4.6 USING MOTORS WITH A RANDOM WOUND SYSTEM

Several methods of making a random wound motor that will not experience partial discharges at the peak voltage seen on an ASD have been identified.

One method uses a wind in place coil insertion method instead of the more commonly used method of winding on an arbor (i.e. former) and then injecting into the stator slots. The theory behind this is that careful insertion can assure that the turn placement is more like a form coil winding where the first turn only touches the second turn and the second only touches the first and third, etc.

A second method is to use heaver builds of magnet wires. This method increases the voltage at which partial discharge starts. For a given slot size in the motor's stator, heavier insulation build causes higher slot fill that needs to be accommodated. Additionally, the starting voltage for partial discharge increases roughly by the square root of the insulation build thickness, so large build increases are required to obtain modest increases in the partial discharge starting voltage.

A third method is to use extra insulation within a phase in the motor- strategically placed to assure that no wire-to-wire voltages exist that would allow partial discharges. While adding extra labour and material, this method can be very effective.

A fourth method that has been identified is to use extra insulating sleeves on the turns closest to the line leads.