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Occurrence of Harmonics with Induction Machine and Switched Reluctance Machine: A Survey and Analysis

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Abstract: Today, the quality of the power supplied to sensitive electronic equipment is an important issue. Various non-linear loads can be found in Industrial, commercial and residential sectors. This study presents harmonic analysis of electric drives such as induction machine and switched reluctance machine and experimental results taken during the operation. The results show that the distortion in the voltage and current are more than the specified values of international standards. The key issue covered under this study is the purpose of suppressing the harmonics. Finally some of the important methodologies to reduce the harmonics are also discussed in this study which may utilize for specific problems.

Key words: Harmonics, power quality, induction machine, switched reluctance machine

INTRODUCTION

Power quality surveys are very much important to find the quality of the power available at a particular point of location. Power quality of the low voltage network is an important challenge for the industry of today. Advances in the Power technologies will estimate that about more than 80% of the electric power is flowing through some kind of non-linear loads and the percentage is growing. These loads distort the supply current as well as supply voltage from its pure sinusoidal form and the quality of the supply is degraded heavily.

Harmonics is one of the main problems to cause the distorted current waveform. Harmonics refers to all sinusoidal voltages and currents that are integral multiples of the fundamental power system frequency. Non-linear loads are the sources of harmonic current and they inject the harmonic currents into the power system. The voltage distortion is the result of distorted current passing through the impedance of power delivery system (Sankaran, 2001; Roger, 1996; Koval, 1997)

The main sources of harmonics are high speed electronic switching devices and controls in industrial and commercial applications, switched mode power supplies and computers, electronic ballasts, dimmer switches, UPS, battery chargers and adjustable speed drives. The main problems due to the presence of harmonics are increase in losses and temperature in machines, overheating in cables and additional stressing of cable insulation, higher capacitor stresses, higher earth fault currents, tripping of circuit breakers, over stressing of power factor correction capacitors.

This study emphasis a comprehensive power quality survey mainly on Drive side. Andrews *et al.* (1996) presents the analytical technique used to correct power factor in a modern steel manufacturing facility. The study included field measurements, harmonic analysis, and filter design work to reduce the amount of harmonic distortion in the plant. Shipp (1996) discusses the power quality problems of variable speed drives with recent technology in power electronics. Edward Reid (1996) outlines the significant factors associated with power quality by summarizing the key considerations, the relevant standards, the areas where standards are being developed and useful application guidelines. This study emphasis the analysis for the adjustable speed drives and induction and switched reluctance machines are taken for the same.

International standards for power quality: To limit the distortion due to different types of non-linear loads, internationally some standards are available. Some of the standards available for the voltage variations are described in Edward Reid (1996),

- ANSI Standard C 84.1 - Service voltage is within +/- 5%
- NEMA Standard MG-1 - Voltage unbalance does not exceed 1%
- ANSI Standard C 84.1 -Maximum voltage unbalance within 3% at electric - utility revenue meter under no-load conditions
- IEEE 519 - Voltage variations due to flicker is within 5- 6% that may vary from 10 s^{-1} to 1 h^{-1}

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- ANSI Standard C 84.1-Temporary fundamental frequency should not less than 88.3%

Some of the standards available for the Harmonic distortion are,

- ANSI/IEEE standard C 57.12.00 and C 57.12.01-Current distortion in transformers within 5%
- ANSI Standard C 82.1-High frequency ballast should have maximum I (THD) of 32%
- IEEE/ANSI 519, IEEE recommended practices and requirements for harmonic control in electrical power systems (Table 1 and 2).

Analysis of electrical drives: In Industrial environments, power quality is important one to maintain the product output. When the equipment runs under poor power quality conditions, there will be loss of production as well as the product quality may also be affected. Therefore, it is necessary to operate the machine under in good power quality conditions.

Adjustable speed drives are one of the main reasons for the generation of harmonics, notching etc., When an adjustable speed drive that is not functioning properly means, the drive has some problem with the incoming power source, the signal and power wiring technique, the programming, or perhaps the drive has not been specified properly for the application.

ASD's are having the advantages such as higher efficiency, reduced energy consumption by 30-50%, minimizing wear and tear. ASD's are extensively used in pumps, compressor, fans and blower and air conditioning units (Shipp, 1996). Due to the improvement in the semiconductor technology and the controllers, the ASD's are more common in the low cost drives. Most of the ASD's have no input power factor correction circuits. This results in harmonic pollution of the utility supply, which could be avoided (Andrews *et al.*, 1996).

Nowadays, there is an tremendous increase in the use of Variable Frequency Drives (VFDs) which uses power electric devices. The voltages and currents emanating from a VFD inject harmonic frequency components into the motor. The magnetic field is produced in the motor core, due to the application of the voltage, which leads to the iron losses in the magnetic frame of the motor. The hysteresis and eddy current losses are part of iron losses that are produced in the core due to the alternating magnetic field. The Hysteresis losses and eddy current losses are depends on frequency. Hysteresis losses are proportional to frequency and eddy current losses vary as the square of the frequency. The higher order harmonics, which has higher frequency voltage components produce additional losses in the core of AC motors, which in turn, increase the operating temperature of the core and the windings surrounding in the core. Application of non-sinusoidal voltages to motors results in harmonic current circulation in the windings of motors (Sankaran, 2001; Dugan, 1996). The net rms current is $I_{rms} = \sqrt{(I_1^2 + I_2^2 + I_3^2 + ...}$ where the subscripts 1, 2, 3, etc.

Table 1: Voltage distortion limits

	Individual (%)	Total (%)
< 69 kV	3.0	5.0
<161 kV	1.5	2.5
> 161 kV	1.0	1.5

Table 2: Current distortion limits(<69 kV)

I_{sc}/I_L kV	< 11	< 17	< 23	< 25
< 20	4	2.0	1.5	0.6
< 50	7	3.5	2.5	1.0
< 100	10	4.5	4.0	1.5
< 1000	12	5.5	5.0	2.0
> 1000	15	7.0	6.0	2.5

Table 3: Comparison of voltage, current and power for various load conditions

Parameters	Loading	25 (%)	50 (%)	75 (%)	100 (%)	106(%)
Voltage	V12	410.5	404.8	403.1	401.1	400.3
	V23	409.6	402.1	401.8	398.9	396.5
	V31	410.6	401.6	397.4	397.7	393.9
Current	I1	18.43	33.9	50.24	68.96	74.34
	I2	20.34	35.48	50.27	68.35	75.71
	I3	17.85	33.25	49.23	64.9	73.57
Power	Active (kW)	8.524	16.65	25.41	35.59	39.67
	Reactive (kVAR)	10.36	17.12	23.56	30.11	32.45
	Apparent (kVA)	13.42	23.88	34.65	46.62	51.25
	Power Factor	0.635	0.697	0.733	0.763	0.774
	Frequency (hZ)	49.91	49.7	49.63	49.52	49.56

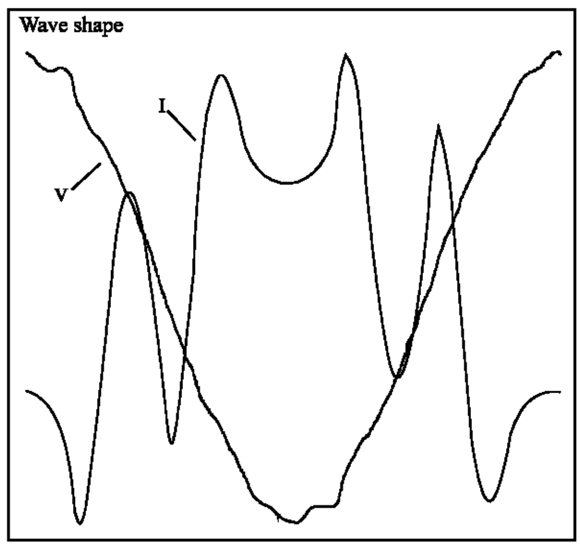

Fig. 1: Current and voltage waveforms

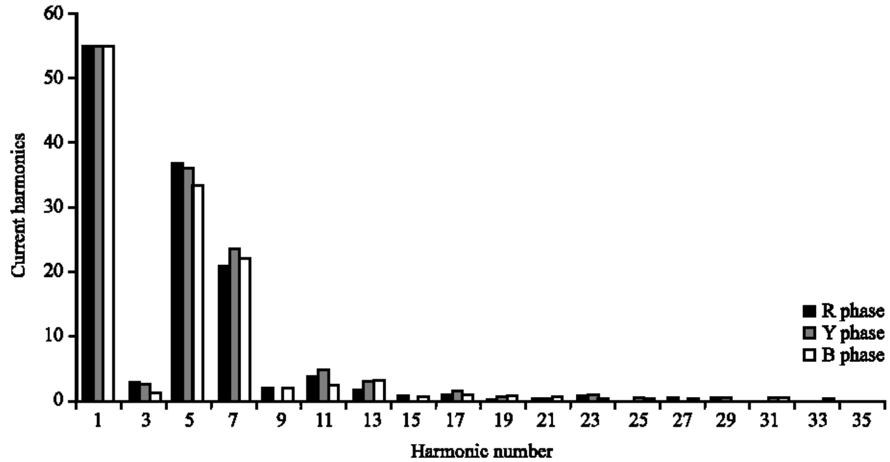

Fig. 2: Current harmonics at 100% loading

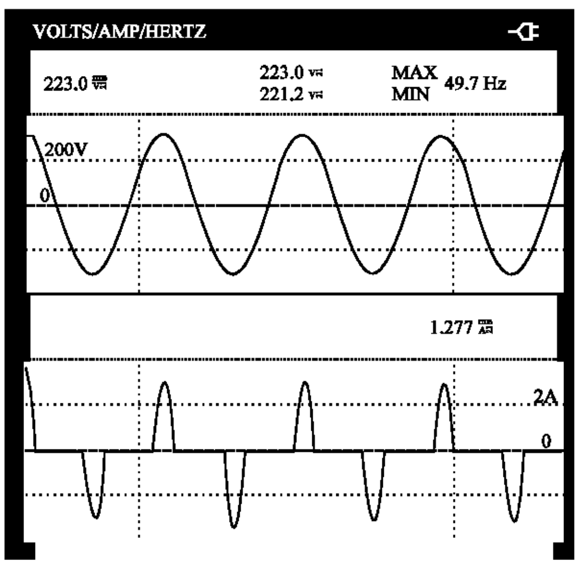

Fig. 3: Input supply voltage and current for a DC link voltage of 84 V

represent the respective harmonic currents. The heating losses in the motor windings vary as the square of the rms current. Due to skin effect, actual losses would be slightly higher than calculated values. Stray motor losses, which include winding eddy current losses, high frequency rotor and stator surface losses, and tooth pulsation losses, also increase due to harmonic voltages and currents.

The torque produced in AC motors is due to the interaction between the air gap magnetic field and the rotor-induced currents. When a motor is supplied non-sinusoidal voltages and currents, the air gap magnetic fields and the rotor currents contain harmonic frequency components. Due to the harmonics in AC motors, the torsional oscillation of the motor shaft occurs.

Table 4: Current harmonics for various load conditions

Harmonic No.	25(%)	50(%)	75(%)	100(%)	106(%)
1	10.830	22.470	38.330	54.530	64.660
3	0.256	1.881	0.759	3.056	3.984
5	8.998	17.500	27.630	36.900	42.560
7	7.850	13.460	18.190	21.220	23.100
9	0.486	0.751	0.857	2.402	2.111
11	4.133	5.280	4.856	4.239	4.267
13	2.843	2.640	2.031	1.952	2.615
15	0.406	0.212	0.910	1.228	1.140
17	0.971	1.775	1.960	1.184	1.095
19	0.724	1.757	0.530	0.530	0.795
21	0.168	0.106	0.309	0.698	1.087
THD	120.930	102.850	87.710	78.980	75.720

Table 5: Current harmonics magnitudes for various DC link voltages

Harmonic	DC link voltage						
No.	10	20	30	40	53	60	84
1	100	100	100	100.0	100	100	100
3	80	60	68	75.0	73	72	80
5	49	17	28	39.0	36	53	50
7	20	4	10	12.0	8	25	20
9	3	2	11	8.0	8	7	1
11	8	1	4	4.0	7	6	5
13	6	0	2	0.5	1	5	5

The harmonics are grouped into positive (+) sequence component, negative (-) sequence component and zero (0) sequence components. The positive sequence harmonics (harmonic numbers 1, 4, 7, 10, 13, etc.) produce magnetic fields and currents rotating in the same direction as the fundamental frequency harmonic. Negative sequence harmonics (harmonic numbers 2, 5, 8, 11, 14, etc.) develop magnetic fields and currents that rotate in a direction opposite to the positive frequency set. Zero sequence harmonics (harmonic numbers 3, 9, 15, 21, etc.) do not develop usable torque, but produce additional losses in the machine. The interaction between the positive and negative sequence magnetic fields and currents produces torsional oscillations of the motor shaft. These oscillations result in shaft vibrations. If the

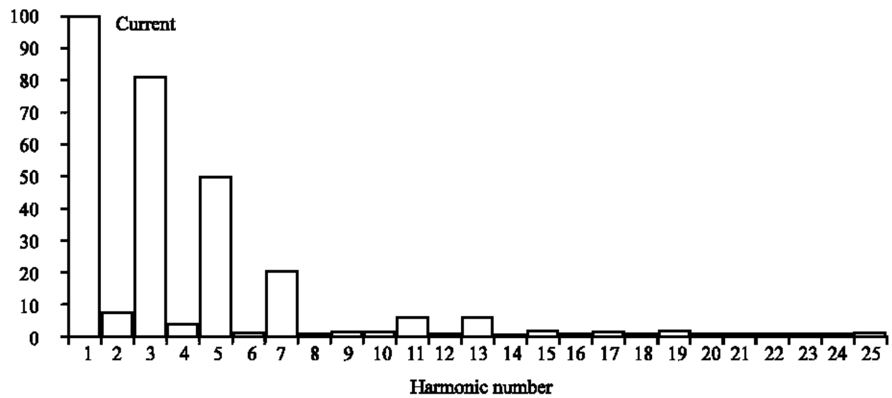

Fig. 4: Input current harmonic spectrum waveform for a DC link voltage of 84 V

frequency of oscillations coincides with the natural mechanical frequency of the shaft, the vibrations are amplified and severe damage to the motor shaft may occur. It is important that for large VFD motor installations, harmonic analyses be performed to determine the levels of harmonic distortions and assess their impact on the motor. From the above facts, it is necessary to make an survey which will help to access how much harmonics are present in the drives. For that an induction motor and Switched Reluctance Motor (SRM) were taken for the analysis.

Induction motor drives: In this harmonic analysis a 37 kW, 3 phase, 415 V squirrel cage induction motor is taken for the analysis. The readings are taken in the input side of induction motor. Table 3 shows the voltage, current, power, power factor and frequency for every phases at 25, 50 , 75, 100 and 106% of loading, respectively.

Table 4 gives the current harmonics for the induction motor at different loads 25, 50, 75, 100 and 106%, respectively. It gives the details about the odd harmonics only. The even harmonics of the system is very less as compared to the odd harmonics. The voltage and current waveforms are as like in the Fig. 1 and the current harmonics for the induction motor at 100% loading is shown in the Fig. 2.

Switched reluctance motors: Switched Reluctance motors are normally preferred for high-speed applications. It consists of rectifier, DC link capacitance and converter circuit. The main disadvantages of the switched reluctance motor drive are requirements of a large DC link capacitor and power converter. The harmonics generated in the input side of the SRM exceeds the limits given in the IEEE standards. SRM requires some form of Input Power factor correction circuits. In this power quality survey, the harmonics of switched reluctance machine in its input terminals are taken. Figure 3 shows details regarding the voltage, current waveforms for a DC link voltage of 84 V and the Fig. 4 shows the details of the input current harmonic spectrum. Table 5 gives the different harmonics ranging from fundamental to 11th harmonics and its associated magnitude.

Table 5 indicates that the current harmonics are more than the internationally specified values.

Methods to improve power quality: The conventional methods to reduce the harmonic distortion are over sizing neutral conductors, using separate neutral conductors, transformer connections, true RMS operating circuit breakers, capacitor banks, EMI/RFI filters for telephone interference.

The conventional methods to reduce the harmonic currents in loads are by increasing number of steps in the waveform of a inverter, changing the step magnitude, suitably switching the inverters, changing the size and moving of the capacitors.

The conventional methods to reduce grounding problems are to use separate wires for disturbance generating loads and sensitive loads, power conductors and control conductors should not run in the same conduit, neutral conductor must be connected to ground in only one location, for computer and electronic systems use isolation transformers, isolated ground can be used to reduce the noise problems

The newer methodology to reduce the harmonics in the system is to use filtering techniques. Passive filters and Active filters are the two types of filtering methods available. In Active filtering method, boost cell type, switched capacitor filter type, inverter type methods are used to reduce the harmonics in the system. The suitable method to be used by considering the cost of the scheme and size of the circuit to be implemented.

RESULTS AND DISCUSSION

The power quality analysis of induction and Switched reluctance motor drives has been done. In Induction motors, Table 3 and 4 gives the details regarding the various parameters like voltage, current, power, power factor and current harmonics for various loaded conditions. Figure 1 and 2 shows the current and voltage waveform and the current harmonics at 100% loading. The current waveform of the induction motor was severely distorted. From the analysis, it is understood that, in many cases the total harmonic distortion as well as the individual harmonics are more than the IEEE specified values.

In switched reluctance motor, Fig. 3 shows the current waveforms are highly distorted and Fig. 4 gives details regarding the input harmonics for a DC link voltage of 84 V. Table 5 shows the odd harmonics for different values of DC link voltages which are more compared with the even harmonics. In SRM also the harmonics present are more than the IEEE standards.

From this analysis, it is understood that there may be some methodology will be adopted to reduce the harmonics in the system. Various methods to improve power quality of the system also described. By employing suitable methods the quality of the supply will be improved.

CONCLUSION

This study emphasis the need for the analysis of the power quality for Induction machine and switched reluctance machines. This analysis gives the details about various parameters like current, voltage, power, power factor and current harmonics of both induction machines and switched reluctance machines. The analysis is focused that the harmonics in the highlighted systems in this study are more compared to the IEEE standards. To reduce the harmonics, researchers may adopt the methods mentioned in this study and utilize them for their specific problems.

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