MEASUREMENTS OF HARMONICS AT OFFICE EQUIPMENTS IN A LARGE OFFICE BUILDING

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Abstract:

With rapidly changing technologies and electrical environments, many "side effects" are created. Harmonics are one of the most potentially troublesome and unpredictable problems effecting the smooth operation of today's modern facilities such as computers, fax, printers, copy machines etc. This paper presents an analysis of harmonic content in the modern office equipments.

Keywords: Harmonic limits, total harmonic distortion, office equipment harmonics.

I.INTRODUCTION

Harmonics are periodic signals that occur in power systems due to various reasons. The frequency of harmonics is an integer multiple of the fundamental frequency of the power system which is 50 or 60 Hz [1]. The presence of harmonics in voltages and currents of a power system can cause interference with communication circuits, heating of power transformers, problems in relaying, loss of life of components due to increased displacement current, resonant conditions, high harmonic voltages and current distortion. Therefore, monitoring and verification of the harmonics for admissible levels becomes necessary for reliable distribution of electric energy.

II. MEASUREMENT OF HARMONICS

Harmonic measurements are different from ordinary power system measurements. The frequency bandwidth requirements for harmonic studies are in the order of few kiloHertz as compared to 60 Hz required for normal power studies. The various equipments that could be used for harmonic measurements are oscilloscopes, spectrum analyzers, harmonic or wave analyzers and digital analyzers. However, the use of digital measuring equipment that uses fast Fourier transform technique can provide real time data acquisition with better accuracy. The BMI 8800 Power Scope is a digital analyzer that is used for the harmonic studies in this paper. According to IEEE standard 519 [2], harmonics measuring instruments must not have uncertainties larger than 5%. The instrument used has a RMS voltage accuracy of $\pm 0.5\%$ and a RMS current accuracy of $\pm 0.3\%$ and hence complies with the requirements [3]. For 60 Hz power systems the instrument is capable of monitoring till the thirty third harmonic, with a voltage and current sampling rate of about 5.12 kHz [5].

III. PERMISSIBLE LEVEL OF HARMONICS

A practical harmonic index that is physically meaningful, that can correlate with severity of harmonic effects and can provide possibility of measurements for the indices is necessary for harmonic compliance studies. The IEEE 519 standard is therefore used as the guideline for estimating the compliance of harmonic limits. The standard provides the limits for the voltage and current harmonics. For the current harmonics, the standard emphasizes limitations on individual harmonic distortion and total demand distortion (TDD) based on the short circuit ratio at the point of common coupling (PCC) and order of the harmonic for different voltage levels. The IEEE C57 standard mentions that a harmonic current of 5% of the rating of the transformer is the maximum allowable limit on harmonic current. The IEEE 519 standard provides current harmonic limits for all system voltages in practice. However for harmonic studies in an office building, current distortion limits up to 69kV is sufficient as in Table-1.

Table -1 Current distortion limits for general distribution systems (120V to 69000V) [2]

Short Circuit Ratio	Individual Harmonic Order (Odd Harmonics)					
I_{sc}/I_L	< 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h < 35	35 ≤ h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0
Even harmonics are limited to 25% of the odd harmonic limits above.						
* All power generating equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.						
where I_{sc} = Maximum short circuit current at PCC. I_L = Maximum demand load current (fundamental frequency component) at PCC.						

The standard states that current distortions are caused by the users and recommends the limits for consumers while voltage harmonics are caused by the power utilities and emphasizes that utilities maintain voltage harmonics in the system within the limits specified by the IEEE 519 standard.
The voltage harmonic limits are specified based on the bus voltage at the PCC for individual voltage distortion and total voltage distortion as in Table -2

Table-2 Voltage Distortion Limits [2]

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5
Note: High Voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user		

IV. WORKED SOURCES OF HARMONICS

The Engineering Research Center (ERC) located in the University is a huge office building where the harmonic study is done. The possible sources of harmonics in the ERC are xerox machines, computers, printers, oscilloscopes, scanners, elevators, environmental chambers and microwave ovens. Most of the sources listed have a rectifier stage that introduces harmonics into the power system.

V. POWER FLOW IN THE ERC

The location of the different sources and their impact on the particular electrical network is studied using the single line diagram of the ERC as in Figure-1. The single line diagram shows clearly the presence of different feeders and their corresponding ratings. The different harmonic loads in the ERC are found to be operating under a 120V supply. The three phase supply is mainly to operate the different induction motors in the laboratories and the environmental chambers. The environmental chambers are run using three phase induction motors that do not introduce harmonics into the power system. Hence the 1200A bus on the eastern side that supplies three phase, 277/480 V to the different levels of the building is assumed not to introduce harmonics into the ERC power system. Therefore, importance is given to the different loads supplied by the western distribution network of the ERC. Based on the feeder configuration and using a statistical estimate of the number of different harmonic loads for a unit capacity of the feeder the total harmonic load could be estimated for the entire building.

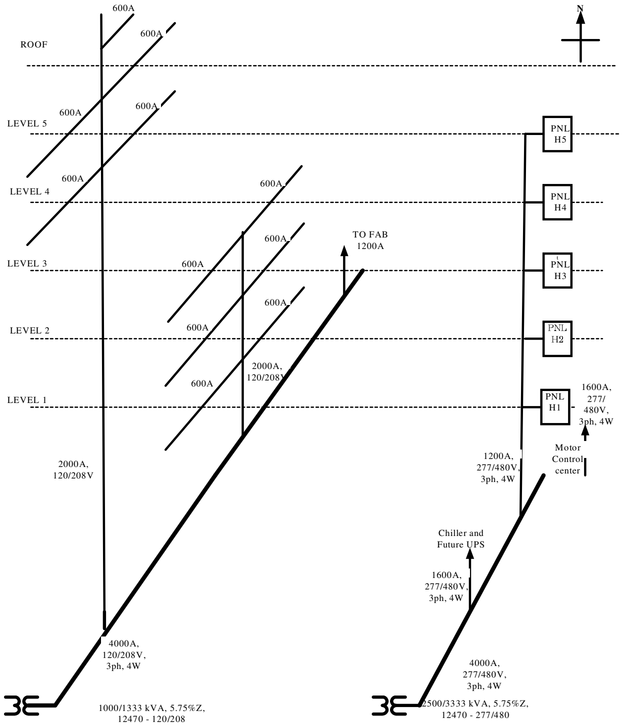

Figure -1 Modified single line diagram of the ERC showing power supply distribution [4]

VI. MEASURED HARMONIC LEVELS

Harmonics in the voltage and current will be the maximum when the devices are operating under full load. Care is taken to measure harmonics under such load conditions. The current and voltage harmonic levels measured in the different equipments are tabulated in Table-3. The Table-3 accounts for the individual harmonic distortion of the different odd and even harmonic terms in terms of percentage of the fundamental component. The total harmonic distortion is also listed for the different types of loads analyzed.
Interestingly the elevators in ERC do not introduce harmonics in to the power system. The elevators are operated using a DC series motor powered by a DC generator that has been mechanically coupled to a three phase induction motor. The motion of the elevator is controlled using resistance switching techniques on the armature current of the DC series motor and reduction gearing stages. The input stage of the DC drive system is either a 25HP or a 30HP three phase induction motor that has a large time constant. The presence of reduction gearing stages and machines of large time constants eliminates the injection of harmonics from the DC drives into the power system. Also, as the environmental chambers in the west wing of ERC are run using induction machines, harmonic measurements are not done on this load.

Table-3 Individual and total harmonic distortion observed in different equipments

Harmonics		FT 6665 V %	FT 6665 I %	GX115 V%	GX115 I %	ViewSonic E70 V%	ViewSonic E70 I %	LaserJet 4100N V%	LaserJet 4100N I %	6200C V %	6200C I %	Le Croy LT344 V %	Le Croy LT344 I %	Sharp Carousel II V %	Sharp Carousel II I %
	Fundamental	100	100	100	100	100	100	100	100	100	100	100	100	100	100
D D O	3	2.0	9.3	2.3	90	2.4	86.7	2.0	4.3	2.2	94.7	1.7	2.3	2.0	27.3
	5	1.9	16.4	1.1	70.1	1.1	57.9	1.0	4.5	1.2	74.9	1.2	4.1	0.9	11.5
	7	0.6	9.6	0.5	46.2	0.5	27.3	0.4	2.7	0.5	53.9	0.6	2.3	0.6	4.8
	9	0.8	6.7	0.9	23.6	1.0	4.8	1.0	1.9	1.2	28.5	1.1	4.1	1.1	2.5
	11	0.0	0.0	0.0	7.4	0.0	10.4	0.0	1.0	0.3	9.6	0.4	0.5	0.3	1.2
	13	0.3	0.0	0.0	5.4	0.0	12.1	0.0	0.0	0.0	3.9	0.0	1.0	0.0	0.9
	15	0.5	2.8	0.5	7.7	0.5	6.7	0.5	0.5	0.5	9.2	0.5	2.5	0.5	0.5
	17	0.3	2.5	0.0	5.9	0.0	0.8	0.0	0.4	0.0	8.6	0.2	0.8	0.0	0.4
	19	0.0	2.2	0.0	3.6	0.0	4.2	0.0	0.0	0.0	4.7	0.0	0.4	0.0	0.4
	21	0.0	1.8	0.3	3.1	0.3	4.5	0.2	0.0	0.2	0.0	0.2	1.3	0.0	0.3
E V E N	2	0.0	0.0	0.0	0.0	0.0	5.1	0.3	30.0	0.0	0.0	0.0	0.0	0.0	8.2
	4	0.0	0.0	0.0	0.0	0.0	4.6	0.0	10.3	0.0	0.0	0.0	0.0	0.0	1.0
	6	0.0	0.0	0.0	0.0	0.0	2.3	0.0	1.8	0.0	2.5	0.0	0.2	0.0	0.5
	8	0.0	0.0	0.0	0.0	0.0	2.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.4
	10	0.0	0.2	0.0	0.0	0.0	2.3	0.0	0.6	0.0	0.0	0.0	0.3	0.0	0.0
	12	0.0	0.0	0.0	0.0	0.0	1.8	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
	14	0.0	0.3	0.0	0.0	0.0	1.1	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0
	16	0.0	0.3	0.0	0.0	0.0	1.3	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
	18	0.0	0.2	0.0	0.4	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	20	0.0	0.0	0.0	0.4	0.0	0.6	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
THD		3.0	22.7	2.8	126	2.9	110	2.6	32.8	2.9	136	2.6	7.6	2.6	31.3

VI. DISTRIBUTION OF THE DIFFERENT HARMONIC LOADS

A statistical survey is done on the fifth level of the ERC to determine the number of different harmonics introducing loads. Assuming that same loads are distributed uniformly through the different levels of the building, the total number of harmonics injecting equipments is estimated based on the capacity of the feeders supplying different levels of ERC. The total load distribution in the ERC is tabulated in Table-4.

Table-4 Estimates of harmonic loads in the ERC

Level	Feeder Capacity (A)	Xerox Machine (Count)	CPU (Count)	Monitor (Count)	Printer (Count)	CRO (Count)	Scanner (Count)	Microwave (Count)	Environmental Chamber (Count)	Elevator (Count)
5	1200	2	98	98	42	5	4	7	2	
4	1200	2	98	98	42	5	4	7	2	
3	1200	2	98	98	42	5	4	7	2	3
2	1200	2	98	98	42	5	4	7	2	
1	1200	2	98	98	42	5	4	7	2	
FAB	1200	Total load seen by a 1200A supply bus in any of the Levels								
Total	6000	12	588	588	252	30	24	42	14	3

VIII. COMPLIANCE WITH THE IEEE 519 STANDARD

The IEEE 519 standard discussed previously requires the current and voltage harmonics to be within specified limits in order that the harmonics do not interfere with other customers at the point of common coupling. The different parameters required for analyzing the current harmonic limits are the short circuit ratio at the PCC of the transformer and the TDD. The TDD is determined using Equation (1) as

$$\%TDD = THD * \left(\frac{I_1}{Circuitrating}\right) \tag{1}$$

Where THD = Total harmonic distortion and I_1 is the RMS fundamental line current.

$$I_1 = \sqrt{\frac{I_{rms}^2}{1+THD^2}} \quad \text{A} \tag{2}$$

The harmonic current, I_h, is estimated using Equation (2) as

$$I_h = \sqrt{I_{rms}^2 - I_1^2} \quad \text{A} \tag{3}$$

Table -5 Harmonic current and TDD in different types of loads analyzed

Equipment	I_{rms} (A)	THD_i (%)	I_1 (A)	Circuit rating (A)	TDD (%)	I_h (A)
Xerox	9.5	22.7	9.264	20	10.515	2.103
CPU	0.9	126.2	0.559	15	4.703	0.705
Monitor	0.5	109.8	0.337	15	2.464	0.37
Printer	2.9	32.8	2.756	15	6.025	0.904
Scanner	0.1	136.5	0.059	15	0.538	0.081
Microwave	8.3	31.3	7.921	15	16.529	2.479
CRO	1.2	7.6	1.197	15	0.606	0.091

Assuming that all loads operate at the same time, the total harmonic current due to the different harmonic loads is estimated using the total number of loads as calculated in Table-4 and the harmonic currents consumed by the different loads as obtained in Table-5.

Total harmonic current in all three phases

= 12*2.103 + 588*0.705 + 588*0.37 + 252*0.904 + 30*0.091 + 24*0.081 + 42*2.479 + 0

= 993.936A

Assuming that the loads in the building are distributed uniformly amongst the three phases, the harmonic current in each phase,

I_h = 993.93 / 3 = 331.31 A.

The current rating of the secondary of the transformer is obtained from the nameplate details of the transformer show in Table-6. The percentage of harmonic current with respect to the load current of the transformer is found to be 8.95%.

Table-6 Nameplate details of the western side distribution transformer of the ERC

KVA	Voltage (V)		Current (A)	Impedance (%)
	Primary	Secondary		
Self cooled -1000	12470	120/208	3700	5.75%
Forced air - 1333	12470	120/208	3700	5.75%

Assuming that the load current in the ERC to be 90% of the rated current of the secondary of transformer, ERC load current,

$$I_{rms} = 0.90 * 3700 = 3330 \text{ A}.$$

The harmonic current calculated per phase is, I_h = 331.31 A. Using (3), the fundamental current in ERC is calculated as,

$$I_1 = \sqrt{3330^2 - 331.31^2} = 3313.478 \text{ A}.$$

The total harmonic current distortion in the ERC is calculated using Equation (2) as,

$$\%THD = \sqrt{\frac{I_{rms}^2 - I_1^2}{I_1^2}} = \sqrt{\frac{3330^2 - 3313.478^2}{3313.478^2}} = 0.01.$$

As the harmonic loads are assumed to be distributed uniformly among the three phases, the individual harmonic distortion per phase for different harmonic orders at the PCC can be calculated. It is also assumed that the different orders of harmonics can be added algebraically within that particular order. The individual harmonic distortions are tabulated in Table-7 based on the previous assumptions.

Using Equation (1), %TDD is calculated as,

$$\%TDD = 0.01 * (\frac{3313.478}{3700}) = 0.008955$$

The ERC is powered using a dedicated transformer. Therefore, the PCC lies on the primary side of the transformer. The SCR at the primary side of the transformer is assumed to be very high since it is supplied at 12.47kV and the impedance of the incoming feeder is assumed to be very small. Therefore for IEEE 519 standard verification for the harmonic currents, the SCR is assumed to be greater than 1000. The values obtained for individual harmonic distortion for different harmonics in Table-7 are compared with the IEEE 519 standard limits for current in Table-1. It is seen that none of the individual harmonic distortion limits for both even and odd harmonics are violated. Also the %TDD values are within the limits of 20% specified in the IEEE 519 standard for current distortion.

It can be seen from Table-7 that the individual harmonic distortion and total harmonic distortion for the voltage is almost the same in every load analyzed. It is observed from measurements that, the effect of impedance on the loss of harmonics is not significant. Therefore, it is assumed that the same harmonics appear at the point of common coupling. Also, the impedance at the point of common coupling is assumed to be very small.

Therefore comparing the individual and total harmonic distortions in Table-7 with the limits specified in the IEEE 519 standard in Table-2, it is seen that all the individual harmonic distortions for voltage are well within the specified limit of 3% and the THD is also below 5% as specified in the standard.

IX. CONCLUSION

Measurements for different harmonic loads are taken using a digital harmonic analyzer, BMI 8800 Power Scope, in the ERC building. A statistical survey is taken to calculate the number of different harmonic loads present in the ERC. Suitable assumptions are made for the calculation of the voltage and current harmonics at the point of common coupling. It is found that the limits in both the current and voltage harmonic levels, as specified by the IEEE 519 standard, are not violated. However the harmonic current that is estimated to be 8.95% of the current rating per phase of the transformer, violates the transformer heating consideration limit of 5% of rated current, as specified by the IEEE C57 standard.

Table-7 Individual harmonic distortions per phase of the different harmonics measured

ITEMS		Xerox FT 6665	CPU Dell Optiplex GX115	Monitor ViewSonic E70	Printer HP LaserJet 4100N	Scanner HP ScanJet 6200C	CRO Le Croy LT344	Microwave Sharp Carousel II	Total harmonic current	Individual current harmonic distortion
Num-ber		4	196	196	84	10	8	14		
Harmo-nics		(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(%)
ODD	3	0.88	0.81	0.43	0.12	0.09	0.03	2.26	289.42	8.734
	5	1.58	0.63	0.29	0.12	0.07	0.05	.95	211.12	6.371
	7	0.91	0.41	0.14	0.08	0.05	0.03	0.4	124.5	3.757
	9	0.64	0.21	0.02	0.05	0.03	0.05	0.2	55.34	1.677
	11	0.0	0.06	0.05	0.03	0.0	0.01	0.1	25.56	0.771
	13	0.0	0.05	0.06	0.0	0.0	0.01	0.07	22.62	0.682
	15	0.26	0.07	0.03	0.02	0.0	0.03	0.04	23.12	0.697
	17	0.24	0.05	0.01	0.01	0.0	0.01	0.03	14.06	0.424
	19	0.21	0.03	0.01	0.0	0.0	0.0	0.03	9.1	0.274
	21	0.17	0.03	0.01	0.0	0.0	0.01	0.02	8.88	0.267
EVEN	2	0.0	0.0	0.02	0.87	0.0	0.0	0.68	86.52	2.611
	4	0.0	0.0	0.02	0.30	0.0	0.0	0.08	30.24	0.912
	6	0.0	0.0	0.01	0.05	0.0	0.0	0.04	6.72	0.202
	8	0.0	0.0	0.01	0.09	0.0	0.0	0.03	9.94	0.299
	10	0.02	0.0	0.01	0.02	0.0	0.1	0.0	4.52	0.136
	12	0.0	0.0	0.01	0.03	0.0	0.0	0.0	4.48	0.135
	14	0.03	0.0	0.01	0.03	0.0	0.0	0.0	4.6	0.138
	16	0.03	0.0	0.01	0.02	0.0	0.0	0.0	8.36	0.252
	18	0.02	0.01	0.0	0.0	0.0	0.0	0.0	2.04	0.061
	20	0.0	0.01	0.0	0.01	0.0	0.0	0.0	2.8	0.084

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