An MCE Technical Publication

Harmonic Analysis and Comparison

- ***SYSTEM 12* -** 12 Pulse SCR Elevator Drive
- Conventional Six Pulse Elevator Drive
- Flux Vector VFAC Elevator Drive
- Includes Supplemental Jobsite Analysis

Motion Control Engineering, Incorporated

Revised March 1999

Purpose

This Technical Publication reports analysis and comparison of AC line harmonic distortion produced by three modern static drive types.

Motion Control Engineering, Inc. ***SYSTEM 12*** using 12-pulse DC SCR drive technology is compared to a conventional 6-pulse DC SCR drive and the typical "quiet" variable frequency AC inverter or flux vector drive. Testing was conducted under "controlled" test tower conditions. This research study presents a true comparison of drive-generated AC power line distortion (harmonic distortion).

Elevator Test Tower Research Overview

Most of today's elevator control specifications require the use of static drives. Increased use and experience with static drives has focused attention on the potential for AC power supply distortion and other problems. In many cases AC power line distortion does not become a major factor. Nevertheless, it is important that everyone dealing with static drives have a basic understanding of the nature of AC line distortion.

Power supply distortion caused by static drives can result in:

1) Degraded emergency power generator performance
2) Induction motor heating
3) Power losses in transformers
4) Objectionable audible noise
• Interference with sensitive medical equipment, computers, radios and television equipment

AC power supply distortion caused by elevator equipment is an issue for consultants, architecture/engineering firms, contractors and building owners.

This study concludes that use of MCE's ***SYSTEM 12*** drive results in significantly less AC line distortion than most other types of static drives.

Tested Drives

Three types of static drives were evaluated for generation of harmonic distortion. They are the types in most frequent use today.

1) MCE's ***SYSTEM 12*** using 12-pulse DC SCR drive technology for DC motors.
2) A conventional 6-pulse DC SCR drive for DC motors.
3) A variable frequency (VFAC) drive for AC motors. The tested unit is a "quiet" type utilizing "IGBT" devices.

Testing Methodology

The geared elevator installed in the test tower at **MCE's Research & Development Center** in Rancho Cordova (Sacramento) California was used for the tests.

The same AC power supply, drive isolation transformer, machine and elevator were used for all tests. An Imperial 20 HP DC motor was used for the DC drive tests. An Imperial 20 HP AC motor was used for the AC drive test.

It is our judgement that this methodology represents the most equitable possible arrangement for comparison of the three types of static drives.

The test tower elevator operates at 350 fpm with a 20 HP motor and a 480 VAC 3-phase power supply. The drive isolation transformer was a 27-KVA unit reconfigurable for conventional SCR or ***SYSTEM 12*** operation. No line filter was used in any of the three drive tests. A Fluke Model 41 Power Harmonics Analyzer was used for all measurements and computations. Data was downloaded to a printer.

General comments regarding the tests:

It was decided to measure worst-case conditions for the drives. Results were evaluated during *full load acceleration in the up direction*. Up acceleration for the VFAC unit was not as great as for the DC SCR drives so the current levels were correspondingly lower. Nevertheless, the waveforms and results for all the tested drives are considered to be typical, accurately representing each drive type.

Drive Characteristics

1) MCE's ***SYSTEM 12***, with **12-pulse DC SCR** technology for elevator control applications, is a unique 12-pulse 4-quadrant, fully regenerative DC SCR drive utilizing 19 SCRs. Test results reflect the benefits of this advanced technology.

2) The conventional **6-pulse DC SCR** drive was a Baldor Sweo 6-pulse 4-quadrant, fully regenerative DC SCR drive. This drive is typical of DC SCR drives generally available in the U.S. for elevator control applications. Test results are applicable to drives such as Magnetek DSD412, GE DC300E, Reliance, Emerson and others.

3) The **VFAC** drive evaluated was a Saftronics (Yaskawa) **Flux Vector** type. In regard to production of AC line harmonic distortion, the Yaskawa is considered to be typical of VFAC drives, either conventional or flux vector types. This is the case because the power supply is simply a 3-phase, six rectifier bridge feeding a capacitor bank, typical of VFAC designs presently available.

   The single exception to universal applicability of test data is a commercially available VFAC drive claiming very low levels of harmonic distortion. As far as can be determined, these product claims are accurate; however, cost is approximately two times that of any competitive drive. Thus, these drives are not considered a viable alternative to the drives examined in this study.

Furthermore, this particular drive type, along with most other AC drives, radiates RFI (Radio Frequency Interference) in far greater amounts and across a much wider and higher band of frequencies than either 6-pulse or 12-pulse DC SCR drives. As a result, sophisticated containment strategies and careful installation practices are required to keep radiation in check.

Evaluating the Tables

Two pages of data from the Harmonic Analyzer are presented for each of the three drive types studied. The first page shows the voltage and current waveforms along with graphs showing relative magnitudes for voltage and current harmonics. The second page presents a tabular summary of the measurements taken.

The tables contain a considerable amount of information. To compare the AC line distortion generated by each of the three drives, pay particular attention to:

1) The **Total Harmonic Distortion (THD Rms)** values for both voltage and, **especially**, **current** -- the Voltage Total Harmonic Distortion and the Current Total Harmonic Distortion.

2) The **Current Magnitude (IMag)** column which shows the actual magnitude, in amperes, for each harmonic.

THD Rms measurements for **current** represent the total amount of current the drive is drawing from, or putting back into, the AC line at frequencies other than the main fundamental frequency of 60 Hz. These ***current harmonics*** originating from the drive are the **"junk"** that distorts the AC power line. They can be the **cause** of AC line problems.

THD Rms measurements for voltage represent the ***voltage distortion or the amount of deviation*** from a perfect 60 Hz sine wave. Voltage Total Harmonic Distortion is the result, or the **effect** of the current harmonics that the drive is producing.

There are a number of **important facts** to consider regarding current and voltage harmonics:

1) Identical current harmonic magnitudes (Current Total Harmonic Distortion) **will not** have the same effect on all AC power lines in terms of the amount of voltage harmonics produced (Voltage Total Harmonic Distortion).

   If the AC line is "stiff," i.e., not easily affected, you can put a lot of current distortion on the line and voltage distortion measurements may be nominal. If the AC line is "soft" (as with a marginally sized power supply or a small emergency power generator), very moderate amounts of current distortion can generate considerable Voltage Total Harmonic Distortion, which can have serious consequences.

2) The Voltage Total Harmonic Distortion measured on the AC line is not only the result of elevator static drives. Residual base-line values can be measured by turning the drive off and recording harmonic distortion from other sources. When the static drive is **on**, measurements will reflect the **total** distortion including the base-line values plus the contribution of the elevator drive(s).

Evaluating the Data

The shape of the voltage and current waveforms provides meaningful information for evaluation of the various types of static drives. The ideal shape for both waveforms is a perfect sine wave. In all cases the voltage waveform is a close approximation of a sine wave. It is the **current waveform** that most clearly illustrates **the effect of harmonic distortion generated by static drives.**

The harmonic components generated by static drives can be calculated using the following formula:

$$\mathbf{H = nP \pm 1}$$

where n = 1,2,3....etc. and
P = the pulse number of the diode or SCR bridge

Yaskawa Flux Vector VFAC Drive

The voltage waveform for the VFAC drive has a noticeable flattening at the top and bottom. The VFAC drive visibly distorted the voltage sine wave, which is not easy to do -- the AC line for the MCE test tower elevator is very stiff.

Examination of the shape of the current waveform reveals the real story insofar as line distortion being generated by the VFAC drive is concerned. The waveform depicts how the VFAC drive draws current from the AC line. The current sine wave is obviously distorted. The VFAC is clearly the **worst** of all three drive types, a surprise considering the previously acknowledged superiority of AC technology in the elevator industry. The tests were repeated numerous times to verify that these figures were correct. Review of published literature corroborates findings -- suggesting that test results are typical.

Consider the bar graphs showing the relative magnitude of current harmonics. The fifth harmonic is nearly half the magnitude of the first harmonic. The first harmonic is actually the 60 Hz fundamental -- in the hypothetical ideal power system it would be the only bar illustrated.

Turning your attention to the data tables, the most important thing to note is the Current Total Harmonic Distortion (THD Rms under the Current column) at 44.3%. The current magnitude (IMag) column shows the largest harmonic (fifth) as a percentage of the 60 Hz fundamental, or 12.1 amps/28.4 amps = 42.6%. The VFAC drive demonstrates a propensity to generate harmonic distortion.

Conventional 6-Pulse DC SCR Drive

The voltage waveform doesn't provide much information because it is very close to a sine wave. This is confirmed by measured Voltage Total Harmonic Distortion of 2.6% (THD Rms under the Voltage column). Also note voltage harmonics are almost invisible on the bar graphs.

Examining the current waveform you can see that it is an improvement over the VFAC drive, but it is still only a rough approximation of a sine wave. Current harmonic distortion is apparent.

For a 6-pulse DC SCR drive, the main harmonics are five, seven, eleven, thirteen and so forth. These are the same significant harmonics as those in the VFAC drive. This is explained by the fact that the typical VFAC drive can be considered a 6-pulse system.

Looking at the data table it is important to note that Current Total Harmonic Distortion is 25.9% (THD Rms under the Current column). This is a significant improvement over the VFAC drive's numbers. The current magnitude (IMag) column shows the largest harmonic (fifth) as a percentage of the 60 Hz fundamental, or 10.6 amps/45.5 amps = 23.3%. Again, a significant improvement over the VFAC drive.

12-Pulse DC SCR Drive (MCE *SYSTEM 12*)

As expected, the voltage waveform doesn't reveal much information because it so closely approximates a sine wave. The Voltage Total Harmonic Distortion confirms this, measured at only 2.6%, equal to the 6-pulse DC SCR drive.

The bar graph illustrating voltage harmonics appears identical to the 6-pulse DC SCR drive, but this is misleading. The AC line is very stiff and hard to effect. Further, the graph represents residual distortion on the line, not the effect of the 12-pulse DC SCR drive.

The ***SYSTEM 12*** current waveform more closely resembles that of an ideal sine wave than either waveforms for the 6-pulse DC SCR or VFAC drives. The 12-pulse waveform shows significant improvement over the other two drive types.

When the **current** harmonics are examined, one can see they are **greatly reduced** in comparison to the other drive types. The significant harmonics for the 12-pulse drive are 11, 13, 23, 25 and so forth.

Finally, checking the data table, the Current Total Harmonic Distortion is **only 13.5%** (THD Rms under the Current column). This represents meaningful improvement over both the

VFAC and 6-pulse DC SCR drives. The current magnitude (IMag) column shows the largest harmonic (11th) as a percentage of the 60 Hz fundamental, or 4.9 amps/44.3 amps = 11.1%.

The 12-pulse drive offers a **factor of two improvement** in Total Harmonic Distortion when compared to the typical 6-pulse DC SCR drive and a **factor of four improvement** when compared to the typical VFAC drive.

Conclusion

The purpose of this technical publication is to provide an awareness of the potential for adverse AC line distortion when elevators are controlled by static drives. It has been demonstrated how different types of static drives compare to the state-of-the-art in 12-pulse DC SCR technology.

Data indicates that non-regenerative VFAC drives present the biggest challenge insofar as AC line distortion is concerned. VFAC drives are also a potential source of RFI noise. Careful consideration is required when selecting these drives for a particular application.

This study shows that the conventional 6-pulse DC SCR drive definitely is not as clean as a 12-pulse DC SCR drive. In cases where there is any concern about AC line distortion use of the 12-pulse DC SCR drive is advisable.

Examination of the data supports the conclusion that MCE's ***SYSTEM 12*** using 12-pulse technology is the most effective method for minimizing AC line distortion.

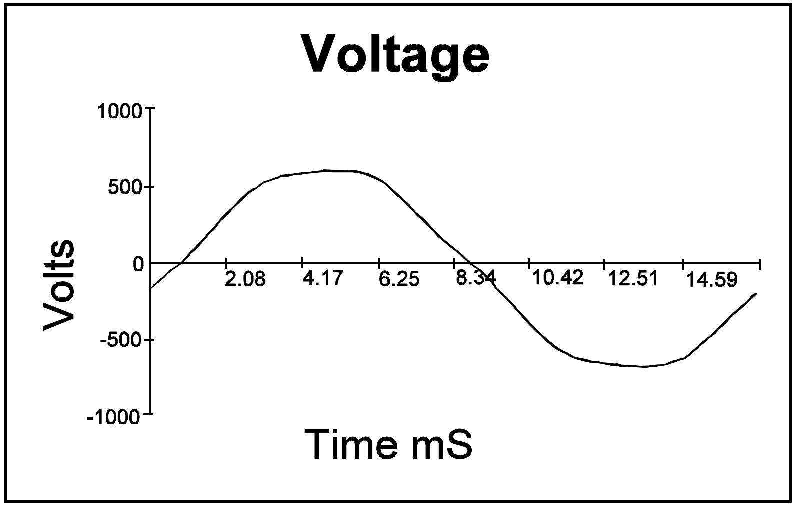
The advantages of the 12-pulse drive are grounded in solid theory. The reader may wish to review, ***"Application of 12-Pulse Converters -- reducing electrical interference and audible noise from DC-motor drives"*** which appeared in the February 1992 issue of **Elevator World** magazine. Additional advantages of 12-pulse DC SCR drives are discussed in this article.

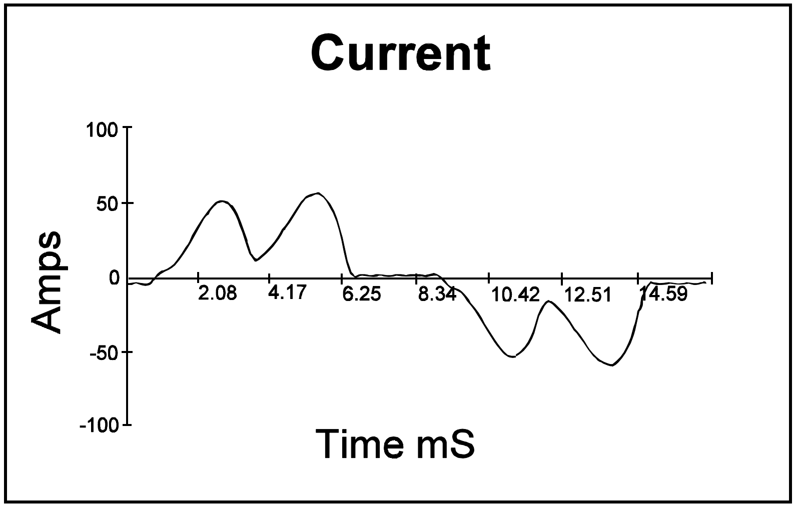
Static drive technology continually changes. As improved applications become available the nature of AC line pollution problems will also change. It is the hope of the authors that MCE's series of Technical Publications is informative and a catalyst for ongoing dialogue and sharing of information between consultants, elevator contractors, owners and other interested parties. MCE Technical Publications are available on our website at www.mceinc.com.

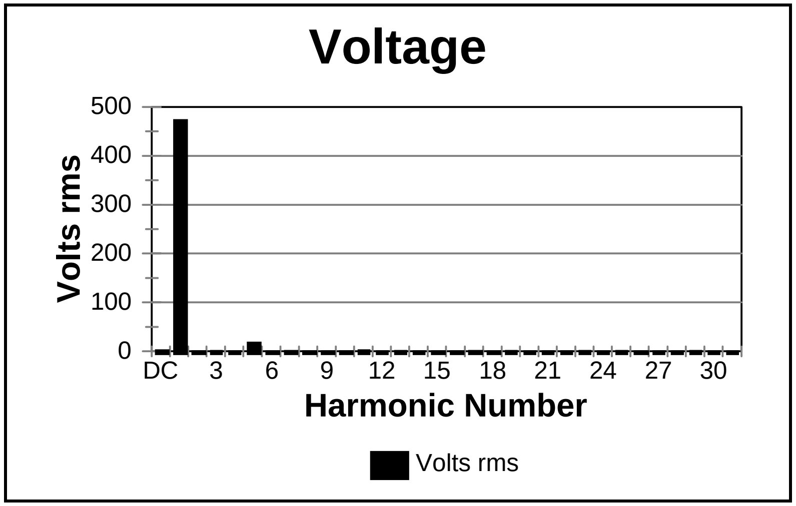
Don Alley, MCE *Vice President, Research and Development*
MCE *R&D Staff*
August 1994

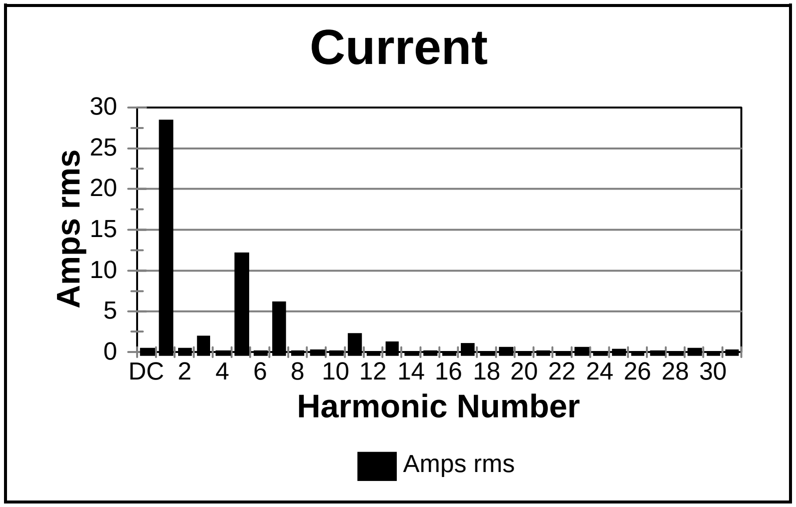
Yaskawa Flux Vector VFAC Drive

MCE test tower data; 350 fpm, 20 HP AC motor, full load up acceleration. Ideal voltage and current should be illustrated as perfect sine waves. Fifth an seventh current harmonics are severe. The voltage waveform peaks are “flattened” unlike either SCR drive.









Yaskawa Flux Vector VFAC Drive

MCE test tower data; 350 fpm, 20HP AC motor, full load up acceleration. Data is considered to be typical for most VFAC drives. **RMS Current Total Hormonic Distortion (THD Rms) or 44.3%.** Current magnitude (Imag) of the largest harmonic (fifth) as a percentage of the 60 Hz fundamental, or 12.1 ampa/28.4 amps = **42.6%**.

Readings - 11/02/94 08:43:50

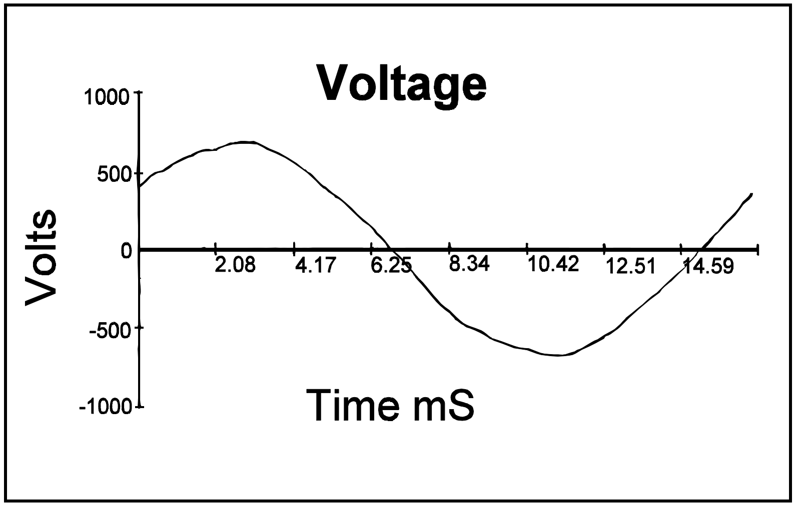
Summary Information			Voltage	Current	Recorded Information
Frequency	60.0	RMS	473	31.7	V RMS
Power		Peak	652	59.3	A RMS
KW	13.3	DC Offset	-2	-0.4	V Peak
KVA	15.0	Crest	1.38	1.87	A Peak
KVAR	2.8	THD Rms	3.8	44.3	V THD-F%
Peak KW	38.8	THD Fund	3.8	49.4	A THD-F%
Phase	12° lead	HRMS	18	14.0	K Watts
Total PF	0.89	KFactor		7.9	KVAR
DPF	0.98				TPF
					DPF
					Frequency

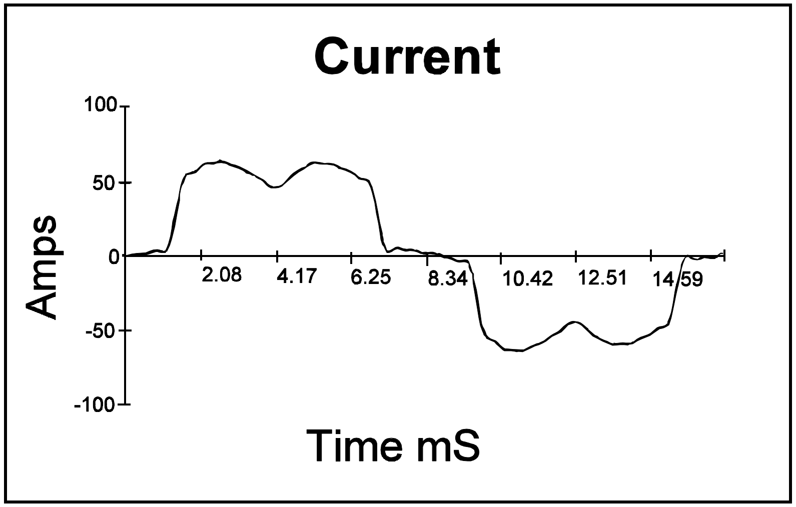
Harmonic Distortion

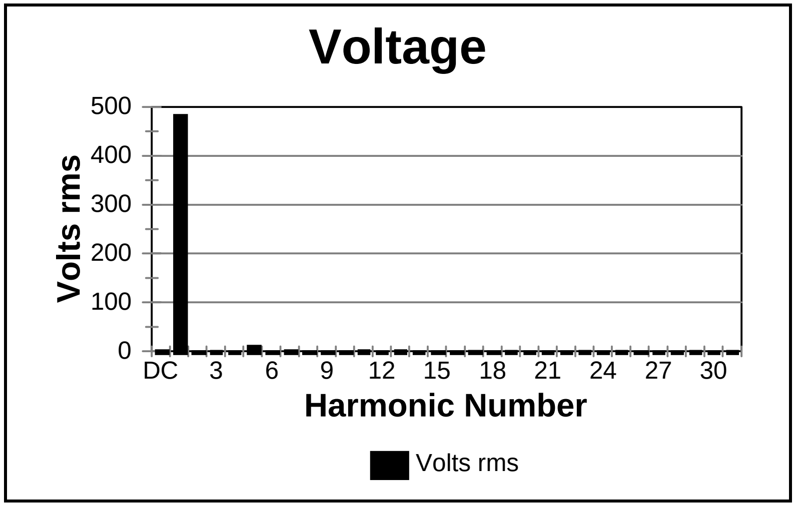
	Freq.	V Mag	%V RMS	V ϕ°	I Mag	% I RMS	I ϕ°	Power (KW)
DC	0.0	2	0.4	0	0.4	1.2	0	0.0
1	60.0	473	100.3	-12	28.4	90.6	0	13.1
2	119.9	0	0.1	-154	0.4	1.3	65	0.0
3	179.9	1	0.2	-75	1.9	6.0	158	0.0
4	239.8	0	0.0	-11	0.1	0.4	-125	0.0
5	299.8	18	3.8	154	12.1	38.7	-158	0.1
6	359.8	0	0.0	172	0.1	0.2	89	0.0
7	419.7	1	0.2	-141	6.1	19.6	9	0.0
8	479.7	0	0.0	72	0.1	0.2	-84	0.0
9	539.7	0	0.0	-41	0.2	0.5	-11	0.0
10	599.6	0	0.0	-146	0.1	0.2	47	0.0
11	659.6	2	0.3	59	2.2	7.1	133	0.0
12	719.5	0	0.0	46	0.0	0.0	-95	0.0
13	799.5	1	0.2	120	1.2	3.9	-106	0.0
14	839.5	0	0.0	5	0.0	0.1	150	0.0
15	899.4	0	0.0	164	0.1	0.2	-128	0.0
16	959.4	0	0.0	42	0.0	0.0	-165	0.0
17	1019.3	1	0.2	-38	1.0	3.1	27	0.0
18	1079.3	0	0.0	39	0.0	0.0	-32	0.0
19	1139.3	1	0.1	-1	0.5	1.7	131	0.0
20	1199.2	0	0.0	92	0.0	0.1	44	0.0
21	1259.3	0	0.0	53	0.1	0.2	46	0.0
22	1319.2	0	0.0	17	0.0	0.1	-176	0.0
23	1379.1	1	0.1	-143	0.5	1.7	-83	0.0
24	1439.1	0	0.0	41	0.0	0.0	81	0.0
25	1499.0	1	0.1	-120	0.3	0.9	7	0.0
26	1559.0	0	0.0	134	0.0	0.1	-54	0.0
27	1619.0	0	0.0	-144	0.1	0.2	-37	0.0
28	1678.9	0	0.0	155	0.0	0.0	-70	0.0
29	1738.9	1	0.1	89	0.4	1.1	169	0.0
30	1798.8	0	0.0	113	0.0	0.0	59	0.0
31	1858.8	0	0.1	136	0.2	0.7	-119	0.0

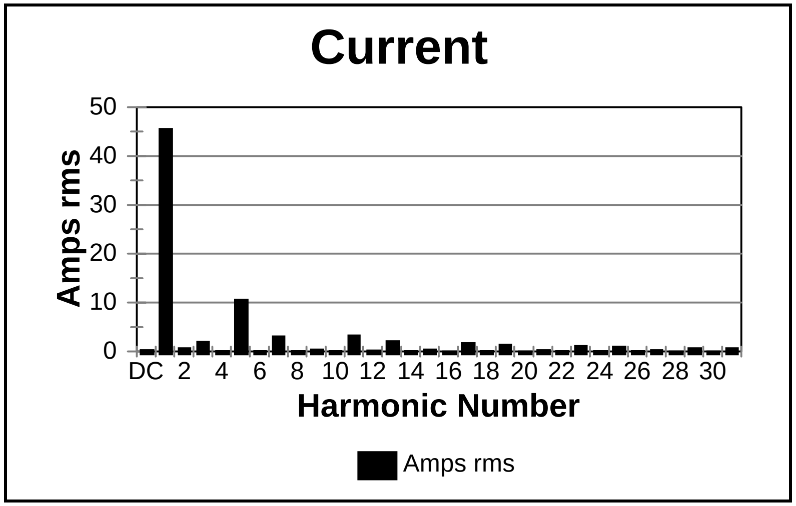
Conventional 6-Pulse DC SCR Drive

Data taken from MCE test tower; 350 fpm, 20 HP DC motor, full load up acceleration. Ideal voltage and current should be illustrated as perfect sine waves. Note that the largest current harmonics are the fifth and seventh. This data is typical and would be identical for a 6-pulse SCR drive of any manufacturer.









Conventional 6-Pulse DC SCR Drive

Data taken from MCE test tower, 350 fpm, 20HP DC motor, full load up acceleration. Note particularly the **RMS Current Total Harmonic Distortion (THD RMS of 25.9%.** Also note the current magnitude (Imag) of the largest (fifth) as a percentage of the 60 Hz fundamental, or 10.6 amps/45.5 amps = 23.3%.

Readings - 09/22/94 16:12:57

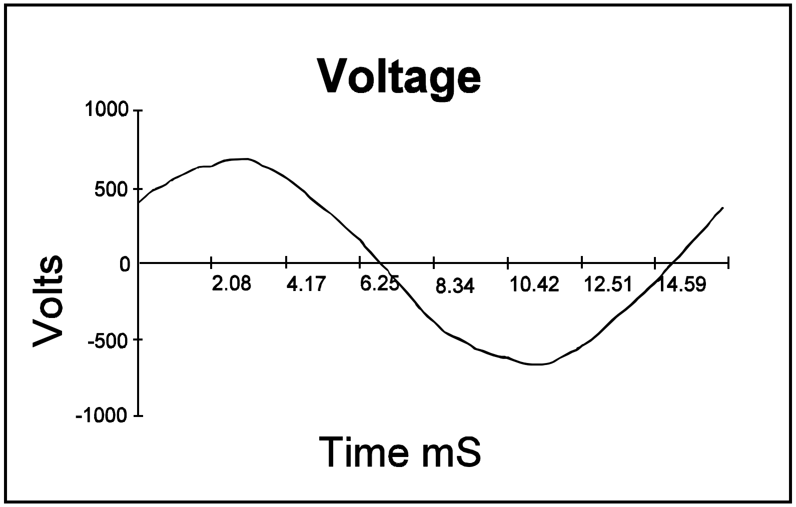
Summary Information			Voltage	Current	Recorded Information
Frequency	60.0	RMS	484	47.3	V RMS
Power		Peak	695	65.9	A RMS
KW	16.8	DC Offset	-2	-0.3	V Peak
KVA	22.9	Crest	1.44	1.39	A Peak
KVAR	14.4	THD Rms	2.6	25.9	V THD-F%
Peak KW	46.8	THD Fund	2.6	26.9	A THD-F%
Phase	41° lag	HRMS	12	12.2	K Watts
Total PF	0.74	KFactor		5.1	KVAR
DPF	0.76				TPF
					DPF
					Frequency

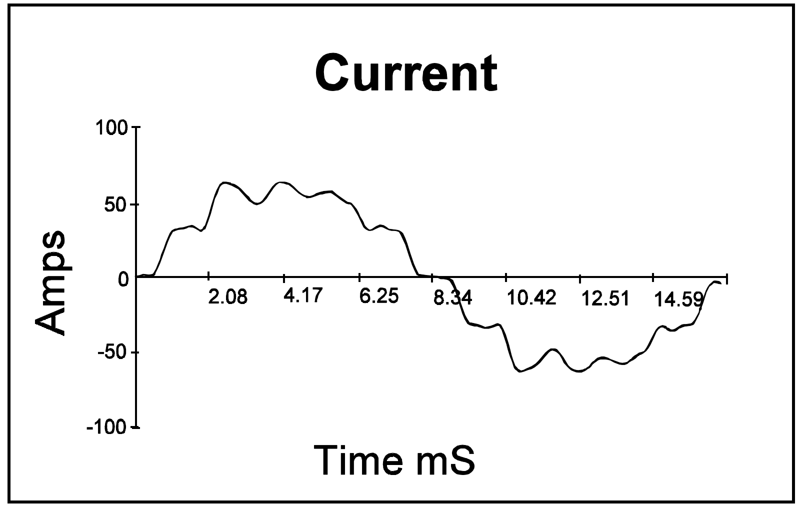
Harmonic Distortion

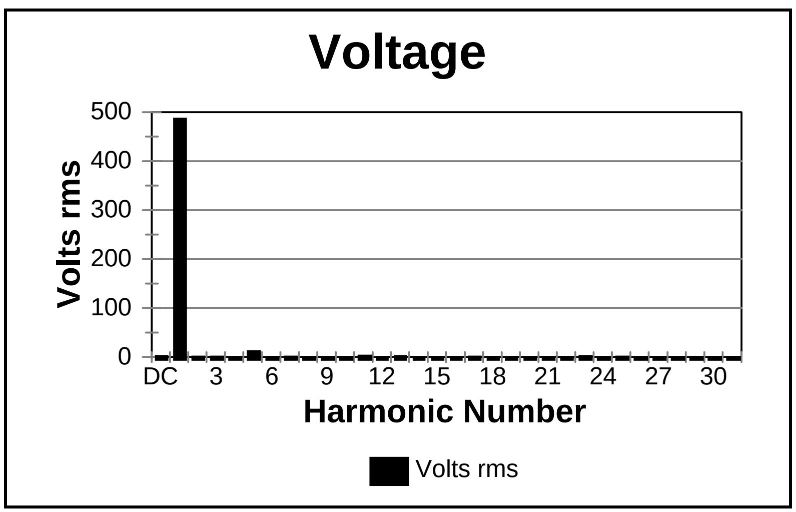
	Freq.	V Mag	%V RMS	V ϕ°	I Mag	% I RMS
DC	0.0	2	0.3	0	0.3	0.6
1	60.0	484	100.3	41	45.5	96.9
2	119.9	0	0.1	65	0.7	1.5
3	179.9	1	0.1	56	2.0	4.2
4	239.8	0	0.0	-105	0.1	0.1
5	299.8	11	2.4	130	10.6	22.5
6	359.8	0	0.0	-95	0.1	0.2
7	419.7	2	0.5	49	3.1	6.5
8	479.7	0	0.0	-39	0.1	0.3
9	539.7	0	0.0	142	0.4	0.8
10	599.6	0	0.0	30	0.1	0.3
11	659.6	2	0.5	-90	3.3	7.0
12	719.5	0	0.0	-13	0.2	0.3
13	799.5	2	0.3	-138	2.1	4.5
14	839.5	0	0.0	23	0.1	0.1
15	899.4	0	0.1	-98	0.4	0.8
16	959.4	0	0.0	84	0.0	0.1
17	1019.3	1	0.3	108	1.7	3.6
18	1079.3	0	0.0	94	0.1	0.1
19	1139.3	1	0.3	39	1.4	3.0
20	1199.2	0	0.0	-49	0.0	0.1
21	1259.3	0	0.0	70	0.3	0.7
22	1319.2	0	0.0	0	0.1	0.2
23	1379.1	1	0.3	-84	1.1	2.3
24	1439.1	0	0.0	-40	0.1	0.2
25	1499.0	1	0.3	-146	1.0	2.2
26	1559.0	0	0.0	-47	0.1	0.1
27	1619.0	0	0.0	-136	0.3	0.6
28	1678.9	0	0.0	41	0.0	0.1
29	1738.9	1	0.2	86	0.7	1.4
30	1798.8	0	0.0	96	0.0	0.1
31	1858.8	1	0.2	34	0.7	1.5

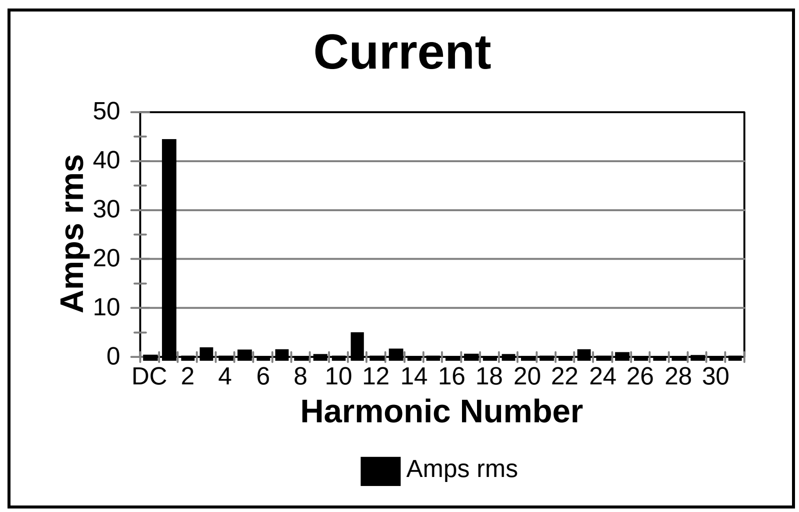
12-Pulse SCR Drive (MCE's *" System 12")*

Data taken from MCE test tower; 350 fpm, 20 HP DC motor, full load up acceleration. Ideal voltage and current should be illustrated as perfect sine waves. Note that the largest current harmonics are the eleventh and thirteenth.









12-Pulse DC SCR Drive (MCE's *"SYSTEM 12"*)

Data taken from MCE test tower, 350 fpm, 20 HP DC motor, full load up acceleration. Note particularly the RMS Current Total Harmonic Distortion (THD RMS of 13.5%. Also note the current magnitude (Imag) of the largest (eleventh) as a percentage of the 60 Hz fundamental, or 4.9 amps/45.3 amps = 11.1%.

Readings - 08/25/94 11:40:17

Summary Information			Voltage	Current	Recorded Information
Frequency	60.0	RMS	487	44.7	V RMS
Power		Peak	699	65.1	A RMS
KW	17.8	DC Offset	-2	-0.3	V Peak
KVA	21.8	Crest	1.43	1.46	A Peak
KVAR	12.0	THD Rms	2.6	13.5	V THD-F%
Peak KW	45.1	THD Fund	2.6	13.6	A THD-F%
Phase	34° lag	HRMS	13	6.0	K Watts
Total PF	0.82	KFactor		3.5	KVAR
DPF	0.83				TPF
					DPF
					Frequency

Harmonic Distortion

	Freq.	V Mag	%V RMS	V ϕ°	I Mag	% I RMS
DC	0.0	2	0.4	0	0.3	0.7
1	60.0	487	100.3	34	44.3	99.8
2	119.9	1	0.1	-107	0.1	0.1
3	179.9	1	0.2	70	1.8	4.1
4	239.8	0	0.1	-75	0.1	0.1
5	299.8	12	2.4	86	1.3	2.9
6	359.8	0	0.0	67	0.0	0.0
7	419.7	1	0.3	15	1.4	3.2
8	479.7	0	0.0	138	0.0	0.1
9	539.7	0	0.0	-140	0.4	0.9
10	599.6	0	0.0	165	0.1	0.1
11	659.6	3	0.7	105	4.9	11.1
12	719.5	0	0.0	-97	0.1	0.2
13	799.5	2	0.3	-3	1.5	3.3
14	839.5	0	0.0	-59	0.0	0.1
15	899.4	0	0.0	-25	0.1	0.2
16	959.4	0	0.0	141	0.0	0.1
17	1019.3	1	0.1	-57	0.5	1.2
18	1079.3	0	0.0	-158	0.0	0.0
19	1139.3	0	0.1	12	0.4	0.8
20	1199.2	0	0.0	171	0.0	0.0
21	1259.3	0	0.0	8	0.1	0.3
22	1319.2	0	0.0	26	0.0	0.1
23	1379.1	2	0.3	-84	1.4	3.0
24	1439.1	0	0.0	-10	0.1	0.2
25	1499.0	1	0.3	-146	0.8	1.8
26	1559.0	0	0.0	169	0.0	0.1
27	1619.0	0	0.0	-65	0.0	0.0
28	1678.9	0	0.0	-128	0.0	0.1
29	1738.9	0	0.1	157	0.2	0.4
30	1798.8	0	0.0	-94	0.0	0.0
31	1858.8	0	0.1	-115	0.1	0.3

SUPPLEMENTAL JOBSITE ANALYSIS

Purpose

Supplemental jobsite analysis was undertaken to compare the results of the Test Tower study with actual jobsite measurements. The general discussions of the Test Tower Research are applicable to this supplemental study.

Tested Drives

Two types of static drives were evaluated at the jobsite. They are the Magnatek 6-pulse DC SCR drive and MCE's ***SYSTEM 12*** using 12-pulse DC SCR drive. The job sites are as follows:

1) International Towers Building -- 700 fpm; 2500 lb capacity; Magnatek 6-pulse drive; General Dynamics ED machine; 35.4 HP; 115 amp/260 volt armature; 480 AC line voltage.

2) Plaza Building -- 500 fpm; 3000 lb capacity; MCE ***SYSTEM 12***; Otis 131HT machine; 32 HP; 177 amp/150 volt armature; 480 AC line voltage.

Testing Methodology

The gearless elevators were tested using a Fluke Model 41 Power Harmonics Analyzer for all measurements and computations. Data was take from the primary side of the isolation transformers and downloaded to a printer. It was decided to measure worst-case conditions for the drives, which in the absence of test weights, is during empty car acceleration in the down direction.

Evaluating the Data

Conventional 6-Pulse DC SCR Drive - International Towers Building

The voltage waveform doesn't provide much information because it is very close to a sine wave. This is confirmed by measured Voltage Total Harmonic Distortion of 4.1% (THD Rms under the Voltage column). Note that voltage harmonics are insignificant on the bar graphs.

For a 6-pulse DC SCR drive, the main harmonics are five, seven, eleven, thirteen and so forth. Looking at the data table it is important to note that Current Total Harmonic Distortion is 26.9% (THD Rms under the Current column). The current magnitude (Imag) column shows the largest harmonic (fifth) as a percentage of the 60 Hz fundamental, or 13.7 amps/64.7 amps = 21.2%.

12-Pulse DC SCR Drive - Plaza Building

As expected, the 12-pulse voltage waveform doesn't reveal any more information than the 6-Pulse voltage waveform because it also closely approximates a sine wave. The Voltage Total Harmonic Distortion confirms this, measured at only 2.5% lower than that of the 6-pulse DC SCR drive.

The ***System 12*** current waveform more closely resembles that of an ideal sine wave than the waveform for the 6-pulse DC SCR. When the **current** harmonics are examined, one can see they are **greatly reduced** in comparison to the 6-pulse drive. The significant harmonics for the 12-pulse drive are 11, 13, 23, 25 and so forth.

Finally, checking the data table, the Current Total Harmonic Distortion is **only 6.5%** (THD Rms under the Current column). This represents meaningful improvement over the 6-pulse DC SCR drive. The current magnitude (Imag) column shows the largest harmonic (11th) as a percentage of the 60 Hz fundamental, or 4.7 amps/93.3 amps = 5.0%.

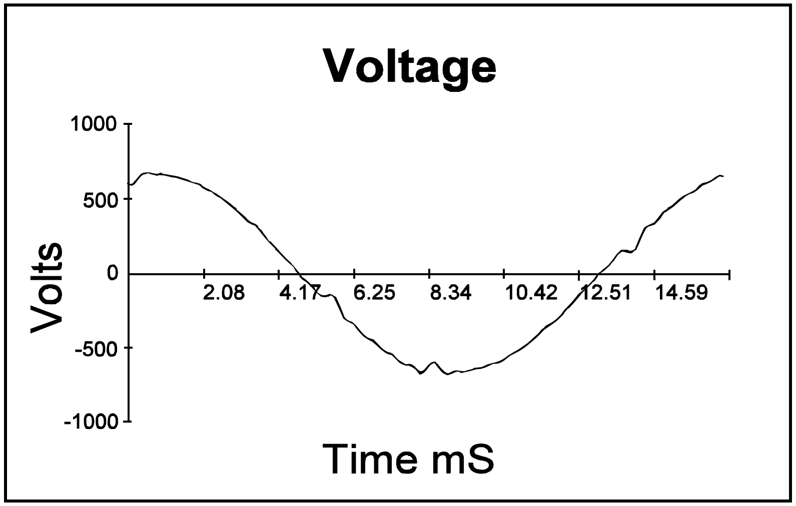
The Plaza Building ***System 12*** drive offers a **factor of four improvement** in Total Harmonic Distortion when compared to the International Towers Building 6-pulse DC SCR drive.

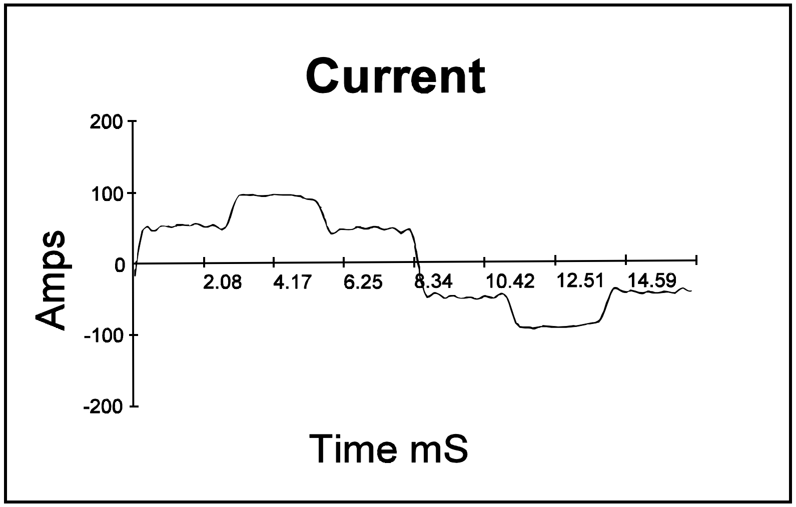
Conclusion

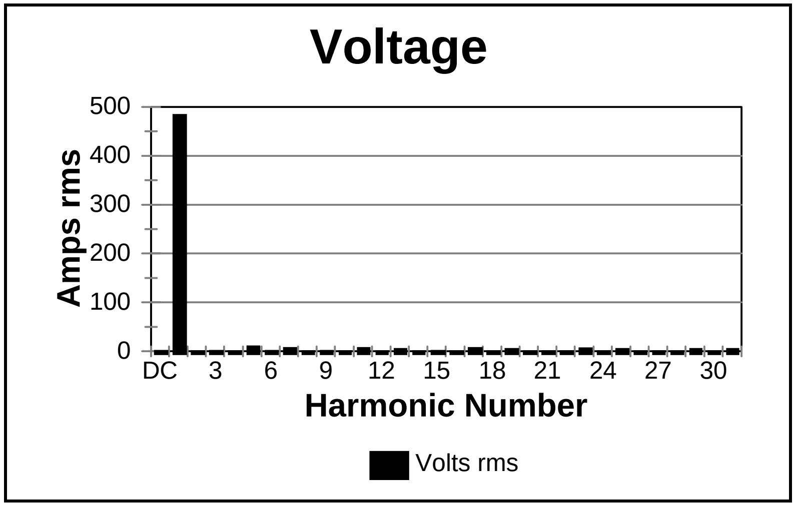
The supplemental analysis further validates the hypotheses of the Test Tower Research in that a 12-pulse SCR drive produces substantially less harmonic distortion than other static drives typically used. It must be noted that levels of Harmonic Distortion will vary from installation to installation as the result of job-specific variables (current drawn, car direction and loading, line stiffness, other static drives sharing the line, baseline distortion).

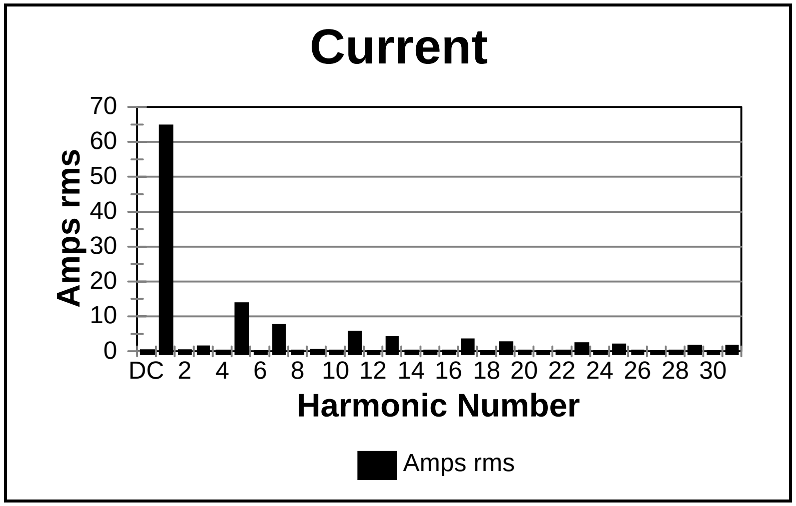
Conventional 6-Pulse DC SCR Drive

Data taken from International Tower Building; 700 fpm, 35.4 HP DC motor, empty car down acceleration. Ideal voltage and current should be illustrated as perfect sine waves. Note that the largest current harmonics are the fifth and seventh. This data is typical and would be identical for **any** 6-pulse SCR drive of **any** manufacturer.









Conventional 6-Pulse DC SCR Drive

Data taken from International Tower Building – 700 fpm, 35.4 HP DC motor, empty car down acceleration. Note particularly the **RMS Current Total Harmonic Distortion (THD RMS of 26.9%.** Also note the current magnitude (Imag) of the largest (fifth) as a percentage of the 60 Hz fundamental, or 13.7/64.7 amps = 21.2%.

Readings - 11/03/95 15:59:14

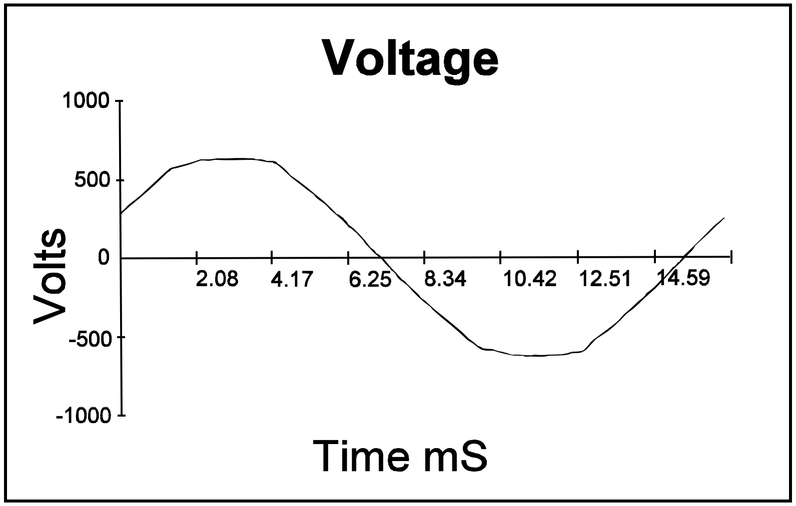
Summary Information			**Voltage**	**Current**	**Recorded Information**
Frequency	60.0	RMS	484	67.2	V RMS
Power		Peak	692	97.9	A RMS
KW	7.1	DC Offset	-1	-0.3	V Peak
KVA	32.5	Crest	1.43	1.46	A Peak
KVAR	30.5	THD Rms	4.1	26.9	V THD-F%
Peak KW	39.4	THD Fund	4.1	27.9	A THD-F%
Phase	77° lag	HRMS	20	18.1	K Watts
Total PF	0.22	KFactor		7.5	KVAR
DPF	0.22				TPF
					DPF
					Frequency

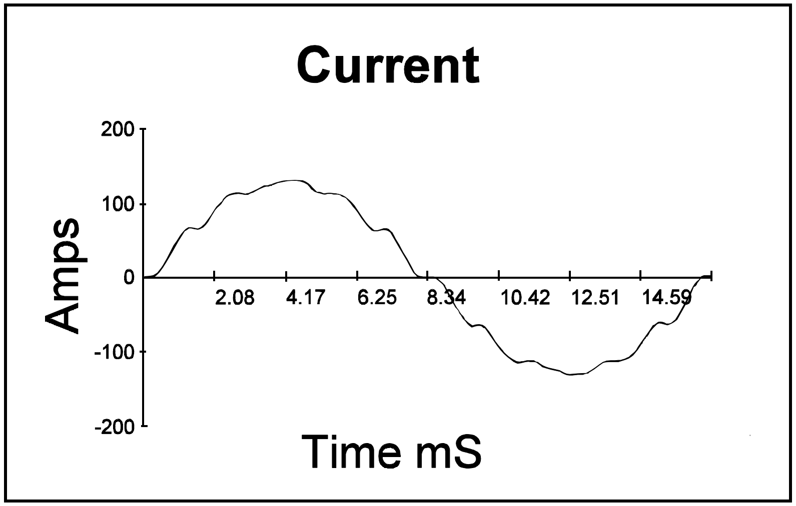
Harmonic Distortion

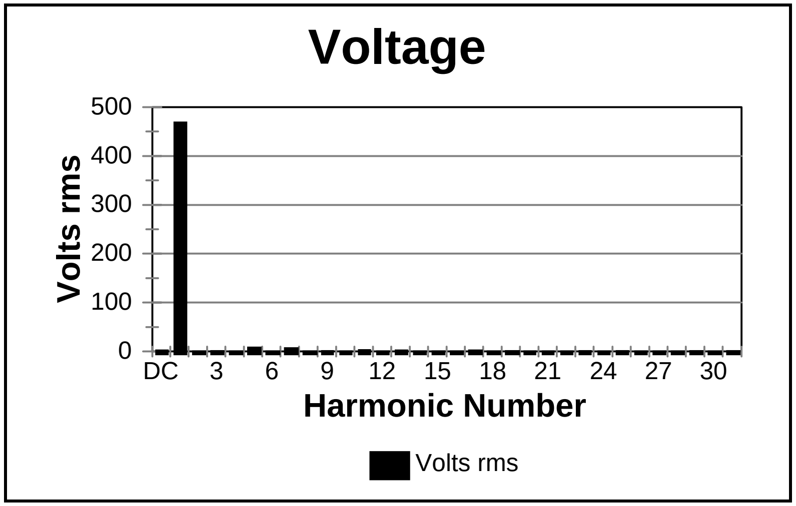
	Freq.	V Mag	%V RMS	V ϕ°	I Mag	% I RMS	I ϕ°	Power (KW)
DC	0.0	1	0.3	0	0.3	0.5	0	0.0
1	60.0	484	100.2	77	64.7	96.7	0	6.8
2	119.9	0	0.1	-68	0.3	0.5	94	0.0
3	179.9	1	0.2	-127	1.4	2.1	-51	0.0
4	239.8	0	0.0	-27	0.2	0.3	46	0.0
5	299.8	10	2.0	-175	13.7	20.5	-11	-0.1
6	359.8	1	0.1	-37	0.1	0.1	98	0.0
7	419.7	7	1.4	-94	7.5	11.2	-14	0.0
8	479.7	0	0.0	-31	0.2	0.3	82	0.0
9	539.7	1	0.2	101	0.4	0.6	-164	0.0
10	599.6	0	0.0	-15	0.2	0.3	49	0.0
11	659.6	7	1.4	-147	5.6	8.3	-21	0.0
12	719.5	0	0.0	-56	0.1	0.1	56	0.0
13	799.5	5	1.1	-104	4.1	6.1	-32	0.0
14	839.5	0	0.0	-61	0.2	0.3	70	0.0
15	899.4	1	0.1	0	0.2	0.3	110	0.0
16	959.4	0	0.1	-46	0.2	0.3	39	0.0
17	1019.3	7	1.4	-164	3.4	5.1	-38	0.0
18	1079.3	0	0.0	-63	0.1	0.1	29	0.0
19	1139.3	5	1.0	-108	2.6	3.8	-42	0.0
20	1199.2	0	0.1	-51	0.2	0.3	60	0.0
21	1259.3	0	0.1	-108	0.1	0.1	-12	0.0
22	1319.2	0	0.1	-58	0.2	0.3	15	0.0
23	1379.1	6	1.2	179	2.3	3.4	-53	0.0
24	1439.1	0	0.1	-59	0.1	0.1	37	0.0
25	1499.0	5	1.1	-117	2.0	2.9	-53	0.0
26	1559.0	0	0.1	-77	0.2	0.3	37	0.0
27	1619.0	0	0.1	150	0.1	0.1	-116	0.0
28	1678.9	0	0.1	-71	0.2	0.3	0	0.0
29	1738.9	5	1.0	169	1.6	2.4	-64	0.0
30	1798.8	0	0.1	-87	0.1	0.1	-2	0.0
31	1858.8	5	1.0	-136	1.6	2.4	-71	0.0

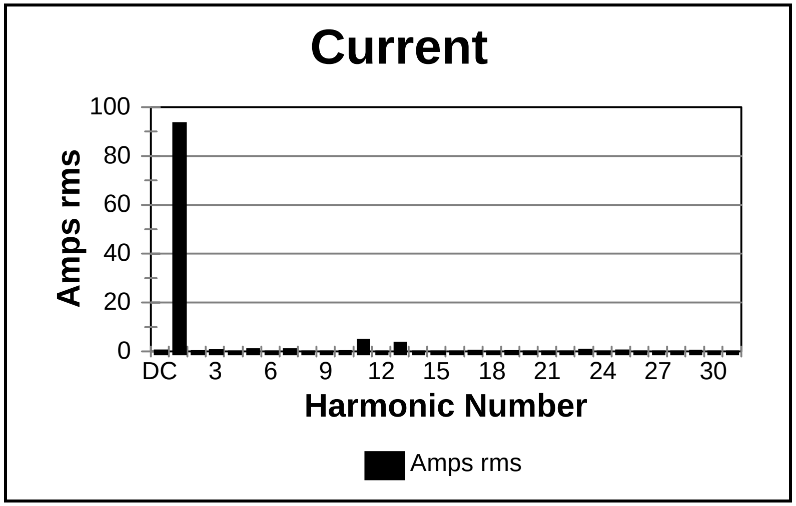
12-Pulse SCR Drive (MCE's *" System 12")*

Data taken from the Plaza Building; 500 fpm, 32 HP DC motor, empty car down acceleration. Ideal voltage and current should be illustrated as perfect sine waves. Note that the largest current harmonics are the eleventh and thirteenth.









12-Pulse DC SCR Drive (MCE's *"SYSTEM 12"*)

Data taken from Plaza Building, 500 fpm, 32 HP DC motor, empty car down acceleration. Note particularly the **RMS Current Total Harmonic Distortion (THD RMS of 13.5%.** Also note the current magnitude (Imag) of the largest (eleventh) as a percentage of the 60 Hz fundamental, or 4.7 amps/93.5 amps = 5.0%.

Readings - 11/06/95 15:31:22

Summary Information			Voltage	Current	Recorded Information
Frequency	60.0	RMS	469	93.7	V RMS
Power		Peak	645	135.3	A RMS
KW	39	DC Offset	-2	-0.4	V Peak
KVA	44	Crest	1.38	1.44	A Peak
KVAR	20	THD Rms	2.5	6.5	V THD-F%
Peak KW	85	THD Fund	2.5	6.6	A THD-F%
Phase	27° lag	HRMS	12	6.1	K Watts
Total PF	0.89	KFactor		1.6	KVAR
DPF	0.89				TPF
					DPF
					Frequency

Harmonic Distortion

	Freq.	V Mag	%V RMS	V ϕ°	I Mag	% I RMS	I ϕ°	Power (KW)
DC	0.0	2	0.3	0	0.4	0.4	0	0.0
1	60.0	469	100.3	27	93.5	100.1	0	6.8
2	119.9	0	0.1	-115	0.2	0.2	143	0.0
3	179.9	1	0.3	122	0.5	0.5	-167	0.0
4	239.8	0	0.1	-41	0.1	0.2	77	0.0
5	299.8	8	1.7	-37	1.0	1.1	-160	-0.1
6	359.8	0	0.0	18	0.0	0.0	32	0.0
7	419.7	7	1.6	-168	1.0	1.1	137	0.0
8	479.7	0	0.0	124	0.1	0.2	-91	0.0
9	539.7	1	0.1	-18	0.1	0.1	59	0.0
10	599.6	0	0.0	158	0.2	0.2	-148	0.0
11	659.6	3	0.6	131	4.7	5.0	171	0.0
12	719.5	0	0.0	-112	0.1	0.1	124	0.0
13	799.5	2	0.4	17	3.5	3.7	179	0.0
14	839.5	0	0.0	-79	0.1	0.1	42	0.0
15	899.4	0	0.1	102	0.1	0.2	84	0.0
16	959.4	0	0.0	-5	0.1	0.1	-69	0.0
17	1019.3	2	0.4	-46	0.3	0.4	-60	0.0
18	1079.3	0	0.0	89	0.0	0.0	-169	0.0
19	1139.3	1	0.2	128	0.2	0.2	4	0.0
20	1199.2	0	0.0	107	0.0	0.0	-138	0.0
21	1259.3	0	0.1	-101	0.1	0.1	153	0.0
22	1319.2	0	0.0	-46	0.0	0.0	136	0.0
23	1379.1	1	0.3	98	0.7	0.7	-179	0.0
24	1439.1	0	0.0	-146	0.0	0.0	84	0.0
25	1499.0	1	0.2	-84	0.4	0.4	97	0.0
26	1559.0	0	0.0	-79	0.1	0.1	-55	0.0
27	1619.0	0	0.1	32	0.0	0.0	-51	0.0
28	1678.9	0	0.0	0	0.0	0.0	-97	0.0
29	1738.9	1	0.2	-120	0.3	0.3	-19	0.0
30	1798.8	0	0.0	-165	0.0	0.0	-158	0.0
31	1858.8	1	0.1	51	0.1	0.1	-33	0.0