

# A MAGNETIC DEVICE FOR IMPROVING POWER QUALITY

by

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## ABSTRACT

Power Quality can be described as the best quality power to operate specific equipment or process with the lowest level of operating problems.

Several techniques such as providing harmonic mitigation, power factor improvement, and transient suppression devices are available for power quality improvement. Reduction of L.C. resonance, the phase balancing of voltages and load currents also enhances power quality. A circuit comprised of symmetrical wrap-around magnetic chokes between all three(3) phases, simultaneously accomplishes all the above improvements to various degrees. Basic understanding of Power Quality, Device Overview, and Test Data of this simple and rugged device are presented.

## BASIC UNDERSTANDING OF POWER QUALITY

It is necessary to understand non-linear loads, harmonics, power factor, sags, surges, and transients.

**Non-Linear Load** - The Current Waveform does not look like the Voltage Waveform.

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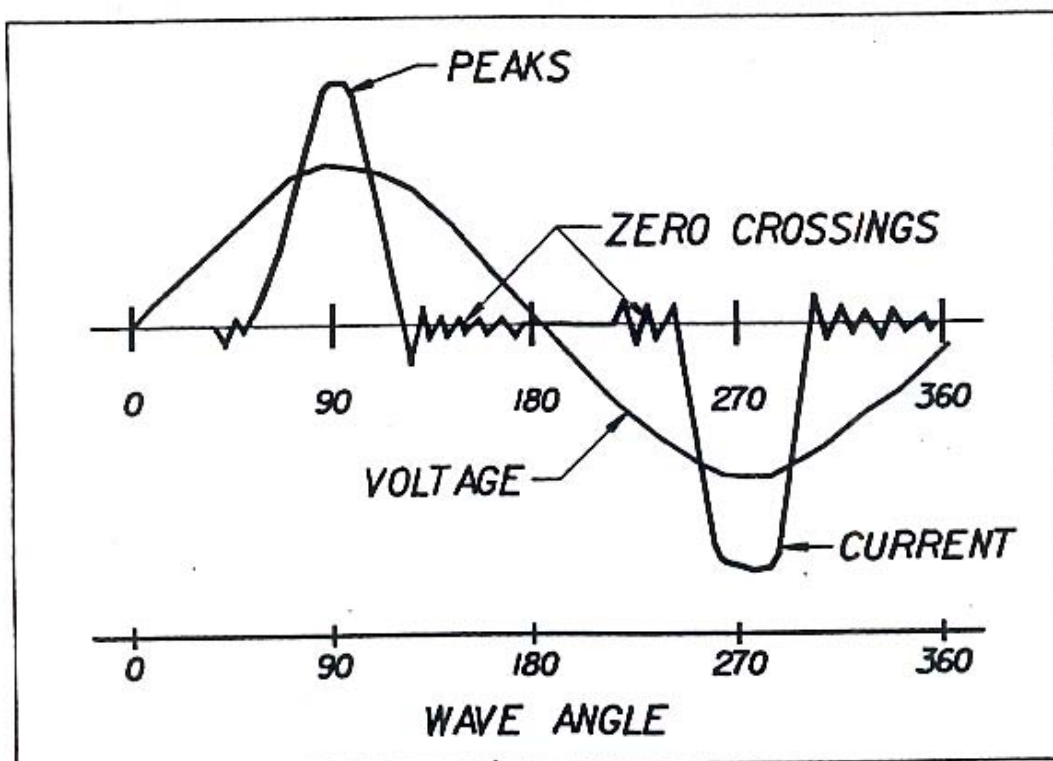
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**Harmonics** - Harmonics are currents or voltages with frequencies that are integer multiples of fundamental power frequency. If the fundamental is 60Hz, the second harmonic is 120Hz, the third harmonic is 180Hz, etc.. Harmonics are created by non-linear pulses that draw current in abrupt pulses rather than in a smooth sinusoidal manner. These pulses cause distorted current wave shapes which in turn cause harmonic currents to flow back to other parts of the Power System.

Each harmonic has a name, frequency, and sequence. The sequence refers to phasor rotation with respect to fundamental (F); i.e., in an induction motor, a positive sequence harmonic would generate a magnetic field that is rotated in the same direction as the fundamental. A negative sequence harmonic would rotate in the reverse direction.

The first nine(9) harmonics, along with the effects, are listed below:

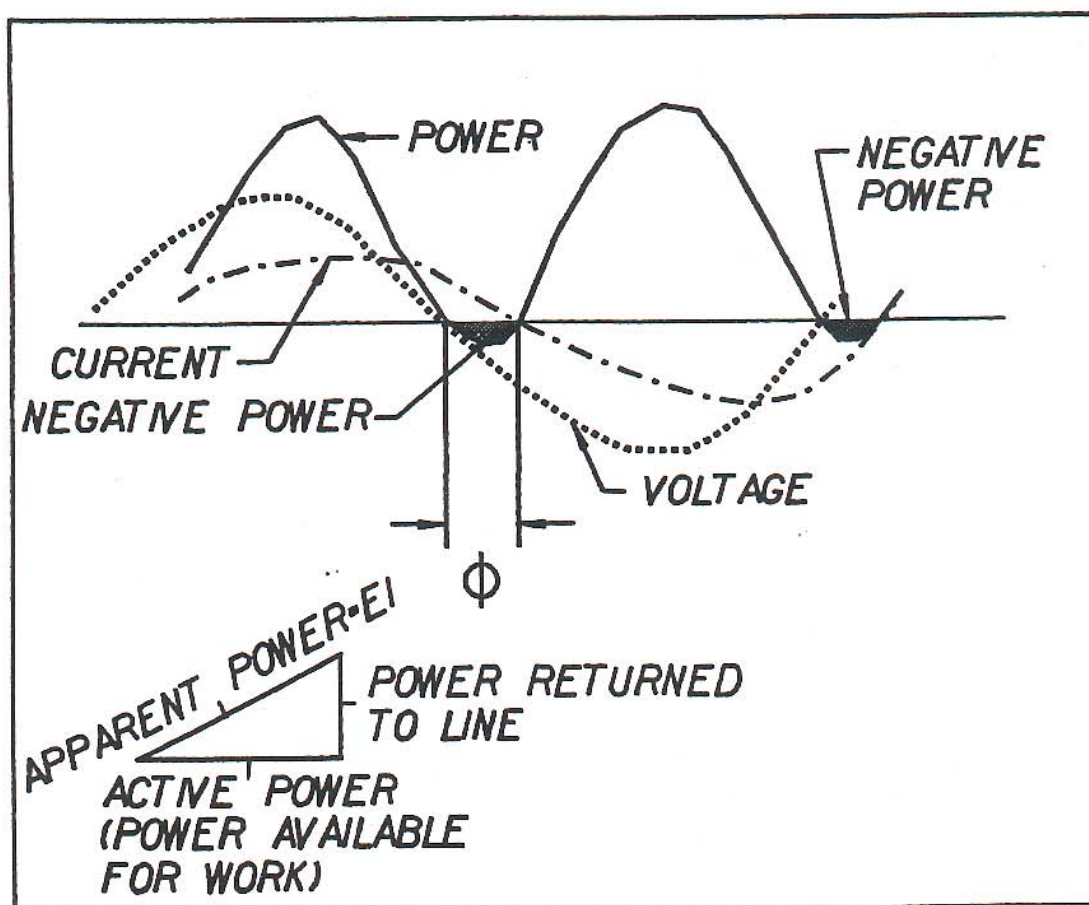
Name	First	2nd*	3rd	4th*	5th	6th*	7th	8th*	9th
Frequency	60	120	180	240	300	360	420	480	540
Sequence	+	-	0	+	-	0	+	-	0

\* Even harmonics disappear when waves are symmetrical.

Sequence	Rotation	Effects (From skin effects, eddy currents, etc...)
Positive	Forward	Heating of Conductors and Breakers, etc.
Negative	Reverse	Heating as above + Motor problems
Zero	None	Heating + add on Neutral of 3-Phase, 4-wire system

Zero Sequence Harmonics and Odd Multiples of the 3rd are called "Triplens".

**Power Factor:** - Power Factor is defined as the "active" power divided by the "apparent" power.\* During the part of each cycle, when the voltage is negative but the current is positive, their product is negative. This is negative power and it is not available for work. It is actually the power returned to the line.



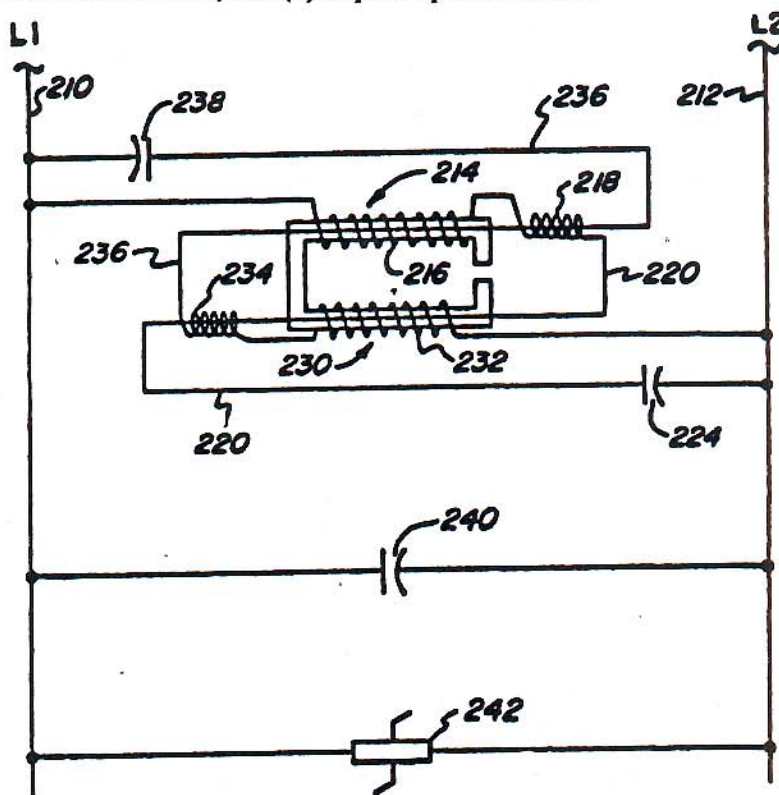
Sags and surges can be described as current and voltage fluctuations in milliseconds or more. Sags and surges are caused by severe weather - lightning, power line switching, large motors and inductive loads



turning off / on, short circuits, copiers / printers, fault / fuse clearing. Sags and surges cause data disruptions, damage to sensitive electronic devices, damage to power supplies, and total system failures. Transients are high-speed and high energy electrical noise. Transients relate to voltage or current excursions of microseconds and nanoseconds duration. Atmospheric lightning represents the most dangerous transients in transmission and distribution networks. Bolts of lightning have voltages between 500kv and 1000kv, durations between .5 and .20 microseconds and amperages 1,000 and 50,000 amps. If lightning strikes a transmission line, disturbances can travel from 10 to 20 miles within an electrical distribution system.

### DEVICE OVERVIEW

The magnetic device for power quality improvement is called "USES" unit. "USES" units are installed at electrical panels supplying inductive load or at the disconnect links for large motors, i.e. elevators, air-conditioning units, heavy-duty machinery, etc. Units are also recommended for any panel at which surge protection is a major concern.. The "USES" is a single phase or three-phase passive line conditioner that functions to (a) reduce demand from the power system, (b) provide transient surge protection, (c) reduce harmonics, and (d) improve power factor.

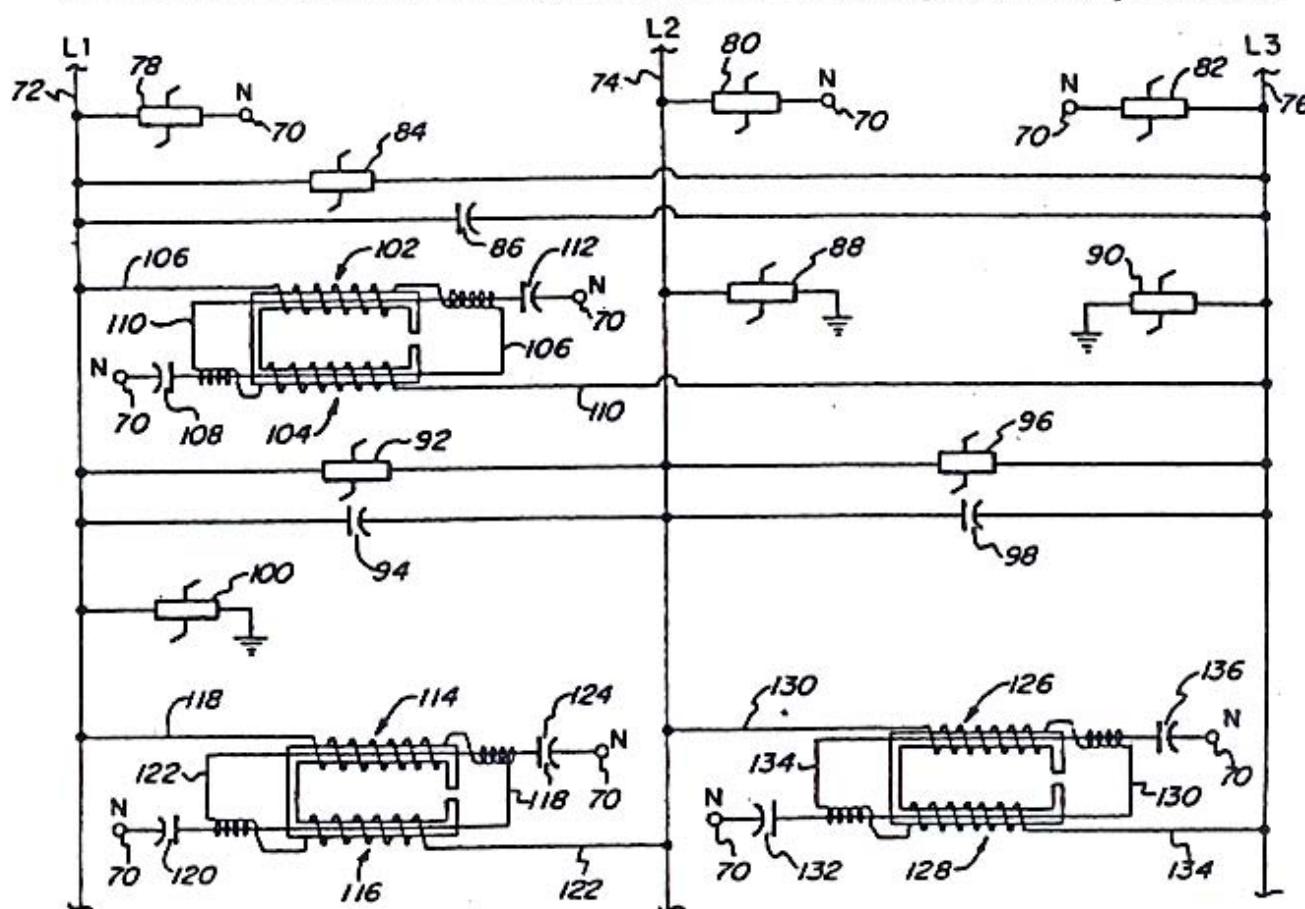


**The USES Circuit in Single Phase System**

**FIGURE 1**

In FIGURE 1, two(2) chokes designated as 214 and 230 are used. Choke 214 comprises a first winding 216 in series with second winding 218. The choke terminates in a line 220 that is passed through the windings 232, 234 of choke 230. Line 220 is coupled to a capacitor 224 and the series combination of

choke 214 and capacitor 224 is coupled across an AC power source comprising line 210 and line 212. Similarly, choke 230 with the line 236 passing through the windings of choke 214, is coupled in series with a capacitor 238. The series combination of choke 230 and capacitor 238 is coupled across AC power source. A capacitor 240 and surge suppressor 242 are also coupled across the power source.



**FIGURE 2**

A three-phase embodiment of the power conditioner is illustrated in **FIGURE 2**. Again, the power conditioner can be placed at the service panel where incoming power is received from a utility. Additional power conditioners can also be placed at or near significant loads. The power conditioner is coupled to the three(3) incoming power lines **L1, L2, L3** represented by reference numerals 72, 74, and 76, respectively, and also to neutral as represented at terminal 70. MOV devices 78, 80, and 82 provide transient suppression from each line to neutral. MOV devices 84, 92, and 96 provide transient suppression between the various power lines. MOV devices 88, 90, and 100 provide transient suppression from each respective line to ground. Capacitors 86, 94, and 98 are coupled between respective power lines to provide filtering and power factor correction.

Chokes 114 and 116 are coupled between lines 72 and 74. Choke 114 and series capacitor 120 provide a first path 118 from line 72 to neutral. Choke 116 and series capacitor 124 provide a second path 122 from line 74 to neutral.

In a similar fashion, two other pairs of chokes couple lines 74 and 76 and lines 72 and 76. The three sets of wrap-around chokes provide magnetic coupling between the three electric phases: **L1, L2** and **L3**.



Chokes 102 and 104 are coupled between lines 72 and 76. Choke 102 and series capacitor 108 provide a fifth path 106 from line 72 to neutral. Choke 104 and series capacitor 112 provide a sixth path 110 from line 76 to neutral.

## **TESTING**

The USES unit is connected to a 150 HP compressor motor, identified at Northrop Grumman, Sykesville, Maryland facility as "Chiller 2A". The motor is a 460 volt induction motor started across-the-line. The USES unit under test is Model # CMES3D480, as noted on the Installation picture on page 8.

The Chiller 2A is rated 150 HP at 460 v, with full load current (running load amperes, RLA) equal to 182A. The USES unit is connected in parallel to the 3-phase motor feed on the line side of the motor starter contactor. The USES unit has its own 30A molded case breaker for switched isolation.

The one-line diagram on page 7 shows the electrical configuration of Chiller 2A and its feed from Substation #4, 225A molded case breaker. Also shown on this one-line diagram are the connection points of both the USES and the power monitoring.

### **Motor / Compressor Data**

Manufacturer: McQuay International, Inc.

460 V, 3-phase, 60 Hz, 182 FLA (RLA), 409 LRA (Wye), 1,228 LRA (Delta), 0.882 rated power factor (FLA)

### **Power Analyzer Description**

The Power Platform PPI, manufactured by Dranetz-BMI, Inc., Edison, NJ, was used as the primary recording device for this project. The PPI, when used with the Task 8000 Task card, allows the meter to measure and record power parameters for both single phase and three phase systems. These parameters include : voltage, current, real power, reactive power, apparent power, power factor and voltage and current harmonics.

In conjunction with the PPI, two(2) other power meters were used as comparable data measurements. These were the ACE 2000, manufactured by CPM, Inc., Toronto, Canada, and the Fluke 41B. Data from these units are not included in this report; however, verification of recorded parameters of these units compared very closely with the Dranetz PPI data.

### **Test Procedure**

The overall purpose of this testing was to measure and record power parameters of Chiller 2A under various load conditions both with and without the USES unit connected to the feeder. The power analyzer (PPI) was connected to the load side of the 225A feeder breaker. Power measurements were recorded by manual initiation as opposed to threshold triggering during specific loading conditions and USES operation. For instance, with Chiller 2A running at 100% RLA, and the USES unit breaker closed, measurements were initiated. At the same loading, the USES breaker was opened, and a new set of measurements was recorded. Load was changed on the chiller by varying the programmable chilled

water temperature point. This adjustment allowed for a load range from 100% to 50% RLA. Consequently, power measurements were recorded under 100%, 90%, 75% and 50% load conditions for the USES connected and disconnected to the feeder.

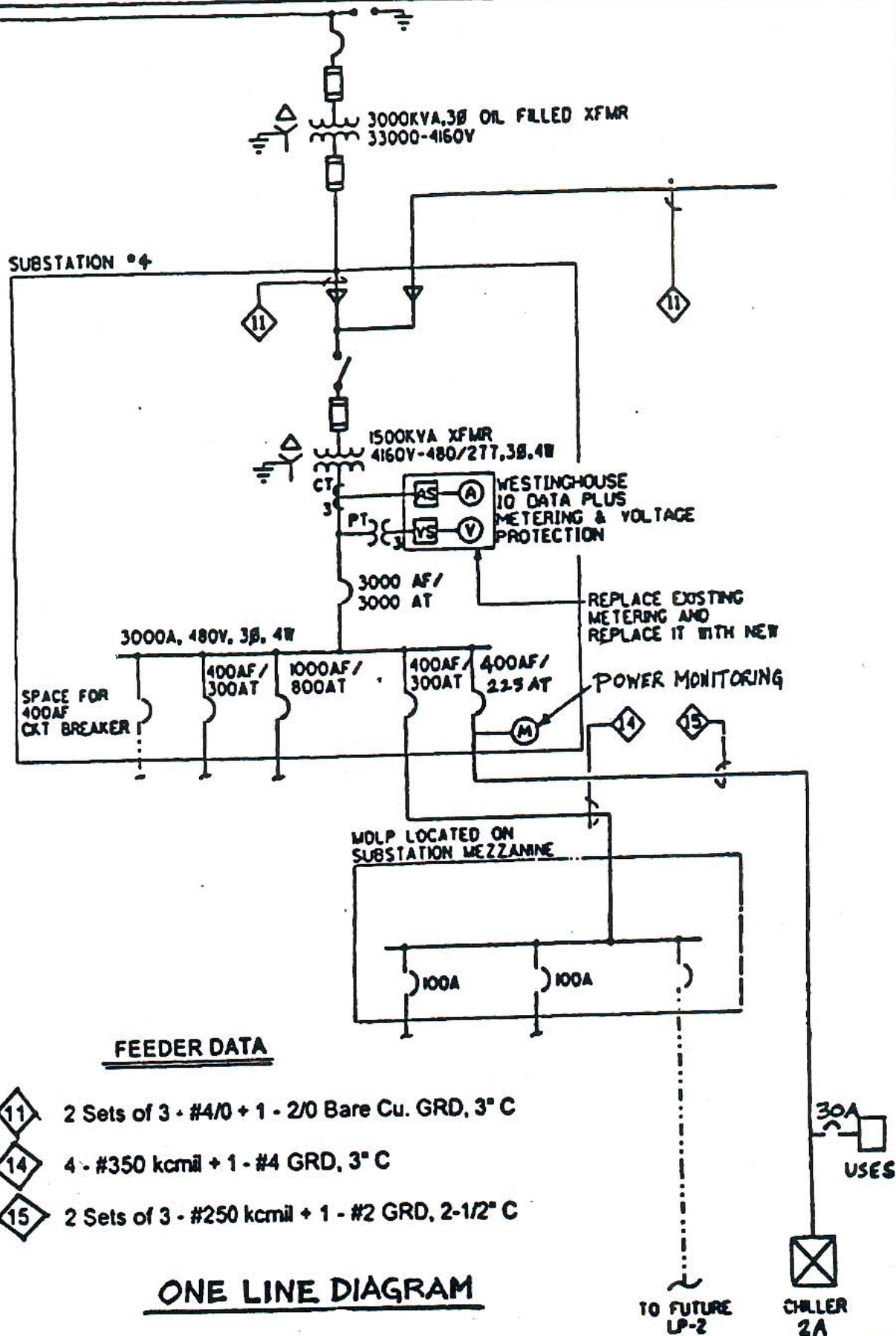
### Test Results

Pointed results from the PPI recorded measurements are provided on pages 10 through 13 for 75% loading. These data sheets contain power measurements, voltage, current phases diagrams, sinusoidal waveforms, and harmonic data. For ease of comparison, these measurements are summarized in the Data Summary Table below for each load condition and with the USES unit switched on and off.

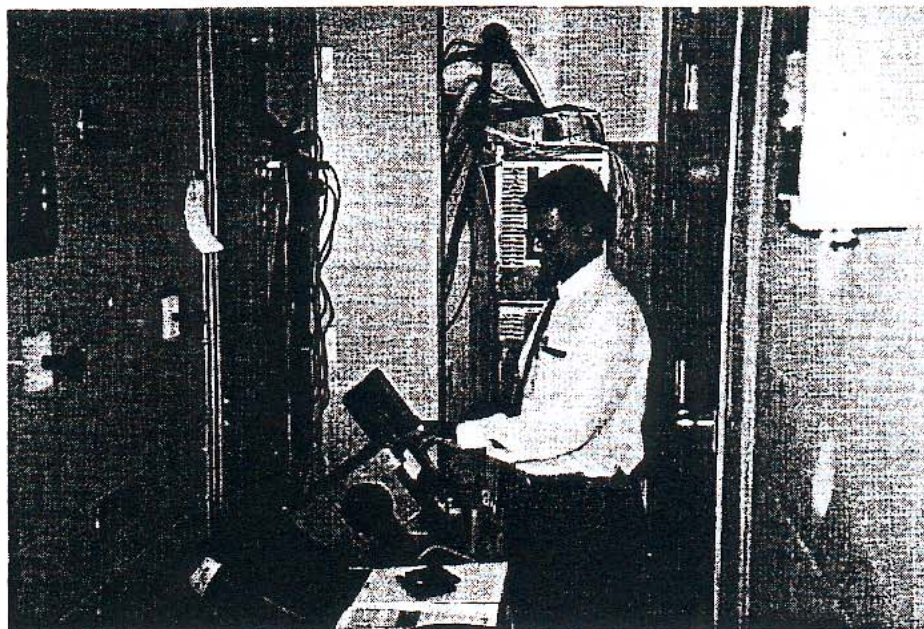
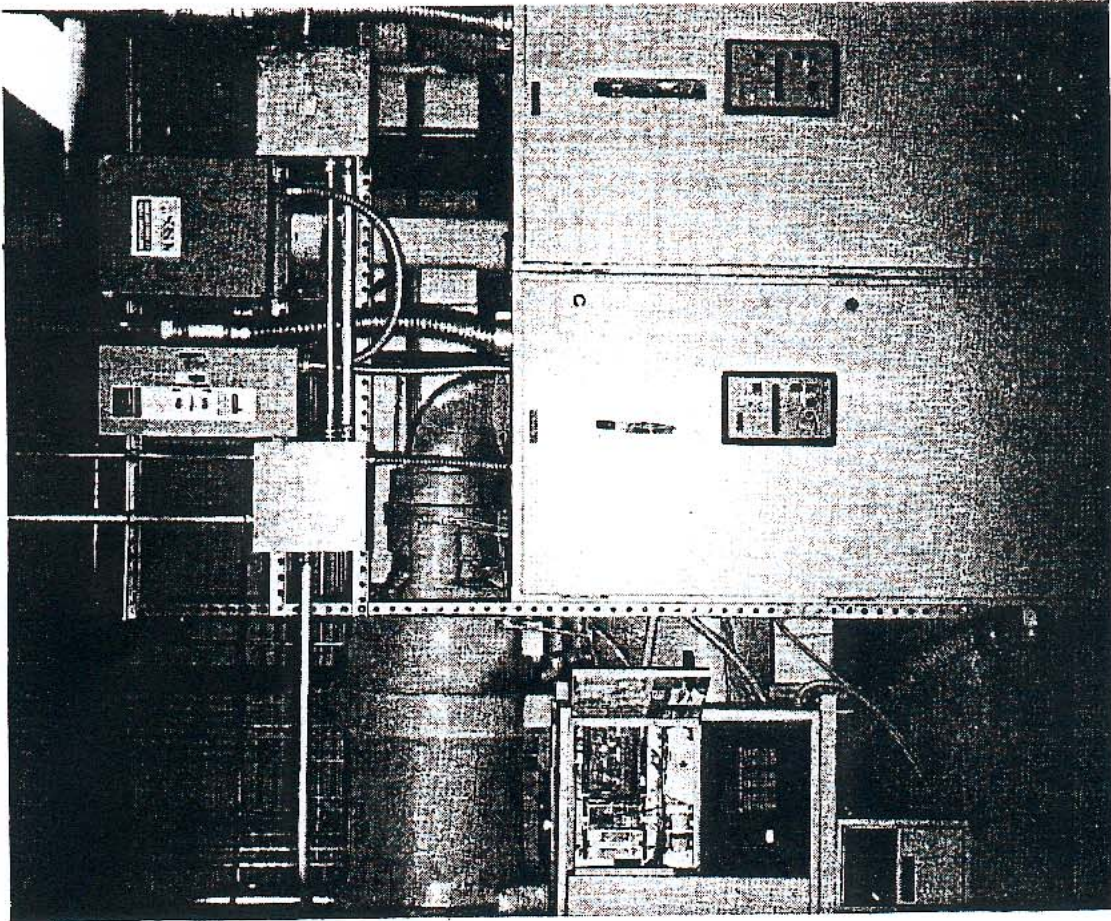
**DATA SUMMARY TABLE**

	100% RLA		90% RLA		75% RLA		50% RLA	
	ON	OFF	ON	OFF	ON	OFF	ON	OFF
$V_{LL}$	495.3	495.5	497.2	495.8	496.1	497.3	497.9	495.8
Abs.Chg.	-0.2		1.4		-1.2		2.1	
$I_L$	170.6	188.6	143.1	162.4	115.4	131.2	69.9	93.2
% Chg.	-9.5%		-11.9%		-12.0%		-25.0%	
PF	0.998	0.996	1.000	0.991	0.997	0.968	0.915	0.836
% Chg.	0.20%		0.90%		2.90%		7.90%	
kW	84.3	93.1	71.1	79.8	57.1	63.1	31.8	38.6
% Chg.	-9.5%		-10.9%		-9.5%		-17.6%	
kVARS	-5.1	8.1	0.6	10.9	4.1	16.3	14.1	25.4
% Chg.	-163.0%		-94.5%		-74.8%		-44.5%	
kVA	84.5	93.5	71.0	80.5	57.2	65.2	34.8	46.2
% Chg.	-9.6%		-11.8%		-12.3%		-24.7%	
$V_{THD}$	1.965	1.949	2.084	1.932	2.026	1.965	2.119	2.033
% Chg.	0.8%		7.9%		3.1%		4.2%	
$I_{THD}$	1.938	2.844	2.372	3.310	2.884	4.206	3.990	4.911
% Chg.	-31.9%		-28.3%		-31.4%		-18.8%	











# 75% RLA - USES ON

# 75% RLA - USES OFF

DRANETZ PPI-8000 N-G 2R									
ALL CHANNELS SUMMARY REPORT									
		14:25:46 Apr-08-99		14:33:39 Apr-08-99					
		f= 60.00hz (A )		f= 59.99hz (A )					
		--ABC--		--ABC--					
		--O--		--O--					
		--C--		--C--					
		--B--		--B--					
		--A--		--A--					
U	495.6	497.0	495.8	496.1	498.6	496.8	496.8	497.3	
I	111.7	115.5	118.9	126.3	132.0	135.2	135.2	139.5	
W	55.27k	57.10k	58.84k	60.99k	63.09k	65.34k	65.34k	189.4k	
PF	0.998	0.995	0.998	0.997	0.959	0.973	0.973	0.968	
VAR	3.186k	3.38k	3.584k	62.72k	65.79k	67.15k	67.15k	195.6k	
UCF	1.401	1.396	1.394	14.65k	18.64k	15.49k	15.49k	48.79k	
ICF	1.448	1.447	1.418	1.398	1.396	1.394	1.394		
Uthd	2.026	1.865	1.885	1.965	1.825	1.853	1.853		
Uthf	2.884	2.792	2.845	4.206	3.934	3.841	3.841		
Utlf	7.235k	7.844k	5.980k	4.115k	4.182k	3.906k	3.906k		
TDF	5.806k	7.384k	6.415k	2.056k	1.958k	2.115k	2.115k		
DPF	0.997	0.996	0.997	0.997	0.997	0.997	0.997		
PH U	0.999	0.996	0.999	0.974	0.960	0.974	0.974		
		859.6		861.8		862.1			
		859.8		861.8		862.1			
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		858.5		861.8		862.1			



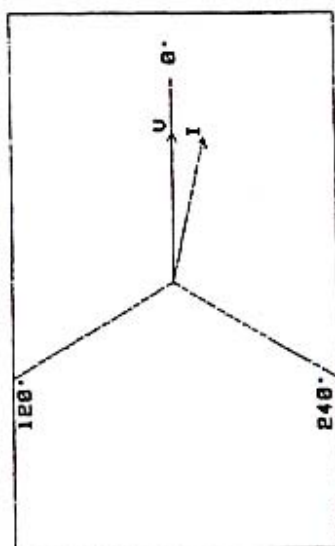
# 75% RLA - USES OFF

14:34:28 Apr-08-99

DRANETZ PPI-8000 N-G 2R

PHASOR: A

VOLTAGE:  
497 ± 888°  
CURRENT:  
126 ± 345°

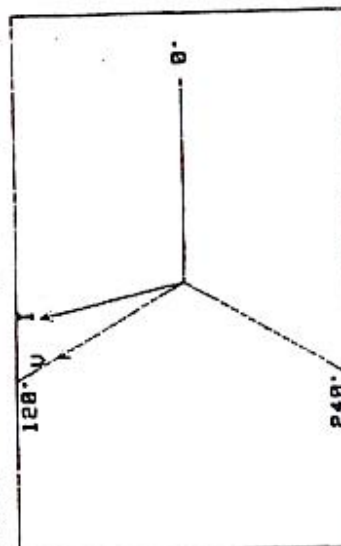


14:34:33 Apr-08-99

DRANETZ PPI-8000 N-G 2R

PHASOR: B

VOLTAGE:  
499 ± 120°  
CURRENT:  
132 ± 183°

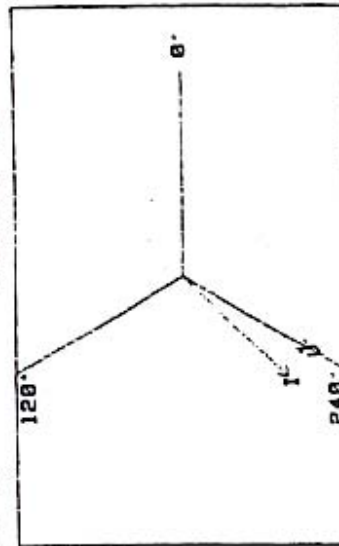


14:34:37 Apr-08-99

DRANETZ PPI-8000 N-G 2R

PHASOR: C

VOLTAGE:  
497 ± 240°  
CURRENT:  
135 ± 227°



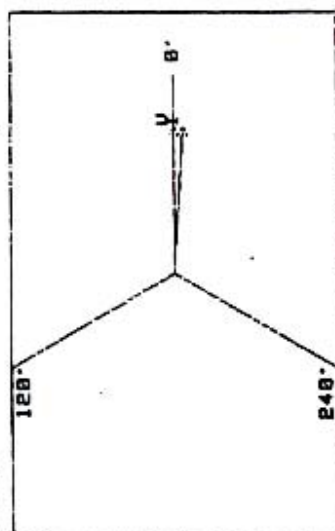
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14:27:58 Apr-08-99

DRANETZ PPI-8000 N-G 2R

PHASOR: A

VOLTAGE:  
497 ± 888°  
CURRENT:  
186 ± 356°

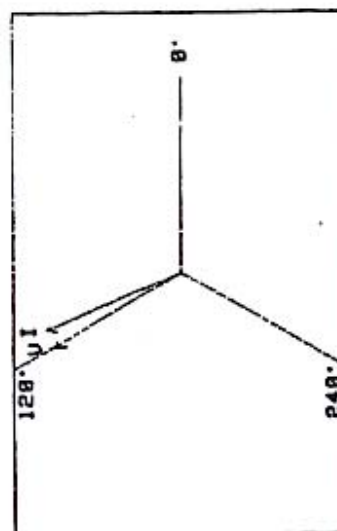


14:28:05 Apr-08-99

DRANETZ PPI-8000 N-G 2R

PHASOR: B

VOLTAGE:  
498 ± 120°  
CURRENT:  
111 ± 113°

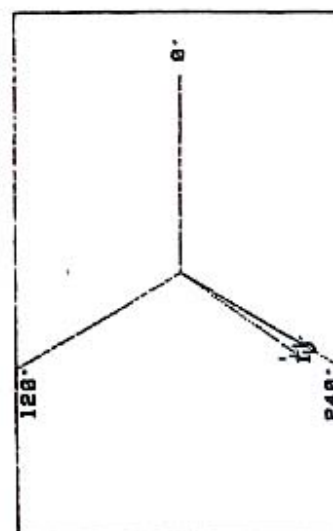


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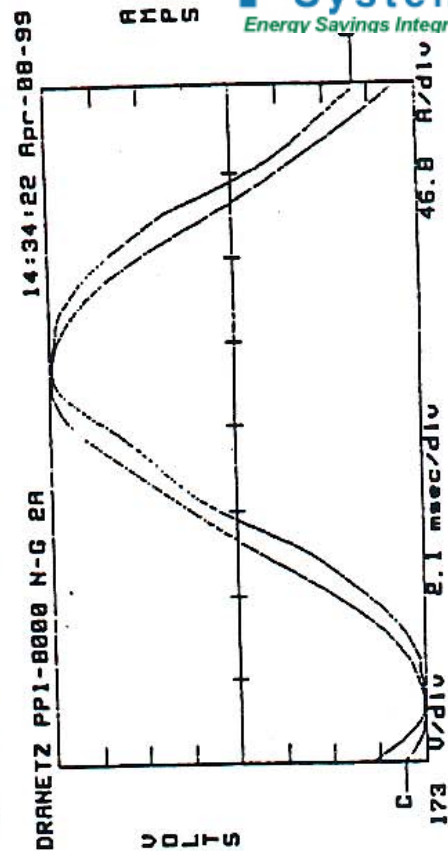
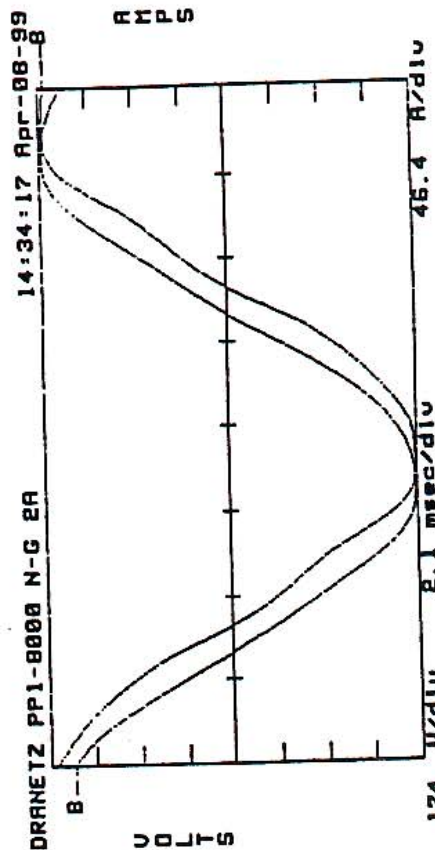
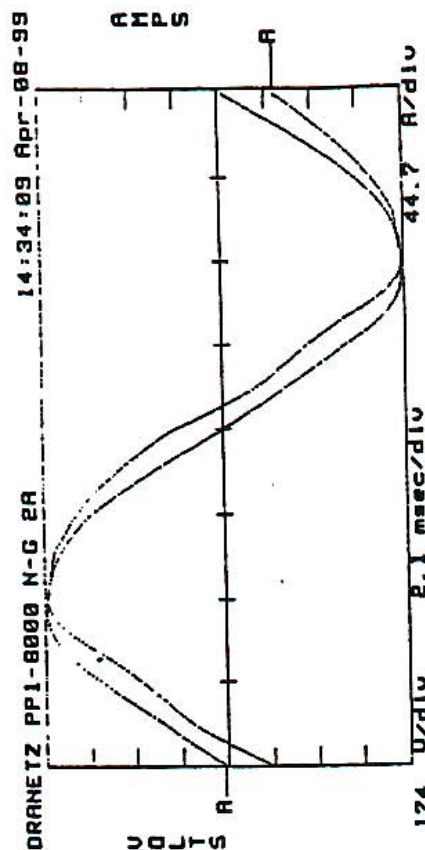
DRANETZ PPI-8000 N-G 2R

PHASOR: C

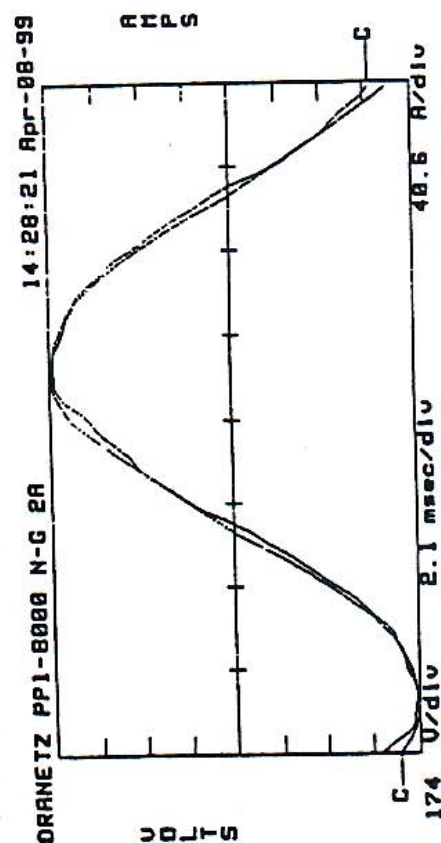
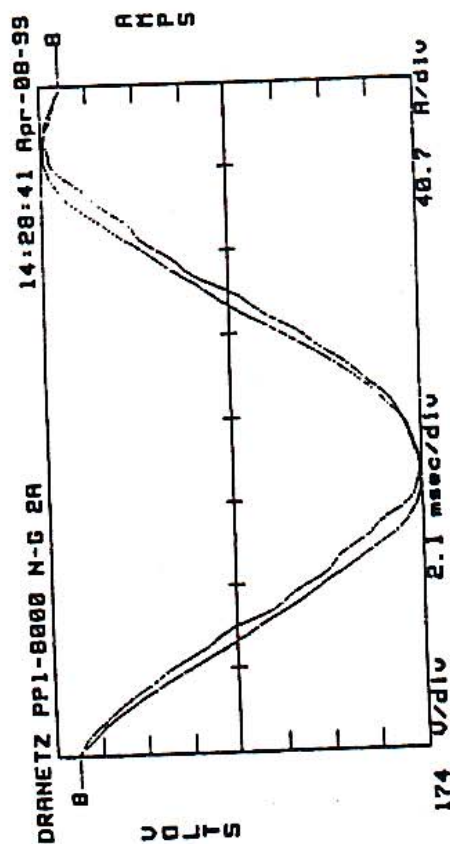
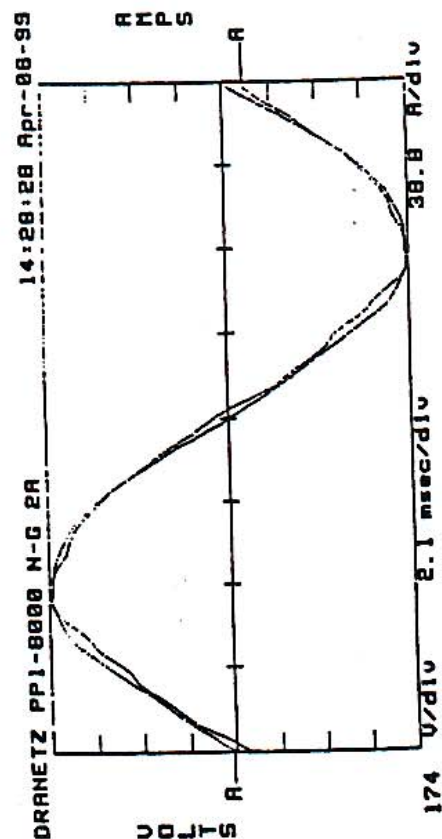
VOLTAGE:  
497 ± 240°  
CURRENT:  
114 ± 236°



# 75% RLA - USES OFF



# 75% RLA - USES ON





75% RLA - USES OFF

75% RLA - USES ON

DRANETZ PPI-8000 N-G 2A									
HARMONICS:CH A									
APR-88-99 14:35:41									
126.0 A, 60.0Hz									
XFUND	ITHD	PHS	MAGX	H#	MAGX	PHS	H#	MAGX	PHS
02	0.142	263	0.057	36	0.000	077	36	0.000	169
03	0.091	123	0.000	37	0.000	255	37	0.000	336
04	0.057	082	0.000	38	0.000	243	38	0.000	215
05	0.028	028	0.000	39	0.000	063	39	0.000	207
06	0.014	012	0.000	40	0.000	126	40	0.000	015
07	0.007	006	0.000	41	0.000	303	41	0.000	053
08	0.003	003	0.000	42	0.000	020	42	0.000	147
09	0.001	001	0.000	43	0.000	286	43	0.000	039
10	0.000	000	0.000	44	0.000	156	44	0.000	170
11	0.000	000	0.000	45	0.000	359	45	0.000	106
12	0.000	000	0.000	46	0.000	192	46	0.000	063
13	0.000	000	0.000	47	0.000	196	47	0.000	212
14	0.000	000	0.000	48	0.000	358	48	0.000	032
15	0.000	000	0.000	49	0.000	130	49	0.000	344
16	0.000	000	0.000	50	0.000	219			
17	0.000	000	0.000			061			
18	0.000	000	0.000						

DRANETZ PPI-8000 N-G 2A									
HARMONICS:CH B									
APR-88-99 14:35:47									
133.4 A, 60.0Hz									
XFUND	ITHD	PHS	MAGX	H#	MAGX	PHS	H#	MAGX	PHS
02	0.108	216	0.108	36	0.000	125	36	0.000	304
03	0.069	113	0.000	37	0.000	302	37	0.000	094
04	0.043	061	0.000	38	0.000	196	38	0.000	023
05	0.022	030	0.000	39	0.000	193	39	0.000	092
06	0.011	015	0.000	40	0.000	170	40	0.000	339
07	0.005	007	0.000	41	0.000	314	41	0.000	170
08	0.002	003	0.000	42	0.000	097	42	0.000	289
09	0.001	001	0.000	43	0.000	021	43	0.000	042
10	0.000	000	0.000	44	0.000	221	44	0.000	150
11	0.000	000	0.000	45	0.000	127	45	0.000	356
12	0.000	000	0.000	46	0.000	147	46	0.000	029
13	0.000	000	0.000	47	0.000	209	47	0.000	279
14	0.000	000	0.000	48	0.000	053	48	0.000	334
15	0.000	000	0.000	49	0.000	159	49	0.000	168
16	0.000	000	0.000	50	0.000	215			
17	0.000	000	0.000			169			
18	0.000	000	0.000			230			

DRANETZ PPI-8000 N-G 2A									
HARMONICS:CH C									
APR-88-99 14:35:52									
135.9 A, 60.0Hz									
XFUND	ITHD	PHS	MAGX	H#	MAGX	PHS	H#	MAGX	PHS
02	0.080	160	0.106	36	0.000	076	36	0.000	070
03	0.053	107	0.000	37	0.000	243	37	0.000	286
04	0.034	068	0.000	38	0.000	020	38	0.000	210
05	0.017	034	0.000	39	0.000	100	39	0.000	009
06	0.008	016	0.000	40	0.000	127	40	0.000	006
07	0.004	008	0.000	41	0.000	025	41	0.000	109
08	0.002	004	0.000	42	0.000	271	42	0.000	273
09	0.001	002	0.000	43	0.000	141	43	0.000	186
10	0.000	001	0.000	44	0.000	102	44	0.000	051
11	0.000	000	0.000	45	0.000	280	45	0.000	009
12	0.000	000	0.000	46	0.000	356	46	0.000	167
13	0.000	000	0.000	47	0.000	273	47	0.000	000
14	0.000	000	0.000	48	0.000	071	48	0.000	165
15	0.000	000	0.000	49	0.000	101			
16	0.000	000	0.000	50	0.000				
17	0.000	000	0.000						
18	0.000	000	0.000						

DRANETZ PPI-8000 N-G 2A									
HARMONICS:CH A									
APR-88-99 14:29:22									
109.4 A, 60.0Hz									
XFUND	ITHD	PHS	MAGX	H#	MAGX	PHS	H#	MAGX	PHS
02	0.155	310	0.264	36	0.000	046	36	0.000	087
03	0.095	185	0.033	37	0.000	166	37	0.000	268
04	0.056	113	0.000	38	0.000	109	38	0.000	214
05	0.028	057	0.000	39	0.000	058	39	0.000	058
06	0.014	028	0.000	40	0.000	012	40	0.000	012
07	0.007	014	0.000	41	0.000	207	41	0.000	207
08	0.003	007	0.000	42	0.000	114	42	0.000	114
09	0.001	003	0.000	43	0.000	160	43	0.000	160
10	0.000	001	0.000	44	0.000	166	44	0.000	166
11	0.000	000	0.000	45	0.000	231	45	0.000	231
12	0.000	000	0.000	46	0.000	067	46	0.000	067
13	0.000	000	0.000	47	0.000	304	47	0.000	304
14	0.000	000	0.000	48	0.000	028	48	0.000	028
15	0.000	000	0.000	49	0.000		49	0.000	
16	0.000	000	0.000	50	0.000			0.000	
17	0.000	000	0.000						
18	0.000	000	0.000						

DRANETZ PPI-8000 N-G 2A									
HARMONICS:CH B									
APR-88-99 14:29:27									
113.8 A, 60.0Hz									
XFUND	ITHD	PHS	MAGX	H#	MAGX	PHS	H#	MAGX	PHS
02	0.252	504	0.560	36	0.000	095	36	0.000	249
03	0.154	308	0.000	37	0.000	210	37	0.000	060
04	0.093	186	0.000	38	0.000	296	38	0.000	086
05	0.046	093	0.000	39	0.000	002	39	0.000	310
06	0.023	046	0.000	40	0.000	177	40	0.000	021
07	0.011	023	0.000	41	0.000	305	41	0.000	049
08	0.005	011	0.000	42	0.000	310	42	0.000	310
09	0.002	005	0.000	43	0.000	247	43	0.000	247
10	0.001	002	0.000	44	0.000	197	44	0.000	197
11	0.000	001	0.000	45	0.000	199	45	0.000	119
12	0.000	000	0.000	46	0.000	043	46	0.000	198
13	0.000	000	0.000	47	0.000	144	47	0.000	163
14	0.000	000	0.000	48	0.000	225	48	0.000	207
15	0.000	000	0.000	49	0.000	180			
16	0.000	000	0.000	50	0.000	125			
17	0.000	000	0.000						
18	0.000	000	0.000						

DRANETZ PPI-8000 N-G 2A									
HARMONICS:CH C									
APR-88-99 14:29:33									
118.0 A, 60.0Hz									
XFUND	ITHD	PHS	MAGX	H#	MAGX	PHS	H#	MAGX	PHS
02	0.122	244	0.519	36	0.000	073	36	0.000	081
03	0.074	148	0.000	37	0.000	204	37	0.000	261
04	0.046	092	0.000	38	0.000	021	38	0.000	204
05	0.023	046	0.000	39	0.000	007	39	0.000	339
06	0.011	023	0.000	40	0.000	215	40	0.000	215
07	0.005	011	0.000	41	0.000	174	41	0.000	174
08	0.002	005	0.000	42	0.000	191	42	0.000	191
09	0.001	002	0.000	43	0.000	137	43	0.000	137
10	0.000	001	0.000	44	0.000	085	44	0.000	085
11	0.000	000	0.000	45	0.000	325	45	0.000	325
12	0.000	000	0.000	46	0.000	051	46	0.000	051
13	0.000	000	0.000	47	0.000	270	47	0.000	270
14	0.000	000	0.000	48	0.000		48	0.000	
15	0.000	000	0.000	49	0.000		49	0.000	
16	0.000	000	0.000	50	0.000			0.000	
17	0.000	000	0.000						
18	0.000	000	0.000						



## DISCUSSION OF THE DATA

To study the effects of the USES Unit over a range of motor amperage, the power parameters were recorded at four (4) load levels, 50%, 75%, 90% and 100% rated load amperage (RLA). The Data Summary Table, at all load levels, shows that the USES Unit decreases the amperage and power demand and increases the motor voltage and power factor. KVAR is reduced considerably and the amperage THD is reduced by about 30 %. The data summary predicts that the motor operation will use less power and will be cooler and smoother both mechanically and electrically. To gain insight into the USES mechanism however, we must compare the individual phase data.

For each on/off measurement condition, the average deviation of the three (3) phase amperages and voltages were calculated. The average deviations between phases with USES are uniformly smaller by 0.3 A and 0.2 V at the three upper load levels, but not at 50%. The regular pattern of convergence demonstrates that USES balances, through the magnetic chokes, the phase amperages and voltages. Within the induction motor, improved phase balance would result in more symmetrical magnetic fields and reduced eddy currents. At 50% load level where motor operation is less efficient, although USES caused greater reduction in amperage, other factors cause the phase conditions to diverge slightly. Through this phase balancing of amperage and voltage, USES would attenuate both amperage and voltage transients that appear on only one phase. The balancing would also capture and distribute energy between phases, thus making it available to 3-phase machinery. We have given the complete 3-phase data for the 75% load level. The data for the other load levels can be found in the Cutler Hammer Report.

During the testing, measurements were also made with the motor off but with USES on. Each phase drew 27 amps at 498 volts. From the 3-phase USES Circuit Diagram in Figure 2, it is apparent that the wrap-around magnetic chokes co-generate the 27 amp signals from the adjacent phases, and that each signal would be 120 degrees out-of-phase with respect to the main phase amperages. At the points of connection of the USES leads, there is vectorial addition of the 27 amp signal to the main phase amperage. In each phase, the 27 amp signal is capacitive reactive current which seeks to cancel inductive reactive current produced by the inductive loads. This cancellation causes the amperage demand reduction up line from the point of USES connection and is the mechanism for displacement power factor correction. USES is a superior method of power factor correction because only a small, out-of-phase current does the job. Traditional power factor correction capacitors, because of the large currents involved, must be located near the motors or at the service entrance where the cables are heavy-duty. Eliminating the capacitors reduces RCL resonance and other motor-related problems. Also, USES does not heat up or fail in high harmonic environments.

By comparing the harmonic data in the Summary Data Table and in the phase data tables, it is seen that with USES the current harmonic distortion, ITHD, is reduced by 30% while the VTHD is increased by 4%. The harmonic distortion is generated within the motor, and the 30% decrease in ITHD is evidence of smoother electrical and mechanical operation, which leads to higher efficiency and longer motor life. Study of the effects of USES on transient attenuation, and on ITHD and VTHD will be the goals of future testing.



## CONCLUSION

This Study provides conclusive evidence that by providing passive magnetic linkage between electrical phases, the USES Unit does reduce amperage demand and power demand for inductive loads. The USES Circuit and the Testing are precisely described. Analysis of the data in three (3) phases suggests mechanisms by which USES attenuates transients, improves displacement power factor and balances electrical phases. The USES Unit reduces inductive circuit current harmonics by 30% which suggests that the power quality is significantly improved. The other pronounced functions of harmonic distortion reduction and transient voltage suppression are to be further tested separately in the future.

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