

South Carolina Association of
Municipal Power Systems

Electrical Distribution System Harmonics

June 24, 2013

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Engineers-Consultants

30 Minutes

- Harmonics are an issue today*
- Not much of an issue 30 yr ago*

Linear System Vs

Non-Linear System



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ELECTRICAL DISTRIBUTION SYSTEM HARMONICS

7 topics

0.5

- THE THEORETICAL "LINEAR" AC ELECTRIC SYSTEM
- THE REAL WORLD "NON-LINEAR" AC ELECTRIC SYSTEM
- MATHEMATICAL EQUIVALENT "NON-LINEAR" ELECTRIC SYSTEM
- PROBLEMS CAUSED BY NON-LINEAR LOADS
- CIRCUIT ANALYSIS METHODOLOGY
- INDUSTRY STANDARDS
- SOLUTIONS TO HARMONIC PROBLEMS

7 topics



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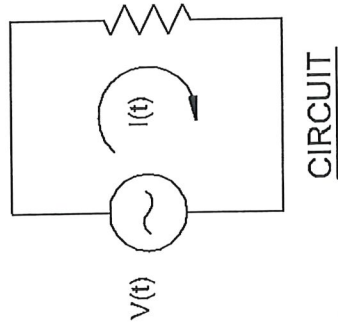
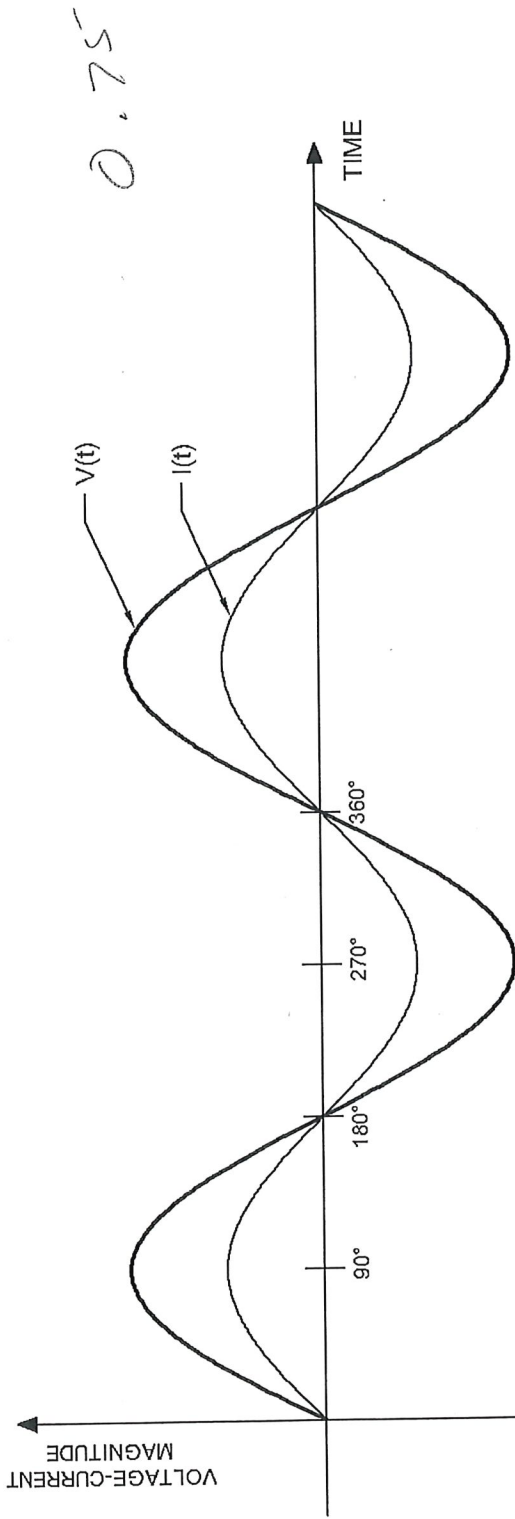
ELECTRICAL DISTRIBUTION SYSTEM HARMONICS

3- Basic Elements

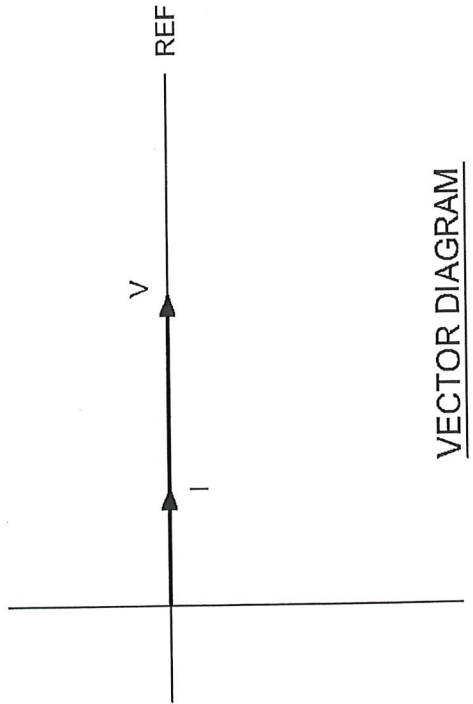
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WAVEFORM

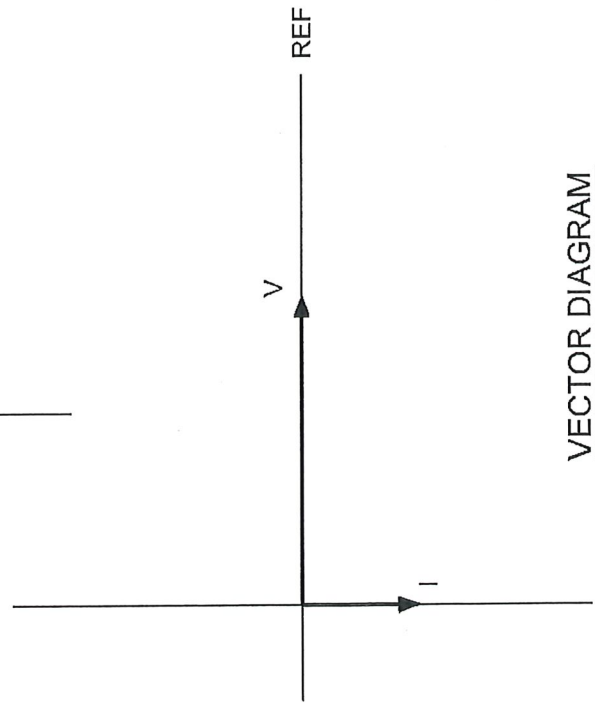
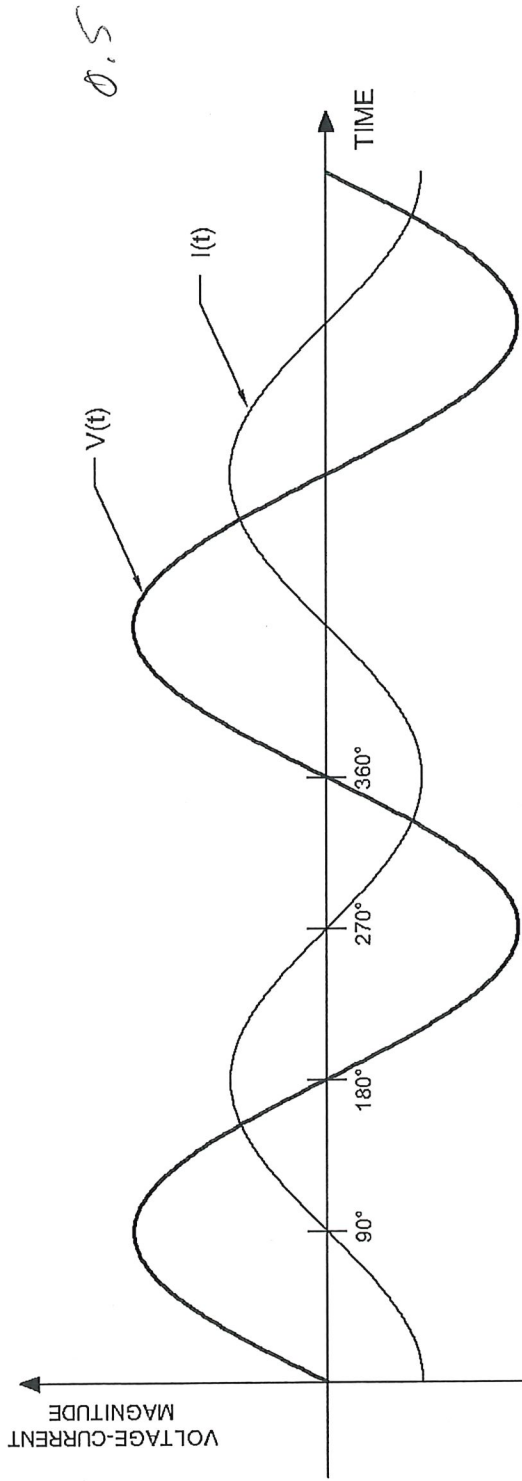


VECTOR DIAGRAM

LINEAR RESISTANCE
CURRENT FLOW
FIGURE 1

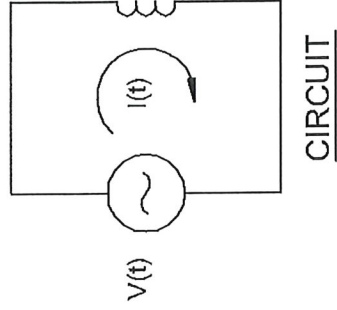


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VECTOR DIAGRAM

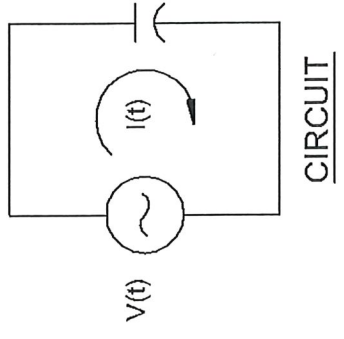
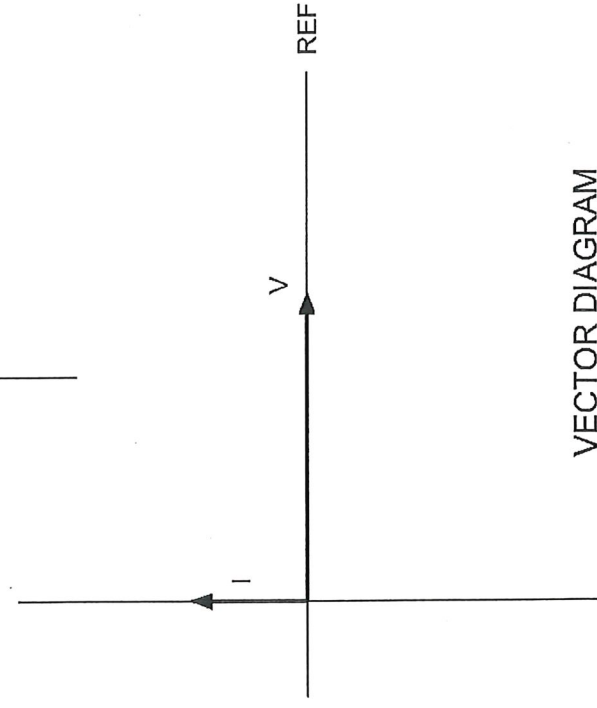
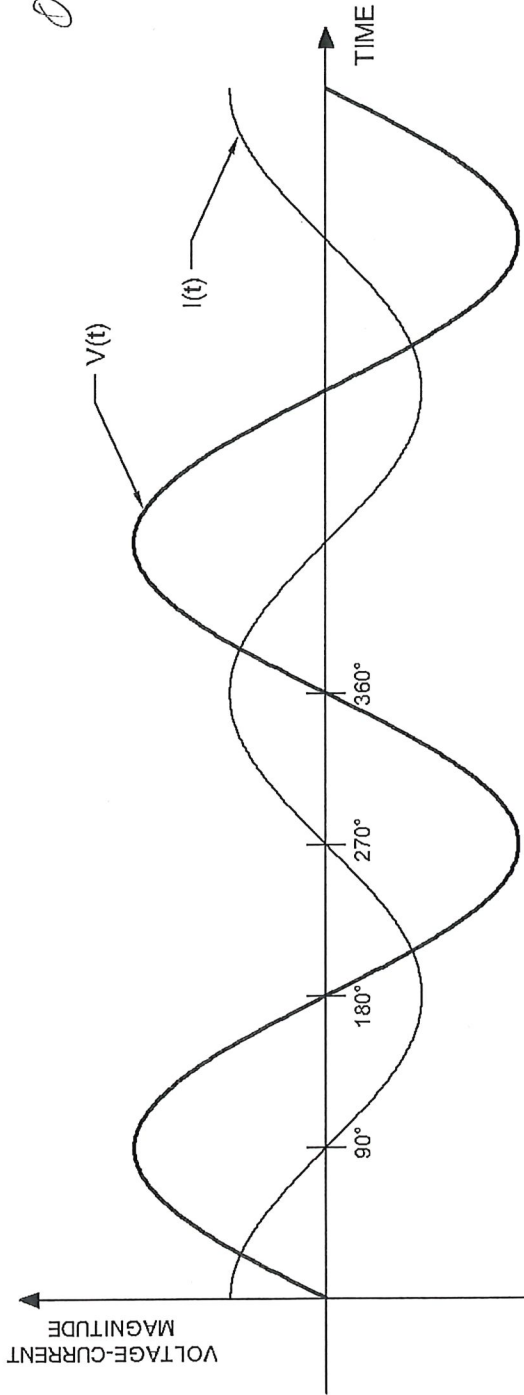
WAVEFORM



LINEAR INDUCTANCE
CURRENT FLOW
FIGURE 2



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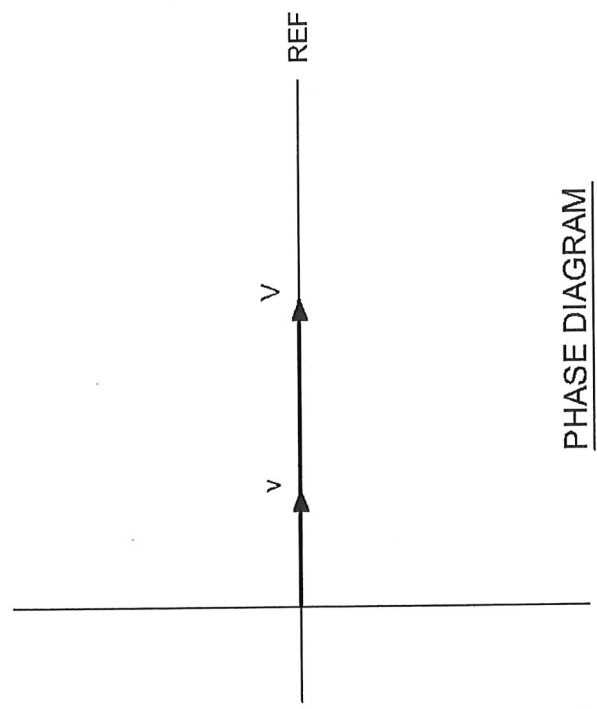
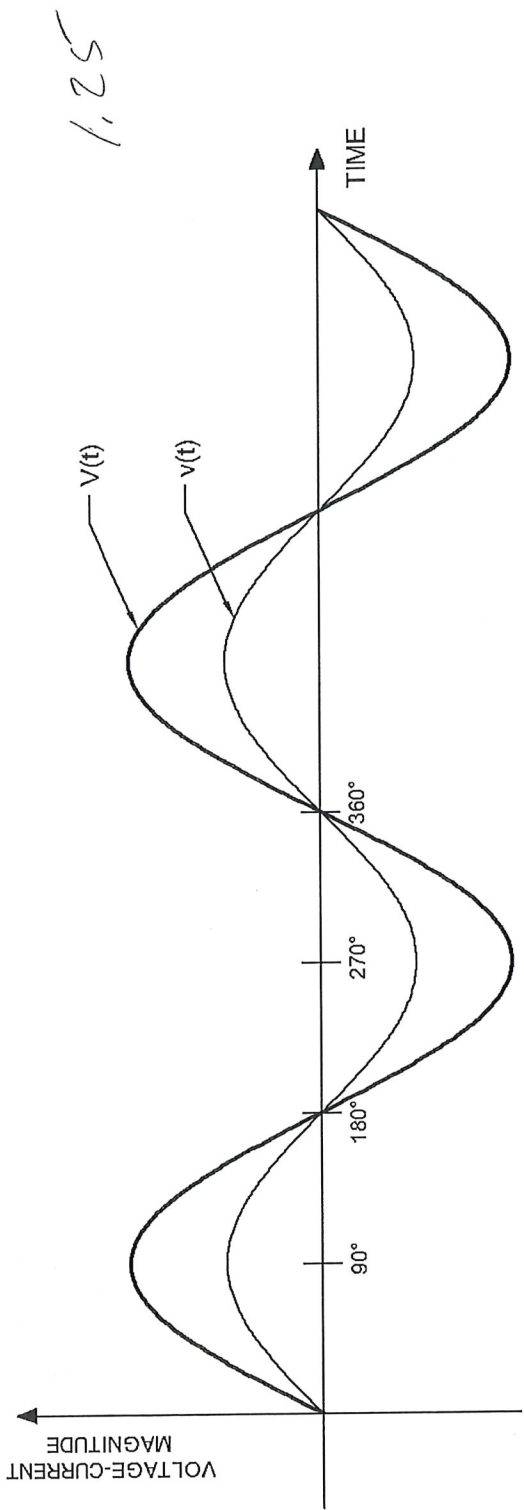
WAVEFORM

VECTOR DIAGRAM

LINEAR CAPACITANCE
CURRENT FLOW
FIGURE 3

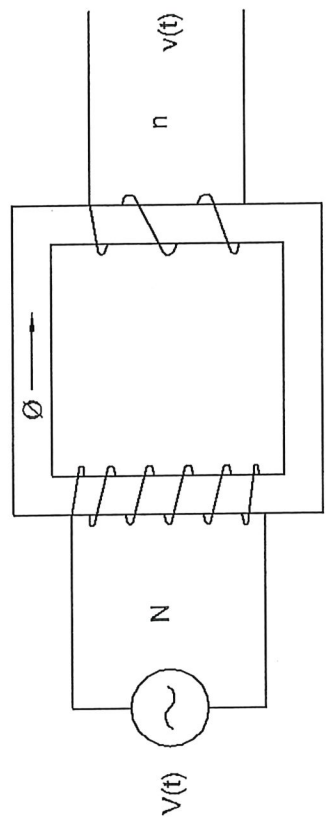


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PHASE DIAGRAM

WAVEFORM



SIMPLE TRANSFORMER

IDEAL TRANSFORMER
FIGURE 4



ELECTRICAL DISTRIBUTION SYSTEM HARMONICS

0

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R & C

still linear
the culprit

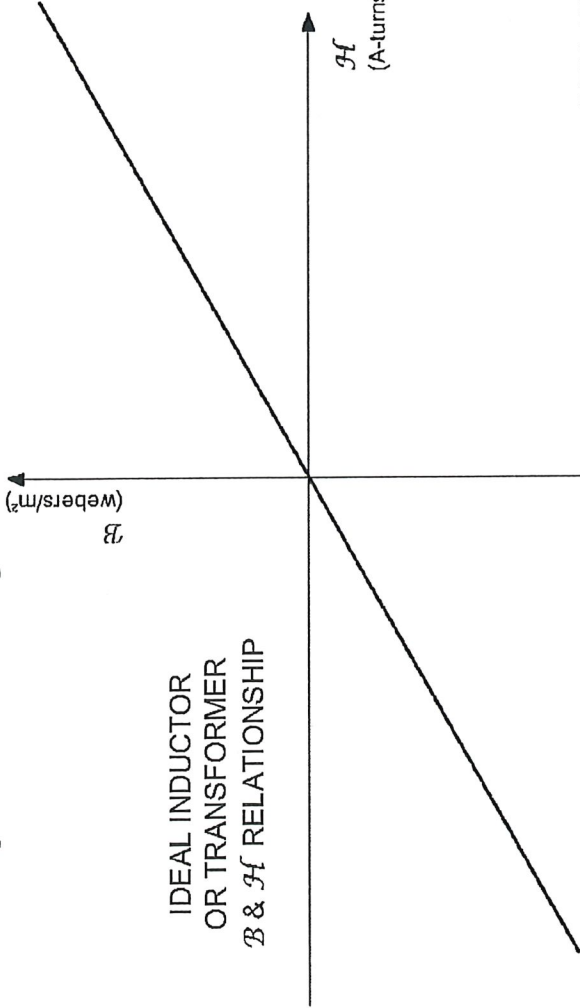
Syst voltages
non-sinusoidal



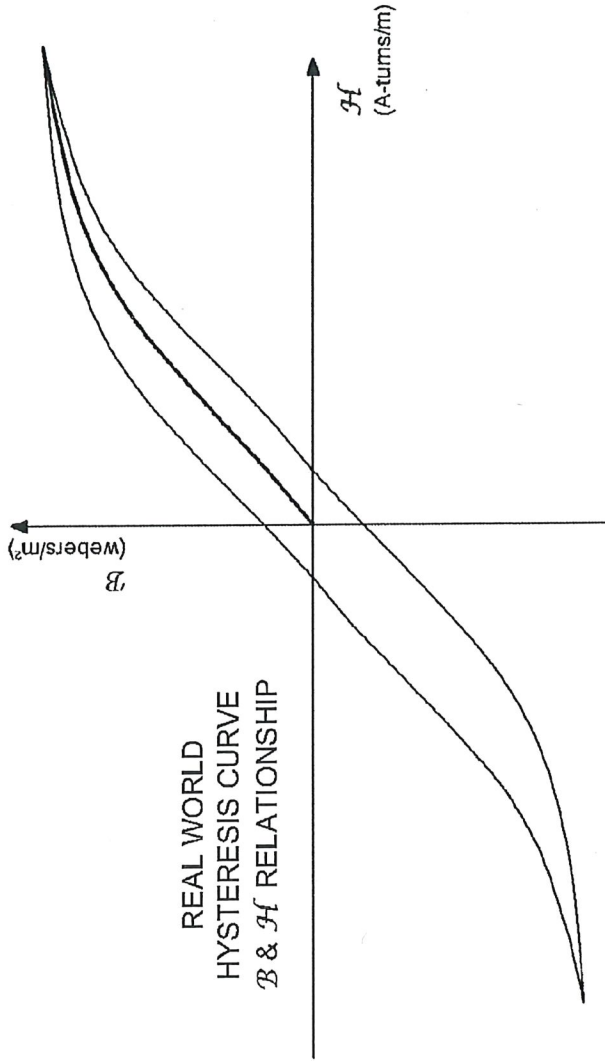
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1.25

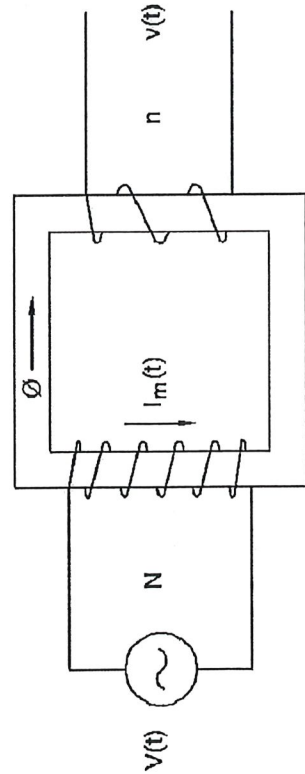
IDEAL INDUCTOR
OR TRANSFORMER
 B & \mathcal{H} RELATIONSHIP



HYSTERESIS CURVE
STEEL CORE
FIGURE 5



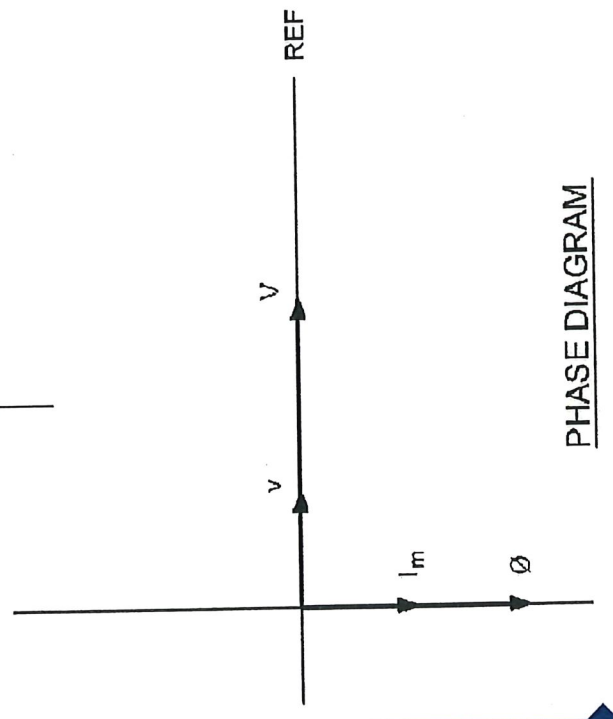
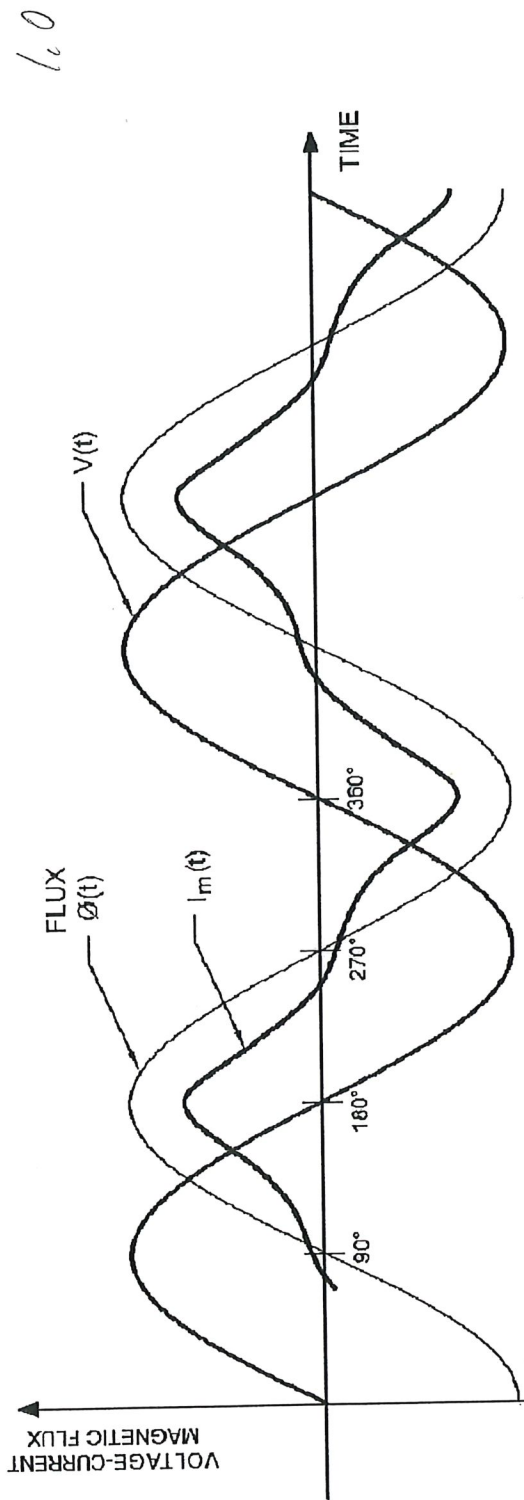
REAL WORLD
HYSTERESIS CURVE
 B & \mathcal{H} RELATIONSHIP



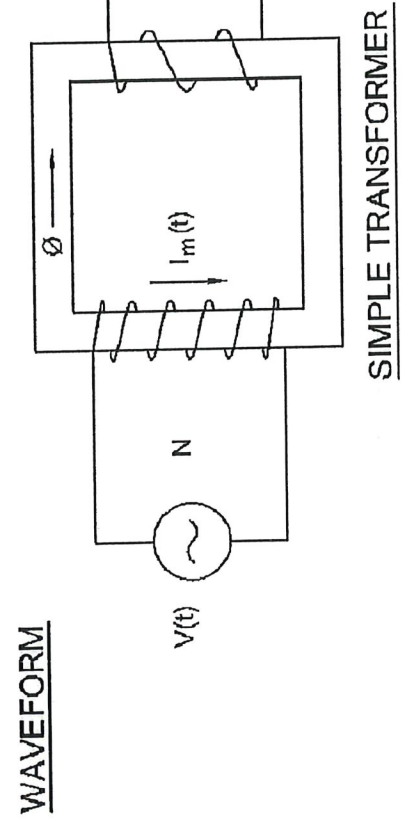
SIMPLE TRANSFORMER



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PHASE DIAGRAM

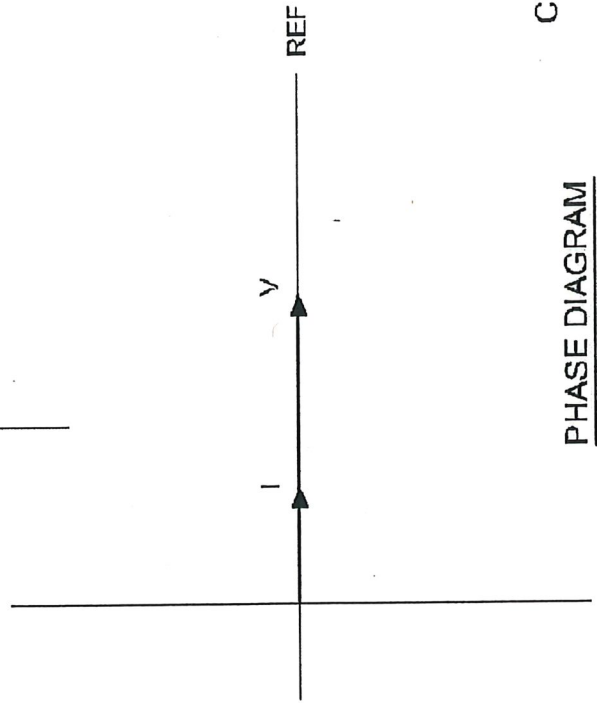
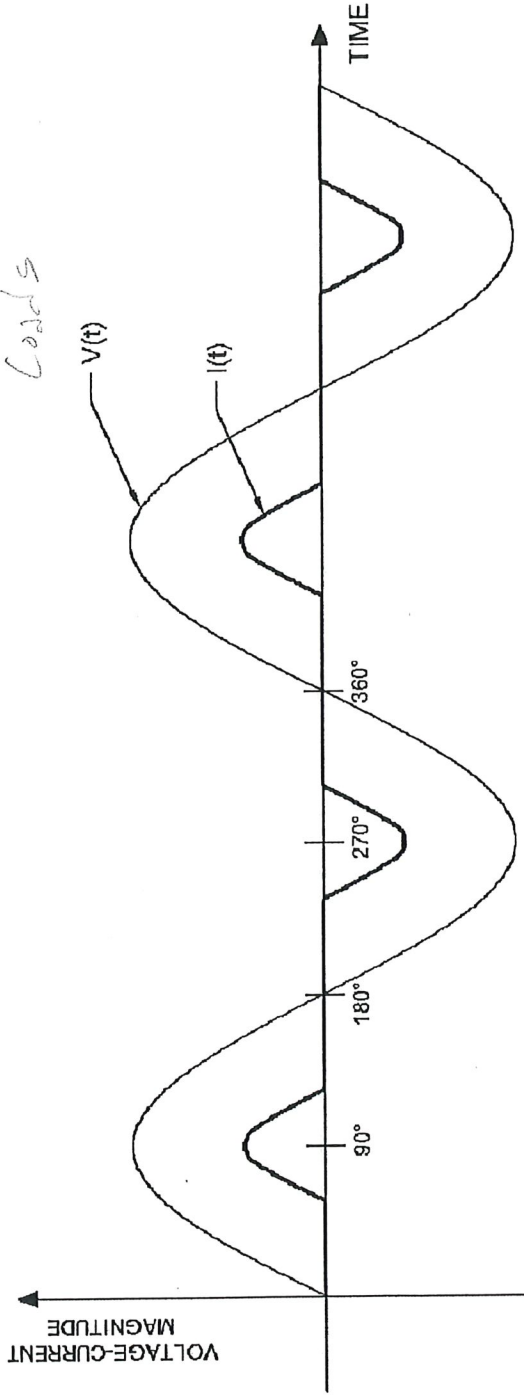


TRANSFORMER
MAGNETIZING CURRENT
FIGURE 6

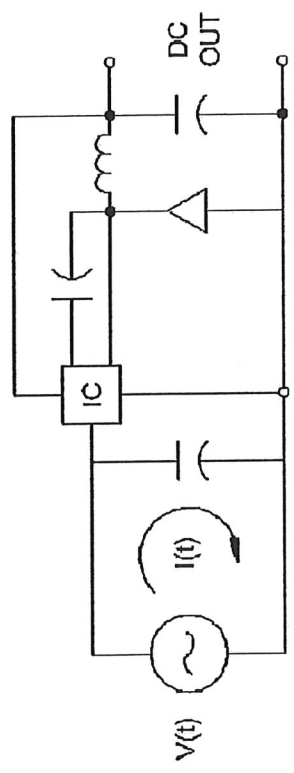


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*Non linear Customer
Loads 0.5*



WAVEFORM



CIRCUIT

COMPUTER POWER SUPPLY
FIGURE 7



PHASE DIAGRAM

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VFD WAVEFORM

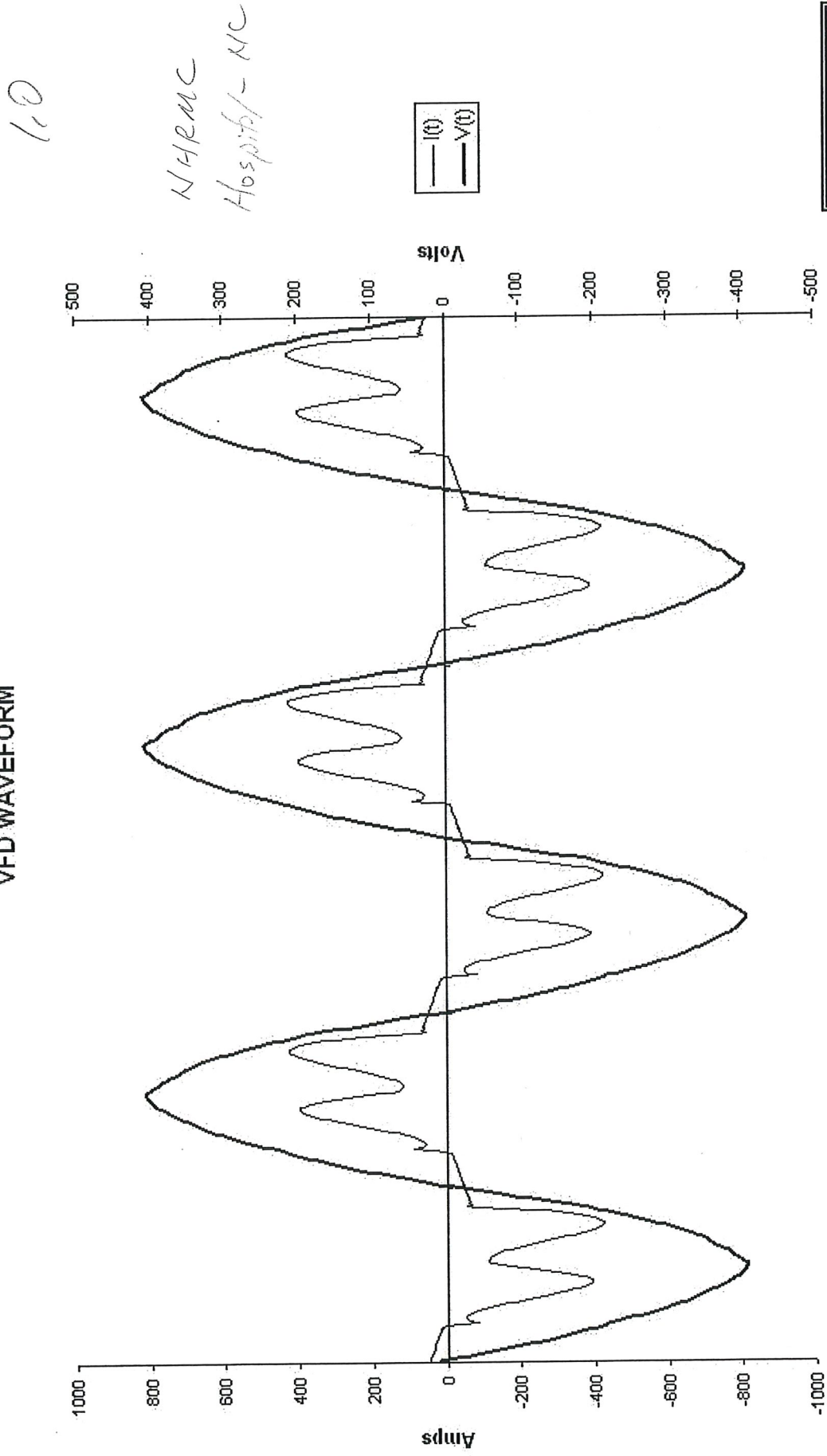


FIGURE 8



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ELECTRICAL DISTRIBUTION SYSTEM HARMONICS

©

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Fourier Series of Sinusoidal Terms Equivalent to Distorted Waveform

1.25

$$A(t) = A_0 + A_1 \sin(\omega t + \Theta_1) + A_2 \sin(2 \omega t + \Theta_2) + A_3 \sin(3 \omega t + \Theta_3) + A_4 \sin(4 \omega t + \Theta_4) + \dots$$

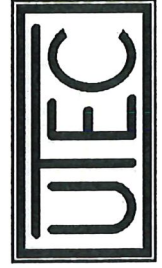
- Magnitude A
- Fundamental Frequency $\omega = 2 \cdot \pi \cdot f$
- Time t
- Phase Angle Θ

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1.0

Harmonic Order	Magnitude as % of Fundamental	Angle of Sine Terms (deg)
dc	0.0%	0.0
1	100.0%	0.4
2	0.8%	-142.1
3	0.8%	-38.6
4	0.5%	-136.7
5	25.8%	-127.1
6	0.7%	54.7
7	10.2%	30.8
8	0.4%	-166.6
9	0.2%	153.7
10	0.2%	-161.4
11	4.4%	-163.5
12	0.2%	5.9
13	2.2%	-86.4

Harmonic Order	Magnitude as % of Fundamental	Angle of Sine Terms (deg)
14	0.2%	92.7
15	0.2%	72.8
16	0.1%	143.5
17	1.5%	133.0
18	0.1%	-85.0
19	1.3%	-176.4
20	0.1%	17.0
21	0.1%	32.7
22	0.1%	78.4
23	0.8%	81.6
24	0.0%	-113.8
25	0.7%	122.6
26	0.1%	-41.8
27	0.1%	-2.5



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0.5

VFD CURRENT HARMONIC COMPONENTS

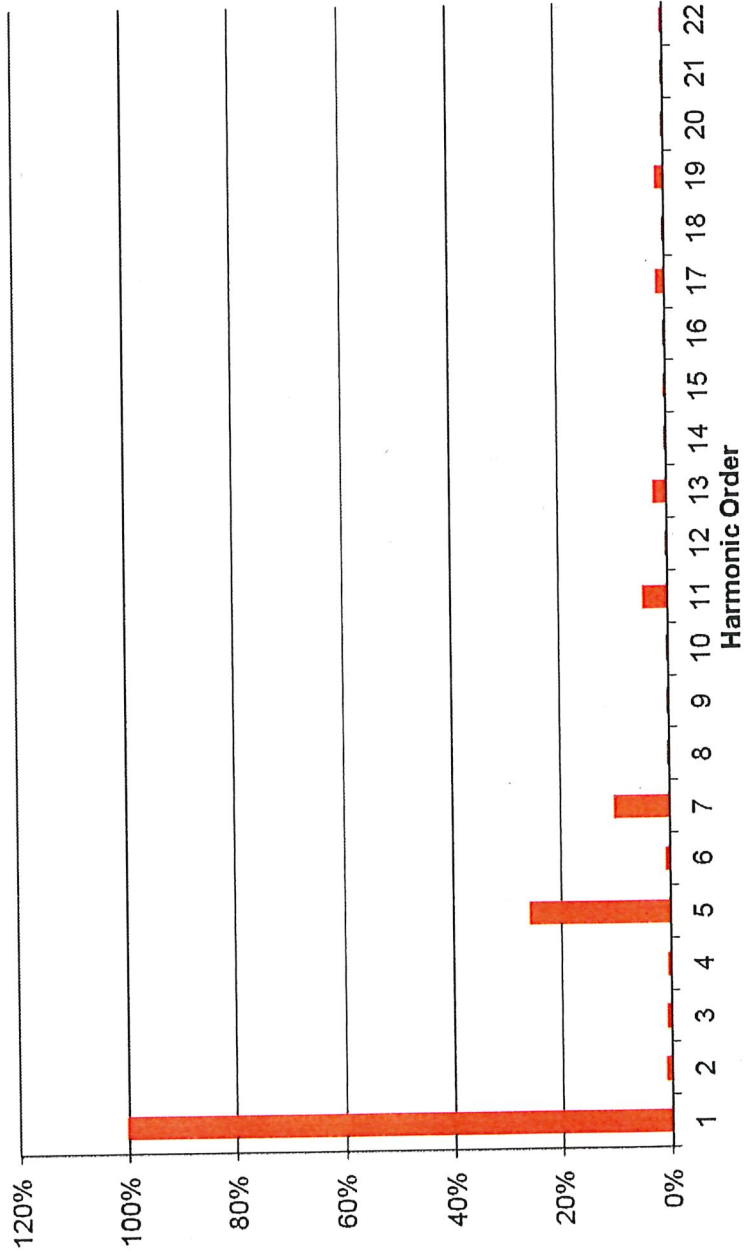
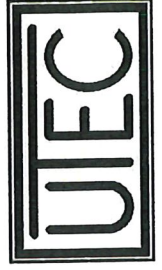
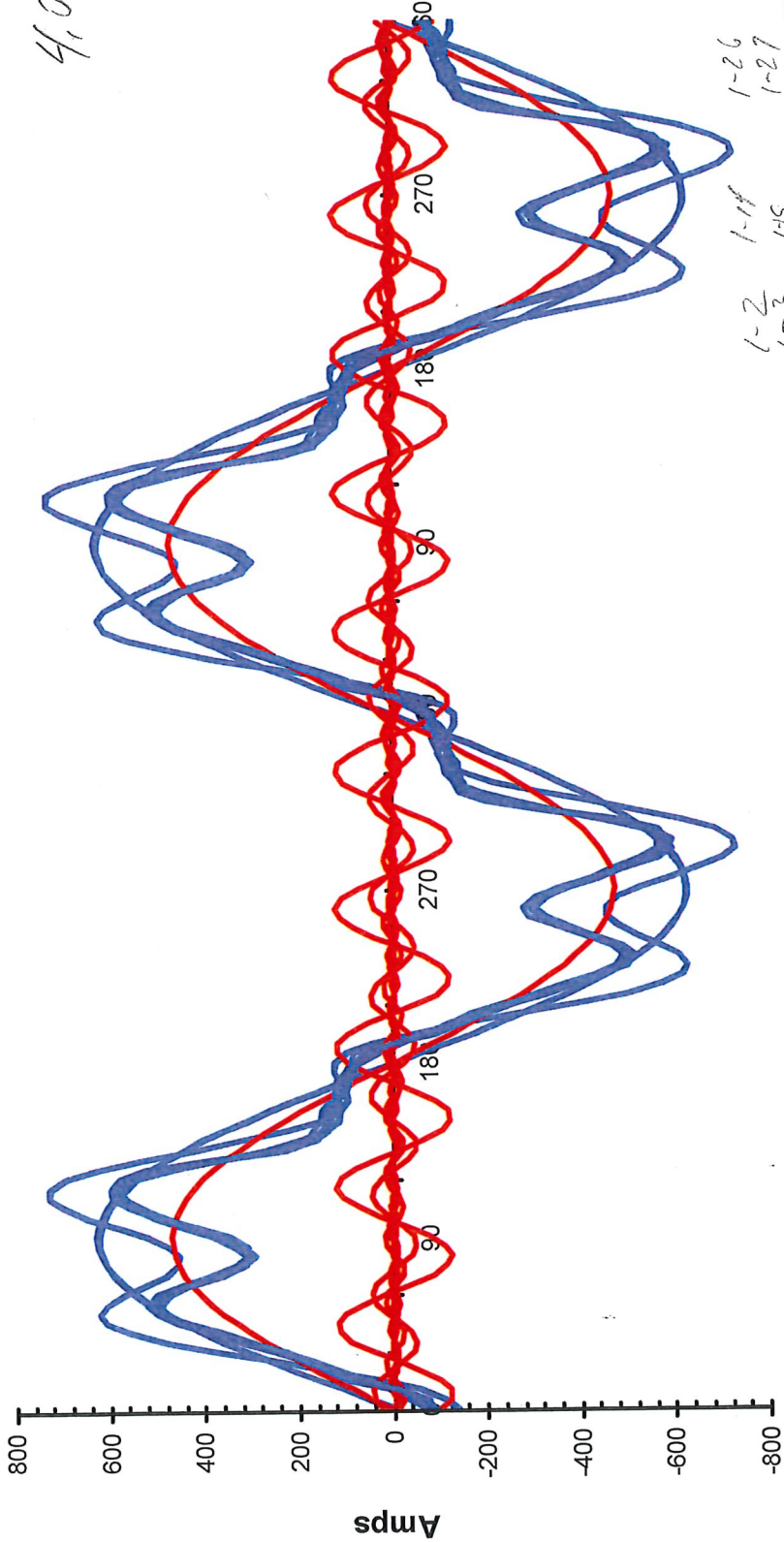


FIGURE 9



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FUNDAMENTAL CURRENT (60 Hz)



- 1-2
- 1-3
- 1-4
- 1-5
- 1-6
- 1-7
- 1-8
- 1-9
- 1-10
- 1-11
- 1-12
- 1-13
- 1-14
- 1-15
- 1-16
- 1-17
- 1-18
- 1-19
- 1-20
- 1-21
- 1-22
- 1-23
- 1-24
- 1-25





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PROBLEMS CAUSED BY NON-LINEAR LOADS

- High Neutral Current
- Equipment Overheating
- Control Equipment Malfunctioning
- Telephone Circuit Noise





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CIRCUIT ANALYSIS METHODOLOGY

1.0

$$X_L = j \omega L \text{ Ohms}$$

1	60	=	377
2	120	=	754
3	180	=	1,131
4	240	=	1,508
5	300	=	1,885
	!	=	!

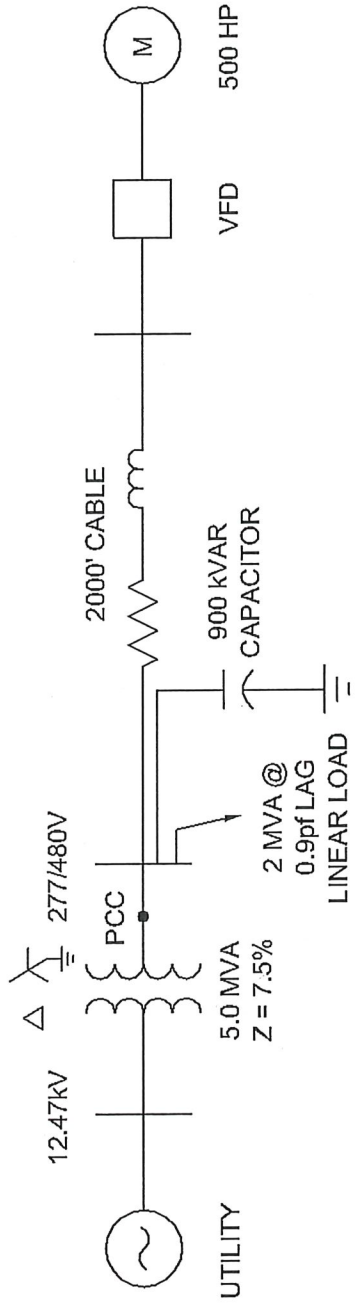
$$X_C = -j / (\omega C) \text{ Ohms}$$

27	1,620	=	10,179
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1.25



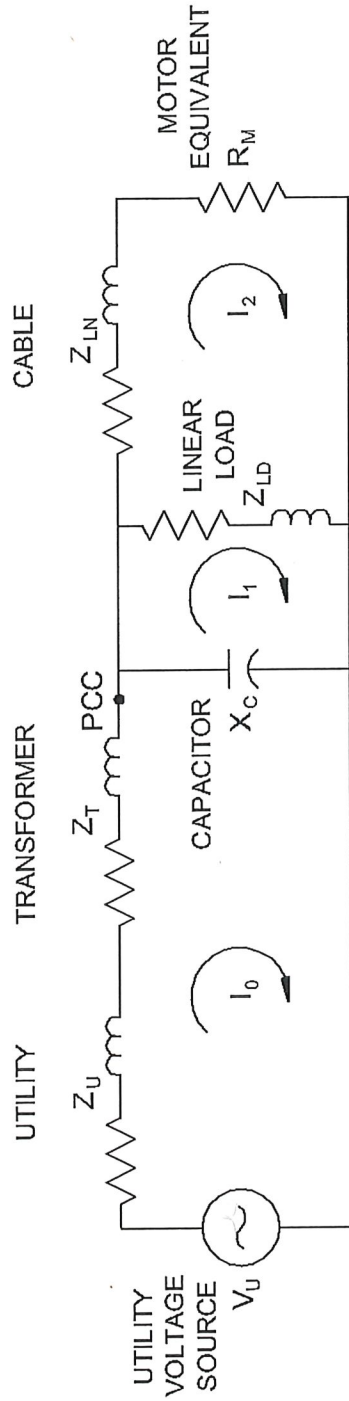
ONE LINE

EXAMPLE SYSTEM
FIGURE 10



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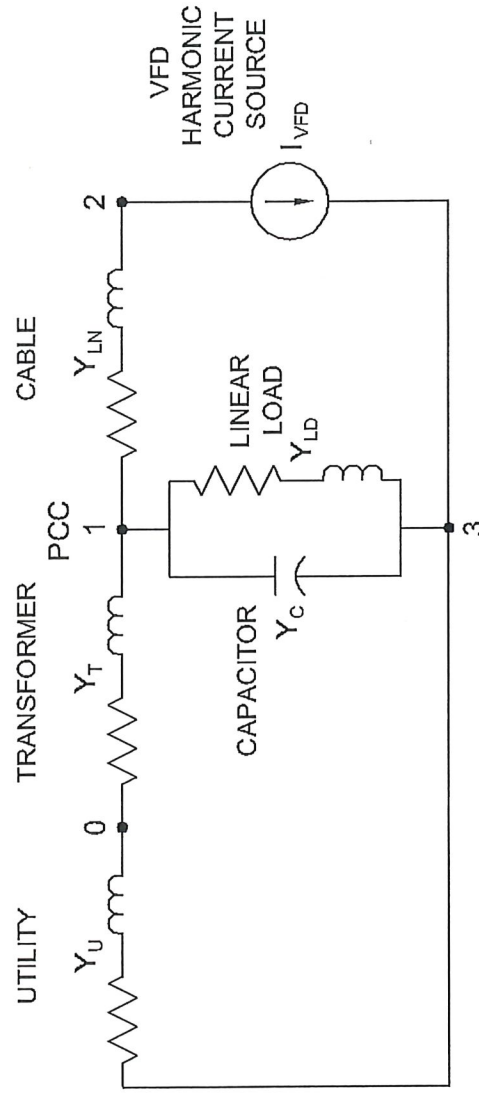
60 HZ ANALYSIS IMPEDANCE DIAGRAM

EXAMPLE SYSTEM
FIGURE 10



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0.5



HARMONIC ANALYSIS ADMITTANCE DIAGRAM

EXAMPLE SYSTEM
FIGURE 10



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CURRENT AT PCC HARMONIC COMPONENTS

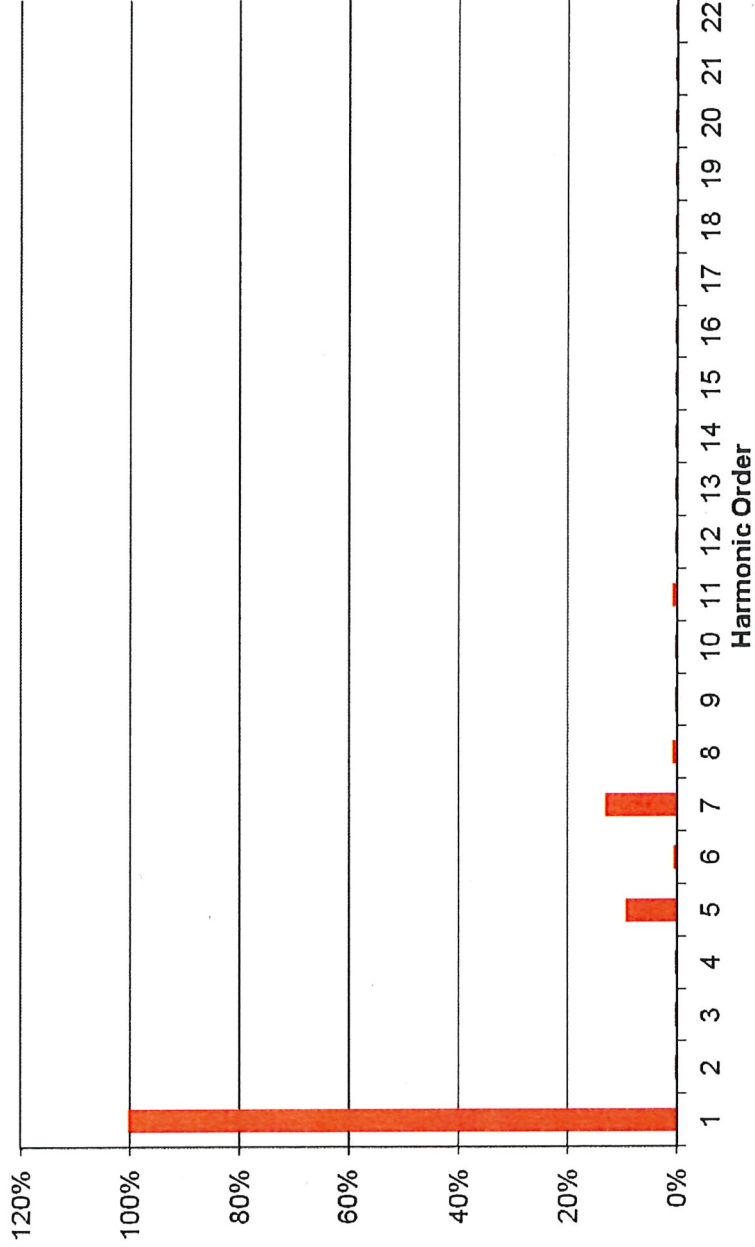


FIGURE 11
PCC HARMONIC COMPONENTS HISTOGRAM



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VOLTAGE AT PCC HARMONIC COMPONENTS

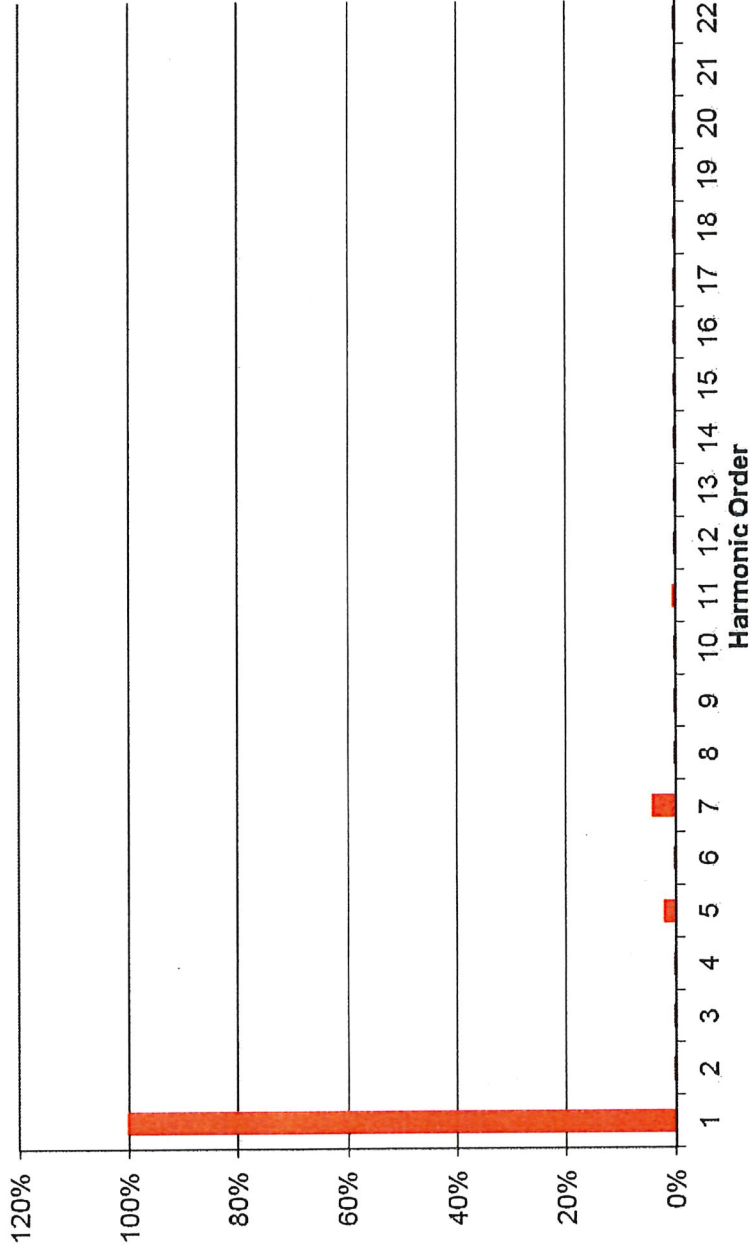
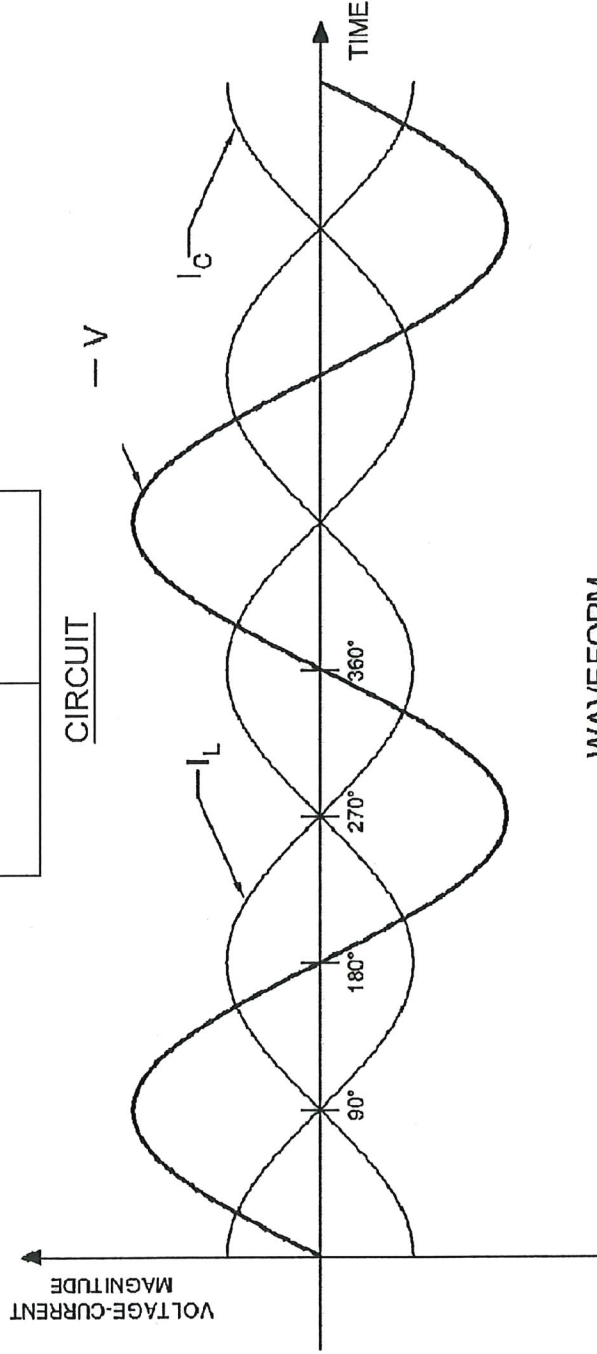
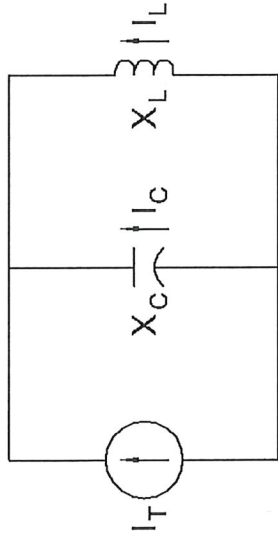


FIGURE 11
PCC HARMONIC COMPONENTS HISTOGRAM



PARALLEL RESONANCE

0.5



$$X_L = X_C$$





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INDUSTRY STANDARDS

1.25

- IEEE Std 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems*
- Utility Limitation for Systems Below 69 kV
 - Voltage THD < 5%
 - Individual Voltage Harmonic < 3%
- Customer Limitation
 - Depends on Utility System Strength (ISC)
 - Depends on Maximum Demand Load (IL)
 - For ISC/IL < 20
 - Current THD < 5%
 - Current Harmonic (below 12th) < 4%

Series 20



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SOLUTIONS TO HARMONIC PROBLEMS

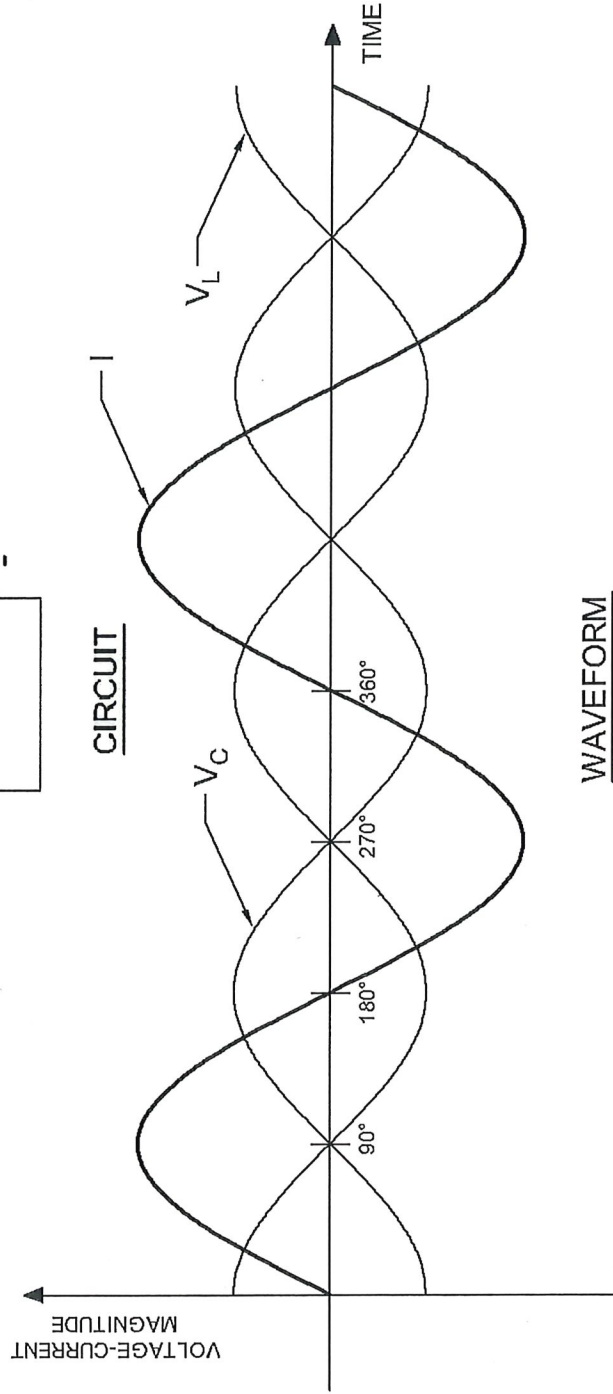
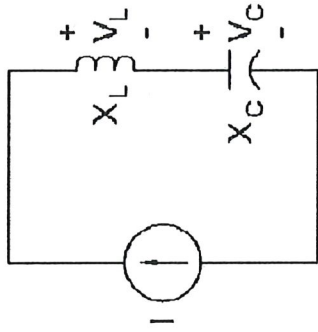
165

- Passive Filters
 - Series
 - Shunt
- Active Harmonic Filters
- Harmonic Mitigation Transformers (HMT's)
- Circuit Modification
- Equipment and Cable Sizing



TUNED SHUNT FILTER

01



WAVEFORM

$$X_L = X_C$$



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QUESTIONS & DISCUSSION THANK YOU!

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jghrist@utilitytec.com

