COST EFFECTIVE HARMONIC SUPPRESSION
in
A. C. POWER SYSTEMS

by

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ABSTRACT

COST EFFECTIVE HARMONIC SUPPRESSION IN AC POWER SYSTEMS

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The aim of this paper is three parts: First, develop a workable model for specific devices which are known to inject harmonics into power distribution systems. Second, combine this model with the distribution system elements and solve the resulting network to yield harmonic voltages. Third, describe the experimental results for a method of harmonic current reduction thyristor converters. The principle of this method is to modify the current waveforms on the ac windings of the converter transformer by filtering harmonic currents at a particular frequency. In practice, filtering the fifth harmonic current of the power frequency is the most efficient. Experimental results prove that the method is effective in reducing the alternating-current harmonics, and it is applicable to any type of thyristor converters.

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Finally, I dedicate this thesis to my parents, Mr. and Mrs. Abdel-Kader and Alamiah Abu-Hashim, whose love, support and encouragement enabled me to complete my studies.

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LIST OF SYMBOLS

SYMBOL	DEFINITION
ENGLISH LETTERS	
C	Capacitor bank Capacitance, μF
$F(\mu,\alpha)$	Overlap function
h	Harmonic Order
H_{FV}	Voltage harmonic factor
H_{FI}	Current harmonic factor
I	Rated fundamental current, A
$I_{(3,5,7,...)}$	Harmonic current of the 3rd, 5th, 7th,... order, A
I_a	ac current phase, A
I_{bus}	Current Matrix, A
I_c	Commutating current, A
I_d	dc current, A
Ijk	Harmonic current flowing on link between nodes j & K, A
K	Total cost, $
Kc	Cost of capacitor, $
Kl	Cost of inductor, $
Kmin	Minimum cost for the filter, $
L	Inductance of the inductor, H
Mf	Magnitude factor
n	Any integer
P	Pulse number of converter
Qc	Reactive power in terms of the capacitor, MVAR
Ql	Reactive power in terms of the inductor, MVAR

SYMBOL	DEFINITION
Q	Average reactive power, MVAR
Qb	Capacitor bank size, MVAR
R	Resistance, Ω
S	Apparent power, MVA
Sf	Size of capacitor for the fundamental load, MVAR
Sh	Size of capacitor for the harmonic load, MVAR
t	Time delay, s
Uc	Unit cost of the capacitor, $
Ul	Unit cost of the inductor, $
V	Rated fundamental voltage, V
$V_{(3,5,7\ \ldots.)}$	Harmonic voltage of the 3rd, 5th, 7th,... order, V
V_{bus}	Voltage matrix, V
Vc	Voltage across the capacitor, V
Vd	dc voltage, V
Vdf	Voltage distortion
V_{d0}	Ideal no-load direct voltage, V
V_h	Voltage of hth harmonic, V
$V_j \& V_k$	Harmonic voltages at nodes j & K, V
Vl	Voltage across the inductor, V
V_{ll}	Line-to-line voltage, V
V_{ln}	Line-to-neutral voltage, V
%VR	Percent voltage rise
X	Reactance, Ω
Xc	Fundamental frequency reactance of the capacitor, Ω

SYMBOL	DEFINITION
Xl	Fundamental frequency reactance of the inductor, Ω
Xl_h	Reactance tuned to harmonic h for the inductor, Ω
Xch	Reactance tuned to harmonic h for the capacitor, Ω
Y	Admittance, Mho
Y_{bus}	Admittance matrix, Mho
Z_{bus}	Impedance matrix, Ω
Zf	Filter impedance, Ω
Z_{jk}	Impedance of link between nodes j & k, Ω
GREEK LETTERS	
α	Control angle or the delay angle
δ	Extinction angle
Ω	Ohm
μ	Overlap angle
w	Radian frequency

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Chapter I

INTRODUCTION

1.1 Background and Objective

Harmonics circulating in electric power systems has gained importance in recent years because of the high levels of harmonic voltages found on distribution systems. Today's power system harmonic problems may be traced, in general, to a number of factors. These factors include:

I. The drastic increase in the use of nonlinear loads made possible by new technologies. Silicon-controlled rectifiers (SCRs), power transistors, and microprocessors are the most important single parameter for the vast increase in power harmonics. These load-generated harmonics have created -for the first time- a new situation where harmonics are generated, propagated, and injected in every line and feeder on the system. Furthermore, the future availability, economics, and expanding use of the solid state devices in all consumer, industrial, and commercial electric equipment, promise a drastic change in the characteristics and the nature of utility loads in the 1990s. This will necessitate a critical examination by utilities at the new loads and their impact on the power system and other consumers.

II. To a lesser extent--but of importance--is the fact that a drastic change in the design philosophy of all power equipment and load equipment has taken place. In the past, manufacturers tended towards underrating or overdesigning most equipment. Now, in order to be competitive, power devices and equipment must be critically designed. In the case of iron core devices, this means that the operating points are located into the more nonlinear region, resulting in a sharp rise in harmonics.

For more than fifty years, harmonics have been reported to cause operational problems. Some of the major known effects are summarized as follows:

1. Capacitor bank overloading. Dielectric stress is proportional to the crest voltage, which may be either raised or lowered by harmonic voltages. Total reactive power, including fundamental and harmonics, should not exceed the rated reactive power of the capacitor.
2. Interference with ripple control and power line carrier systems is a possible result of harmonics on the system. Ripple systems, using audio frequency tones, and carrier systems, employing carrier frequencies in the 5-50 kHz range, serve as communication lines to accomplish remote switching, load control, and metering. Harmonics and high frequency noise could produce interference to yield undesirable operation, misoperation, or restraint of equipment or equipment

controls.

3. Harmonic currents in induction and synchronous machines cause additional heating losses of these machines. These effects are, for the most part, attributable to harmonics of lower order , reduce the torque available at rated speed from the motors and cause parasitic torques at lower speeds that can prevent a motor that is being started from attaining full speed.
4. Overvoltages and excessive currents on the system may be due to resonance of harmonics on the network. These resonances occur as the result of many different possibilities. Capacitor bank-caused resonance and transmission line length to wave length matching are only two of the more common possibilities.
5. Dielectric instability of insulated cables is a direct result of overvoltages on the system mentioned earlier.
6. Inductive interference with telecommunication systems refers to the coupling effect between the harmonic frequencies and communication lines. The effect depends mainly on the method of coupling, but a harmonic increase will probably have a detrimental effect.
7. Errors in induction kilowatt-hour meters due to harmonics result from the measurement of a distorted wave shape by devices built to measure the average values of near-perfect wave shapes.
8. The existence of harmonics in the transmission and

distribution systems will certainly increase the chances for signal interference and relay malfunction, particularly solid state and microprocessor controlled systems.

9. Recently, power system harmonics are being considered as the major cause of excitation control problems that preceded a generator failure.

10. Harmonics interference with large motor controllers have been reported to cause major problems for the motors, as well as the uniformity of the motors output.

These effects depend, of course, on the harmonic source, its location on the power system, and the network characteristics that promote propagation of harmonics.

Since there are numerous sources of harmonics, some of which produce resonance with the network impedance at certain frequencies, e.g., capacitor banks, rotating machines, voltage controllers, etc., and some of which generate such harmonics, e.g., ac/dc converters, static compensaters, motor control devices, etc. Consequently, there is a need to predict the magnitudes of these harmonics and to calculate the network impedance at those harmonic frequencies, especially the lower harmonic frequencies must be calculated, since the most damaging frequencies to power devices and machines appear to be the lower frequency range, i.e. below 4.2 kHZ (70th harmonic).

1.2 Overview

This research is divided into three parts in order to discuss harmonic distributions in a system network produced by the line-commutated power converters and techniques for controlling the harmonic associated with them at the least cost:

1. Develop a workable model for specific devices which are known to inject harmonics into the power distribution systems, in this case the line-commutated ac/dc converter (Chapter 2)
2. Develop a distribution system model (i.e., 5 bus network)
   and then combine it with the model of part #1, and the resulting network is solved to yield harmonic voltages (Chapter 3)
3. Develop cost effective techniques for controlling and suppressing the harmonic interference in the power distribution network (Chapter 4).

Chapter II

DEVELOP A WORKABLE MODEL FOR HARMONIC CURRENT INJECTING DEVICES.

2.1 Introduction

The ac/dc converters are the main sources of harmonic current at the present time.

There are two basic types of large-capacity static power converters, self-commutated and line-commutated converters that are widely used in industry.

Self-commutated converters differ from line-commutated in that they incorporate their own means for commutation, i.e., they commutate independently of the line voltage.

Line-commutated converters use the converter's ac supply as the commutating voltage. These converters can be conveniently grouped into the following three broad types: (i) large power converters such as those used in metal reduction industry and high voltage dc transmission; (ii) medium size converters such as those used in the manufacturing industry for motor control and also in railway applications; (iii) low power rectification from single phase supplies such as television sets and battery chargers.

The converters in group (i) will be used in this research as the harmonic source for the derivation of the characteristic harmonics injected into the system, since they are the closest to the ideal.

2.2 Line-Commutated ac/dc power converters

Line-commutated converters use the converter's ac supply as a commutating voltage. The standard (HVDC) converter is the 3-phase full wave bridge using six controlled (thyristor) valves, as shown in Fig. 2.1. This is known as a 6-pulse converter group or bridge, because there are six valve firing pulses and six pulses per power frequency cycle in the output at the dc terminals.

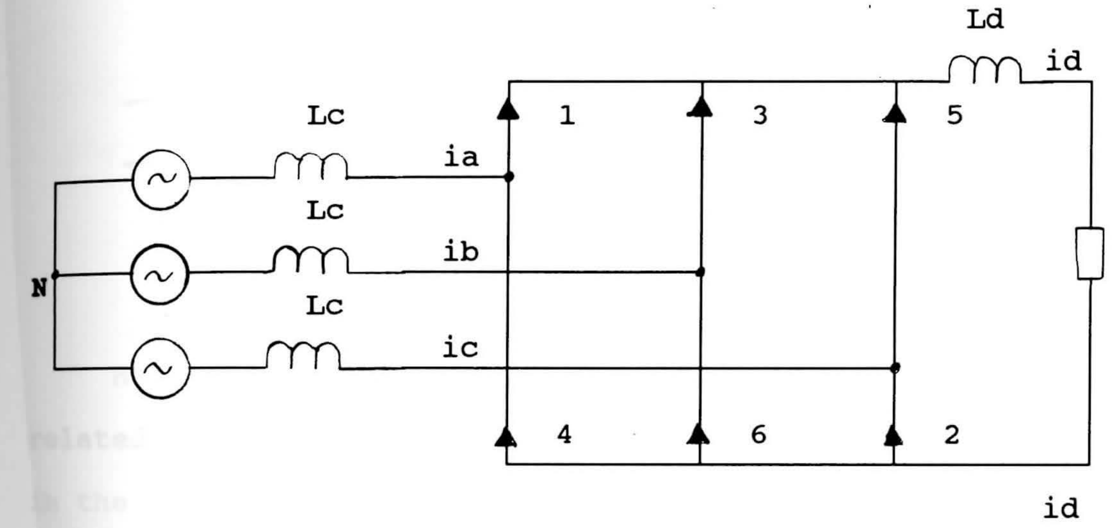


Fig. 2.1 A six-pulse line commutated converter

In a 6-pulse bridge circuit Fig. 2.1, the valves 1, 3 and 5 commutate the outgoing direct current Id between themselves, while the valves 2, 4 and 6 commutate the incoming direct current Id; the two 3-pulse conversion processes form the 6-pulse bridge conversion. For clarity Fig. 2.2 is drawn for one half of the 6-pulse bridge, i.e., the commutations between valves 1, 3 and 5 only are shown.

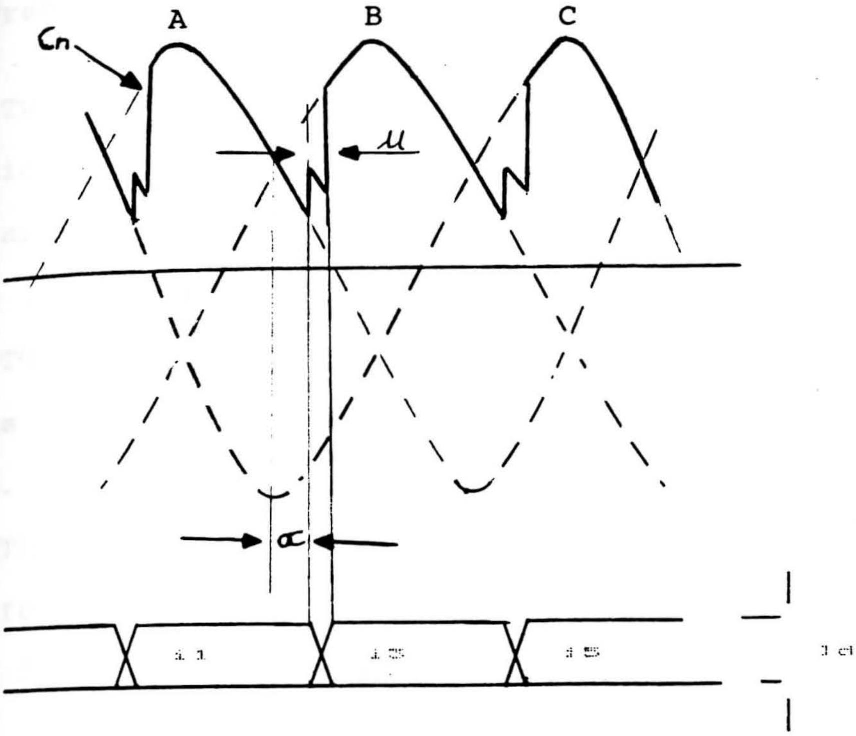


Fig. 2.2 Rectifier operation

Harmonics produced by line-commutated converters are related to the pulse number (the number of cycles of ripple in the direct voltage per cycle of the alternating voltage) of the device.

The ac side harmonics are

$$h = nP \pm 1$$

h = Harmonic order
n = Any integer (1,2,3,4,......)
P = Pulse number of converter (in our case $P=6$)
I = Fundamental current

See Appendix C

2.3 Predicting the overlap angle

Two other factors determine the harmonic magnitudes in addition to the pulse number and the fundamental current. They are the delay angle (control angle) and the commutation angle (overlap angle).

The delay angle, which is denoted by (α), corresponds to a time delay for the firing of the valve, which is always given.

The overlap angle is the amount of time it takes to transfer current from one conducting element to another.

The ideal no-load dc voltage is (3)

$$V_{d0} = (3\sqrt{6}/\pi)\ V_{ln}$$
$$= (3\sqrt{2}/\pi)\ V_{ll} \qquad (2.1)$$

V_{d0} = Ideal no-load direct voltage
V_{ll} = line-to-line voltage
V_{ln} = line-to-neutral voltage

For a delay angle (α) the average voltage V_d is found by integrating the instantaneous voltages over such a period with both limits of integration simply increased by α

$$V_d = (V_{d0}/\ T) \int_{\alpha - 60}^{\alpha} \mathrm{COS}(\phi + 30)\ d\phi$$
$$= V_{d0}\ [\mathrm{SIN}(\alpha + 30°) - \mathrm{SIN}(\alpha - 30°)]$$
$$= V_{d0}\ (2\ \mathrm{SIN}(30°))\ \mathrm{COS}(\alpha)$$
$$V_d = V_{d0}\ \mathrm{COS}(\alpha) \qquad (2.2)$$

With the overlap, the dc voltage drop due to overlap $\delta\ V_d$ and their direct voltage will be:(Kimbark)

$$V_d = V_{d0} \cos(\alpha) - \delta V_d$$

$$= V_{d0} \cos(\alpha) - V_{d0}/2 \, [\cos(\alpha) - \cos(\alpha - \mu)]$$

$$V_d = V_{d0} \, [\cos(\alpha) + \cos(\alpha + \mu)] / 2 \qquad (2.3)$$

Assuming a purely inductive commutation circuit, the commutating current is defined by:

$$I_c = (V_{11}/\surd 2wL) \, (\cos(\alpha) - \cos(wt)) \qquad (2.4)$$

when wL is the reactance per phase of the commutation circuit from the transformer leakage reactance at the end of the commutation. $I_c = I_d$ and $wt = \mu$

Eq. (2.4) becomes:

$$I_d = (V_{11}/\surd 2wL) \, (\cos(\alpha) - \cos(\alpha + \mu)) \qquad (2.5)$$

2.4 Derivation of the overlap angle.

The most severe situation of harmonic generation exists when $\alpha = 0$ and output dc power which is given by $P = V_d I_d$ is maximum.

From Eq. (2.3), the dc voltage will be:

$$V_d = V_{d0} \quad (1 + \cos(\mu))/2$$

$$= (3\surd 2/2\pi) \quad (1 + \cos(\mu)) \, V_{11} \qquad (2.6)$$

and the dc current will be:

$$I_d = (V_{11}/\surd 2wL) \, (1 - \cos(\mu)) \qquad (2.7)$$

Since V_d and I_d are functions of the overlap angle (μ), a computational algorithm based on equations (2.6) and (2.7) to determine the overlap angle "μ" is developed as follows:

1) Set $\mu = 60°$ (Since 60° is max overlap)
2) $\mu = (\mu - 1)°$
3) Compute Vd and Id using equations (2.6) and (2.7)
4) If $V_d \ I_d \geq P_d$, go to step 2
5) Using steps 2 to 4 determine μ to any degree of accuracy required such that $V_d I_d = P_d$

A digital computer program in Fortran language was written and executed shown in Appendix (D) to determine the overlap angle μ.

Line commutated power converters are represented as harmonic current sources at their characteristic frequencies. The rms value of each characteristic harmonic current can be computed from the following relationships

$$Ih = \sqrt{6}\ I_d\ F(\mu,\alpha)/\{\pi h[\cos(\alpha) - \cos(\alpha + \mu)\} \qquad (2.8)$$

using Equation (2.5) the harmonic current can be solved in terms of the line voltage.

$$Ih = (\sqrt{3}\ V_{ll}\ F(\mu,\alpha))/(\pi wLh) \qquad (2.9)$$

where:

$$F(\mu,\alpha) = \sqrt{\{(\mathrm{SIN}[(h-1)\mu/2]/h-1)^2 + (\mathrm{SIN}[(h-1)\mu/2]/h+1)^2 - 2 * (\mathrm{SIN}[(h-1)\mu/2]/h-1) * (\mathrm{SIN}[(h+1)\mu/2/h+1]) * \mathrm{COS}\ (2\ \alpha + \mu)\}}$$

V_{ll} = Line-to-Line voltage at the ac bus of the converter
wL = Equivalent short circuit reactance
$F(\mu,\alpha)$ = Overlap function
I_d = dc current
u = Overlap angle
α = Firing angle

(Kimbark)

Chapter III

DEVELOP A DISTRIBUTION SYSTEM MODEL

3.1 Introduction

In order to study the harmonic powerflow in a power system, the first step is to establish the appropriate mathematical models for all of the power system components. Among the harmonic producing components, special attention is paid to the line commutated controlled rectifier load which is discussed in great detail in Chapter 2. Standard representations are used for other power system components. Transmission lines are represented by single phase equivalent π models. These are discussed in greater detail in sections 3.2 and 3.3.

The system which is selected for this study is a small test system with a single large harmonic source. It is assumed to be a completely symmetrical, balanced system.

3.2 Assembling the impedance matrix

Several well known algorithms are in use today to assemble an impedance matrix of a known system.

The impedance matrix of a power system changes for each frequency; that is, it will vary directly or inversely with frequency depending on the element, e.g., the transmission lines impedance is:

$$X_C = 1/2\pi fC = 1.779/f * 10^{6} \ln D/r \quad \Omega \qquad (3.1)$$

$$X_L = 2\pi fL = 4\pi f/10^{7} * \ln Dm/Ds \quad \Omega \qquad (3.2)$$

It is necessary to assemble an impedance matrix for each harmonic frequency present. A sample system is shown in Fig. 3.1, and its harmonic equivalent circuit shown in Fig. 3.2. The 5th and 7th π-equivalent impedance matrix is calculated in Appendix (A).

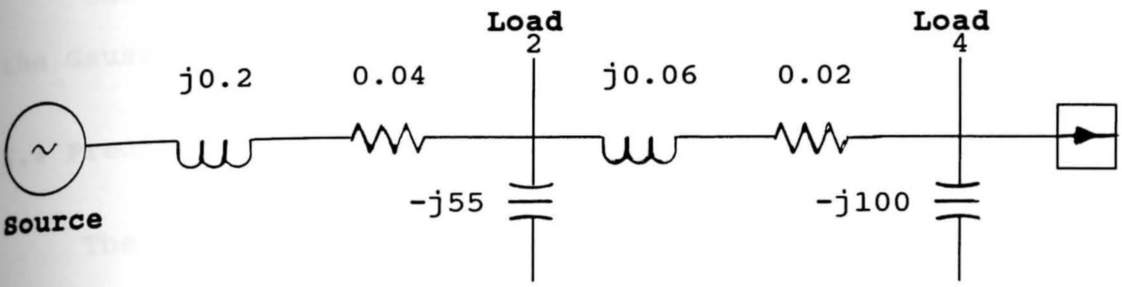


Fig. 3.1 Example distribution system. All impedance values in per unit at 60 Hz to a 100 MVA base

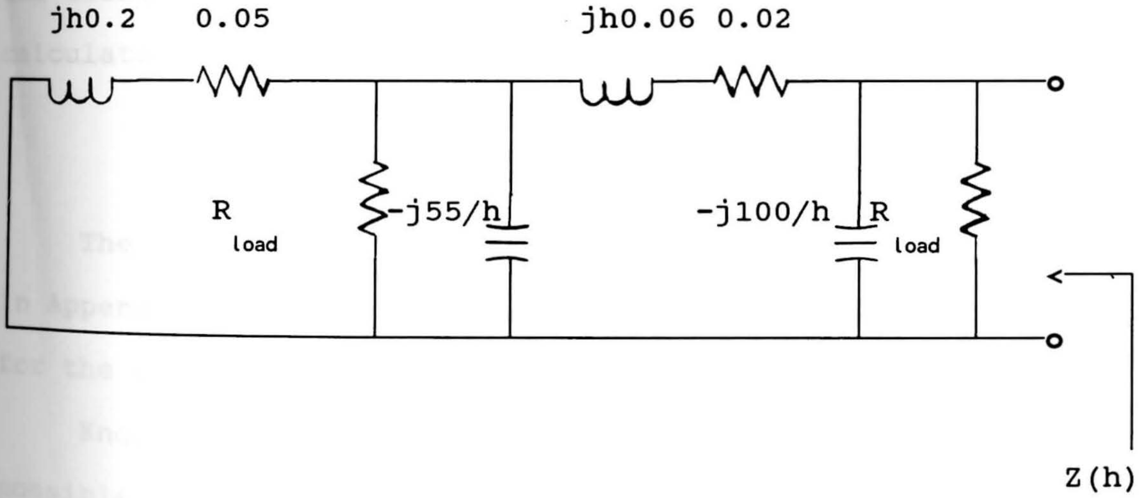


Fig. 3.2 Harmonic equivalent circuit of the system shown in Fig. 3.1. Loads represented by a resistance. h = per unit frequency with h = 1 corresponding to 60 Hz

3.3 Calculating the values of the bus voltages

A 5-bus system is assembled with two generating units connected at bus 1 and bus 2, and a 45 MW ac/dc converter connected at bus 4. A one line diagram of the system is shown in Fig. 3.3.

The values of the bus voltages are calculated using the Gauss-Seidel method as shown in Appendix (E).

3.4 Prediction of Harmonic currents in the system

The magnitude of the harmonic currents generated and the impedance matrices for the various frequencies present are obtainable from the system and the converter data which is normally known or calculated.

Once the generated harmonic currents are calculated, and using equation (2.9), the bus harmonic voltages are calculated from

$$[Vbus] = [Ybus]^{-1} * [Ibus] \tag{3.3}$$

The harmonic voltage values for each bus are calculated in Appendix (E) . For these harmonics, the reference nodes for the voltage are at ground potential.

Knowing the harmonic voltages at every node, it is possible to determine the harmonic current flow in any link.

$$Ijk = (Vj-Vk)/Zjk \tag{3.4}$$

Ijk = Harmonic current flowing through the link between nodes j α k
Vj,Vk = Harmonic voltages between nodes j and k
Zjk = Impedance of the link between nodes j and k

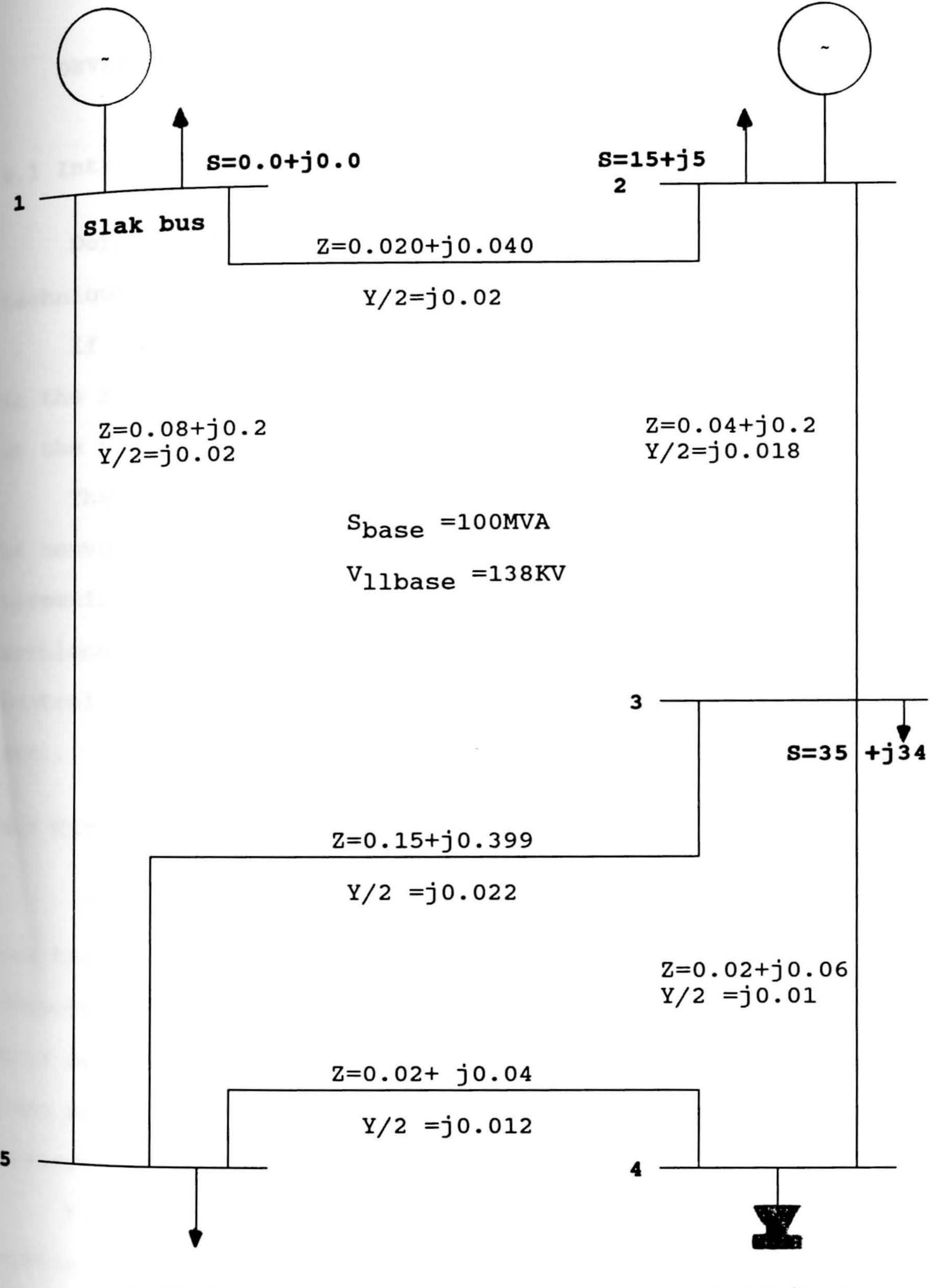


Fig 3.3 One Line Diagram of 5-bus tested system

Chapter IV

DEVELOP COST EFFECTIVE TECHNIQUES FOR CONTROLLING AND SUPPRESSING THE HARMONIC

4.1 Introduction

Depending on the circumstances, harmonic control techniques may be required at certain harmonic sources.

If the source of the harmonic is a large power converter in the Megawatt power rating range, controlling the harmonic at the power converter appears to be essential.

The two principal methods used for harmonic suppression at converter installations are harmonic cancellation and harmonic filtering. These are discussed in greater detail in sections 4.2 and 4.3. There are several other harmonic control methods, e.g., current injection, active filters, etc...

4.2 Harmonic cancellation

Harmonic cancellation uses the utility's transformer to sum the outputs of multiple-phase-shifted converter-bridge outputs to cancel certain characteristic harmonic pairs. This method of reducing the harmonic is very effective as long as all SCR'S are conducting, but it requires complicated transformer connections.

Figure (4.1) illustrates a line-commutated converter system using harmonic cancellation to obtain effective 12-pulse operation.

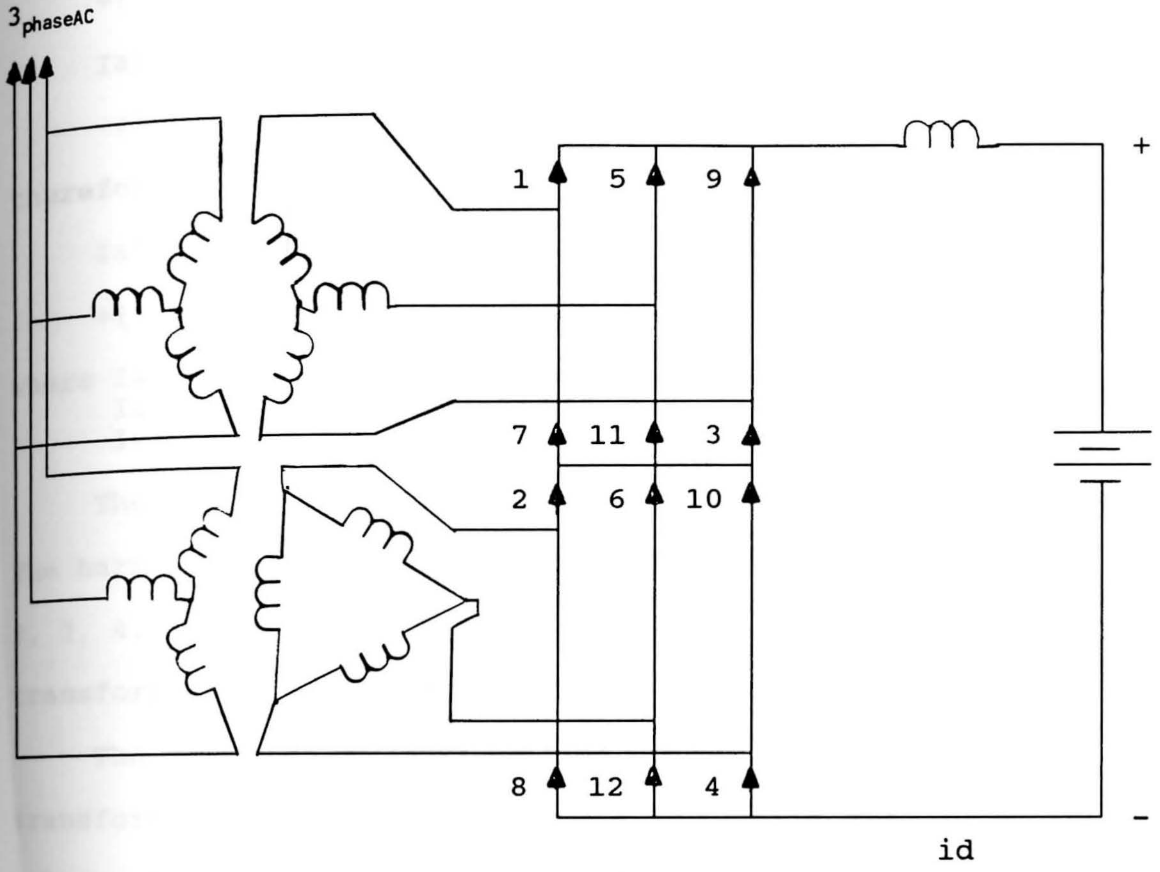


Fig. 4.1 Twelve-pulse converter configuration

The twelve-pulse configurations consist of two six-pulse groups fed from two sets of three-phase transformers in parallel with their fundamental voltage equal and phase-shifted by 30°.

To maintain 12-pulse operation, the two six-pulse groups must operate with the same control angle (α), and therefore, the fundamental frequency currents on the ac side of the two transformers are in phase with one another.

The resultant ac current is given by the sum of the two fourier series of the wye-wye (eq.C-18) and the wye-delta (eq.C-19) transforms of Appendix (C).

$$Ia1 = (2\sqrt{3}/\pi) I_d \; [COS(wt) - (1/5)COS(5wt)$$

$$+(1/7)COS\ (7wt) - (1/11)COS(11wt) + \ldots.\ ] \qquad (4.1)$$

$$Ia2 = (2\sqrt{3}/\pi) I_d \; [COS(wt) + (1/5)COS(5wt)$$

$$-(1/7)\ COS(7wt) - (1/11)COS(11wt) + \ldots] \qquad (4.2)$$

therefore

$$Ia3 = 2(2\sqrt{3}/\pi)\ I_d \; [COS(wt) - (1/11)COS(11wt)$$

$$+(1/13)COS(13wt) - (1/23)COS(23wt)\ldots\ ] \qquad (4.3)$$

where Ia1 =wye-wye transformers ac harmonic current phase a
Ia2 =wye-delta transformers ac harmonic current phase a
Ia3 =the sum of Ia1 and Ia2

The Ia3 series only contains harmonics of order 12n ± 1. The harmonic currents of order 6n ± 1 (n is odd) ie. n = 1, 2, 3, 4, ... etc., circulate between the two converter transformers but do not penetrate the ac network.

The addition of further appropriately shifted transformers in parallel provides the basis for increasing pulse configurations. For instance 24-pulse is achieved by means of four transformers with 15 phase shifts.

However, most experts on HVDC transmission feel that it is more economical to use a 12-pulse converter with filters than to use a converter of higher pulse number with the resultant reduction in filters. (Heydt & Grady) This is because losses will increase due to the circulating current in the delta transformer current, and the transformer connections required will be more complex than those for 12-pulse converters.

Therefore, the emphasis in the rest of this chapter will be to find adequate cost effective harmonic filters.

4.3 Filtering

The converter, rectifier or inverter, draws reactive power Q from the ac system. The rectifier is said to take lagging current from the ac system, and the inverter is said to either take lagging current or to deliver leading current to the ac system. Therefore, the ac harmonic filters are designed to serve two purposes: 1) to reduce harmonic voltages and currents, 2) to provide all or part of the reactive power consumed by the converter.

The dc harmonic filters serve only to reduce harmonic voltage on the dc line.

4.4 AC Filter Design

The ac filters in each phase usually comprise:

1) Tuned Filters (Low Passband Filters)

    a) Single tuned
    b) Double tuned

These filters are sharply tuned to one or two of the lower harmonics (e.g., 3, 5, 7, 9)

2) Damped Filters (High Passband Filters)

    a) First order
    b) Second order
    c) Third order
    d) C-type

They provide low impedance for a wide number of high harmonics (e.g. 17th, 19th, ... and higher).

3) Switchable shunt capacitors.

4.5 Assumptions for the designing of filters

In order to design a filter, these data have to be taken into consideration:

1) For the converter:

   a) Pulse numbers (P)
   b) Number of poles and bridges
   c) I_d and V_d
   d) Converter angles (α, δ, μ)
   e) Modes of abnormal operation (one or more bridges out of service)

2) For the ac network:

   a) Unbalance of ac voltage
   b) Power frequency and its variations
   c) Impedance at harmonic conditions
   d) Requirement on maximum reactive power that can be supplied or absorbed by the network
   e) Preexisting harmonic levels

3) Criteria adopted for adequate filtering:

   a) Maximum voltage of an individual harmonic
   b) To meet the IEEE standard 519-1981 for the voltage harmonic factor HF_V expressed as:

$$HF_V = [(V3)^2 + (V5)^2 + (V7)^2 + (V9)^2 \ldots]^{\frac{1}{2}} / V1 \qquad (4.4)$$

and the current harmonic factor HF_I expressed as

$$HF_I = [(I3)^2 + (I5)^2 + (I7)^2 + (I9)^2 \ldots]^{\frac{1}{2}} / I1 \qquad (4.5)$$

Where

V1 = rated fundamental voltage
V(3,5,7....) = rms voltages of (3rd,5th,7th ...) harmonic
I1 = rated fundamental current
I(3,5,7....) = harmonic current of the (3rd,5th,7th....) order (Gonen)

4.6 Minimum cost for single tuned filter

Shunt harmonic filters connected to the converter ac busbars provide a low impedance into which most of the harmonic currents are diverted. Shunt filters also generate reactive power at fundamental frequency providing some or all of reactive power by the converters.

The most direct method of achieving a low impedance at a given frequency is by means of a tuned filter as shown in Fig 4.2.

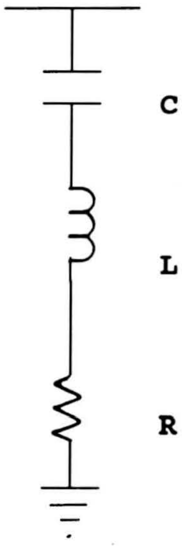


Fig. 4.2 Single-tuned shunt filter

The most damaging frequencies to power devices and machines appear to be in the range-below 5 KHZ-frequency. Consideration is given to the design of a single-tuned filter which is a series RLC circuit Fig. 4.2, tuned to the frequency of one low characteristic harmonic impedance given by

$$Zf = R + j(wL - 1/wC)$$

$$Zf = R + j(Xl - Xc) \qquad (4.6)$$

from which

$$X = 1/wC = wL$$

where X = reactance, Ω
C = capacitance, F
L = inductance, H

therefore

$$Xl = wL \tag{4.7}$$

$$Xc = 1/wC \tag{4.8}$$

where Xl = fundamental-frequency reactance of the inductor, Ω
Xc = fundamental-frequency reactance of the capacitor, Ω

But for a filter tuned to harmonic h, the fundamental-frequency reactance tuned to harmonic h of the inductor is Xl_h, and the fundamental-frequency reactance tuned to harmonic h of the capacitor is Xc_h.

Since

$$Xl_h*h = Xc_h/h \tag{4.9}$$

where h = harmonic order

and

Xl_h in terms of C = Xc/h^2

Xc_h in terms of L = $h^2 wL = h^2 Xc$

therefore

$$L = 1/w^2 Ch^2 \tag{4.10}$$

Similarly

$$C = 1/w^2 Lh^2 \tag{4.11}$$

and

$$Vl = Vc/h^2 \tag{4.12}$$

$$Xl = Xc/h^2 \tag{4.13}$$

where Vl = inductance voltage, KV
Vc = capacitor voltage, KV

Since the filter supplies the vars and filtering for the system, the constant voltage source for the fundamental frequency calculation and the constant current source for the harmonic source calculation are used.

Therefore, the vars losses in terms of the capacitor rating are:

$$Sf1 = Vc^2 wC = Vc^2/Xc \qquad (4.14)$$

and

$$Sh1 = I_h^2/hwC \qquad (4.15)$$

where $SF1$ = size of capacitor for the fundamental load, MVAR
$Sh1$ = size of capacitor for the harmonic load, MVAR
I_h = harmonic current of h order

Therefore, the total reactive power (Qc) in terms of the capacitor is:

$$Qc = Sf1 + Sh1 \quad \text{MVAr} \qquad (4.16)$$

Substituting Eq. (4.14), (4.15) into Eq. (4.16)

$$Qc = Vc^2 wC + I_h^2/hwC \qquad (4.17)$$

Note: The harmonic loading is the same as for the capacitor since the reactance is equal at harmonic frequency.

Using Uc as the unit cost for the capacitor, therefore the filter cost for the capacitor reactive power is

$$Kc = Uc * Qc \qquad (4.19)$$

where Kc = cost, \$
Uc = Unit cost of the capacitor, \$

The vars losses in terms of the inductor rating are:

$$Sf2 = Vc^2/h^2 wl = Vc^2 \ wC/h^2 \qquad (4.20)$$

$$Sh2 = I_h^2/hwC \qquad (4.21)$$

Therefore, the total reactive power of the inductor (Ql) in terms of the capacitor rating is

$$Ql = Sf2 + Sh2 \quad \text{MVAr} \tag{4.22}$$

Substituting Eq. (4.20) and (4.21) into Eq. (4.22)

$$\begin{aligned} Ql &= Vc^2/h^2 wL + I_h^2/hwC \\ &= Vc^2 wC + I_h^2/hwC \end{aligned} \tag{4.23}$$

Since the reactive loss of the inductor is greatly affected by its insulation level (e.g., oil insulated/cooled units, or natural air cooled reactor of open construction..), the total cost approximation for the inductor:

$$kl = Uk + Ul * Ql \quad \$ \tag{4.24}$$

where Uk = Constant cost, \$
Ul = Unit cost of the inductor, \$

By neglecting the cost of the resistor the total cost of the filter is:

$$K = Uk + Ql\ Ul + Qc\ Uc \quad \$ \tag{4.25}$$

Substituting Eq. (4.16), (4.23) into Eq. (4.25) the total cost of the filter

$$\begin{aligned} K &= Uk + (Sf1 + Sh1)\ Uc + (Sf2 + Sh2)\ Ul \\ &= Uk + Uc * I_h^2/hwC + Uc * Vc^2 wC + \\ &\quad Ul * Vc^2 wC/h^2 + Ul * I_h^2/hwC \end{aligned} \tag{4.26}$$

Since the size of the filter is the reactive power of the capacitor at fundamental frequency only, and using the size in terms of V as

$$S = Vc^2 wC \quad \text{MVAR} \tag{4.27}$$

Substituting S into Eq.(4.26)

$$K = Uk + S(Ul/h^2 + Uc) + (Vc^2 I_h^2 * (Ul + Uc))/hs \quad \$ \qquad (4.28)$$

Since the size S is a variable, the size for the minimum cost occurs when dK/dS = 0

That is,

$$dK/dS = (Ul/h^2 + Uc) - (Vc^2 I_h^2 * (Ul + Uc))/hs^2$$

$$= 0 \qquad (4.29)$$

Therefore from Eq.(4.29) the minimum size for the filter

$$Smin = [(Vc^2 I_h^2 (Ul+Uc)/h)(1/((Ul/h^2)+Uc))]^{\frac{1}{2}} \quad KVAR \qquad (4.30)$$

By having the minimum size of the KVAR's for the filter, the minimum cost would be by substituting Smin Eq.(4.30) into Eq.(4.28).

Therefore the minimum cost for the filter ($/phase) is

$$Kmin = Uk+2\ [(Vc^2 I_h^2 (Ul + Uc)/h)*((Ul/h^2)+Uc)]^{\frac{1}{2}} \quad \$ \qquad (4.30)$$

Chapter V

EXAMPLE AND NUMERICAL RESULTS

5.1 Introduction

In this chapter, the minimum cost single tuned filter was chosen to suppress the 5th harmonic (since it has the highest magnitude shown in Fig. 5.2, at bus 4, which supplies the ac/dc converter of the 5-bus power system network shown in Fig. 3.3).

The same procedure was applied to the 16 bus power system network shown in Fig. 5.1 for testing.

5.2 Example: Minimum-cost Tuned Filter

For the 5-bus system with the following rating.

AC side	DC side
$S = 100$ MVA	$P = 45$ MW
$V_{LL} = 138$ kV	$Vdc = 140$ kV
$I = 418.36$ A	$Id = 320$ A
$F = 60$ Hz	

$Uc = \$3.5/KVAR$	$\mu = 45°$
$UL = \$8/KVAR$	$\alpha = 25°$
$Uk = k\$8/phase$	$\text{Cos}\ \phi = 0.866$

a) Determine: The minimum cost fifth harmonic filter for a 6-pulse converter and the size in MVAR per phase.

b) Determine: The capacitance for the minimum-cost filter.

c) Determine: The inductance for the minimum-cost filter.

Solution:

a) $$Kmin = Uk + 2 \{ [Vc^2 \; I_h^2 (Ul + Uc)/h] * [(Ul/h^2 + Uc] \}$$

From Appendix (E) for the 5th harmonic current $I_{h5} = 43.9$ A

Therefore:

$$Kmin = 8000 + 2 \{ [(138/\surd 3)^2 + (43.9 * 1/10^3)^2 (11500)]$$
$$* [(8*10^3/25) * (0.0019) (11500)/5] * [3820]^{1/2}$$
$$= 8000 + 2 \{ (6348) * (0.0019) (11500)/5]$$
$$* [3820]^{1/2}$$
$$= 8000 + 2 [27740.76 * 3820]^{1/2}$$
$$= 8000 + 2 [10294.15]$$
$$= 8000 + 20588$$
$$= 8000 + 20588$$
$$Kmin = 28,588 \quad \$/phase$$

using Eq. (4.30)

$$Smin = [V^2 I_h^2 \; (Ul + Uc)/h * 1/((Ul/\; h^2) + Uc)]^{1/2}$$
$$Smin = \{ [\; (138/\surd 2)^2 * (43.9 * 10^{-3})^2 \; (11500)/5]$$
$$* 1/[(8*10/5^2) + 3.5 * 10^3 \;]^{1/2} \}$$
$$= [27740.76/3820]^{1/2}$$
$$Smin = 2.6948 \quad MVAR/phase$$

b) The capacitor for the minimum cost filters from equation (4.27).

$$C = Smin/Vc^2 w$$

using Eq. (4.30)

$$Smin = [V^2 I_h^2 \; (Ul + Uc)/h * 1/((Ul/\; h^2) + Uc)]^{1/2}$$

$= [27740.76/3820]$

$= 2.6948$ MVAR/phase

Therefore:

$C = 2.6948/\{377 * (138/\surd 3)^2\} = 1.126 * 10^{-6}$ F

$= 1.126$ μF

c) The inductor is: Using equation (4.10)

$L = 1/w^2 ch^2$

$= 1/\{(377)^2 * (1.126 * 10^{-6}) * (5)^2\}$

$= .2499$ H

5.3 Example: 16 bus system

A 16-bus power system network was chosen for testing, a one-line diagram is shown in Fig. 5.1. The system data, such as line admittance data, load and generation data are given in Appendix B. Example 5.2 was applied to the 5th harmonic of bus 5 of the 16 bus power system network, taking the different rating into consideration using the same unit cost for the capacitor and the inductor.

For the 5th harmonic filter, the values are given to be:

a) The minimum cost fifth harmonic filter for a 6-pulse converter is

Kmin = 22,955.88 $/phase

The minimum size in MVAR per phase is

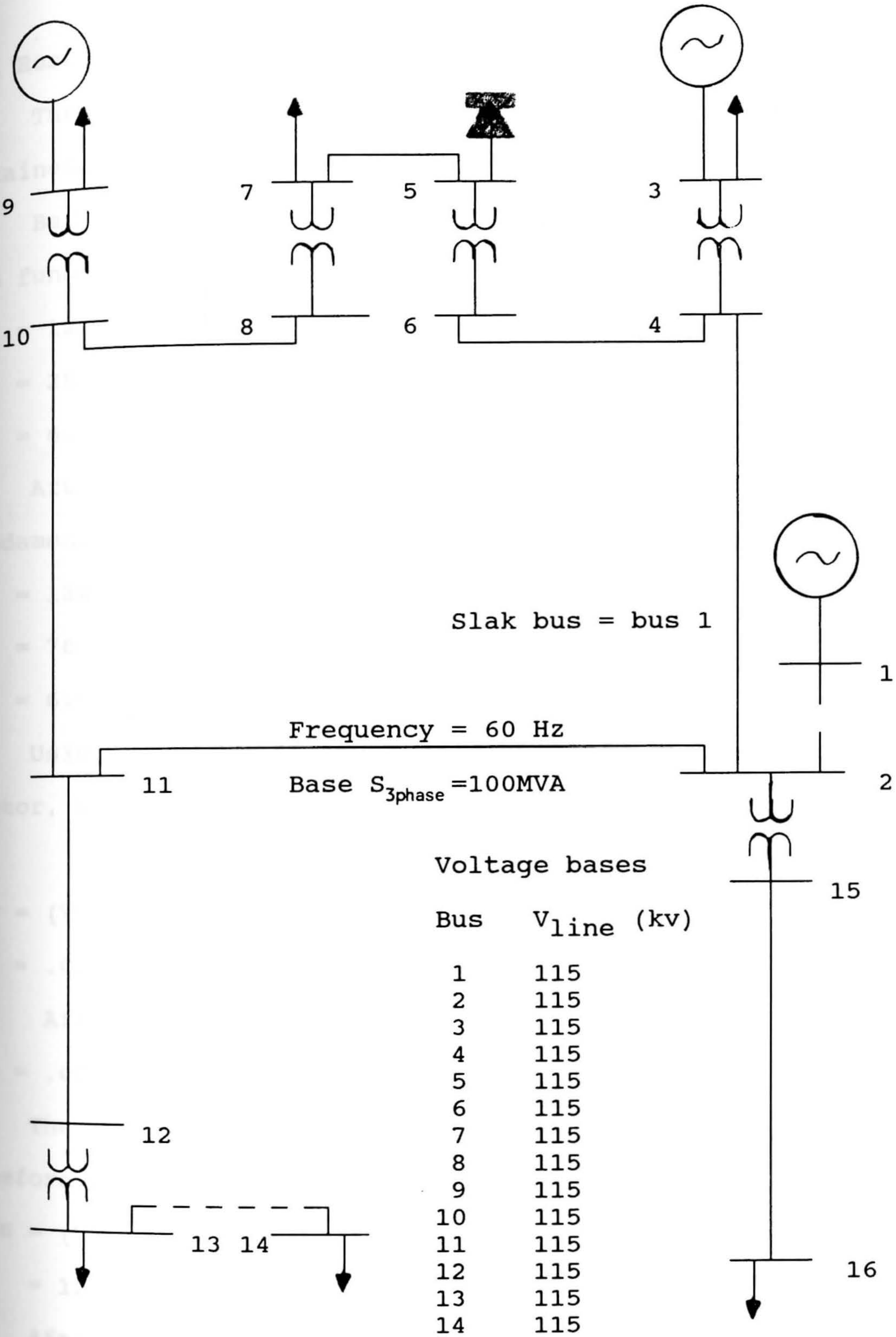
Smin = 1.95757 MVAR/phase

The capacitance for the minimum cost filter is

C = 1.177 μF

The inductance for the minimum cost filter is

$L = 0.239112$ H



Slak bus = bus 1

Frequency = 60 Hz

Base S_{3phase} =100MVA

Voltage bases

Bus	V_{line} (kv)
1	115
2	115
3	115
4	115
5	115
6	115
7	115
8	115
9	115
10	115
11	115
12	115
13	115
14	115
15	115
16	115

Fig. 5.1 One-line diagram of 16-bus test system with per unit bases

5.4 Results

The results for the 5 bus power system network were obtained from Appendix E.

Before adding the minimum-cost tuned filter to bus 4, the fundamental harmonic voltage magnitudes at bus 4 are

$V1 = 122750.86$ V

$V5 = 252.2625$ V

$V7 = 6.5392$ V

After adding the minimum-cost tuned filter to bus 4, the fundamental harmonic voltage magnitudes bus 4 are

$V1 = 124247.7$ V

$V5 = 76.9$ V

$V7 = 6.617$ V

Using Equation (4.4) to find the voltage harmonic factor, HFv or the voltage distortion factor without filter is

$$HFv = (V5^2 + V7^2 + V11^2 + V13^2 \ldots)^{\frac{1}{2}} / V1$$

$$= .0021$$

After adding the filter

$$HFv = .0006$$

The root means square (rms) value of the voltage at bus 4 before adding the filter is

$$Vrms = (V1^2 + V5^2 + V7^2 + V11^2 \ldots)^{\frac{1}{2}}$$

$$= 122751.119 \text{ V}$$

After adding the filter

$$Vrms = 124247 \text{ V}$$

The magnitude factor (MF) without filter is

$$MF = (1/V1) * \sum_{n=2}^{\infty} Vn$$

$$= (252.2625 + 6.5392)/122750.86$$

$$= .0021$$

The magnitude factor (MF) with filter is

$$= (76.9369 + 6.6173)/124247.7$$

$$= .0007$$

The % voltage increase at bus 4 is

$$\%VR = [(124247.72 - 12275.119)/ 122751.119] * 100$$

$$= 1.21\%$$

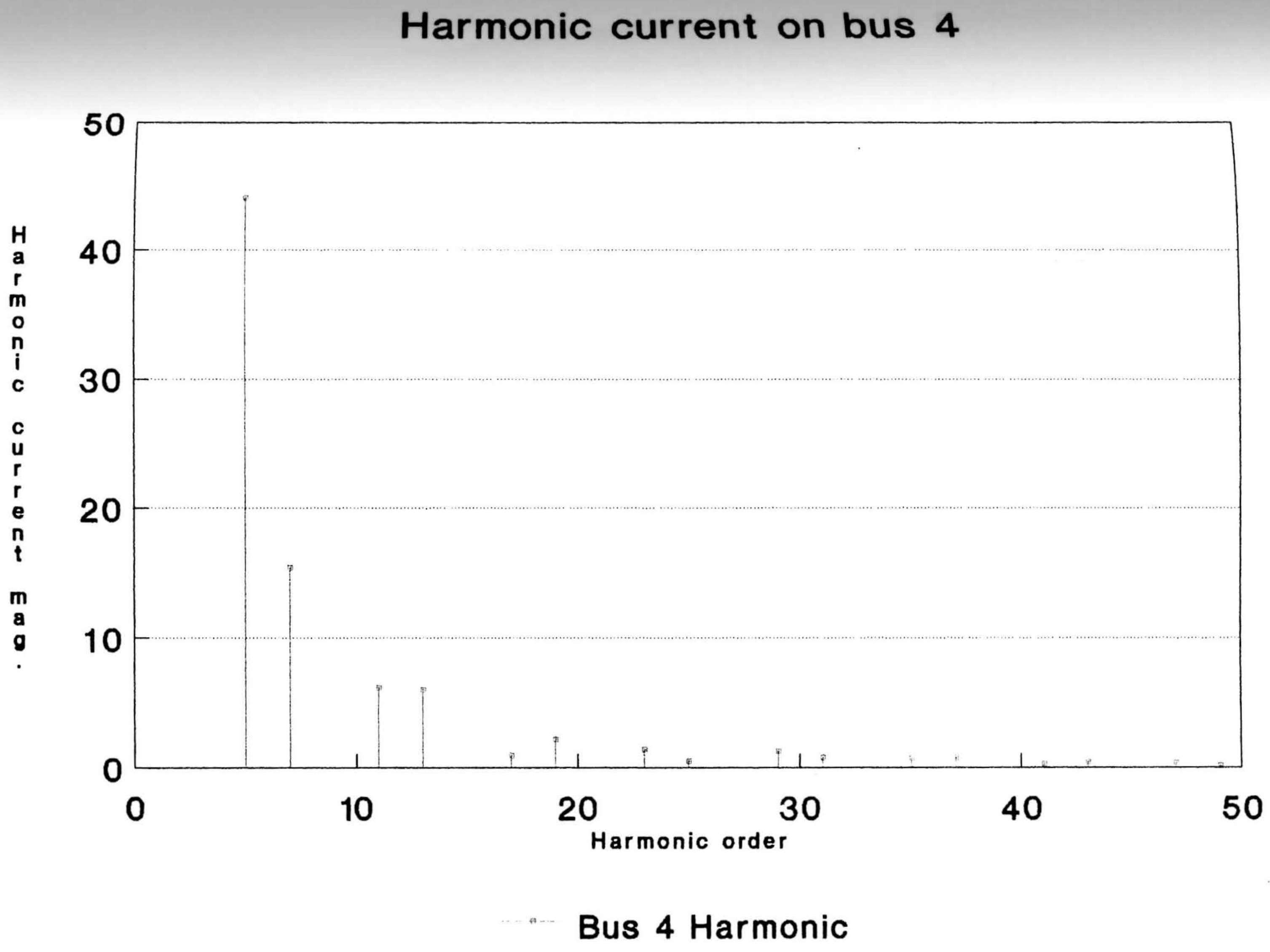


Fig. 5.2 Five bus system harmonic

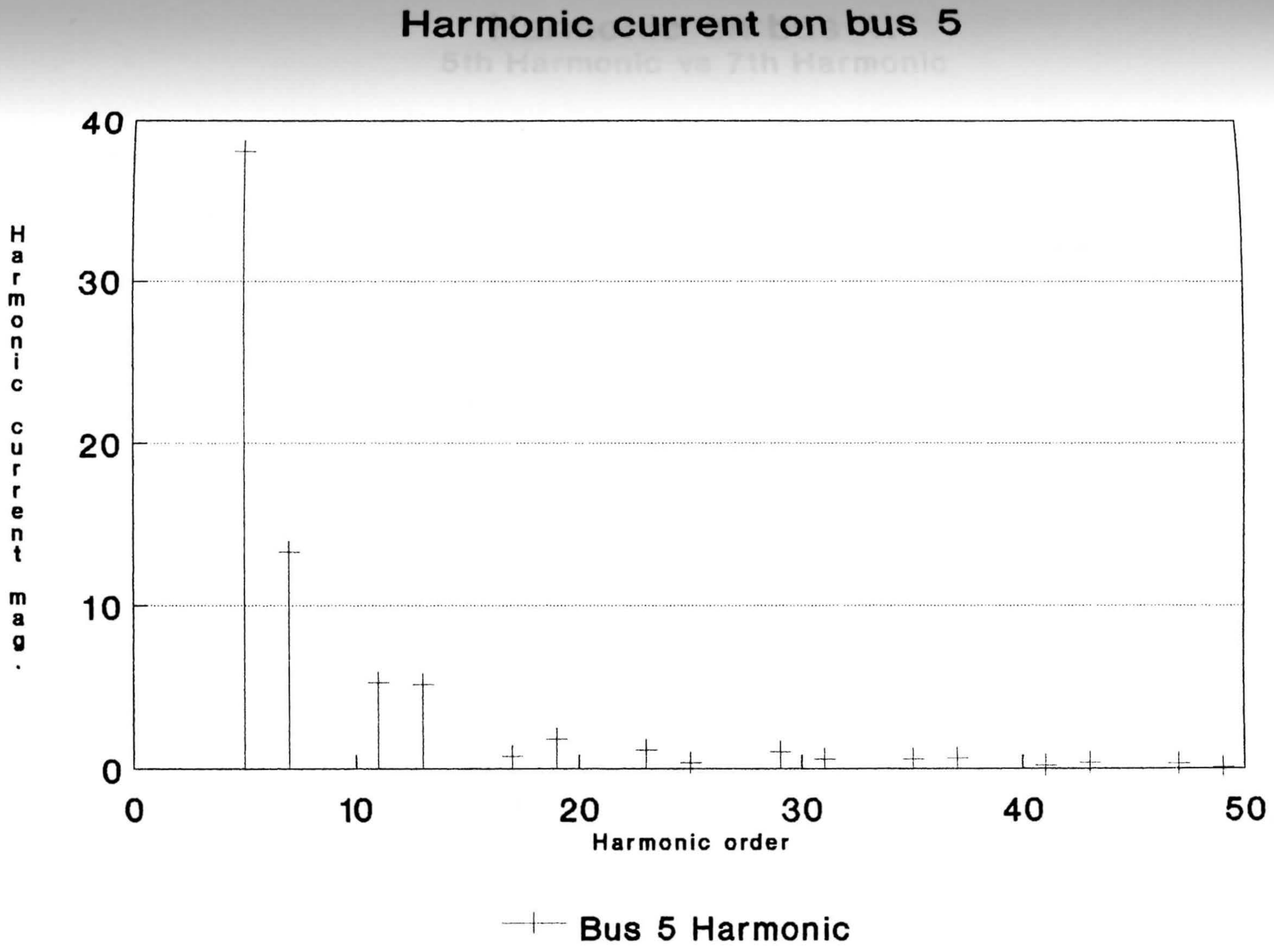


Fig. 5.3 sixteen bus system harmonic

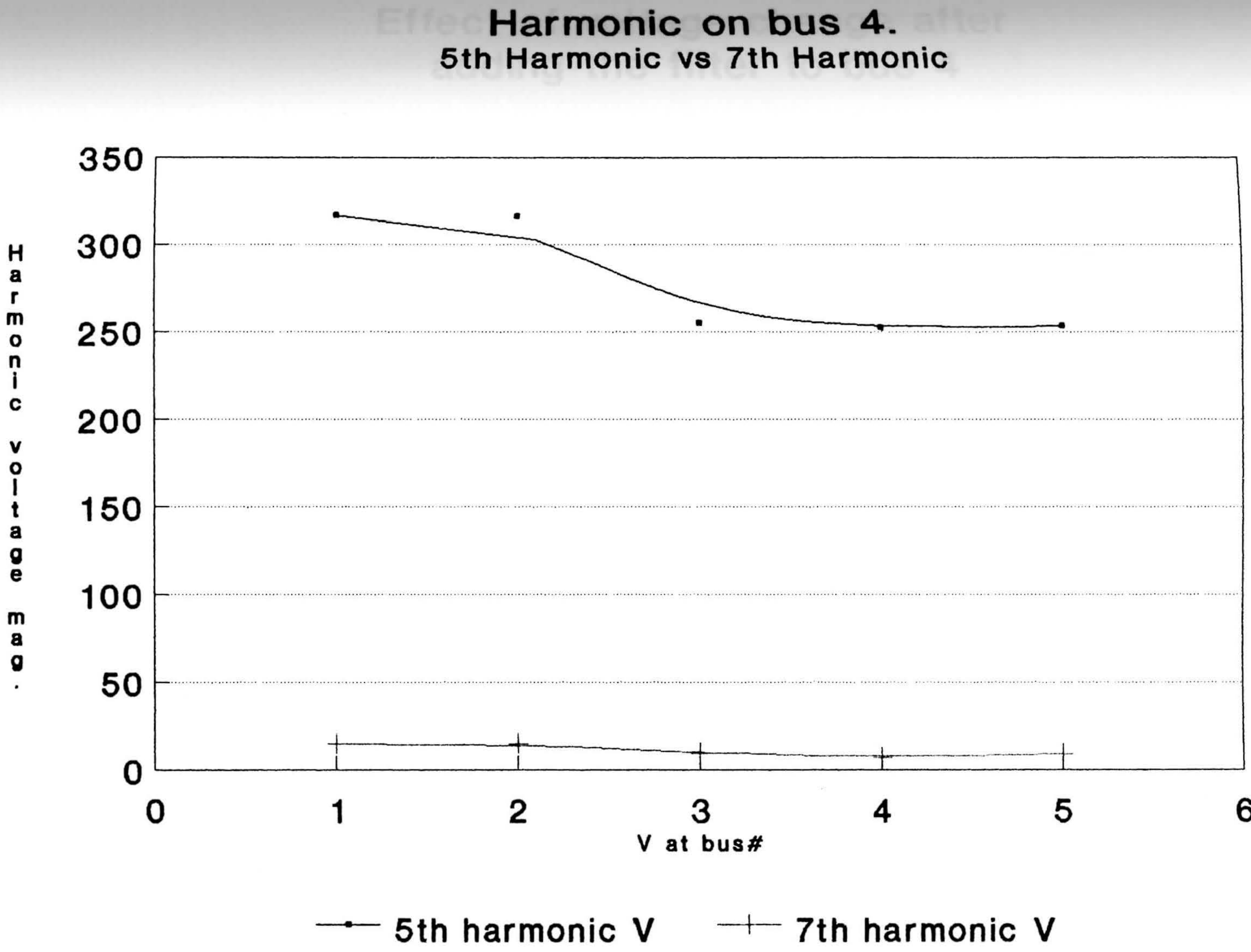


Fig. 5.4 Five Bus system harmonic

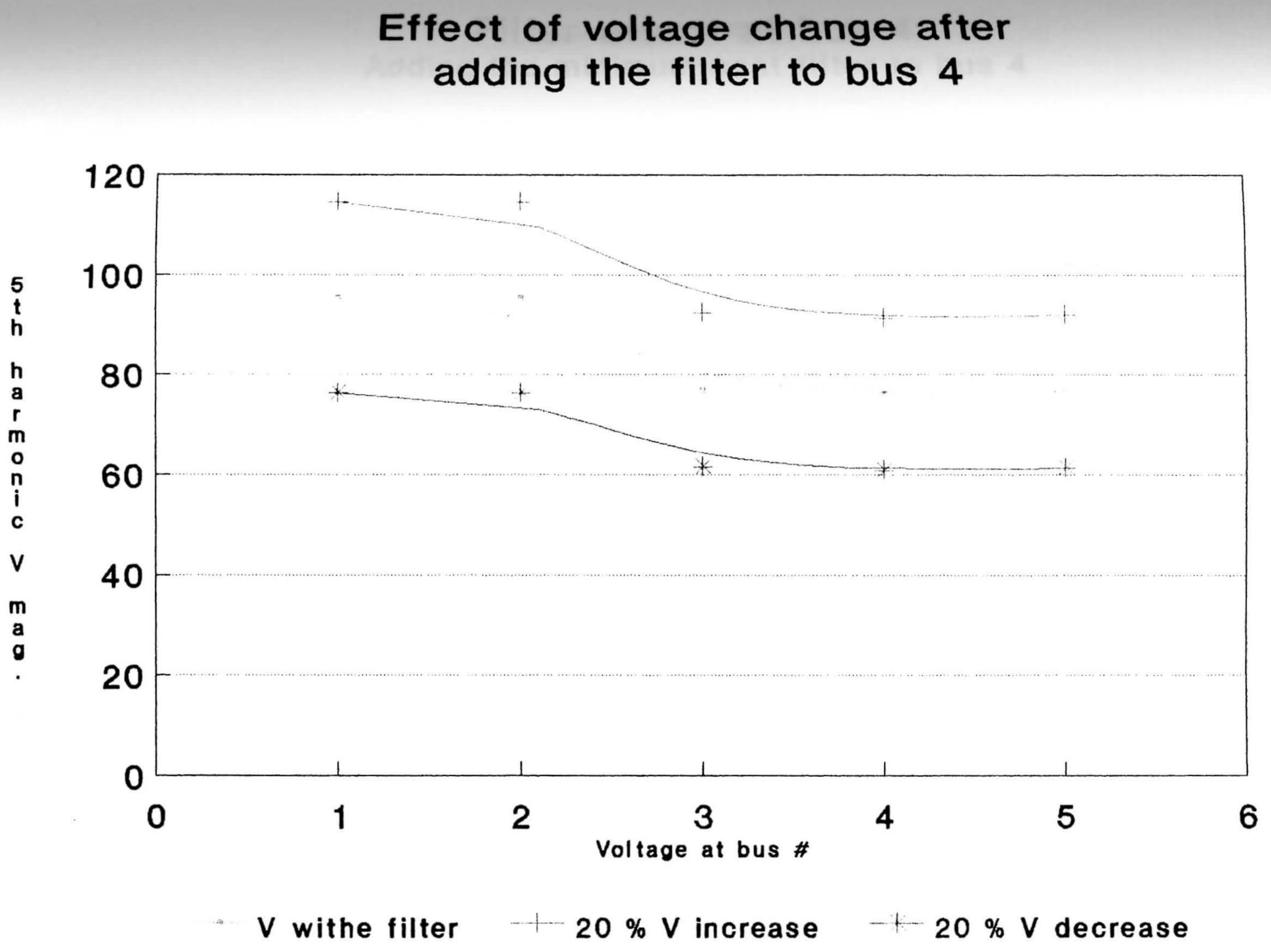


Fig. 5.5 Five Bus system harmonic

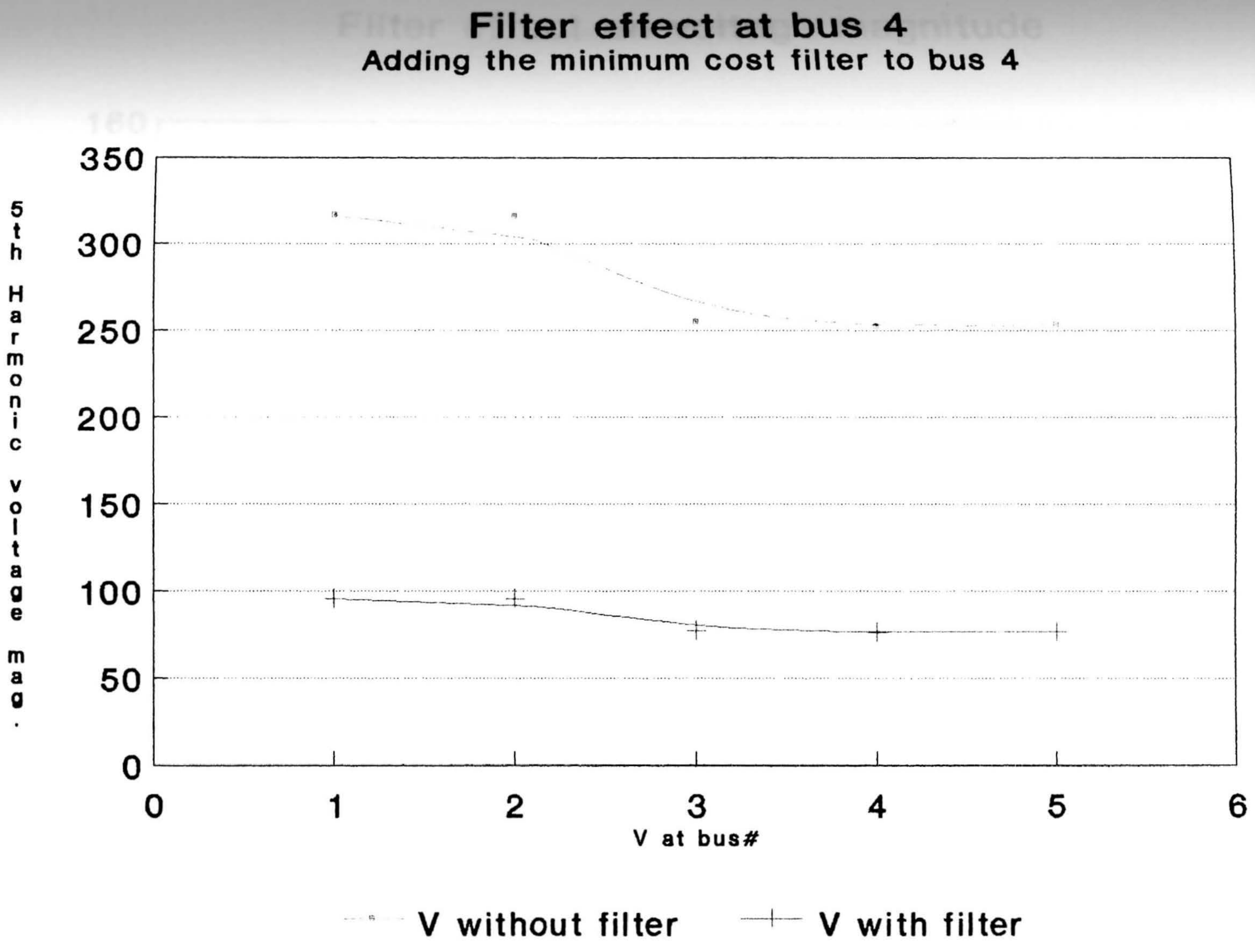


Fig. 5.6 Five bus system harmonic

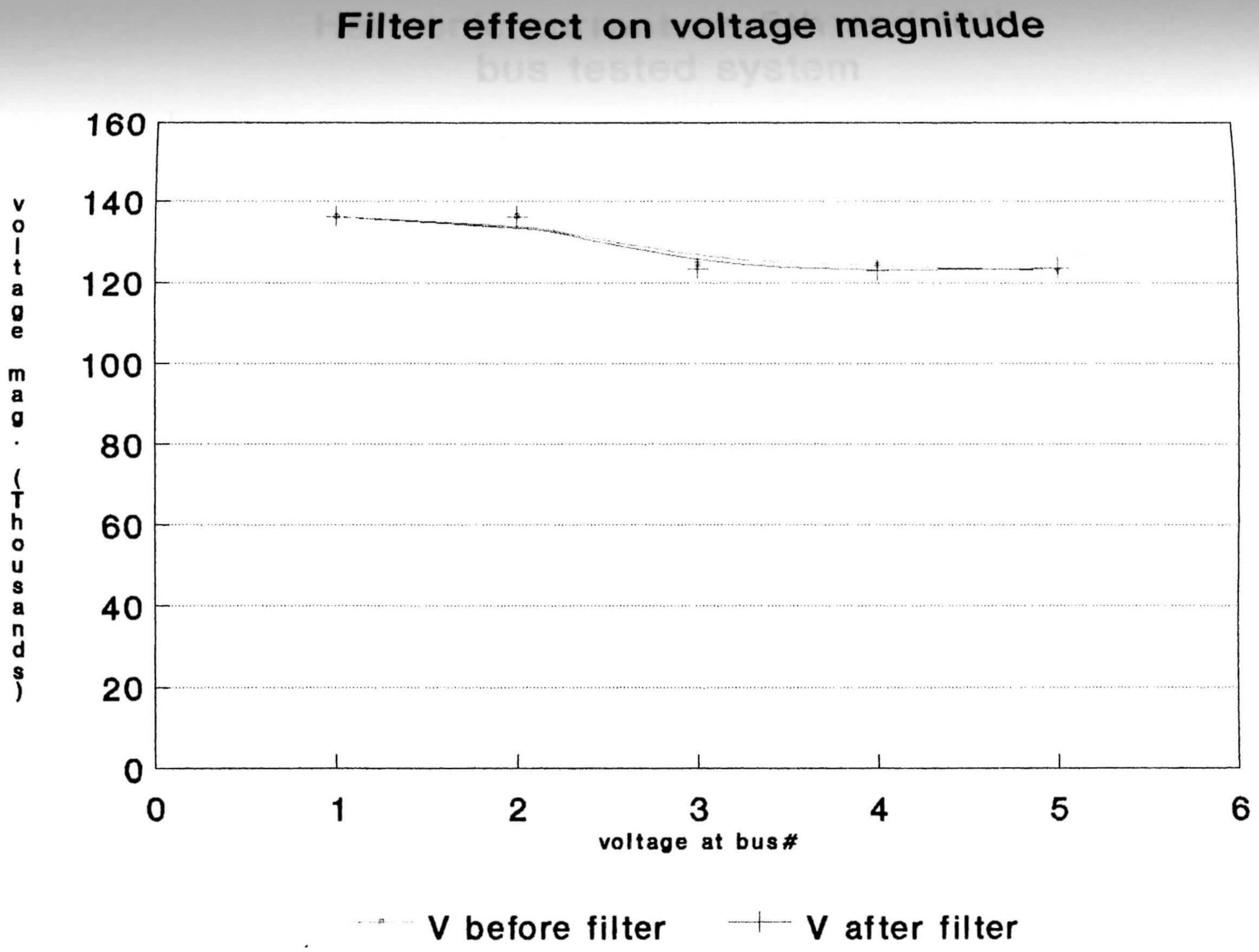


Fig. 5.7 Five bus system harmonic

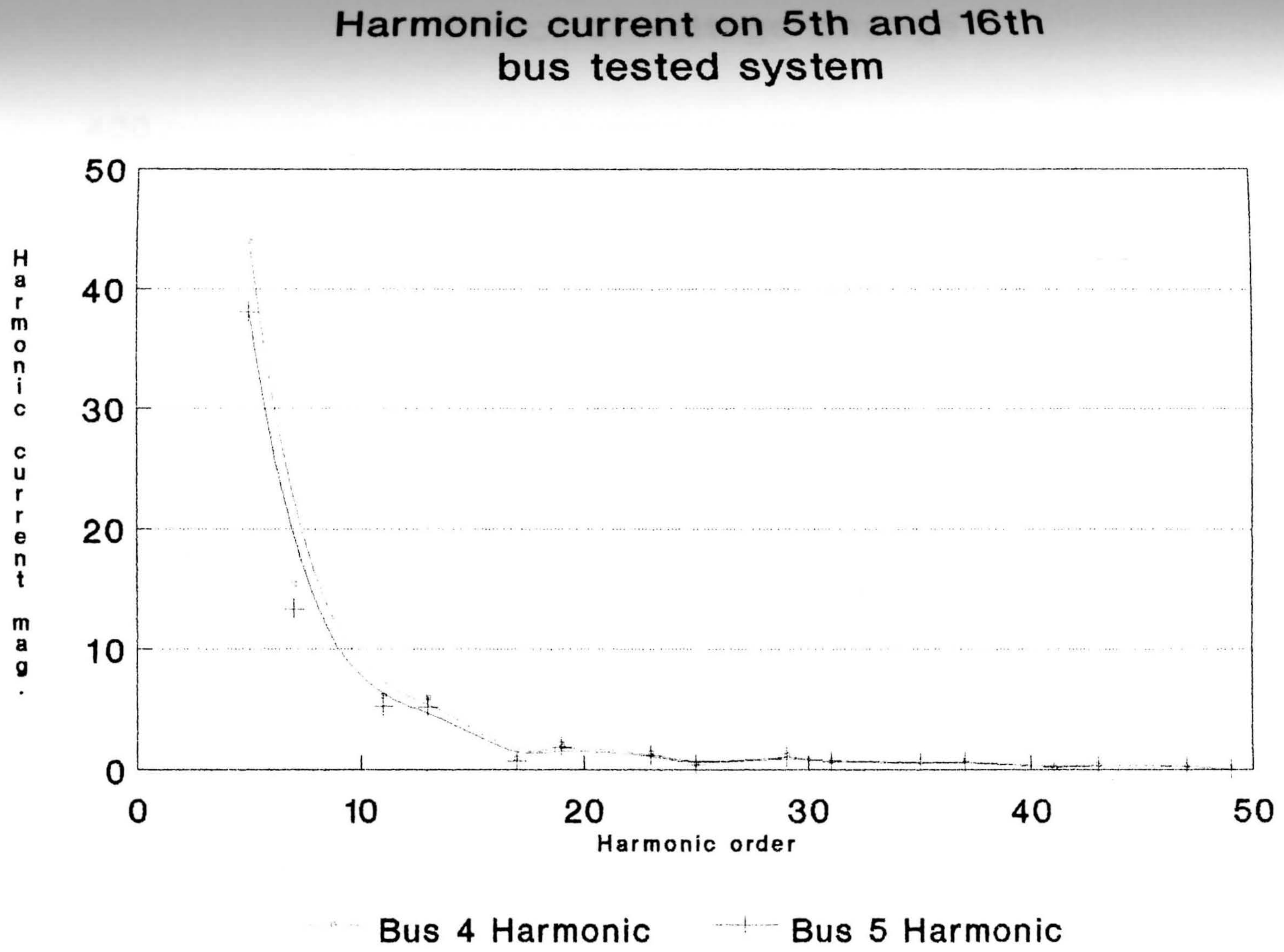


Fig. 5.8 Five bus vs sixteen bus system

Chapter VI

CONCLUSION

6.1 Introduction

The response of electrical networks to harmonic voltages and currents is a significant factor in the application of ac/dc power converters on distribution systems. Since system configurations continually change (particularly the installation and switching of capacitor banks), tolerable network harmonic response may not only become intolerable at times in specific locations but also over wide areas served by the system.

When large (5-50 MW) ac/dc power converters are used on a distribution system, harmonic controls are essential. The basis for selecting harmonic cancellation or harmonic filtering is related to the operating characteristics of line-commutated and self-commutated converters. The proliferation of lower rated electronic power switching devices on systems continues, and will continue, to increase background harmonic and noise levels. Therefore, converter manufacturers must reduce the impact of large converters by harmonic cancellation or harmonic filtering.

6.2 Summary

The main contribution of this research is to provide a method of how to suppress the harmonics generated by the ac/dc converters to a low level to meet the IEEE standard

519-1981 for the voltage harmonic factor HFV (<0.001%) at an adequate cost.

From the results of Examples 1 and 2, the requirement was met by suppressing the harmonic level to an acceptable level while keeping the voltage change to its minimum (1.21%) at the bus after the addition of the minimum-cost filter to the system.

As indicated, the changes by the addition of a filter to the 5 bus system have a greater effect on the system than the addition of the filter for the 16-bus since the 5-bus system has a higher internal impedance than the 16 bus system which makes the 16 bus system a unique system, since its effect by the harmonic distribution inside its system is minimized due to its low impedance.

6.3 Recommendations for future efforts

Since the previous testing was done on an assumed balance symmetrical 3-phase system, the following suggestions are made:

1) To examine the harmonic distribution on unbalanced, unsymmetrical systems, which is the usual case on a power transmsion and distribution system.
2) To take the harmonic caused by the capacitor bank overloading or overexcited transformer into consideration for calculating the harmonic interferences.
3) To develop a voltage control system around the testing

bus to keep to a minimum the voltage change caused by the addition of the filter.

4) To develop convenient methods and equipment for the purpose of making harmonic measurements.

APPENDICES

APPENDIX A

SYSTEM DATA FOR 5-BUS TEST SYSTEM

Table A.1 Line data in per-unit on system Bases.

BUS	BUS	Z	Y/2
1	2	0.02+J0.04	0.020
2	3	0.04+J0.20	0.018
3	4	0.02+J0.06	0.010
3	5	0.15+J0.39	0.022
4	5	0.02+J0.04	0.010
5	1	0.08+J0.20	0.020

Table A.2 System Generator Data

BUS #	P3ph (MW)	Q3ph (MVAR)
1	——	——
2	35	25

Table A.3 System Load Data

BUS #	P3ph (MW)	Q3ph (MVAR)
1	——	——
2	15	5
3	35	34
4	45	0
5	60	10

APPENDIX A

A.1 Calculation of the 5th harmonic Y matrix

$Y11 = Y12 + Y15 + Yc1$

$= (1/Z12) + (1/Z15) + Zc1$

$= (1/.02+j.04*5) + (1/.08+j.2*5) + (j.04*5)$

$= 0.5745 - j5.7441$ mhos

$Y22 = Y12 + Y23 + YC2$

$= (1/.02+j.04*5) + (1/.04+j.2*5) + (j.038*5)$

$= 0.5350 - j5.7589$ mhos

$Y33 = Y23 + Y34 + Y35 + Yc3$

$= (1/.04+j.2*5)+(1/.02+j.06*5)+(1/.15+j.399*5)+(j.05*5)$

$= 0.2987 - j4.5654$ mhos

$Y44 = Y34 + Y45 + Yc4$

$= (1/.02+j.06*5) + (1/.02+j.04*5) + (j.02*5)$

$= 0.8162 - j8.1691$ mhos

$Y55 = Y15 + Y35 + Y45 + Yc5$

$= (1/.08+j.2*5)+(1/.15+j.39*5)+(1/.02+j.04*5)+(j.052*5)$

$= 0.6158 - j6.2072$ mhos

APPENDIX A

A.2 Calculation of the 7th harmonic Y matrix

Y11 = Y12 + Y15 + Yc1

= (1/.02+j.04*7) + (1/.08+j.2*7) + (j.04*7)

= 0.2945 - j3.9853 mhos

Y22 = Y12 + Y23 + Yc2

= (1/.02+j.04*7) + (1/.04+j.2*7) + (j.038*7)

= 0.2742 - j4.001 mhos

Y33 = Y23 + Y34 + Y35 + Yc3

= (1/.04+j.2*7)+(1/.02+j.06*7)+(1/.15+j.399*7)+(j.05*7)

= 0.1527 - j3.0963 mhos

Y44 = Y34 + Y45 + Yc4

= (1/.02+j.06*7) + (1/.02+j.04*7) + (j.02*7)

= 0.3669 - J5.7889 mhos

Y55 = Y15 + Y35 + Y45 + Yc5

= (1/.08+j.2*7)+(1/.15+j.39*7)+(1/.02+j.04*7)+(j.052*7)

= 0.3137 - j4.2583 mhos

APPENDIX A

The 7th harmonic Y matrix admitance is:

$$\begin{bmatrix} 0.294+j3.99 & -0.25+j3.55 & 0.0 & 0.0 & -.0407+j.712 \\ -0.254+j3.55 & 0.2742-j4.0 & -.02+j.7137 & 0.0 & 0.0 \\ 0.0 & -.02+j0.714 & .153-j3.096 & -.113+j2.38 & -.019+j.3570 \\ 0.0 & 0.0 & -.113+j2.37 & .366-j5.789 & -.02+j0.2833 \\ -0.04+j0.712 & 0.0 & -.019+j.357 & -.253+j3.55 & .313-j4.258 \end{bmatrix}$$

Inverting the above admittance matrix (by using a standard program on a digital computer) yields the following 7th harmonic impedance Z matrix.

$$\begin{bmatrix} .3797+j2.73 & .398+j2.6763 & .238+1.384j & .16+.9182j & .0914+j.5726 \\ .3847+j2.61 & .405+J2.8210 & .2404+j1.42 & .1598+j.921 & .089+j.5547 \\ .1771+j1.02 & .1866+j1.098 & .137+j1.058 & .0879+j.593 & .0426+j.2597 \\ .0758+j.419 & .0801+j.4497 & .0604+j.434 & .0487+j.415 & .0175+j.1065 \\ .1545+j.891 & .159+j.9125 & .1081+j.681 & .079-j.5485 & .0528+j.4394 \end{bmatrix}$$

APPENDIX A

The 5th harmonic Y matrix admittance is

$$\begin{bmatrix} 0.575-j5.744 & -.495+j4.95 & 0.0 & 0.0 & -.0795+j.994 \\ -.495+j4.951 & 0.535-j5.76 & -.04+j0.998 & 0.0 & 0.0 \\ 0.0 & -.039+j.998 & 0.298-j4.57 & -0.22+j3.32 & -.030+j0.498 \\ 0.0 & 0.0 & -0.22+j3.32 & 0.716-j8.17 & -.495+j4.951 \\ -.0795+j.994 & 0.0 & -.038+j.049 & -.495+j4.95 & 0.616-j6.207 \end{bmatrix}$$

Inverting the above admittance matrix (by using a standard program on a digital computer) yields the following 5th harmonic impedance Z matrix.

$$\begin{bmatrix} .857-j8.137 & .851-j8.2202 & .758-j7.075 & .756-j7.161 & .754-j7.0717 \\ .85-j8.222 & .863-j8.1171 & .763-j7.049 & .759-j7.157 & .755-j7.0817 \\ .742-j7.075 & .749-j7.0477 & .693-j5.573 & .685-j5.766 & .675-j5.7764 \\ .754-j7.161 & .759-j7.1552 & .696-j5.766 & .708-j5.700 & .696-j5.7393 \\ .762-j7.071 & .765-j7.0798 & .694-j5.776 & .7036-5.739 & .7098-j5.596 \end{bmatrix}$$

APPENDIX B

SYSTEM DATA FOR 16-BUS TEST SYSTEM

Table B.1 Line Data in Per-Unit on system Bases.

Bus	-- Bus	R	X	B
4	6	0.006650	0.035190	0.074580
8	10	0.006650	0.035190	0.074580
10	11	0.009980	0.052790	0.111900
2	4	0.016640	0.087980	0.186440
2	11	0.016640	0.087980	0.186440
5	7	0.008302	0.045550	0.008129
15	16	0.027680	0.151800	0.027100
11	12	0.006656	0.035192	0.074576
13	14	0.052100	0.177300	0.003707

Table B.2 Transformer Data in per-Unit on system Bases.

Bus	-- Bus	Type	R	X	Tap
1	2	Fix	0.003500	0.035000	1.000
15	2	Fix	0.002722	0.032670	1.000
13	12	Fix	0.002083	0.041670	1.025
3	4	Fix	0.003846	0.038460	1.000
5	6	Fix	0.001667	0.041670	1.000
7	8	Fix	0.001667	0.041670	1.000
9	10	Fix	0.001200	0.024000	1.000

APPENDIX B

Table B.3 System Generator Data

Bus	V_L^{rated} (KV)	P_G^{sched} (MW)	Q_{max} (MVAr)	Q_{min} (MVAr)
1	345.0	——	——	——
3	13.8	110	80	- 40
9	250.0	220	140	-100

Table B.4 System Input Bus Data in Per-Unit on system Bases

Bus	Type	V_{mag}	Delta	P_{gen}	Q_{max}	Q_{min}	P_{load}	Q_{load}
1	Slack	1.00	0.00	——	——	——	0.00	0.00
2	Load	1.00	0.00	0.00	——	——	0.00	0.00
3	Gen	1.05	0.00	1.10	0.80	-0.40	0.10	0.55
4	Load	1.00	0.00	0.00	——	——	0.00	0.00
5	Load	1.00	0.00	0.00	——	——	2.95	0.05
6	Load	1.00	0.00	0.00	——	——	0.00	0.00
7	Load	1.00	0.00	0.00	——	——	0.90	0.20
8	Load	1.00	0.00	0.00	——	——	0.00	0.00
9	Gen	1.05	0.00	2.20	1.40	-1.00	0.15	0.04
10	Load	1.00	0.00	0.00	——	——	0.00	0.00
11	Load	1.00	0.00	0.00	——	——	0.00	0.00
12	Load	1.00	0.00	0.00	——	——	0.00	0.00
13	Load	1.00	0.00	0.00	——	——	0.50	0.02
14	Load	1.00	0.00	0.00	——	——	0.35	0.03
15	Load	1.00	0.00	0.00	——	——	0.00	0.00
16	Load	1.00	0.00	0.00	——	——	1.50	0.20

APPENDIX C

FOURIER ANALYSIS

Analysis based on Fourier series and closed form is usually single for various waveforms. For periodic functions:

$$y = F(x) \qquad (1)$$

$$y = c_1 + a_1 \text{ COS } x + a_2 \text{ COS } 2x + \ldots + b_1 \text{ SIN } x + b_2 \ldots.$$

or

$$y = c_0 + c_1 \text{ SIN } (x+\alpha_1) + c_2 \text{ SIN } (2x+\alpha_2) + \ldots c_n \text{ SIN } (n+\alpha_n) \qquad (2)$$

where

$$c_n = [a_n^2 + b_n^2]^{\frac{1}{2}} \qquad (3)$$

$$c_0 = 1/2\pi \int_0^{2\pi} F(x)\, dx \qquad (4)$$

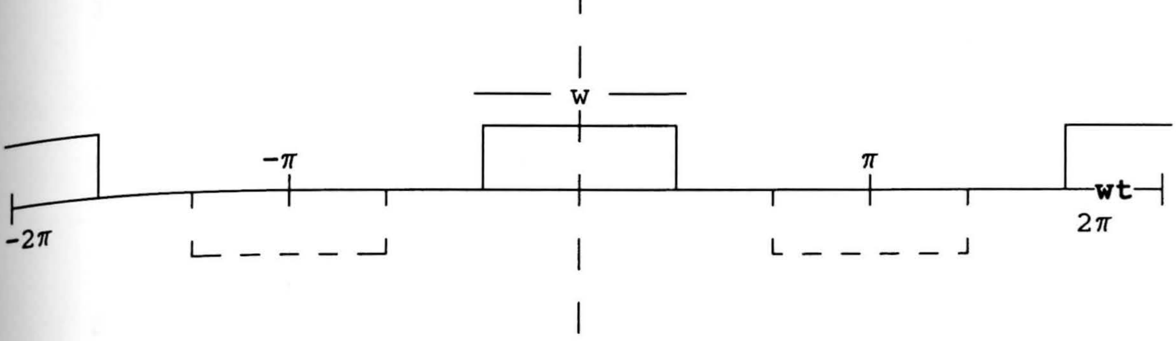
$$a_n = 1/\pi \int_0^{2\pi} F(x) \text{ COS}(nx)\, dx \qquad (5)$$

$$b_n = 1/\pi \int_0^{2\pi} F(x) \text{ SIN}(nx)\, dx \qquad (6)$$

Using these equations, it is interesting and useful to analyze the commonly found wave shapes for the voltages and the current harmonics in the transmission and distribution networks.

Figure (C-1) represents such a typical waveform used to analyze the current harmonics.

APPENDIX C



Fig(C-1) Trains of positive and negative rectangular pulses

The trigonometric form of the fourier series for the above waveform is developed as follows:

$$F1(wt) = A_0/2 + \Sigma\ (Ah^* \ COS(hwt) + Bh^* \ SIN(hwt)) \qquad 7$$

h = harmonic number
w = rad/sec

$$A_0/2 = (1/2\pi) \int_{-w/2}^{w/2} d(wt)$$

$$= (1/2\pi)\ [w/2 + w/2]$$

$$A_0/2 = w/2h \qquad 8$$

$$A_h = (1/\pi) \int_{-w/2}^{w/2} COS(hwt)\ d(wt)$$

$$= (1/(\pi * h))\ [SIN(hw/2) + SIN(hw/2)]$$

$$A_h = (2/(\pi * h))\ SIN(wh/2) \qquad 9$$

$$B_h = (1/\pi) \int_{-w/2}^{w/2} SIN(hwt)\ d(wt)$$

$$= (1/(\pi * h))\ [-COS(wh/2) + COS(-wh/2)]$$

$$B_h = 0 \qquad 10$$

So eq. (7) will be

$$F_1(wt) = w/2\pi + \sum_{h=1}^{n} ((2/h\pi)\ SIN(wh/2) * COS(hwt) + 0\ )$$

APPENDIX C

$F_1(wt) = w/2\pi + (2/\pi) * \mathrm{SIN}(w/2) * \mathrm{COS}(wt)$

$+ (2/2\pi) * \mathrm{SIN}(2w/2) * \mathrm{COS}2wt$

$+ (2/3\pi) * \mathrm{SIN}(3w/2) * \mathrm{COS}3wt$

$+ (2/4\pi) * \mathrm{SIN}(4w/2) * \mathrm{COS}4wt$

$+ \; . \; . \; . \; . \; . \;)$ 11

Since the converter produces positive and negative pulses, as shown in Fig (C-1), the negative group gives the following fourier series:

$F_2(wt) = -A_0/2 + \sum_{h=1}^{n}(-Ah * \mathrm{COS}(hwt) - Bh * \mathrm{SIN}(hwt))$ 12

Where:

$A_0/2 = -1/2\pi \int_{-w/2 \pm h\pi}^{w/2 \pm h\pi} d(wt)$

$A_0/2 = -w/2\pi$ 13

$A_h = -1/\pi \int_{-w/2 \pm h\pi}^{w/2 \pm h\pi} * \mathrm{COS}(hwt)\,d(wt)$

$= -2/h\pi\ [\mathrm{SIN}(hw/2 \pm h\pi)]$ 14

If h is even, $\mathrm{SIN}(hw/2 \pm h\pi) = \mathrm{SIN}(hw/2)$

If h is odd, $\mathrm{SIN}(hw/2 \pm h\pi) = -\mathrm{SIN}(hw/2)$

$B_h = -1/\pi \int_{-w/2 \pm h\pi}^{w/2 \pm h\pi} * \mathrm{SIN}(hwt)\,d(wt)$

$= 0$ 15

So eq. (7) for the negative pulses is:

$F_2(wt) = -w/2\pi + \sum_{h=1}^{n} -2/h\pi\ [\mathrm{SIN}(hw/2 \pm h\pi)\ \mathrm{COS}hwt]$

$F_2(wt) = -w/2\pi + (2/\pi * \mathrm{SIN}(w/2)\mathrm{COS}(wt)$

$- 2/2\pi * \mathrm{SIN}(2w/2)\mathrm{COS}(2wt)$

$+ 2/3\pi * \mathrm{SIN}(3w/2)\mathrm{COS}(3wt)$

$- 2/4\pi * \mathrm{SIN}(4w/2)\mathrm{COS}(4wt)$

$+ \; . \; . \; . \; . \; . \;)$ 16

APPENDIX C

The sum of the two fourier series of the positive pulses Eq.(11) and the negative pulses Eq.(16) is:

$$F_3(wt) = F_1(wt) + F_2(wt)$$

$$= (4/\pi)\ [\mathrm{SIN}(w/2)\mathrm{COS}(wt) + (1/3)\mathrm{SIN}(3w/2)\mathrm{COS}(3wt)$$

$$+ (1/5)\ \mathrm{SIN}(5w/2)\mathrm{COS}(5wt) + (1/7)\mathrm{SIN}(7w/2)\mathrm{COS}(7wt)$$

$$+ (1/9)\ \mathrm{SIN}(5w/2)\mathrm{COS}(5wt)\ .\ .\ .\ .\ .\ .\ ] \qquad 17$$

Notice the even order harmonic have been eliminated.

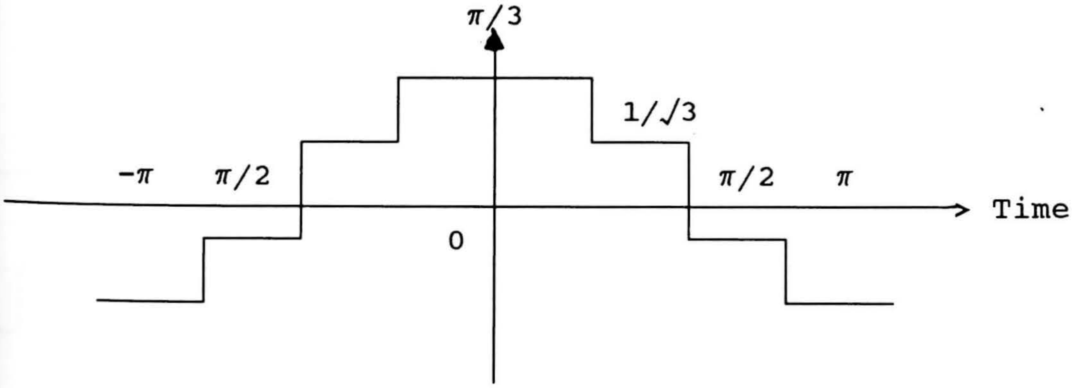
For a 6-pulse converter $w = 2\pi/3$ and changing the height to I_d (direct current) the ac current phase a is:

$$Ia1 = (2\surd 3/\pi)\ I_d * (\mathrm{COS}(wt) - (1/5)\ \mathrm{COS}(5wt) +$$

$$+ (1/7)\ \mathrm{COS}(wt) - (1/11)\ \mathrm{COS}(11wt)$$

$$+ (1/13)\ \mathrm{COS}(13wt)\ .....\ ) \qquad 18$$

For the wye-star transformer connection, a factor of $\surd 3$ is introduced in the transformer ratio and the current waveform is as shown in Fig.(C-2).



Fig(C-2) Time domain representation of a 6-pulse waveform with delta-star

And its fourier series is:

$$Ia2 = (2\sqrt{3}/\pi)\ I_d * [COS(wt + COS(5wt) -(1/7)COS(7wt) - (1/11)\ COS(11wt) +(1/13)\ COS(13wt) +(1/17)\ COS(17wt)\ ....] \qquad 19$$

For a 12-pulse configuration shown in Fig. (C-3) composed of two 6-pulse converters fed from sets of 3 phase transformers, connected in parallel, the resultant of the ac current adding the wye-wye Eq.(18) and the delta-wye Eq.(19) transformers result in the following fourier series:

$$Ia3 =(4\sqrt{3}/\pi) * I_d * [COS(wt) -(1/11)\ COS(11wt) +(1/13)COS(13wt) -(1/23)COS(23wt)+.....\ ] \qquad 20$$

Notice this series contains only harmonics of orders 12n ± 1. Harmonic currents of order 6n ± 1 (n = odd) circulate between the two transformers but do not appear in the ac network.

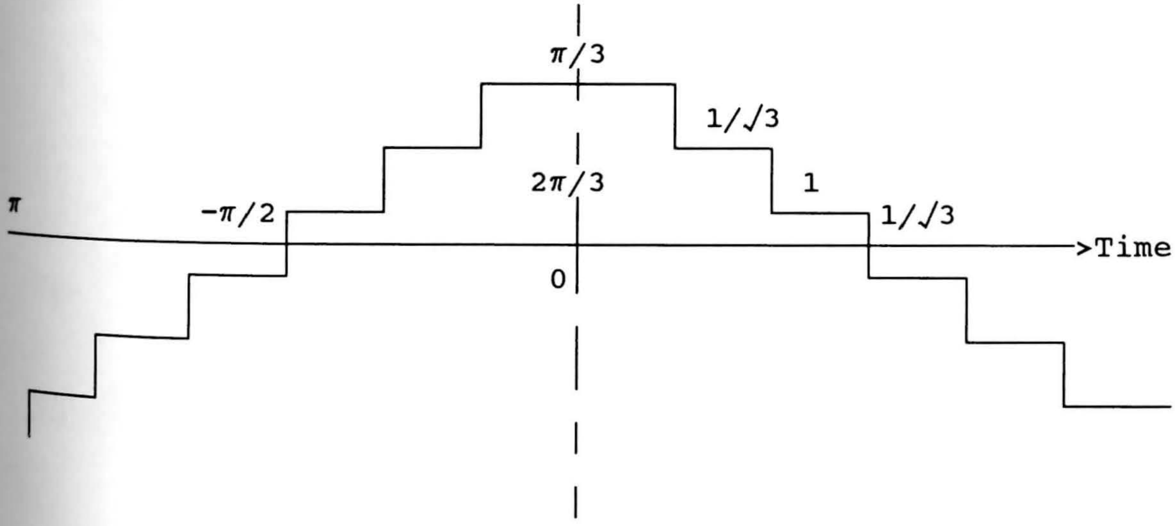


Fig. (C-3) Time domain representation of the 12-pulse phase current

APPENDIX D

```
     $JOB
     C        THIS PART OF THE PROGRAM CALCULATES THE OVERLAP ANGLE OR THE
     C        ANGLE OF COMMUTATION "U" FOR A KNOWN DC LOAD
     C        ================================================================
              DIMENSION G(70),DV(70),D(70),P(70)
              COMPLEX V1,V2,V3,V4,V5,VD1,VD2,VD,ID,VD3,VD4,VD5 ,P
              REAL DL,PH1,PH2,AL,F,K,TH,H,W,L,S,Q
              W  = 376.9911
              S  = 45000000.0
              L  = 0.21
              V1 =(120949.1,-20956.84)
              WRITE(6,*)'        DC VOLTAGE                   DC CURRENT
             . DC POWER '
              WRITE(6,*)'        ***********                ************             *
             .**********'
              DO 1 I=1,60
                X=I
                U=((60-X)/180)*3.1416
              G(I)=(3*V1*(1+COS(U)))/(1.414*3.1416)
              D(I)=(V1*(1-COS(U))/(1.414*W*L))
              P(I)= D(I)*G(I)
              Q = REAL (P(I))
              IF (Q .LT. S) GO TO 10
              WRITE(6,*) G(I),D(I),P(I)
       1      CONTINUE
      10      TH = (U/3.1416)*180
              WRITE(6,*) G(I),D(I),P(I)
              WRITE(6,*) '  '
              WRITE(6,*) '    '
              WRITE(6,*) 'THE ANGLE OF COMMUTATION "U" IS'
              WRITE(6,*) '==============================='
              WRITE(6,*) '  '
              WRITE(6,*) TH
              WRITE(6,*) '  '
              WRITE(6,*) '   '
              STOP
              END
```

```
     $ENTRY
    DC VOLTAGE                     DC CURRENT                  DC POWER
    ***********                   ************                **********
  123750.4000000                 523.9768000 (  0.6484235E 08,    0.0000000E 00)
  124965.9000000                 507.8986000 (  0.6347003E 08,    0.0000000E 00)
  126168.3000000                 491.9948000 (  0.6207416E 08,    0.0000000E 00)
  127357.0000000                 476.2702000 (  0.6065637E 08,    0.0000000E 00)
  128531.9000000                 460.7294000 (  0.5921845E 08,    0.0000000E 00)
  129692.5000000                 445.3774000 (  0.5776211E 08,    0.0000000E 00)
  130838.5000000                 430.2192000 (  0.5628926E 08,    0.0000000E 00)
  131969.5000000                 415.2587000 (  0.5480152E 08,    0.0000000E 00)
  133085.1000000                 400.5009000 (  0.5330074E 08,    0.0000000E 00)
  134185.2000000                 385.9501000 (  0.5178882E 08,    0.0000000E 00)
  135269.3000000                 371.6110000 (  0.5026757E 08,    0.0000000E 00)
  136336.9000000                 357.4880000 (  0.4873882E 08,    0.0000000E 00)
  137388.0000000                 343.5849000 (  0.4720445E 08,    0.0000000E 00)
  138422.1000000                 329.9062000 (  0.4566632E 08,    0.0000000E 00)
  139438.9000000                 316.4565000 (  0.4412635E 08,    0.0000000E 00)


THE ANGLE OF COMMUTATION "U" IS
===============================
```

```
          45.0000000

 STATEMENTS EXECUTED=      150
 CORE USAGE      OBJECT CODE=     2000 BYTES,ARRAY AREA=     1400 BYTES,TOTAL AREA AVAILABLE= 2406288  BYTES
 DIAGNOSTICS         NUMBER OF ERRORS=        0, NUMBER OF WARNINGS=        0, NUMBER OF EXTENSIONS=       0
 COMPILE TIME=     0.01 SEC,EXECUTION TIME=     0.01 SEC,     16.09.53    MONDAY       22 APR 91    WATFIV - MAR 1980 V2L0

        C$STOP
```

APPENDIX E

```
$JOB
C        5 BUS TEST SYSTEM WITH PER-UNIT BASES
C        S=100MVA,V=138KVLL,I=S/1.7321*KVLL=418.3698,Z=VL/I=190.44OHM
C       ****************************************************
        COMPLEX Y(5,5),V1,V2,V3,V4,V5,S1,S2,S3,S4,S5,I5,SB1,SB2,SB3,SB4
        COMPLEX SB5,VV1,VV2,VV3,VV4,VV5,DV1,DV2,DV3,DV4,DV5,I1,I2,I3,I4
        COMPLEX LV15,LV12,LV23,LV35,LV34,LI15,LI12,LI23,LI34,LI35,LI17
        COMPLEX SL12,SL21,SL23,SL32,SL35,SL53,SL34,SL43,SL15,SL51,PL12
        COMPLEX IH ,I7,I8,I9,I10,I11,V6,Z5(5,5),IH15,IH25,IH35,IH45,IH55
        COMPLEX VH15,VH25,VH35,VH45,VH55,Z(5,5),Z7(5,5),VH17,VH27,VH37
        COMPLEX VH47,VH57,IH17,IH27,IH37,IH47,IH57,IH1H,IH2H,IH3H,IH4H
        COMPLEX IH5H,VH1H,VH2H,VH3H,VH4H,VH5H,ZH(5,5)
C       COMPLEX VH9H,VH10H
        DIMENSION F(40),G(40),H(40),P(40),Q(40),R(40),S(40),T(40),V(40)
        DIMENSION W(40),L(40)
        REAL DL,AL,U,D1,F2,VH8H
        COMMON TOL
        INTEGER O,A,B,C,D,E
        TOL=.00001
        V1=(1.0,0.0)
        V2=(1.0,0.0)
        V3=(1.0,0.0)
        V4=(1.0,0.0)
        V5=(1.0,0.0)
        S1=(0.0,0.0)
        S2=(0.20,0.20)
        S3=(-0.35,-0.34)
        S4=(-0.45,0.00)
        S5=(-0.60,-0.10)
        NOBUS=5
        A=1
        B=2
        C=3
        D=4
        E=5
        WRITE(6,*)'    '
        WRITE(6,*)'  '
        READ,((Y(K,O),O=1,5),K=1,5)
        READ,((Z(J,K),K=1,5),J=1,5)
        READ,((Z7(I,O),O=1,5),I=1,5)
        READ,((ZH(I,O),O=1,5),I=1,5)
         PRINT,'Y MATRIX'
         WRITE(6,*)'***********'
         PRINT 5 ,((Y(K,O),O=1,5),K=1,5)
5        FORMAT(10E13.5)
         WRITE(6,*)' '
         WRITE(6,*)'5TH HARMONIC Z MATRIX'
         WRITE(6,*)'*********************'
         PRINT 22 ,((Z(J,K),K=1,5),J=1,5)
22       FORMAT(10E13.5)
         WRITE(6,*)'     '
         WRITE(6,*)'7TH HARMONIC Z MATRIX'
         WRITE(6,*)'*********************'
         PRINT 23 ,((Z7(I,O),O=1,5),I=1,5)
23       FORMAT(10E13.5)
         WRITE(6,*) '5TH HARMONIC Z MATRIX AFTER ADDING THE FILTER'
         WRITE(6,*) '*********************************************'
         PRINT 24 ,((ZH(I,O),O=1,5),I=1,5)
24       FORMAT(10E13.5)
         WRITE(6,*)'      '
```

```
      WRITE(6,*)'      '
C     THIS PART OF THE PROGRAM CALCULATS VALUES FOR THE BUS VOLTAGES
C     ================================================================
      WRITE(6,*)'VALUES FOR THE BUS VOLTAGES'
      WRITE(6,*)'***************************'
      WRITE(6,*)'V2=REAL   V2=IMAGE  V3=REAL V3=IMAG    V4=REAL V4=IMAG
     .   V5=REAL V5=IMAG'
1     VV2=(1/Y(2,2))*(CONJG(S2)/(CONJG(V2))-(V1*Y(2,1)+V3*Y(2,3)+V4*
     . Y(2,4)+V5*Y(2,5)))
      DV2=VV2-V2
      V2=V2+(1.4*DV2)
C     WRITE(6,*)'V2 ='
C     WRITE(6,*)  V2
      VV3=(1/Y(3,3))*(CONJG(S3)/(CONJG(V3))-(V1*Y(3,1)+V2*Y(3,2)+V4*
     * Y(3,4)+V5*Y(3,5)))
      DV3=VV3-V3
      V3=V3+(1.4*DV3)
C     WRITE(6,*)'V3 ='
C     WRITE(6,*) V3
      VV4=(1/Y(4,4))*(CONJG(S4)/(CONJG(V4))-(V1*Y(4,1)+V2*Y(4,2)+V3*
     * Y(4,3)+V5*Y(4,5)))
      DV4=VV4-V4
      V4=V4+(1.4*DV4)
C     WRITE(6,*) V4
C     WRITE(6,*) 'V5'
      VV5=(1/Y(5,5))*(CONJG(S5)/(CONJG(V5))-(V1*Y(5,1)+V2*Y(5,2)+V3*
     * Y(5,3)+V4*Y(5,4)))
      DV5=VV5-V5
      V5=V5+(1.4*DV5)
C     WRITE(6,*) 'V2=REAL    V2=IMAG    V3=REAL    V4=REAL    V4=IMAG
C    .   V5=REAL V5=IMAG'
      WRITE(6,10) V2,V3,V4,V5
10    FORMAT(1X,F8.6,1X,F8.5,2X,F8.5,1X,F8.5,2X,F8.5,1X,F8.5,2X,F8.5,
     . 1X,F8.5)
      GG2=ABS(REAL(DV2))
      BB2=ABS(AIMAG(DV2))
      GG3=ABS(REAL(DV3))
      BB3=ABS(AIMAG(DV3))
      GG4=ABS(REAL(DV4))
      BB4=ABS(AIMAG(DV4))
      GG5=ABS(REAL(DV5))
      BB5=ABS(AIMAG(DV5))
C     IF(GG1.GT.TOL) GO TO 1
      IF(GG2.GT.TOL) GO TO 1
      IF(BB2.GT.TOL) GO TO 1
      IF(GG3.GT.TOL) GO TO 1
      IF(BB3.GT.TOL) GO TO 1
      IF(GG4.GT.TOL) GO TO 1
      IF(BB4.GT.TOL) GO TO 1
      IF(GG5.GT.TOL) GO TO 1
      IF(BB5.GT.TOL) GO TO 1
      WRITE(6,*) '      '
C     THIS PART OF THE PROGRAM CALCULATES THE POWER AT EACH BUS
C     ========================================================
      I1=(V1*Y(1,1))+(V2*Y(1,2))+(V3*Y(1,3))+(V4*Y(1,4))+(V5*Y(1,5))
      I2=(V1*Y(2,1))+(V2*Y(2,2))+(V3*Y(2,3))+(V4*Y(2,4))+(V5*Y(2,5))
      I3=(V1*Y(3,1))+(V2*Y(3,2))+(V3*Y(3,3))+(V4*Y(3,4))+(V5*Y(3,5))
      I4=(V1*Y(4,1))+(V2*Y(4,2))+(V3*Y(4,3))+(V4*Y(4,4))+(V5*Y(4,5))
      I5=(V1*Y(5,1))+(V2*Y(5,2))+(V3*Y(5,3))+(V4*Y(5,4))+(V5*Y(5,5))
      SB1=V1*CONJG(I1)
```

```
      SB2=V2*CONJG(I2)
      SB3=V3*CONJG(I3)
      SB4=V4*CONJG(I4)
      SB5=V5*CONJG(I5)
C     THIS PART OF THE PROGRAM CALCULATES THE RMS VALUE OF EACH CHARAT.
C     HARMONIC CURRENT
C     =================================================================
C
C     WRITE(6,*) 'VALUE FOR V6'
      I7=I1*418.3698
      I8=I2*418.3698
      I9=I3*418.3698
      I10=I4*418.3698
      I11=I5*418.3698
      V6 = V4*1.00*138000
C     WRITE(6,*) V6
      WRITE(6,*) 'POS. SEQ. HARMONIC CURRENT FROM BUS 4'
      WRITE(6,*) '**************************************'
      U= ((45.0/180.0)*3.1416)
      AL=((25.0/180.0)*3.1416)
      DL= ((57.3/180.0)*3.1416)
C     I7=1700.0
      DO 15 I=1,8
       X=(6*I)+1
       F(I)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                            ((SIN(X+1)*(U/2))/(X+1))**2
     . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     . *AL)+U))**0.5
      D1=COS(AL)-COS(DL)
      L(I)=(2.4495*(54.1)*F(I))/(3.141*X*(COS(AL)-COS(AL-U)))
      G(I)=(1.7321*V6*F(I))/(3.1416*377.0*0.21*X)
15    WRITE(6,*) X,G(I)
C     WRITE(6,*) G(1)
      DO 16 I=1,8
       X=(6*I)+1
       R(I)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                            ((SIN(X+1)*(U/2))/(X+1))**2
     . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     . *AL)+U))**0.5
      D1=COS(AL)-COS(DL)
      L(I)=(2.4495*(54.1)*F(I))/(3.141*X*(COS(AL)-COS(AL-U)))
      Q(I)=(1.7321*V6*R(I))/(3.1416*377.0*0.21*X)
16    CONTINUE
      WRITE(6,*) '      '
      WRITE(6,*) 'NEG. SEQ. HARMONIC CURRENT FROM BUS 4 '
      WRITE(6,*) '**************************************'
      DO 25 J=1,8
       X=(6*J)-1
       W(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                            ((SIN(X+1)*(U/2))/(X+1))**2
     . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     . *AL)+U))**0.5
      D1=COS(AL)-COS(DL)
      T(J)=(2.4495*(54.1)*W(J))/(3.141*X*(COS(AL)-COS(AL-U)))
      S(J)=(1.7321*V6*W(J))/(3.1416*377.0*0.21*X)
25    WRITE(6,*) X,S(J)
C     WRITE(6,*)  S(1)
C     WRITE(6,*) '***************************************************'
      DO 20 J=1,8
       X=(6*J)-1
```

```
      H(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                         ((SIN(X+1)*(U/2))/(X+1))**2
     . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     . *AL)+U))**0.5
      D1=COS(AL)-COS(DL)
C     IH=(F2*I7)/(X*D1)
      P(J)=(1.7321*V6*H(J))/(3.1416*377.0*0.21*X)
20    CONTINUE
C0    WRITE (6,*)   P(J)
C     THIS PART OF THE PROGRAM CACULATE THE RMS VALUE OF THE HARMONIC
C     VOLTAG ON EACH BUS CAUSED BY THE 5TH HARMONIC OF BUS 4
C     ****************************************************************
      IH15=(0.0,0.0)
      IH25=(0.0,0.0)
      IH35=(0.0,0.0)
      IH45= P(1)
      IH55=(0.0,0.0)
      VH15=((Z (1,1)*IH15)+(Z (1,2)*IH25)+(Z (1,3)*IH35)+(Z (1,4)*IH45
     .  )+(Z (1,5)*IH55))
      VH25=((Z (2,1)*IH15)+(Z (2,2)*IH25)+(Z (2,3)*IH35)+(Z (2,4)*IH45
     .  )+(Z (2,5)*IH55))
      VH35=((Z (3,1)*IH15)+(Z (3,2)*IH25)+(Z (3,3)*IH35)+(Z (3,4)*IH45
     .  )+(Z (3,5)*IH55))
      VH45=((Z (4,1)*IH15)+(Z (4,2)*IH25)+(Z (4,3)*IH35)+(Z (4,4)*IH45
     .  )+(Z (4,5)*IH55))
      VH55=((Z (5,1)*IH15)+(Z (5,2)*IH25)+(Z (5,3)*IH35)+(Z (5,4)*IH45
     .   )+ (Z (5,5)*IH55))
      WRITE(6,*)'   '
      WRITE(6,*) '  '
      WRITE(6,*)'5TH HARMONIC VOLTAGE AT '
      WRITE(6,*)'**********************'
      WRITE(6,*)'     BUS1               BUS2              BUS3
     .           BUS4          BUS5'
C     WRITE(6,*) '     '
      WRITE(6,*) '     '
      WRITE(6,*) VH15,VH25,VH35,VH45,VH55
C    FORMAT(1X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,
C    . 1X,F9.3,2X,F8.4,1X,F9.3)
C     THIS PART OF THE PROGRAM CACULATE THE RMS VALUE OF THE HARMONIC
C     VOLTAG ON EACH BUS CAUSED BY THE 7TH HARMONIC OF BUS 4
C     ****************************************************************
      IH17=(0.0,0.0)
      IH27=(0.0,0.0)
      IH37=(0.0,0.0)
      IH47= Q(1)
      IH57=(0.0,0.0)
      VH17=((Z7(1,1)*IH17)+(Z7(1,2)*IH27)+(Z7(1,3)*IH37)+(Z7(1,4)*IH47
     .  )+(Z7(1,5)*IH57))
      VH27=((Z7(2,1)*IH17)+(Z7(2,2)*IH27)+(Z7(2,3)*IH37)+(Z7(2,4)*IH47
     .  )+(Z7(2,5)*IH57))
      VH37=((Z7(3,1)*IH17)+(Z7(3,2)*IH27)+(Z7(3,3)*IH37)+(Z7(3,4)*IH47
     .  )+(Z7(3,5)*IH57))
      VH47=((Z7(4,1)*IH17)+(Z7(4,2)*IH27)+(Z7(4,3)*IH37)+(Z7(4,4)*IH47
     .  )+(Z7(4,5)*IH57))
      VH57=((Z7(5,1)*IH17)+(Z7(5,2)*IH27)+(Z7(5,3)*IH37)+(Z7(5,4)*IH47
     .   )+ (Z7(5,5)*IH57))
      WRITE(6,*)'   '
      WRITE(6,*) '  '
      WRITE(6,*)'7TH HARMONIC VOLTAGE AT:'
      WRITE(6,*)'************************'
```

```
      WRITE(6,*)'          BUS1                     BUS2                     BUS3
     .          BUS4                     BUS5'
C     WRITE(6,*) '    '
      WRITE(6,*) '    '
      WRITE(6,4) VH17,VH27,VH37,VH47,VH57
4     FORMAT(1X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,
     . 1X,F9.3,2X,F8.4,1X,F9.3)
C     THIS PART OF THE PROGRAM CACULATE THE RMS VALUE OF THE HARMONIC
C     VOLTAG ON EACH BUS CAUSED BY THE 7TH HARMONIC OF BUS 4
C     ****************************************************************
      IH1H=(0.0,0.0)
      IH2H=(0.0,0.0)
      IH3H=(0.0,0.0)
      IH4H= P(1)
      IH5H=(0.0,0.0)
      VH1H=((ZH(1,1)*IH1H)+(ZH(1,2)*IH2H)+(ZH(1,3)*IH3H)+(ZH(1,4)*IH4H
     .   )+(ZH(1,5)*IH5H))
      VH2H=((ZH(2,1)*IH1H)+(ZH(2,2)*IH2H)+(ZH(2,3)*IH3H)+(ZH(2,4)*IH4H
     .   )+(ZH(2,5)*IH5H))
      VH3H=((ZH(3,1)*IH1H)+(ZH(3,2)*IH2H)+(ZH(3,3)*IH3H)+(ZH(3,4)*IH4H
     .   )+(ZH(3,5)*IH5H))
      VH4H=((ZH(4,1)*IH1H)+(ZH(4,2)*IH2H)+(ZH(4,3)*IH3H)+(ZH(4,4)*IH4H
     .   )+(ZH(4,5)*IH5H))
      VH5H=((ZH(5,1)*IH1H)+(ZH(5,2)*IH2H)+(ZH(5,3)*IH3H)+(ZH(5,4)*IH4H
     .    )+ (ZH(5,5)*IH5H))
      VH1L=ABS(REAL(VH1H))
      VH2L=ABS(AIMAG(VH1H))
      VH3L=((VH1L)**2)+((VH2L)**2)
      VH6H=SQRT(VH3L)
C     VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH4L=ABS(REAL(VH2H))
      VH5L=ABS(AIMAG(VH2H))
      VH6L=((VH4L)**2)+((VH5L)**2)
      VH7H=SQRT(VH6L)
C     VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH7L=ABS(REAL(VH3H))
      VH8L=ABS(AIMAG(VH3H))
      VH9L=((VH7L)**2)+((VH8L)**2)
      VH8H=SQRT(VH9L)
C     VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH1F=ABS(REAL(VH4H))
      VH2F=ABS(AIMAG(VH4H))
      VH3F=((VH1F)**2)+((VH2F)**2)
      VH9H=SQRT(VH3F)
C     VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH4F=ABS(REAL(VH5H))
      VH5F=ABS(AIMAG(VH5H))
      VH6F=((VH4F)**2)+((VH5F)**2)
      VH7F=SQRT(VH6F)
      WRITE(6,*)'  '
      WRITE(6,*) '  '
      WRITE(6,*)'AFTER ADDING THE FILTER,THE 5TH HARMONIC VOLTAGE AT:'
      WRITE(6,*)'****************************************************'
      WRITE(6,*)'          BUS1                     BUS2                     BUS3
     .          BUS4                     BUS5'
C     WRITE(6,*) '    '
      WRITE(6,*) '    '
      WRITE(6,*) VH6H,VH7H,VH8H,VH9H,VH7F
C     FORMAT(1X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,
C    . 1X,F9.3,2X,F8.4,1X,F9.3)
```

```
C     DO 25 J=3,15
C      X=J
C      Q(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
C    .                                   ((SIN(X+1)*(U/2))/(X+1))**2
C    . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
C    . *AL)+U))**0.5
C     D1=COS(AL)-COS(DL)
C     R(J)=( 42.7633*3.1416*X*(COS(AL)-COS(AL-U))/(2.4495*Q(J)))
C     R(J)=(Q(J)*I9 )/(X*D1)
C5    WRITE(6,*) J,R(J)
C     WRITE(6,*) 'HARMONIC FROM I4'
C     DO 30 J=3,20
C      X=J
C      S(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
C    .                                   ((SIN(X+1)*(U/2))/(X+1))**2
C    . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
C    . *AL)+U))**0.5
C     D1=COS(AL)-COS(DL)
C     IH=(F2*I7)/(X*D1)
C     T(J)=(2.449*(261.79)*S(J))/(3.1416*X*(COS(AL)-COS(AL+U)))
C0    WRITE(6,*) J,T(J)
C     WRITE(6,*) 'HARMONIC FROM I5'
C     DO 35 J=3,8
C      X=J
C      V(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
C    .                                   ((SIN(X+1)*(U/2))/(X+1))**2
C    . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
C    . *AL)+U))**0.5
C     D1=COS(AL)-COS(DL)
C     IH=(F2*I7)/(X*D1)
C     W(J)=(V6*(COS(AL)-COS(AL-U))/(1.4142*377*0.21))
C5    WRITE(6,*) J,W(J)
      STOP
      END

$ENTRY
```

```
Y MATRIX
***********
 0.11720E 02 -0.24270E 02 -0.10000E 02  0.20000E 02  0.00000E 00  0.00000E 00  0.00000E 00  0.00000E 00 -0.17243E 01  0.43100E 01
-0.10000E 02  0.20000E 02  0.10960E 02 -0.24770E 02 -0.96150E 00  0.48081E 01  0.00000E 00  0.00000E 00  0.00000E 00  0.00000E 00
 0.00000E 00  0.00000E 00 -0.96200E 00  0.48081E 01  0.67840E 01 -0.21950E 02 -0.50000E 01  0.15000E 02 -0.82220E 00  0.21920E 01
 0.00000E 00  0.00000E 00  0.00000E 00  0.00000E 00 -0.50000E 01  0.15000E 02  0.15000E 02 -0.34980E 02 -0.10000E 02  0.20000E 02
-0.17240E 01  0.43100E 01  0.00000E 00  0.00000E 00 -0.82200E 00  0.21920E 01 -0.10000E 02  0.20000E 02  0.12550E 02 -0.26450E 02

5TH HARMONIC Z MATRIX
*********************
 0.85700E 00 -0.81360E 01  0.85150E 00 -0.82200E 01  0.75760E 00 -0.70700E 01  0.75600E 00 -0.71600E 01  0.75400E 00 -0.70710E 01
 0.85000E 00 -0.82200E 01  0.86300E 00 -0.81170E 01  0.76320E 00 -0.70490E 01  0.75950E 00 -0.71570E 01  0.75500E 00 -0.70800E 01
 0.74200E 00 -0.70746E 01  0.74900E 00 -0.70477E 01  0.69200E 00 -0.55700E 01  0.68500E 00 -0.57660E 01  0.67500E 00 -0.57760E 01
 0.75400E 00 -0.71600E 01  0.75900E 00 -0.71550E 01  0.69600E 00 -0.57650E 01  0.70800E 00 -0.57000E 01  0.69600E 00 -0.57393E 01
 0.76200E 00 -0.70710E 01  0.76400E 00 -0.70798E 01  0.69390E 00 -0.57760E 01  0.70360E 00 -0.57390E 01  0.70900E 00 -0.56000E 01

7TH HARMONIC Z MATRIX
*********************
 0.25400E-01 -0.30600E 00  0.14500E-01 -0.43800E 00 -0.12000E-01 -0.93700E 00  0.14400E-01 -0.95150E 00 -0.13000E-01 -0.92000E 0
 0.14500E-01 -0.43870E 00  0.23000E-01 -0.30290E 00 -0.90000E-02 -0.91000E 00 -0.13600E-01 -0.95400E 00 -0.14000E-01 -0.95000E-0
-0.12000E-01 -0.93700E 00 -0.90000E-02 -0.91000E 00  0.13900E-01 -0.43800E 00  0.63000E-02 -0.61200E 00  0.00000E 00 -0.70380E 0
-0.14400E-01 -0.95200E 00 -0.13600E-01 -0.95400E 00  0.63000E-02 -0.61200E 00  0.17000E-01 -0.42600E 00  0.82000E-02 -0.56600E 0
```

```
-0.13000E-01 -0.92300E 00 -0.14000E-01 -0.94560E 00  0.00000E 00 -0.70380E 00  0.82000E-02 -0.56600E 00  0.17000E-01 -0.45160E 00
5TH HARMONIC Z MATRIX AFTER ADDING THE FILTER
**********************************************
 0.76600E-01 -0.18650E 01  0.67000E-01 -0.19540E 01  0.51000E-01 -0.20268E 01  0.40800E-01 -0.21700E 01  0.49000E-01 -0.20470E 01
 0.66800E-01 -0.19540E 01  0.76000E-01 -0.18540E 01  0.54700E-01 -0.20000E 01  0.41900E-01 -0.21698E 01  0.48000E-01 -0.20600E 01
 0.47000E-01 -0.20263E 01  0.50700E-01 -0.20036E 01  0.69800E-01 -0.15100E 01  0.55800E-01 -0.17500E 01  0.54000E-01 -0.17300E 01
 0.40000E-01 -0.21707E 01  0.41900E-01 -0.21692E 01  0.59200E-01 -0.17500E 01  0.64400E-01 -0.17300E 01  0.59000E-01 -0.17420E 01
 0.51200E-01 -0.20470E 01  0.50000E-01 -0.20597E 01  0.58900E-01 -0.17320E 01  0.62000E-01 -0.17424E 01  0.76000E-01 -0.15700E 01


VALUES FOR THE BUS VOLTAGES
******************************
V2=REAL   V2=IMAGE  V3=REAL  V3=IMAG     V4=REAL  V4=IMAG     V5=REAL  V5=IMAG
1.015466  0.00454   0.98156 -0.01427    0.98278 -0.02288    0.96544 -0.05137
1.003701  0.00019   0.96402 -0.03939    0.95191 -0.07138    0.94328 -0.08586
1.002862 -0.00331   0.93827 -0.08235    0.92970 -0.10509    0.92459 -0.11290
0.994492 -0.01116   0.92144 -0.10319    0.91303 -0.12597    0.91157 -0.12671
0.992684 -0.01231   0.90948 -0.11717    0.90155 -0.13711    0.90265 -0.13473
0.989710 -0.01466   0.90076 -0.12402    0.89351 -0.14325    0.89630 -0.13892
0.988417 -0.01495   0.89500 -0.12789    0.88799 -0.14654    0.89207 -0.14129
0.987317 -0.01547   0.89090 -0.13004    0.88423 -0.14846    0.88914 -0.14270
0.986642 -0.01557   0.88819 -0.13130    0.88168 -0.14962    0.88718 -0.14357
0.986182 -0.01569   0.88632 -0.13210    0.87996 -0.15036    0.88585 -0.14414
0.985867 -0.01574   0.88508 -0.13261    0.87880 -0.15085    0.88496 -0.14452
0.985661 -0.01578   0.88424 -0.13296    0.87802 -0.15118    0.88436 -0.14477
0.985519 -0.01580   0.88367 -0.13320    0.87750 -0.15141    0.88396 -0.14495
0.985425 -0.01582   0.88329 -0.13336    0.87715 -0.15156    0.88369 -0.14507
0.985362 -0.01583   0.88303 -0.13346    0.87691 -0.15166    0.88350 -0.14514
0.985319 -0.01584   0.88286 -0.13353    0.87675 -0.15173    0.88338 -0.14520
0.985290 -0.01584   0.88275 -0.13358    0.87664 -0.15177    0.88330 -0.14523
0.985271 -0.01585   0.88267 -0.13362    0.87657 -0.15181    0.88324 -0.14526
0.985258 -0.01585   0.88262 -0.13364    0.87652 -0.15183    0.88321 -0.14527
0.985249 -0.01585   0.88258 -0.13365    0.87649 -0.15184    0.88318 -0.14529
0.985242 -0.01585   0.88255 -0.13366    0.87647 -0.15185    0.88316 -0.14529
0.985239 -0.01585   0.88254 -0.13367    0.87645 -0.15186    0.88315 -0.14530
0.985236 -0.01585   0.88253 -0.13367    0.87644 -0.15186    0.88314 -0.14530

POS. SEQ. HARMONIC CURRENT FROM BUS 4
**************************************
          7.0000000           15.3375600
         13.0000000            5.9559940
         19.0000000            2.0826170
         25.0000000            0.3880531
         31.0000000            0.6662747
         37.0000000            0.6718808
         43.0000000            0.3665623
         49.0000000            0.0354308

NEG. SEQ. HARMONIC CURRENT FROM BUS 4
**************************************
          5.0000000           43.9190600
         11.0000000            6.0948710
         17.0000000            0.8117840
         23.0000000            1.2960960
         29.0000000            1.1579720
         35.0000000            0.6136953
         41.0000000            0.1760522
         47.0000000            0.2976099
```

```
5TH HARMONIC VOLTAGE AT
***********************
      BUS1                     BUS2                    BUS3                      BUS4            BUS5

(  0.3320280E 02,  -0.3144604E 03) (  0.3335652E 02,  -0.3143286E 03) (  0.3008455E 02,  -0.2532373E 03) (  0.3109470E 02,
  -0.2503387E 03) (  0.3090144E 02,  -0.2520515E 03)


7TH HARMONIC VOLTAGE AT:
*************************
      BUS1                BUS2                     BUS3                    BUS4                      BUS5

  0.2209    -14.594    -0.2086    -14.632    0.0966    -9.387    0.2607    -6.534    0.1258    -8.681


AFTER ADDING THE FILTER,THE 5TH HARMONIC VOLTAGE AT:
****************************************************
      BUS1                BUS2                     BUS3                    BUS4                      BUS5

          95.3211800             95.3133000                76.8973900              76.0325400                76.5729800

STATEMENTS EXECUTED=       847

CORE USAGE       OBJECT CODE=   20368 BYTES,ARRAY AREA=    2764 BYTES,TOTAL AREA AVAILABLE= 2406288  BYTES

DIAGNOSTICS        NUMBER OF ERRORS=       0, NUMBER OF WARNINGS=       0, NUMBER OF EXTENSIONS=       0

COMPILE TIME=     0.10 SEC,EXECUTION TIME=     0.06 SEC,     15.33.06    SATURDAY     25 MAY 91    WATFIV - MAR 1980 V2L0

         C$STOP
```

APPENDIX F

```
$JOB
C       16 BUS TEST SYSTEM WITH PER-UNIT BASES AT BUS 5
C       S,3PHASE=100MVA, VL-L=115KV,FREQUENCY=60HZ
C      ****************************************************
      COMPLEX V1,V2,V3,V4,V5,S1,S2,S3,S4,S5,I5,SB1,SB2,SB3,SB4
      COMPLEX SB5,VV1,VV2,VV3,VV4,VV5,DV1,DV2,DV3,DV4,DV5,I1,I2,I3,I4
      COMPLEX LV15,LV12,LV23,LV35,LV34,LI15,LI12,LI23,LI34,LI35,LI17
      COMPLEX SL12,SL21,SL23,SL32,SL35,SL53,SL34,SL43,SL15,SL51,PL12
      COMPLEX IH ,I7,I8,I9,I10,I11,IH15,IH25,IH35,IH45,IH55,Z5(16,16)
      COMPLEX VH15,VH25,VH35,VH45,VH55,Z(5,5),Z7(5,5),VH17,VH27,VH37
      COMPLEX VH47,VH57,IH17,IH27,IH37,IH47,IH57,IH1H,IH2H,IH3H,IH4H
      COMPLEX IH5H,VH1H,VH2H,VH3H,VH4H,VH5H,Y(16,16),V6,V7,ZH(16,16)
      COMPLEX V9,V10,V11,V12,V13,V14,V15,V16,S6,S7,S8,S9,S10,S11,S12
      COMPLEX S13,S14,S15,S16,VV6,VV7,VV8,VV9,VV10,VV11,VV12,VV13,V8
      COMPLEX VV14,VV15,VV16,DV6,DV7,DV8,DV9,DV10,DV11,DV12,DV13,DV14
      COMPLEX DV15,DV16,Z1616,VH7H
      DIMENSION F(40),G(40),H(40),P(40),Q(40),R(40),S(40),T(40),V(40)
      DIMENSION W(40),L(40)
      REAL DL,AL,U,D1,F2,VH8H
      COMMON TOL
      INTEGER O,A,B,C,D,E
C      Z1616=(-.0032,-.0483)*132.25
C      WRITE (6,*) Z1616
      TOL=.00001
      V1=(1.0,0.0)
      V2=(1.0,0.0)
      V3=(1.05,0.0)
      V4=(1.0,0.0)
      V5=(1.0,0.0)
      V6=(1.0,0.0)
      V7=(1.0,0.0)
      V8=(1.0,0.0)
      V9=(1.05,0.0)
      V10=(1.0,0.0)
      V11=(1.0,0.0)
      V12=(1.0,0.0)
      V13=(1.0,0.0)
      V14=(1.0,0.0)
      V15=(1.0,0.0)
      V16=(1.0,0.0)
      S1=(0.0,0.0)
      S2=(00.0,0.00)
      S3=(1.00,0.25)
      S4=(0.00,0.000)
      S5=(-2.95,-.05)
      S6=(0.00,0.00)
      S7=(-0.9,-0.20)
      S8=(0.0,0.0)
      S9=(2.05,1.36)
      S10=(0.00,0.00)
      S11=(0.00,0.00)
      S12=(0.00,0.00)
      S13=(-.50,-.02)
      S14=(-0.35,-0.03)
      S15=(0.00,0.00)
      S16=(-1.5,-0.20)
      NOBUS=16
      A=1
      B=2
      C=3
```

```
      D=4
      E=5
      WRITE(6,*)'     '
      WRITE(6,*)'    '
      READ,((Y(J,K),K=1,16),J=1,16)
C     READ,((Z(J,K),K=1,16),J=1,16)
      READ,((Z5(J,K),K=1,16),J=1,16)
C     WRITE (6,*) Z5(5,5)
      READ,((ZH(J,K),K=1,16),J=1,16)
C     WRITE (6,*) ZH(5,5)
       PRINT,'Y MATRIX'
       WRITE(6,*)'***********'
       PRINT  ,((Y(J,K),K=1,16),J=1,16)
C      FORMAT(8E9.4)
       WRITE(6,*)'  '
       WRITE(6,*)'5TH HARMONIC Z MATRIX'
       WRITE(6,*)'*********************'
C      PRINT    ,((Z(J,K),K=1,5),J=1,5)
C2     FORMAT(10E13.5)
       WRITE(6,*)'      '
C      WRITE(6,*)'7TH HARMONIC Z MATRIX'
C      WRITE(6,*)'*********************'
       PRINT    ,((Z5(J,K),K=1,16),J=1,16)
       WRITE(6,*) '     '
       WRITE(6,*) '     '
       WRITE(6,*) '5TH HARMONIC Z MATRIX AFTER ADDING THE FILTER'
       WRITE(6,*) '*********************************************'
       WRITE(6,*) '     '
       PRINT    ,((ZH(J,K),K=1,16),J=1,16)
C4     FORMAT(10E13.5)
       WRITE(6,*)'      '
       WRITE(6,*)'      '
C      THIS PART OF THE PROGRAM CALCULATS VALUES FOR THE BUS VOLTAGES
C      ===============================================================
       WRITE(6,*)'VALUES FOR THE BUS VOLTAGES'
       WRITE(6,*)'****************************'
       WRITE(6,*)'V2=REAL    V2=IMAGE  V5=REAL V5=IMAG    V7=REAL V7=IMAG
     .   V16=REAL V16=IMAG'
    1  VV2=(1/Y(2,2))*(CONJG(S2)/(CONJG(V2))-(V1*Y(2,1)+V3*Y(2,3)+V4*
     . Y(2,4)+V5*Y(2,5)+V6*Y(2,6)+V7*Y(2,7)+V8*Y(2,8)+V9*Y(2,9)+V10*
     . Y(2,10)+V11*Y(2,11)+V12*Y(2,12)+V13*Y(2,13)+V14*Y(2,14)+V15*
     . Y(2,15)+V16*Y(2,16)))
       DV2=VV2-V2
       V2=V2+(1.4*DV2)
       VV3=(1/Y(3,3))*(CONJG(S3)/(CONJG(V3))-(V1*Y(3,1)+V2*Y(3,2)+V4*
     . Y(3,4)+V5*Y(3,5)+V6*Y(3,6)+V7*Y(3,7)+V8*Y(3,8)+V9*Y(3,9)+V10*
     . Y(3,10)+V11*Y(3,11)+V12*Y(3,12)+V13*Y(3,13)+V14*Y(3,14)+V15*
     . Y(3,15)+V16*Y(3,16)))
       DV3=VV3-V3
       V3=V3+(1.4*DV3)
       VV4=(1/Y(4,4))*(CONJG(S4)/(CONJG(V4))-(V1*Y(4,1)+V2*Y(4,2)+V3*
     . Y(4,3)+V5*Y(4,5)+V6*Y(4,6)+V7*Y(4,7)+V8*Y(4,8)+V9*Y(4,9)+V10*
     . Y(4,10)+V11*Y(4,11)+V12*Y(4,12)+V13*Y(4,13)+V14*Y(4,14)+V15*
     . Y(4,15)+V16*Y(4,16)))
       DV4=VV4-V4
       V4=V4+(1.4*DV4)
       VV5=(1/Y(5,5))*(CONJG(S5)/(CONJG(V5))-(V1*Y(5,1)+V2*Y(5,2)+V3*
     . Y(5,3)+V4*Y(5,4)+V6*Y(5,6)+V7*Y(5,7)+V8*Y(5,8)+V9*Y(5,9)+V10*
     . Y(5,10)+V11*Y(5,11)+V12*Y(5,12)+V13*Y(5,13)+V14*Y(5,14)+V15*
     . Y(5,15)+V16*Y(5,16)))
```

```
      DV5=VV5-V5
      V5=V5+(1.4*DV5)
      VV6=(1/Y(6,6))*(CONJG(S6)/(CONJG(V6))-(V1*Y(6,1)+V2*Y(6,2)+V3*
     . Y(6,3)+V4*Y(6,4)+V5*Y(6,5)+V7*Y(6,7)+V8*Y(6,8)+V9*Y(6,9)+V10*
     . Y(6,10)+V11*Y(6,11)+V12*Y(6,12)+V13*Y(6,13)+V14*Y(6,14)+V15*
     . Y(6,15)+V16*Y(6,16)))
      DV6=VV6-V6
      V6=V6+(1.4*DV6)
      VV7=(1/Y(7,7))*(CONJG(S7)/(CONJG(V7))-(V1*Y(7,1)+V2*Y(7,2)+V3*
     . Y(7,3)+V4*Y(7,4)+V5*Y(7,5)+V6*Y(7,6)+V8*Y(7,8)+V9*Y(7,9)+V10*
     . Y(7,10)+V11*Y(7,11)+V12*Y(7,12)+V13*Y(7,13)+V14*Y(7,14)+V15*
     . Y(7,15)+V16*Y(7,16)))
      DV7=VV7-V7
      V7=V7+(1.4*DV7)
      VV8=(1/Y(8,8))*(CONJG(S8)/(CONJG(V8))-(V1*Y(8,1)+V2*Y(8,2)+V3*
     . Y(8,3)+V4*Y(8,4)+V5*Y(8,5)+V6*Y(8,6)+V7*Y(8,7)+V9*Y(8,9)+V10*
     . Y(8,10)+V11*Y(8,11)+V12*Y(8,12)+V13*Y(8,13)+V14*Y(8,14)+V15*
     . Y(8,15)+V16*Y(8,16)))
      DV8=VV8-V8
      V8=V8+(1.4*DV8)
      VV9=(1/Y(9,9))*(CONJG(S9)/(CONJG(V9))-(V1*Y(9,1)+V2*Y(9,2)+V3*
     . Y(9,3)+V4*Y(9,4)+V5*Y(9,5)+V6*Y(9,6)+V7*Y(9,7)+V8*Y(9,8)+V10*
     . Y(9,10)+V11*Y(9,11)+V12*Y(9,12)+V13*Y(9,13)+V14*Y(9,14)+V15*
     . Y(9,15)+V16*Y(9,16)))
      DV9=VV9-V9
      V9=V9+(1.4*DV9)
      VV10=(1/Y(10,10))*(CONJG(S10)/(CONJG(V10))-(V1*Y(10,1)+V2*
     . Y(10,2)+V3*Y(10,3)+V4*Y(10,4)+V5*Y(10,5)+V6*Y(10,6)+V7*Y(10,7)
     . +V8*Y(10,8)+V9*Y(10,9)+V11*Y(10,11)+V12*Y(10,12)+V13*Y(10,13)+
     . V14*Y(10,14)+V15*Y(10,15)+V16*Y(10,16)))
      DV10=VV10-V10
      V10=V10+(1.4*DV10)
      VV11=(1/Y(11,11))*(CONJG(S11)/(CONJG(V11))-(V1*Y(11,1)+V2*
     . Y(11,2)+V3*Y(11,3)+V4*Y(11,4)+V5*Y(11,5)+V6*Y(11,6)+V7*Y(11,7)
     . +V8*Y(11,8)+V9*Y(11,9)+V10*Y(11,10)+V12*Y(11,12)+V13*Y(11,13)+
     . V14*Y(11,14)+V15*Y(11,15)+V16*Y(11,16)))
      DV11=VV11-V11
      V11=V11+(1.4*DV11)
      VV12=(1/Y(12,12))*(CONJG(S12)/(CONJG(V12))-(V1*Y(12,1)+V2*
     . Y(12,2)+V3*Y(12,3)+V4*Y(12,4)+V5*Y(12,5)+V6*Y(12,6)+V7*Y(12,7)
     . +V8*Y(12,8)+V9*Y(12,9)+V10*Y(12,10)+V11*Y(12,11)+V13*Y(12,13)+
     . V14*Y(12,14)+V15*Y(12,15)+V16*Y(12,16)))
      DV12=VV12-V12
      V12=V12+(1.4*DV12)
      VV13=(1/Y(13,13))*(CONJG(S13)/(CONJG(V13))-(V1*Y(13,1)+V2*
     . Y(13,2)+V3*Y(13,3)+V4*Y(13,4)+V5*Y(13,5)+V6*Y(13,6)+V7*Y(13,7)
     . +V8*Y(13,8)+V9*Y(13,9)+V10*Y(13,10)+V11*Y(13,11)+V12*Y(13,12)+
     . V14*Y(13,14)+V15*Y(13,15)+V16*Y(13,16)))
      DV13=VV13-V13
      V13=V13+(1.4*DV13)
      VV14=(1/Y(14,14))*(CONJG(S14)/(CONJG(V14))-(V1*Y(14,1)+V2*
     . Y(14,2)+V3*Y(14,3)+V4*Y(14,4)+V5*Y(14,5)+V6*Y(14,6)+V7*Y(14,7)
     . +V8*Y(14,8)+V9*Y(14,9)+V10*Y(14,10)+V11*Y(14,11)+V12*Y(14,12)+
     . V13*Y(14,13)+V15*Y(14,15)+V16*Y(14,16)))
      DV14=VV14-V14
      V14=V14+(1.4*DV14)
      VV15=(1/Y(15,15))*(CONJG(S15)/(CONJG(V15))-(V1*Y(15,1)+V2*
     . Y(15,2)+V3*Y(15,3)+V4*Y(15,4)+V5*Y(15,5)+V6*Y(15,6)+V7*Y(15,7)
     . +V8*Y(15,8)+V9*Y(15,9)+V10*Y(15,10)+V11*Y(15,11)+V12*Y(15,12)+
     . V13*Y(15,13)+V14*Y(15,14)+V16*Y(15,16)))
```

```
      DV15=VV15-V15
      V15=V15+(1.4*DV15)
      VV16=(1/Y(16,16))*(CONJG(S16)/(CONJG(V16))-(V1*Y(16,1)+V2*
     . Y(16,2)+V3*Y(16,3)+V4*Y(16,4)+V5*Y(16,5)+V6*Y(16,6)+V7*Y(16,7)
     . +V8*Y(16,8)+V9*Y(16,9)+V10*Y(16,10)+V11*Y(16,11)+V12*Y(16,12)+
     . V13*Y(16,13)+V14*Y(16,14)+V15*Y(16,15)))
      DV16=VV16-V16
      V16=V16+(1.4*DV16)
      WRITE (6,*) '    '
C     WRITE(6,*) 'V2=REAL     V2=IMAG    V5=REAL   V5=REAL   V7=IMAG
C    .   V5=REAL  V5=IMAG'
      WRITE(6,*)'   '
      WRITE(6,8)  V2,V5,V7,V16
 8    FORMAT(1X,F8.6,1X,F8.5,2X,F8.5,1X,F8.5,2X,F8.5,1X,F8.5,2X,F8.5,
     . 1X,F8.5)
      GG2=ABS(REAL(DV2))
      BB2=ABS(AIMAG(DV2))
      GG3=ABS(REAL(DV3))
      BB3=ABS(AIMAG(DV3))
      GG4=ABS(REAL(DV4))
      BB4=ABS(AIMAG(DV4))
      GG5=ABS(REAL(DV5))
      BB5=ABS(AIMAG(DV5))
      GG6=ABS(REAL(DV6))
      BB6=ABS(AIMAG(DV6))
      GG7=ABS(REAL(DV7))
      BB7=ABS(AIMAG(DV7))
      GG8=ABS(REAL(DV8))
      BB8=ABS(AIMAG(DV8))
      GG9=ABS(REAL(DV9))
      BB9=ABS(AIMAG(DV9))
      GG10=ABS(REAL(DV10))
      BB10=ABS(AIMAG(DV10))
      GG11=ABS(REAL(DV11))
      BB11=ABS(AIMAG(DV11))
      GG12=ABS(REAL(DV12))
      BB12=ABS(AIMAG(DV12))
      GG13=ABS(REAL(DV13))
      BB13=ABS(AIMAG(DV13))
      GG14=ABS(REAL(DV14))
      BB14=ABS(AIMAG(DV14))
      GG15=ABS(REAL(DV15))
      BB15=ABS(AIMAG(DV15))
      GG16=ABS(REAL(DV16))
      BB16=ABS(AIMAG(DV16))
C     IF(GG1.GT.TOL) GO TO 1
      IF(GG2.GT.TOL) GO TO 1
      IF(BB2.GT.TOL) GO TO 1
      IF(GG3.GT.TOL) GO TO 1
      IF(BB3.GT.TOL) GO TO 1
      IF(GG4.GT.TOL) GO TO 1
      IF(BB4.GT.TOL) GO TO 1
      IF(GG5.GT.TOL) GO TO 1
      IF(BB5.GT.TOL) GO TO 1
      IF(GG6.GT.TOL) GO TO 1
      IF(BB6.GT.TOL) GO TO 1
      IF(GG7.GT.TOL) GO TO 1
      IF(BB7.GT.TOL) GO TO 1
      IF(GG8.GT.TOL) GO TO 1
      IF(BB8.GT.TOL) GO TO 1
```

```
      IF(GG9.GT.TOL) GO TO 1
      IF(BB9.GT.TOL) GO TO 1
      IF(GG10.GT.TOL) GO TO 1
      IF(BB10.GT.TOL) GO TO 1
      IF(GG11.GT.TOL) GO TO 1
      IF(BB11.GT.TOL) GO TO 1
      IF(GG12.GT.TOL) GO TO 1
      IF(BB12.GT.TOL) GO TO 1
      IF(GG13.GT.TOL) GO TO 1
      IF(BB13.GT.TOL) GO TO 1
      IF(GG14.GT.TOL) GO TO 1
      IF(BB14.GT.TOL) GO TO 1
      IF(GG15.GT.TOL) GO TO 1
      IF(BB15.GT.TOL) GO TO 1
      IF(GG16.GT.TOL) GO TO 1
      IF(BB16.GT.TOL) GO TO 1
C     THIS PART OF THE PROGRAM CALCULATES THE POWER AT EACH BUS
C     ==========================================================
C     I1=(V1*Y(1,1))+(V2*Y(1,2))+(V3*Y(1,3))+(V4*Y(1,4))+(V5*Y(1,5))
C     I2=(V1*Y(2,1))+(V2*Y(2,2))+(V3*Y(2,3))+(V4*Y(2,4))+(V5*Y(2,5))
C     I3=(V1*Y(3,1))+(V2*Y(3,2))+(V3*Y(3,3))+(V4*Y(3,4))+(V5*Y(3,5))
C     I4=(V1*Y(4,1))+(V2*Y(4,2))+(V3*Y(4,3))+(V4*Y(4,4))+(V5*Y(4,5))
      I5=(V1*Y(5,1))+(V2*Y(5,2))+(V3*Y(5,3))+(V4*Y(5,4))+(V5*Y(5,5))+
     .(V6*Y(5,6))+(V7*Y(5,7))+(V8*Y(5,8))+(V9*Y(5,9))+(V10*Y(5,10))+
     .(V11*Y(5,11))+(V12*Y(5,12))+(V13*Y(5,13))+(V14*Y(5,14))+
     .(V15*Y(5,15))+(V16*Y(5,16))
C     WRITE(6,*) 'I5='
C     WRITE(6,*) I5
C     SB1=V1*CONJG(I1)
C     SB2=V2*CONJG(I2)
C     SB3=V3*CONJG(I3)
C     SB4=V4*CONJG(I4)
C     SB5=V5*CONJG(I5)
C     THIS PART OF THE PROGRAM CALCULATES THE RMS VALUE OF EACH CHARAT.
C     HARMONIC CURRENT
C     ==================================================================
C
C     WRITE(6,*) 'VALUE FOR V6'
C     I7=I1*418.3698
C     I8=I2*418.3698
C     I9=I3*418.3698
C     I10=I4*418.3698
C     I11=I5*502.3698
      VB = V5 *115000
C     WRITE(6,*) '    '
      WRITE(6,*) '   '
      WRITE(6,*) 'POS. SEQ. HARMONIC CURRENT FROM BUS 5'
      WRITE(6,*) '*************************************'
      U= ((45.0/180.0)*3.1416)
      AL=((25.0/180.0)*3.1416)
      DL= ((57.3/180.0)*3.1416)
C     I7=1700.0
      DO 15 I=1,8
       X=(6*I)+1
       F(I)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                                     ((SIN(X+1)*(U/2))/(X+1))**2
     .-2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     .*AL)+U))**0.5
CC    D1=COS(AL)-COS(DL)
C     L(I)=(2.4495*(54.1)*F(I))/(3.141*X*(COS(AL)-COS(AL-U)))
```

```
      G(I)=(1.7321*VB*F(I))/(3.1416*377.0*0.21*X)
15    WRITE(6,*) X,G(I)
CC    WRITE(6,*) G(1)
      DO 16 I=1,8
       X=(6*I)+1
       R(I)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                             ((SIN(X+1)*(U/2))/(X+1))**2
     . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     . *AL)+U))**0.5
C     D1=COS(AL)-COS(DL)
C     L(I)=(2.4495*(54.1)*F(I))/(3.141*X*(COS(AL)-COS(AL-U)))
      Q(I)=(1.7321*V5*R(I))/(3.1416*377.0*0.21*X)
16    CONTINUE
      WRITE(6,*) '     '
      WRITE(6,*) 'NEG. SEQ. HARMONIC CURRENT FROM BUS 5'
      WRITE(6,*) '*************************************'
      WRIIE(6,*)'     '
      DO 25 J=1,8
       X=(6*J)-1
       W(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                             ((SIN(X+1)*(U/2))/(X+1))**2
     . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     . *AL)+U))**0.5
CC    D1=COS(AL)-COS(DL)
C     T(J)=(2.4495*(54.1)*W(J))/(3.141*X*(COS(AL)-COS(AL-U)))
      S(J)=(1.7321*VB*W(J))/(3.1416*377.0*0.21*X)
25    WRITE(6,*) X,S(J)
C     WRITE(6,*)  S(1)
      WRITE(6,*) '**************************************************'
      DO 20 J=1,8
       X=(6*J)-1
       H(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
     .                             ((SIN(X+1)*(U/2))/(X+1))**2
     . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
     . *AL)+U))**0.5
C     D1=COS(AL)-COS(DL)
C     IH=(F2*I7)/(X*D1)
      P(J)=(1.7321*VB*H(J))/(3.1416*377.0*0.21*X)
20    CONTINUE
      WRITE (6,*) 'IH5 = '
      WRITE (6,*)    P(1)
C     THIS PART OF THE PROGRAM CACULATE THE RMS VALUE OF THE HARMONIC
C     VOLTAG ON EACH BUS CAUSED BY THE 5TH HARMONIC OF BUS 4
C     ************************************************************
      IH15=(0.0,0.0)
      IH25= (0.0,0.0)
      IH35=(0.0,0.0)
      IH45= (0.0,0.0)
      IH55= P(1)
      VH15=((Z5(1,1)*IH15)+(Z5(1,2)*IH25)+(Z5(1,3)*IH35)+(Z5(1,4)*IH45
     .  )+(Z5(1,5)*IH55))
      VH25=((Z5(2,1)*IH15)+(Z5(2,2)*IH25)+(Z5(2,3)*IH35)+(Z5(2,4)*IH45
     .  )+(Z5(2,5)*IH55))
      VH35=((Z5(3,1)*IH15)+(Z5(3,2)*IH25)+(Z5(3,3)*IH35)+(Z5(3,4)*IH45
     .  )+(Z5(3,5)*IH55))
      VH45=((Z5(4,1)*IH15)+(Z5(4,2)*IH25)+(Z5(4,3)*IH35)+(Z5(4,4)*IH45
     .  )+(Z5(4,5)*IH55))
      VH55=((Z5(2,1)*IH15)+(Z5(2,2)*IH25)+(Z5(5,3)*IH35)+(Z5(5,4)*IH45
     .   )+ (Z5(5,5)*IH55))
      VX15=ABS(REAL(VH55))
```

```
      VX25=ABS(AIMAG(VH55))
      VX35=((VX15)**2)+(VX25)**2
      VX45=SQRT(VX35)
      WRITE(6,*) '  '
      WRITE(6,*)'5TH HARMONIC VOLTAGE AT:'
      WRITE(6,*)'**********************'
      WRITE(6,*)'       BUS5 = '
      WRITE(6,*) '       '
      WRITE(6,*) VX45
CCCC  FORMAT(1X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,
C    . 1X,F9.3,2X,F8.4,1X,F9.3)
C     THIS PART OF THE PROGRAM CACULATE THE RMS VALUE OF THE HARMONIC
C     VOLTAG ON EACH BUS CAUSED BY THE 7TH HARMONIC OF BUS 4
C     ************************************************************
C     IH17=(0.0,0.0)
C     IH27=(0.0,0.0)
C     IH37=(0.0,0.0)
C     IH47= Q(1)
C     IH57=(0.0,0.0)
C     VH17=((Z7(1,1)*IH17)+(Z7(1,2)*IH27)+(Z7(1,3)*IH37)+(Z7(1,4)*IH47
C    .  )+(Z7(1,5)*IH57))
C     VH27=((Z7(2,1)*IH17)+(Z7(2,2)*IH27)+(Z7(2,3)*IH37)+(Z7(2,4)*IH47
C    .  )+(Z7(2,5)*IH57))
C     VH37=((Z7(3,1)*IH17)+(Z7(3,2)*IH27)+(Z7(3,3)*IH37)+(Z7(3,4)*IH47
C    .  )+(Z7(3,5)*IH57))
C     VH47=((Z7(4,1)*IH17)+(Z7(4,2)*IH27)+(Z7(4,3)*IH37)+(Z7(4,4)*IH47
C    .  )+(Z7(4,5)*IH57))
C     VH57=((Z7(5,1)*IH17)+(Z7(5,2)*IH27)+(Z7(5,3)*IH37)+(Z7(5,4)*IH47
C    .    )+ (Z7(5,5)*IH57))
C     WRITE(6,*)'    '
C     WRITE(6,*) '  '
C     WRITE(6,*)'7TH HARMONIC VOLTAGE AT:'
C     WRITE(6,*)'************************'
C     WRITE(6,*)'       BUS1                 BUS2                      BUS3
C    .           BUS4                 BUS5'
C     WRITE(6,*) '      '
C     WRITE(6,*) '      '
C     WRITE(6,4) VH17,VH27,VH37,VH47,VH57
C     FORMAT(1X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,
C    . 1X,F9.3,2X,F8.4,1X,F9.3)
C     THIS PART OF THE PROGRAM CACULATE THE RMS VALUE OF THE HARMONIC
C     VOLTAG ON EACH BUS CAUSED BY THE 7TH HARMONIC OF BUS 4
C     ************************************************************
      IH1H=(0.0,0.0)
      IH2H=(0.0,0.0)
      IH3H=(0.0,0.0)
      IH4H=(0.0,0.0)
      IH5H= P(1)
      VH1H=((ZH(1,1)*IH1H)+(ZH(1,2)*IH2H)+(ZH(1,3)*IH3H)+(ZH(1,4)*IH4H
     .  )+(ZH(1,5)*IH5H))
      VH2H=((ZH(2,1)*IH1H)+(ZH(2,2)*IH2H)+(ZH(2,3)*IH3H)+(ZH(2,4)*IH4H
     .  )+(ZH(2,5)*IH5H))
      VH3H=((ZH(3,1)*IH1H)+(ZH(3,2)*IH2H)+(ZH(3,3)*IH3H)+(ZH(3,4)*IH4H
     .  )+(ZH(3,5)*IH5H))
      VH4H=((ZH(4,1)*IH1H)+(ZH(4,2)*IH2H)+(ZH(4,3)*IH3H)+(ZH(4,4)*IH4H
     .  )+(ZH(4,5)*IH5H))
      VH5H=((ZH(5,1)*IH1H)+(ZH(5,2)*IH2H)+(ZH(5,3)*IH3H)+(ZH(5,4)*IH4H
     .    )+ (ZH(5,5)*IH5H))
      VH1L=ABS(REAL(VH1H))
      VH2L=ABS(AIMAG(VH1H))
```

```
      VH3L=((VH1L)**2)+((VH2L)**2)
      VH6H=SQRT(VH3L)
C     VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH4L=ABS(REAL(VH2H))
      VH5L=ABS(AIMAG(VH2H))
      VH6L=((VH4L)**2)+((VH5L)**2)
      VH7H=SQRT(VH6L)
C     VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH7L=ABS(REAL(VH3H))
      VH8L=ABS(AIMAG(VH3H))
      VH9L=((VH7L)**2)+((VH8L)**2)
      VH8H=SQRT(VH9L)
CC    VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH1F=ABS(REAL(VH4H))
      VH2F=ABS(AIMAG(VH4H))
      VH3F=((VH1F)**2)+((VH2F)**2)
      VH9H=SQRT(VH3F)
C     VH10H= ((COS((VH7H)/(VH6H)))/(SIN((VH7H)/(VH6H))))
      VH4F=ABS(REAL(VH5H))
      VH5F=ABS(AIMAG(VH5H))
      VH6F=((VH4F)**2)+((VH5F)**2)
      VH7F=SQRT(VH6F)
      WRITE(6,*)'    '
      WRITE(6,*) '  '
      WRITE(6,*)'AFTER ADDING THE FILTER,THE 5TH HARMONIC VOLTAGE AT:'
      WRITE(6,*)'*********************************************'
      WRITE(6,*)'       BUS5 ='
      WRITE(6,*) '      '
      WRITE(6,*) '      '
      WRITE(6,*) VH7F
C     FORMAT(1X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,1X,F9.3,2X,F8.4,
C    . 1X,F9.3,2X,F8.4,1X,F9.3)
C     DO 25 J=3,15
C      X=J
C      Q(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
C    .                                 ((SIN(X+1)*(U/2))/(X+1))**2
C    . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
C    . *AL)+U))**0.5
C     D1=COS(AL)-COS(DL)
C     R(J)=( 42.7633*3.1416*X*(COS(AL)-COS(AL-U))/(2.4495*Q(J)))
C     R(J)=(Q(J)*I9 )/(X*D1)
C5    WRITE(6,*) J,R(J)
C     WRITE(6,*) 'HARMONIC FROM I4'
C     DO 30 J=3,20
C      X=J
C      S(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
C    .                                 ((SIN(X+1)*(U/2))/(X+1))**2
C    . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
C    . *AL)+U))**0.5
C     D1=COS(AL)-COS(DL)
C     IH=(F2*I7)/(X*D1)
C     T(J)=(2.449*(261.79)*S(J))/(3.1416*X*(COS(AL)-COS(AL+U)))
C0    WRITE(6,*) J,T(J)
C     WRITE(6,*) 'HARMONIC FROM I5'
C     DO 35 J=3,8
C      X=J
C      V(J)= (((SIN((X-1)*(U/2))/(X-1))**2)+
C    .                                 ((SIN(X+1)*(U/2))/(X+1))**2
C    . -2*((SIN((X-1)*(U/2))/(X-1))*(SIN((X+1)*(U/2))/(X+1)))*COS((2
C    . *AL)+U))**0.5
```

```
      C       D1=COS(AL)-COS(DL)
      C       IH=(F2*I7)/(X*D1)
      C       W(J)=(V6*(COS(AL)-COS(AL-U))/(1.4142*377*0.21))
      C5      WRITE(6,*) J,W(J)
              STOP
              END

      $ENTRY


Y MATRIX
***********
(  0.2828900E 01, -0.2828850E 02) ( -0.2828900E 01,  0.2828850E 02) (  0.0000000E 00,  0.0000000E 00) (  0.0000000E 00,
   0.0000000E 00) (  0.0000000E 00,  0.0000000E 00) (  0.0000000E 00,  0.0000000E 00) (  0.0000000E 00,  0.0000000E 00)
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5TH HARMONIC Z MATRIX
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( -0.5900000E 00,  -0.4762000E 02) ( -0.7800000E 00,  -0.5320000E 02) ( -0.2100000E 00,  -0.4134000E 02) ( -0.3000000E-01,
  -0.3542999E 02) (  0.3000000E 00,  -0.2930000E 02) (  0.3000000E 00,  -0.2930000E 02) (  0.8800000E 00,  -0.1650999E 02)
(  0.1840000E 01,   0.7150000E 01) (  0.2130000E 01,   0.3489000E 02) (  0.2160000E 01,   0.3517000E 02) ( -0.6900000E 00,
  -0.4864999E 02) ( -0.8300000E 00,  -0.5128999E 02) ( -0.6800000E 00,  -0.4795000E 02) ( -0.6800000E 00,  -0.4795000E 02)
( -0.1060000E 01,  -0.5664000E 02) ( -0.1050000E 01,  -0.5664000E 02) ( -0.6200000E 00,  -0.4802000E 02) ( -0.8100000E 00,
  -0.5364000E 02) ( -0.2400000E 00,  -0.4167999E 02) ( -0.5000000E-01,  -0.3572000E 02) (  0.2900000E 00,  -0.2953999E 02)
(  0.2900000E 00,  -0.2953999E 02) (  0.8800000E 00,  -0.1664999E 02) (  0.1860000E 01,   0.7210000E 01) (  0.2160000E 01,
   0.3517000E 02) (  0.9220000E 01,   0.1538900E 03) ( -0.2700000E 00,  -0.4905000E 02) ( -0.8700000E 00,  -0.5171001E 02)
(  0.8100000E 00,  -0.1529000E 02) (  0.8100000E 00,  -0.1529000E 02) ( -0.1500000E 00,  -0.3622000E 02) ( -0.1500000E 00,
  -0.3622000E 02) ( -0.4300000E 00,  -0.4389999E 02) ( -0.3500000E 00,  -0.4044000E 02) ( -0.6300000E 00,  -0.4749001E 02)
( -0.7200000E 00,  -0.5060001E 02) ( -0.8000000E 00,  -0.5159000E 02) ( -0.8000000E 00,  -0.5159000E 02) ( -0.6200000E 00,
  -0.4675999E 02) ( -0.6900000E 00,  -0.4848000E 02) ( -0.6900000E 00,  -0.4864999E 02) ( -0.7200000E 00,  -0.4905000E 02)
(  0.1200000E 01,   0.6510000E 01) (  0.1280000E 01,   0.6860000E 01) (  0.8200000E 00,  -0.1612000E 02) (  0.8200000E 00,
  -0.1612000E 02) ( -0.2400000E 00,  -0.3817999E 02) ( -0.2300000E 00,  -0.3817999E 02) ( -0.5500000E 00,  -0.4628000E 02)
( -0.4500000E 00,  -0.4263000E 02) ( -0.7600000E 00,  -0.5006000E 02) ( -0.8600000E 00,  -0.5334000E 02) ( -0.9500000E 00,
  -0.5438000E 02) (  0.9500000E 00,  -0.5438000E 02) ( -0.7500000E 00,  -0.4928999E 02) ( -0.8300000E 00,  -0.5110001E 02)
( -0.8300000E 00,  -0.5128999E 02) ( -0.8700000E 00,  -0.5171001E 02) (  0.1280000E 01,   0.6860000E 01) (  0.5440000E 01,
   0.1132400E 03)


5TH HARMONIC Z MATRIX AFTER ADDING THE FILTER
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(  0.6210000E 01,   0.9336000E 02) (  0.5750000E 01,  -0.1165000E 03) (  0.4280000E 01,  -0.8211000E 02) (  0.4280000E 01,
  -0.8211000E 02) (  0.1720000E 01,  -0.2928000E 02) (  0.3550000E 01,  -0.5892999E 02) (  0.2200000E 01,  -0.6825000E 02)
(  0.3640000E 01,  -0.1035900E 03) (  0.3930000E 01,  -0.1301300E 03) (  0.3930000E 01,  -0.1301300E 03) (  0.4430000E 01,
  -0.1539800E 03) (  0.4430000E 01,  -0.1596500E 03) (  0.4460000E 01,  -0.1602300E 03) (  0.4410000E 01,  -0.1615600E 03)
(  0.5810000E 01,  -0.1191800E 03) (  0.5880000E 01,  -0.1256500E 03) (  0.5750000E 01,  -0.1165000E 03) (  0.5750000E 01,
   0.1165000E 03) (  0.4280000E 01,   0.8211000E 02) (  0.4280000E 01,   0.8211000E 02) (  0.1710000E 01,   0.2928000E 02)
(  0.3550000E 01,   0.5892999E 02) (  0.2200000E 01,  -0.6825000E 02) (  0.3640000E 01,  -0.1035900E 03) (  0.3930000E 01,
  -0.1301300E 03) (  0.3930000E 01,   0.1301300E 03) (  0.4430000E 01,  -0.1539800E 03) (  0.4430000E 01,  -0.1596500E 03)
(  0.4460000E 01,  -0.1602300E 03) (  0.4410000E 01,  -0.1615600E 03) (  0.5810000E 01,  -0.1191800E 03) (  0.5880000E 01,
  -0.1256500E 03) (  0.4280000E 01,  -0.8211000E 02) (  0.4280000E 01,  -0.8211000E 02) (  0.4890000E 01,   0.3830000E 01)
(  0.4380000E 01,  -0.2161000E 02) (  0.1400000E 01,  -0.1348000E 02) (  0.3120000E 01,  -0.1817999E 02) (  0.1870000E 01,
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   -0.4122000E 02) (  0.3000000E 01,   0.6639999E 02) (  0.3280000E 01,   0.8555000E 02) (  0.3280000E 01,   0.8555000E 02)
 (  0.3670000E 01,   0.1037900E 03) (  0.3690000E 01,   0.1076100E 03) (  0.3710000E 01,  -0.1080100E 03) (  0.3680000E 01,
    0.1089000E 03) (  0.4330000E 01,  -0.8400000E 02) (  0.4390000E 01,  -0.8856000E 02) (  0.4280000E 01,  -0.8211000E 02)
 (  0.4280000E 01,  -0.8211000E 02) (  0.4380000E 01,  -0.2160001E 02) (  0.4380000E 01,  -0.2160001E 02) (  0.1400000E 01,
   -0.1348000E 02) (  0.3120000E 01,  -0.1817999E 02) (  0.1870000E 01,  -0.4122000E 02) (  0.3000000E 01,  -0.6639999E 02)
 (  0.3280000E 01,  -0.8555000E 02) (  0.3280000E 01,  -0.8555000E 02) (  0.3670000E 01,  -0.1037900E 03) (  0.3690000E 01,
   -0.1076100E 03) (  0.3710000E 01,  -0.1080000E 03) (  0.3680000E 01,  -0.1089000E 03) (  0.4330000E 01,  -0.8400000E 02)
 (  0.4390000E 01,  -0.8856000E 02) (  0.1720000E 01,  -0.2928000E 02) (  0.1710000E 01,  -0.2928000E 02) (  0.1400000E 01,
   -0.1348000E 02) (  0.1400000E 01,  -0.1348000E 02) (  0.5800000E 00,   0.3910000E 01) (  0.1170000E 01,  -0.5600000E 01)
 (  0.8700000E 00,  -0.6310000E 01) (  0.1400000E 01,  -0.1562000E 02) (  0.1580000E 01,  -0.2300000E 02) (  0.1580000E 01,
   -0.2300000E 02) (  0.1760000E 01,  -0.3123000E 02) (  0.1790000E 01,  -0.3238000E 02) (  0.1800000E 01,  -0.3250000E 02)
 (  0.1790000E 01,  -0.3277000E 02) (  0.1740000E 01,  -0.2995000E 02) (  0.1770000E 01,  -0.3158000E 02) (  0.3550000E 01,
   -0.5892999E 02) (  0.3550000E 01,  -0.5892999E 02) (  0.3120000E 01,  -0.1817999E 02) (  0.3120000E 01,  -0.1817999E 02)
 (  0.1170000E 01,  -0.5600000E 01) (  0.2680000E 01,   0.2200000E 00) (  0.1690000E 01,  -0.2567000E 02) (  0.2680000E 01,
   -0.4389999E 02) (  0.3010000E 01,  -0.5789999E 02) (  0.3010000E 01,  -0.5789999E 02) (  0.3370000E 01,  -0.7180000E 02)
 (  0.3420000E 01,  -0.7445000E 02) (  0.3440000E 01,  -0.7472000E 02) (  0.3430000E 01,  -0.7534000E 02) (  0.3600000E 01,
   -0.6028000E 02) (  0.3670000E 01,  -0.6356000E 02) (  0.2200000E 01,  -0.6825000E 02) (  0.2200000E 01,  -0.6825000E 02)
 (  0.1870000E 01,  -0.4122000E 02) (  0.1870000E 01,  -0.4122000E 02) (  0.8700000E 00,   0.6310000E 01) (  0.1690000E 01,
    0.2567000E 02) (  0.2130000E 01,   0.5600000E 00) (  0.2890000E 01,  -0.2283000E 02) (  0.2900000E 01,   0.4092000E 02)
 (  0.2900000E 01,  -0.4092000E 02) (  0.2740000E 01,  -0.6303000E 02) (  0.2780000E 01,  -0.6535001E 02) (  0.2790000E 01,
   -0.6559000E 02) (  0.2780000E 01,  -0.6613000E 02) (  0.2210000E 01,   0.6981000E 02) (  0.2190000E 01,  -0.7360001E 02)
 (  0.3640000E 01,  -0.1035900E 03) (  0.3640000E 01,  -0.1035900E 03) (  0.3000000E 01,  -0.6639999E 02) (  0.3000000E 01,
   -0.6639999E 02) (  0.1400000E 01,  -0.1562000E 02) (  0.2680000E 01,  -0.4389999E 02) (  0.2890000E 01,  -0.2283000E 02)
 (  0.4430000E 01,   0.2928000E 02) (  0.4560000E 01,  -0.5711000E 02) (  0.4560000E 01,   0.5711000E 02) (  0.4450000E 01,
   -0.9182001E 02) (  0.4510000E 01,  -0.9520000E 02) (  0.4530000E 01,  -0.9555000E 02) (  0.4520000E 01,  -0.9634000E 02)
 (  0.3660000E 01,  -0.1059700E 03) (  0.3640000E 01,  -0.1117200E 03) (  0.3930000E 01,  -0.1301300E 03) (  0.3930000E 01,
   -0.1301300E 03) (  0.3280000E 01,  -0.8550999E 02) (  0.3280000E 01,  -0.8555000E 02) (  0.1580000E 01,  -0.2300000E 02)
 (  0.3010000E 01,   0.5789999E 02) (  0.2900000E 01,  -0.4092000E 02) (  0.4560000E 01,  -0.5711000E 02) (  0.5610000E 01,
   -0.5310001E 02) (  0.5450000E 01,   0.6897000E 02) (  0.5090000E 01,   0.1132200E 03) (  0.5160000E 01,  -0.1173900E 03)
 (  0.5180000E 01,  -0.1178200E 03) (  0.5170000E 01,  -0.1187900E 03) (  0.3940000E 01,  -0.1331200E 03) (  0.3880000E 01,
   -0.1403400E 03) (  0.3930000E 01,  -0.1301300E 03) (  0.3930000E 01,   0.1301300E 03) (  0.3280000E 01,  -0.8555000E 02)
 (  0.3280000E 01,  -0.8555000E 02) (  0.1580000E 01,  -0.2300000E 02) (  0.3010000E 01,  -0.5789999E 02) (  0.2900000E 01,
   -0.4092000E 02) (  0.4560000E 01,  -0.5711000E 02) (  0.5450000E 01,  -0.6897000E 02) (  0.5450000E 01,  -0.6897000E 02)
 (  0.5090000E 01,  -0.1132200E 03) (  0.5160000E 01,  -0.1173900E 03) (  0.5180000E 01,  -0.1178200E 03) (  0.5170000E 01,
   -0.1187900E 03) (  0.3940000E 01,  -0.1131200E 03) (  0.3880000E 01,  -0.1403400E 03) (  0.4430000E 01,  -0.1539800E 03)
 (  0.4430000E 01,  -0.1539800E 03) (  0.3660000E 01,  -0.1037900E 03) (  0.3660000E 01,  -0.1037900E 03) (  0.1760000E 01,
   -0.3123000E 02) (  0.3370000E 01,  -0.7180000E 02) (  0.2740000E 01,  -0.6303000E 02) (  0.4450000E 01,  -0.9182001E 02)
 (  0.5090000E 01,  -0.1132200E 03) (  0.5090000E 01,  -0.1132200E 03) (  0.5920000E 01,  -0.1314300E 03) (  0.6000000E 01,
   -0.1362600E 03) (  0.6020000E 01,  -0.1367600E 03) (  0.6000000E 01,  -0.1379000E 03) (  0.4450000E 01,  -0.1575200E 03)
 (  0.4360000E 01,  -0.1660700E 03) (  0.4430000E 01,  -0.1596500E 03) (  0.4430000E 01,  -0.1596500E 03) (  0.3690000E 01,
   -0.1076100E 03) (  0.3690000E 01,  -0.1076100E 03) (  0.1790000E 01,  -0.3238000E 02) (  0.3420000E 01,  -0.7445000E 02)
 (  0.2780000E 01,  -0.6535001E 02) (  0.4510000E 01,  -0.9520000E 02) (  0.5160000E 01,  -0.1173900E 03) (  0.5160000E 01,
   -0.1173900E 03) (  0.6000000E 01,  -0.1362600E 03) (  0.7020000E 01,  -0.1171500E 03) (  0.7050000E 01,  -0.1175800E 03)
 (  0.7040000E 01,  -0.1185500E 03) (  0.4440000E 01,  -0.1633200E 03) (  0.4340000E 01,  -0.1721800E 03) (  0.4460000E 01,
   -0.1602300E 03) (  0.4460000E 01,  -0.1602300E 03) (  0.3710000E 01,  -0.1080000E 03) (  0.3710000E 01,  -0.1080000E 03)
 (  0.1800000E 01,  -0.3250000E 02) (  0.3440000E 01,  -0.7472000E 02) (  0.2790000E 01,  -0.6559000E 02) (  0.4530000E 01,
   -0.9555000E 02) (  0.5180000E 01,  -0.1178200E 03) (  0.5180000E 01,  -0.1178200E 03) (  0.6020000E 01,  -0.1367600E 03)
 (  0.7050000E 01,  -0.1175800E 03) (  0.7360000E 01,  -0.9034000E 02) (  0.7370000E 01,  -0.9109000E 02) (  0.4470000E 01,
   -0.1639100E 03) (  0.4370000E 01,  -0.1728100E 03) (  0.4410000E 01,  -0.1615600E 03) (  0.4410000E 01,  -0.1615600E 03)
 (  0.3680000E 01,  -0.1089000E 03) (  0.3680000E 01,  -0.1089000E 03) (  0.1790000E 01,  -0.3277000E 02) (  0.3430000E 01,
   -0.7534000E 02) (  0.2780000E 01,  -0.6613000E 02) (  0.4520000E 01,  -0.9634000E 02) (  0.5170000E 01,  -0.1187900E 03)
 (  0.5170000E 01,  -0.1187900E 03) (  0.6000000E 01,  -0.1379000E 03) (  0.7040000E 01,  -0.1185500E 03) (  0.7370000E 01,
   -0.9109000E 02) (  0.1439000E 02,   0.2635001E 02) (  0.4420000E 01,  -0.1652700E 03) (  0.4310000E 01,  -0.1742400E 03)
 (  0.5810000E 01,  -0.1191800E 03) (  0.5810000E 01,  -0.1191800E 03) (  0.4330000E 01,  -0.8400000E 02) (  0.4330000E 01,
   -0.8400000E 02) (  0.1740000E 01,  -0.2995000E 02) (  0.3600000E 01,  -0.6028000E 02) (  0.2210000E 01,  -0.6981000E 02)
 (  0.3660000E 01,  -0.1059700E 03) (  0.3940000E 01,  -0.1331200E 03) (  0.3940000E 01,  -0.1331200E 03) (  0.4450000E 01,
   -0.1575200E 03) (  0.4440000E 01,  -0.1633200E 03) (  0.4470000E 01,  -0.1639100E 03) (  0.4420000E 01,  -0.1652700E 03)
 (  0.6260000E 01,  -0.9981000E 02) (  0.6390000E 01,  -0.1052400E 03) (  0.5880000E 01,  -0.1256500E 03) (  0.5880000E 01,
   -0.1256500E 03) (  0.4390000E 01,  -0.8856000E 02) (  0.4390000E 01,  -0.8856000E 02) (  0.1770000E 01,  -0.3158000E 02)
 (  0.3660000E 01,  -0.6356000E 02) (  0.2190000E 01,  -0.7360001E 02) (  0.3640000E 01,  -0.1172100E 03) (  0.3880000E 01,
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APPENDIX F

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   -0.1403400E 03) (  0.3880000E 01,   -0.1403400E 03) (  0.4360000E 01,   -0.1660700E 03) (  0.4340000E 01,   -0.1721800E 03)
 (  0.4370000E 01,   -0.1728100E 03) (  0.4310000E 01,   -0.1742400E 03) (  0.6390000E 01,   -0.1052400E 03) (  0.1059000E 02,
   -0.5140000E 01)


 VALUES FOR THE BUS VOLTAGES
 ******************************
 V2=REAL    V2=IMAGE  V5=REAL V5=IMAG    V7=REAL V7=IMAG   V16=REAL V16=IMAG


 1.003197 -0.00038   0.98894 -0.09018   0.98814 -0.08728   0.90780 -0.31293

 1.007100  0.00609   0.97287 -0.13862   0.97122 -0.12529   0.82157 -0.24801

 1.001447 -0.03670   0.96261 -0.16762   0.97565 -0.12169   0.80945 -0.32462

 0.991680 -0.03500   0.95780 -0.18071   0.98327 -0.13402   0.78725 -0.28867

 0.992844 -0.05277   0.95898 -0.19496   0.98608 -0.14456   0.79003 -0.33116

 0.990008 -0.05533   0.95883 -0.20643   0.98822 -0.15647   0.78025 -0.31155

 0.991194 -0.06447   0.95957 -0.21578   0.98907 -0.16925   0.78225 -0.33178

 0.990485 -0.06588   0.96020 -0.22675   0.98971 -0.18220   0.77890 -0.32322

 0.991426 -0.07181   0.96000 -0.23693   0.98960 -0.19396   0.78023 -0.33434

 0.991300 -0.07423   0.95946 -0.24666   0.98925 -0.20484   0.77863 -0.33137

 0.991791 -0.07874   0.95855 -0.25567   0.98861 -0.21474   0.77899 -0.33792

 0.991687 -0.08139   0.95747 -0.26405   0.98783 -0.22390   0.77785 -0.33753

 0.991837 -0.08491   0.95623 -0.27172   0.98690 -0.23221   0.77759 -0.34167

 0.991678 -0.08739   0.95492 -0.27878   0.98589 -0.23985   0.77662 -0.34236

 0.991622 -0.09019   0.95354 -0.28521   0.98480 -0.24681   0.77606 -0.34518

 0.991407 -0.09239   0.95215 -0.29112   0.98366 -0.25319   0.77517 -0.34626

 0.991230 -0.09466   0.95073 -0.29652   0.98248 -0.25902   0.77447 -0.34831
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0.990969	-0.09657	0.94931	-0.30146	0.98128	-0.26437	0.77362	-0.34946
0.990720	-0.09843	0.94789	-0.30599	0.98006	-0.26925	0.77286	-0.35103
0.990425	-0.10006	0.94648	-0.31014	0.97884	-0.27373	0.77204	-0.35213
0.990134	-0.10160	0.94509	-0.31393	0.97761	-0.27782	0.77127	-0.35338
0.989819	-0.10298	0.94372	-0.31742	0.97640	-0.28157	0.77048	-0.35436
0.989504	-0.10427	0.94237	-0.32061	0.97519	-0.28501	0.76972	-0.35539
0.989179	-0.10544	0.94105	-0.32353	0.97400	-0.28816	0.76896	-0.35626
0.988856	-0.10652	0.93976	-0.32622	0.97283	-0.29104	0.76823	-0.35711
0.988528	-0.10750	0.93850	-0.32868	0.97169	-0.29368	0.76751	-0.35786
0.988204	-0.10841	0.93728	-0.33094	0.97057	-0.29611	0.76680	-0.35858
0.987881	-0.10924	0.93609	-0.33301	0.96948	-0.29833	0.76612	-0.35922
0.987563	-0.11000	0.93494	-0.33492	0.96841	-0.30037	0.76546	-0.35983
0.987250	-0.11070	0.93383	-0.33667	0.96738	-0.30224	0.76481	-0.36038
0.986943	-0.11135	0.93275	-0.33828	0.96638	-0.30396	0.76419	-0.36090
0.986642	-0.11194	0.93171	-0.33975	0.96541	-0.30554	0.76359	-0.36138
0.986348	-0.11248	0.93071	-0.34111	0.96448	-0.30699	0.76300	-0.36182
0.986062	-0.11298	0.92974	-0.34236	0.96357	-0.30832	0.76244	-0.36223
0.985783	-0.11344	0.92881	-0.34351	0.96270	-0.30954	0.76190	-0.36260
0.985514	-0.11386	0.92792	-0.34457	0.96186	-0.31067	0.76138	-0.36295
0.985252	-0.11425	0.92706	-0.34555	0.96106	-0.31170	0.76088	-0.36328

0.984999	-0.11461	0.92624	-0.34644	0.96028	-0.31265	0.76040	-0.36358
0.984756	-0.11494	0.92545	-0.34727	0.95954	-0.31353	0.75994	-0.36386
0.984520	-0.11524	0.92469	-0.34804	0.95883	-0.31434	0.75950	-0.36412
0.984293	-0.11552	0.92397	-0.34874	0.95814	-0.31508	0.75907	-0.36436
0.984075	-0.11578	0.92328	-0.34939	0.95749	-0.31576	0.75867	-0.36458
0.983864	-0.11602	0.92262	-0.34999	0.95686	-0.31639	0.75828	-0.36479
0.983662	-0.11624	0.92198	-0.35054	0.95626	-0.31698	0.75790	-0.36498
0.983469	-0.11644	0.92138	-0.35106	0.95568	-0.31751	0.75755	-0.36516
0.983284	-0.11663	0.92080	-0.35153	0.95513	-0.31801	0.75721	-0.36533
0.983105	-0.11680	0.92025	-0.35197	0.95461	-0.31847	0.75688	-0.36548
0.982934	-0.11696	0.91973	-0.35237	0.95411	-0.31889	0.75657	-0.36563
0.982771	-0.11711	0.91922	-0.35274	0.95363	-0.31928	0.75628	-0.36576
0.982615	-0.11725	0.91874	-0.35309	0.95318	-0.31964	0.75599	-0.36589
0.982465	-0.11737	0.91829	-0.35341	0.95274	-0.31997	0.75573	-0.36600
0.982322	-0.11749	0.91785	-0.35371	0.95233	-0.32028	0.75547	-0.36611
0.982186	-0.11760	0.91744	-0.35399	0.95193	-0.32057	0.75522	-0.36621
0.982056	-0.11770	0.91705	-0.35424	0.95156	-0.32084	0.75499	-0.36631
0.981932	-0.11779	0.91667	-0.35448	0.95120	-0.32108	0.75477	-0.36640
0.981814	-0.11788	0.91632	-0.35470	0.95086	-0.32131	0.75456	-0.36648
0.981701	-0.11796	0.91598	-0.35491	0.95054	-0.32152	0.75436	-0.36656

0.981594	-0.11803	0.91566	-0.35510	0.95023	-0.32171	0.75417	-0.36663
0.981491	-0.11810	0.91535	-0.35527	0.94994	-0.32190	0.75398	-0.36670
0.981394	-0.11817	0.91506	-0.35544	0.94966	-0.32207	0.75381	-0.36676
0.981301	-0.11823	0.91478	-0.35559	0.94939	-0.32222	0.75365	-0.36682
0.981212	-0.11828	0.91452	-0.35573	0.94914	-0.32237	0.75349	-0.36688
0.981128	-0.11833	0.91427	-0.35587	0.94890	-0.32250	0.75334	-0.36693
0.981048	-0.11838	0.91403	-0.35599	0.94867	-0.32263	0.75320	-0.36698
0.980971	-0.11843	0.91381	-0.35611	0.94846	-0.32275	0.75306	-0.36702
0.980899	-0.11847	0.91359	-0.35621	0.94825	-0.32285	0.75294	-0.36707
0.980830	-0.11851	0.91339	-0.35631	0.94805	-0.32296	0.75282	-0.36711
0.980764	-0.11854	0.91319	-0.35641	0.94787	-0.32305	0.75270	-0.36714
0.980702	-0.11858	0.91301	-0.35649	0.94770	-0.32314	0.75259	-0.36718
0.980642	-0.11861	0.91284	-0.35658	0.94753	-0.32322	0.75249	-0.36721
0.980587	-0.11864	0.91267	-0.35665	0.94737	-0.32330	0.75239	-0.36724
0.980533	-0.11867	0.91252	-0.35672	0.94722	-0.32337	0.75230	-0.36727
0.980483	-0.11869	0.91237	-0.35679	0.94708	-0.32344	0.75221	-0.36730
0.980435	-0.11872	0.91223	-0.35685	0.94694	-0.32350	0.75212	-0.36733
0.980389	-0.11874	0.91209	-0.35691	0.94681	-0.32356	0.75204	-0.36735
0.980345	-0.11876	0.91196	-0.35696	0.94669	-0.32361	0.75197	-0.36737
0.980304	-0.11878	0.91185	-0.35702	0.94657	-0.32366	0.75190	-0.36739

0.980265	-0.11880	0.91173	-0.35706	0.94646	-0.32371	0.75183	-0.36741
0.980228	-0.11881	0.91162	-0.35711	0.94636	-0.32376	0.75176	-0.36743
0.980193	-0.11883	0.91152	-0.35715	0.94626	-0.32380	0.75170	-0.36745
0.980159	-0.11885	0.91142	-0.35719	0.94617	-0.32384	0.75164	-0.36747
0.980127	-0.11886	0.91133	-0.35723	0.94608	-0.32387	0.75159	-0.36748
0.980097	-0.11887	0.91124	-0.35726	0.94600	-0.32391	0.75153	-0.36750
0.980068	-0.11889	0.91116	-0.35729	0.94592	-0.32394	0.75148	-0.36751
0.980041	-0.11890	0.91108	-0.35732	0.94584	-0.32397	0.75144	-0.36752
0.980016	-0.11891	0.91101	-0.35735	0.94577	-0.32400	0.75139	-0.36754
0.979992	-0.11892	0.91094	-0.35738	0.94570	-0.32403	0.75135	-0.36755
0.979969	-0.11893	0.91087	-0.35741	0.94564	-0.32405	0.75131	-0.36756
0.979948	-0.11894	0.91081	-0.35743	0.94558	-0.32407	0.75128	-0.36757
0.979927	-0.11895	0.91075	-0.35745	0.94552	-0.32410	0.75124	-0.36758
0.979907	-0.11895	0.91069	-0.35747	0.94546	-0.32412	0.75120	-0.36759
0.979888	-0.11896	0.91064	-0.35749	0.94541	-0.32414	0.75117	-0.36760
0.979870	-0.11897	0.91058	-0.35751	0.94536	-0.32415	0.75114	-0.36761
0.979853	-0.11897	0.91054	-0.35753	0.94532	-0.32417	0.75111	-0.36761
0.979837	-0.11898	0.91049	-0.35754	0.94527	-0.32419	0.75108	-0.36762
0.979822	-0.11899	0.91045	-0.35756	0.94523	-0.32420	0.75106	-0.36763
0.979808	-0.11899	0.91041	-0.35757	0.94519	-0.32422	0.75103	-0.36764

0.979795	-0.11900	0.91037	-0.35759	0.94515	-0.32423	0.75101	-0.36764
0.979782	-0.11900	0.91033	-0.35760	0.94512	-0.32424	0.75099	-0.36765
0.979770	-0.11901	0.91030	-0.35761	0.94508	-0.32425	0.75097	-0.36765
0.979758	-0.11901	0.91026	-0.35762	0.94505	-0.32427	0.75095	-0.36766
0.979748	-0.11902	0.91023	-0.35764	0.94502	-0.32428	0.75093	-0.36766
0.979738	-0.11902	0.91020	-0.35765	0.94499	-0.32429	0.75091	-0.36767
0.979728	-0.11902	0.91017	-0.35766	0.94497	-0.32430	0.75089	-0.36767
0.979719	-0.11903	0.91015	-0.35766	0.94494	-0.32430	0.75088	-0.36768
0.979710	-0.11903	0.91012	-0.35767	0.94492	-0.32431	0.75086	-0.36768
0.979701	-0.11903	0.91010	-0.35768	0.94489	-0.32432	0.75085	-0.36768
0.979694	-0.11904	0.91007	-0.35769	0.94487	-0.32433	0.75084	-0.36769
0.979686	-0.11904	0.91005	-0.35770	0.94485	-0.32433	0.75082	-0.36769
0.979679	-0.11904	0.91003	-0.35770	0.94483	-0.32434	0.75081	-0.36769
0.979672	-0.11904	0.91001	-0.35771	0.94481	-0.32435	0.75080	-0.36770
0.979666	-0.11905	0.91000	-0.35771	0.94480	-0.32435	0.75079	-0.36770
0.979660	-0.11905	0.90998	-0.35772	0.94478	-0.32436	0.75078	-0.36770
0.979655	-0.11905	0.90996	-0.35773	0.94476	-0.32436	0.75077	-0.36770
0.979649	-0.11905	0.90995	-0.35773	0.94475	-0.32437	0.75076	-0.36771
0.979645	-0.11905	0.90993	-0.35774	0.94474	-0.32437	0.75075	-0.36771
0.979640	-0.11905	0.90992	-0.35774	0.94472	-0.32438	0.75074	-0.36771

```
POS. SEQ. HARMONIC CURRENT FROM BUS 5
************************************
           7.0000000          13.2695100
          13.0000000           5.1529110
          19.0000000           1.8018060
          25.0000000           0.3357296
          31.0000000           0.5764368
          37.0000000           0.5812874
          43.0000000           0.3171365
          49.0000000           0.0306535

NEG. SEQ. HARMONIC CURRENT FROM BUS 5
************************************

           5.0000000          37.9971900
          11.0000000           5.2730640
          17.0000000           0.7023263
          23.0000000           1.1213360
          29.0000000           1.0018350
          35.0000000           0.5309472
          41.0000000           0.1523140
          47.0000000           0.2574813
*************************************************
IH5 =
          37.9971900

5TH HARMONIC VOLTAGE AT:
**********************
      BUS5 =

         220.1647000


AFTER ADDING THE FILTER,THE 5TH HARMONIC VOLTAGE AT:
**************************************************
      BUS5 =

         150.1946000

STATEMENTS EXECUTED=    9598

CORE USAGE        OBJECT CODE=   34240 BYTES,ARRAY AREA=    8308 BYTES,TOTAL AREA AVAILABLE= 2406288  BYTES

DIAGNOSTICS         NUMBER OF ERRORS=       0, NUMBER OF WARNINGS=       0, NUMBER OF EXTENSIONS=       0

COMPILE TIME=    0.16 SEC,EXECUTION TIME=     0.50 SEC,     15.49.00    SATURDAY     25 MAY 91    WATFIV - MAR 1980 V2L0

         C$STOP
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