Cape Peninsula
University of Technology

MEASUREMENT METHODOLOGY INVESTIGATING HOME ENTERTAINMENT CONSOLES AND COMPARISON AGAINST ENERGY STAR AND HARMONIC STANDARDS

by

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DECLARATION

I, Albertus Johannes Bredekamp, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

People are spending more time being entertained at home now than ever before. It is currently common to find a home entertainment console containing an LCD or Plasma television, DVD player and surround sound amplifier in many homes. The number of home entertainment devices is increasing, yet our understanding of the effect that they have on power quality is incomplete. This study determines the power consumption of home entertainment equipment as well as the effect that such devices have on harmonic distortion levels.

A methodology is developed for the measurement of the power consumption of home entertainment equipment including television sets, DVD players and home theatre. The results are compared to the Energy Star standard to determine if the power consumption of these devices is within the limits imposed. The methodology presented consists of three parts, performing measurements, generating results and comparison to energy and harmonic standards.

The developed methodology includes steps for mathematically combining the measured voltage and current waveforms of individual devices. The goal is to determine total current and voltage waveforms for a combination of devices. The methodology also describes how to analyze the resultant synthesized waveforms so as to determine the power consumption at each harmonic.

The levels of current harmonics for individual devices and groups of devices are determined and then compared to the EN6100-3-2 standard to ascertain if they are within the limits imposed. The power consumption and current harmonics of each combination as well as individual devices were analysed. Using the developed methodology, four case studies were conducted, grouping different home entertainment devices together.

It was found that the power consumption of LCD television sets are below the limits imposed by the Energy Star standard while for Plasma based televisions it was above these limits. Current harmonic levels for CRT based televisions were found to be above the limits imposed by the EN6100-3-2 standard while those for LCD and Plasma based televisions the levels were below the limits.

The research concludes that the current harmonics of new LCD and Plasma based televisions does not pose any concern for power quality.

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DEDICATION

For my mom,

Sarah Johanna Bredekamp

1942 - 2012

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GLOSSARY

A	Amp, Unit of current
APL	Average Picture Level
BLM	Back-light modulation
C	Capacitance
CD	Compact Disc
CRT	Cathode Ray Tube
DSTV	Digital Satellite Television
DVD	Digital Versatile Disc
f_1	Fundamental Frequency
Farad	Unit of Capacitance
Henry	Unit of Inductance
I_1	RMS current at f_1
j	Imaginary part
J	Joule, Unit of Energy
L	Inductance in Henries
LCD	Liquid Crystal Display
LED	Light Emitting Diode
P	Real Power in Watts
PF	Power Factor
P_1	Real power (RMS) at f_1
Q	Reactive Power in VARs
Q_1	Reactive power at f_1
R	Resistance
Re	Real Part
RMS	Root Mean Square at f_1
S	Apparent Power in VA
S_1	Complex power at fundamental frequency (f_1)
t	Time
UHF	Ultra High Frequency
V	Volt, Unit of voltage
V_1	RMS voltage at f_1
VCR	Video Cassette Recorder
W	Watt, Unit of Power
Z	Impedance
φ	the phase difference between voltage and current
ω	Angular

CHAPTER ONE
INTRODUCTION

1.1 Background

Since the introduction of analogue television into South Africa in 1976 (Harisson, R., & Ekman 1976, 26(1):102-109), television has entered every aspect of our lives. It has become the primary form of home entertainment for many South Africans. The first colour television sets in South Africa were quite expensive making for a slow initial uptake (Bevan, C., 2008). Later as many more households started to purchase television sets this new load on the power grid started to become more prominent.

With the availability of the first affordable video cassette recorders (VCRs) on the local market during the early eighties, consumers were now for the first time able to watch one channel while recording another as well as rent movies and view them in their own homes. A VCR needed to be operated together with a TV. The TV together with a VCR was the first combined devices to enhance home entertainment.

When the Electronic Media Network (MNET) started their broadcasts in 1986 (Williams, D.,2008 financialmail.co.za), South Africans were first introduced to the set-top box to be used with the TV and VCR. A set-top box is an analogue device used to convert from one type of signal to another. In the case of the MNET set-top box (more commonly called a decoder) the conversion was made from a scrambled to a descrambled signal. This allowed consumers to further enhance their home entertainment as they could now receive an additional TV channel. Consumers would subscribe to this new channel and would have to pay a fee for access. For many South Africans at the time MNET was considered a luxury. Uptake was slow and the impact of the new power demand from set-top boxes was spread over many years. Such analogue set-top boxes remain in operation but are being rapidly phased out in favour of digital equipment.

Digital satellite television (DSTV) was first introduced to South Africa by Multichoice in 1992. It required a TV and a digital satellite decoder. Once again this new technology was considered a luxury and as such the uptake has been slow. This new power demand from yet another set-top box has spread over many years. Multichoice reached 2 million subscribers in November 2007 (MyBroadBand.co.za NEWS, 2007, “MultiChoice reaches 2 million subscribers”). This additional load from digital satellite decoders appeared gradually over 15 years.

South Africa is poised to make the transition from an analogue to a digital television receiving system. The reasons are both economical and technological.

Figure 1.1: Analogue and digital television feeds (traditional setup)

Figure 1.1 shows the television reception setup of South Africans as it exists in 2011. People own a traditional analogue Cathode Ray Tube (CRT) based television with 480 lines of vertical resolution. They have an Ultra High Frequency (UHF) antenna receiving an analogue television signal from land based transmitters and/or a satellite dish receiving a digital television signal from a satellite which is fed to the analogue CRT via a digital satellite decoder (Pay TV).

In April 2013, analogue transmissions will be switched off. All consumers will need to switch to digital receiving systems or face having no reception. (TECHCENTRAL, 2010. "Digital television migration delayed to 2013"). Figure 1.2 shows the scenario rapidly developing in South Africa once the transition to digital land based television transmission is complete. Viewers with only traditional analogue reception equipment (Figure 1.1) will be required to purchase a set-top box to convert the digital television signal to an analogue signal suitable for display by the television (Figure 1.2).

Figure 1.2: Digital television system feeds displayed on a CRT TV with new converter box

Figure 1.3: Digital television feeds displayed on a digital TV with surround sound

Figure 1.3 shows the next stage of the migration to digital television. The traditional analogue CRT TVs will be replaced with a new LCD or plasma TV with a digital tuner. The set-top box for the UHF antenna is no longer needed. The latest home entertainment system will most likely add a DVD player with full surround sound. Also the trend is to add video gaming consoles to the equation as people are spending more time being entertained at home now than they ever did in the past.

1.2 Shortcomings

Both in South Africa (Electrical Utility Company ESKOM) and elsewhere in the world electric power utilities are constantly striving to enhance their level of service to their customers while at the same time minimizing their impact on the environment. In order to achieve these goals, utilities need to have access to accurate information relating to how and when consumers are using electrical power. This information is vital for grid capacity and power plant construction planning. Utilities need to also provide power of high quality which is stable in voltage and frequency, but also free from excessive harmonic distortion.

According to Samotyj et al (Samotyj, M.J., Mielczarski, W., & Wasiluk-Hassa, M.M., 2002, pp.276-282), modern digital home entertainment equipment demand power of high quality from the grid. With the explosion of electronic media such as the Internet in the 1990s and the wide adoption of new home entertainment media such as DVDs, Plasma/LCD televisions and surround sound since the beginning of the 21st century, the home power usage landscape has changed considerably since 1976. The current state of home power usage due to home entertainment devices is not known.

Digital LCD, LED and Plasma televisions will soon completely displace analogue CRT televisions due to their compact design, superior picture quality and the phasing out of analogue transmissions. Almost all the television sets currently on display in a typical electronics store are non-CRT based.

Bredekamp et al measured the power consumption of home entertainment equipment in 2004 (Bredekamp AJ, Uken EA and Borrill L.,2006, p.211-216). The shortcoming with this study was that it did not include LCD, Plasma and LED based TV sets. Also, no study was conducted on combinations of home entertainment equipment to establish, compare, evaluate and analyse their real power consumption under standby and running operating conditions. In a typical household home entertainment device such as DVD players, amplifiers, decoders and TV sets will often be placed in a single storage unit or console.

Roth et al (Residential consumer electronics electricity consumption in the United States, Kurt Roth & Kurtis McKenney, 2007) studied the power consumption of a variety of consumer electronic devices including home entertainment equipment. Due to the wide scope of this study, no detailed analysis of home entertainment equipment was conducted. This study did not include digital televisions (LCD, LED, Plasma). The results were also only applicable to the United States.

Besides their power consumption, one must also consider that home entertainment equipment are non-linear loads.(Tricolite, 2010. Difference between linear loads and non-linear loads, Power Quality Today, 2010, Increasing Level of Nonlinear Loads Adds to Harmonic Woes). A non-linear load is an ac load where the current is not proportional to the voltage. The current will also be distorted (non-sinusoidal). This distortion introduces harmonics.

Some work (Grady, W.M.; Mansoor, A.; Fuchs, E.F.; Verde, P.; Doyle, M., 2002, Browne, N. Perera, S. Ribeiro, P.F, 2007) has been recorded to date that investigate the harmonic distortion generated by televisions. The bulk of power studies performed on television sets so far have focused on the standby mode power consumption with little or no attention to the power and harmonics during on-mode. (Rabaey,J., 2009,Hang-Seok Choi Huh, D.Y., 2006, Mcgarry,L., 2004,Wacyk,I. Giannopoulos, D. and Mukherjee, S., 2000, Clement, K. Pardon, I. and Driesen, J., 2008)

One area of concern is the prevalence of simulation studies as opposed to the analysis and comparison of actual measurements with calculated and/or modelled results. Guidelines for the modelling of the net harmonic currents produced by distributed single-phase loads such as computers, televisions, and incandescent light dimmers have already been established.(Grady, W.M.; Mansoor, A.; Fuchs, E.F.; Verde, P.; Doyle, M.;2002) This study focused on multiple types of distributed loads and how the harmonics produced by a combination of such loads can be modelled considering harmonic current cancellation due to phase angle diversity, and attenuation due to system impedance. No specific study of home entertainment devices was made.

1.3 The need for research

This study will seek to determine the power consumption of home entertainment equipment in on-mode, as well as the effect that home entertainment equipment has on harmonic distortion levels. For the purpose of this research home entertainment devices will include televisions, DVD players and hi-fi/surround sound equipment.

1.4 Research statement and boundaries of research

The objective of this thesis is to investigate and develop a methodology for the measurement of the power consumption of home entertainment devices, specifically television sets. Case studies will be conducted combining the harmonic and power measurements from separate devices mathematically as if the devices are connected to the same power outlet socket. The power consumption and harmonics of the combined devices, or console as a whole, will then be evaluated against existing international standards for maximum levels of power consumption and harmonics. The validity of the methodology used will also be confirmed by comparing measured and calculated results.

1.5 Main Contribution

The main contribution of this research will be the development of a methodology for the measurement and evaluation of the harmonics produced by home entertainment devices as well as the power consumed by such devices at fundamental and harmonic frequencies.

1.6 Outline of thesis

The thesis is divided into seven chapters:

Chapter 2 is a literature review of what is known about the topic, its significance and the need for research to be conducted into this field.

Chapter 3 investigates existing standards for power consumption and power harmonics as they apply to home entertainment devices.

In **Chapter 4** the contribution of the thesis is explained. It includes the development of a methodology for measuring and evaluating the power consumption at fundamental and harmonic frequencies.

In **Chapter 5** case studies are conducted. The scenario for each case study and its purpose is explained.

In **Chapter 6** the results from the case studies conducted are analysed and findings made.

In **Chapter 7** conclusions and recommendations on the main contribution of the thesis are made. The direction for future research is also offered.

1.7 Summary

This chapter begins with background information on the changing power usage landscape in South Africa due to the steady growth in the home entertainment sector. The shortcomings in our existing knowledge of the effect of home entertainment devices on power harmonics as well as power consumption is pointed out. This leads to the formulation of the objective for this investigation. The layout and organization of the thesis is also included in this chapter.

CHAPTER TWO
THEORY AND CONCEPTS

This chapter will first seek to clearly define and describe the terms and concepts used in the context of this research.

2.1 Power and Energy

Power is the rate of doing work and energy is the power consumed in time. The relationship between energy, power and time is as follows (The Physics Hypertextbook, 2010):

$$Energy = Power \times time \tag{2.1}$$

or

$$P = {}^{E}/_{t} \tag{2.2}$$

where:

P = Power in Watt (W)

E = Energy in Joule (J)

t = time in seconds (s)

Work can relate to mechanical or electrical work. In the context of this research only electrical work will be considered and the power will therefore be considered to be electrical power.

2.2 Power in AC systems

In direct current (DC) circuits, power is calculated by:

$$P_{dc} = I_{dc}V_{dc} \tag{2.3}$$

where:

P_{dc} = power in Watts

I_{dc} = current in Amperes

V_{dc} = voltage in Volts

According to ohms law the dc resistance is the ratio of dc voltage (V_{dc}) to the dc current (I_{dc}).

$$R_{dc} = {}^{V_{dc}}\!/_{I_{dc}} \qquad (2.4)$$

where:
R_{dc}= the resistance in ohms

In alternating current (AC) circuits voltage and current varies with time and the term impedance (Z) is used to describe the ratio of AC voltage to AC current. Impedance is a complex quantity ($\overline{Z}$) meaning it has a real (Re) and imaginary component (Im). Reactance is the imaginary part of electrical impedance (GeorgiaState University Department of Physics and Astronomy, 2010, Hyperphysics.com). The +jX means an inductive reactive component and –jX means a capacitive reactive component and can be defined as (Answers.com, 2010, Electrical Impedance):

$$\bar{Z} = \bar{R} \pm j\bar{X} \qquad (2.5)$$

where:
$\overline{Z}$ = impedance in ohms
$\overline{R}$ = resistance in ohms (real component)
$\overline{X}$ = reactance in ohms (imaginary or reactive component)

This means that for an inductor:

$$\overline{Z_\iota} = j\omega L \qquad (2.6)$$

where:
L = Inductance in Henries

and for a capacitor

$$\overline{Z_c} = -\frac{1}{\omega C} = -\frac{1}{2\pi f C} = -jX_c \qquad (2.7)$$

where:
C = Capacitance in Farad

The relationship between impedance and its components can be seen in figure 2.1. From equation 2.5 it is evident that both resistance and reactance is required to calculate impedance.

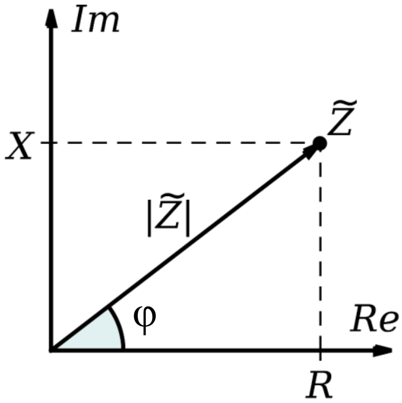


Figure 2.1: The complex impedance plane (Answers.com, 2010. *Electrical Impedance)*

From figure 2.1, and according to Pythagoras, it can also be seen that (GeorgiaState University Department of Physics and Astronomy, 2010, Hyperphysics.com):

$$|Z| = \sqrt{R^2 + X^2} \tag{2.8}$$

where:

$|Z|$ = absolute value of the impedance in ohms

Therefore:

$$\bar{V} = \bar{I}\bar{Z} \tag{2.9}$$

where:

$\bar{V}$ = complex AC voltage and is usually expressed as a root mean square (RMS) value

$\bar{I}$ = complex AC current (RMS current)

If the reactance is positive (inductive, equation 2.5) then its power triangle is as follows:

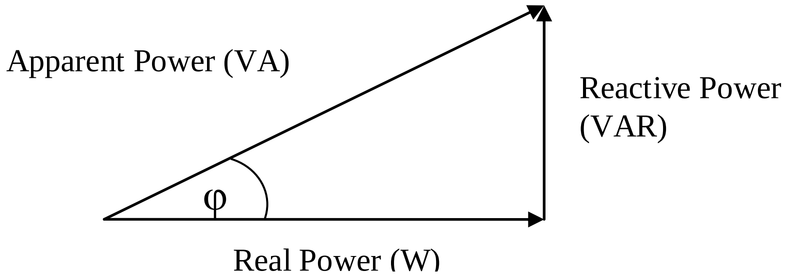


Figure 2.2: The Power triangle when reactance is positive (2.5)

Figure 2.2 shows the power triangle where:

S = Apparent Power in VA

Q = Reactive Power in VARs

P = Real Power in Watts

If the reactance is negative (capacitive, equation 2.5), then the power triangle will be the opposite of figure 2.2, namely:

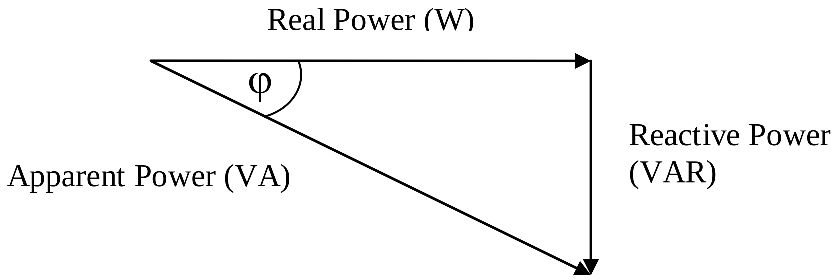


Figure 2.3: The Power triangle when reactance is negative (2.5)

So that for a single phase circuit (New World Encyclopedia, 2010, Electric Power):

$$\overline{S_1} = \overline{V_1}\,\overline{I_1^*} \tag{2.10}$$

$$\overline{S_1} = P_1 + jQ_1 \tag{2.11}$$

where:

S_1 = Complex power at fundamental frequency at f_1

P_1 = Real power (RMS) at f_1

Q_1 = Inductive reactive power at f_1

V_1 = RMS voltage at f_1

I_1 = RMS current at f_1

and for a capacitive circuit (New World Encyclopedia 2010, Electric Power):

$$\overline{S_1} = P_1 - jQ_{c(1)} \tag{2.12}$$

where:

$Q_{c(1)}$ = Capacitive reactive power at f_1

When an AC network is inductive ($+jX_L$), the current lags the voltage, whereas if the network is capacitive ($-jX_C$), the current leads the voltage. Thus there is a phase relationship between voltage and current and this is called phase angle (φ_1). Thus in steady state and when using RMS values, the real power (P_1) and the reactive power (Q_1 or $Q_{c(1)}$) can also be found from the following equations (McGranaghan et al, 2002:175):

$$P_1 = S_1 \cos\varphi_1 = V_1\, I_1 \cos\varphi_1 \tag{2.13}$$

$$Q_1 \text{or } Q_c S_1 \sin\varphi_1 = V_1 I_1 \sin\varphi_1 \tag{2.14}$$

where:

S_1= absolute value of the apparent power

φ_1= phase angle at f_1

Thus, the ratio of P_1 and S_1 is called the displacement power factor (dpf) so that (McGranaghan et al, 2002:177)

$$Power\ Factor\ (f_1) = \frac{P_1}{S_1} \tag{2.15}$$

or,

$$\cos\varphi_1 = \frac{P_1}{S_1} \tag{2.16}$$

If the network is purely resistive, then the dpf is unity and the voltage and current are in phase whereas, if the network is inductive the dpf is lagging while if capacitive it is leading.

2.3 Graphical analysis

As the voltage and current in an AC network is time varying, it is important to understand the basics of such a circuit through the use of graphical analysis.

2.3.1 Power in purely resistive AC circuits

When an alternating sinusoidal voltage is applied to a purely resistive circuit, a current flows which is in phase with the applied voltage. Figure 2.4 shows how in a purely resistive circuit, the applied voltage (turquoise) and the resulting current (magenta) are in phase.

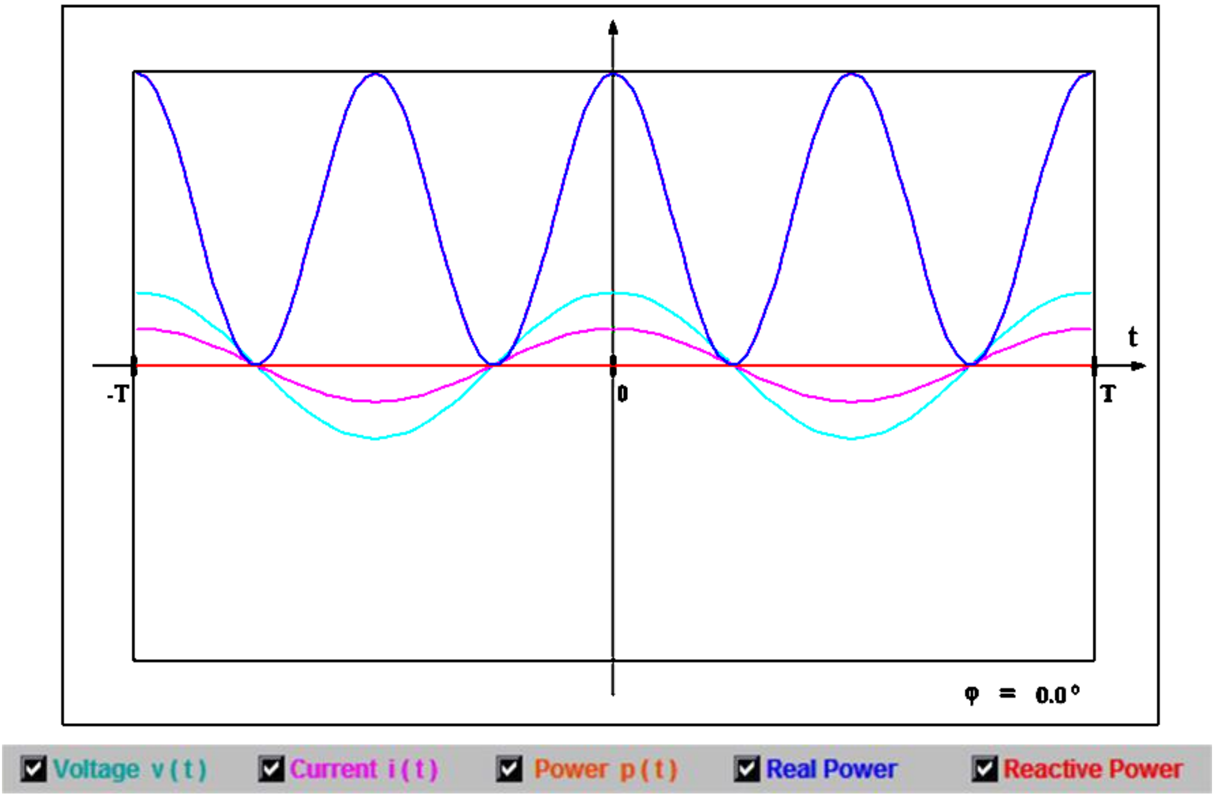


Figure 2.4: Java applet demonstrating the voltage and current waveforms of a purely resistive AC circuit

(Adapted from Amanaogawa.com, 2010. Power Components for Sinusoidal Signal)

From Figure 2.4, if we define the sinusoidal voltage applied to a circuit as (Amanaogawa.com, 2006. Power in Circuits):

$$v(t) = V_0 \cos(\omega t + \varphi) \qquad (2.17)$$

the resulting current can be expressed as:

$$i(t) = I_0 \cos(\omega t) \tag{2.18}$$

Where:

φ = the phase difference between voltage and current

I_0 = the peak current

V_0= the peak voltage

In the case of figure 2.4 the circuit has a real input impedance ie. purely resistive so that φ=0. The instantaneous power at the load *p(t)* is the product of *v(t)* and *i(t)* (Hyperphysics, GeorgiaState University Department of Physics and Astronomy, 2010. AC Power):

$$p(t) = v(t)i(t) = V_0 I_0 \cos(\omega t + \varphi)\cos(\ \omega t) \tag{2.19}$$

$$p(t) = \left({}^{V_0 I_0}\!/_{2}\right)[\cos\varphi + \cos(2\omega t + \varphi)] \tag{2.20}$$

The power has two Fourier components. An average value :

$$({}^{V_0 I_0}\!/_{2})\cos\varphi \tag{2.21}$$

But since φ=0° (for a purely resistive circuit) and cos 0°=1,

The average value is:

$$({}^{V_0 I_0}\!/_{2}) \tag{2.22}$$

And an oscillatory component with frequency 2f (Amanaogawa.com, 2006, Power in Circuits):

$$({}^{V_0 I_0}\!/_{2})\cos(2\omega t + \varphi) \tag{2.23}$$

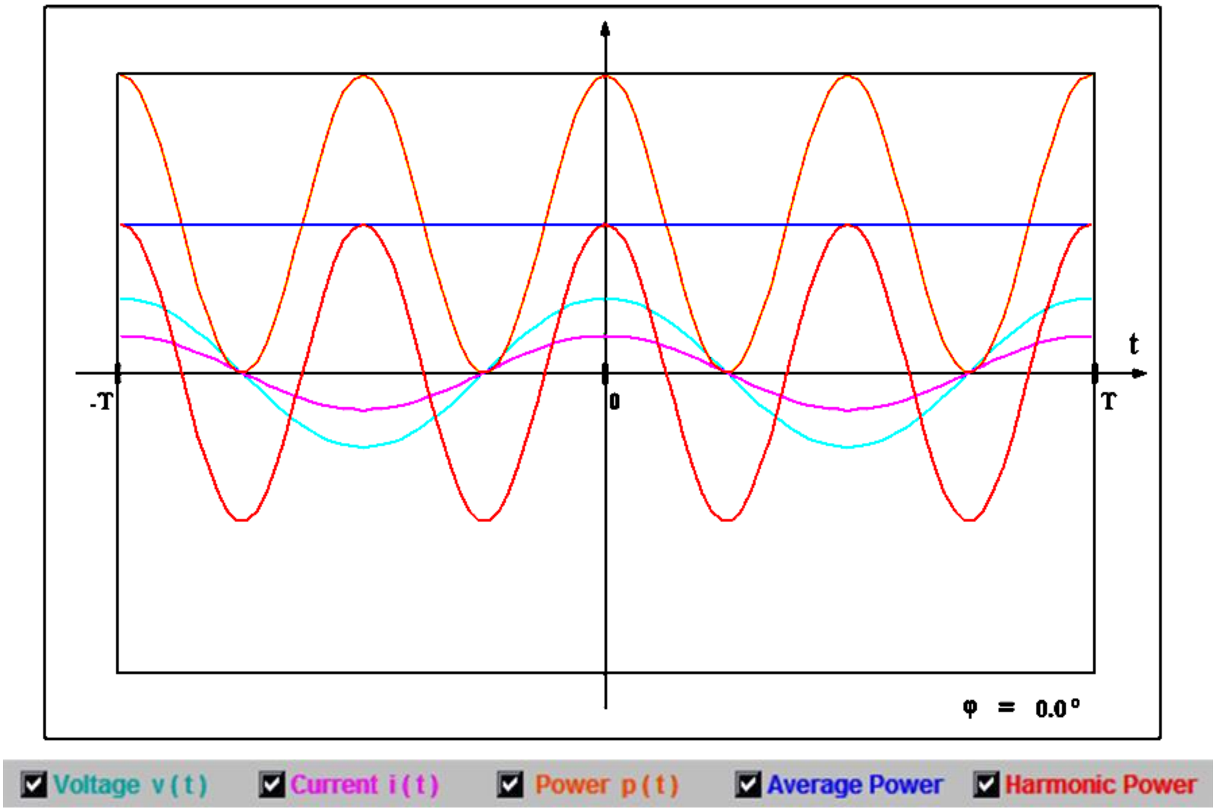


Figure 2.5: Java applet demonstrating the power fourier components for a purely resistive circuit

(Adapted from Amanaogawa.com, 2010. Power Components for Sinusoidal Signal)

The power p(t) is always positive and therefore flowing from generator to load. In figure 2.5, p(t) is presented in orange. The average power is presented by the straight blue line. The oscillatory power component is shown by the red waveform. It can be seen from figure 2.5 that the sum of the average and oscillatory power components produces the orange waveform p(t). Equation 2.20 represents a continuously varying quantity. Since the voltage and current waveforms are sinusoids the average power can be represented by (Hyperphysics, GeorgiaState University Department of Physics and Astronomy, 2010, AC Power)

$$P_{avg} = V_1 I_1 \cos\varphi \qquad (2.24)$$

where:

φ = the phase difference between voltage and current

For a resistive circuit, a net transfer of energy (joule) takes place which is dissipated by the resistive element as heat. In the case of the resistive circuit all the power used by the circuit is real power (watt) and there is no reactive power (VAR) component so that the apparent power (VA) is equal to the real power (watt). In this case the dpf is equal to unity.

2.3.2 Power in purely inductive AC circuits

In any closed circuit current will produce a magnetic flux (*Φ*) around a conductor. According to Lenz, the magnetic field always acts to oppose changes in the flux by generating a back EMF that tends to reduce or oppose the rate of change in the current.

An inductor is a circuit element made up of a number of turns of wire to form a coil that can store energy in a magnetic field created by the current passing through it. The coil can be wound around a ferrous core or be air-cored. The unit of inductance is the Henry and is defined as (sensorcentral.com, 2010, International System of Units, 2010, Derived units with special names)

$$L = {}^{N\Phi}/_{I} \tag{2.25}$$

where:
N = the number of turns of wire in the loop
Φ = the magnetic flux in the area spanned by the loop (weber)
I = is the current through the conductor (ampere)

From equation 2.25 it can be seen that 1H = 1Wb/A and that Henry is a measure of the ability of an inductor to store energy in its magnetic field (sensorcentral.com, 2010, International System of Units, 2010, Derived units with special names). The fact that an inductor is able to store energy in its magnetic field is of particular importance in the context of this research. Where in a purely resistive circuit all of the energy transferred to the load was dissipated as heat, in the case of a purely inductive load the energy delivered to the load can in fact be returned to the generator. This means that in a purely inductive circuit there is no net usage of energy per unit time (watt). The conductors that connect the inductor to the power source, however, must still be capable of carrying the current to produce the magnetic field around the inductor in the first place.

Figure 2.6 shows the situation when a sinusoidal voltage (turquoise) is applied to a purely inductive circuit. Notice that the current (magenta) is no longer in phase with the voltage (turquoise) due to Lenz' law. No net transfer of energy takes place and only reactive power flows (red).

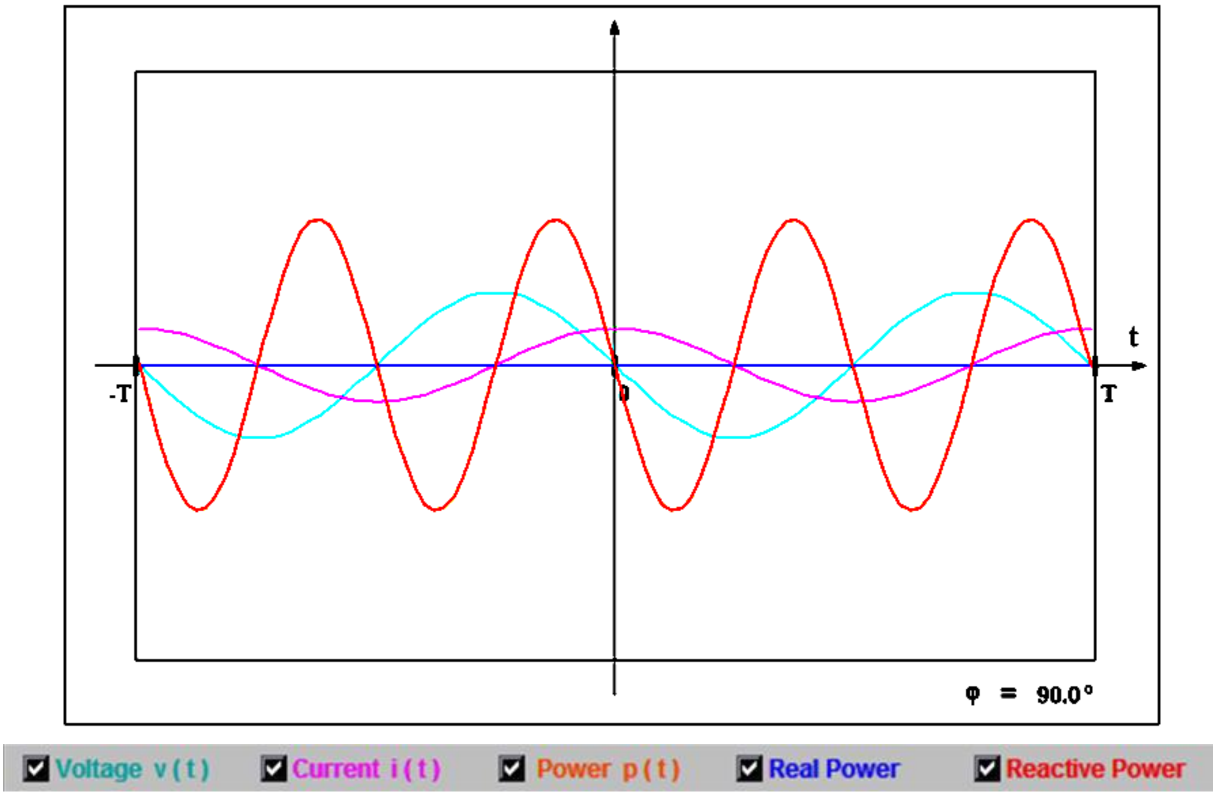


Figure 2.6: Java applet demonstrating the voltage and current waveforms of a purely inductive AC circuit

(Adapted from Amanaogawa.com, 2010. Power Components for Sinusoidal Signal)

In figure 2.6 the voltage and current is represented by equations 2.17 and 2.18 respectively. In this case the phase angle φ=90°.

From equation 2.20 and figure 2.6, the time dependant power is therefore given by:

$$p(t) = \left({V_0 I_0}/{2}\right)[\cos 90° + \cos(2\omega t + 90°)] \tag{2.26}$$

But since cos 90°= 0 the time dependant power for a purely inductive circuit can be rewritten as:

$$p(t) = \left({V_0 I_0}/{2}\right)\cos(2\omega t + 90°) \tag{2.27}$$

Note that the average power Fourier component from equation 2.20 is now zero, meaning that no net transfer of energy is taking place. The only remaining power component remaining from equation 2.20 is the oscillatory component as demonstrated in equation 2.23. During certain periods of oscillation p(t) can be negative, meaning that energy is flowing from the load back to the generator as demonstrated by the power in figure 2.7 (red waveform).

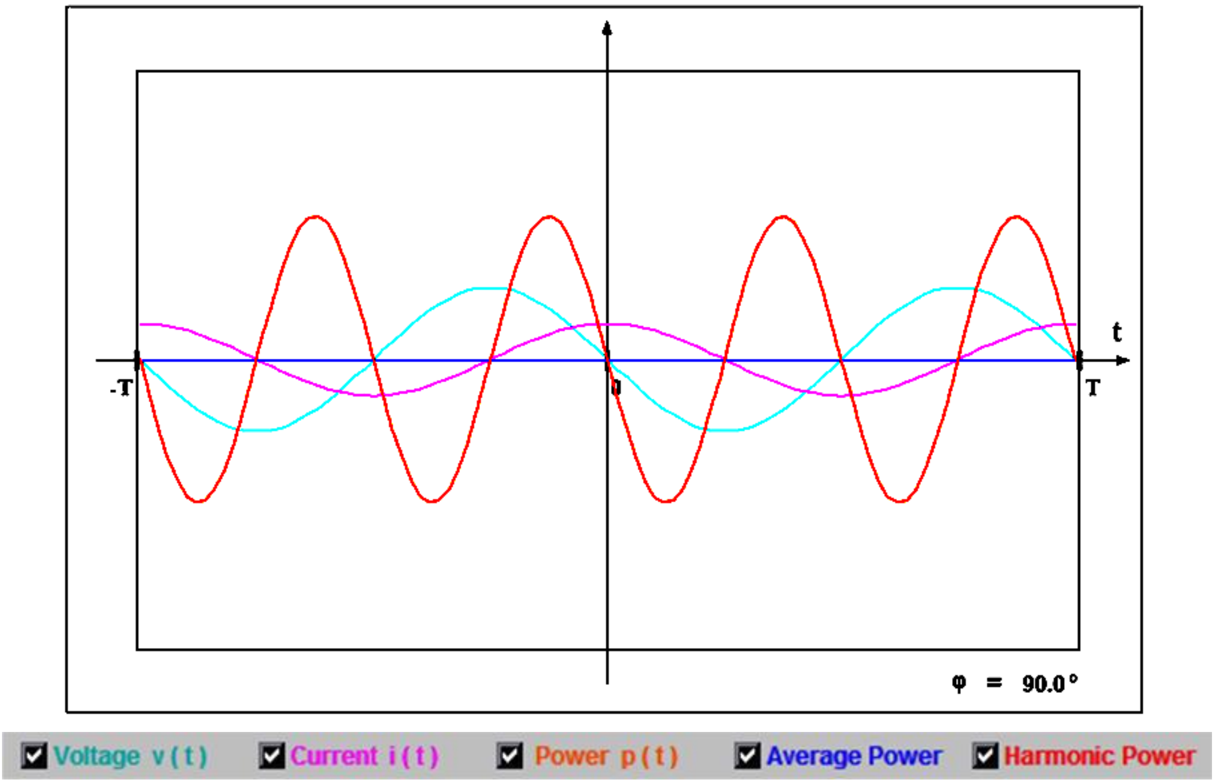


Figure 2.7: Java applet demonstrating the power fourier components for a purely inductive circuit

(Adapted from Amanaogawa.com, 2010. Power Components for Sinusoidal Signal)

Engineers need to know the reactive power of an inductive circuit, because it contributes to the apparent power in a network. Referring to figure 2.7, the real power is the power due to the resistive component of the circuit and the reactive power is the power due to the reactive component of the circuit. See equations 2.11 and 2.14.

2.3.3 Power in purely capacitive AC circuits

A capacitor is a passive electronic component consisting of two parallel plates separated by a non-conductive dielectric. When a potential difference exists across the two parallel plates an electrostatic field is generated. This electrostatic field can store energy. A capacitor is characterized by its capacitance measured in Farads (F). The Farad is the ratio of the electric charge on each plate to the potential difference between them. In the case of a perfect capacitor it can be expressed as:

$$C = \frac{Q_{charge}}{V_{charge}} \tag{2.26}$$

Where:

Q_{charge} = the charge on each plate in coulomb

V_{charge} = the voltage across the plates

It can be seen that a capacitance of one farad causes a charge of one coulomb to accumulate between the plates when one volt is applied across the plates. Figure 2.8 shows what happens when a sinusoidal voltage is applied to a purely capacitive circuit. Notice that the current (magenta) is no longer in phase with the voltage (turquoise). The *-j* phase in equation 2.7 indicates that the AC voltage lags the AC current by 90°:

Also, since the reactance of the capacitor has no resistive component, only reactive power flows as can be seen in figure 2.8 (red waveform). This means that while the real power P (watt) is zero, the reactive power VAR is non-zero. Conductors and transformers must still be sized to cope with the reactive power. Even though no net transfer of energy takes place there is still a contribution to the apparent power. Energy stored in the electrostatic field of the capacitor is returned to the generator on alternating cycles.

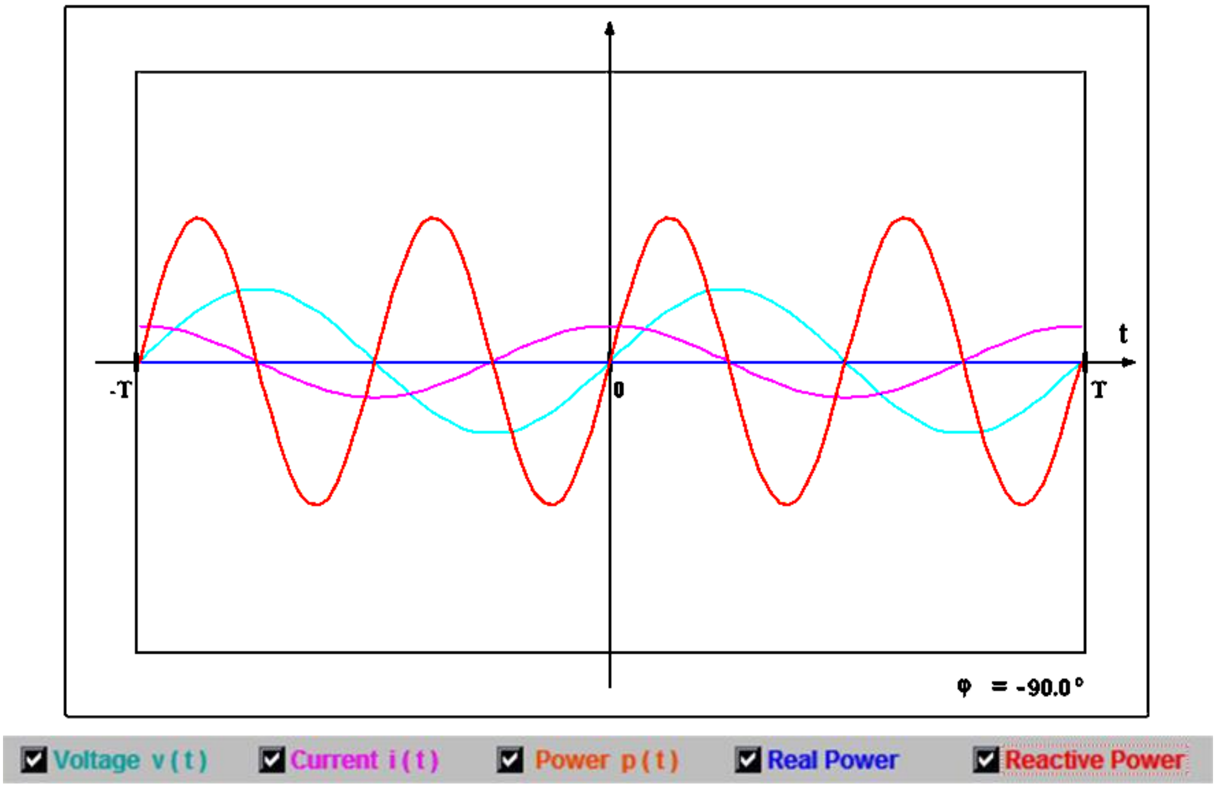


Figure 2.8: Java applet demonstrating the voltage and current waveforms of a purely capacitive AC circuit

(Adapted from Amanaogawa.com, 2010. Power Components for Sinusoidal Signal)

From equation 2.20 and figure 2.8 the time dependant power is given by:

$$p(t) = \left({}^{V_0 I_0}/_2\right)[\cos(-90°) + \cos(2\omega t - 90°)] \quad (2.27)$$

But since cos (-90°) = 0 the time dependant power for a purely capacitive circuit can be rewritten as:

$$p(t) = \left({}^{V_0 I_0}/_2\right)\cos(2\omega t - 90°) \quad (2.28)$$

Figure 2.9 shows the Fourier power component (red waveform). In the case of a purely capacitive circuit there is no net transfer of energy as power is periodically transferred to the load and back to the generator.

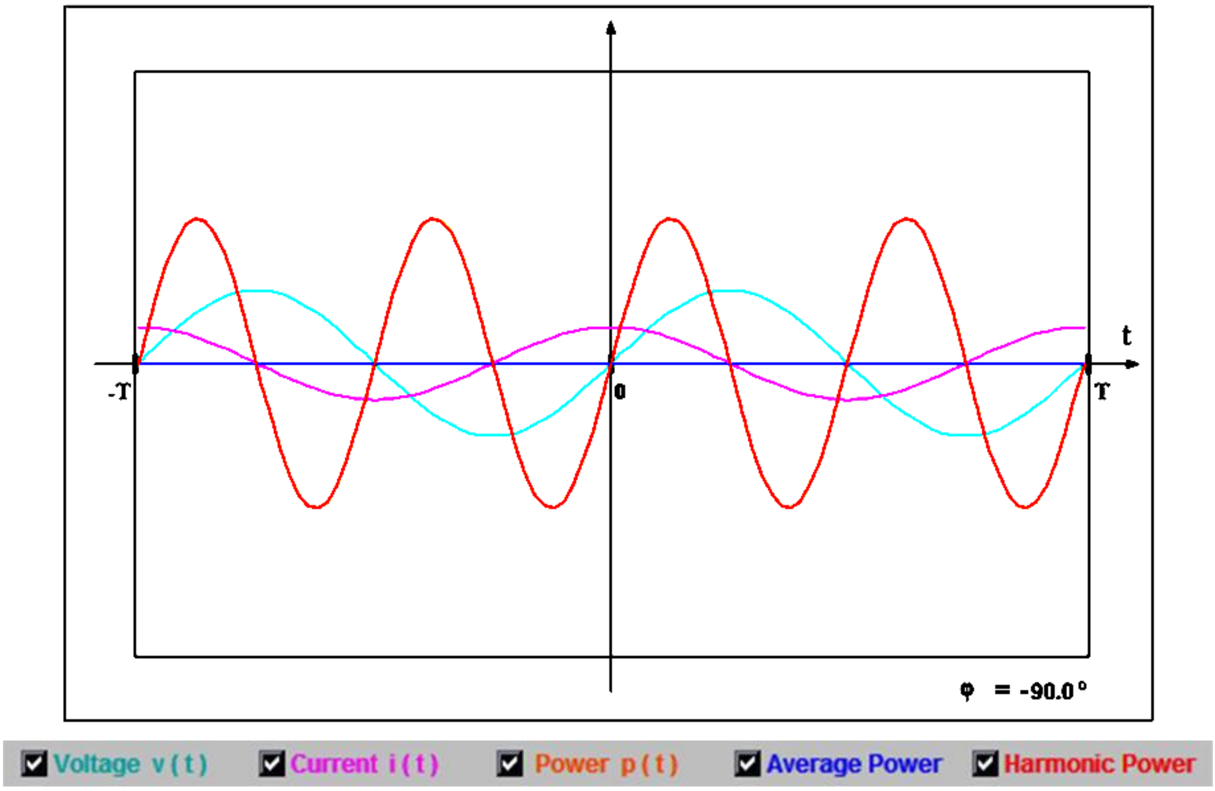


Figure 2.9: Java applet demonstrating the power Fourier components for a purely capacitive circuit

(Adapted from Amanaogawa.com, 2010. Power Components for Sinusoidal Signal)

2.4 Example of power calculation in an AC circuit with a combination of capacitive, inductive and resistive elements

For φ = -45°

Figure 2.10 shows the current and voltage waveforms for an AC circuit with φ= -45° ie, voltage lagging current.

The power triangle is as given in figure 2.2. Applying equation 2.20, the time dependant power can be presented by:

$$p(t) = \left(V_0 I_0 / 2\right) [\cos(-45°)\cos(2\omega t - 45°)]$$

In this case neither the average, nor the oscillatory Fourier terms are zero as in sections 2.3.2 and 2.3.3. This means that both real (P) and reactive power (Q) is flowing. A similar graphical analysis can be conducted for a network where the capacitive reactance is greater than the inductive reactance ($X_C > X_L$). In such a case, the reactive power will be seen as flowing from the capacitor to the source, thus reactive power is not consumed but supplied.

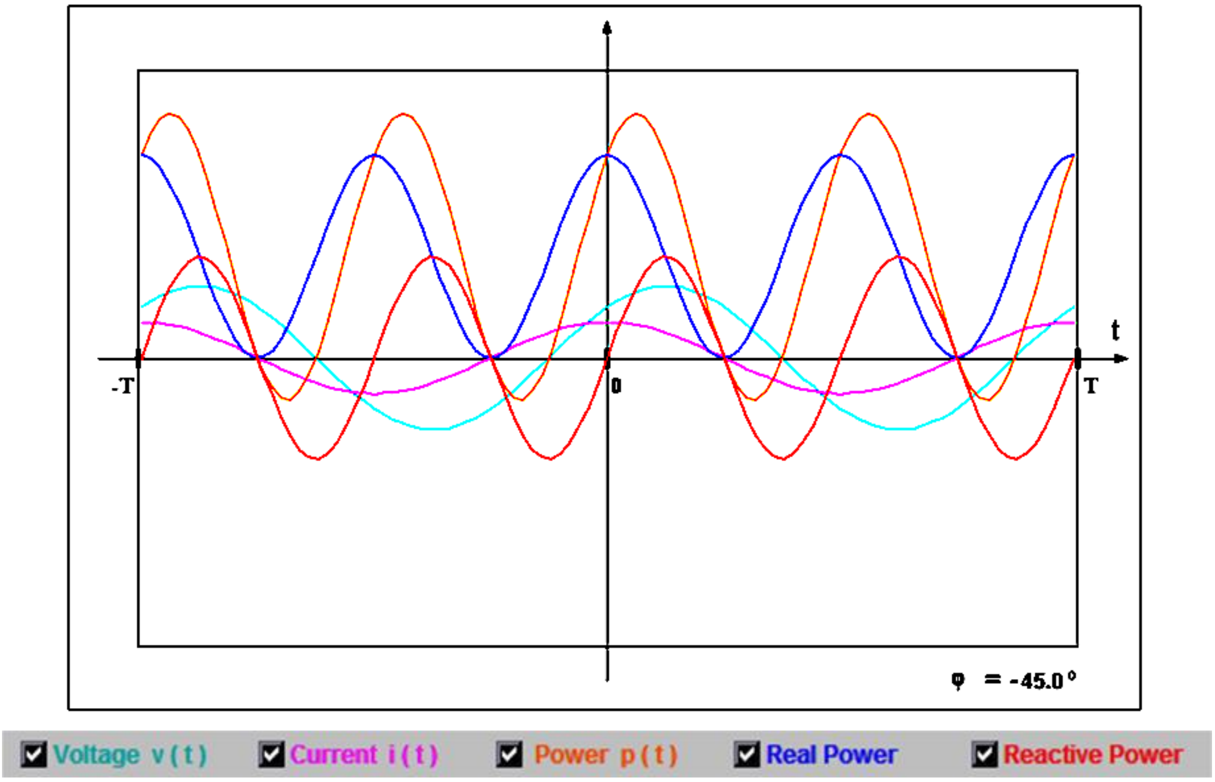


Figure 2.10: Java applet demonstrating the voltage and current waveforms of an AC circuit with φ = -45°

(Adapted from Amanaogawa.com, 2010. Power Components for Sinusoidal Signal)

2.5 Harmonics

Section 2.1 presented equations for the calculation of power when the voltage and current waveforms are sinusoidal. Using the same equations as-is when dealing with non-sinusoidal voltage and current waveforms will produce incorrect results. For correct calculation of power under non-sinusoidal voltage and current conditions, the power due to harmonics must be considered.

Harmonic distortion of current occurs when a sinusoidal voltage is applied to a non-linear load, which results in a distortion of the current waveform.

2.5.1 Linear and Non-Linear loads

A load is said to be linear if the voltage and current waveforms are sinusoidal. Also, for a load to be linear the current at any time must be proportional to the voltage. Loads that fall into this category are loads such as neon lamps and heaters. The graphical analyses of section 2.3 all assume linear loads.

Most if not all domestic loads, however, are non-linear. A non-linear load is an ac load where the current is not proportional to the voltage. Loads that fall into this category are loads such as Silicon Controlled Rectifier (SCR) controlled light dimmers, computers, laser printers, switch-mode power supplies, refrigerators and televisions (Tricolite, 2010. Difference between linear loads and non-linear loads).

Figure 2.11 shows a measured current waveform for a typical non-linear load, in this case a DVD player. The current waveform no longer has a sinusoidal shape and is,

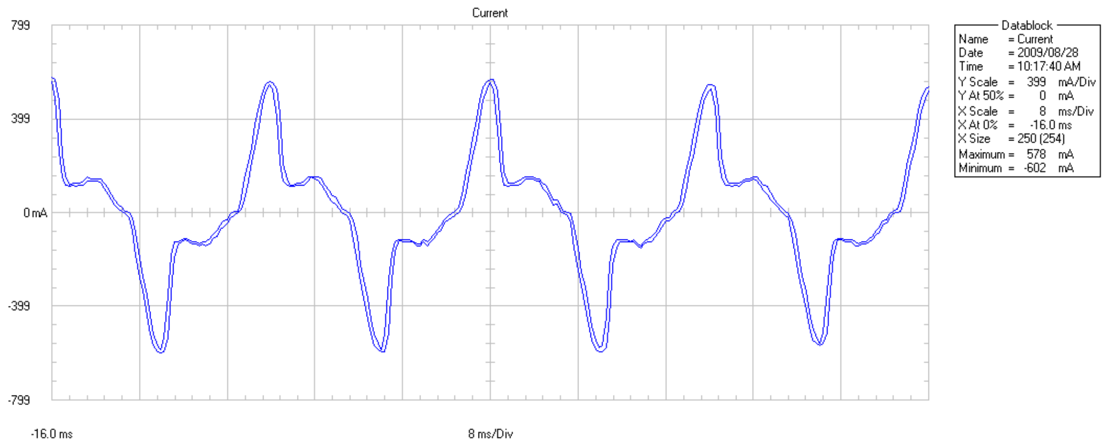


Figure 2.11: Measured current waveform of a typical non-linear load (Bredekamp, 2011)

instead, severely distorted. The current waveform in figure 2.11 is a complex waveform which according to Fourier can be represented as the sum of sine and cosine functions of different amplitude and frequency or harmonics (McGranaghan et al, 2002:170). Figure 2.12 shows a bar graph of these harmonics. Harmonics labelled 1, 5 and 7 indicate the odd harmonics and correspond to 50, 250 and 350 Hertz, respectively while 3 and 9 correspond to triplen harmonics (McGranaghan et al, 2002:179).The load current harmonics in figure 2.12 are typical for a non-linear load as they contain odd and triplen harmonics. The reason for this is that waveform of figure 2.11 is periodic. Even harmonics are usually only found with non-periodic waveforms.

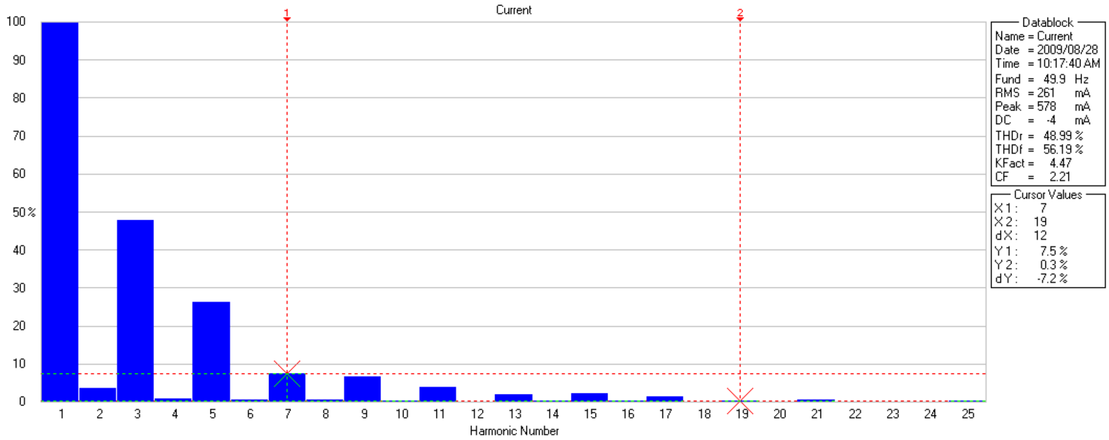


Figure 2.12: Spectrum view of the waveform in figure 2.11 showing the harmonic components

Harmonics are undesirable in power systems as they can cause numerous problems such as overheated transformers, excessive neutral currents and overstressed components to name but a few (Power Quality Today, 2010, Increasing Level of Nonlinear Loads Adds to Harmonic Woes).

2.5.2 Calculation of power in the presence of harmonics

To determine the power under non-sinusoidal conditions, it is necessary to first represent the current and voltage waveform in such a way that the separate harmonics can be viewed. Figure 2.11 represent a complex waveform that can be represented by (Shepherd, J. Morton, A.H. and Spence, L.F., 1998:157)

$$y = Y_{1m}\sin(\omega t + \psi_1) + Y_{2m}\sin(2\omega t + \psi_2) + \cdots \qquad (2.29)$$

where:

Y_{nm}= amplitude of the harmonic numbered n

ψ_n = phase angle of harmonic numbered n

m = peak value of harmonic

The process of harmonic analysis is then a case of finding the coefficients Y_{1m}, Y_{2m} …etc., and the phase angles Ψ_1, Ψ_2 … etc. Fourier analysis of the waveform in figure 2.11 will allow us to determine the aforementioned coefficients and phase angles.

Figure 2.14 demonstrate how a single circuit with non-sinusoidal voltages and currents can be decomposed into three separate circuits each with sinusoidal voltages and currents. Figure 2.14 (B) will allow us to calculate the power due to the fundamental while figures 2.14 (C) and (D) will allow us to calculate the powers due the third and fifth harmonics (Atkinson-Hope, 2000:78)

Figure 2.14(A) shows a linear load being powered from a distorted voltage source, V_{source} (background harmonics). The linear load produces a current, $I_{circuit}$. Performing a Fourier analysis on the waveforms of V_{source} and $I_{circuit}$ will allow us to express both waveforms in terms of their harmonic components using equation (2.29) (McGranaghan et al, 2002:173):

$$\boxed{\begin{matrix} V_{source} \\ \\ I_{circuit} \end{matrix}} = \boxed{\begin{matrix} V_{1peak}\sin(\omega t + \psi_{V1}) \\ \\ I_{1peak}\sin(\omega t + \psi_{I1}) \end{matrix}} + \boxed{\begin{matrix} V_{3peak}\sin(3\omega t + \psi_{V3}) \\ \\ I_{3peak}\sin(3\omega t + \psi_{I3}) \end{matrix}} + \boxed{\begin{matrix} V_{5peak}\sin(5\omega t + \psi_{V5}) \\ \\ I_{5peak}\sin(5\omega t + \psi_{I5}) \end{matrix}}$$

A B C D

Figure 2.13: V_{source} and $I_{circuit}$ expressed in terms of their harmonic components

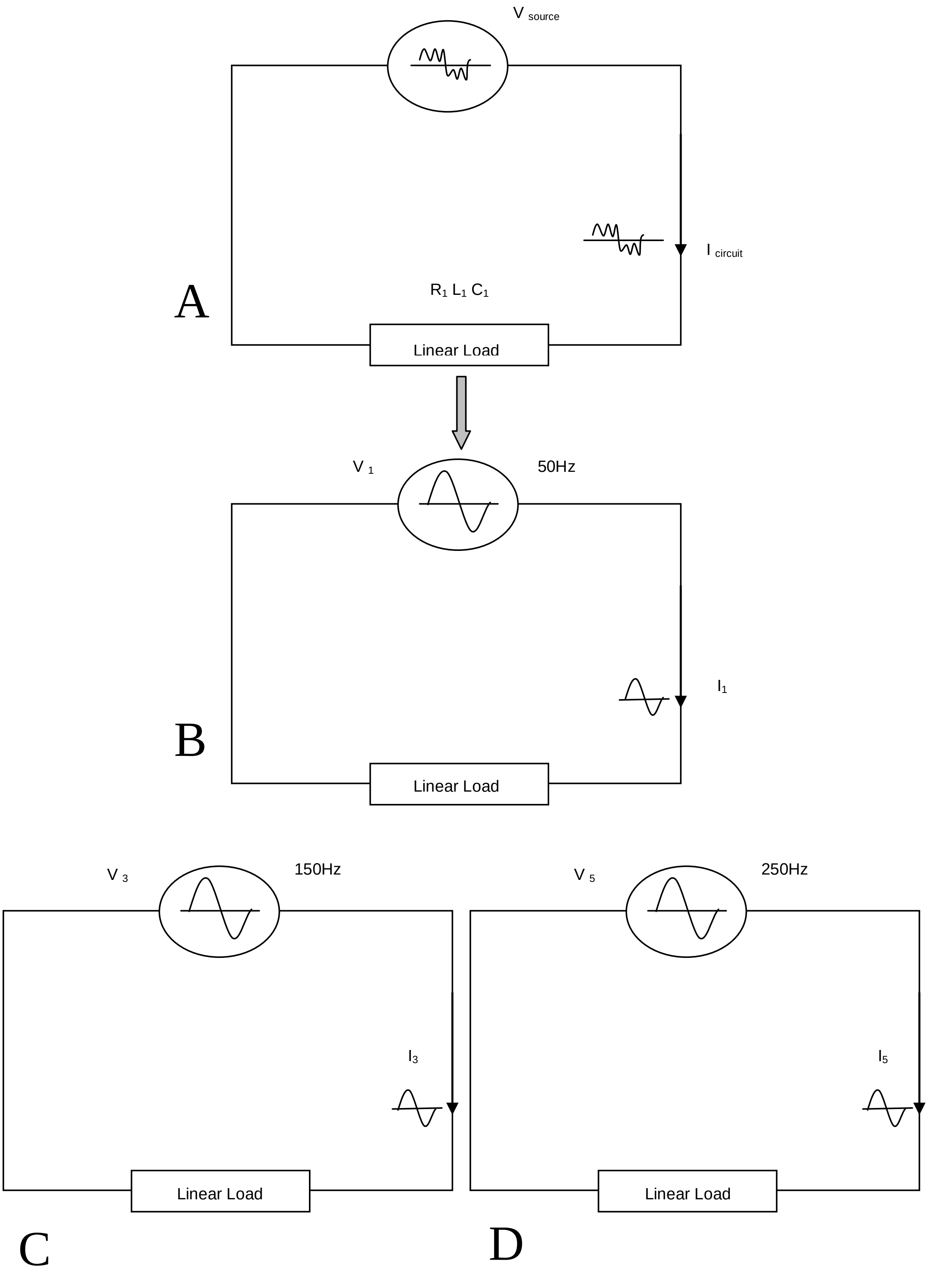


Figure 2.14: Decomposition for a linear load being fed from a voltage source (background harmonics)

In figure 2.13 the combinations marked B, C and D correspond to the voltage and current components of harmonics 1, 3 and 5 in figure 2.14 (B), (C) and (D), respectively. In terms of phasor diagrams V_{source} and $I_{circuit}$ from figure 2.14 can also be expressed as:

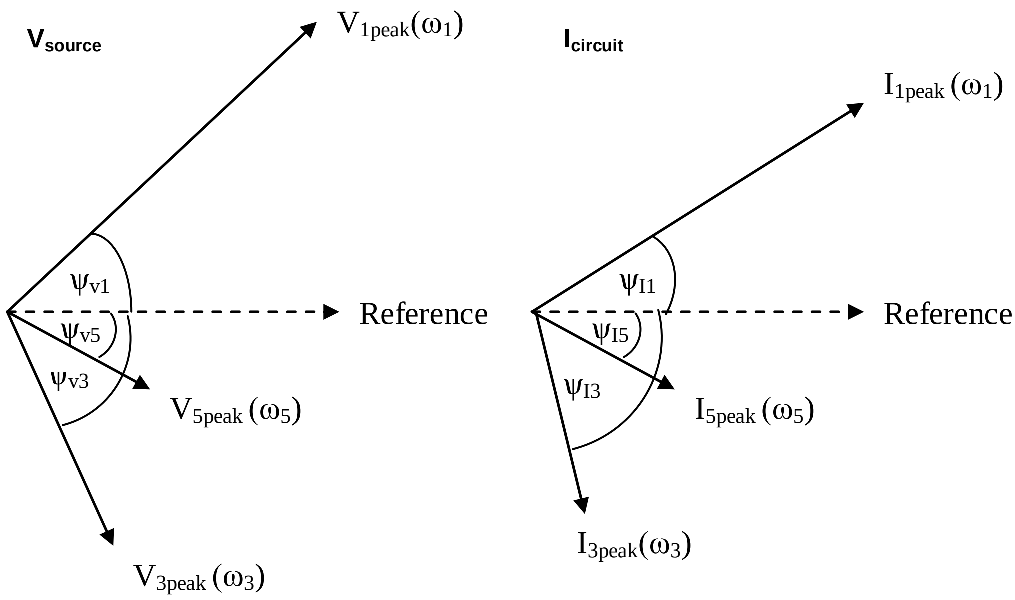


Figure 2.15: Phasor diagram for V_{source} and $I_{circuit}$

Using equation (2.24), and the values from figure 2.14 (B), the power due to harmonic n can be expressed as:

$$P_n = V_n I_n \cos(\varphi_{I_n}^{V_n}) \tag{2.30}$$

where:

P_n = the power due to harmonic number n

V_n = RMS value of the voltage at harmonic n

I_n = RMS value of the current at harmonic n

$\varphi_{I_n}^{V_n}$ = the phase difference between voltage harmonic n and current harmonic n

Depending on the values of ψ_{I1} and ψ_{V1} in equation (2.30) P_n can be negative. This means that P_T in the presence of harmonics can be expressed as (Atkinson-Hope, 2000:78):

$$P_T = \sum_{h=1}^{n} P_h = \pm P_1 \pm P_3 \pm P_5 \pm \cdots P_n \tag{2.31}$$

where:

P_1, P_3 and P_5 = the power due to harmonics 1, 3 and 5 respectively

P_h = power due to harmonics

P_T = total power

The RMS values of V_{source} and $I_{circuit}$ can be expressed as (Atkinson-Hope, 2000:78):

$$V_{source\ RMS} = \sqrt{(V_1)^2 + (V_3)^2 + (V_5)^2} \tag{2.32}$$

and

$$I_{circuit\ RMS} = \sqrt{(I_1)^2 + (I_3)^2 + (I_5)^2} \tag{2.33}$$

2.5.3 Total Harmonic Distortion

Total Harmonic Distortion (THD) is an index used to quantify the level of harmonics present in a voltage or current waveform. THD is defined as (McGranaghan et al, 2002:182):

$$THD = \frac{\sqrt{\sum_{h>1}^{h_{max}} {M_h}^2}}{M_1} \tag{2.34}$$

where:

M_h = value of the harmonic component h of the quantity M

Equation (2.34) can be used to express the THD for current and voltage as:

$$\%I_{THD} = \frac{\sqrt{\sum_{h=2}^{h_{max}} {I_h}^2}}{I_1} \times 100 \tag{2.35}$$

where:

I_h = either the RMS values or the amplitudes of the current harmonics

and

$$\%V_{THD} = \frac{\sqrt{\sum_{h=2}^{h_{max}} {V_h}^2}}{V_1} \times 100 \tag{2.36}$$

where:

V_h = either the RMS values or the amplitudes of the voltage harmonics

2.6 Summary

The theory and concepts behind the calculation of power under sinusoidal and non-sinusoidal conditions is discussed. The known formulae of the real, reactive apparent as well as complex AC power in sinusoidal steady state are presented. Examples of power calculations for purely resistive, inductive and capacitive circuits are included along with plots of voltage, current and power under sinusoidal conditions. Non-linear loads and harmonics are discussed as well as their effect on the power calculation methodology used.

CHAPTER THREE
HARMONIC AND POWER STANDARDS

3.1 Introduction

The power consumption and harmonic emissions of home entertainment devices are limited by legislation and standards. What follows is an overview of the most prominent and relevant power consumption and harmonics standards applied to home entertainment equipment. The standards and concepts presented here will be used during the analysis portion of this thesis as a base for comparison.

3.2 Power Consumption Standards

The Energy Star program had its start in the United States in 1992 and has since been adopted by Australia, Canada, Japan, New Zealand, Taiwan and the European Union (Energy Star, 2009. Energy Star Index)

Figure 3.1: The Energy star logo is placed on devices meeting energy star criteria for power consumption (Energy Star, 2009. *Energy Star Index)*

The United States Environmental Protection Agency (EPA) created the Energy Star program in 1992 in an attempt to reduce not only energy consumption, but also greenhouse gas emission from power plants. The program was intended to be part of a series of voluntary programs whose goal was to demonstrate the potential for profit in reducing power consumption and greenhouse gas emissions.

Energy Star was initiated as a voluntary labelling program for personal computers. In 1995 the program was expanded by introducing labelling for residential heating and cooling systems as well as new homes. Currently more than 40 000 Energy Star products are available which include major appliances, office equipment, lighting, and consumer electronics. According to EPA estimates about $14 billion in energy costs was saved in 2006 alone. The Energy Star program has helped spread the use of LED traffic lights, efficient fluorescent lighting, power management systems for office equipment, and low standby power use.

3.2.1 Energy Star Specifications categories

Energy Star specifications differ from item to item. Only portions of the standard that relate to home entertainment equipment will be presented here. The metrics used to determine whether a device qualifies for Energy Star certification will also be discussed. A metric is a parameter of a device used as a criterion to determine whether it qualifies or not. An example of a metric is a child's height which is used to determine whether they are allowed to ride a fairground ride or not.

3.2.2 TV/VCR , TV/DVD Combination Units and standalone Televisions

Table 3.1 shows the metrics used for TV/VCR and TV/DVD combination units. The metrics used are P_{MAX} and $P_{Standby}$ where P_{MAX} is the maximum power consumption during on mode and $P_{Standby}$ is the maximum power consumed during standby mode (Energy Star, 2009, ENERGY STAR® Program Requirements for Televisions Partner Commitments).

Table 3.1: Energy Star metric for TV/VCR and TV/DVD Combination Units

<table>
<tr><th>Metric Used</th><th colspan="2">Allowed to qualify</th></tr>
<tr><td rowspan="8">Maximum On Mode Power Consumption P_{MAX}</td><td>Screen Area</td><td>Maximum On Mode Power Consumption (A expressed in cm^2)</td></tr>
<tr><td colspan="2">Non-High Definition TVs (i.e. ≤ 480 Native Vertical Resolution)</td></tr>
<tr><td>All Screen Areas</td><td>P_{Max} = 0.01860*A + 25</td></tr>
<tr><td colspan="2">High Definition and Full High Definition TVs (i.e. > 480 Native Vertical Resolution)</td></tr>
<tr><td>A < 4,387 cm^2</td><td>P_{Max} = 0.03100*A + 32</td></tr>
<tr><td>4,387 cm^2 ≤ A < 6,742 cm^2</td><td>P_{Max} = 0.03720*A + 27</td></tr>
<tr><td>A ≥ 6,742 cm^2</td><td>P_{Max} = 0.02418*A + 151</td></tr>
</table>

This device category includes all units that combine a television and VCR or television and DVD player into one case as well as standalone television sets. Energy Star define a combination unit as, "A system in which the TV and an additional device(s) (e.g., DVD player, HDD, VCR, etc.) are combined into a single unit and which meets all of the following criteria: the additional device(s) is included in the television casing; it is not possible to measure the power requirements of the two (or more) components separately without removal of the television casing; and the system is connected to the wall outlet through a single power cable." Energy Star also define a standalone television as, ”A commercially available electronic product designed primarily for the display and reception of audiovisual signals from terrestrial, cable, satellite, Internet Protocol TV (IPTV), or other transmission of analogue and/or digital signals, consisting of a tuner/receiver and a display encased in a single housing. The product usually relies upon a cathode-ray tube (CRT), liquid crystal display (LCD), plasma display, or other display device.

Referring to table 3.1 the standard is divided into non-high definition televisions and high definition televisions. Maximum power consumption (P_{MAX}) is expressed in terms of the viewable screen area (A). The specification is further divided for high and non-high definition television sets. Non high definition televisions are traditionally CRT based. These sets are analogue and have a native vertical resolution of ≤ 480 lines. High definition televisions have a native vertical resolution of > 480 lines. These sets are often LCD or plasma based. The standard for high definition televisions are divided into three subcategories depending on the screen area of the particular television set.

The maximum allowable standby power consumption however is fixed at 1 Watt regardless of resolution of screen area.

3.2.3 Digital-to-Analogue Converter Boxes (DTAs)

Digital-to-Analogue Converter Boxes (DTAs) or set-top boxes are devices used to convert digital television broadcast signals into analogue signals suitable for display on a traditional analogue television. An example of such a set-top box would be a DSTV decoder.

Referring to table 3.2, to qualify for Energy Star certification such converter boxes must draw no more than 8 watt of power during normal operation and no more that 1 watt in sleep (standby) mode (Energy Star, 2009. ENERGY STAR® Program Requirements for Digital-to-Analog Converter Boxes (DTAs) Partner Commitments)

Table 3.2: Energy Star metric for Digital-to-Analogue Converter Boxes (DTAs)

Metric Used	Allowed to qualify
watt	On Mode ≤ 8 Watt
	Sleep Mode ≤ 1 Watt

Energy Star defines sleep mode as, “A state in which the device has greater power consumption, capability, and responsiveness than it does in the “Off” state, and has less (or similar) power consumption, capability and responsiveness than it does in the “On” state.” What this means is that the device is in-between being completely off and completely on.

3.2.4 DVD and Home Audio Products

Energy Star only places limits on the maximum standby mode power consumption of DVD and home audio products as shown in table 3.3. It can be seen that the limit for DVD and home audio products are set at less than or equal to 1 Watt during standby mode (Energy Star, 2009, ENERGY STAR® Program Requirements for Consumer Audio and DVD Products Partner Commitments)

Table 3.3: Energy Star metric for DVD products

Metric Used	Allowed to qualify
watt	Consumer Audio Products ≤ 1Watt
	DVD Products ≤ 1Watt

Energy Star defines a consumer audio product as, ”A commercially available electronic product encased in a single housing whose intended purpose, other than providing non-video status displays, is the production or recording of signals in the audio domain as reproduced by headphones, loudspeakers, or other transducers.” This category cover players designed to play back audio only DVDs and CDs as well as Hi-Fi components such as radio tuners and cassette decks.

Energy Star also defines a DVD product as, ”A commercially available electronic product encased in a single housing whose intended purpose is the production or recording of digitized video signals on a spinning reflective disc media.” This category would cover the traditional DVD player as it exists in most living rooms. This player is designed for playback (and sometimes recording) of video material onto DVD media.

3.3 Harmonics Standards

The European Power Supply Manufacturers Association (EPSMA) places limits on the harmonic current emissions of electronic devices. European Standard EN 61000-3-2 describes limits on the harmonic currents that can be injected by loads back on to the network (McGranaghan et al, 2002:284, European Power Supply Manufacturers Association, 2010, Guidelines to the standard EN 61000-3-2)

According to the standard, as of 1 January 2001, all electrical and electronic equipment connected to the public mains network must comply with this standard. The standard covers all devices up to and including 16A maximum rated input current.

There are four different classes in the standard that have different limiting values. The different classes of devices as defined in standard EN 61000-3-2 are shown in table 3.4. A flow chart showing the process of deciding which class a device falls into is available in Appendix C, figure C.1

Table 3.4: Classes of equipment as defined by EN 61000-3-2

Class A	Balanced 3-phase equipment, household appliances excluding equipment identified as class D, tools, excluding portable tools, dimmers for incandescent lamps, audio equipment, and all other equipment, except that stated in one of the following classes
Class B	Portable tools, arc welding equipment excluding professional equipment
Class C	Lighting equipment
Class D	PC, PC monitors, radio or TV receivers of input power less than or equal to 600W

There are no limits defined for the following devices:

- Equipment with an input power less than 75W
- Professional equipment with input power less that 1kW. Professional equipment is defined as equipment used in specific trades or industries and is not available for sale to the public.
- Symmetrical controlled heating elements with input power of less than or equal to 200W
- Independent dimming devices for light bulbs

Only classes A and D are applicable to this research. According to table 3.4 class A includes audio equipment while class D includes TV receivers. Table 3.5 shows the limits for class A devices. Table 3.6 shows the limits for class D devices as a power related current (mA/W) with an absolute maximum also indicated.

Table 3.5: Limits for class A equipment

Harmonic order **n**	**Maximum Permissible Harmonic Current** **A**
Odd Harmonics	
3	2.3
5	1.4
7	0.77
9	0.40
11	0.33
13	0.21
15≤n≤39	0.15*8/n
Even Harmonics	
2	1.08
4	0.43
6	0.30
8≤n≤40	0.23*8/n

For tables 3.5 and 3.6 the maximum permissible current per harmonic order refers to the rms harmonic current (Schaffner EMV AG, 2006:4).

In order to calculate the maximum allowed harmonic currents for a device given its power consumption use the following equation:

$$allowed\ current\ at\ harmonic\ n = P_T \times Imax_n \qquad (3.1)$$

P_T = Total Power consumed by device
$Imax_n$ = maximum allowed current at harmonic n in ampere per watt (A/W) from table 3.6

Table 3.6: Limits for class D equipment

Harmonic order n	Maximum Permissible Harmonic Current per Watt mA/W	Maximum Permissible Harmonic Current A
3	3.4	2.30
5	1.9	1.14
7	1.0	0.77
9	0.5	0.40
11	0.35	0.33
$13 \leq n \leq 39$ (odd harmonics only)	3.85/n	Apply limits for class A

3.3.1 Methods of reducing harmonic line currents

In order to limit the harmonics emitted by home entertainment devices and comply with European Standard EN 61000-3-2, manufacturers now include special circuits in power supplies to reduce harmonic line currents.

Harmonic line currents can be reduced using two techniques. The most commonly used techniques for reducing harmonic line currents are line filters using either passive components (passive filter) or active electronics (active filter) commonly called harmonic current reduction techniques. Line current reduction using passive components (inductors and capacitors) introduces a high impedance for the harmonics thereby smoothing the input current to an electronic device. Harmonic line current reduction techniques using active electronics are capable of shaping the input current of an electronic device relative to the applied line voltage so that the input current achieves a sinusoidal shape in phase with the line voltage. (European Power Supply Manufacturers Association, 2010, Guidelines to the standard EN 61000-3-2)

Figures 3.2a shows the typical input current (blue) without harmonic line current reduction techniques. Figure 3.2b shows the typical input current with passive harmonic line current reduction. Figure 3.2c shows the typical input current using active harmonic line current reduction. Notice that when using active harmonic line current reduction the current becomes a perfect or near perfect sinusoidal shape.

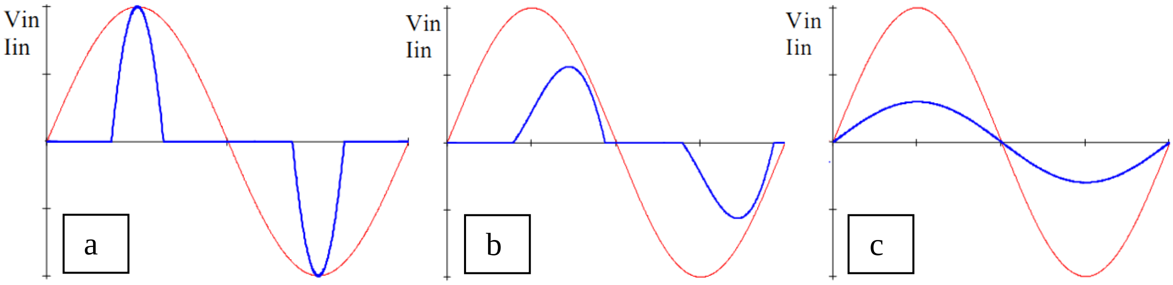


Figure 3.2: Comparison of current waveforms with and without line current reduction

3.3.2 Advantages and disadvantages of different types of harmonic line current reduction techniques

Table 3.7 outlines the advantages and disadvantages of passive vs. active line current reduction techniques (European Power Supply Manufacturers Association, 2010, Guidelines to the standard EN 61000-3-2)

Table 3.7: Passive vs. Active harmonic line current reduction comparison

Passive harmonic line current reduction	
Advantage	**Disadvantage**
Simple and robust circuitry	Large and heavy low frequency magnetics needed
Cheaper than active filter	Not applicable for wide input range and higher power
	No sinusoidal input current
Active harmonic line current reduction	
Advantage	**Disadvantage**
Extensive elimination of line current harmonics	Additional expense of circuitry
Power factor near 1 (typically 0.6 uncorrected) and increased available power from the mains wall socket	Increased number of parts
Wide input voltage range possible	Negative impact on efficiency

3.4 Television power measurement standards

3.4.1 Average Picture Level

When measuring the power consumption of a television set the APL (Average Picture Level) has to be taken into account. APL is an indication of the brightness of a scene being viewed on a television. The brighter the image being viewed, the higher the APL value and visa versa. The reason APL is important is that the power consumption of a television set varies with picture brightness. For a CRT set, the brighter the image being displayed, the more intense the electron beam of the CRT has to be with a corresponding increase in current drawn. The same is true for plasma sets except each pixel has its own electron source. The brighter the image being displayed the more electrons are needed per pixel with a corresponding increase in current drawn. LCD based TVs do not produce light. The image is formed by filtering the light (with coloured liquid crystal filters) produced by a back-light. The back-light is often a cold cathode fluorescent tube or LEDs. Back-light modulation (BLM) is a technique introduced with LCD TVs whereby the back-lights' intensity is varied according to the brightness of the scene.

Referring to figure 3.3 it can be seen that the power consumption of a 26 inch LCD panel (yellow) with no back-light modulation (NBLM) remained constant for all APLs while the power consumption of a 42 inch plasma, 36 inch CRT and 40 inch LCD television with BLM varied with APL (Jones, K. Harrison, B., 2007. The impact of changing TV technologies and market trends on the energy consumption of TVs and the need for a better TV energy test method, *ECEEE 2007 Summer Study)*.

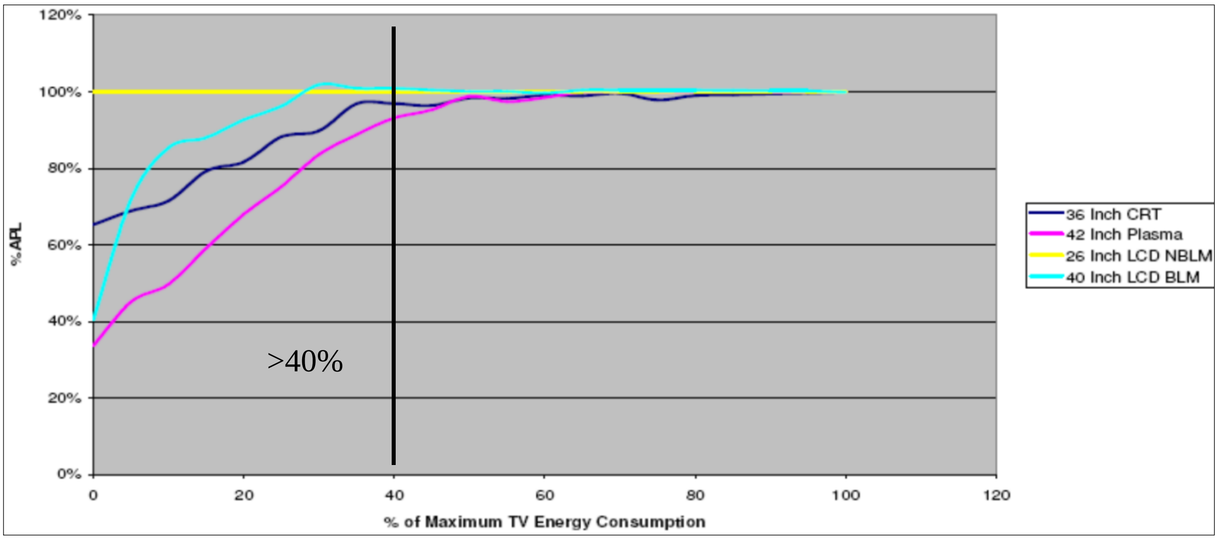


Figure 3.3: Comparison of differing TV technology power consumption characteristics (Jones, K. Harrison, B., 2007)

From figure 3.3 it is also evident that APLs above 40% have very little effect on power consumption. Studies in the USA, UK, Australia, Netherlands and Japan have produced the histogram of figure 3.4.

From figure 3.4 it can be seen that the APLs for all the countries are very similar. It is therefore reasonable to assume that South African APLs will be similar as well. Figure 3.4 shows few pictures in excess of 50% with the average of the samples varying from 30 % (Australia) to 35% (Japan). Since it can be shown that most television pictures have an APL below 50%, and this being the region where television energy consumption has its greatest variation, it is vital to consider APL as a factor when measuring television power consumption.

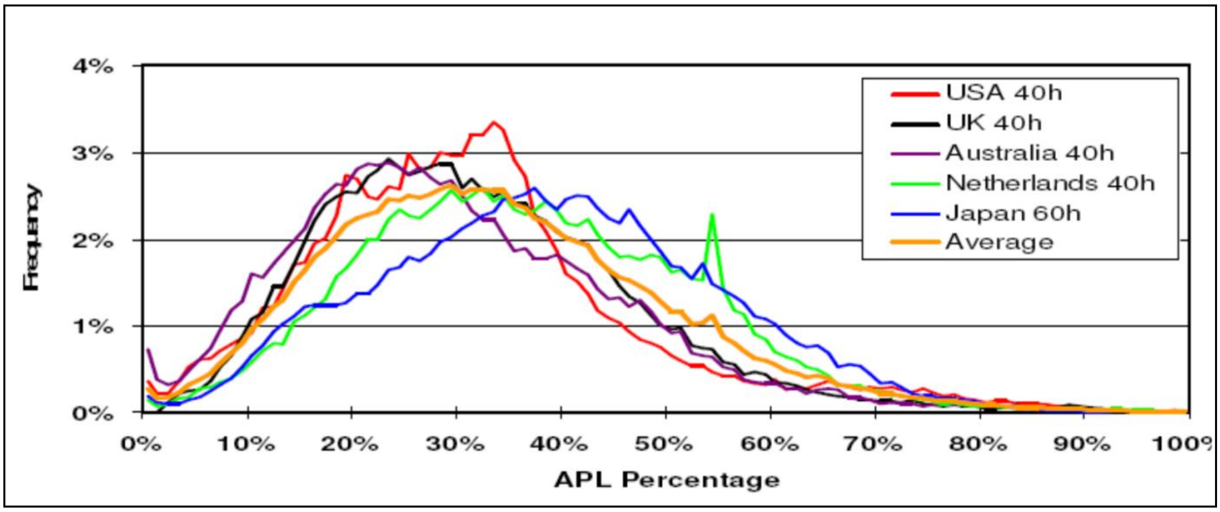


Figure 3.4: APLs for different countries (Jones, K. Harrison, B., 2007)

For the purposes of this research the Japan Electronics and Information Technology Industries Association (JEITA) and International Electrotechnical Commission (IEC) 62087 measurement methods are relevant as they address the variability introduced into the power consumption of a television by varying APLs. The JEITA and IEC standards introduce standard video material to be used on all televisions when performing measurements of power consumption. These standardized video materials are distributed on DVD and Blu-Ray discs. The two standards are detailed in the following sections.

3.4.2 IEC 62087

For the purposes of this research we are interested in the power consumption of a television set at a specific and static APL which requires the use of a static test pattern. The IEC 62087 standard uses a three bar black and white pattern for the measurement of On Mode power. This pattern has an APL of 50%. It has previously been shown that televisions at this APL level will show a power consumption of 100% (figure 3.3).

To more realistically test the power consumption of television sets, the revised IEC test method includes natural moving image test clips that produce more realistic measurements of power consumption. The IEC (IEC, 2010, Methods of measurement for the power consumption of audio, video and related equipment) makes a DVD and Blu-Ray disc set available that is used to provide standard pictures for display on a television while power consumption measurements are made (IEC, 2010, World's most boring DVD and Blu-ray Disc™ to measure energy efficiency of new generation TVs).The video material to be used during testing contains a wide variety of material including clips with fast-moving action, wildlife footage and a range of studio-based coverage and even cartoons.

3.4.3 JEITA

The other standard relevant to the measurements performed in this research is the JEITA standard that uses four patterns, 0% Black (black display), 100% White Raster (brightest display), three bar Black and White (50% APL) and colour bars (50% APL). The results of the measurements are then averaged according to the formula (Jones, K. Harrison, B., 2007):

$$\left(\frac{P_w+P_b}{2}+P_c+P_t\right)/3 \tag{3.1}$$

where:

P_w = power measured at 100% white

P_b = power measured at 0% black

P_c = power measured with colour bars

P_t = power measured with three bars

The JEITA method effectively gives a weighting of 83.25% to 100% power consumption when in fact very few pictures ever reach this level and 16.75% to the power consumed at an APL of 0% when less than 1% of pictures are ever at this level.

Jones and Harrison, argued that the IEC 62087 and JEITA standards for measuring power consumption in television sets are inadequate and unrealistic. It was shown that in addition to the power consumption of the pictures being displayed the test method should also consider the contribution to power consumption of the following factors:

- Audio – How much amplification is provided for audio and what are the typical listening levels?
- Digital Tuners – These tuners often stay active during standby in order to download updates to television firmware.
- Standby Power – How much power does the set consume during standby mode
- Energy Saving Features and Settings – What energy saving features are available and are they enabled by default.

3.5 Summary

Chapter 3 provides an overview of the power consumption and harmonics standards relevant to this research. The Energy Star standard, as it applies to the power consumption of home entertainment equipment, is reviewed. European Standard EN 61000-3-2, which limits harmonic line currents, is reviewed as well as its application to home entertainment devices. Standards for the measurement of the power consumption of television sets namely the IEC 62087 and JEITA standards are reviewed. The problem of Average Picture Level and its relevance to television power measurements is discussed.

CHAPTER FOUR

DEVELOPED METHODOLOGIES FOR THE MEASUREMENT OF HOME ENTERTAINMENT EQUIPMENT

4.1 Introduction

Section 1.2 described the shortcomings in our understanding of the power consumption of home entertainment devices as well as the harmonics that they produce. This chapter introduces the methodologies developed for the measurement, and results generation, of home entertainment equipment. This chapter also includes the harmonic study methods used to arrive at the data needed for analysis and conclusions.

Figure 4.1 presents an overview of the methodology which can be divided into three parts, A, B and C. During part A, measurements are performed, followed by part B where the results are generated. Finally, in step C, the generated results are compared to existing energy standards. The steps involved in each part will be presented in the following sections.

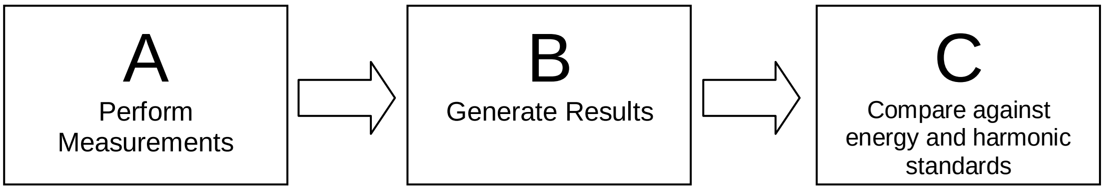


Figure 4.1: Sequence of major sections in methodology

4.2 Part A: Perform Measurements

The first step in the development of the methodology used in part A, was to establish a method of how to perform the measurement of the power consumption and harmonics of individual devices as well as their combinations.

The devices measured included television sets, DVD players, CD players and multi-channel home theatre amplifier/receivers (AV Receivers). These devices will be measured both individually and as combinations. As discussed in section 3.4, television receivers require special consideration during power measurements due to the variability introduced by APL. A special procedure was therefore developed for the measurement of television receivers.

Figure 4.2 shows details of the steps of part A.

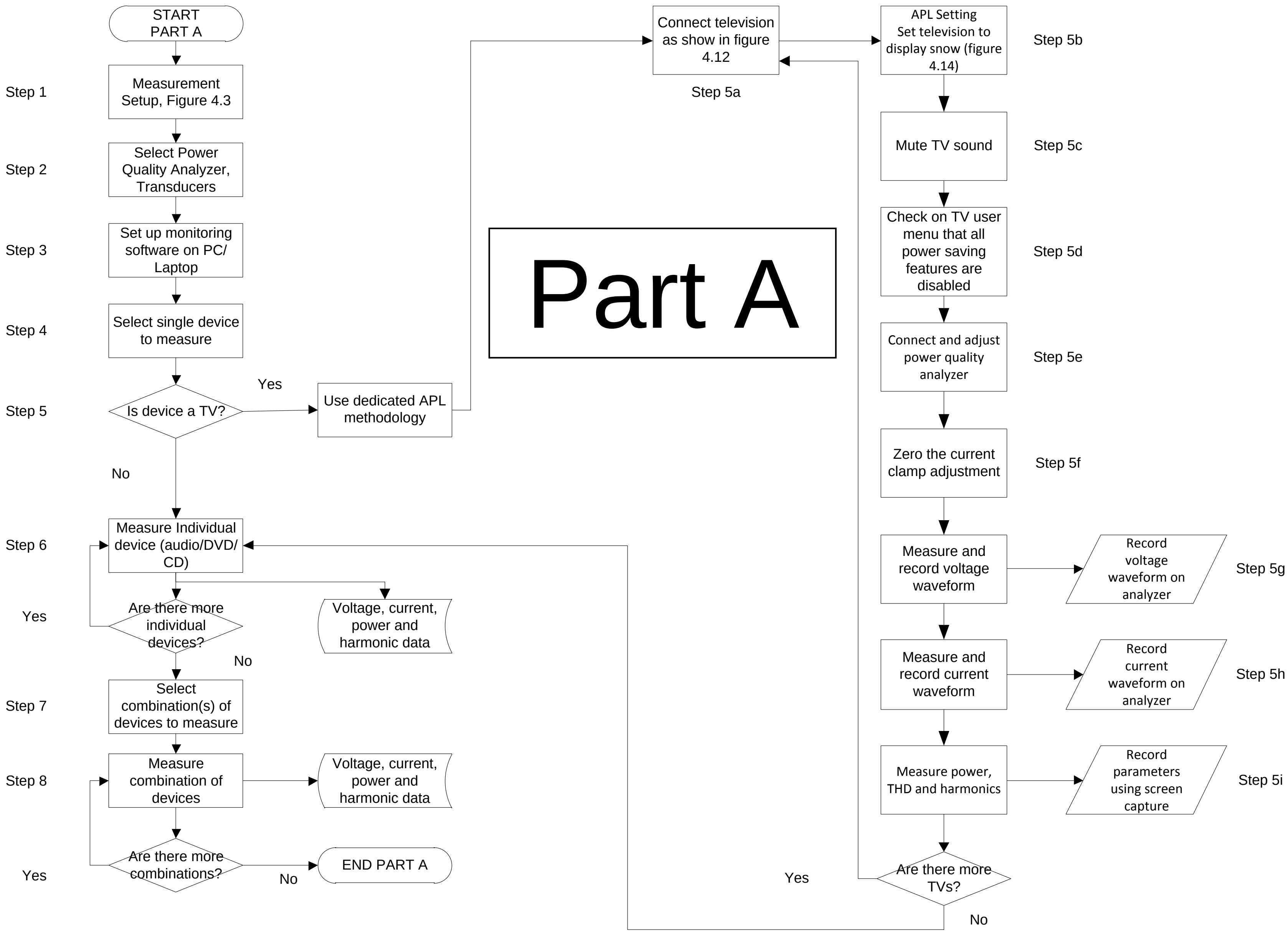


Figure 4.2: Detail of steps in part A, Perform Measurements

4.2.1 Step1: Measurement Setup

The first step in the methodology is to develop a measurement setup for conducting the required investigation for this research.

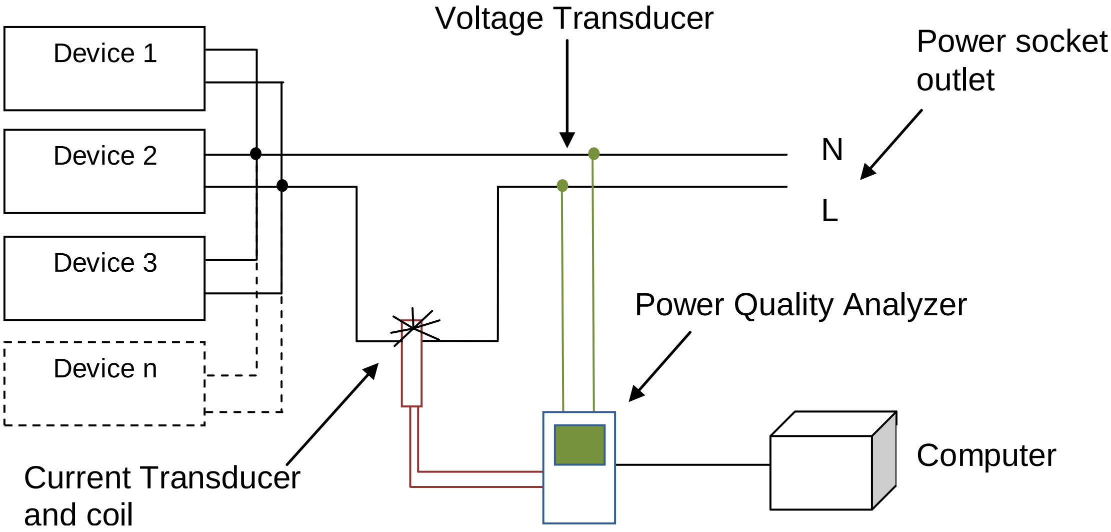


Figure 4.3: General measurement setup

Figure 4.3 shows the general measurement setup used. The setup provides for the measurement of individual, as well as combinations, of devices. Voltage and current transducers are applied between the device(s) and the power socket outlet (LN) to measure current and voltage. A power quality analyzer is used together with a computer (PC or laptop) to record measurements.

4.2.2 Step 2: Select Power Quality Analyzer and Transducers

The second step in the methodology is to select a power quality analyzer and appropriate transducers as the investigation involve the measurement of non-sinusoidal quantities.

4.2.2.1 Fluke 43 Power Quality Analyzer

Various analyzers were reviewed and the Fluke 43B Power Quality Analyzer was chosen for measurements since it had the required capabilities. The Fluke 43B can measure voltage, current and power at fundamental and harmonic frequencies as well as capture voltage sags, transients and inrush currents. It is a handheld device having the capabilities for accurate evaluation of power quality and combines analysis with a multimeter and scope function. For a complete specification sheet of the Fluke 43B, please refer to Appendix D. (fluke.com, Fluke 43B Single Phase Power Quality Analyzer Specifications, 2011)

The Fluke 43B is a single phase device suitable for performing measurements on devices designed for use in the home. Its portability was also an advantage seeing that many of the measurements had to be done outside of a laboratory environment. Figure 4.4 shows the Fluke 43B Power Quality Analyzer.

Figure 4.4: Fluke 43B Power Quality Analyzer
(fluke.com, Fluke 43B Power Quality Analyzer, 2011)

The Fluke 43B is designed to be used together with FlukeView software running on a computer as indicated in figure 4.3. The analyzer interfaces to the computer using an optically isolated serial cable. This makes it possible for measurement data to be stored on the computer for further processing.

The Fluke 43 accessories include the i400s AC Current Clamp with two ranges:

- 40 A Range Suitable for measurements from 0.5 A to 40 A
- 400 A Range Suitable for measurements from 5 A to 400 A

Figure 4.5 shows the Fluke i400s AC Current Clamp and how it is clamped to a conductor. The Banana Plug connects to the Fluke 43B. A switch on the clamp allows the user to select either the 40A or the 400A range.

The i400s clamp has a basic accuracy of 2% + 0.015A (45-400 Hz) on its 40A range and 2% + 0.04 A (45-400 Hz) on its 400A range. If the probe was set to its 40A range 2% of 40A is 0.8A. This means that with a current of 20A being measured using the 40A range setting the meter can display (20A – 0.8A – 0.015A) to (20A + 0.8A + 0.015A) or 19.185A to 20.815A.

This clamp was not considered suitable as the types of devices investigated typically would not consume more than about 0.5 to 1.5A at power socket voltage level. From the previous example it can be seen that the measurement uncertainty alone is already 0.815A, thus a clamp capable of measuring smaller currents with increased accuracy needed to be selected.

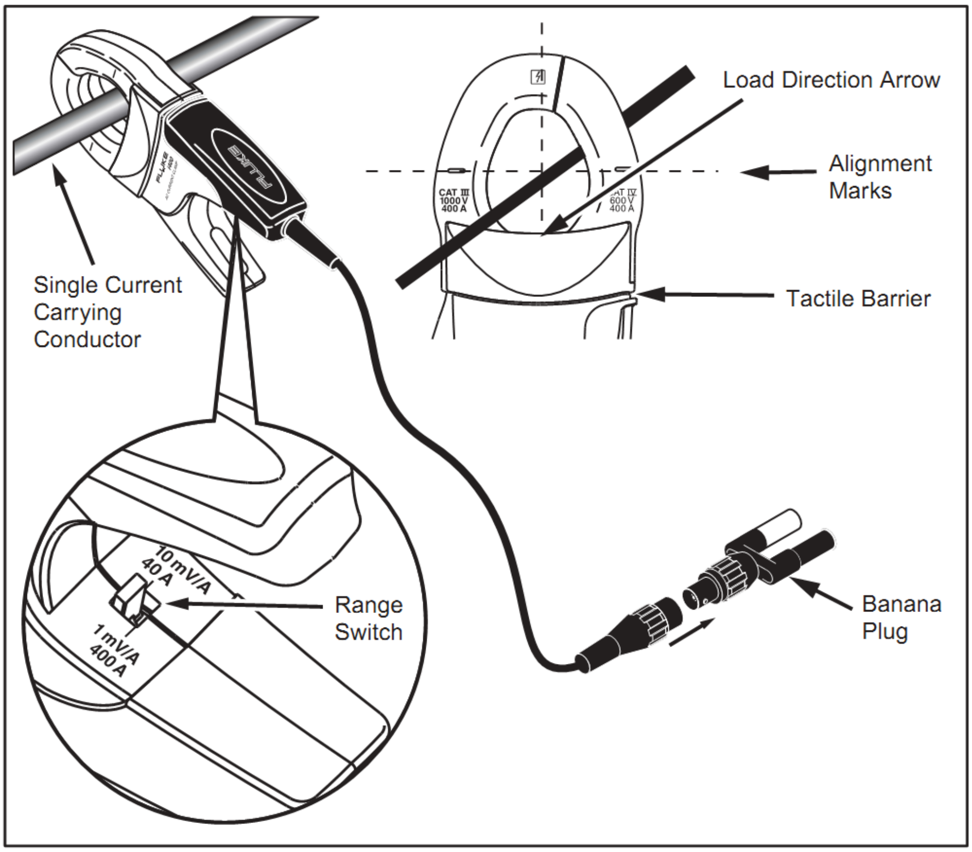


Figure 4.5: Fluke AC Current Clamp
(fluke.com, FLUKE Instruction Sheet i400s Current Clamp, 2004)

4.2.2.2 Fluke 80i-110s AC/DC Current Clamp

Another accessory available for the Fluke 43B is the Fluke 80i-110s current clamp. Due to the types of measurements to be performed a current clamp needed to be chosen that was capable of accurately measuring currents of less than 2A. Figure 4.7 shows the Fluke 80i-110s AC/DC Current Probe Clamp which is capable of measurements in this range. Figure 4.7 also shows the range and zero adjustments.

The 80i-110s has two ranges. A 10A range (100mv/A), and a 100A range (10mV/A). The 80i-110s feeds a voltage to the Fluke 43B which is proportional to the current in the jaws of the clamp. This means that with the clamp set to its 10A range (100mV/A) the Fluke 43B will receive a voltage of 1V for a 10A current in the jaws of the 80i-110s. The Fluke 43B must be “told” how to interpret the voltage coming from the current probe clamp. This is done in the Fluke 43Bs Instrument Setup menu. Figure 4.6 shows the setting highlighted in red. For example, the user will set the Fluke 43B to use a 100mV/A probe when the clamp range switch on the clamp is set to 100mV/A.

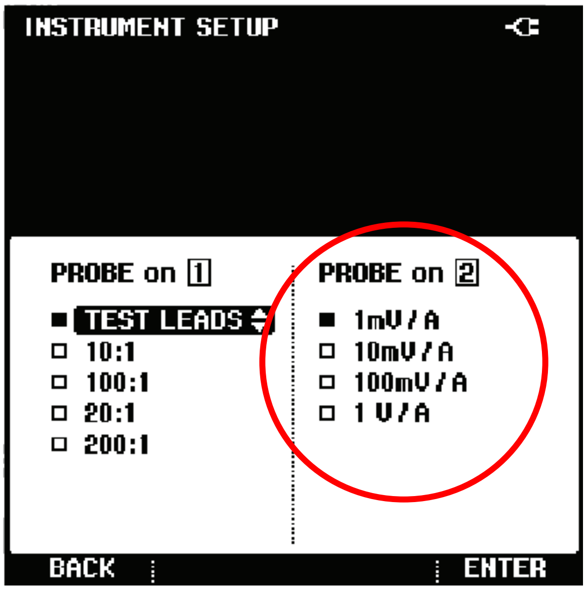


Figure 4.6: Fluke 43B Instrument Setup screen setting for current probe clamp sensitivity

(fluke.com, FLUKE 43B Power Quality Analyzer Getting Started, June 2005)

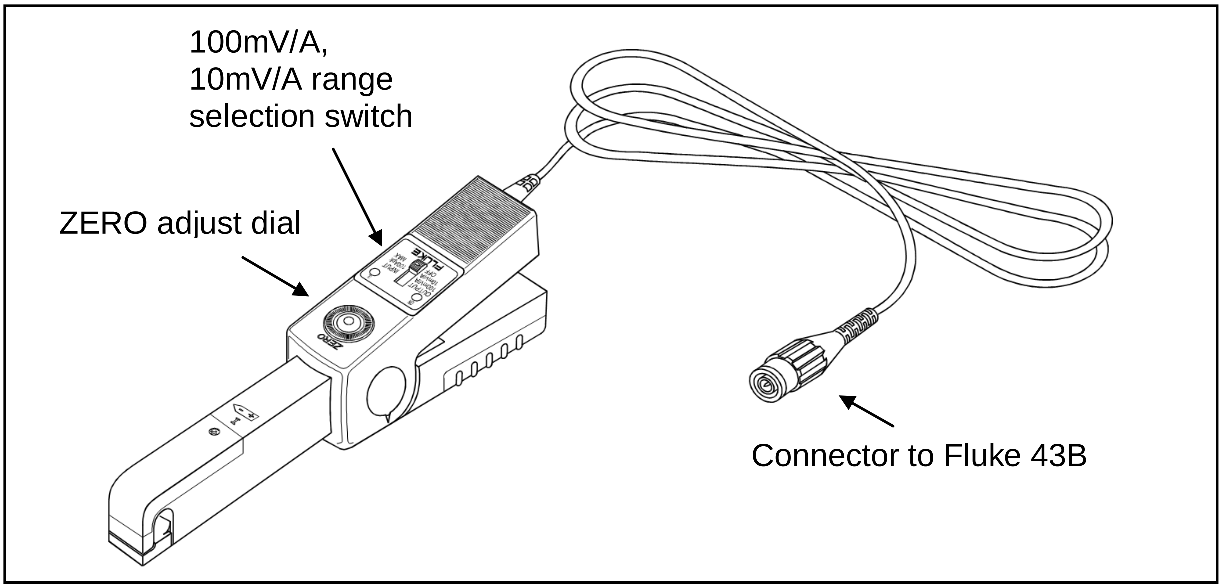


Figure 4.7: Fluke 80i-110s AC/DC Current Probe Clamp

(fluke.com, FLUKE 80i-110s

AC/DC Current Probe Instruction Sheet, 2005)

Table 4.1: Technical Specifications of 801-110s current probe clamp (fluke.com, FLUKE 80i-110s AC/DC Current Probe, 2011)

Specifications	
Nominal current range	10 A, AC/DC 100 A, AC/DC
Continuous current range	0.1 A - 10 A AC/DC 1 A - 100 A AC/DC
Maximum Non-Destructive Current	140 A - 2 kHz
Lowest measurable current	0.1 A
Basic Accuracy	10mV/A setting : 50mA to 40A ± 4% of reading + 50mA 100mV/A setting: 50mA to 10A ± 3% of reading + 50mA
Useable frequency	DC - 100 kHz
Output level(s)	100 mV/A 10 mV/A
Zero error adjustment	Yes

Table 4.1 shows the technical specifications of the 80i-110s current clamp. Table 4.1 indicates that the lowest measurable current is 0.1A. This is problematic since the devices to be measured may draw less than 0.1A. Table 4.1 also shows the accuracy of the 80i-110s on its 10 and 100mV/A ranges for DC or peak AC currents. The indicated accuracy is problematic. As an example consider the following:

A device draws 100mA. With Fluke 43B set to use a 100mV/A probe and the probe set to its 100mV/A range the Fluke 43B should display 100mA. However, taking into consideration the accuracy of the probe clamp from Table 4.1 the actual reading can be determined as follows:

3% of reading = 0.03 x 100mA = 3mA

The error is therefore ±(3mA+50mA) or ±53mA

The Fluke 43B can therefore indicate the current to be anywhere between 47 –and 153mA.

4.2.2.3 Current Clamp Arrangement

To accurately measure the very small currents in question it was necessary to construct and add a toroidal coil as shown in figures 4.8 and 4.9. Current from the load is passed through a 10 turn toroidal coil. The current probe is clamped around the coil during measurements as shown in Figure 4.9 to form a dedicated current clamp arrangement. By transformer action, this multiplies the current in the probe jaws by 10 providing a more substantial current to the transducer as step down transformers step up current (the current ratio of a transformer is the inverse of the turns ratio as shown in equation 4.1)

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} \tag{4.1}$$

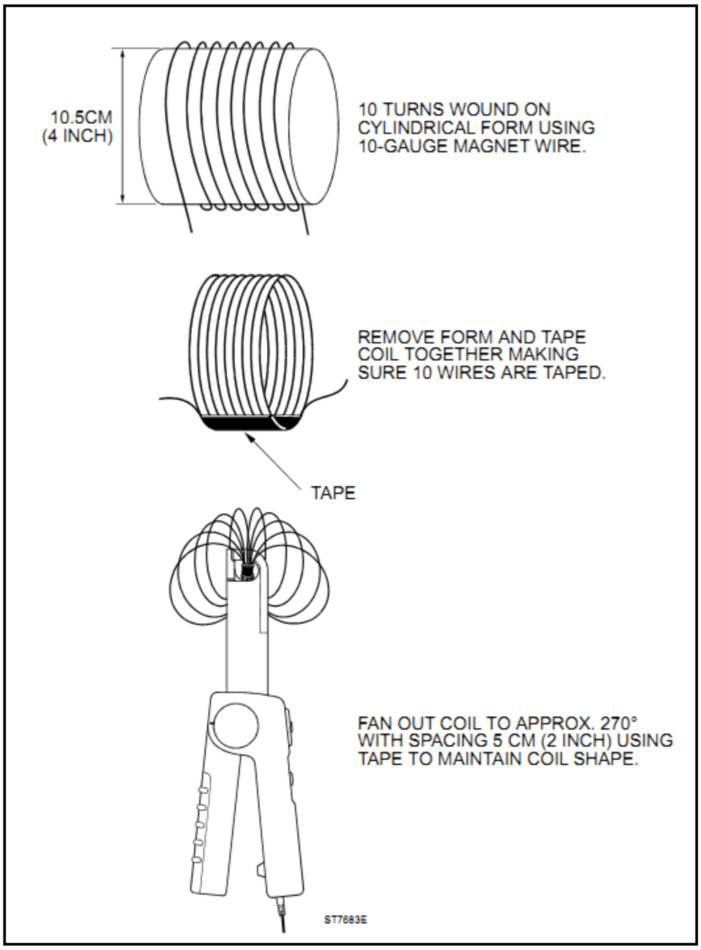


Figure 4.8: Construction of toroidal coil (fluke.com, FLUKE 80i-110s AC/DC Current Probe Instruction Sheet, 2005)

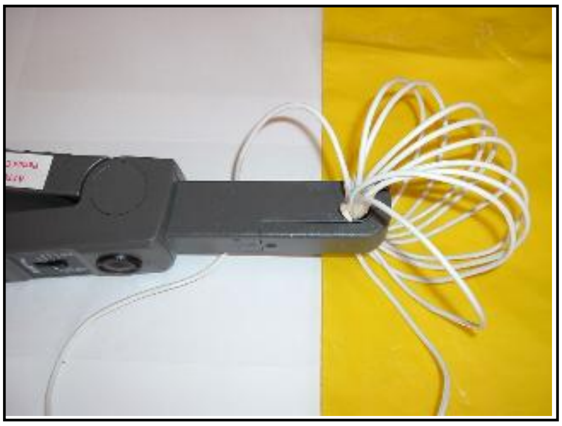


Figure 4.9: Coil in use (Bredekamp AJ, 2010)

It has previously been demonstrated that when measuring a current of 100mA and using no coil with a clamp set to 100mV/A the accuracy will be ±53mA. Repeating the same measurement using the coil with the Fluke 43B set to use a 100mV/A probe and the probe set to its 100mV/A range the Fluke 43B should display 1000mA. The Fluke 43B is over-reading by a factor of ten because the coil is multiplying the current in the jaws of the clamp by ten. Using Table 4.1 the accuracy is:

3% of reading = 0.03 x 1000mA = 30mA
The error is therefore ±(30mA+50mA) or ±80mA

The Fluke 43B can therefore indicate the current to be anywhere between 920 and 1080mA. To obtain the final reading, divide the reading on the Fluke 43B by ten. This makes the final reading anywhere between 92 –and 108mA. The accuracy has been improved from ±53mA to ±8mA.

This means that using the added coil with the probe clamp, measuring a current of 100mA will display a reading of 100mA±8mA on the Fluke 43B.

The previous example manually corrected the reading, by dividing the reading on the Fluke 43B by ten. To automatically correct the reading the Fluke 43B was set to use a 1V/A current probe whenever the probe was set to its 100mV/A range, a ratio of 0.1.

4.2.2.4 Voltage Transducer Arrangement

For power measurements the Fluke 43B also requires a voltage transducer which is provided for the $220V_{RMS}$ (50Hz) AC level. The voltage transducer takes the form of two crocodile clips clipped to a stripped portion of the power cable between the device to be measured and the wall socket outlet. See figure 4.3

The Fluke 43B must be “told” what kind of voltage transducer is being used. In this case “Test Leads” were used. The selected setting is highlighted in figure 4.10.

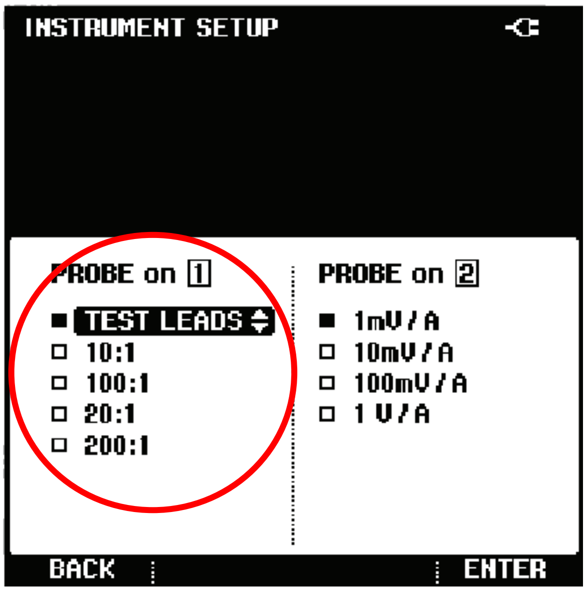


Figure 4.10: Fluke 43B Instrument Setup screen setting for voltage transducer (fluke.com, FLUKE 43B Power Quality Analyzer Getting Started, June 2005)

4.2.2.5 Power Measurement Arrangement

To measure the power consumption of a device, a piece of 2-core cable was placed between the device to be measured and the power socket outlet as shown in figure 4.3.

Inserted into one of the conductors of the 2-core cable is a 10-turn toroidal coil such that the load current passes through the coil. The jaws of the current probe were then clamped over the coil as shown in Figures 4.3 and 4.9. During measurements the coil was fanned out as shown in Figure 4.9. to minimize inductance.

Clipped onto a stripped portion of the 2-core cable is the voltage transducer. The current and voltage transducers provide the Fluke 43B with the measurements needed to determine the power.

4.2.3 Step 3: Set up monitoring software on computer

4.2.3.1 FlukeView

FlukeView is the software that accompanies the Fluke 43B. It has the advantage that it allows a personal computer (PC) or laptop to connect directly to the meter either via Universal Serial Bus (USB) or a standard serial port.

Figure 4.11 shows that FlukeView provides a graphical user interface (GUI) that enables a user to view/store the meter screen captures (e.g. the parameters set for measurements, power consumption, THD etc), voltage and current waveforms and spectrums. The generated results are saved as files on the computer.

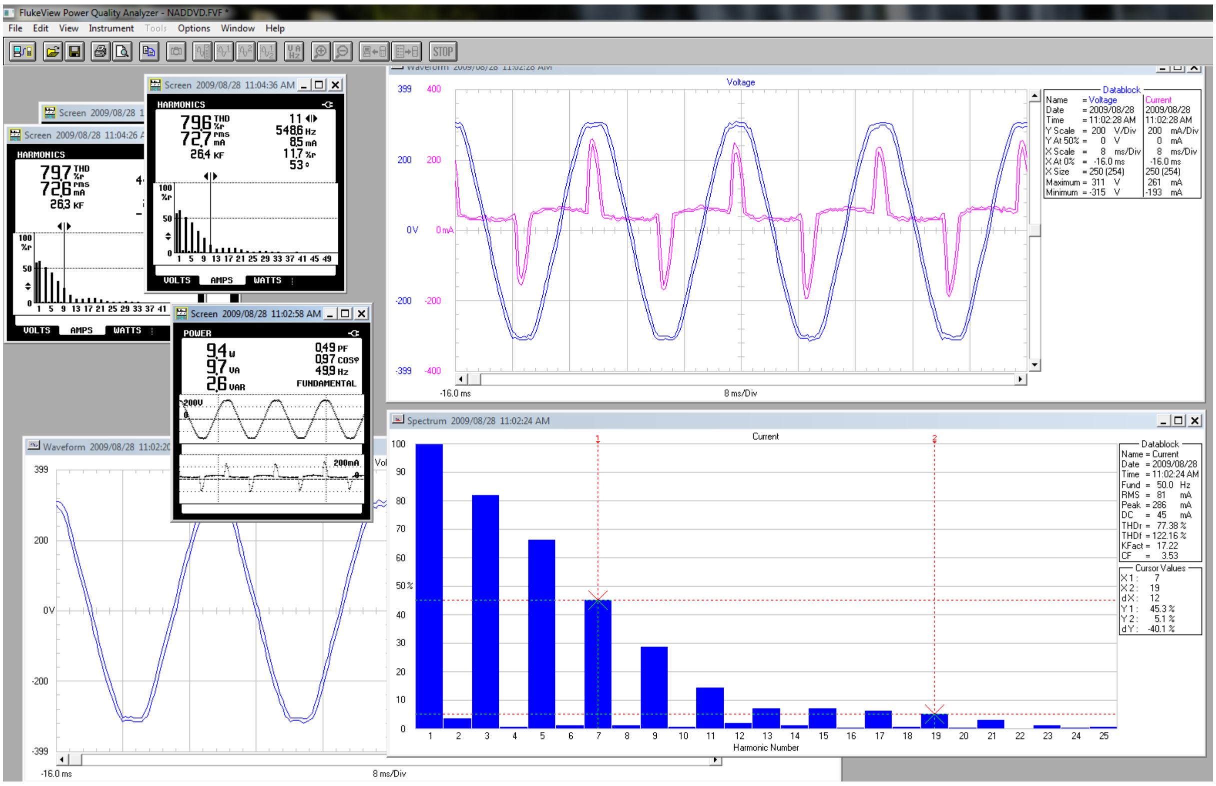


Figure 4.11: FlukeView showing voltage and current waveforms, current spectra and meter screen captures (Bredekamp AJ, 2011)

4.2.4 Step 4: Select single device to measure

This study focused on home entertainment devices. The devices selected included both new and existing equipment. New equipment included devices that were currently available for purchase at an electronics store. A major electronics store was kind enough to provide access to their floor displays of home entertainment equipment so that single device measurements could be undertaken. This selection was assumed to reflect the current state of the art in home entertainment equipment that exists in South Africa and which is expected to be present in the near future.

Existing equipment means older equipment, more than 5 years old. This existing equipment was measured in a laboratory and/or a selected home. The selected existing equipment was considered to be state of the art 5 years ago. Tables B.1 and B.2, as well as B.4 and B.5 in appendix B list the equipment that was measured for this study. Table B.1 lists the power consumption of new television sets as measured in an electronics store in 2010. Table B.2 lists the power consumption of existing television sets as measured in 2010 (eg; SAMSUNG 74cm, 127W and LG 60cm, 52W). Table B.4 lists the power consumption of new CD/DVD players (eg; NAD T514 DVD player, 9.4W and NAD C715 CD/Radio Receiver, 17.2W) and new AV receivers (eg; NAD T737, 47.2W) as measured in an electronics store in 2010. Finally table B.5 lists the power consumption of existing CD/DVD players and AV receivers as measured in 2010 (eg; Yamaha DVD Player, 17.7W and Yamaha RX-V630RDS AV Receiver, 41.4W).

The measured devices therefore included both new and existing televisions, CD/DVD players and AV receivers.

4.2.5 Step 5: Is device a television?

For this next step, the device to be measured is identified. Section 3.4 describes APL and the IEC 62087 and JEITA as being essential considerations for television power measurement. It is therefore necessary to use a different measurement technique for televisions than for other home (eg; DVD/Audio) entertainment devices. Thus the methodology makes specific allowance for TVs and takes APL into account (Step 5).

4.2.5.1 Step 5 Continued: Measure individual TVs

Figure 4.12 shows the measurement setup for measuring individual TVs (new and existing).

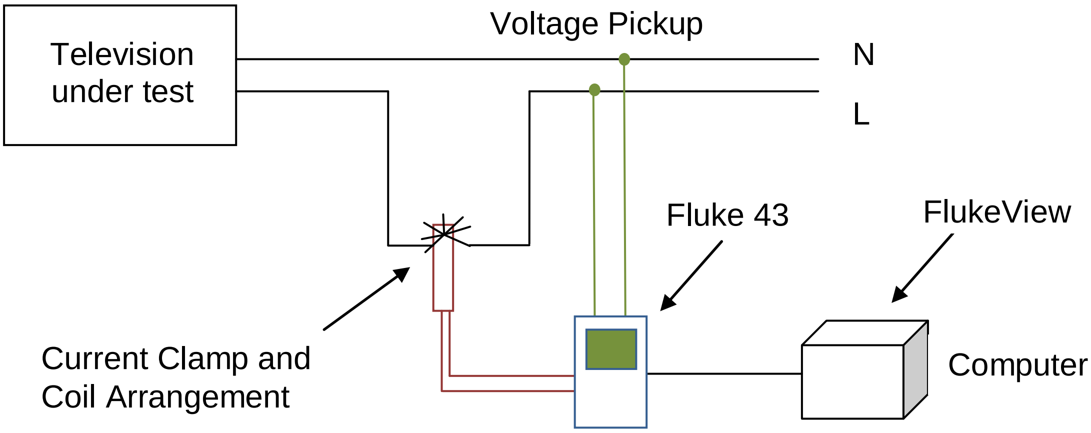


Figure 4.12: Measurement setup connection diagram

The power consumption as well as voltage and current waveforms of individual televisions were measured. Figure 4.13 shows the television display area in an electronics store where the measurements of new devices were undertaken. An extension cord was made to connect the TV under test to the power socket outlet. A 10-turn coil and current clamp arrangement is installed into the live wire of the cord.

The voltage pickup clips of the Fluke 43B power quality analyzer was clipped to a stripped portion of the cord.

The TV under test was then placed into different operational modes and the voltage, current, power and current harmonics measured and recorded on a computer using FlukeView. The detailed measurement methodology is presented in the next section and is also shown in figure 4.2 steps 5a to 5i.

4.2.5.2 Dedicated APL methodology for the measurement of television sets

To ensure that a wide variety of modern television sets were measured, the power consumption of new television sets on display at an electronics store was evaluated as shown in figures 4.13 to 4.15 using the newly developed dedicated APL measurement methodology steps given in figure 4.2. The importance of this methodology is that power consumption is measured whilst considering APL settings. This is a contribution not found in existing literature.

Store management would not permit the introduction of customised test images so it was decided to test all sets under the following conditions:

- All power saving features was bypassed. This was done to determine the worst-case scenario power measurement.
- All televisions were set to display a snow pattern. A snow pattern on a television set has a random distribution of peak white and black pixels. See figure 4.14. Lawrence Berkeley National Laboratory also used a “snow” pattern to perform television power measurements. (Assessment of Options for Improving Energy Efficiency Test Procedures for Displays, ENERGY STAR, Natural Resources Canada and NYSERDA, Ecos, 2010). A snow pattern simply provides a standard “image” that will be the same on all sets measured.
- Controls for brightness, contrast and colour saturation was adjusted to represent actual viewing APLs. Experienced sales staff in store was asked to set the viewing APL and these settings are used as representative of APLs found in homes.
- The sound on all televisions was muted during testing. Given the shop environment it would not have been practical to use a sound pressure sensor (sound pressure level) to ensure all sets were of equal loudness during testing. Measurements of the power consumption of a television set including

sound output at a set level can be included in future work, as a sound booth environment would be needed.

- Before any measurements were conducted the current clamp arrangement was carefully zeroed. This was accomplished by adjusting the ZERO adjust dial on the clamp as shown in figure 4.7 until the Fluke 43B displayed 0mA with no current flowing through the jaws.
- Voltage and current waveforms were captured to a laptop running FlukeView connected to the Fluke 43B as shown in figure 4.15
- Screen captures of the Fluke 43B display of power and harmonic measurements were also captured to the laptop.

This methodology was also used to measure the power consumption of existing (older type) television sets in a home environment.

Figure 4.13: Television display where the measurements were conducted (Bredekamp AJ, 2010)

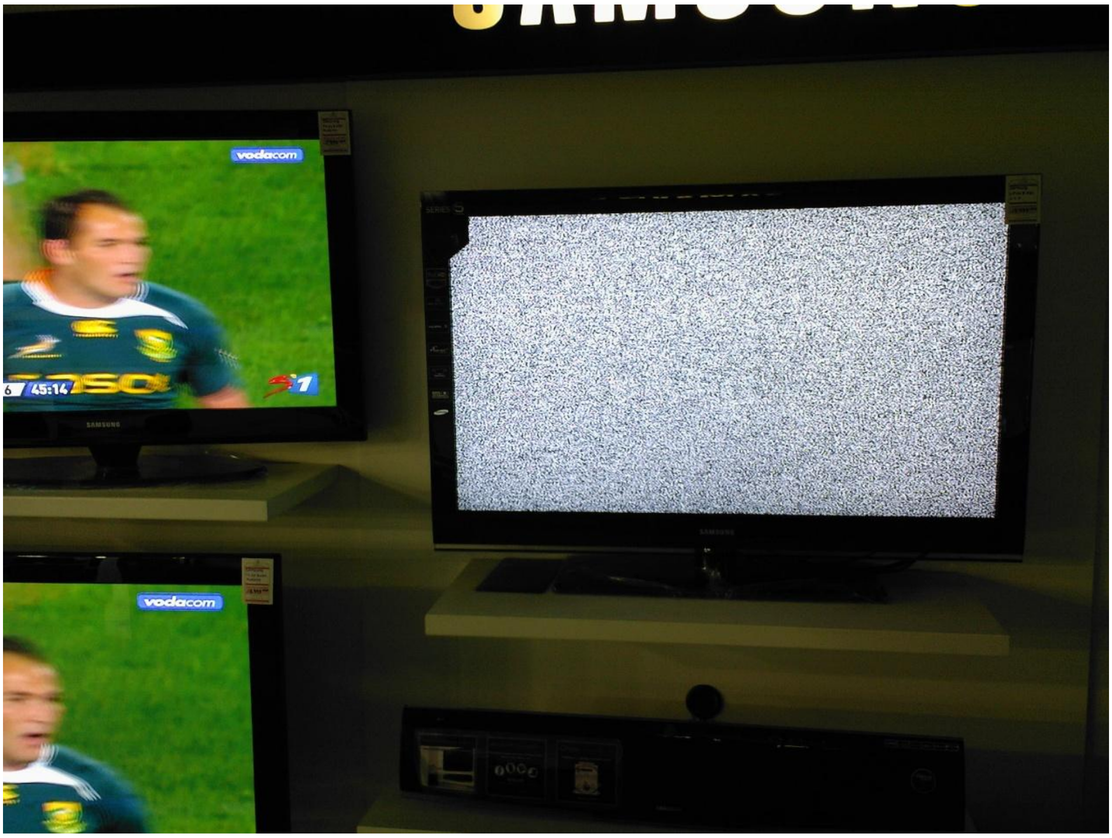


Figure 4.14: Television set to display snow pattern for testing (Bredekamp AJ, 2010)

Figure 4.15: The power consumption of a television set being measured showing the current clamp arrangement, Fluke 43B and laptop computer (Bredekamp AJ, 2010)

4.2.6 Step 6: Measure individual devices (audio/DVD/CD)

Step 6 provides the methodology for the measurement of other typical home entertainment devices.

To measure individual home entertainment devices, the measurement setup of figure 4.16 was used for each device. Measurements were captured to a laptop computer attached to the Fluke 43B.

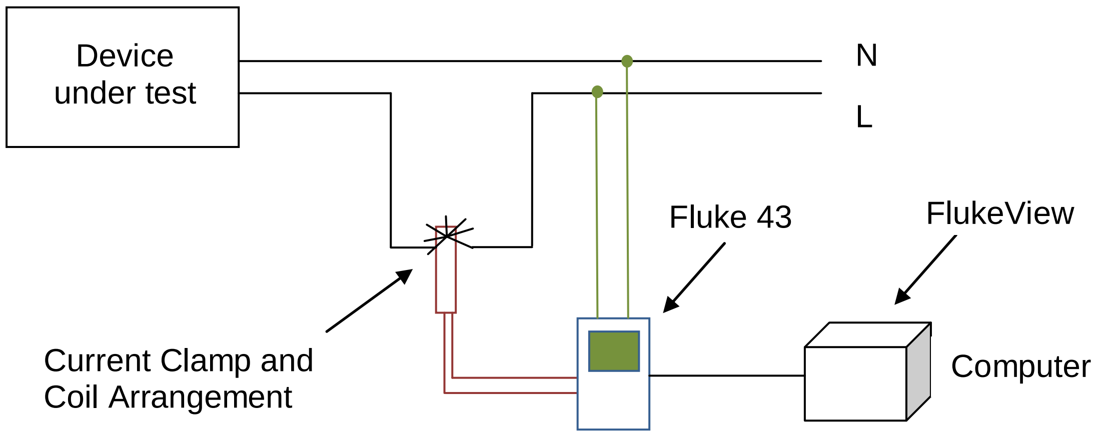


Figure 4.16: Measurement setup connection diagram

4.2.6.1 Measurement Methodology for CD/DVD players and home theatre amplifiers

To perform measurements the setup of figure 4.16 was used. To ensure maximum power drawn, CD/DVD players were measured while actually playing back a disc. Also, the volume controls of home theatre amplifiers were adjusted to the middle of their range. Due to limitations imposed by the measurement environment (a store display) it was not practical to employ a sound pressure meter to ensure all listening levels was of equal loudness.

As stated before tables B.4 and B.5 in Appendix B, list the devices measured. Table B.4 shows a list of new devices measured in-store. Table B.5 shows a list of existing devices that were measured in a home environment. As with televisions, existing DVD/Audio equipment means older equipment, more than 5 years old.

4.2.7 Step 7: Select combination(s) of devices to measure

In Step 7, combinations of devices are selected to be grouped together and then measured as per figures 4.3 and 4.17.

4.2.8 Step 8: Measure combination of devices

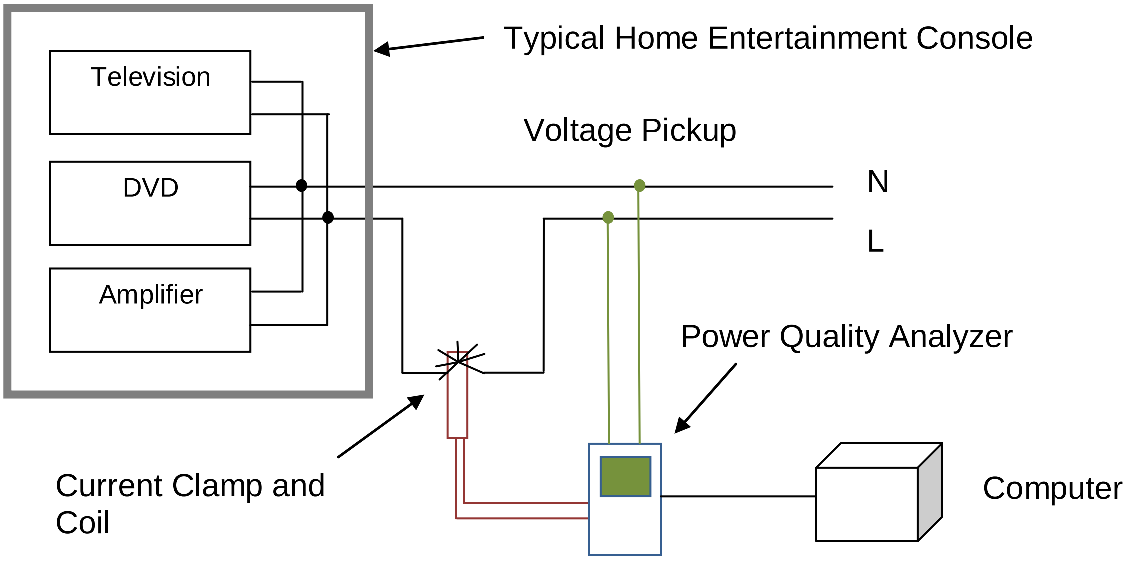


Figure 4.17: Example of measurement setup for combination of devices

Figure 4.17 shows an example of the measurement setup used to measure a combination of devices as might be identified in Step 7. The television would be operated under APL setup and CD/DVD devices under disc playing operation. The volume controls of amplifiers are set to their mid-points.

This concludes part A. The next section will introduce the methodology used to generate results from the measurement data.

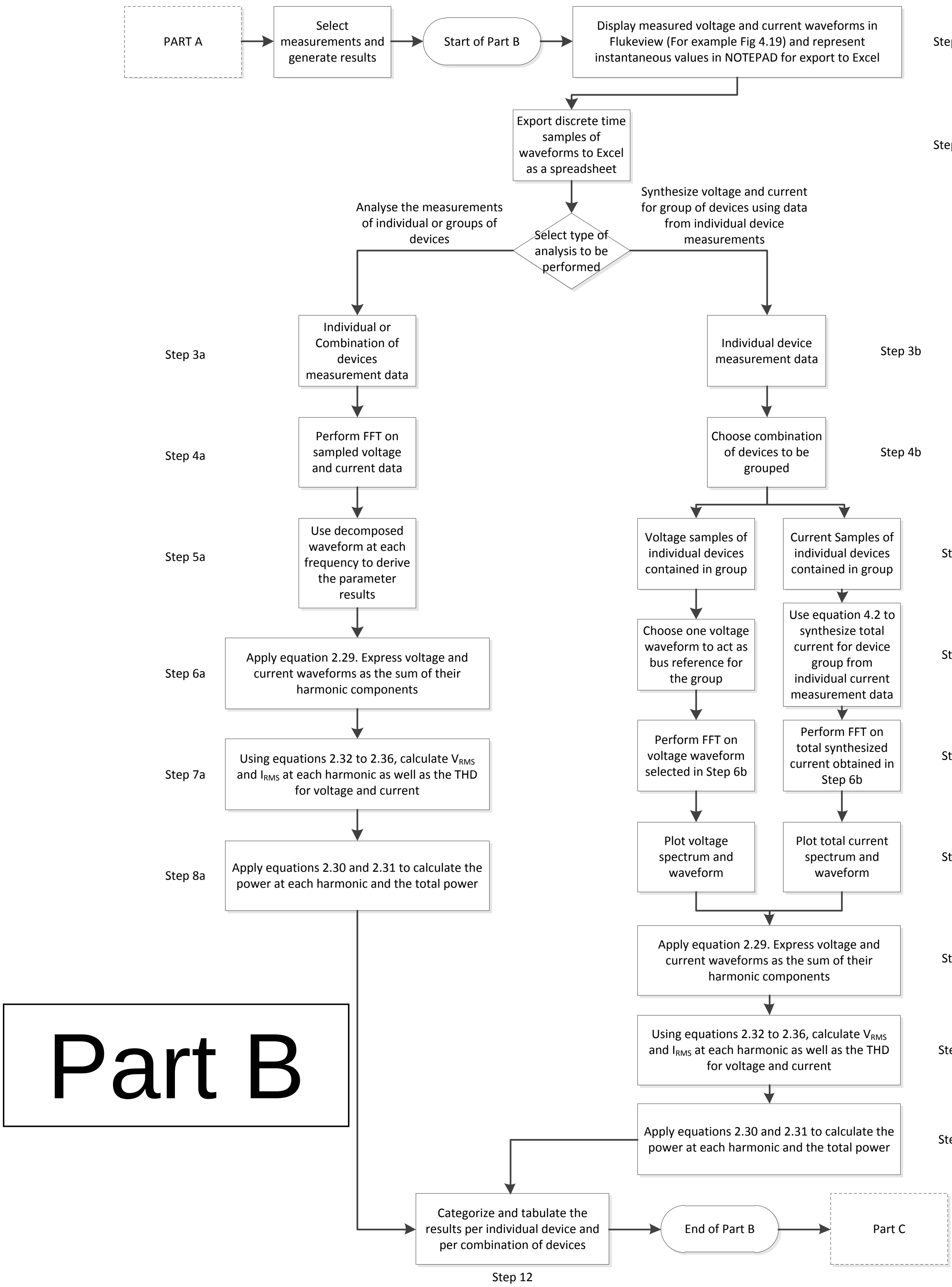


Figure 4.18: Detail of steps in part B

4.3 Part B: Generate Results

Once the measurement stage of the research methodology (Part A) has been completed, the next stage, Part B (Figure 4.1), is completed. Part B is the methodology to generate the results using the FlukeView and Microsoft Excel software. Figure 4.18 shows the methodology used to generate visualisation results for the measurements taken during the Part A (steps 1-8) investigation.

4.3.1 Step 1: Display measured voltage and current waveforms in FlukeView

The measurement results for each device were first displayed in FlukeView as shown in figure 4.19. Figure 4.19 shows an example of the voltage and current waveform as stored in FlukeView for a particular measurement. The discrete time samples that make up these waveforms, in FlukeView, are then exported to Microsoft Excel for further processing as indicated by the arrow from figure 4.19 to figure 4.20.

4.3.2 Step 2: Export discrete time samples of waveforms to Microsoft Excel as a spreadsheet

The spreadsheet used for the processing of the captured data was Microsoft Excel which forms part of the Microsoft Office Suite (office.microsoft.com Office 2010 Products, 2010). Microsoft Excel was used to synthesise the total current waveforms from separate measurements and also to generate the current and voltage harmonic spectra through the use of the Fast Fourier Transform function. Finally, Excel was used to calculate the power due to each harmonic as well as the total power. Please refer to Appendix A to view the spreadsheets generated in Excel.

Voltage and current waveforms captured to FlukeView in Part A, steps 5, 6 and 8, were exported to Excel for further processing. Figure 4.19 shows the sampled data values as displayed in Notepad (right) when the “Copy Data” option in FlukeView is used under the “EDIT” menu with the data values pasted into Notepad. Figure 4.20 shows the sampled current and voltage samples pasted into Excel with headings indicating which device it is associated with. Each device, in this case a SAMSUNG 32” TV, has a column for current samples and one for voltage samples. The current and voltage samples are aligned in time.

The same procedure is used if the data represents voltage and current measurements for a combination of devices. First the voltage and current waveforms of the combination are displayed in FlukeView and then copied to Excel (via Notepad) for further processing.

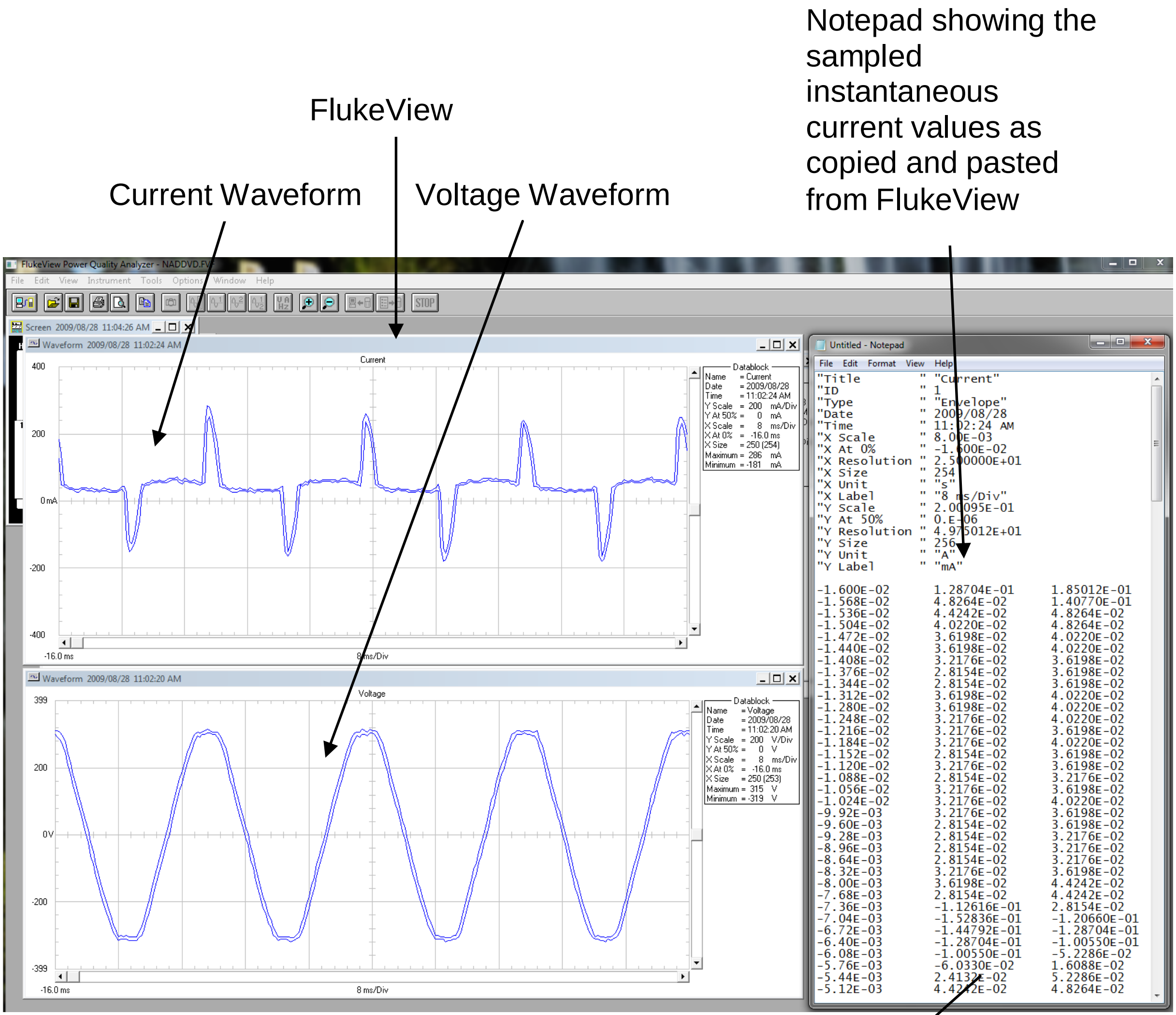


Figure 4.19: Waveforms in FlukeView and the sampled data values in Notepad (Bredekamp AJ, 2010)

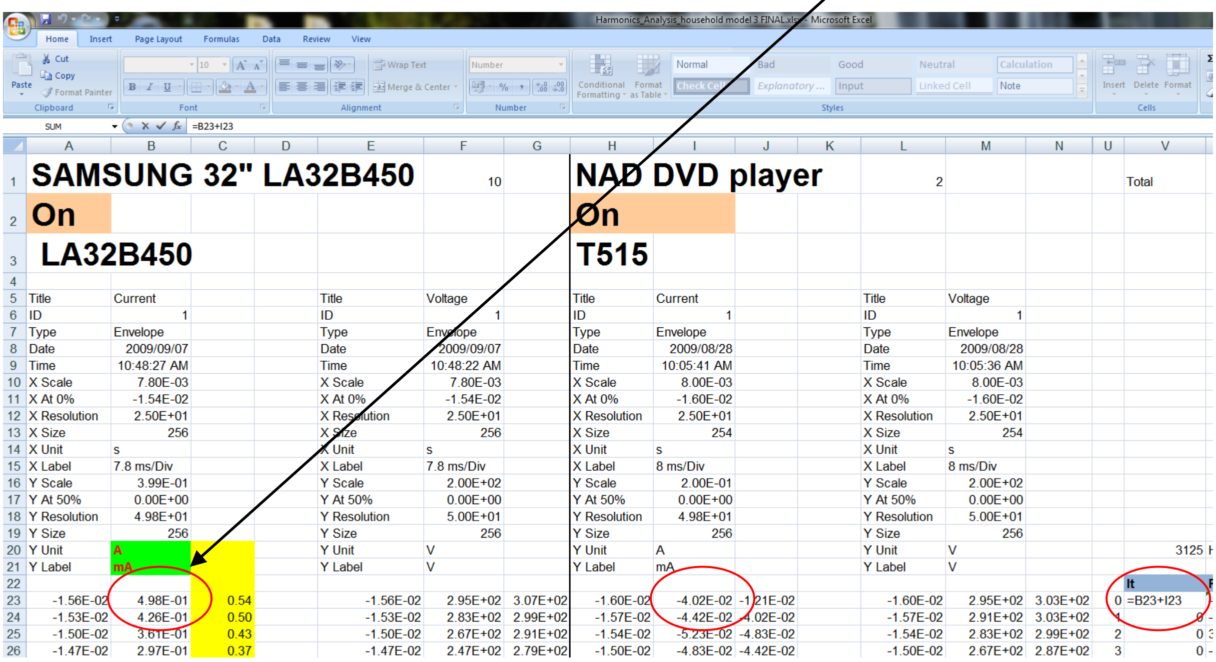


Figure 4.20: Using Microsoft Excel to produce the total current waveform by the addition of two sampled values at the same time interval. Arrow indicates data transferred from Notepad to Excel

4.3.3 Perform calculations in Microsoft Excel

At step 3 the methodology splits into two paths depending on whether one will be analysing the data from devices measured as a combination/individually, or synthesizing voltage and current for a combination of devices using data from individual device measurements. The next section will demonstrate how Microsoft Excel was used to perform calculations specific to portions of the methodology.

4.3.4 Step 6.b: Synthesize total current waveform from individual current measurements

One of the goals of this research was to combine results from home entertainment devices mathematically and determine the total current that would be drawn by the combination using individual device measurements. Figure 4.20 shows how, applying equation 4.2, the total current waveform was synthesised by the addition of two or more sampled current values at the same sampling interval. The instantaneous total current is then given by:

$$i(t)_s = i(t)_1 + i(t)_{1+n} \qquad (4.2)$$

where:

$i(t)_s$ = the total instantaneous synthesised current

$i(t)_1$= instantaneous current for device 1

$i(t)_{1+n}$= instantaneous current for device 1+n

4.3.5 Steps 4.a and 7.b: Perform FFT on voltage and current waveforms

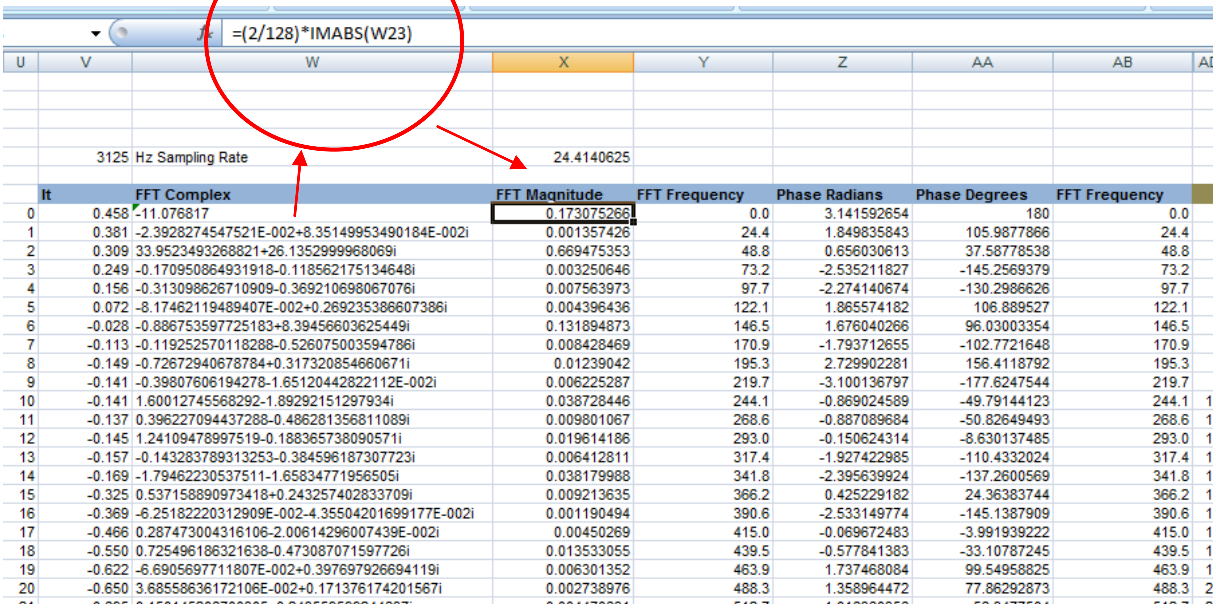
Once the total current waveform was synthesised in step 6b, the Fast Fourier Transform tool in Excel was applied to the total current waveform data to determine the frequency spectrum.

Figure 4.21 shows the section in the spreadsheet where the Fast Fourier Transform tool was used on the data of column V labelled “I_t” (total synthesized current). Column V contains the discrete time sampled values making up the total current waveform synthesized in step 6b. Applying the Fast Fourier Transform tool to the data points of column V produces the output in column W labelled “FFT Complex”. Column W now contains the frequency components in complex form of the total current waveform. It was necessary to extract the magnitude and phase angle of each frequency component from the complex value in column W to allow further processing.

Figure 4.21 also shows how applying the IMABS Excel function to the data in column W returns the magnitude shown in column X. The IMABS() function returns the absolute value of a complex number.

Figure 4.22 shows how the phase angle of the frequency component is determined from the complex number in column W by using the IMARGUMENT Excel function. IMARGUMENT returns the angle of the complex number in column W as radians.

Using this process, a list of the current harmonics magnitudes and their associated phase angles were produced. The same procedure was followed for the voltage waveform to determine the voltage spectrum. Only one of the three voltage waveforms was chosen (step 6b) to be used in power calculations. Please refer to Appendix A for the spreadsheets created during Part B.

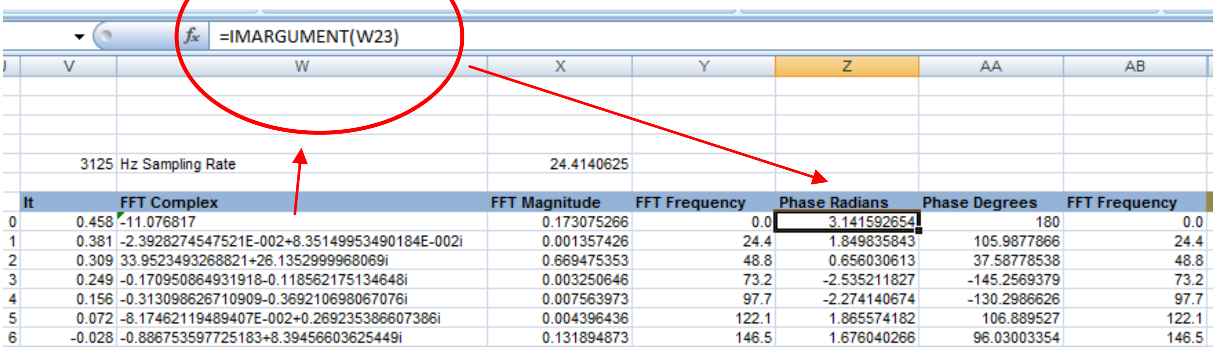


=(2/128)*IMABS(W23)

3125 Hz Sampling Rate 24.4140625

	It	FFT Complex	FFT Magnitude	FFT Frequency	Phase Radians	Phase Degrees	FFT Frequency	
0	0.458	-11.076817	0.173075266	0.0	3.141592654	180	0.0	
1	0.381	-2.3928274547521E-002+8.35149953490184E-002i	0.001357426	24.4	1.849835843	105.9877866	24.4	
2	0.309	33.9523493268821+26.1352999968069i	0.669475353	48.8	0.656030613	37.58778538	48.8	
3	0.249	-0.170950864931918-0.118562175134648i	0.003250646	73.2	-2.535211827	-145.2569379	73.2	
4	0.156	-0.313098626710909-0.369210698067076i	0.007563973	97.7	-2.274140674	-130.2986626	97.7	
5	0.072	-8.17462119489407E-002+0.269235386607386i	0.004396436	122.1	1.865574182	106.889527	122.1	
6	-0.028	-0.886753597725183+8.39456603625449i	0.131894873	146.5	1.676040266	96.03003354	146.5	
7	-0.113	-0.119252570118288-0.526075003594786i	0.008428469	170.9	-1.793712655	-102.7721648	170.9	
8	-0.149	-0.72672940678784+0.31732085466071i	0.01239042	195.3	2.729902281	156.4118792	195.3	
9	-0.141	-0.39807606194278-1.65120442822112E-002i	0.006225287	219.7	-3.100136797	-177.6247544	219.7	
10	-0.141	1.60012745568292-1.89292151297934i	0.038728446	244.1	-0.869024589	-49.79144123	244.1	1
11	-0.137	0.396227094437288-0.486281356811089i	0.009801067	268.6	-0.887089684	-50.82649493	268.6	1
12	-0.145	1.24109478997519-0.18836573809057i	0.019614186	293.0	-0.150624314	-8.630137485	293.0	1
13	-0.157	-0.143283789313253-0.384596187307723i	0.006412811	317.4	-1.927422985	-110.4332024	317.4	1
14	-0.169	-1.79462230537511-1.65834771956505i	0.038179988	341.8	-2.395639924	-137.2600569	341.8	1
15	-0.325	0.537158890973418+0.243257402833709i	0.009213635	366.2	0.425229182	24.36383744	366.2	1
16	-0.369	-6.25182220312909E-002-4.35504201699177E-002i	0.001190494	390.6	-2.533149774	-145.1387909	390.6	1
17	-0.466	0.287473004316106-2.00614296007439E-002i	0.00450269	415.0	-0.069672483	-3.991939222	415.0	1
18	-0.550	0.725496186321638-0.473087071597726i	0.013533055	439.5	-0.577841383	-33.10787245	439.5	1
19	-0.622	-6.6905697711807E-002+0.397697926694119i	0.006301352	463.9	1.737468084	99.54958825	463.9	1
20	-0.650	3.68558636172106E-002+0.171376174201567i	0.002738976	488.3	1.358964472	77.86292873	488.3	2

Figure 4.21: Fourier Transform section of Excel spreadsheet showing frequency component magnitude (Bredekamp AJ, 2010)



=IMARGUMENT(W23)

3125 Hz Sampling Rate 24.4140625

	It	FFT Complex	FFT Magnitude	FFT Frequency	Phase Radians	Phase Degrees	FFT Frequency
0	0.458	-11.076817	0.173075266	0.0	3.141592654	180	0.0
1	0.381	-2.3928274547521E-002+8.35149953490184E-002i	0.001357426	24.4	1.849835843	105.9877866	24.4
2	0.309	33.9523493268821+26.1352999968069i	0.669475353	48.8	0.656030613	37.58778538	48.8
3	0.249	-0.170950864931918-0.118562175134648i	0.003250646	73.2	-2.535211827	-145.2569379	73.2
4	0.156	-0.313098626710909-0.369210698067076i	0.007563973	97.7	-2.274140674	-130.2986626	97.7
5	0.072	-8.17462119489407E-002+0.269235386607386i	0.004396436	122.1	1.865574182	106.889527	122.1
6	-0.028	-0.886753597725183+8.39456603625449i	0.131894873	146.5	1.676040266	96.03003354	146.5

Figure 4.22: Fourier Transform section of Excel spreadsheet showing frequency component magnitude phase in radians (Bredekamp AJ, 2010)

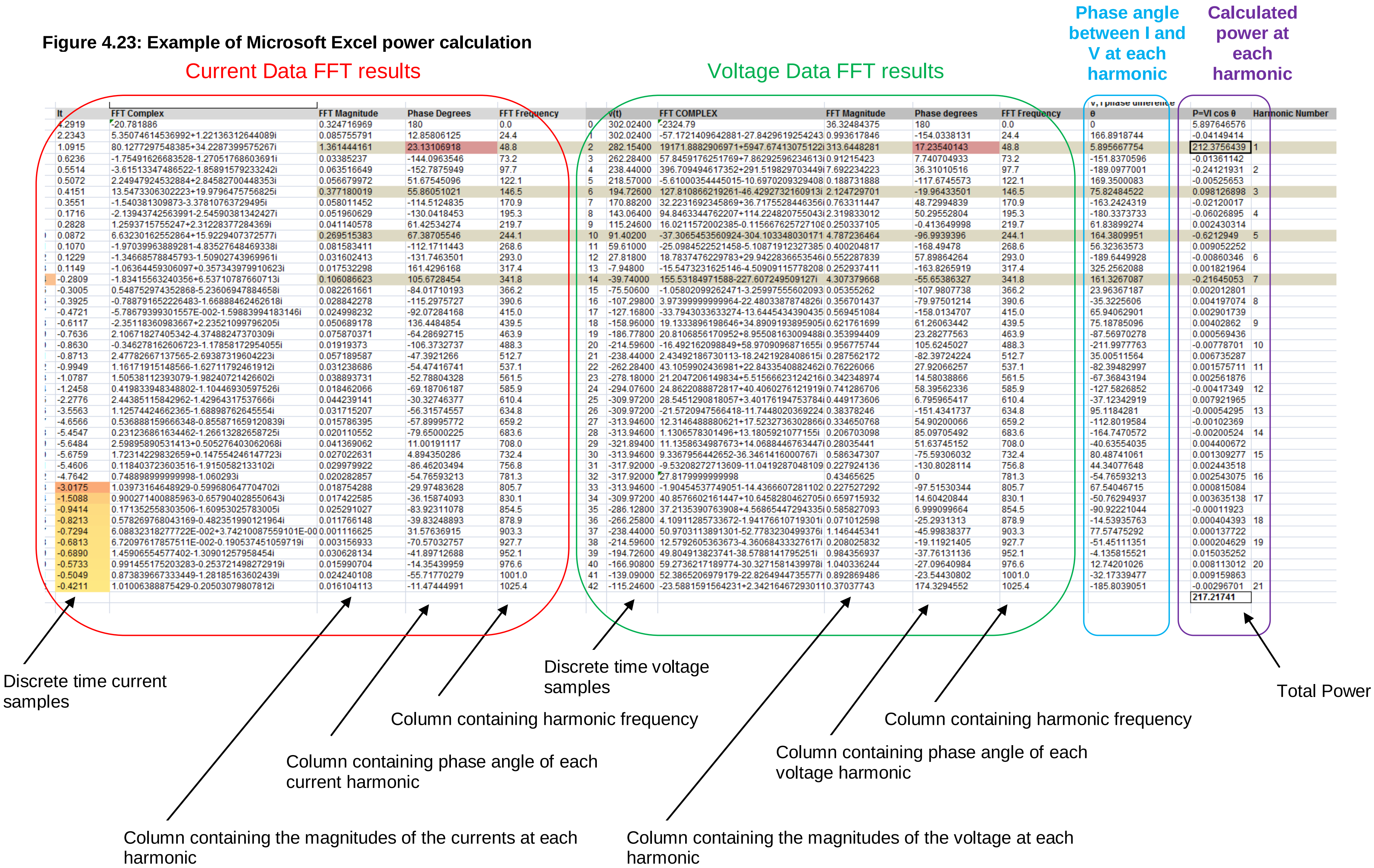
4.3.6 Step 8b Plot total current and voltage waveforms

Plotting the data of column X labelled "FFT Magnitude" (circled in red) in figure 4.21 against frequency will produce the current spectrum. Similarly the magnitudes of the voltage frequency components can be plotted against frequency to produce the voltage spectrum.

4.3.7 Step 8a and 11b: Calculate power at each harmonic and the total power

Figure 4.23 shows how the power due to each harmonic, as well as the total power, is calculated in Microsoft Excel. Equation 2.30, along with the methodology of section 2.5.2, is used with the magnitudes and phase angles of the currents and voltages at each harmonic to determine the power due to each harmonic as well as the total power.

Figure 4.23: Example of Microsoft Excel power calculation



It	FFT Complex	FFT Magnitude	Phase Degrees	FFT Frequency		V(t)	FFT COMPLEX	FFT Magnitude	Phase degrees	FFT Frequency	V, I phase difference θ	P=VI cos θ	Harmonic Number
4.2919	-20.781886	0.324716969	180	0.0	0	302.02400	-2324.79	36.32484375	180	0.0	0	5.897646576	
2.2343	5.35074614536992+1.22136312644089i	0.085755791	12.85806125	24.4	1	302.02400	-57.1721409642881-27.8429619254243	0.993617846	-154.0338131	24.4	166.8918744	-0.04149414	
1.0915	80.1277297548385+34.2287399575267i	1.361444161	23.13106918	48.8	2	282.15400	19171.8882906971+5947.67413075122i	313.6448281	17.23540143	48.8	5.895667754	212.3756439	1
0.6236	-1.75491626683528-1.27051768603691i	0.03385237	-144.0963546	73.2	3	262.28400	57.8459176251769+7.86292596234613i	0.91215423	7.740704933	73.2	-151.8370596	-0.01361142	
0.5514	-3.61513347486522-1.85891579233242i	0.063516649	-152.7875949	97.7	4	238.44000	396.709494617352+291.519829703449i	7.692234223	36.31010516	97.7	-189.0977001	-0.24121931	2
0.5072	2.24947924532884+2.84582700448353i	0.056679972	51.67545096	122.1	5	218.57000	-5.61000354445015-10.6970209329408	0.188731888	-117.6745573	122.1	169.3500083	-0.00525653	
0.4151	13.5473306302223+19.9796475756825i	0.377180019	55.86051021	146.5	6	194.72600	127.810866219261-46.4292732160913i	2.124729701	-19.96433501	146.5	75.82484522	0.098126898	3
0.3551	-1.540381309873-3.37810763729495i	0.058011452	-114.5124835	170.9	7	170.88200	32.2231692345869+36.7175528446356i	0.763311447	48.72994839	170.9	-163.2424319	-0.02120017	
0.1716	-2.13943742563991-2.54590381342427i	0.051960629	-130.0418453	195.3	8	143.06400	94.8463344762207+114.224820755043i	2.319833012	50.29552804	195.3	-180.3373733	-0.06026895	4
0.2828	1.2593715755247+2.31228377284369i	0.041140578	61.42534274	219.7	9	115.24600	16.0211572002385-0.11566762572710E	0.250337105	-0.413649998	219.7	61.83899274	0.002430314	
0.0872	6.63230162552864+15.9229407372577i	0.269515383	67.38705546	244.1	10	91.40200	-37.3065453560924-304.103348030171	4.787236464	-96.9939396	244.1	164.3809951	-0.6212949	5
0.1070	-1.97039963889281-4.83527648469338i	0.081583411	-112.1711443	268.6	11	59.61000	-25.0984522521458-5.10871912327385	0.400204817	-168.49478	268.6	56.32363573	0.009052252	
0.1229	-1.34668578845793-1.50902743969961i	0.031602413	-131.7463501	293.0	12	27.81800	18.7837476229783+29.9422836653546i	0.552287839	57.89864264	293.0	-189.6449928	-0.00860346	6
0.1149	-1.06364459306097+0.357343979910623i	0.017532298	161.4296168	317.4	13	-7.94800	-15.5473231625146-4.50909115778208	0.252937411	-163.8265919	317.4	325.2562088	0.001821964	
-0.2809	-1.83415563240356+6.53710787660713i	0.106086623	105.6728454	341.8	14	-39.74000	155.53184971588-227.607249509127i	4.307379668	-55.65386327	341.8	161.3267087	-0.21645053	7
-0.3005	0.548752974352868-5.23606947884658i	0.082261661	-84.01710193	366.2	15	-75.50600	-1.05802099262471-3.25997555602093	0.05355262	-107.9807738	366.2	23.96367187	0.002012801	
-0.3925	-0.788791652226483-1.66888462462618i	0.028842278	-115.2975727	390.6	16	-107.29800	3.97399999999964-22.4803387874826i	0.356701437	-79.97501214	390.6	-35.3225606	0.004197074	8
-0.4721	-5.78679399301557E-002-1.59883994183146i	0.024998232	-92.07284168	415.0	17	-127.16800	-33.7943033633274-13.6445434390435	0.569451084	-158.0134707	415.0	65.94062901	0.002901739	
-0.6117	-2.35118360983667+2.23521099796205i	0.050689178	136.4484854	439.5	18	-158.96000	19.1333896198646+34.8909193895905i	0.621761699	61.26063442	439.5	75.18785096	0.00402862	9
-0.7636	2.10671827405342-4.37488247370309i	0.075870371	-64.28692715	463.9	19	-186.77800	20.8106856170952+8.95508163009488i	0.353994409	23.28277563	463.9	-87.56970278	0.000569436	
-0.8630	-0.346278162606723-1.17858172954055i	0.01919373	-106.3732737	488.3	20	-214.59600	-16.492162098849+58.9709096871655i	0.956775744	105.6245027	488.3	-211.9977763	-0.00778701	10
-0.8713	2.47782667137565-2.69387319604223i	0.057189587	-47.3921266	512.7	21	-238.44000	2.43492186730113-18.2421928408615i	0.287562172	-82.39724224	512.7	35.00511564	0.006735287	
-0.9949	1.16171915148566-1.62711792461912i	0.031238686	-54.47416741	537.1	22	-262.28400	43.1059902436981+22.8433540882462i	0.76226066	27.92066257	537.1	-82.39482997	0.001575711	11
-1.0787	1.50538112393079-1.98240721426602i	0.038893731	-52.78804328	561.5	23	-278.18000	21.2047206149834+5.51566623124216i	0.342348974	14.58038866	561.5	-67.36843194	0.002561876	
-1.2458	0.419833948348802-1.10446930597526i	0.018462066	-69.18706187	585.9	24	-294.07600	24.8622088872817+40.4060276121919i	0.741286706	58.39562336	585.9	-127.5826852	-0.00417349	12
-2.2776	2.44385115842962-1.42964317537666i	0.044239141	-30.32746377	610.4	25	-309.97200	28.5451290818057+3.40176194753784i	0.449173606	6.795965417	610.4	-37.12342919	0.007921965	
-3.5563	1.12574424662365-1.68898762645554i	0.031715207	-56.31574557	634.8	26	-309.97200	-21.5720947566418-11.7448020369224	0.38378246	-151.4341737	634.8	95.1184281	-0.00054295	13
-4.6566	0.536888159666348-0.855871659120839i	0.015786395	-57.89995772	659.2	27	-313.94600	12.3146488880621+17.5232736302866i	0.334650768	54.90200066	659.2	-112.8019584	-0.00102369	
-5.4547	0.231236861634462-1.26613282658725i	0.020110552	-79.65000225	683.6	28	-313.94600	1.1306578301496+13.1805921077155i	0.206703098	85.09705492	683.6	-164.7470572	-0.00200524	14
-5.6484	2.59895890531413+0.505276403062068i	0.041369062	11.00191117	708.0	29	-321.89400	11.1358634987673+14.0688446763447i	0.28035441	51.63745152	708.0	-40.63554035	0.004400672	
-5.6759	1.72314229832659+0.147554246147723i	0.027022631	4.894350286	732.4	30	-313.94600	9.3367956442652-36.3461416000767i	0.586347307	-75.59306032	732.4	80.48741061	0.001309277	15
-5.4606	0.118403723603516-1.9150582133102i	0.029979922	-86.46203494	756.8	31	-317.92000	-9.53208272713609-11.0419287048109	0.227924136	-130.8028114	756.8	44.34077648	0.002443518	
-4.7642	0.748898999999998-1.060293i	0.020282857	-54.76593213	781.3	32	-317.92000	27.8179999999998	0.43465625	0	781.3	-54.76593213	0.002543075	16
-3.0175	1.03973164648929-0.599680647704702i	0.018754288	-29.97483628	805.7	33	-313.94600	-1.90454537749051-14.4366607281102	0.227527292	-97.51530344	805.7	67.54046715	0.000815084	
-1.5088	0.900271400885963-0.657904028550643i	0.017422585	-36.15874093	830.1	34	-309.97200	40.8576602161447+10.6458280462705i	0.659715932	14.60420844	830.1	-50.76294937	0.003635138	17
-0.9414	0.171352558303506-1.60953025783005i	0.025291027	-83.92311078	854.5	35	-286.12800	37.2135390763908+4.56865447294335i	0.585827093	6.999099664	854.5	-90.92221044	-0.00011923	
-0.8213	0.578269768043169-0.482351990121964i	0.011766148	-39.83248893	878.9	36	-266.25800	4.10911285733672-1.94176610719301i	0.071012598	-25.2931313	878.9	-14.53935763	0.000404393	18
-0.7294	6.08832318277722E-002+3.74210087559101E-00	0.001116625	31.57636915	903.3	37	-238.44000	50.9703113891301-52.7783230499376i	1.146445341	-45.99838377	903.3	77.57475292	0.000137722	
-0.6813	6.72097617857511E-002-0.190537451059719i	0.003156933	-70.57032757	927.7	38	-214.59600	12.5792605363673-4.36068433327617i	0.208025832	-19.11921405	927.7	-51.45111351	0.000204629	19
-0.6890	1.45906554577402-1.30901257958454i	0.030628134	-41.89712688	952.1	39	-194.72600	49.804913823741-38.5788141795251i	0.984356937	-37.76131136	952.1	-4.135815521	0.015035252	
-0.5733	0.991455175203283-0.253721498272919i	0.015990704	-14.35439959	976.6	40	-166.90800	59.2736217189774-30.3271581439978i	1.040336244	-27.09640984	976.6	12.74201026	0.008113012	20
-0.5049	0.873839667333449-1.28185163602439i	0.024240108	-55.71770279	1001.0	41	-139.09000	52.3865206979179-22.8264944735577i	0.892869486	-23.54430802	1001.0	-32.17339477	0.009159863	
-0.4211	1.01006388875429-0.20503079807812i	0.016104113	-11.47444991	1025.4	42	-115.24600	-23.5881591564231+2.34216467293011	0.37037743	174.3294552	1025.4	-185.8039051	-0.00296701	21
												217.21741	

4.4 Part C: Compare against energy and harmonic standards

The final stage, Part C, compares the results generated in Part B to international standards for power consumption (Energy Star) and current harmonics (EN61000-3-2) as described in sections 3.2.2, and 3.3. Part C is the methodology to perform these comparisons. Figure 4.24 shows the steps of the methodology for Part C.

4.4.1 Step 1a: Compare harmonic power between case studies

Step 1a uses the results generated in Part B for each case study. This step compares the total power at the fundamental as well as third and fifth harmonics between case studies.

4.4.2 Step 2a: Compare I_{RMS} per harmonic to EN6100-3-2 standard for each case study

Step 2a compares the I_{RMS} per harmonic for each case study to the maximum allowed under the EN6100-3-2 standard for class D equipment. To perform the comparison it is necessary to calculate the allowed current harmonics in mA/W using Table 3.6. Once the allowed value for each current harmonic have been calculated, taking into account the total power consumption of the group of devices (console) in the case study, the allowed value can be compared to the measured value.

The purpose of the comparison is to determine if any of the groups of devices have excessive harmonics present in the total current drawn by the combination of devices.

4.4.3 Step 1b: Compare power consumption of new and existing television sets

Power measurements performed on television sets in Part A are compared for different types of television sets. In this step the power consumption of new television sets (LCD, LED or Plasma) are compared to the power consumption of existing sets (CRT). The purpose of the comparison is to determine how the power consumption of new television sets compares to that of existing sets.

4.4.4 Step 2b: Compare I_{RMS} per harmonic to EN6100-3-2 standard for different types of televisions

In this step the value of I_{RMS} per harmonic for individual television sets is compared to the maximum allowed by EN61000-3-2 for class D equipment. The purpose of the comparison is to determine if any of the televisions have excessive harmonics present in the total current drawn by the set.

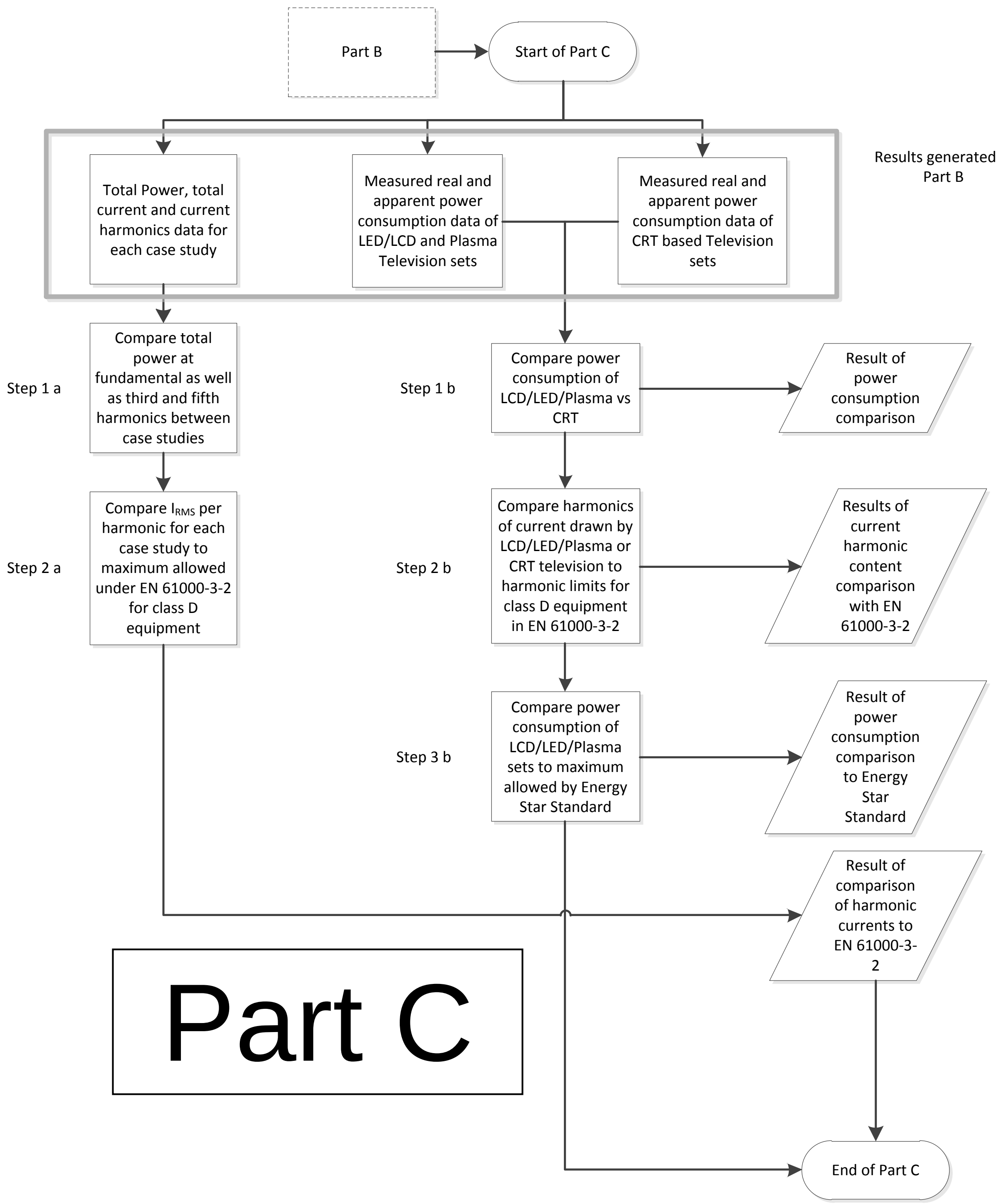


Figure 4.24: Detail of steps in part C

To perform the comparison it is necessary to calculate the allowed current harmonics in mA/W using Table 3.6 and equation 3.1. Once the allowed value for each current harmonic have been calculated, taking into account the total power consumption of the television set in question, the allowed value can be compared to the measured value.

4.4.5 Step 3b: Compare power consumption of televisions to Energy Star Standard

The final step in Part C compares the power consumption of individual televisions to the maximum allowed under the Energy Star standard as listed in table B.6. in Appendix B.

4.5 Summary

This chapter summarizes the research contribution made to the field of power consumption and harmonic measurement of home entertainment equipment. The hardware and supporting measurement software tools used to generate results are described. The measurement procedure for television sets and for CD/DVD players and home theatre amplifiers is described.

The developed procedure shows how a measurement is turned into results. It is also shown how the developed methodology enables the total current and harmonic spectra to be generated. Finally the procedure used to compare the generated results with existing standards for power consumption and harmonics is described.

These methodologies will now be applied to case studies to demonstrate their effectiveness.

CHAPTER FIVE
CASE STUDIES ON HOME ENTERTAINMENT EQUIPMENT

5.1 Introduction

In this section five case studies will be undertaken and the developed methodologies of chapter 4 will be applied to produce results.

Case studies one through four will measure the power consumption and harmonics of separate home entertainment devices. The purpose of these case studies will be to determine the effect that different combinations of home entertainment devices have on harmonic and power consumption levels. For these case studies the total current drawn by a set of the combined devices will be synthesised using the individual measured currents drawn by individual devices.

To verify the method of total current synthesis used in step 6b of Part B (figure 4.18), case study one will also measure the power consumption and harmonics of the selected combination of devices as may be found in a home entertainment console. For case study one the measured total current will be compared to the synthesized total current.

Case study five will measure the current spectra of four types of television sets, a 74cm CRT, 42” Plasma, 42” LCD and a 40”LED. The purpose of these measurements is to determine the harmonic content and harmonic distortion levels of these four types of television set.

A summary of the power consumption of new television sets can be viewed in Appendix B, Table B.1

It was not possible to group devices together during the in-store measurements of new equipment so the devices in a typical users’ existing home entertainment setup were measured instead. In the case of the measurements conducted in the home environment, the devices were all existing equipment 5 years or older. This combination of existing devices represented case study one which also acted as a control to check the validity of the methodology used.

5.2 Selection of case studies

For the purposes of this research investigation, a variety of devices were selected to be grouped together to represent equipment as it may be found in a home entertainment console at home. Such a combination usually includes a television set, DVD player, AV Receiver/Amplifier and/or DSTV decoder. Table 5.1 show the devices that were grouped together for case studies 1 to 4.

In the case of case study 1, the devices were measured as a combination. In addition the devices contained in case study 1 was also combined mathematically and the total current drawn synthesized using individual measurements. Doing both allowed case study 1 to act as a test of the methodology in Part B to see if measured and synthesized results agree.

In case studies 2, 3 and 4, the power consumption, voltage, current drawn and harmonics of the combinations of devices were synthesised mathematically using individual measurements only.

Table 5.1: Combinations of new and existing devices

Case Study	Devices in Case Study
1 **Existing Equipment**	• **SAMSUNG 42" CRT Television** • **Yamaha DVD player** • **Yamaha AV Receiver/amplifier** • **DSTV PVR decoder**
2 **New Equipment**	• **SAMSUNG 46" LCD Television** • **NAD DVD player** • **NAD AV Receiver/amplifier** • **NAD CD Receiver/amplifier**
3 **New Equipment**	• **SAMSUNG 50" PLASMA Television** • **NAD DVD player** • **NAD AV Receiver/amplifier** • **NAD CD Receiver/amplifier**
4 **New Equipment**	• **SAMSUNG 32"LCD Television** • **NAD DVD player**

5.2.1 Case Study 1

Figure 5.1 shows the connection diagram of the devices for case study 1.

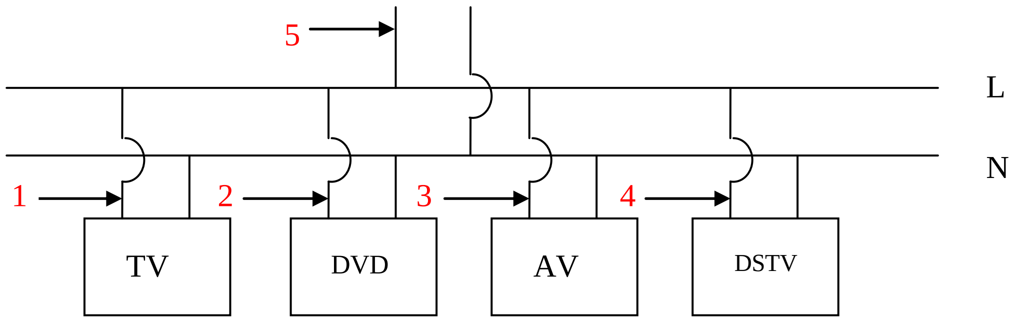


Figure 5.1: Bus view of the devices for case study 1

Firstly the methodology of Part A is applied to the home entertainment set-up shown in Figure 5.1 and measurement results obtained.

Measurements were performed at locations 1, 2, 3 and 4. The individual current and voltage waveforms are shown in figures 5.2 and 5.3. Voltage is common to LN therefore the waveforms at each device is identical as the cables used do not introduce any voltage drops or phase shifts. Since four separate voltage and current measurements were taken originally, four different voltage and current waveforms are shown in figures 5.2 and 5.3. It can be seen from figure 5.3 that the Fluke power quality analyzer triggers at the peak of the voltage waveform to start voltage and current capture. The waveforms of figures 5.2 and 5.3 are therefore aligned in time. Measurements were also performed for the total current drawn by the combination of TV, DVD player, AV receiver and DSTV decoder at location 5. The resulting current and voltage waveforms are shown in figures 5.4 and 5.6. This concludes Part A.

The methodology of Part B was then used to synthesize the total current at location 5 from the separate currents shown in figure 5.2. The resultant waveform is shown in figure 5.5. In addition, the spectrum of the current at location 5 was calculated from the waveform in figure 5.5 using the methodology of Part B, steps 7b and 8b. The resultant spectrum is shown in figure 5.8.

From figures 5.4 and 5.5 it is evident that there is a high degree of correlation between the measured and synthesised total current waveforms. Also, from the calculated and measured current spectra at location 5 (figures 5.8 and 5.9) it is again evident that there is a high degree of correlation between measured and calculated values.

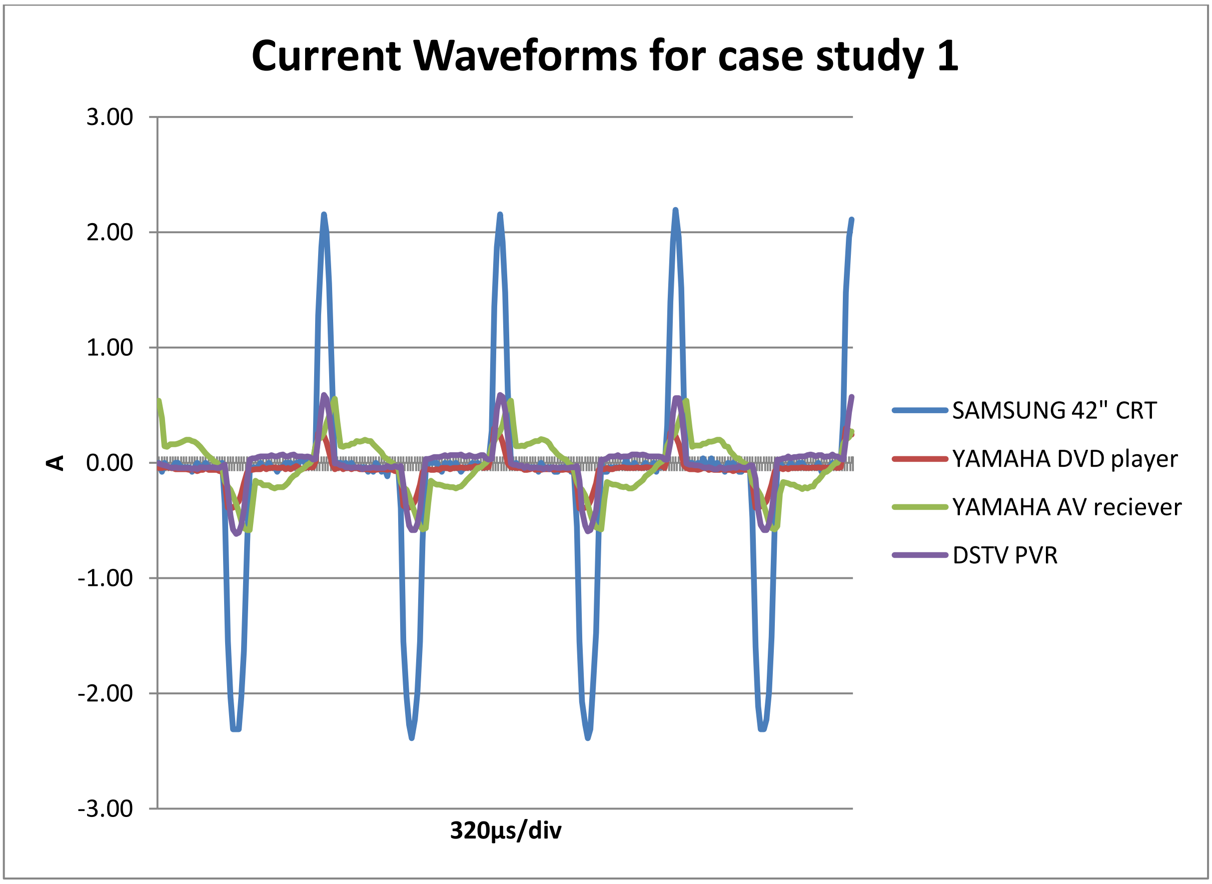


Figure 5.2: Measured current waveforms at locations 1, 2, 3 and 4

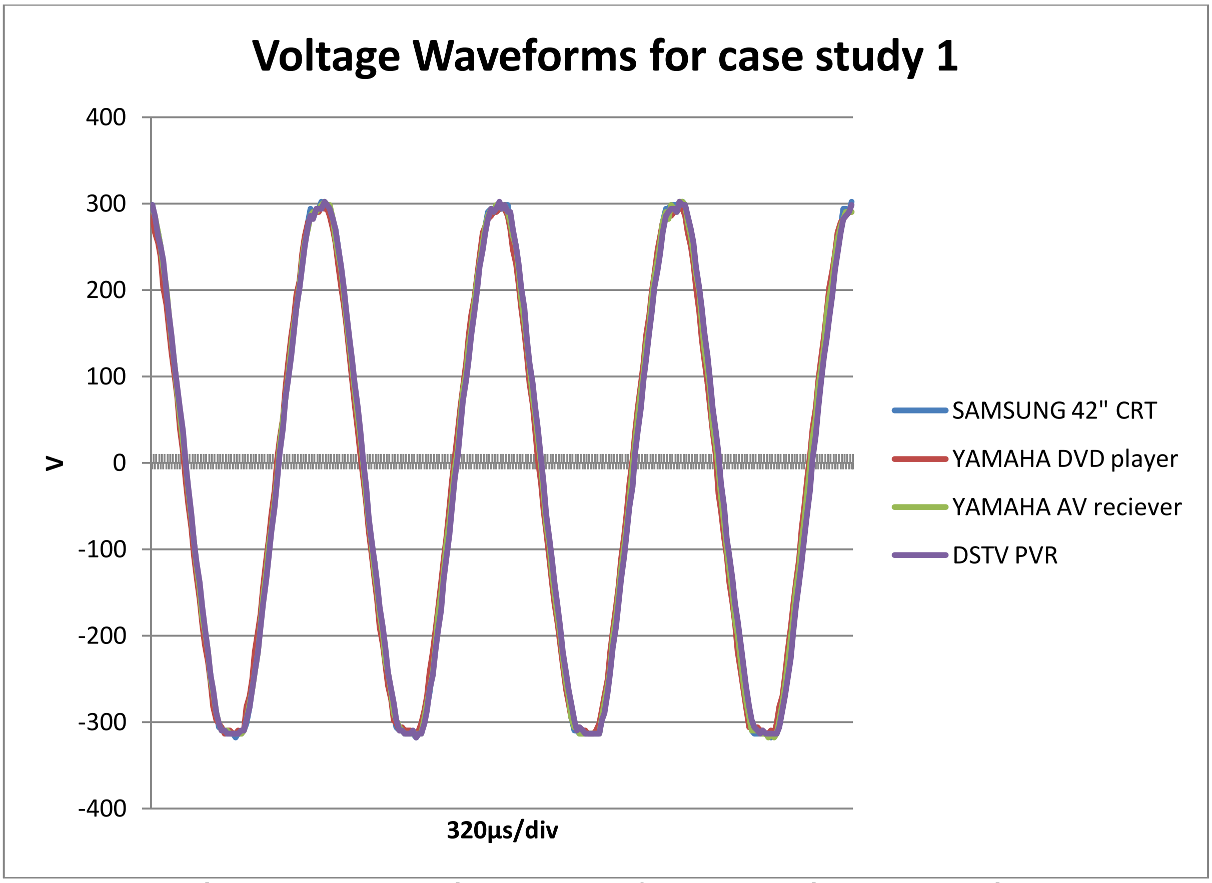


Figure 5.3: Measured voltage waveforms at locations 1, 2, 3 and 4

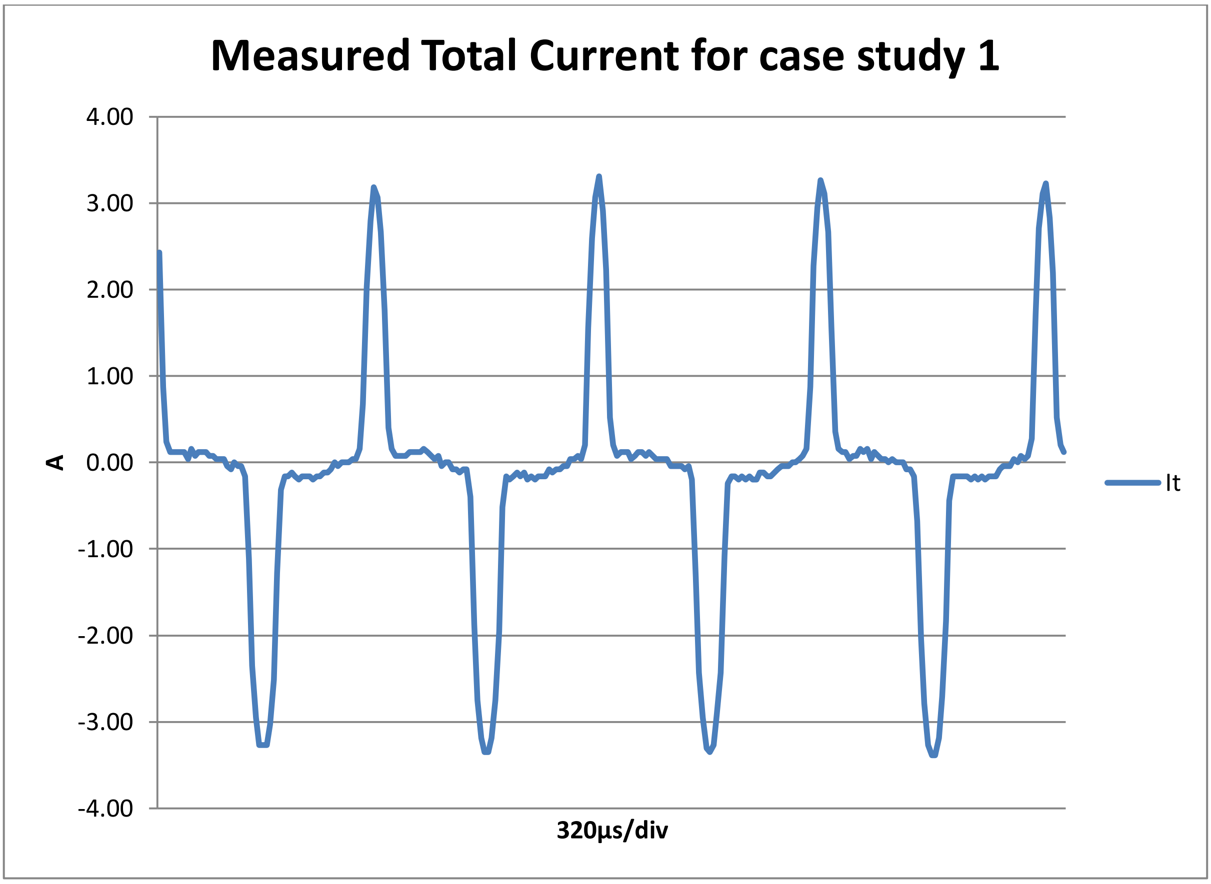


Figure 5.4: Measured current waveform at location 5

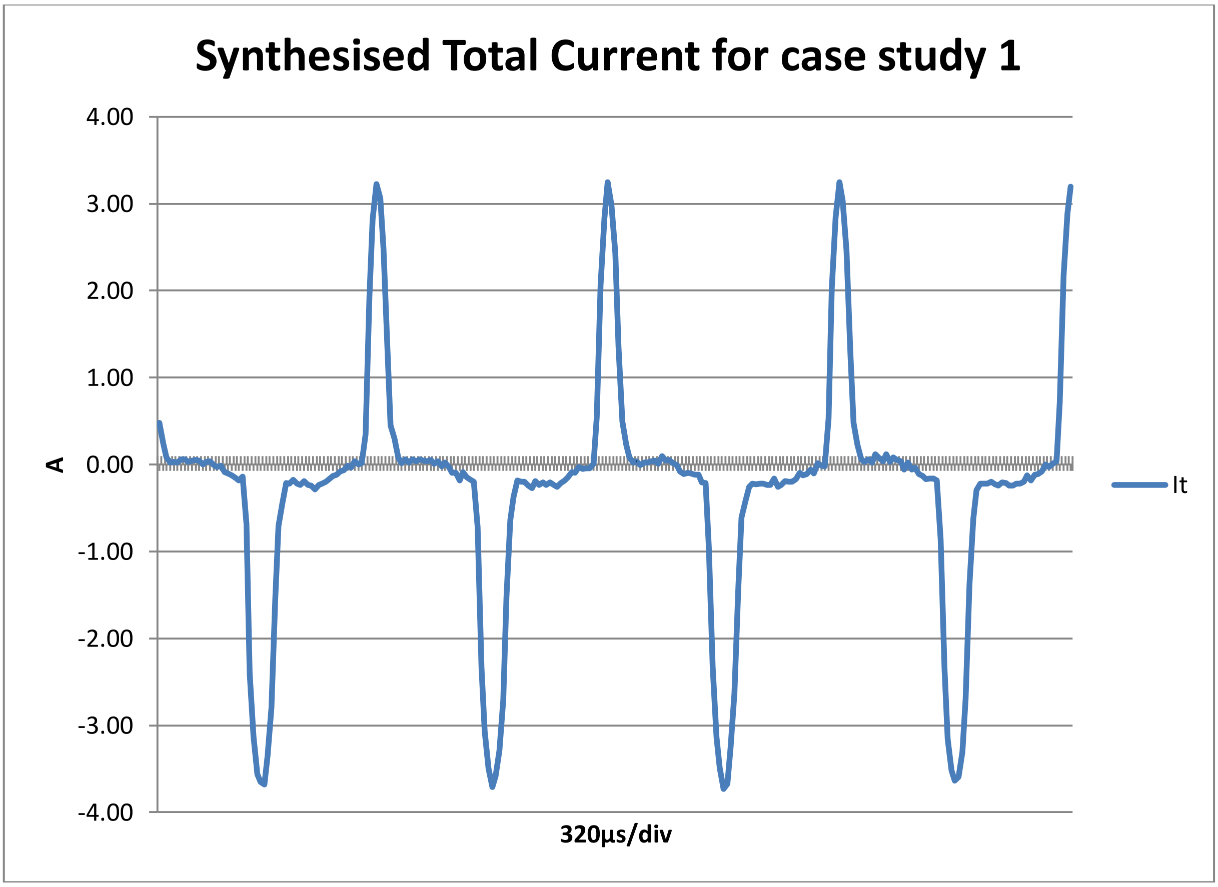


Figure 5.5: Synthesised total current at location 5

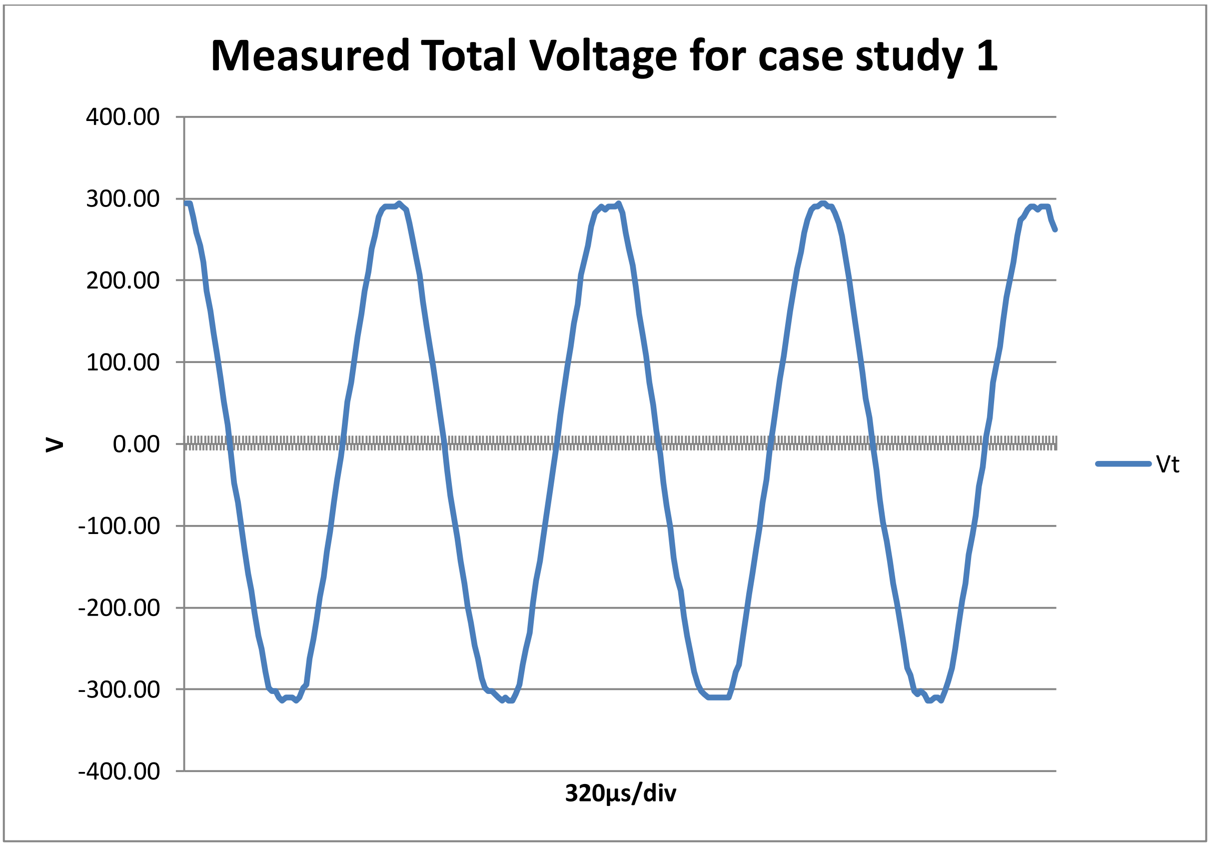


Figure 5.6: Measured voltage waveform at location 5

Table 5.2 and 5.3 show the results of the Fourier transform on the waveforms of figures 5.5 and 5.6 respectively as obtained during Part B, step 7b. For each harmonic the phase angle Ψ is shown. Each harmonic is also represented as a percentage of the 1st harmonic.

The data from table 5.2 was used to plot the spectrum of figure 5.8. The measured spectrum is shown in figure 5.9. It can be seen that there is a high degree of correlation between the measured and calculated spectra. Figure 5.7 shows the measured total power as seen on the Fluke 43B power quality analyzer.

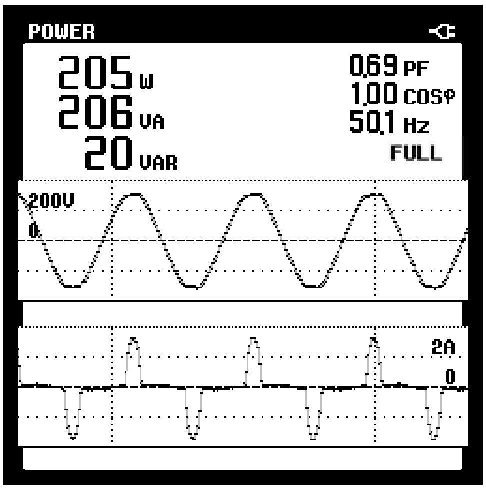


Figure 5.7: Measured values at location 5

Table 5.2: Results of the Fourier analysis of the synthesised total current for case study one

Ampere (peak)	Percentage of fundamental	Phase Angle Ψ in degrees	Frequency	Harmonic Number
1.326812607		16.33849987	48.828125	1
0.193350189	14.6%	-136.0884576	97.65625	2
1.017027681	76.7%	63.24617105	146.484375	3
0.104926631	7.9%	-91.17004022	195.3125	4
0.70984134	53.5%	102.8851834	244.140625	5
0.020240595	1.5%	77.2527674	292.96875	6
0.398506176	30.0%	148.2086934	341.796875	7
0.089327847	6.7%	160.1692453	390.625	8
0.144628506	10.9%	-157.8310256	439.453125	9
0.115674929	8.7%	-149.5663177	488.28125	10
0.031033537	2.3%	-33.06769186	537.109375	11
0.089087974	6.7%	-97.51961188	585.9375	12
0.058729407	4.4%	80.69384066	634.765625	13
0.049118851	3.7%	-35.35897053	683.59375	14
0.066141613	5.0%	144.7026953	732.421875	15

Table 5.3: Results of the Fourier analysis of the measured voltage for case study one

Voltage (peak)	Phase Angle Ψ in degrees	Frequency	Harmonic Number
313.6448281	17.23540143	48.828125	1
7.692234223	36.31010516	97.65625	2
2.124729701	-19.96433501	146.484375	3
2.319833012	50.29552804	195.3125	4
4.787236464	-96.9939396	244.140625	5
0.552287839	57.89864264	292.96875	6
4.307379668	-55.65386327	341.796875	7
0.356701437	-79.97501214	390.625	8
0.621761699	61.26063442	439.453125	9
0.956775744	105.6245027	488.28125	10
0.76226066	27.92066257	537.109375	11
0.741286706	58.39562336	585.9375	12
0.38378246	-151.4341737	634.765625	13
0.206703098	85.09705492	683.59375	14
0.586347307	-75.59306032	732.421875	15

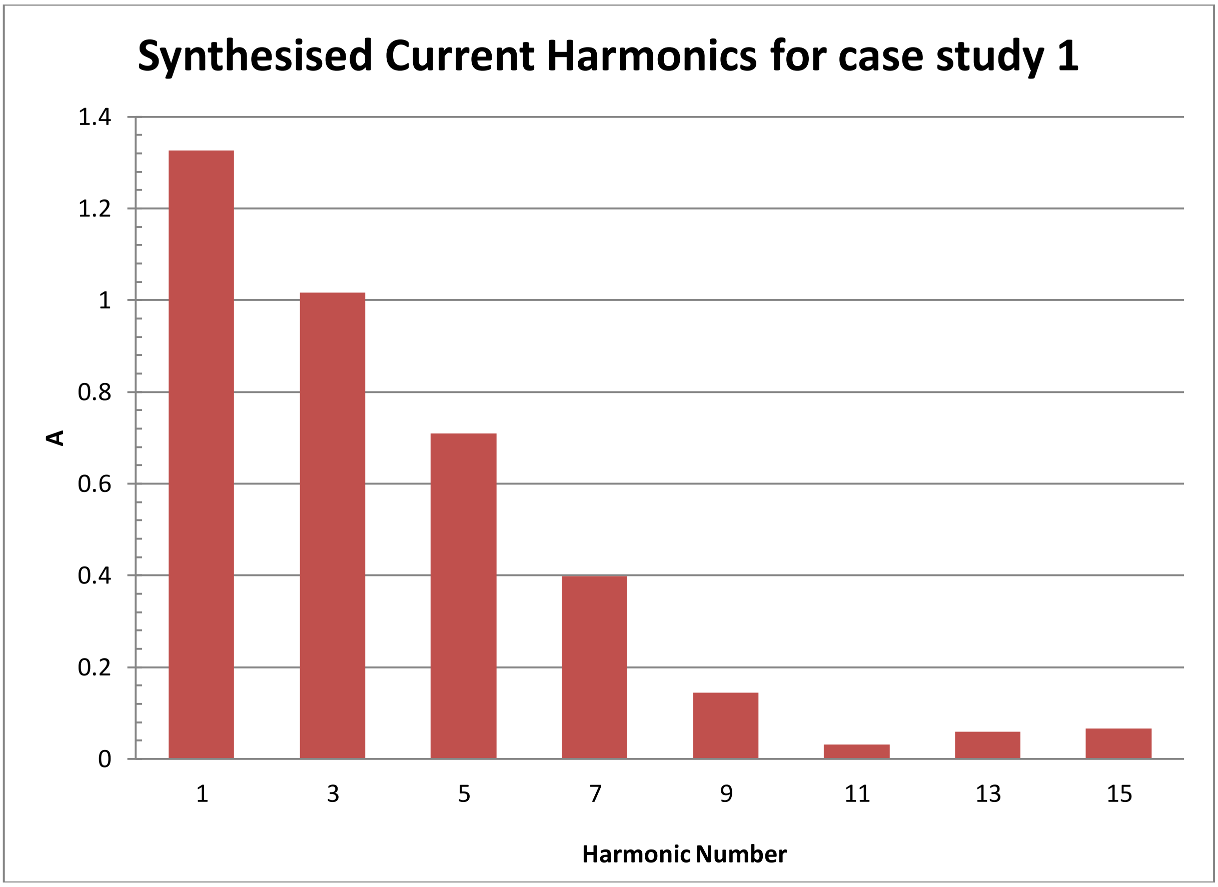


Figure 5.8: Synthesised spectrum of current at location 5

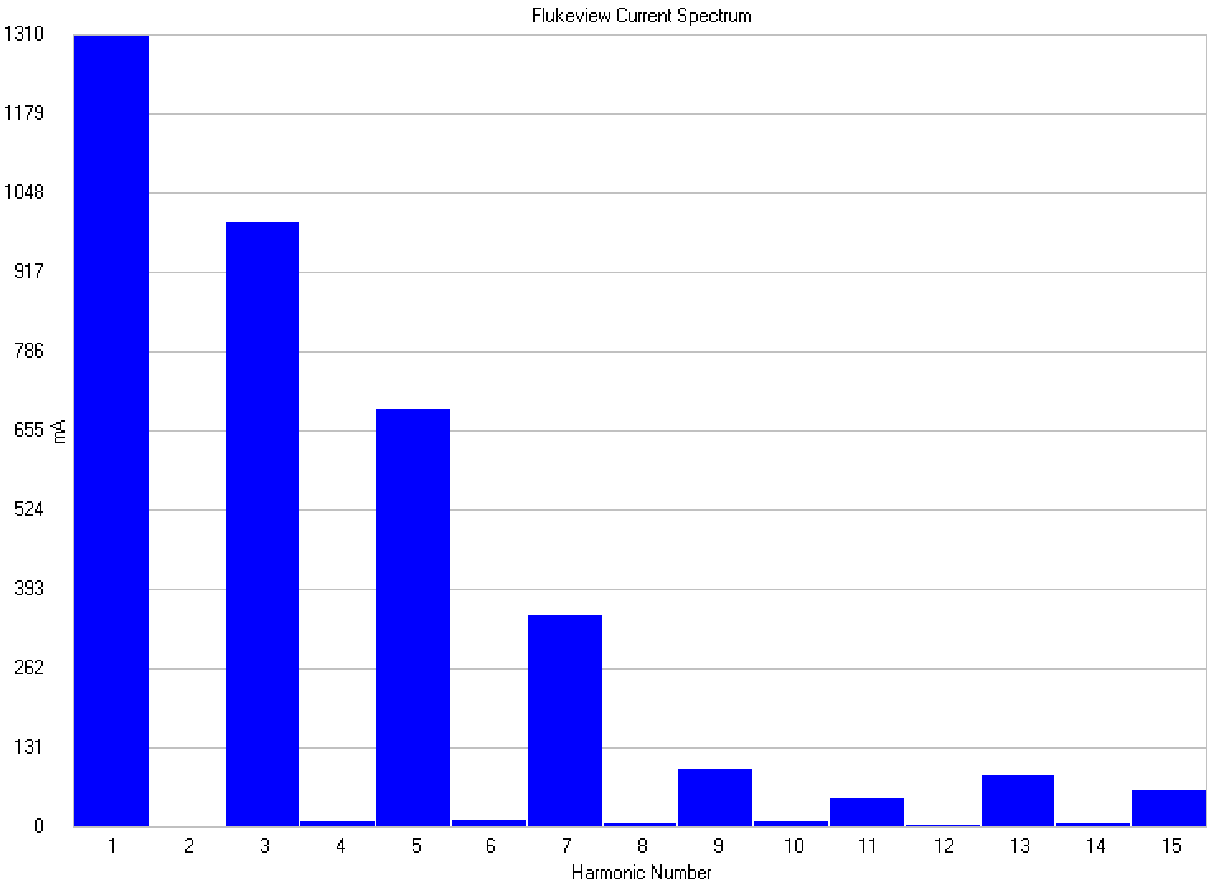


Figure 5.9: Measured spectrum as displayed in FlukeView of current at location 5

5.3.1 Case Study 2

Figure 5.10 shows the connection diagram of the devices for case study 2.

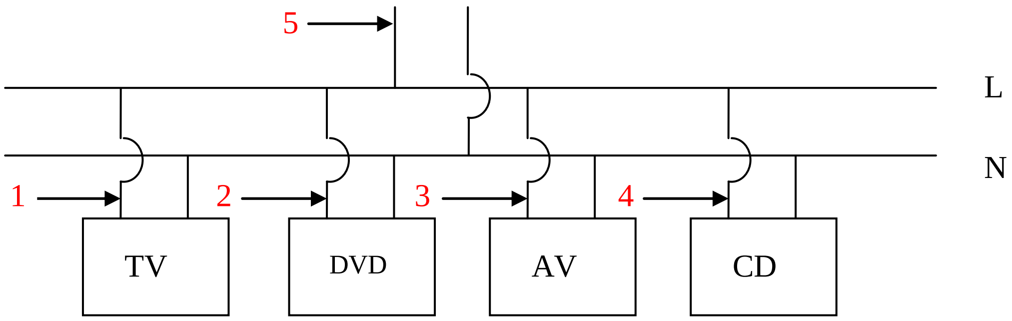


Figure 5.10: Bus view of the devices for case study 2

Using the methodology of Part A, measurements were performed at locations 1, 2, 3 and 4 .The measured current waveforms are displayed in figure 5.11. The voltage at locations 1, 2, 3 and 4 was also measured and these are shown in figure 5.12. This concludes Part A.

The methodology of Part B was then used to obtain the total current drawn by the combination of devices, as would be measured at location 5. Figure 5.13 shows the resultant current waveform. Table 5.4 details the results of the Fourier transform of the waveform of figure 5.13. Table 5.5 shows the results of performing a Fourier transform on one of the waveforms from figure 5.12.

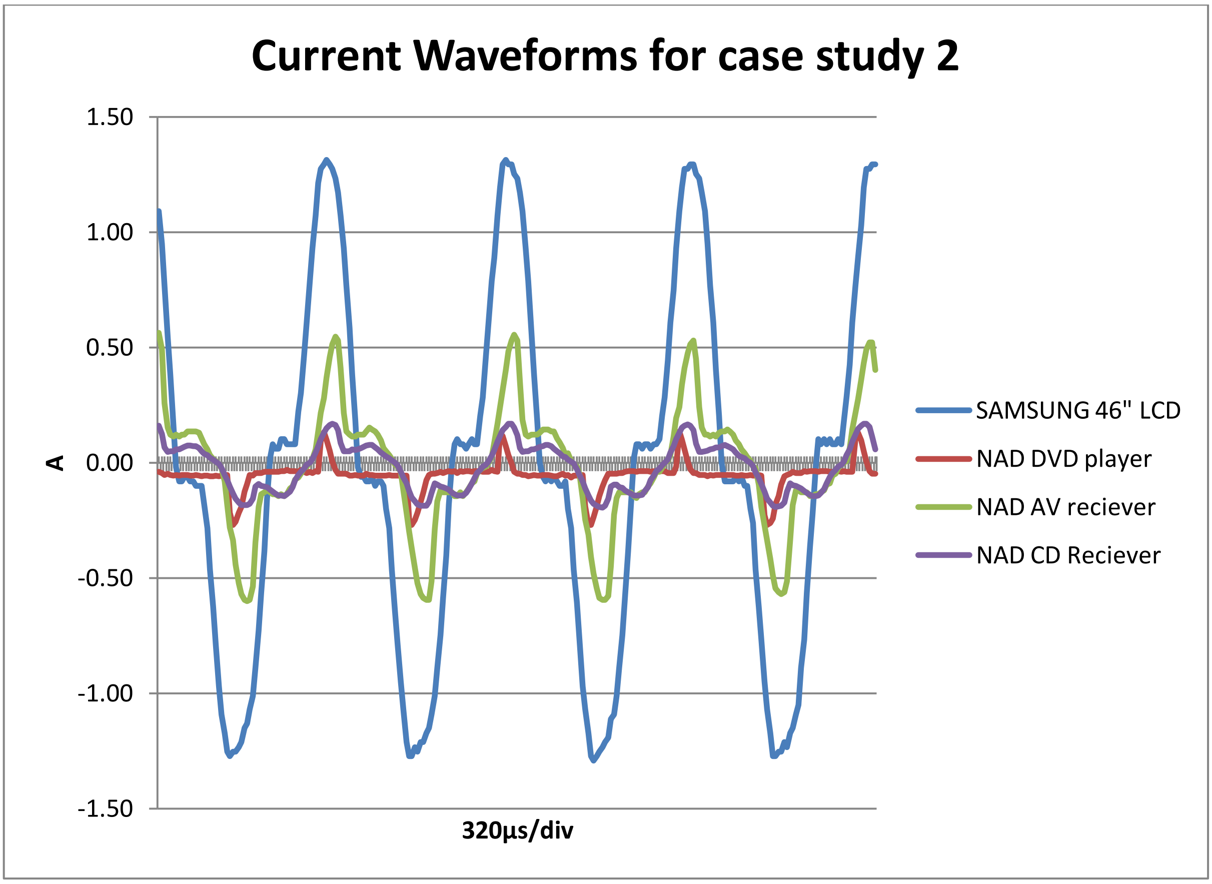


Figure 5.11: Current waveforms at locations 1, 2, 3 and 4

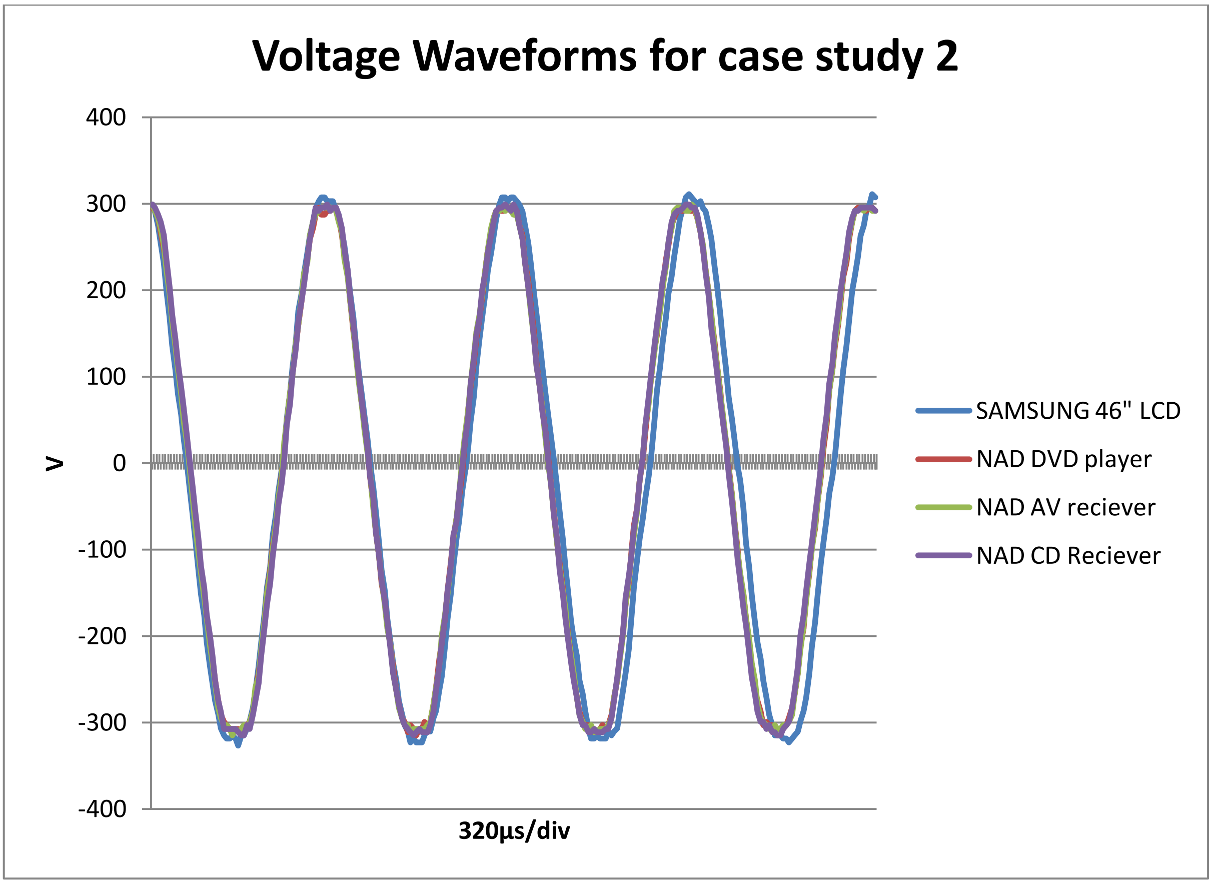


Figure 5.12: Voltage waveforms at locations 1, 2, 3 and 4

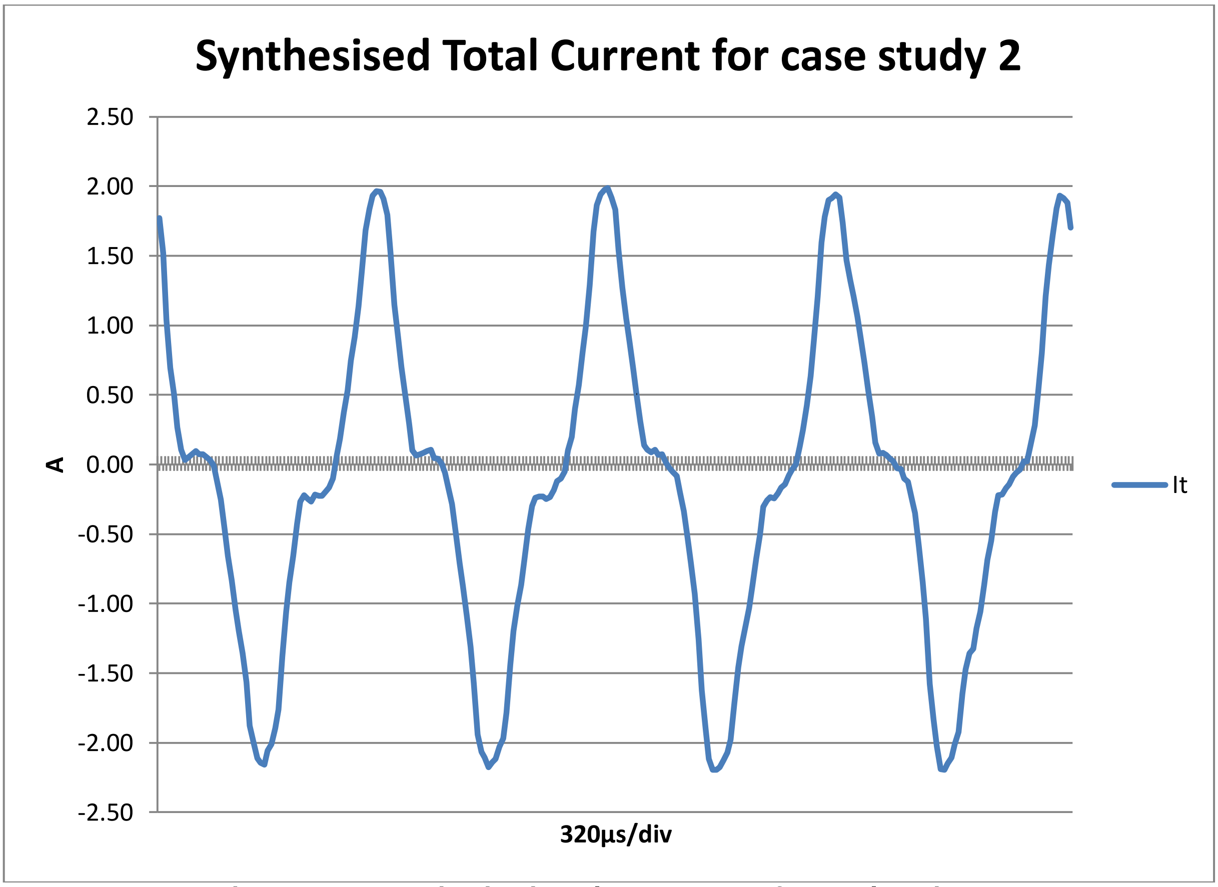


Figure 5.13: Synthesised total current waveform at location 5

Table 5.4: Results of the Fourier transform in Excel of the synthesised total current for case study two

Ampere(peak)	Percentage of fundamental	Phase Angle Ψ	Frequency	Harmonic Number
1.538816674		20.35585931	48.828125	1
0.014619263	1.0%	-178.8022684	97.65625	2
0.548918381	35.7%	72.15750069	146.484375	3
0.043213667	2.8%	93.7432354	195.3125	4
0.052914915	3.4%	41.18198303	244.140625	5
0.003685877	0.2%	53.39309164	292.96875	6
0.025568106	1.7%	-61.84593444	341.796875	7
0.0118874	0.8%	-30.96393639	390.625	8
0.023208361	1.5%	-41.49147746	439.453125	9
0.008392263	0.5%	-101.5871257	488.28125	10
0.025573881	1.7%	56.64964531	537.109375	11
0.003385408	0.2%	-166.8873986	585.9375	12
0.008735172	0.6%	4.466640218	634.765625	13
0.001107449	0.1%	163.7311156	683.59375	14
0.016476897	1.1%	-53.11663596	732.421875	15

Table 5.5: Results of the Fourier transform on one of the measured voltages from figure 5.12

Voltage(peak)	Phase Angle Ψ in degrees	Frequency	Harmonic Number
317.3097774	19.00999836	48.8	1
1.162877754	59.93849443	97.7	2
3.722450638	-83.77363566	146.5	3
0.272969134	-89.29225989	195.3	4
8.327230124	-78.81100608	244.1	5
0.436284431	-163.5063867	293.0	6
4.364294439	-77.49372912	341.8	7
0.710020049	-86.43943975	390.6	8
0.329575396	27.5533227	439.5	9
0.570256084	128.4301259	488.3	10
0.473143422	54.15764728	537.1	11
0.485038923	-142.2120287	585.9	12
0.169137341	83.29545474	634.8	13
0.191009349	-101.1366895	683.6	14
0.780121464	-40.52934447	732.4	15

5.4.1 Case Study 3

Figure 5.14 shows the connection diagram of the devices for case study 3.

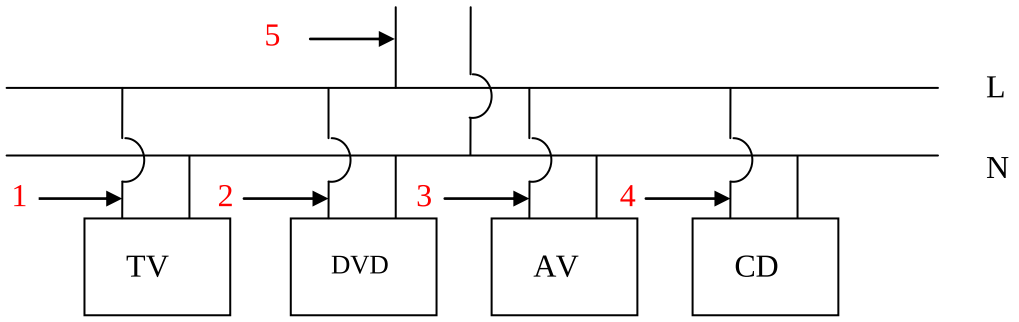


Figure 5.14: Bus view of the devices for case study 3

Figures 5.15 to 5.17, and tables 5.6 and 5.7 show the results of applying methodology A and B to the devices of case study 3.

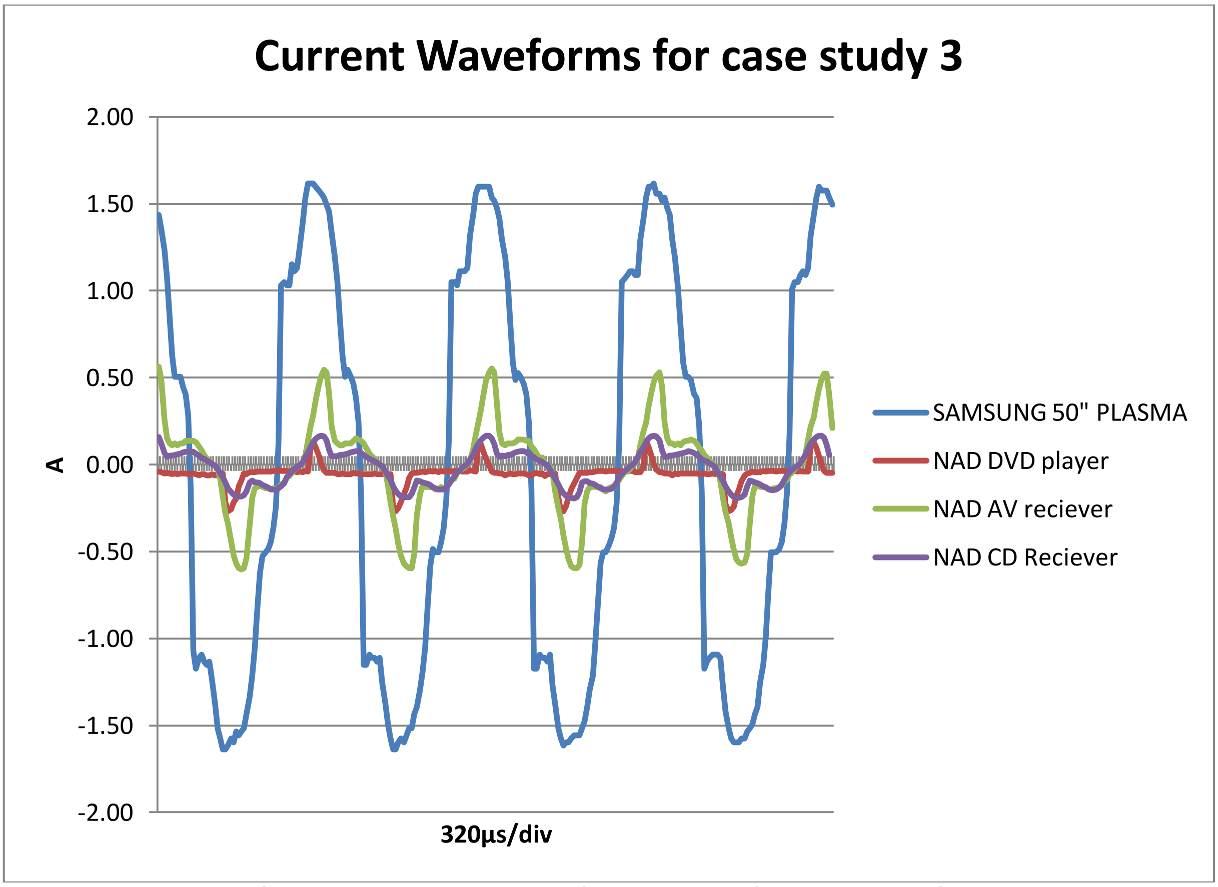


Figure 5.15: Current waveforms at locations 1, 2, 3 and 4

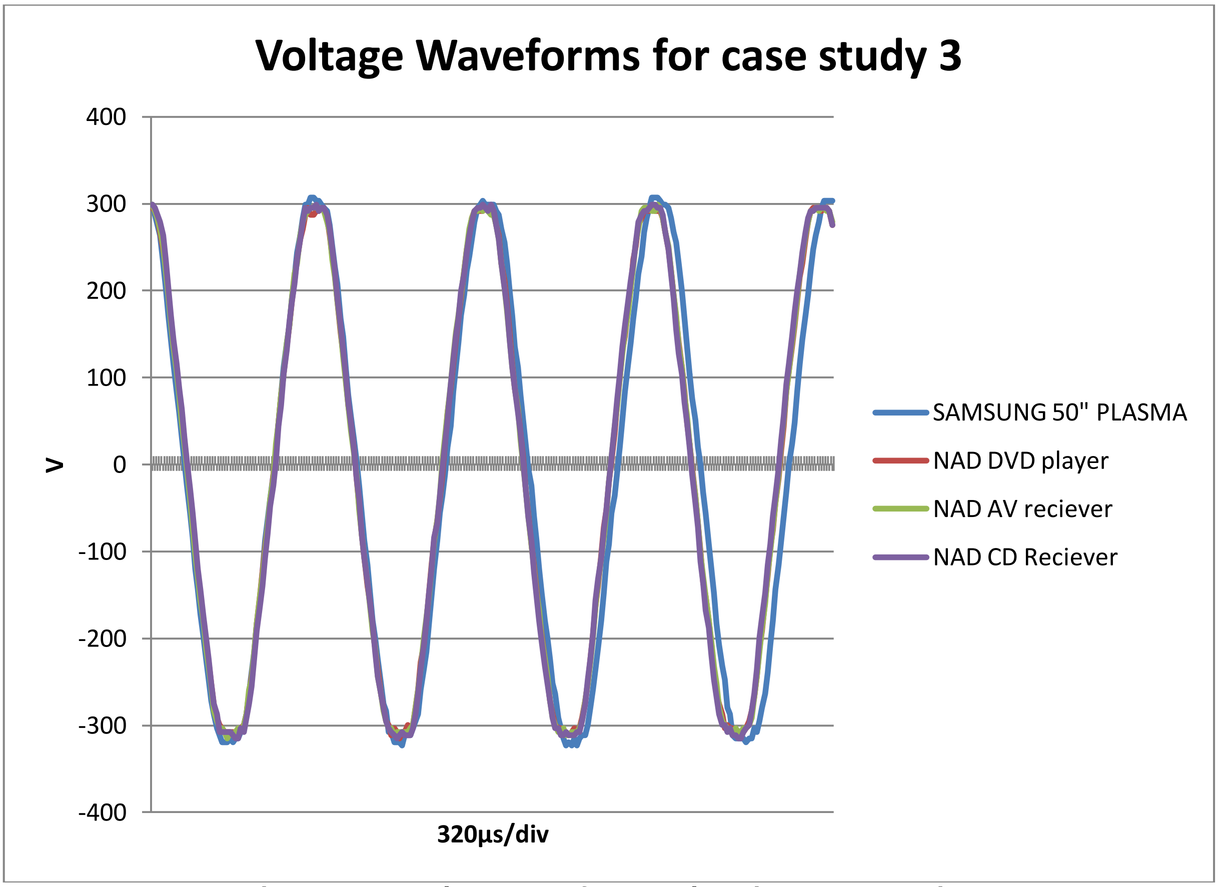


Figure 5.16: Voltage waveforms at locations 1, 2, 3 and 4

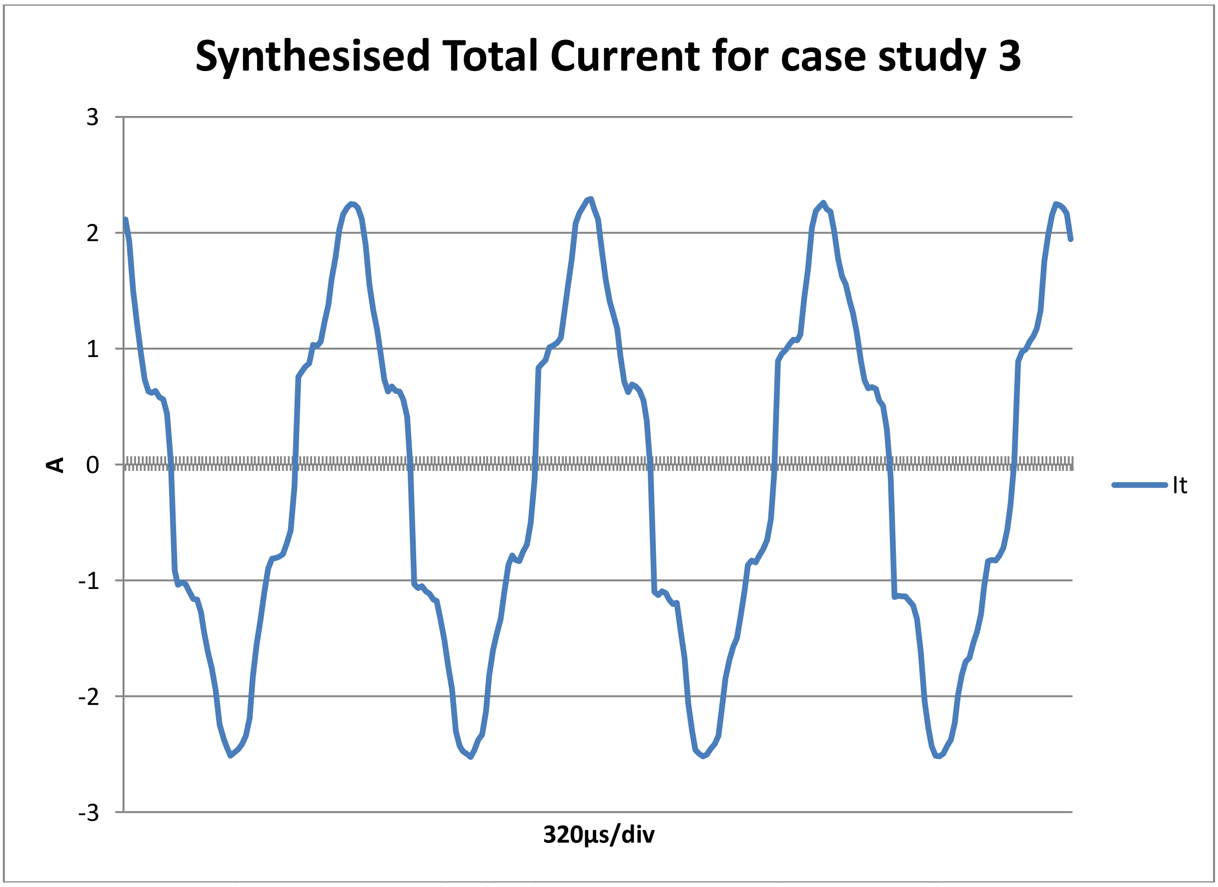


Figure 5.17: Synthesised total current waveform at location 5

Table 5.6: Results of the Fourier transform of the synthesised total current for case study three

Ampere(peak)	Percentage of fundamental	Phase Angle Ψ	Frequency	Harmonic Number
2.117082769		24.15028975	48.828125	1
0.033944826	1.6%	83.44620234	97.65625	2
0.160366477	7.6%	67.44211685	146.484375	3
0.039807042	1.9%	-118.7421556	195.3125	4
0.239768275	11.3%	94.25662025	244.140625	5
0.049674581	2.3%	105.1715063	292.96875	6
0.170254795	8.0%	-45.93429381	341.796875	7
0.05052749	2.4%	-32.19209417	390.625	8
0.056901982	2.7%	-179.4610217	439.453125	9
0.033255268	1.6%	-165.4348346	488.28125	10
0.055707677	2.6%	36.23853526	537.109375	11
0.020511483	1.0%	19.84618682	585.9375	12
0.034924757	1.6%	-105.5482797	634.765625	13
0.034509566	1.6%	-105.3901019	683.59375	14
0.031744955	1.5%	81.14550816	732.421875	15

Table 5.7: Results of the Fourier transform on one of the measured voltages from figure 5.16

Voltage(peak)	Phase Angle Ψ in degrees	Frequency	Harmonic Number
317.3097774	19.00999836	48.8	1
1.162877754	59.93849443	97.7	2
3.722450638	-83.77363566	146.5	3
0.272969134	-89.29225989	195.3	4
8.327230124	-78.81100608	244.1	5
0.436284431	-163.5063867	293.0	6
4.364294439	-77.49372912	341.8	7
0.710020049	-86.43943975	390.6	8
0.329575396	27.5533227	439.5	9
0.570256084	128.4301259	488.3	10
0.473143422	54.15764728	537.1	11
0.485038923	-142.2120287	585.9	12
0.169137341	83.29545474	634.8	13
0.191009349	-101.1366895	683.6	14
0.780121464	-40.52934447	732.4	15

5.5.1 Case Study 4

Figure 5.18 shows the connection diagram of the devices for case study 4.

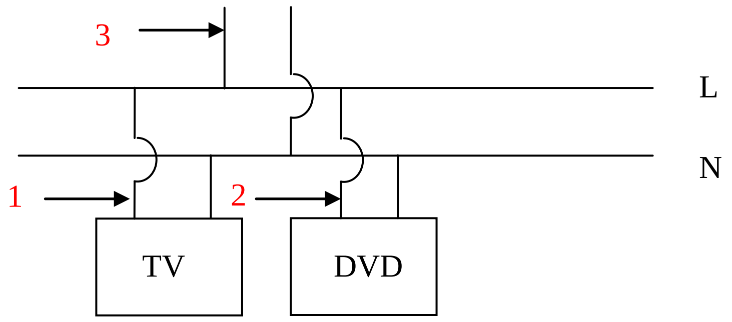


Figure 5.18: Bus view of the devices for case study 4

Figures 5.19 to 5.21, and tables 5.8 and 5.9 show the results of applying methodology A and B to the devices of case study 4.

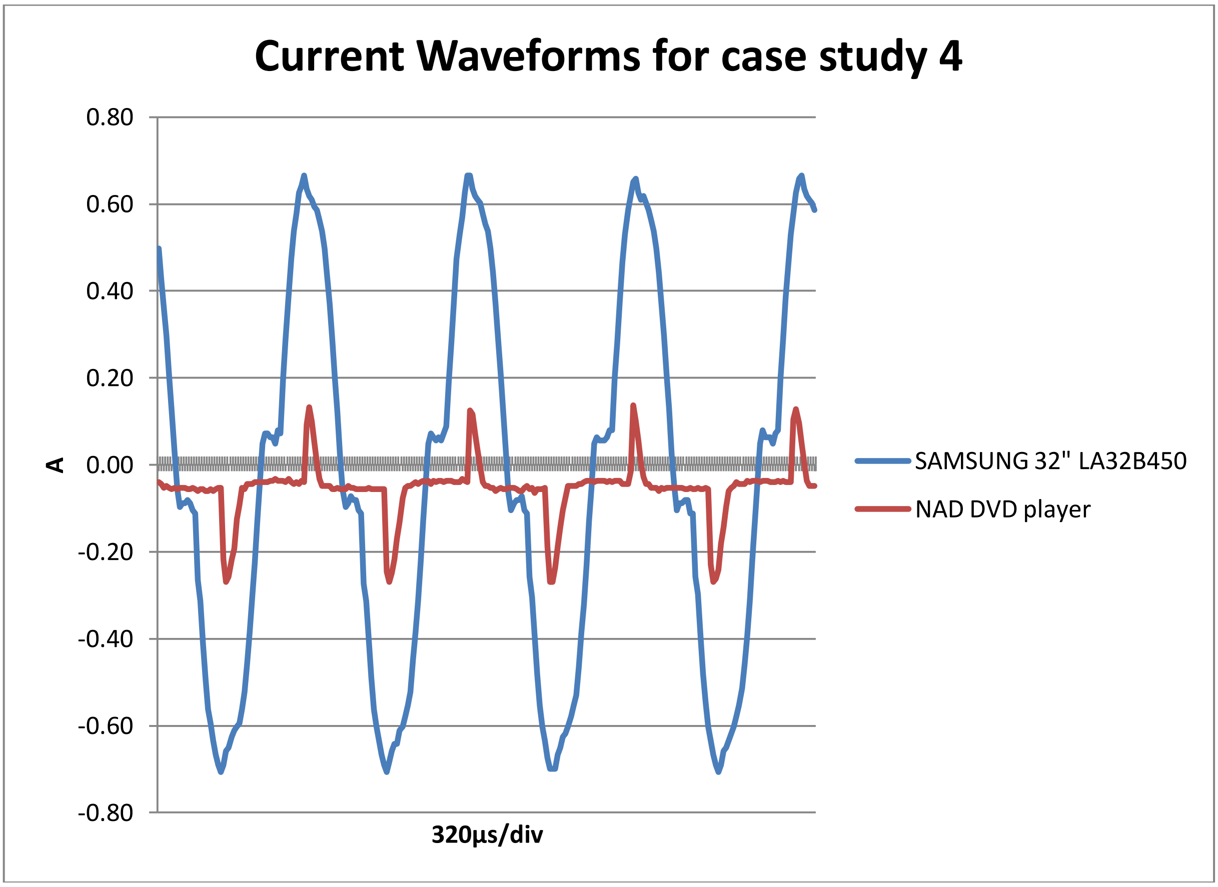


Figure 5.19: Current waveforms at locations 1 and 2

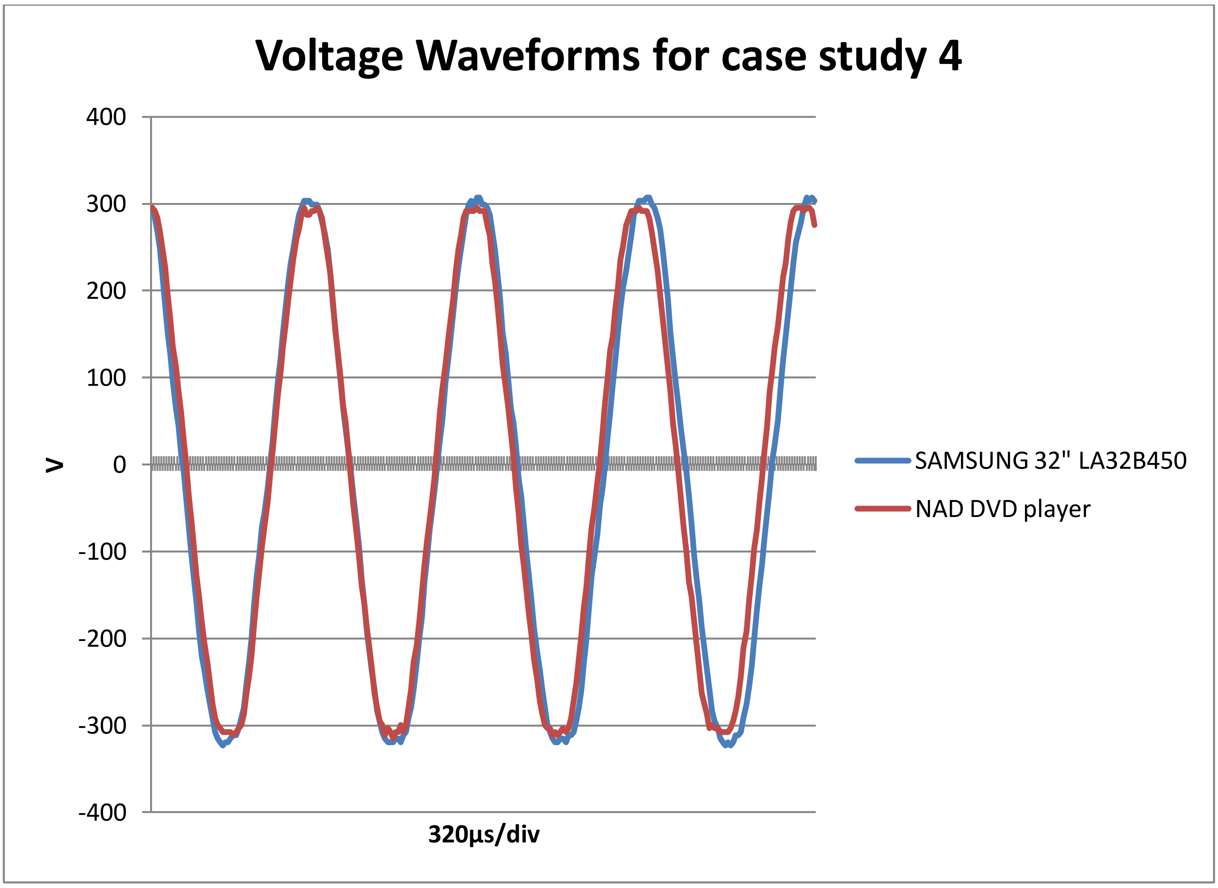


Figure 5.20: Voltage waveforms at locations 1 and 2

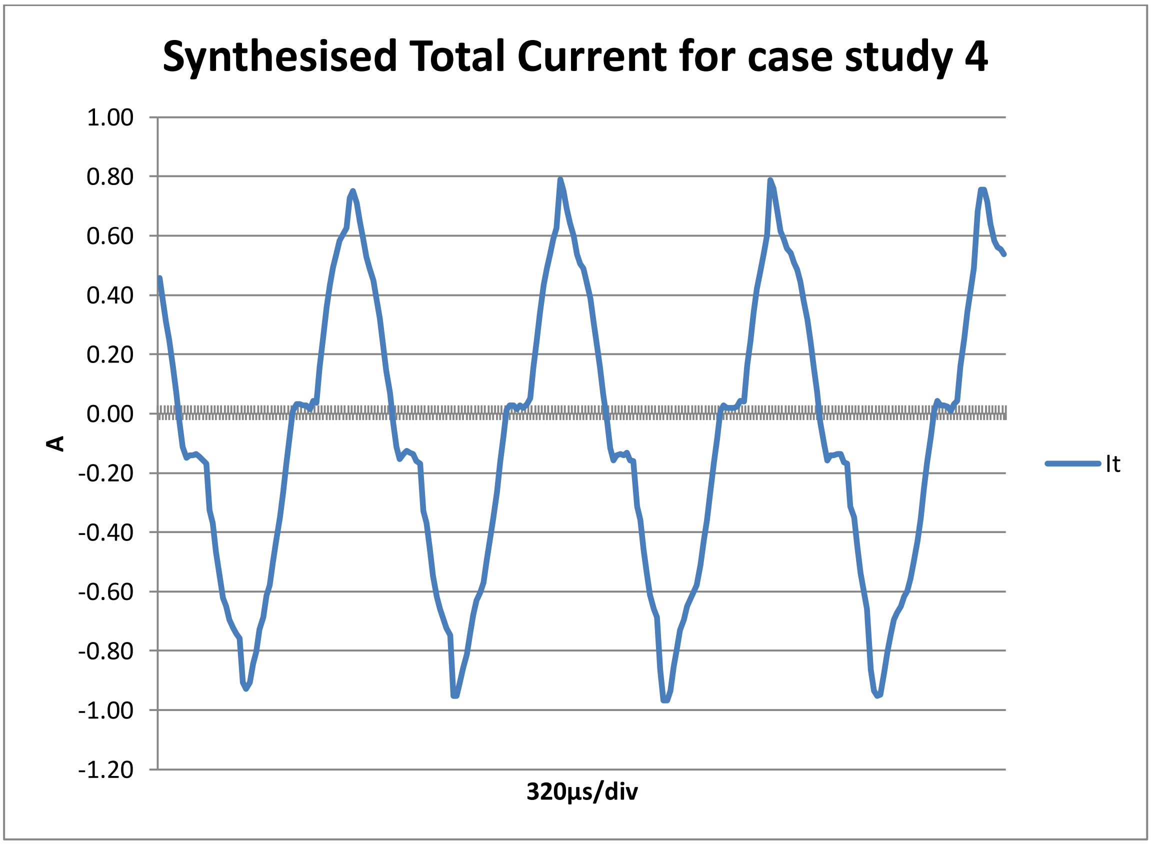


Figure 5.21: Synthesised total current waveform at location 3

Table 5.8: Results of the Fourier transform of the synthesised total current for case study four

Ampere(peak)	Percentage of fundamental	Phase Angle Ψ	Frequency	Harmonic Number
0.669475353		37.58778538	48.828125	1
0.007563973	1.1%	-130.2986626	97.65625	2
0.131894873	19.7%	96.03003354	146.484375	3
0.01239042	1.9%	156.4118792	195.3125	4
0.038728446	5.8%	-49.79144123	244.140625	5
0.019614186	2.9%	-8.630137485	292.96875	6
0.038179988	5.7%	-137.2600569	341.796875	7
0.001190494	0.2%	-145.1387909	390.625	8
0.013533055	2.0%	-33.10787245	439.453125	9
0.002738976	0.4%	77.86292873	488.28125	10
0.011158602	1.7%	57.41584759	537.109375	11
0.002432392	0.4%	-163.5210618	585.9375	12
0.002464325	0.4%	80.67070679	634.765625	13
0.005865872	0.9%	34.10600274	683.59375	14
0.006989528	1.0%	-102.6098153	732.421875	15

Table 5.9: Results of the Fourier transform on one of the measured voltages from figure 5.20

Voltage(peak)	Phase Angle Ψ in degrees	Frequency	Harmonic Number
313.5659207	19.78840719	48.8	1
1.014829895	43.48175675	97.7	2
3.489247571	-87.35664372	146.5	3
0.261179212	176.3041113	195.3	4
7.701697049	-74.9861524	244.1	5
0.798712403	-14.66199402	293.0	6
4.418114705	-65.43891144	341.8	7
0.597396965	-36.94032133	390.6	8
0.959212941	105.6953263	439.5	9
0.117782389	-166.8574123	488.3	10
0.798210742	-19.39757099	537.1	11
0.922493009	85.10627674	585.9	12
0.914663184	-84.1727559	634.8	13
0.429528572	48.81465208	683.6	14
0.459391313	-101.4383855	732.4	15

5.6 Case Study 5

Current spectra of television sets in on-mode

For the final case study, four television sets of similar screen size were chosen to be analysed. Each set used a different display technology, ie LCD, LED, Plasma or CRT. Figures 5.22 to 5.25 shows the current spectra of the selected sets as measured at the input to each of the following:

- 74cm CRT
- 42” Plasma
- 42” LCD
- 40” LED

Using the methodology of Part B, and the current measurements made on individual television sets in Part A, the current spectra of figures 5.22 to 5.25 was produced.

For each of figures 5.22 to 5.25 the y-axis represents peak current values. A summary of the THD levels for the spectra in figures 5.22 to 5.25 are presented in table 5.10. The THD figures in table 5.10 were computed in FlukeView.

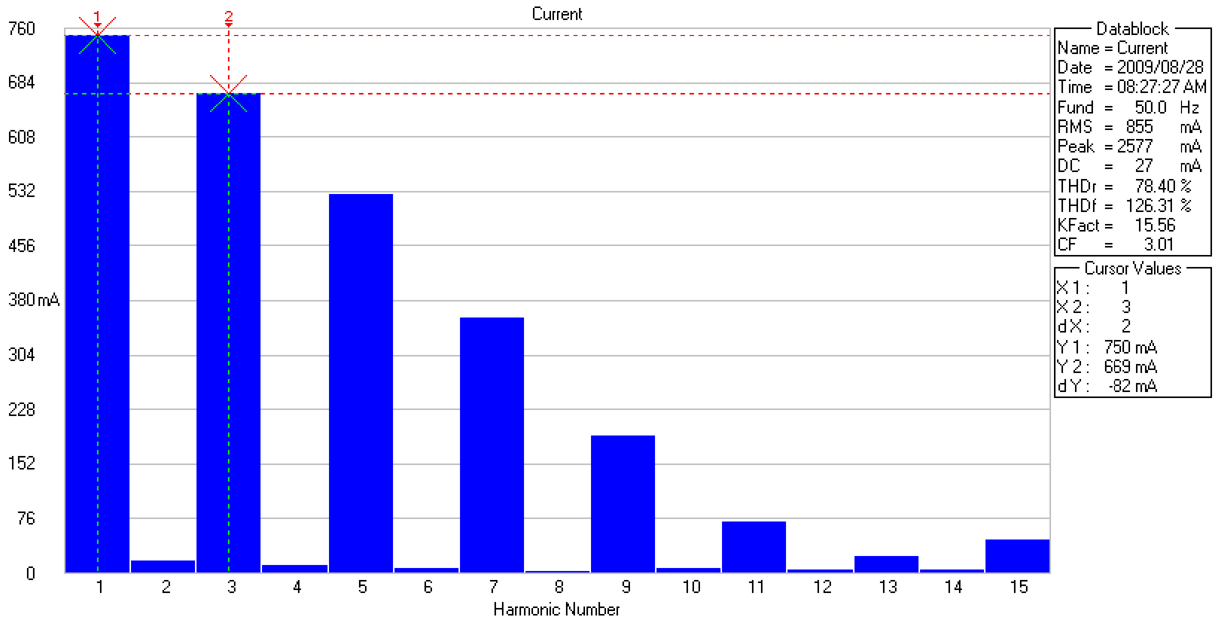


Figure 5.22: Current spectrum of 74cm CRT television

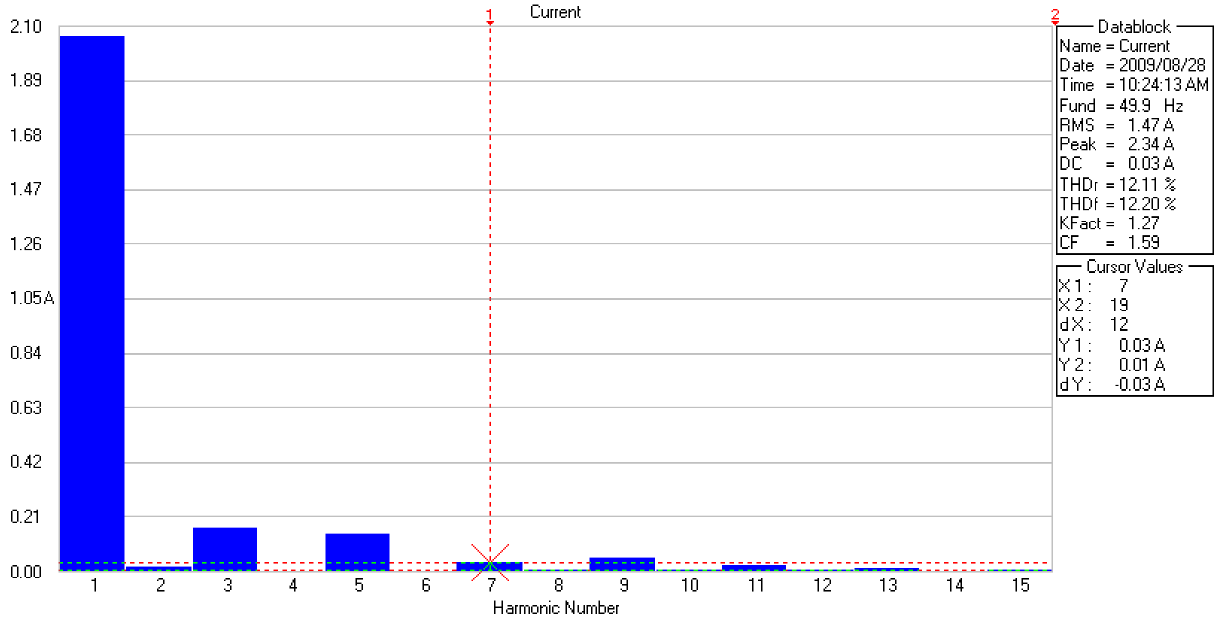


Figure 5.23: Current spectrum of 42” Plasma television

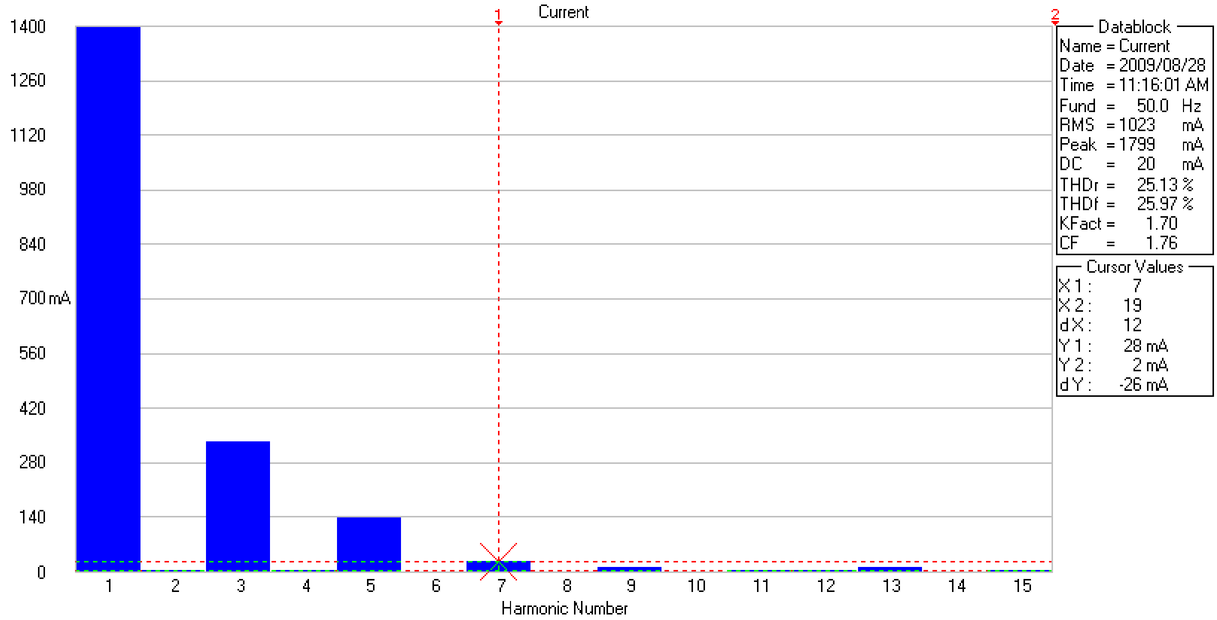


Figure 5.24: Current spectrum of 42” LCD television

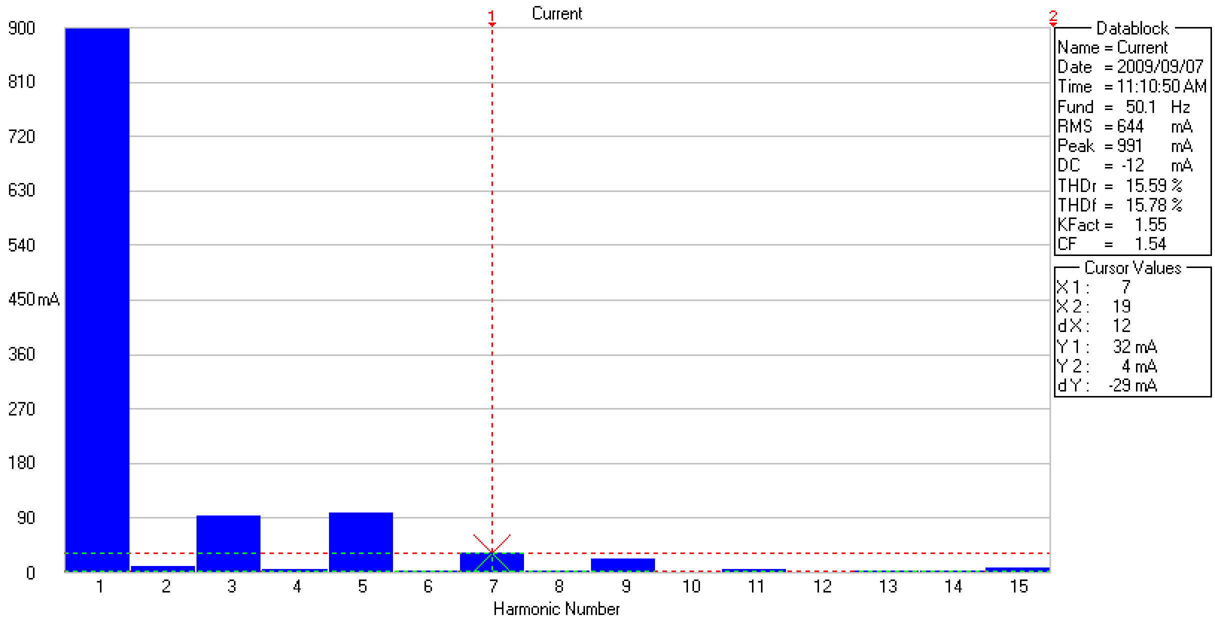


Figure 5.25: Current spectrum of 40" LED television

Table 5.10 : I_{THD} levels for different types of television set

	I_{THD}
CRT	126.31%
Plasma	12.20%
LCD	25.97%
LED	15.78%

5.7 Total Power Calculation

This section presents examples for each of the case studies showing how the total power was calculated according to the methodology of Part B, steps 9b,10b and 11b. Actual calculations were performed using Microsoft Excel.

5.7.1 Calculation Example for Case Study One

Applying Part B step 9b, the voltage and current waveforms of figures 5.3 and 5.5 can be represented by the following using the values from tables 5.2 and 5.3 respectively:

$$i = 1.32\sin(\omega t + 16.33°) + 1.017\sin(3\omega t + 63.24°) + 0.7\sin(5\omega t + 102.88°)ampere$$

$$v = 313.644\sin(\omega t + 17.23°) + 2.124\sin(3\omega t - 19.96°) + 4.787\sin(5\omega t - 96.99°)volts$$

Applying Part B, step 10b,

$$I = \sqrt{\frac{1.32^2}{2} + \frac{1.017^2}{2} + \frac{0.7^2}{2}} = 1.27A$$

And (Part B, step 10b)

$$V = \sqrt{\frac{313.644^2}{2} + \frac{2.124^2}{2} + \frac{4.787^2}{2}} = 221.8V$$

Therefore

Overall power factor$= \frac{205.45}{221.8 \times 1.27} = 0.72$

Applying Part B, step 11b,

Power at fundamental frequency $= \frac{313.644 \times 1.32}{2}\cos -0.896° = 206.9W$

Power at third harmonic $= \frac{2.124 \times 1.017}{2}\cos 83.21° = 0.127W$

Power at fifth harmonic $= \frac{4.787 \times 0.7}{2}\cos 199.87° = -1.575W$

Therefore,

Total Power $= 206.9 + 0.127 - 1.575 = 205.45W$

The overall power factor in this case cannot be stated as either lagging or leading since the circuit contains harmonics. In this case the power factor is simply the ratio of the power to the product of RMS voltage and current (Shepherd, 1998) The calculated power very closely matches the measured power as shown in figure 5.7. This serves to confirm the validity of the calculation method used. The above calculation is repeated for the data of case studies 2 to 4.

5.8 Summary

In this chapter, the methodologies of Parts A and B were applied to five case studies. Case study one served to verify the methodology used by gathering data that can be used to compare calculated and measured results. For case study one, the high degree of correlation between the measured and calculated results established confidence in the methodology used.

Case studies two, three and four combined home entertainment devices into different configurations as may be found in a console at home.

In case study 5 the harmonic distortion levels of four types of television sets were also determined.

The next chapter will present and analyse the results obtained in chapter 5.

CHAPTER SIX
ANALYSIS

6.1 Introduction

This chapter will present and analyse the results obtained in chapter 5 by applying the methodology of Part C.

6.2 Analysis of results

For a complete listing of the measurement results listed by manufacturer and model, please refer to Appendix B.

6.2.1 Power consumption of LCD, LED and Plasma television sets vs CRT based sets

Figures 6.1 represent the data of table B.1 (Appendix B) in graphical form.

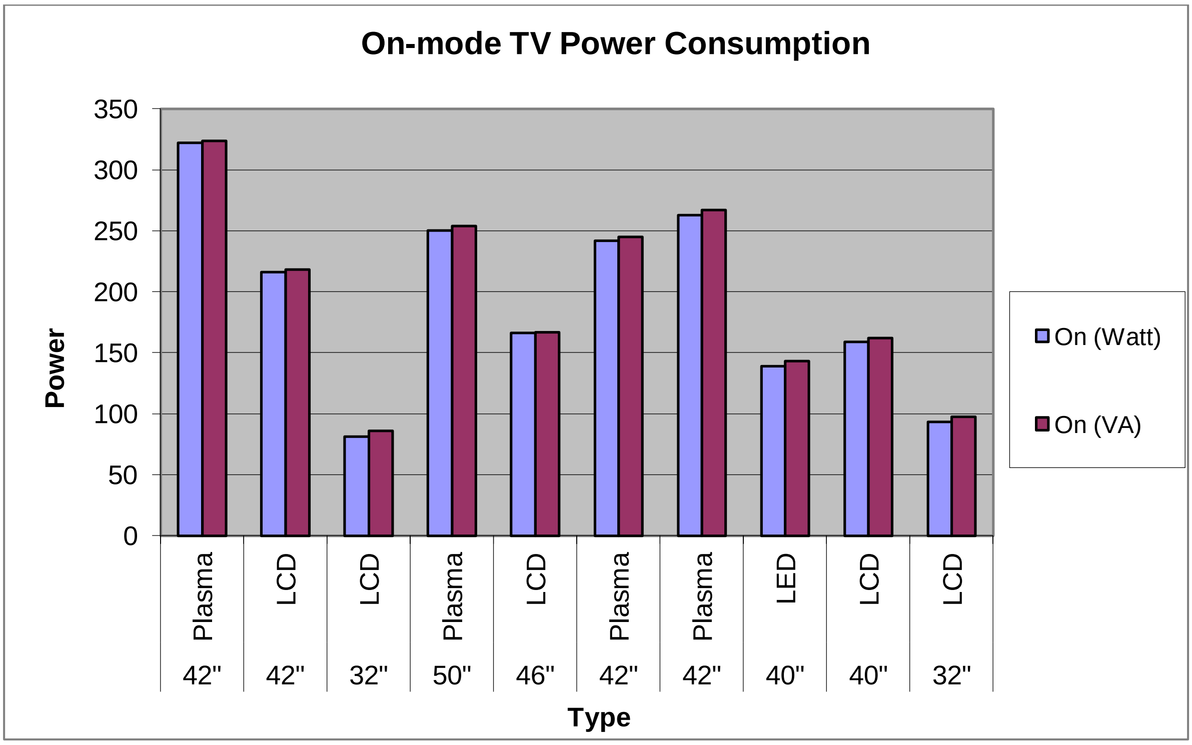


Figure 6.1: The power consumption in Watt and VA of new television sets in On-mode

From figure 6.1 it was found that the real and apparent power consumption of new LCD, LED and Plasma televisions are almost identical. This is due to the active filtering employed by modern television sets. This finding is in line with the European Norm EN61000-3-2, requiring devices consuming more than 75W to employ active filtering (McGranaghan et al, 2002:284, European Power Supply Manufacturers Association, 2010, Guidelines to the standard EN 61000-3-2).

Figure 6.2 shows the data of CRT TV set of table B.2 (Appendix B) in graphical form. Comparing figures 6.1 and 6.2, it was found that the power consumption of LCD, LED and plasma televisions are typically higher that that of older CRT based sets. The y-axis scale of figures 6.1 and 6.2 are the same.

From figure 6.1 it can be seen that the range of power consumption for 42" plasma sets are 242 to 322 Watt and for 42/40" LCD sets, 159 to 216 Watt. A 40" LED set measured used 139 Watt. It was found from figure 6.1 that LED sets use the least power for a specific screen size, followed by LCD and plasma sets. From figure 6.2 it was also found that a 74 cm CRT set still uses less power than most LCD, LED and plasma sets in figure 6.1.

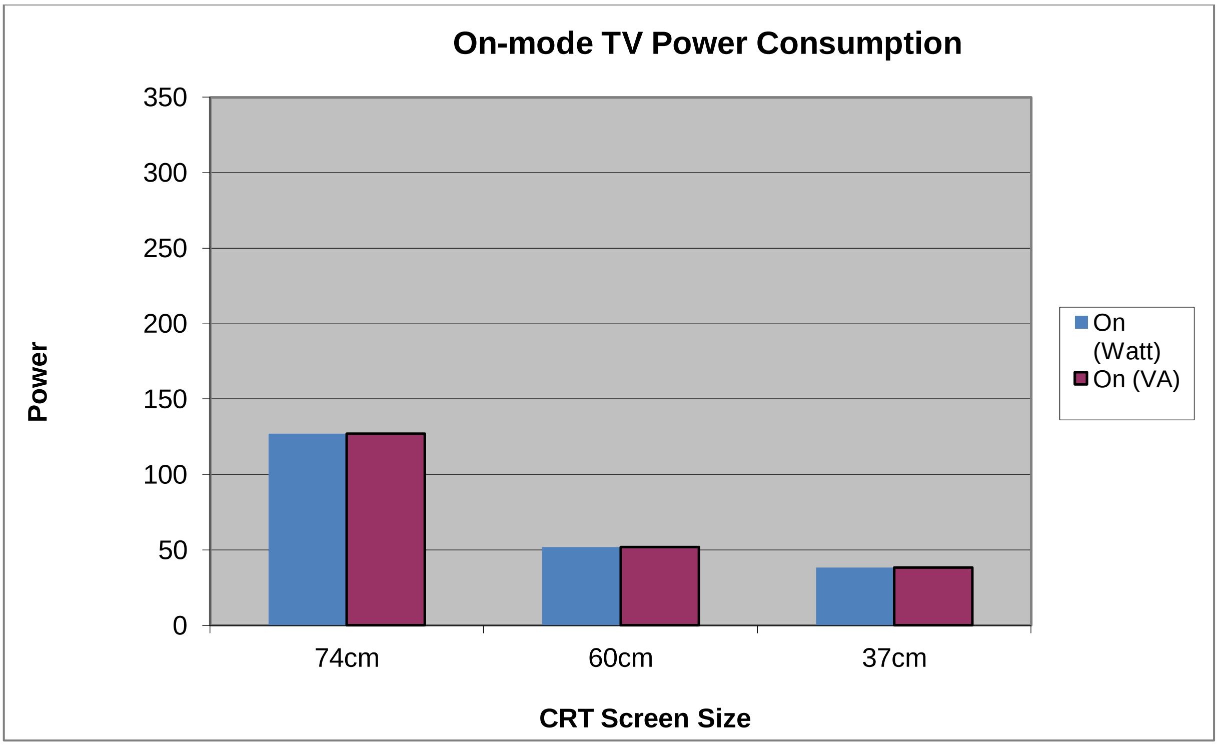


Figure 6.2: Power consumption of CRT television sets that were ten years or older in 2010

6.2.1.1 Comparison to Energy Star Standard

Section 3.2.2 table 3.1, described the Energy Star standard for television sets which set limits on the power consumption based on screen size and resolution.

Table 6.1 is an extract of table B.1 in Appendix B. Table 6.1 shows the difference between the measured power consumed by a television and that allowed by Energy Star. In cases where the set used less power than allowed by Energy Star, the difference between measured and allowed is indicated as a negative (green) number. For example, the 42" LG Plasma television consumed 322 Watts when measured.

The maximum watts allowed by the Energy Star standard are 208 Watts. The difference is thus 322 – 208 = +114 Watts. Thus this TV exceeds the Energy Star standard by 114 Watts. In a similar way the 32” LG LCD when measured consumed 81.3 Watts. The maximum allowed by the Energy Star standard for this TV is 120 Watts. It thus consumed 81.3 – 120 = -38.7 Watts and is thus within the limits set by the standard.

Table 6.1: Comparison of television power consumption to Energy Star Standard

Screen Size	TV Display Type	Maximum allowable on power consumption, Energy Star (Watt)	Real measured power (Watt)	Difference measured, on consumption minus allowed (Watt)	Complies with Energy Star Standard	
					Yes	No
50"	SAMSUNG Plasma	318	250	-68	✔	
42"	LG Plasma	208	322	+114		✔
42"	LG LCD	208	216	+8		✔
42"	SAMSUNG Plasma	208	242	+34		✔
42"	SAMSUNG Plasma	208	263	+55		✔
40”	SAMSUNG LED	Not Specified	139	--	Not Specified	
32"	LG LCD	120	81.3	-38.7	✔	
32"	SAMSUNG LCD	120	93.1	-26.9	✔	

In table 6.1 LCD sets are highlighted blue and plasma sets orange. It was found that all plasma sets, except one, used more power than that allowed for by the Energy Star standard. Plasma sets used 34 to 114 Watts more power than allowed. The one notable exception was a 50” plasma set made by Samsung which used 68 Watts less than allowed for by the standard. Given the screen size of this set it may be that the standard is still too lenient on sets of this size and set the allowed power consumption too high. Only further measurements on more 50” sets will able to determine if the limit is appropriate. Unfortunately only one 50” set was available in-store for measurement at the time.

Referring to figure 6.3, the screen of a plasma television contains thousands of tiny cells, which are each filled with a mixture of neon and xenon gas. When a voltage is applied between a display electrode and an address electrode the gas in that addressed cell is ionised. Once ionised a small current will flow through the plasma.

The ionised gas gives off UV photons which excites a phosphor coating on the inside of the cell to emit visible light. Different types of phosphor will emit red, green or blue light. By varying the pulses of current flowing through the different cells, the control system can increase or decrease the intensity of each cell to create hundreds of different combinations of red, green and blue (PlasmaTV Science, 2012. The Plasma behind the plasma TV screen). From figure 3.3 it can be seen that the power consumption of a plasma television is dependant on the APL (average picture level). This means that the brighter the image, the more power a plasma set will consume.

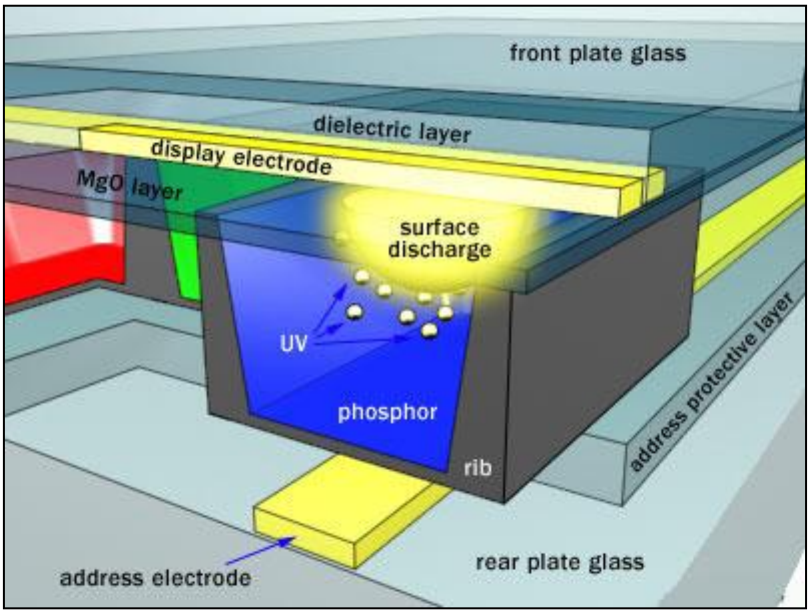


Figure 6.3: Operation of a Plasma Television (PlasmaTV Science, 2012. The Plasma behind the plasma TV screen.)

It was found that all the LCD sets measured used less power than the limit set by the standard except for one 42" set made by LG which used 8 Watts more than is allowed. According to table 6.1, the LCD television used the least power of all the 42" sets measured, however none of the 42" sets measured complied with the Energy Star limits on maximum power consumption.

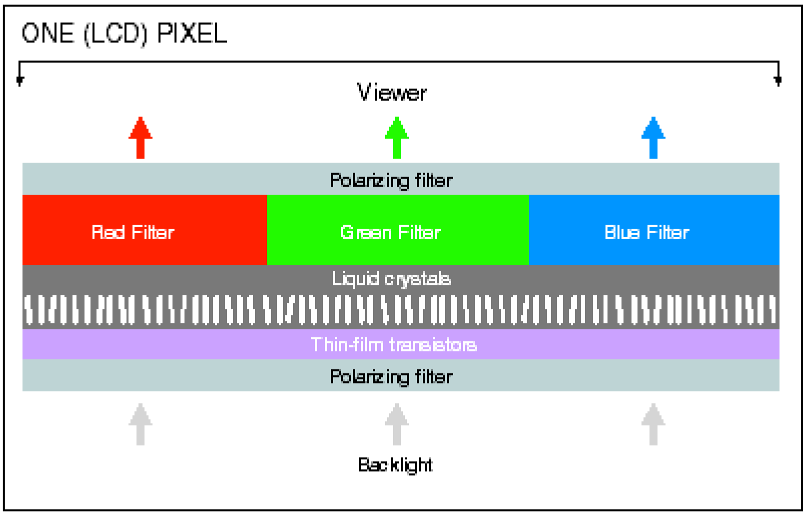


Figure 6.4: Operation of an LCD Television

(Home Theatre Systems Guru, 2011. LCD TV brings the amazing flat panel high definition experience to your home theatre)

Figure 6.4 shows one pixel from an LCD television. Liquid crystals controlled by thin-film transistors act as gates to either block or let through light from a backlight mounted behind the screen. The light let through by the liquid crystals are then sent through red, green or blue filters to create a colour picture. LCD televisions use cold cathode neon backlights (Home Theatre Systems Guru, 2011. LCD TV brings the amazing flat panel high definition experience to your home theatre). From figure 3.3 it can be seen that the power consumption of LCD televisions remain constant for different APLs. This is because the backlight remains at a fixed brightness with the liquid crystals blocking or allowing light through. The brightness of the backlight can, however, be modulated or varied as the brightness of a scene changes. This is called BLM (Back Light Modulation) and from figure 3.3 it can be seen that this technique will vary the power consumption of an LCD set as APL changes.

For the purposes of comparison an LED television was also included in table 6.1. Due to the technology being very new and therefore expensive, only one LED TV was available in-store at the time measurements was undertaken. The Energy Star standard, however, does not yet place a maximum limit on the power consumption of LED televisions.

LED televisions work in exactly the same way as LCD televisions by also utilising coloured filters and liquid crystals. The difference is that the backlight is made up of an array of white LEDs. LED backlights are more efficient than cold cathode neon backlights resulting in lower power consumption for LED televisions.

6.3 On-Mode harmonic analysis of new LED, LCD and Plasma televisions

Table 5.10 shows the I_{THD} levels for different types of television set. This section will compare the current harmonics produced by different types of sets to the limits imposed for class D equipment as described in standard EN 61000-3-2 and explained in section 3.3. Table 3.6 details the maximum permissible harmonic current per Watt as well as the absolute maximum permissible harmonic current for class D equipment.

In order to perform a comparison it is necessary to first calculate the allowed harmonic currents for a television given its power consumption by using equation 3.1. The next step is then to compare the allowed values with the actual measured values. Figure 6.5 shows the FlukeView view of the current spectrum of a television, in this case a 42" plasma set. FlukeView is set to display the current harmonic components as RMS values on the y-axis. Figure 6.6 also shows how in FlukeView the values at the cursors can be read off by progressively placing the cursors at locations 1, 2, 3, 4 and 5 and reading the RMS value for that harmonic in the margin.

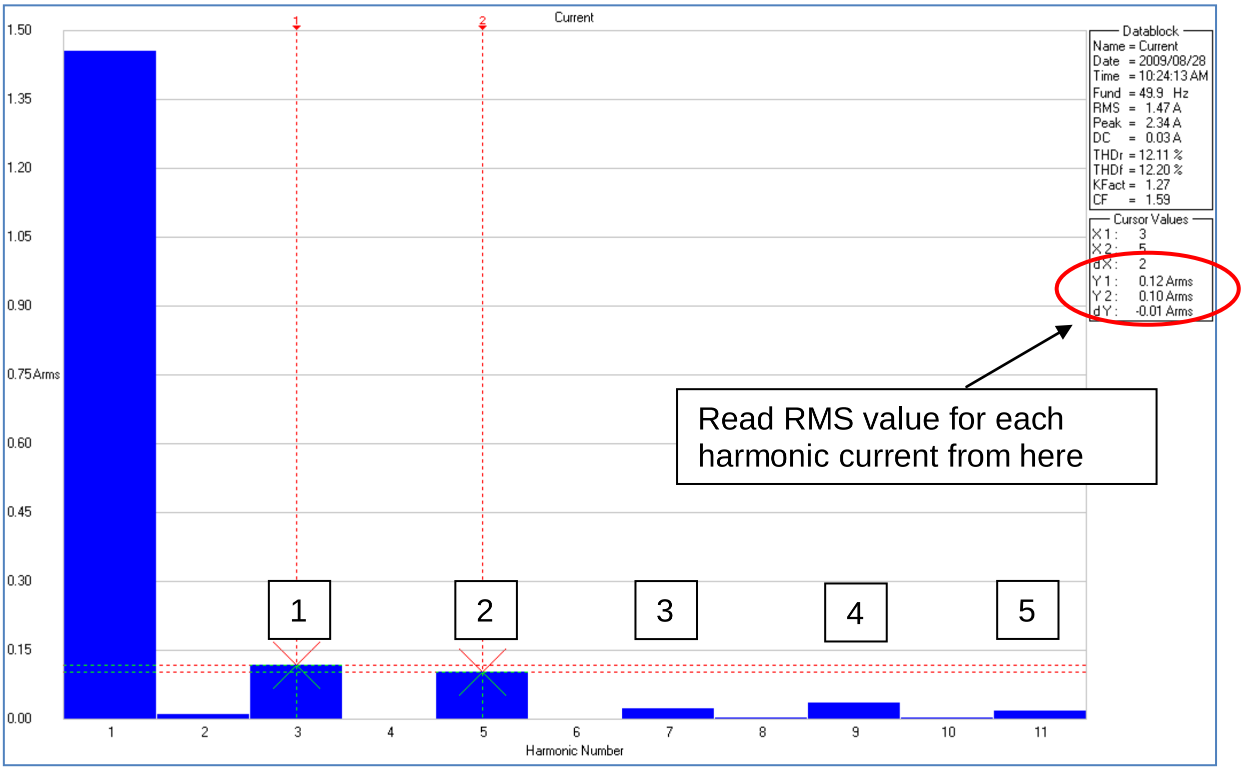


Figure 6.5: Example of FlukeView showing RMS values for the harmonic current components of a 42" Plasma television

The RMS values for harmonics 3, 5, 7, 9 and 11 are then fed into a spreadsheet for comparison with the allowed values as calculated using equation 3.1.

Table 6.2: Values for 42” Plasma Television as read from Figure 6.5

Location on Figure 6.5	Harmonic Number	Measured RMS value of current ARMS
1	3	0.12
2	5	0.10
3	7	0.02
4	9	0.04
5	11	0.02

As an example, table 6.2 lists the values of RMS current per harmonic as read from Figure 6.5. This particular set has a power consumption of 322 Watt (from Table 6.1). Applying equation 3.1 along with the maximum permissible harmonic current values from table 3.6 the values of table 6.3 can be calculated.

Table 6.3: Maximum permissible harmonic current values for a TV using 322 Watt

Harmonic Number	Allowed calculated maximum RMS value of current ARMS
3	1.095
5	0.612
7	0.322
9	0.161
11	0.113

Comparing table 6.2 and 6.3 one can see that the measured RMS harmonic current values from table 6.2 are much less than the allowed values from table 6.3. Table 6.4 shows the results of applying equation 3.1 to the harmonic current values, as read from FlukeView, and power consumption for each type of television set.

From Table 6.4 it was found that all measured LED, LCD and Plasma television sets have harmonic current levels far below that allowed by the EN 61000-3-2 standard. It can therefore be said that all LED, LCD and plasma sets measured comply with the EN61000-3-2 standard.

Finally from table 6.4 it can also be seen that the only television to have harmonic currents in excess of that allowed for by the standard was the 30” CRT set.

Table 6.4: Maximum allowed vs measured current harmonics for television sets in Ampere

Actual MEASURED (A) / ALLOWED (A)		Watt	Harmonic Order									
			3		5		7		9		11	
30”	CRT	**118**	0.401	**0.473**	0.224	**0.373**	0.118	**0.251**	0.059	**0.134**	0.041	**0.050**
32"	LCD	**81.3**	0.276	0.073	0.154	0.016	0.081	0.012	0.041	0.009	0.028	0.006
32"	LCD	**93.1**	0.317	0.062	0.177	0.049	0.093	0.009	0.047	0.004	0.033	0.003
40"	LCD	**159**	0.541	0.170	0.302	0.063	0.159	0.006	0.080	0.004	0.056	0.010
42"	LCD	**216**	0.734	0.236	0.410	0.097	0.216	0.020	0.108	0.007	0.076	0.004
46"	LCD	**166**	0.564	0.220	0.315	0.063	0.166	0.023	0.083	0.009	0.058	0.010
40"	LED	**139**	0.473	0.065	0.264	0.069	0.139	0.023	0.070	0.016	0.049	0.004
50"	Plasma	**250**	0.850	0.050	0.475	0.090	0.250	0.120	0.125	0.050	0.088	0.020
42"	Plasma	**322**	1.095	0.120	0.612	0.100	0.322	0.020	0.161	0.040	0.113	0.020
42"	Plasma	**242**	0.823	0.030	0.460	0.090	0.242	0.110	0.121	0.050	0.085	0.020
42"	Plasma	**263**	0.894	0.060	0.500	0.090	0.263	0.110	0.132	0.050	0.092	0.020

6.4 Analysis and comparison of case studies

6.4.1 Power

Table 6.5: Summary of calculated case study data

	Total I_{RMS} (A)	Power at fundamental (watt)	Power at third harmonic (watt)	Power at fifth harmonic (watt)	PF	Total Power (watt)	Power drawn by Television (watt)	TV power drawn as percentage of total power
	CALCULATED SEE SECTION 5.7.1 FOR EXAMPLE						MEASURED	
Case Study 1	1.27	206.90	0.127	-1.575	0.72	205.45	127	62%
Case Study 2	1.147	244.07	-0.932	-0.110	0.94	243.03	166	68%
Case Study 3	1.5	333.41	-0.260	-0.980	0.98	332.17	250	75%
Case Study 4	0.482	99.93	-0.229	-0.134	0.93	99.84	93.1	94%

Table 6.5 provides a summary of the results for case studies 1 to 4 conducted in chapter 5. An example of the calculations performed to obtain values under each of the headings in table 6.5 is shown in section 5.7.1. From table 6.5 it can be seen that the total calculated power for case study one is 205.45 Watt. This value agrees with the measured total power of 205 Watt in figure 5.7. This result would serve to validate the power calculation and measurement methodology used. In addition, the measured power drawn by the television for a particular case study is listed as well. For example for case study 1, the power drawn by the television as a percentage of the total power drawn by all the devices in the case study was calculated; $\frac{127}{205} \times 100\% = 62\%$

From table 6.5 it was found that the PF for case studies 2, 3 and 4 were close to one. Section 3.3.2 and table 3.7 indicated that an advantage of active harmonic line current reduction is a power factor near 1. Considering that in case studies 2, 3 and 4 the television drew the greatest percentage of the total power, the power factor could be due in most part to the active filtering employed by the television. Note that case study 1 has a power factor of 0.72 which used a CRT television with no filtering. Case studies 2, 3 and 4 all used LCD or Plasma televisions which according to table 6.4 all complied with the EN61000-3-2 standard. This is another indication that active filtering was employed on the LCD and Plasma sets.

Finally, it was found from table 6.5 and figure 6.6 that the power at the third and fifth harmonics for case studies 1 to 4 make up only a very small fraction of the total power consumed. For example for case study 1 the power at the 3rd harmonic is 0.127 Watt which is $\frac{0.127}{206} \times 100\% = 0.06\%$ of the total power, and the power at the 5th harmonic is 1.575 Watt which is $\frac{1.575}{206} \times 100\% = 0.76\%$ of the total power. From table 6.5 the calculated powers for the 3rd and 5th harmonic for case studies 1 to 4 is given in figure 6.6. From figure 6.6 it was found that the power at the third and fifth harmonics for case studies 1 to 4 are predominantly negative thus indicating that power at these harmonics are being returned to the source.

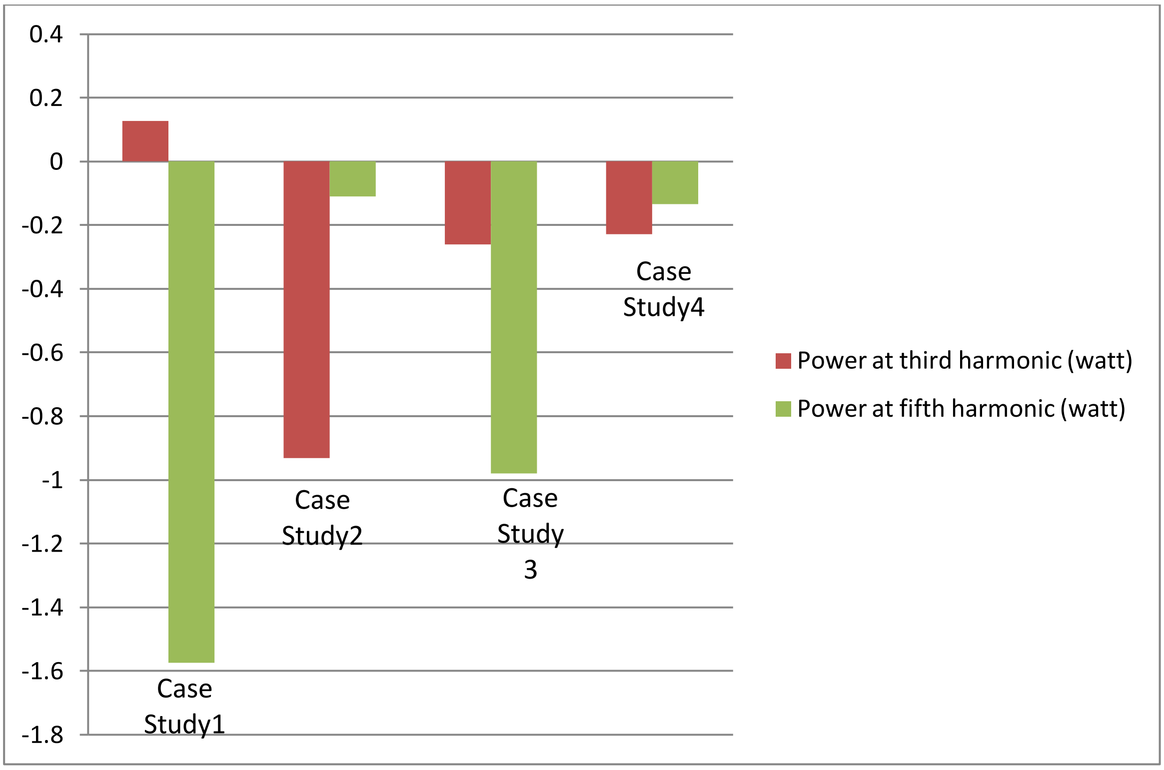


Figure 6.6: Calculated power at third and fifth harmonics for case studies 1, 2, 3 and 4

6.4.2 Harmonic Currents

In this section the current harmonics will be evaluated using calculated values from case studies 1 to 4 and comparing them to the calculated maximum allowed values under the EN 61000-3-2 standard.

Table 6.6 shows the calculated values of RMS current per harmonic for each case study in chapter 5, compared to the calculated maximum allowed for each case study given the total power consumption.

Table 6.6 list the total power consumption of all the devices for case studies 1 to 4. For each case study the maximum allowed and calculated I_{RMS} per harmonic is listed.

The maximum allowed I_{RMS} value is determined by applying equation 3.1 along with the values of table 3.6 to the total power consumed by all devices for a particular case study. Using the results from tables 5.2, 5.4, 5.6 and 5.8 and applying equation 3.1, it is possible to compile the data of table 6.6.

Table 6.6: Comparison of I_{RMS} per harmonic for case studies 1 to 4 with maximum allowed by EN 61000-3-2 for class D equipment

Harmonic Number		3		5		7	
	Total Power (W)	Maximum allowed (A)	Calculated (A)	Maximum allowed (A)	Calculated (A)	Maximum allowed (A)	Calculated (A)
Case Study 1	205.45	0.699	**0.719**	0.390	**0.502**	0.205	**0.282**
Case Study 2	243.03	0.826	0.388	0.462	0.037	0.243	0.018
Case Study 3	332.17	1.129	0.113	0.631	0.170	0.332	0.120
Case Study 4	99.84	0.339	0.093	0.190	0.027	0.100	0.027

Note though that tables 5.2, 5.4, 5.6 and 5.8 all show the peak value of the currents at the 3rd, 5th and 7th harmonics so it is necessary to divide the peak value by $\sqrt{2}$. For example from table 5.2 the peak value of the current at the 3rd harmonic for case study 1 is 1.017. Therefore I_{RMS} at 3rd harmonic; $\frac{1.017}{\sqrt{2}} = 0.719\ A$

From table 6.6 it was found that only in case study one was the harmonic currents greater than that allowed by the EN 61000-3-2 standard. This was the only case study to include a CRT TV which did not use filtering. All the remaining case studies 2 to 4 produced harmonic currents that fall below the maximum set by the standard. Case studies 2 to 4 also contained only LCD or plasma sets and all used active filtering.

6.5 Summary

In this chapter the power consumption of CRT, LCD, LED and Plasma sets are compared with each other as well as to the Energy Star standard. The harmonic currents of television sets are also compared to the EN 61000-3-2 standard.

The total power consumption of the combinations of devices described in case studies one to four is calculated and analysed.

Finally, the harmonic currents produced by the combination of devices in case studies one to four are compared to the EN 61000-3-2 standard.

CHAPTER SEVEN
CONTRIBUTIONS, CONCLUSIONS AND FUTURE WORK

7.1 General Conclusions

One of the objectives of this research was to make a contribution to the field of power quality by studying the effect that home entertainment devices have on power consumption and harmonic distortion levels. Case studies were conducted grouping devices together, as they may be found in a console at home, to determine the effect that a combination of home entertainment devices has on harmonic distortion levels. For this study the harmonics produced, and the power consumed, by devices such as televisions, DVD players and audio amplifiers were measured and compared to international limits for maximum harmonic levels and power consumption.

To perform measurements on home entertainment devices a special methodology was developed that took into account the effects of average picture level (APL) on the power consumption of television sets. The voltage and current waveforms for individual devices, as well as combinations, were measured using the specially developed methodology.

To determine the total current and voltage waveforms for a combination of devices a methodology was also developed to mathematically combine the separate current waveforms of individual devices into a single current waveform. The methodology was then expanded to also include a method of analysing the total current waveform for a group of devices to determine harmonic distortion levels and power consumption.

A methodology was also established by which the results obtained via synthesis and measurement could be compared to international standards.

The final overall methodology presented in this research contains three sections and covers measurement, analysis/synthesis and data comparison methods.

Four case studies were conducted. Case study one grouped together a CRT television, DVD player, AV receiver and DSTV PVR decoder. The voltage and current for each device as well as the combination was measured using the specially developed measurement methodology. This case study acted as a control to determine the effectiveness and accuracy of the developed methodology by comparing measured and synthesised results.

For case studies two, three and four, devices were not measured as a group but rather measured individually and then combined mathematically using the specially developed methodology. The goal was to determine whether the effect on harmonic distortion levels of a group of devices could be determined by mathematically combining measurements from individual devices.

Each case study included either a CRT, LCD or Plasma television. Only in the case of case study one, which included a CRT television, was levels of current harmonics found to be higher than that allowed by the EN 61000-3-2 standard. The higher levels of current harmonics in case study one was found to be entirely due to the CRT television.

Levels of current harmonics for case studies including an LCD or Plasma television as part of a group of devices was found to be below the maximum allowed by the EN 61000-3-2 standard.

It was also found that the evaluated LCD and Plasma television sets complied with the maximum limits on current harmonics imposed by the EN 61000-3-2 standard.

The power consumption of individual home entertainment devices was also measured. The total power consumption of a combination of devices was also calculated from individual device measurements by using the specially developed methodology.

It was found that the power consumption of LCD television sets was below the maximum imposed by the Energy Star standard. Only in one case was the power consumption of an LCD set slightly above the maximum set by the standard.

The power consumption of Plasma televisions were mostly above the maximum set by the Energy Star standard. One notable exception was a 50” Plasma set with power consumption far below the maximum set by the standard.

It was found that LCD based television sets use less power that Plasma sets of equivalent screen size. It was also found that the typical range of power consumption for a home entertainment “unit” or console was 100 to 200W.

7.2 Effectiveness of Methodology

The developed methodology proved to be effective in determining the power consumption and harmonic distortion levels of home entertainment devices. Case study one, conducted in section 5.2.1, demonstrated how the measured and calculated values for power consumption and harmonic distortion matched.

The methodology also established an easy to follow procedure that can be used by others to measure and evaluate the power consumption and harmonic distortion levels of home entertainment equipment without the need for highly specialized hardware and software.

7.3 Recommendations and Future Work

The measurements performed on television sets in section 4.2.5.2 were performed in-store placing limitations on the type of measuring equipment that could be used and also the configuration of the sets to be measured. It is recommended that future measurements on home entertainment devices be performed in a controlled laboratory environment. A clean and stable power supply, free from harmonic and frequency distortions, should be used for all measurements. When measuring television sets, standard test patterns should be used as described in sections 3.4.2 and 3.4.3. The sound volume of television sets and home theatre amplifiers should be set to a standard sound pressure level using an appropriate meter.

Additional combinations of home entertainment devices should be investigated that include game consoles and set-top boxes for digital television. Combinations including alternative display devices such as projectors and LED TVs should also be evaluated.

A larger sample of LCD, Plasma and LED television sets should be measured to more accurately establish trends for power consumption.

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APPENDIX A: CALCULATION OF POWER DUE TO HARMONICS USING EXCEL

Table A.1: Excel power calculation for case study 2

It	FFT Complex	FFT Magnitude	Phase Degrees	FFT Frequency		v(t)	FFT COMPLEX	FFT Magnitude	Phase degrees	FFT Frequency	θ	P=VI cos θ	Harmonic Number
1.7730	-14.89019	0.232659219	180	0.0	0	299.32500	-1037.66	16.2134375	180	0.0	0	1.886102851	
1.5189	2.0521149857942-1.40899552375735E-002i	0.032065052	-0.393390375	24.4	1	295.33400	1204.59970313122+190.940393571228i	19.05685546	9.006985124	24.4	-9.40038	0.301426607	
1.0395	92.3339493875391+34.2577386875579i	1.538816674	20.35585931	48.8	2	287.35200	19200.2724361822+6614.93198089358i	317.3097774	19.00999836	48.8	1.345861	244.0734368	1
0.6966	-0.776542855539145+0.518972202333294i	0.014593708	146.2447538	73.2	3	279.37000	-752.061100868407-417.752829476577i	13.4421624	-150.9488246	73.2	297.1936	0.044824899	
0.5027	-0.935428406271133-1.95573813531458E-002i	0.014619263	-178.8022684	97.7	4	263.40600	37.2812555715501+64.4132439043125i	1.162877754	59.93849443	97.7	-238.741	-0.004410852	2
0.2683	0.742426144560474+1.72907329146269i	0.029401962	66.7623756	122.1	5	235.46900	-152.295069441183-228.372496067963i	4.288992347	-123.6981849	122.1	190.4606	-0.062004471	
0.1045	10.7641213574109+33.4410696392065i	0.548918381	72.15750069	146.5	6	203.54100	25.8384047806962-236.831520622388i	3.722450638	-83.77363566	146.5	155.9311	-0.932833453	3
0.0338	-0.365095778290489-1.64147595038536i	0.026274813	-102.5395625	170.9	7	171.61300	-37.8095784394387-57.1634221276256i	1.070879304	-123.4818293	170.9	20.94227	0.013139221	
0.0499	-0.180557948488277+2.75977449983608i	0.043213667	93.7432354	195.3	8	143.67600	0.215791157634822-17.4686917614632i	0.272969134	-89.29225989	195.3	183.0355	-0.005889723	4
0.0762	-0.184521356115456+0.774733045530548i	0.012443813	103.3967744	219.7	9	115.73900	2.29551924031105-184.462414686445i	2.882448395	-89.28702671	219.7	192.6838	-0.017496668	
0.0983	2.54879548017643+2.22988643411541i	0.052914915	41.18198303	244.1	10	87.80200	103.415358622173-522.812791426469i	8.327230124	-78.81100608	244.1	119.993	-0.110135321	5
0.0741	0.372370102235559-2.09442714057403i	0.033238619	-79.91867278	268.6	11	63.85600	-54.3806080409063+61.8342538680034i	1.286643135	131.3302601	268.6	-211.249	-0.01828089	
0.0720	0.140669980368927+0.189364584367309i	0.003685877	53.39309164	293.0	12	31.92800	-26.7732436619093-7.92734995634624i	0.436284431	-163.5063867	293.0	216.8995	-0.000642987	6
0.0559	0.164258688193327-0.991096469665546i	0.015697124	-80.58966203	317.4	13	3.99100	-24.3600644563819-81.3151546566553i	1.326337687	-106.6769513	317.4	26.08729	0.009349342	
0.0337	0.772106178831254-1.44274810626676i	0.025568106	-61.84593444	341.8	14	-27.93700	60.484642334244-272.687348744769i	4.364294439	-77.49372912	341.8	15.64779	0.053725552	7
-0.0065	0.728860824025927-0.699095040439839i	0.01578026	-43.80584067	366.2	15	-55.87400	-46.1699191527762+47.4820674697761i	1.034819599	134.1972873	366.2	-178.003	-0.008159903	
-0.1196	0.652373909423831-0.391427130734152i	0.0118874	-30.96393639	390.6	16	-87.80200	2.82206316371566-45.3535684734395i	0.710020049	-86.43943975	390.6	55.4755	0.002391804	8
-0.2508	1.38494630258377-0.73760031610261i	0.024517465	-28.03905309	415.0	17	-119.73000	-49.5399385028493+60.35831921984i	1.220084626	129.3779189	415.0	-157.417	-0.013809872	
-0.4709	1.11259659531762-0.984047322259791i	0.023208361	-41.49147746	439.5	18	-143.67600	18.7004922621179+9.75699080716045i	0.329575396	27.5533227	439.5	-69.0448	0.001367769	9
-0.6568	-0.454901006376822-0.457135029619207i	0.0100767	-134.8596548	463.9	19	-175.60400	-5.91511451682646+5.83498982835012i	0.129824557	135.3906974	463.9	-270.25	2.85807E-06	
-0.8326	-0.10788170113029-0.526158865884505i	0.008392263	-101.5871257	488.3	20	-199.55000	-22.6846869207836+28.5900579756549i	0.570256084	128.4301259	488.3	-230.017	-0.001537555	10
-1.0447	1.03337607482922-0.413779549906294i	0.017392805	-21.82191746	512.7	21	-223.49600	-66.8505137486902-35.2442522904122i	1.180814704	-152.2013582	512.7	130.3794	-0.006652633	
-1.1962	0.899803132994687+1.36719934196565i	0.025573881	56.64964531	537.1	22	-251.43300	17.731357806023+24.5468684581557i	0.473143422	54.15764728	537.1	2.491998	0.006044335	11
-1.3576	-0.288833089349957-0.734966201134447i	0.012338803	-111.4542441	561.5	23	-275.37900	52.8881825154437+37.3955651393693i	1.012083747	35.26292544	561.5	-146.717	-0.005219767	
-1.5650	-0.211016758744862-4.91540639920748E-002i	0.003385408	-166.8873986	585.9	24	-287.35200	-24.5323737504092-19.0210118256517i	0.485038923	-142.2120287	585.9	-24.6754	0.000746057	12
-1.8748	0.207535931034876-0.412390081203091i	0.007213552	-63.28610451	610.4	25	-307.30700	7.8062952805213+13.9080640779388i	0.249204051	60.69544571	610.4	-123.982	-0.000502376	
-1.9954	0.557353103185686+4.35381332597151E-002i	0.008735172	4.466640218	634.8	26	-307.30700	1.26378906545043+10.7507633045571i	0.169137341	83.29545474	634.8	-78.8288	0.000143121	13
-2.1099	7.7753750274167E-002-0.984098096054111i	0.015424453	-85.48243602	659.2	27	-307.30700	34.8280247358122+5.85792253783209i	0.551831681	9.547538072	659.2	-95.03	-0.00037314	
-2.1459	-6.80386406877255E-002+1.98557879132129E-002i	0.001107449	163.7311156	683.6	28	-307.30700	-2.361184837236-11.9943991144493i	0.191009349	-101.1366895	683.6	264.8678	-0.0000946	14
-2.1598	0.478140291215706-0.949263074434186i	0.016607534	-63.26577387	708.0	29	-307.30700	-26.0777956385415+20.836426223837i	0.521558681	141.3747865	708.0	-204.641	-0.003936535	
-2.0549	0.632911107509259-0.843468398055855i	0.016476897	-53.11663596	732.4	30	-311.29800	37.9487650091068-32.4449351799494i	0.780121464	-40.52934447	732.4	-12.5873	0.006272519	15
-2.0105											**TOTAL**	**245.2070782**	

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a b

Table A.2: Excel power calculation for case study 3

It	FFT Complex	FFT Magnitude	Phase Degrees	FFT Frequency		v(t)	FFT COMPLEX	FFT Magnitude	Phase degrees	FFT Frequency	θ	P=VI cos θ	Harmonic Number
2.12	-17.27556	0.269930625	180	0.0	0	2.99E+02	-1037.66	16.2134375	180	0.0	0		
1.92	2.39605192475384+0.563722458468384i	0.038460511	13.23928583	24.4	1	2.95E+02	1204.59970313122+190.940393571228i	19.05685546	9.006985124	24.4	4.232300708		
1.50	123.634303994037+55.4345782772576i	2.117082769	24.15028975	48.8	2	2.87E+02	19200.2724361822+6614.93198089358i	317.3097774	19.00999836	48.8	5.140291388	334.5347026	1
1.22	-0.945045156744422+0.146238729400905i	0.014942077	171.2036704	73.2	3	2.79E+02	-752.061100868407-417.752829476577i	13.4421624	-150.9488246	73.2	322.152495	0.079301765	
0.97	0.247957068577085+2.1582720612353i	0.033944826	83.44620234	97.7	4	2.63E+02	37.2812555715501+64.4132439043125i	1.162877754	59.93849443	97.7	23.50770791	0.01809881	2
0.73	0.63060099437428+1.7693258337385 8i	0.029349106	70.38355142	122.1	5	2.35E+02	-152.295069441183-228.372496067963i	4.288992347	-123.6981849	122.1	194.0817363	-0.061047703	
0.63	3.93723140702255+9.47822282164076i	0.160366477	67.44211685	146.5	6	2.04E+02	25.8384047806962-236.831520622388i	3.722450638	-83.77363566	146.5	151.2157525	-0.261597918	3
0.62	-0.628151310627338-1.94820433072724i	0.03198386	-107.8706597	170.9	7	1.72E+02	-37.8095784394387-57.1634221276256i	1.070879304	-123.4818293	170.9	15.61116964	0.016493672	
0.64	-1.22508555437278-2.23376126700329i	0.039807042	-118.7421556	195.3	8	1.44E+02	0.215791157634822-17.4686917614632i	0.272969134	-89.29225989	195.3	-29.44989575	0.004731021	4
0.58	0.119184004555073+0.888058090510214i	0.014000314	82.35615436	219.7	9	1.16E+02	2.29551924031105-184.462414686445i	2.882448395	-89.28702671	219.7	171.6431811	-0.019963348	
0.56	-1.13897552986221+15.3028417516993i	0.239768275	94.25662025	244.1	10	8.78E+01	103.415358622173-522.812791426469i	8.327230124	-78.81100608	244.1	173.0676263	-0.991004514	5
0.44	0.416626277942998-2.42670798492083i	0.038472066	-80.25821992	268.6	11	6.39E+01	-54.3806080409063+61.8342538680034i	1.286643135	131.3302601	268.6	-211.5884801	-0.021082772	
0.01	-0.832018986768991+3.06836872119229i	0.049674581	105.1715063	293.0	12	3.19E+01	-26.7732436619093-7.92734995634624i	0.436284431	-163.5063867	293.0	268.677893	-0.000250023	6
-0.91	0.240388510898533-1.22477552731362i	0.019502239	-78.89562577	317.4	13	3.99E+00	-24.3600644563819-81.3151546566553i	1.326337687	-106.6769513	317.4	27.78132554	0.011442497	
-1.04	7.57819451625254-7.82946178487282i	0.170254795	-45.93429381	341.8	14	-2.79E+01	60.484642334244-272.687348744769i	4.364294439	-77.49372912	341.8	31.55943531	0.316572212	7
-1.02	0.471135556731791-0.787187134451542i	0.014334456	-59.09926176	366.2	15	-5.59E+01	-46.1699191527762+47.4820674697761i	1.034819599	134.1972873	366.2	-193.296549	-0.007217964	
-1.03	2.73662281386715-1.72281605368735i	0.05052749	-32.19209417	390.6	16	-8.78E+01	2.82206316371566-45.3535684734395i	0.710020049	-86.43943975	390.6	54.24734557	0.010480808	8
-1.10	0.824287904681015-0.389112368846804i	0.014242417	-25.27006617	415.0	17	-1.20E+02	-49.5399385028493+60.35831921984i	1.220084626	129.3779189	415.0	-154.647985	-0.007851726	
-1.16	-3.641565705297-3.42570234899234E-002i	0.056901982	-179.4610217	439.5	18	-1.44E+02	18.7004922621179+9.75699080716045i	0.329575396	27.5533227	439.5	-207.0143444	-0.008353676	9
-1.16	-0.394071797278 45-0.631651603325249i	0.011632771	-121.9590181	463.9	19	-1.76E+02	-5.91511451682646+5.83498982835012i	0.129824557	135.3906974	463.9	-257.3497155	-0.000165369	
-1.28	-2.05993718447709-0.53523628448402i	0.033255268	-165.4348346	488.3	20	-2.00E+02	-22.6846869207836+28.5900579756549i	0.570256084	128.4301259	488.3	-293.8649605	0.003836254	10
-1.45	0.683913865684139-0.325536664831736i	0.011834968	-25.4540155	512.7	21	-2.23E+02	-66.8505137486902-35.2442522904122i	1.180814704	-152.2013582	512.7	126.7473427	-0.004180505	
-1.62	2.87563173885893+2.10761579623295i	0.055707677	36.23853526	537.1	22	-2.51E+02	17.731357806023+24.5468684581557i	0.473143422	54.15764728	537.1	-17.91911202	0.01253957 8	11
-1.76	-0.502083152906345-1.26414908295856i	0.021253219	-111.6615328	561.5	23	-2.75E+02	52.8881825154437+37.3955651393693i	1.012083747	35.26292544	561.5	-146.9244583	-0.009012187	
-1.95	1.234768175772+0.445668600160711i	0.020511483	19.84618682	585.9	24	-2.87E+02	-24.5323737504092-19.0210118256517i	0.485038923	-142.2120287	585.9	162.0582155	-0.004732527	12
-2.24	0.519497895440313-0.66042910169267i	0.013129135	-51.8111759	610.4	25	-3.07E+02	7.8062952805213+13.9080640779388i	0.249204051	60.69544571	610.4	-112.5066216	-0.00062621 3	
-2.36	-0.599141808817812-2.15338771776234i	0.034924757	-105.5482797	634.8	26	-3.07E+02	1.26378906545043+10.7507633045571i	0.169137341	83.29545474	634.8	-188.8437345	-0.002918427	13
-2.43	4.69146873814047E-003-0.718012579892861i	0.011219186	-89.62563674	659.2	27	-3.07E+02	34.8280247358122+5.85792253783209i	0.551831681	9.547538072	659.2	-99.17317481	-0.00049349	
-2.51	-0.586142628394419-2.12941417797443i	0.034509566	-105.3901019	683.6	28	-3.07E+02	-2.361184837236-11.9943991144493i	0.191009349	-101.1366895	683.6	-4.253412396	0.003286747	14
-2.48	0.240193719073403-0.758804284305512i	0.012436135	-72.43521321	708.0	29	-3.07E+02	-26.0777956385415+20.836426223837i	0.521558681	141.3747865	708.0	-213.8099997	-0.00269464	
-2.46	0.312727188199497+2.00746447938922i	0.031744955	81.14550816	732.4	30	-3.11E+02	37.9487650091068-32.4449351799494i	0.780121464	-40.52934447	732.4	121.6748526	-0.006502007	15
-2.41	0.207033293717507-0.405209151903638i	0.007109929	-62.93617241	756.8	31	-3.15E+02	-13.7280774090494+16.9386300795923i	0.3406742	129.0233739	756.8	-191.9595463	-0.001184797	
-2.34	-0.709346999999997+1.970225i	0.032719212	109.8005755	781.3	32	-3.15E+02	43.901-11.9729999999997i	0.711006269	-15.2551187	781.3	125.0556942	-0.006680975	
											TOTAL	333.5939252	

Table A.3: Excel power calculation for case study 4

It	FFT Complex	FFT Magnitude	Phase Degrees	FFT Frequency	v(t)	FFT COMPLEX	FFT Magnitude	Phase degrees	FFT Frequency	θ	P=VI cos θ	Harmonic Number
0.46	-11.076817	0.173075266	180	0.0	2.95E+02	-1077.57	16.83703125	180	0.0	0	1.457036828	
0.38	-2.3928274547521E-002+8.35149953490184E-002i	0.001357426	105.9877866	24.4	2.91E+02	1087.4212967882+144.409250331441i	17.14012725	7.564601861	24.4	98.42318472	-0.001704074	
0.31	33.9523493268821+26.1352999968069i	0.669475353	37.58778538	48.8	2.83E+02	18883.1762972336+6794.04619649924i	313.5659207	19.78840719	48.8	17.79937819	99.93806562	**1**
0.25	-0.170950864931918-0.118562175134648i	0.003250646	-145.2569379	73.2	2.67E+02	-595.50762670727-367.731014338249i	10.9358864	-148.3043178	73.2	3.047379893	0.017749211	
0.16	-0.313098626710909-0.369210698067076i	0.007563973	-130.2986626	97.7	2.47E+02	47.1266550314025+44.6930162091962i	1.014829895	43.48175675	97.7	-173.7804194	-0.003815482	2
0.07	-8.17462119489407E-002+0.269235386607386i	0.004396436	106.889527	122.1	2.27E+02	-178.750277533996-149.880555025427i	3.644875553	-140.0204593	122.1	246.9099863	-0.003142211	
-0.03	-0.886753597725183+8.39456603625449i	0.131894873	96.03003354	146.5	1.96E+02	10.2988979485625-223.074231197601i	3.489247571	-87.35664372	146.5	183.3866773	-0.229705072	**3**
-0.11	-0.119252570118288-0.526075003594786i	0.008428469	-102.7721648	170.9	1.68E+02	-100.219806749828-88.1414122191377i	2.085391327	-138.6689869	170.9	35.89682211	0.007119197	
-0.15	-0.72672940678784+0.317320854660671i	0.01239042	156.4118792	195.3	1.36E+02	-16.680705484569+1.07749089536722i	0.261179212	176.3041113	195.3	-19.89223215	0.001521517	4
-0.14	-0.39807606194278-1.65120442822112E-002i	0.006225287	-177.6247544	219.7	1.12E+02	12.4461600268567-146.423512911408i	2.296117649	-85.14147437	219.7	-92.48328003	-0.000309664	
-0.14	1.60012745568292-1.89292151297934i	0.038728446	-49.79144123	244.1	8.38E+01	127.689202305748-476.082310682013i	7.701697049	-74.9861524	244.1	25.19471117	0.134949395	**5**
-0.14	0.396227094437288-0.486281356811089i	0.009801067	-50.82649493	268.6	5.99E+01	-32.2429629905674+44.0343308975674i	0.852763053	126.2124572	268.6	-177.0389522	-0.004173414	
-0.14	1.24109478997519-0.188365738090571i	0.019614186	-8.630137485	293.0	2.79E+01	49.4529935661162-12.9386947518745i	0.798712403	-14.66199402	293.0	6.031856535	0.00778968	6
-0.16	-0.143283789313253-0.384596187307723i	0.006412811	-110.4332024	317.4	0.00E+00	-9.47019783314981-77.2536662438833i	1.216124335	-96.98877731	317.4	-13.44442509	0.003792528	
-0.17	-1.79462230537511-1.6583477195650 5i	0.038179988	-137.2600569	341.8	-3.59E+01	117.53265375783-257.174882704195i	4.418114705	-65.43891144	341.8	-71.82114543	0.026313313	**7**
-0.33	0.537158890973418+0.243257402833709i	0.009213635	24.36383744	366.2	-6.39E+01	-38.3564387818425+71.2732822479357i	1.264669504	118.2873663	366.2	-93.92352883	-0.000398651	
-0.37	-6.25182220312909E-002-4.35504201699177E-002i	0.001190494	-145.1387909	390.6	-9.58E+01	30.5585053097243-22.9776210177069i	0.597396965	-36.94032133	390.6	-108.1984696	-0.000111057	8
-0.47	0.287473004316106-2.00614296007439E-002i	0.00450269	-3.991939222	415.0	-1.28E+02	-43.7066507103299+59.9933018491647i	1.159777935	126.0742928	415.0	-130.066232	-0.001680668	
-0.55	0.725496186321638-0.473087071597726i	0.013533055	-33.10787245	439.5	-1.52E+02	-16.6072399131148+59.1006432960823i	0.959212941	105.6953263	439.5	-138.8031988	-0.004883818	**9**
-0.62	-6.6905697711807E-002+0.397697926694119i	0.006301352	99.54958825	463.9	-1.80E+02	-13.7811435206608-16.3340809009667i	0.33392278	-130.154489	463.9	229.7040772	-0.000680419	
-0.65	3.68558636172106E-002+0.171376174201567i	0.002738976	77.86292873	488.3	-2.04E+02	-7.34062988066319-1.71397081469141i	0.117782389	-166.8574123	488.3	244.720341	-6.88817E-05	10
-0.69	0.150145208700305+0.243559599244837i	0.004470631	58.3477504	512.7	-2.27E+02	-48.6014958161629-38.40095870578i	0.967834626	-141.6870713	512.7	200.0348217	-0.002032496	
-0.72	0.384597005380421+0.601744205309919i	0.011158602	57.41584759	537.1	-2.51E+02	48.1857086163329-16.9665705696445i	0.798210742	-19.39757099	537.1	76.81341859	0.001015936	**11**
-0.74	-0.319975329787012-2.18469547309959E-002i	0.005011254	-176.0940782	561.5	-2.75E+02	27.4120728822802-1.97344168044089i	0.429422137	-4.117716504	561.5	-171.9763617	-0.001065439	
-0.76	-0.149278698345809-4.41586819862495E-002i	0.002432392	-163.5210618	585.9	-2.91E+02	5.03653275593612+58.8243325810908i	0.922493009	85.10627674	585.9	-248.6273386	-0.000408869	12
-0.91	-0.251022571971247+0.22157966978472i	0.00523169	138.5648934	610.4	-2.99E+02	-26.8192179647172-37.7338757772488i	0.723340611	-125.4031761	610.4	263.9680695	-0.000198832	
-0.93	2.55672101491685E-002+0.155630681035968i	0.002464325	80.67070679	634.8	-3.03E+02	5.94337019114261-58.2359489661126i	0.914663184	-84.1727559	634.8	164.8434627	-0.001087811	**13**
-0.91	0.105444186949639-0.24212617303966i	0.004126407	-66.467225	659.2	-3.07E+02	20.9084290412307-30.2239904656956i	0.574237777	-55.32519145	659.2	-11.14203355	0.001162438	
-0.84	0.310844891214436+0.210505311507062i	0.005865872	34.10600274	683.6	-3.07E+02	18.1019703568767+20.6883867052859i	0.429528572	48.81465208	683.6	-14.70864934	0.001218496	14
-0.80	-0.184600854308711-0.240943283103801i	0.004742674	-127.4578541	708.0	-3.07E+02	-12.5868159932413-15.3094238294008i	0.309677249	-129.4257199	708.0	1.967865864	0.000733916	
-0.73	-9.76567549283325E-002-0.43653991724091i	0.006989528	-102.6098153	732.4	-3.07E+02	-5.83063960801879-28.8170961965709i	0.459391313	-101.4383855	732.4	-1.171429731	0.001605129	**15**
										TOTAL	**101.3446063**	

APPENDIX B: POWER MEASUREMENT RESULTS IN TABULAR FORM

B.1 Power consumption of new television sets, 2010 measurements

Table B.1 presents the power consumption in standby and on-mode of new television sets as measured in an electronics store by the author in 2009/2010. Measurements were performed of both the real and apparent power consumption in both on and standby modes. The sets measured included a variety of plasma, LCD and LED based television sets of different sizes. For reference the maximum allowable power consumption for a specific type of set as specified by Energy Star is also shown.

Table B.1: Power consumption of new television sets as measured in 2010

Screen Size	Model	On (Watt)	On (VA)	Standby (Watt)	Standby (VA)	Maximum allowable on power consumption, Energy Star (Watt)
42"	LG Plasma 42PQ60R	322	324	0.3	4.9	208
42"	LG LCD 42LH70	216	218	1.3	17.5	208
32"	LG LCD 32LH70	81.3	85.9	0.7	18.6	120
50"	SAMSUNG PLASMA PS50B430	250	254	0.9	8.2	318
46"	SAMSUNG LCD LA46B530	166	167	0.9	14.6	Not listed
42"	SAMSUNG PLASMA PS42B430	242	245	1.0	8.0	208
42"	SAMSUNG PLASMA PS42B450	263	267	0.9	8.1	208
40"	SAMSUNG LED UA40B6000	139	143	0.1	1.5	Not listed
40"	SAMSUNG LA40B550 LCD	159	162	0.9	14.4	Not listed
32"	SAMSUNG LCD LA32B450	93.1	97.3	0.9	14.9	120

B.2 Power consumption of new television sets, 2004 measurements

Table B.3 presents the power consumption in standby and on-mode of new television sets as measured in an electronics store by the author in 2004/2005 towards his BTECH Electrical Engineering dissertation. At the time no measurements of reactive power was performed as the study did not require this data. Table C.2 presents measurements of older television sets the author has in his home as performed in 2009/2010.

Table B.2: Power consumption of CRT television sets that were ten years or older in 2010

Screen Size	Model	On (Watt)	On (VA)	Standby (Watt)	Standby (VA)
74cm	SAMSUNG CS-29K3NT	127	127	3	4.1
60cm	LG CZ 20F60	52	52	6.7	9.3
37cm	Telefunken	38.1	38.1	8.2	8.2

Table B.3: Power consumption of new CRT television sets as measured by the author in 2004/5

Screen Size	Model	On (Watt)	Standby (Watt)
137 cm	Samsung SP54T8 CRT Rear Projection	206	2.9
111cm	LG RT44NA21T CRT Rear Projection	208	10.5
106cm	LG MT42PM12 Plasma Flat Panel	265	3.8
84cm	Sony KV-XA34	125	1.1
	Samsung 3426	131	2.5
74cm	Sony KV-SR29	120	1.4
	Panasonic 29FJ20	82	1.2
	Samsung CS29Z6 100Hz CRT	185	1.8
	Philips 29PT7322	114	1.3
64cm	Sony KVSW25	75	1.2
	Philips 25PT4323	53	1.2
	Tedelex EC2559	75	3.2
54cm	Sony KVHW212	53	1.0
	LG CT20F95M	58	7.1
	LG 20J 50/55	58	11.6
	LG 21CB55	60	8.0

Table B.4: Power consumption of new CD/DVD players and AV receivers as measured in 2010

Device Type	Model	On (Watt)	On (VA)	Standby (Watt)	Standby (VA)
DVD Player	NAD T514	9.4	9.7	1.3	2.7
CD/Radio Receiver	NAD C715	17.2	21.3	1.4	1.6
AV Receiver	NAD T737	47.2	50.3	2.3	2.4
DVD Player	NAD T515	8.2	8.7	1.1	1.8

Table B.5: Power consumption of existing (5 years or older) CD/DVD players and AV receivers as measured in 2010

Device Type	Model	On (Watt)	On (VA)	Standby (Watt)	Standby (VA)
DVD Player	Yamaha	17.7	17.8	5.2	5.2
AV Receiver	Yamaha RX-V630RDS	41.4	49.8	2.0	2.1

B.3 Energy Star standard for television sets.

Table B.6 presents the allowed on-mode power consumption for CRT and LCD/PLASMA/LED television sets as defined by Energy Star. Sets are listed according to their native vertical resolution. 480 Lines of vertical resolution refer to CRT sets and 768 or 1080 lines refer to LCD/PLASMA sets.

Table B.6: Maximum allowed on mode power consumption to qualify for Energy Star status (Energy Star, 2009. *ENERGY STAR® Program Requirements for Televisions Partner Commitments*)

Viewable Diagonal Screen Size (Inches)	Aspect Ratio	Viewable Screen Size in Inches	Screen Area in Inches^2 (cm^2)	Maximum On Mode Power in Watts	
				480 Lines of Native Vertical Resolution	768 or 1080 Lines of Native Vertical Resolution
20	16:9	17.4 x 9.8	170.5 (1,100)	45	66
32	16:9	27.9 x 15.7	438.0 (2,826)	78	120
42	16:9	36.6 x 20.6	754.0 (4,865)	115	208
50	16:9	43.6 x 24.5	1068.2 (6,892)	153	318
60	16:9	52.3 x 29.4	1537.6 (9,920)	210	391

APPENDIX C:
Flow chart for determining the class a device falls into according to EN 61000-3-2

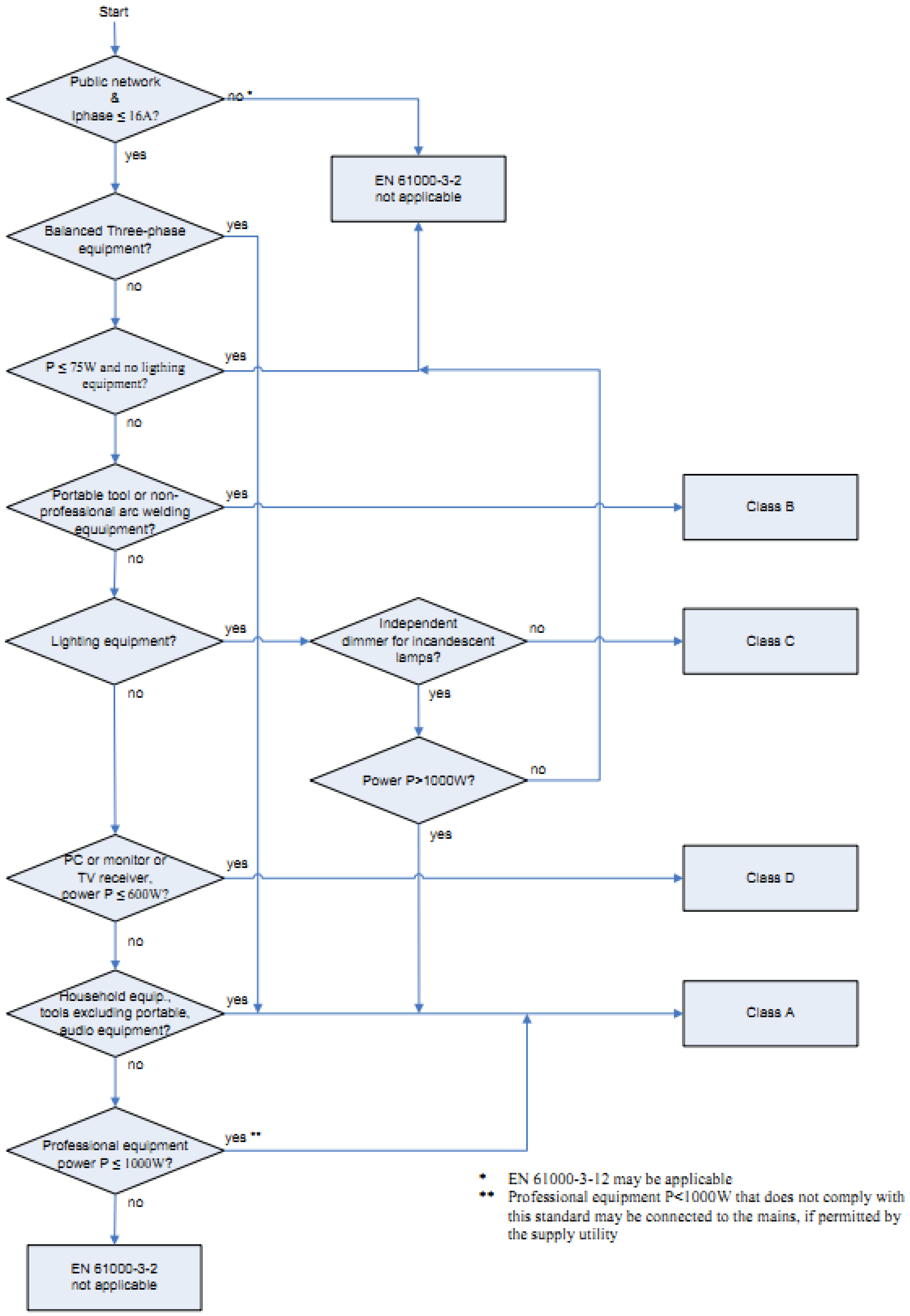

Figure C.1 Flow chart for determining the class a device falls into according to EN 61000-3-2

APPENDIX D:

Table D.1: Fluke 43B Power Quality Analyzer Specifications

Specifications	
Input Characteristics	Input impedance 1 MΩ, 20 pF Voltage rating 600V rms, CAT III
V/A/Hz Display	True-rms voltage (ac + dc) Ranges: 5.000 V, 50.00 V, 500.0 V, 1250 V* Accuracy: ±(1% + 10 counts) True-rms curr nt (ac + dc) Ranges: 50.00 A, 500.0 A, 5.000 kA, 50.00 kA, 1250 kA Accuracy: ±(1% + 10 counts) Frequency Ranges: 10.0 to 15.0 kHz Accuracy: ± ([% of reading] + [counts]): 0.5% + 2 CF Crest factor Ranges: 1.0 - 10.0 Accuracy: ±(5% + 1 count)
Power Display	Watts, VA, VAR 1-phase and 3-phase,3 conductor balanced loads Ranges: 250 W - 1.56 GW Accuracy: ±(4% + 4 counts) Fundamental Power Accuracy: ± (2 % + 6 counts) Total Power PF Power Factor Range: 0 - 1.0 Accuracy: ±0.04 DPF Displacement Power Factor, Cos .F Range: 0.25 - 0.9 Accuracy: ±0.04 Range: 0.90 - 1.0 Accuracy: ±0.03 H2 Frequency Fundamental Ranges: 40.0 to 70.0 Hz Accuracy: ± ([% of reading] + [counts]): 0.5% + 2
Harmonics Display	Voltage, Current, Frequency

	Ranges:	Fundamental to 51st harmonic
	Accuracy:	
	Fundamental:	VA ±(3% + 2 counts) W ±(5% + 2 counts)
	2 to 31st harmonic:	VA ±(5% +3 counts) W ±(10% +10 counts)
	32 to 51st harmonic:	VA ±(15% +5 counts) W ±(30% +5 counts)
	Frequency Fundamental	
	Ranges:	40 Hz to 70 Hz
	Accuracy:	±0.25 Hz
	Phase	
	Range:	V, A (between Fundamental & Harmonics)
	Accuracy:	±3º to ±15º
	Range:	W (between Voltage Fundamental & Current Harmonics)
	Accuracy:	±5º to ±15º
	K-factor (Current and Power)	
	Range:	1.0 to 30.0
	Accuracy:	±10%
	THD Total Harmonic Distortion	
	Range:	0.00 - 99.99
	Accuracy:	±(3% + 8 counts)
Sags and Swells	Recording times:	4 min to 16 days (selectable)
	Vrms Actual, Vrms max, min(AC + DC)	
	Ranges:	5.000V, 50.00V, 500.0V, 1250V*
	Accuracy:	Readings ±(2% +10 counts); Cursor readings ± (2% + 12 counts)
	Arms Actual, Arms max, min (AC + DC)	
	Ranges:	50.00A, 500.0A, 5.000 kA, 50.00 kA
	Accuracy:	±(2% +10 counts)
Transient Capture	Minimum pulse width:	40 ns
	Useful bandwidth input 1:	DC to 1 MHz
	Number of transients:	40
	Voltage threshold settings:	20%, 50%, 100%, 200% above or below reference
	Reference signal:	After START, the Vrms and frequency of the signal are measured. From these data a pure sinewave is calculated as reference for threshold setting.
	Vpeak min,	10 V, 25 V, 50 V, 125 V, 250 V, 500 V, 1250 V

	Vpeak max at cursor: Accuracy: ±5% of full scale
R, C, Diode, Continuity	Resistance ranges: 500.0 Ω, 5.000 kΩ, 50.00 kΩ, 500.0 kΩ, 5.000 MΩ, 30.00 MΩ Resistance accuracy: ±(0.6% + 5 counts) Capacitance ranges: 50.00 nF, 500.0 nF, 5.000 µF, 50.00 µF, 500.0 µF Capacitance accuracy: ±(2% + 10 counts) Diode Ranges: 0 to 3.000 V Diode oltage: Accuracy: ±(2% + 5 counts) Continuity: Beeper on at < 30 Ω ± 5 Ω Max current: 0.5 mA Temperature: °C or °F
Inrush Current	Inrush times: 1 s, 5 s, 10 s, 50 s, 100 s, 5 min Current ranges: 1 A, 5 A, 10 A, 50 A, 100 A, 500 A, 10 0 A Cursor readings: A peak max at cursor 1 and cursor 2 Accuracy: ±5% of full scale Time between cursors: 4 to 235 pixels (1 pixel = inrush time/250) Accuracy: ±(0.2% + 2 pixels)
Temperature (with accessory)	Range: -100 °C - 400 °C Accuracy: ±(0.5% + 5 counts)
Scope Display	Measurements: dc, ac, ac+dc, peak, peak-peak, frequency, duty cycle, phase, pulse width, crest factor Time ranges: 20 ns/div to 60 s/div Max sampling rate: 25 MS/s Bandwidth Voltage channel [1]: 20 MHz at inputs, 1 MHz with TL24 Leads Current channel [2]: DC to 15 kHz at inputs, 10 kHz with i400s Current Clamp Coupling: AC, DC (10 Hz - 3 dB) Vertical sensitivity: 5 mV/div to 500V/div Vertical resolution: 8 bit (256 levels) Record length: 512 samples per channel Base ranges: 60 S/div to 20 nS/div ± (0.4% + 1 pixel) Timebase modes: Normal, roll, single Pre-trigger: Up to 10 divisions Trigger Source: Input 1 or Input 2 or automatic selection Trigger Mode: Automatic Connect-and-View™, ree Run, and Single Shot Connect-and-View™: Advanced automatic triggering that recognizes signal patterns

	Automatically adjusts triggering, timebase and amplitude and displays stable pictures
Memories	20 (screens, settings, data)
Recording	Recording times: 4 min to 16 days (selectable) Parameters: Choose one or two parameters from one of the groups below: Volts/Ampères/Hertz Power: Watts, VA, VAR, PF, DPF, Frequency Harmonics, THD, Volts (Fund. & Harmonic), Ampères (F&H) Watts(F&H) Frequency (H), %(H) of total, Phase(H), KF Temperature Resistance: Resistance, Diode, Continuity, Capacitance Scope: DC Voltage, DC Current, AC Voltage, AC Current, Frequency, Pulse Width + or -, Phase, Duty cycle + or -, Peak max, Peak min, Peak min-max, Crest Factor
Note	*Rated EN 61010-1 600 V CAT III CSA
Environmental Specifications	
Operating Temperature	0°C to +50°C
Safety Specifications	
Electrical Safety	EN 61010-1 CAT III, 600V. CSA listed
Mechanical & General Specifications	
Size	232 x 115 x 50 mm
Weight	1.1 kg
Warranty	3 years
Battery Life	Rechargeable NiMH pack (charger included), 6.5 hrs extended operating time (continuous)
Shock & Vibration	Mil 28800E, Type 3, Class III, Style B
Case	IP51 (dust, drip, waterproof)

(fluke.com, Fluke 43B Single Phase Power Quality Analyzer Specifications, 2011)