Palestine Polytechnic University

College of Engineering

Harmonic study for Palestine Polytechnic University Wadi-Al Haria campus

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Project:

Harmonic study for Palestine Polytechnic University Wadi-Al Haria campus

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By the guidance of our supervisor, and by the acceptance of all members in the testing committee this project is delivered to the Electrical Engineering Department in the College of Engineering to be as a fulfillment of the requirements for the Bachelor degree in Power Technology engineering.

Supervisor signature

The head of department signature

الإهداء

الى ذلك الحضن الدافئ، الى رائحة الجنة، أمي، من سهرت الليل حتى تراني في أجمل حلة، اليك أهدي هذا النجاح.

واليك يا أبي، يا من كنت الشامخ رغم الملمات، كنت المتابع رغم بعد المكان والمسافات، اليك أهدي هذا النجاح.

ولإخوتي جميعا ...يا من كنتم قدوة في الحزم على مواصلة التعليم.

ولأصدقائي ...يا من كان اللقاء يسمو بهم، فتزول الهموم، وتحلو المجالس بالضحكات.

ولأمتي الجريحة التي لا زالت صابرة على جراحها، والتي تفخر بنا وبنجاحنا والتي لأجلها نثابر، ولنصرها نعمل ليل نهار، ولفجر عزها الذي اقترب على البزوغ

إلى الاساتذة والمعلمين، إلى الذين ترعرعت على أيديهم، إلى من تعلمت الكثير من لمسات أناملهم، إلى من قال فيه أمير الشعراء يوما:

"قف للمعلم وفه التبجيلا .. كاد المعلم أن يكون رسولا"

إلى كليتي ... أقسامها وروادها ... كلية الهندسة

.

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Abstract:

Due to the increase of using electricity in all part of life, and increase number of non-linear loads (not comics) which does not commit of the sine wave that offered to it and cases distortion in voltage and current waveform in the electrical network that are existing in. So, it creates a lot of significant dangers problem like increase the stress and heating on the cables, decrease the lifetime of the electrical equipment, malfunction the operation of protection equipment and sensitive loads. so, it has necessary to find a solution to this phenomenon and eliminate it.so In this study, we fix the harmonic problems which exist in the Palestine Polytechnic university electrical network. Where we collect the data, review, analyzing and discuss it by using power quality analyzer device with some necessary software programs and the international standards that according the acceptable percentage of harmonic exists. Then we find the problems and solved it by design passive harmonic filter and shunt active harmonic filter, the design and simulation its operation were done by using MATLAB software program.

الملخص:

في ظل تزايد الاعتماد على الكهرباء في كل مجالات الحياة، وازدياد أعداد الأجهزة الغير خطية (الغير أومية) التي لا تلتزم بالموجة الجيبية المزودة لها مما تؤدي الى احداث تشوهات في موجات التيار والجهد في الشبكة الكهربائية الموجودة بها وبالتالي خلق العديد من المشكلات الخطيرة فيها مثل زيادة الضغط الكهربائي على الكوابل وارتفاع درجة حرارتها وتقليل العمر الافتراضي للآلات الكهربائية واحداث خلل في عمل أجهزة الحماية والأجهزة الحساسة للطاقة الكهربائية. فانه أصبح من الضروري إيجاد حل لهذه الظاهرة والتخلص منها لذلك تعالج هذه الدراسة مشكلة وجود التوافقيات في الشبكة الكهربائية لجامعة بوليتكنك فلسطين، حيث تم تجميع البيانات وعرضها وتحليلها ومناقشتها باستخدام جهاز تحليل الطاقة الكهربائية مع مجموعة من البرامج اللازمة وباستخدام التصنيفات العالمية التي تحدد نسبة التشوه المقبولة في الشبكة. ثم تم التوصل الى المشكلات الموجودة وتم حلها عن طريق تصميم كل من مرشح التوافقيات السلبي ومرشح التوافقيات الفعال، حيث تم تصميم ومحاكات مبدا عملهم عن طريق برنامج الماتلاب.

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CHAPTER ONE

Introduction

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1.1 Overview

Harmonics are typically caused by the use of nonlinear loads, such as power electronic devices, fluorescent lamp, arc furnaces and other nonlinear loads that used in many applications.

The presence of harmonics in the system results several effects (including increased heating losses and stress on cables, malfunction operation of sensitive equipment and protection device and other series problems). also, the presence of harmonic has many international standards that recognizing the acceptable range of it.

In this project, we aim to measure the harmonics parameter for Palestine Polytechnic University Wadi-Alharia campus, classified it according to the international standards and then design the suitable harmonic filter that solves the problem that we faced.

1.2 Motivation

The presence of harmonics in the power system network results in larger power losses, cause a problem by interfacing in the communications system and sometimes cause an operation failure of electric equipment and protection. So, this motivates us to make our project on the electrical harmonic issue to improve the ratability and stability of the electrical system and equipment of our university.

1.3 Objectives

1. Measure Harmonics for main and sub feeders of the Palestine Polytechnic University Wadi-Alharia campus.
2. Analyzing voltages and currents Harmonics.
3. Simulating the real system.
4. Specify problem sources.
5. Suggest feasible solution for each problem.
6. design passive harmonic filter and shunt active harmonic filter to solve the problem.

1.4 Importance

The importance of this project lies in the configuration of the university which consists a lot of nonlinear loads that make serious problem like 1) distortion the current signal significantly. 2) Malfunction the protection devices. 3) Malfunction of different electronic components and circuits. 4)decrease the life time of electrical equipment 5) Decrease the power factor of the system, so we have to solve this issue by design the suitable harmonic filter.

1.5 Methodology

1. Measure the power quality parameter on the main feeder, then branch to the sub feeder.
2. Analysis the data that we collect.
3. Classification the data according to the Institute of Electrical and Electronics Engineers (IEEE) standards.
4. Specify the problem.
5. design the suitable harmonic filter that solve the problem.

1.6 Time table

Semester one.

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task 1	■	■														
Task 2			■	■	■	■	■	■	■							
Task 3										■	■	■	■	■		
Task 4														■	■	
Task 5																■

Semester two.

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task 1																
Task 2																
Task 3		■	■	■	■	■	■	■	■	■						
Task 4											■	■	■	■		
Task 5															■	■

Task 1: Choosing the suitable idea for the project.

Task 2: Clarify and decompose the highlights of the project.

Task 3: Collecting data.

Task 4: Analysis the data.

Task 5: Coordinate the project text.

2

CHAPTER TWO

Harmonics

2.1 Introduction

2.2 Definition of power quality

2.3 Cost of poor power quality

2.4 Classification of power quality

2.5 Power quality problem

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2.7 Effect of harmonics

2.8 Source of harmonics

2.9 Electrical power system quantity under nonsinusoidal condition

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2.13 The benefits of using filtering

2.14 Types of filters

2.15 Passive filter verses active filter

2.1 Introduction

Since the electricity has founded the electrical industry begin, and since that, it became faster and complicated. In the last decades. because the height increasing in manufacturing the most common load has been depending on the artificial intelligence and on programming which depend on the computer and microprocessor, so the most residential and manufacturing loads and equipment have been electrical sensitive. And because that it is becoming more important to feed them with an electrical power supply which should be a pure wave, stability, and reliability and since that the power quality concept has founded.

2.2 Definition of power quality

The idea of power quality has a lot definition. And every definition is different from each other according to the point of view. for example, the define of power quality that the electrical utility use is an electrical level which a consumer's electrical equipment should be able to operate without malfunction or damaged. In the otherwise the machine manufactories define the power quality as the electricity able to work their equipment safety and reliability. And the consumers define it as the electrical energy that operates the electrical equipment correctly and reality without being damaged or stressed. And some other set the power quality to consist a wide range of items so according to Heydt " the electrical power quality can define as the goodness of electrical power supply regarding its voltage wave shape its frequency its voltage regulation as well as the level of impulse and noise and the absence of momentary outages”. [1]

According to the above definition, we see that it covers the entire power system and we can limitation it in voltage current and frequency deviate so any interruption in any of them it will cause a disturbance on electricity.

2.3 Cost of poor power quality

The increasing cares about the poor power quality is because the cost of disturbance that can produce according to it and the consequences result that became after it happen. Poor power quality is estimated to cost the European economy up to 150 € billion annually, according to the Leonardo power quality initiative and the United States loses ranging from 119€ billion to 188€ billion, according to the research by electrical power research institute(EPRL). [2]

And according to the contingency planning research LAN Times, half of all computer problems and the third of all data loss can be traced back to the power line. The "electrical light and power Magazine " said that 30-40% of all business downtime is related to the power quality problem. so according to that statistics, the power quality problem is an important thing to search and fixed it. [3]

2.4 Classification of power quality

We can classify the disturbance of power quality depending on their period into steady state disturbance and transient disturbance.

The steady state disturbance can be a long duration (stay more than 1 minute) and cost involved may be high. But is fewer obvious and less harmful. on the other hand, the transient disturbance can be a short duration (stay less than 1 minute) and cost involved may be extremely high and it is more obvious and harmful.

There are several international standards that classification the power quality like The Institute of Electrical and Electronics Engineers (IEEE) Std 1159-2009 and International Electrotechnical Commission (IEC) power quality standards.

2.5 Power quality problem

We can limitation the major problem of power quality in:

1. voltage sag
2. voltage swells
3. voltage interruption
4. harmonics

In our project we will focus on Harmonics (study and analysis it).

2.6 Harmonics

In the last age anew loads have appeared, the currents of these loads did not change according to its voltage, in another word these loads are not OMICS loads which mean that if we induced on it, a voltage has sine wave the current it is not necessary to have the same shape of the wave, these loads are cooled nonlinear loads.

According to the statistics, half of the residential loads are nonlinear, and the ratio of the manufacturing loads are more than that.

These harmonics does not affect only in the shape of the wave, but also is mace the equipment temperature to rise Significantly, disturbance the process of it and maybe damaged it. The harmonics have been before nonlinear loads, but it is existence was soundless and were formed by the generator.

The definition of harmonics disturbance according to (IEEE Std 519-1992) "is a sinusoidal component of a periodic wave of quantity having a frequency that is an integer multiple of the fundamental frequency". this type of harmonics called fundamental harmonic and there is another type of it such as 1) sub-harmonic which have frequency below the fundamental frequency and can generated when a system is highly inductive or when the power system contains large capacitor bank for power factor correction or filtering .2)inter-harmonic which the frequency of it are not integer multiple of the fundamental frequency and this type can generate by arcing device and computers and can cause a flickers and additional temperature rise in induction machine. [4]

Unlike the fundamental harmonic, the excess of inter and sub-harmonics in power system are lower, and the most harmonic we give it a special desire are the triple harmonic “the odd multiples of the third harmonic (h 3, 9, 15, 21…)” because the system response is often considerably different from it for the rest of the harmonics and it became an important issue for grounded-wye systems with current flowing on the neutral.

2.7 Effect of harmonics

The harmonics case series problems on the electrical power system and equipment and can Produce a lot of fault in the long term of them exist, some of the harmonics problems are:

1) Additional heating in neutral conductors

2) Additional heating in distribution transformers and cables

3) Rising the voltage between neutral point and grounding

4) Decrease the power factor of the system

5) Damage in the capacitor bank correction because the over loads and resonance

6) Malfunction the protection devices and false tripping off

7) Generate resonance leads to over current surges

8) Malfunction of different electronic components and circuits that utilize the voltage waveform for synchronization and timing.

So, because of the wide range of effect the harmonics on the whole electrical power system, the scientists consider it as an important issue and they research to solve it and made a standard to classification and avoid it.

2.8 source of harmonics

The following loads are considered the main source that is responsible for the main source that cases harmonic in a system:

1) The power electronic devices

These devices such as rectifiers, inverters and drives are responsible for generating a lot of harmonics because it changes the output wave shape significantly from the input wave shape and it is considered the largest proportion of the nonlinear loads in the system.

2) Fluorescent lamps:

These lamps are generated an electrical arc that generates the 3rd harmonic in the system.

3) Arc furnaces:

The electrical arc welding is the most example on it, the operation of these devices is related to made a short circuit current, it values are very high, this current temperature is very high and it can melt the metal, and by interrupted this current we can generate the suitable temperature that used to melt the object that we want to be melt. but that interrupted in current are responsible for generating harmonic and it can affect badly on the surrounding loads.

4) Power transformer:

The transformer and other electromagnetic devices don't usually generate harmonic if it is operating in a linear area of (B-H curve) which shows in Figure 2.1, but if it is reaching the saturation area of the curve, the device will generate harmonic because the relationship between voltage and current will be nonlinear. Usually, the harmonic value that generates are not enormous, but because of the big number of transformers in the electrical network system, the generating harmonic become respectable.

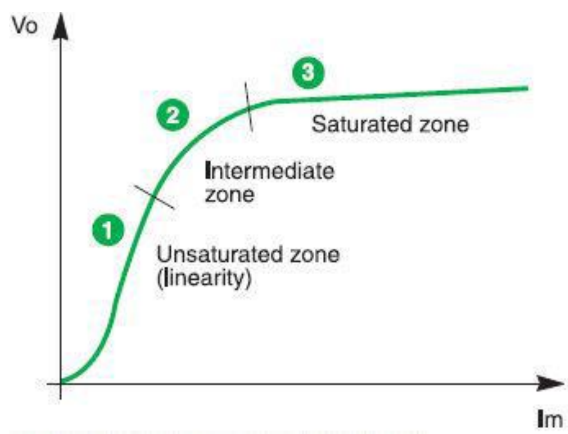


Figure 2.1: B-H curve

2.9 Electrical power system quantity under nonsinusoidal condition

When the signals are not pure wave as in harmonic cases, the Fourier series are used to analysis it.

$$y = f(x) = a_0 + \sum_{h=1}^{\infty} a_h \sin(hx + \emptyset_h) \tag{2.1}$$

a_0: dc component

a_h: harmonic component

h: harmonic number

h_1: fundamental harmonic component

h_2: 2nd harmonic component

$\emptyset_h$: phase shift of harmonic #h

Usually, the harmonic component is often odd harmonic only and the exists of even harmonic are indicates that there is something wrong either with the measurement equipment that used to take the data or with the transducer that used to make the measurement.

In a case of harmonic exists and the wave is not pure sinusoidal we can't use the same quantities that are used in the pure wave, so some of these quantities have a special treat in this case.

1. Apparent power: it is applied to both sinusoidal and nonsinusoidal conditions

$$s = v_{rms} * i_{rms} \tag{2.2}$$

Where:

s: apparent power

v_{rms}: the root mean square value of the voltage.

i_{rms}: the root mean square value of the current.

For the sinusoidal condition:

$$v_{rms} = \sqrt{\sum_{h=1}^{h_{max}} (\frac{1}{\sqrt{2}} v_h)^2} = \frac{1}{\sqrt{2}} \sqrt{{v_1}^2 + {v_2}^2 + {v_3}^2 + \cdots + {v_{h\,max}}^2} \tag{2.3}$$

Where:

v_h: harmonic voltage component for harmonic order h.

v_1: fundamental harmonic voltage

v_2: 2nd harmonic voltage

$v_{h\,max}$: the maximum order of harmonic voltage that exist in the system.

$$i_{rms} = \sqrt{\sum_{h=1}^{h_{max}} \left(\frac{1}{\sqrt{2}}\, i_h\right)^2} = \frac{1}{\sqrt{2}}\sqrt{{i_1}^2 + {i_2}^2 + {i_3}^2 + \cdots + {i_{h\,max}}^2} \qquad (2.4)$$

Where:

i_h: harmonic current component for harmonic order h.

i_1: fundamental harmonic current

i_2: 2nd harmonic current

$i_{h\,max}$: the maximum order of harmonic current that exist in the system.

2. Distortion Voltamperes(D): represents all cross products of voltage and current at different frequencies, which yield no average power and it represents the additional contribution to the apparent power by the harmonics, it has units of voltamperes.

$$D = \sqrt{S^2 - P^2 - Q^2} \qquad (2.5)$$

$$S = \sqrt{P^2 + Q^2 + D^2} \qquad (2.6)$$

Where:

D: Distortion Voltamperes.

S: apparent power.

P: real power.

Q: reactive power.

3. true power factor(TPF): In the nonsinusoidal case the power factor cannot be defined as the cosine of the phase angle. The power factor that takes into account the

contribution from all active power, including both fundamental and harmonic frequencies, is known as the true power factor(TPF)

$$TPF = \frac{p}{s} = \frac{P}{\sqrt{P^2+Q^2+D^2}} \tag{2.7}$$

Where:

TPF: true power factor.
S: apparent power.
P: real power.
D: distortion Voltamperes
Q: reactive power.

2.10 Harmonic indicates

For measure the effect size of harmonic on the waveform there is two indicators are usually used:

1) Total harmonic distortion (THD).

2) Total demand distortion (TDD).

2.10.1 Total Harmonic Distortion

"The total harmonic distortion (THD_V) is used to define the effect of harmonics on the power system voltage. It is used in low-voltage, medium-voltage, and high-voltage systems. It is expressed as a percent of the fundamental" and is also known as voltage distortion factor (VDF) and is defined as: [5]

$$\text{THD}_V = \sqrt{\frac{sum\ of\ all\ surges\ of\ amplitude\ of\ all\ harmonic\ voltage}{square\ of\ the\ amplitude\ of\ the\ fundamental\ voltage}} * 100\% \tag{2.8}$$

$$\text{THD}_V = \frac{\sqrt{\sum_{h=2}^{50} {v_h}^2}}{v_1} * 100\% \quad (2.9)$$

Where

v_h: is the harmonic voltage at harmonic frequency "h" in rms.

v_1: is the rated fundamental voltage in rms.

h: is the harmonic order (h = 1 corresponds to the fundamental)

for the balance voltage case, the three phases have the same THD and we can calculate it once, however in the case of unbalance we need to calculate the THD for each phase.

As there is total harmonic distortion (THDV) for voltage, there is also the total harmonic distortion (THDI)for current which can define as:

$$\text{THD}_I = \frac{\sqrt{\sum_{h=2}^{50} {I_h}^2}}{I_1} * 100\% \quad (2.10)$$

I_h: is the harmonic current at harmonic frequency "h" in rms.

I_1: is the rated fundamental current in rms.

h : is the harmonic order (h = 1 corresponds to the fundamental)

the use of THD_I can cases some miscalculations because 1) there is a nonlinear relationship between the magnitude of the harmonic components and percent THD. 2) a small current may have a high THD but not be a significant threat to the system. so instead of using it to indicate the current we can instead it by another indicator called total demand distortion(TDD).

2.10.2 Total demand distortion

"The total root-sum-square harmonic current distortion, in percent of the maximum demand load current (15 or 30 min demand)" and is defined as: [6]

$$\text{TDD} = \frac{\sqrt{\sum_{h=2}^{50} {I_h}^2}}{I_L} * 100\% \qquad (2.11)$$

where I_L is the maximum demand load current in rms Amps.

2.11 Harmonic distortion limits

There are so many standards you can use to judge whether your electrical power system are good power quality or not, one of these standard is IEEE std 519-1992 which give Recommended practices for Individual consumers and utility and Recommended methodology for evaluating new harmonic sources and attempts to reduce the harmonic effects at any point in the system ,so the philosophy of this standard that aim to make the customer to reduce the harmonic current under the limits that are bordered and make the utility to reduce the harmonic voltage under the limits that are bordered.

2.11.1 Voltage distortion limits

It set the limit for the voltage distortion that the utility supply it to the customers. that limits are the worst case for distortion voltage and if it exceeds the limits a quality problem is generated and we should solve it and attempt to reach under limits.

Table 2.1 shows the allowed percentage of Total Voltage Distortion THD and Individual Voltage Distortion according to the IEEE std 519-1992 at voltage equal 69KV and below.

Table 2.1: voltage distortion limits [7]

Bus voltage at PCC	Individual voltage Distortion (%)	Total Voltage Distortion THD (%)
69 KV and below	**3.0**	**5.0**

2.11.2 Current distortion limits

Because the customer is responsible for the nonlinear load that case the distortion current and the utility are can't control it, so these limits are direct to the customer. the current limits are represented as a percentage of customer average maximum demand load current and it different according to the utility's capacity.

Table 2.2 shows the allowed percentage of Total Demand Distortion THD and Individual harmonics according to the IEEE std 519-1992 at voltage equal 69KV and below and at different short circuit ration.

Table 2.2: current distortion limits [8]

$V_n \leq 69$ KV						
I_{SC} / I_L	h<11	11≤h≤17	17≤h≤23	23≤h≤35	35≤h	TDD
<20	2.0	2.0	1.5	0.6	0.3	50
20-50	7.0	3.5	2.5	1.0	0.5	8.0
50-100	10.0	2.5	2.0	1.5	0.7	12.0
100-1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	150	7.0	6.0	2.5	1.4	20.0

Where

The short circuit current (I_{SC})can be found by the following equations:

$$I_{SC} = \frac{1000 * MVA}{\sqrt{3} * KV} \text{ A} \tag{2.12}$$

The MVA of the transformer are calculated according the

$$MVA = \frac{MVA_{rated}}{z_{pu}} \tag{2.13}$$

And the average demand current (I_L)can be calculated by Find the load average kilowatt demand PD over the most recent 12 months and by using the following equation to find it:

$$I_L = \frac{KW}{PF * \sqrt{3} * KV} \text{ A} \tag{2.14}$$

And then we can find the short circuit ration ($\frac{I_{SC}}{I_L}$) that we can use it to compere the limit with our value.

$$\text{short circuit ration} = \frac{I_{SC}}{I_L} \tag{2.15}$$

2.12 Harmonic control solutions

When the harmonics in the system exceeds more than the standards range of it, it’s existence becomes a problem and it needs a solution to reduce or eliminate it.

The basic option to controlling harmonics are:

1. Reduce the harmonics current that produced by the loads.
2. Add a filter to shunt or block the harmonic's frequency from passing.

The first option of controlling the harmonics are often not very useful for existing load equipment because we can't do anything to it, but we can handle with overloaded transformer by brought it back into normal operation by lowering the applied voltage to the correct range .and we can replace the misoperation equipment that has a problem from its manufacturing with new healthy one, and we can set more tough rule for buying a new power electronic device by putting specially designed characteristics that are don’t generate a lot of harmonics.

The second option are the more reliable and it used by putting the filter near the loaded to prevent spread its effect to the system.

2.13 The benefits of using filtering

1. It can increase the life duration of electrical equipment.
2. Reduce the temperature on the electrical equipment and stress on cables.
3. Improve the continuity and ratability of production process.
4. Eliminate the danger on the protection devices and made it work as well as it should.

2.14 Types of filters

There are many types of filters, it depending on its component that are used and its method of work.

We can be typing the filters into three types:

1. Passive harmonic filter
2. Active harmonic filter
3. Hybrid harmonic filter

2.14.1 Passive harmonic filter

Passive harmonic filter are series of capacitor and reactor that tuned to present a high impedance path to the fundamental recusancy and a low impedance path to a specific frequency (i.e. 5th - 250Hz, 7th - 350Hz) that we are interested to cancel it.

This type of filters is more commonly connected at individual load in the past rather than the point of common coupling case they are application requires consisting loading for effective harmonic execution.

To make the filtering operation affective we connect several banks of passive filters of different types in parallel. The most commonly used passive filter types are:

1. A series filter: are also known as single-tuned or notch filters, and it is the type most used in industry.
2. High pass filter: are used to suppress a wider range of frequencies than the single tuned filter, reducing the size of the components and avoiding capacitive power factor when the system is not loaded.
3. Band pass filter: are not common in the industry, but the component can be used to model high-order filters or double-tuned filters.

4. C-type filter: is a second-order filter, which is designed to have an impedance characteristic similar to the single-tuned filter, with the advantage of having lower power losses.

The figure 2.2,2.3,2.4 and 2.5 shows the types of passive filter.

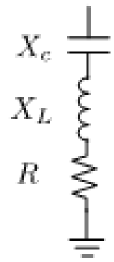


Figure 2.2: Series filters

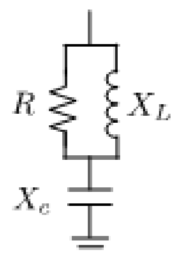


Figure 2.3: High-pass filters

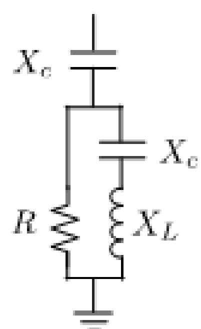


Figure 2.4: Band-pass filters

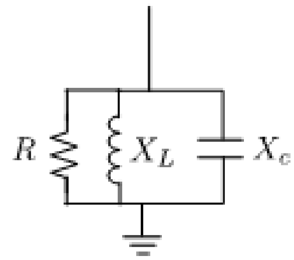


Figure 2.5: c-type filter

2.14.1 .1 Single tuned filter

It is the most type of filter that is use in the industry because it is often sufficient for the application and not expensive.

To design a single tuned passive filter, you should determine the RLC element (the resistance, inductor, capacitor) value that are needed, it is value are determine from the following parameter:

1. Reactive power at nominal voltage (Qc) in MVAR.
2. Tuning frequencies.
3. Quality factor. The quality factor is a measure of the sharpness of the tuning frequency. It is determined by the resistance value.

The following equations are used in design Single tuned filter are:

$$Xc = \frac{kv^2}{Qc} \qquad (2.16)$$

Where:

Xc: DC capacitor voltage.

kv: line to line voltage.

Qc: reactive power in MVAR.

$$C = \frac{1}{2*Pi*f*Xc*n} \quad (2.17)$$

Where:

C: capacitance of the capacitor of the filter.

f: frequency.

Qc: : reactive power in MVAR.

n: number of single tuned filter that is going to design.

$$L = \frac{1}{(2*Pi*f*h)^2*C} \quad (2.18)$$

Where:

L: inductance of the inductor of the filter.

f: frequency.

h: the order of harmonic to be eliminate.

C: capacitance of the capacitor of the filter.

$$R = \frac{\sqrt{\frac{L}{C}}}{Q} \quad (2.19)$$

Where:

R: resistance of the resister of the filter

L: inductance of the inductor of the filter.

C: capacitance of the capacitor of the filter.

Q: quality factor (30<Q<100).

2.14.2 Active harmonic filter

Unlike the passive harmonic filter which contain a passive element only, the active harmonic filter (AHF) is belt by using the digital logic and IGBT semiconductor to synchronize a current waveform that injected into the electrical network to cancel harmonic current caused by nonlinear loads. By injecting the produced current, network harmonic current is greatly reduced and eliminate.

(AHF) can divide into single-phase active filters and three-phase active filters. Moreover, active filters can be classified into shunt (parallel) active filters and series active filters from their circuit configurations. At present, shunt active filters are more preferable than series active filters in terms of form and function, and therefore series active filters are suitable exclusively for harmonic filtering. Most active filters can use as their power circuit either a voltage-source pulse width-modulated (PWM) converter equipped with a dc capacitor or a current- source PWM converter equipped with a dc inductor. At present, the voltage-source converter is more favorable than the current-source converter in terms of cost, physical size, and efficiency.

2.14.2.1 Series active power filter

The series connected active filter is more retable to protect the consumer from insufficient supply voltage quality. This type of filter is recommended for compensation of voltage unbalance, voltage distortion and voltage sag from AC supply and for low power applications.

Series active power filter injects a voltage componant in series with supply voltage and therefore it can be considering as a controlled voltage source, compensating voltage sag and swell on the load side.

the power circuit configuration is based on a three-phase Pulse Width Modulation (PWM) voltage-source inverter connected in series with the power lines through three single-phase coupling transformers. In order to operate as a harmonic isolator, a parallel (LC)

filter must be connected between the non-linear loads and the coupling transformers. Current harmonic and voltage compensation are achieved by generating the suitable voltage waveforms with the three-phase PWM voltage-source inverter, which are reflected in the power system through three coupling transformers.

The figure 2.6 shows the series active filter.

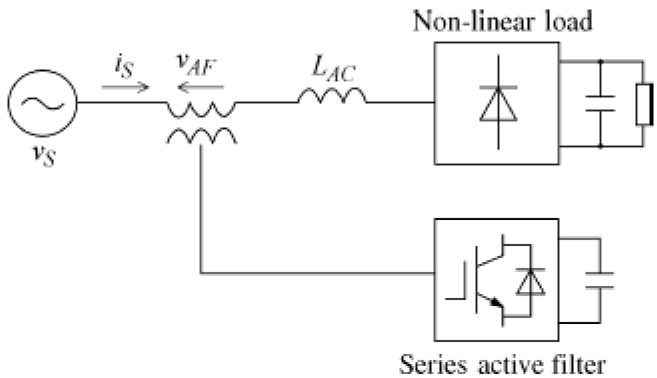


Figure 2.6: Single-phase or three-phase series active filter

2.14.2.2 Shunt Active Power Filters

Unlike series active filter which concentration in voltage issues, the shunt active filter is concentration in current issues, it is compensating current harmonics by injecting equal but opposite harmonic compensating current. In this case, the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180◦. As a result, components of harmonic currents contained in the load current are cancelled by the effect of the active filter, and the source current remains sinusoidal and in phase with the respective phase-to-neutral voltage.

The figure 2.7 shows the shunt active filter.

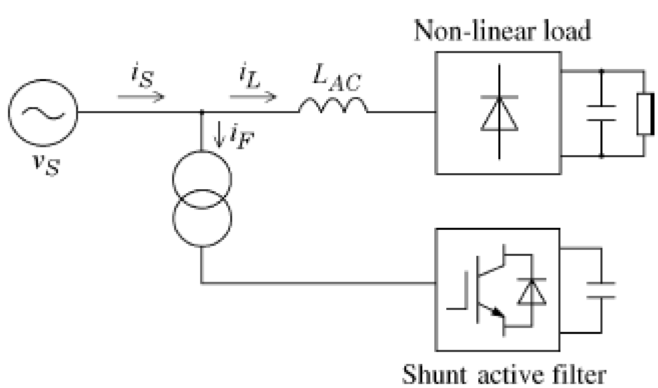


Figure 2.7: Single-phase or three-phase shunt active filter

Because the analysis of harmonic that exist in the Palestine polytechnic university power system are usually is harmonic current, so we will demonstrate the Shunt Active Power Filters in more expanding because it is the most suitable solution for this situation besides of that the Series active filter has a big issue in controller and most of scientists do not recommended in it.

The shunt active filter design has two sections:

1. Power Circuit Topologies.
2. Control Scheme.

2.14.2.2.1 Power Circuit Topologies

Shunt active power filters are normally implemented with PWM voltage-source inverter (PWM-VSI). In this type of application, the PWM-VSI operates as a current-controlled voltage source as showing in the figure2.8.

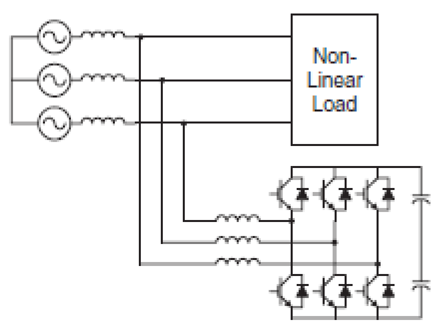


Figure 2.8: current-controlled voltage source

2.14.2.2.2 Control Scheme

The control scheme of a shunt active power filter must calculate the current reference waveform for each phase of the inverter, maintain the dc voltage constant, and generate the inverter gating signals.

The current reference circuit generates the reference currents required to compensate the load current harmonics and reactive power, and also try to maintain constant the dc voltage across the electrolytic capacitors.

The parameter of the control circuit is:

1. Current Reference Generation.
2. Current modulator.
3. Control loop.

2.14.2.2.2.1 Current Reference Generation

There are many possibilities to determine the reference current required to compensate the non-linear load. Normally, shunt active power filters are used to compensate the displacement power factor and low-frequency current harmonics generated by non-linear loads, one alternative to determine the current reference required by the VSI is the use of the synchronous reference frame.

Synchronous Reference Frame Algorithm basically, consists of a variable transformation from the a, b, c, reference frame of the instantaneous power, voltage, and current signals to the α, β reference frame.

We can convert the a, b, c, reference frame to the α, β reference frame by use the following equations:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = [A].\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2.20}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = [A].\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2.21}$$

And the transformation A matrix is:

$$[A] = \sqrt{\tfrac{2}{3}}.\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \tag{2.22}$$

The reference frame is synchronized with the ac mains voltage, and is rotating at the same frequency. The transformation is defined by:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(wt) & \sin(wt) \\ \sin(wt) & \cos(wt) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2.23}$$

As for the instantaneous reactive power theory, d and q terms are composed by a dc and multiple ac components, such as id = iddc +idac (2.24)

and iq = iqdc +iqac (2.25)

The compensation reference signals are obtained from the following expressions:

idref = −idac (2.26)

and iqref = −iqdc – iqa (2.27)

The compensated currents generated by the shunt active power filter are obtained from:

$$\begin{bmatrix} i_{aref} \\ i_{bref} \\ i_{cref} \end{bmatrix} = \sqrt{\tfrac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -1/2 & \sqrt{3}/2 \\ \frac{1}{\sqrt{2}} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 \\ 0 & \cos(wt) & -\sin(wt) \\ 0 & \sin(wt) & \cos(wt) \end{bmatrix} \begin{bmatrix} i_0 \\ i_{dref} \\ i_{qref} \end{bmatrix} \tag{2.28}$$

Phase-Locked Loop (PLL) is a technique that is used to obtain an accurate synchronization to the grid. The PLL circuit provides the rotation speed (rad/sec) to the rotating reference frame. The block diagram of Synchronous Frame-PLL (SF-PLL). It explains that the instantaneous phase angle θ is detected by synchronizing the PLL rotating reference frame to the utility voltage vector. Utility voltage vector sets the director quadrature axis reference voltage vd or vq to zero by PI controller following in the reference being locked to the utility voltage vector phase angle, the voltage frequency f and amplitude vm. Under ideal condition i.e. distorted or unbalance utility conditions, SF-PLL with a high bandwidth can yield a fast and accurate detection of the phase and amplitude of the utility voltage vector. In case the utility voltage is distorted with high-order harmonics, the SF-PLL can still operate with reduced bandwidth but at the cost of the PLL response speed reduction in order to reject and cancel out the effect of these harmonics on the output.

2.14.2.2.2.2 Current Modulator

The effectiveness of an active power filter depends basically on the design characteristics of the current controller, the method implemented to generate the reference template and the modulation technique used. Most of the modulation techniques used in active power filters are based on PWM strategies which can be achieved by Periodical Sampling.

The periodical sampling method switches the power transistors of the converter during the transitions of a square wave clock of fixed frequency (the sampling frequency). this type of control is very simple to implement since it requires a comparator and a D-type flip-flop per phase. The main advantage of this method is that the minimum time between switching transitions is limited to the period of the sampling clock.
The figure2.9 shows the control modulator block for periodical sampling method.

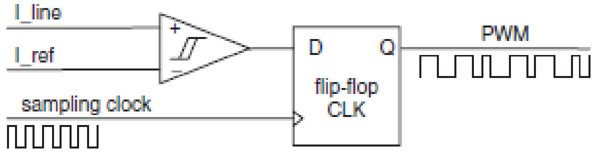


Figure 2.9: control modulator block for periodical sampling method

2.14.2.2.2.3 Control Loop Design

Active power filters based on self-controlled dc bus voltage requires two control loops, one to control the inverter output current and the other to regulate the inverter dc voltage classic design procedure using a PID controller,

the figure2.10 shows the control strategy that are used in shunt active filter.

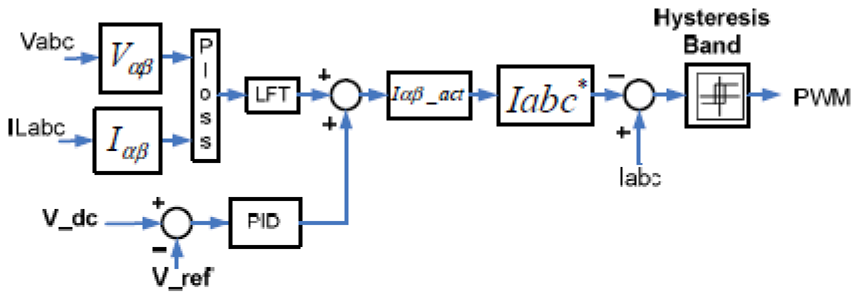


Figure 2.10: control strategy that are used in shunt active filter

2.14.2.2.2.3 Design parameter of shunt active filter

A three-leg voltage source converter (VSC) is used as active harmonic filter and six insulated gates bipolar transient (IGBTS), three interface inductors and one DC capacitor.

The line to line voltage (VL-L) of the (VSC) is considered as the same value of the voltage source in the facilities. The AC inductor and DC capacitor selection are as below:

1. DC capacitor voltage
   The minimum DC bus voltage should be greater than the twice of the peak of the phase voltage of the system and it calculated as the following equations.

$$v_{dc} = \frac{2*\sqrt{2}*v_{L-L}}{\sqrt{3}*M} \tag{2.29}$$

Where:

v_{dc}: DC capacitor voltage.

v_{L-L}: line to line voltage.

M: modulation index and is considered as 1.

2. DC bus capacitor.

The value of dc capacitor (Cdc) depends on the instantaneous energy available to the active filter during transient, the value of the DC bus capacitor is calculated from the following equation:

$$c_{dc} = \frac{6 * v * (a * I) * t}{(v_{dc})^2 - (v_{dc1})^2} \tag{2.30}$$

Where:

v_{dc}: the reference DC voltage.

v_{dc1}: the minimum voltage level of dc bus.

a: over loading factor.

v: phase voltage.

I: phase current.

t: time by which the dc bus voltage is to be recovered.

3. AC inductor.

The selection of the AC inductance (L_f) depends on the current ripple ($I_{cr(p-p)}$), switching frequency (f_s) and dc bus voltage (v_{dc}), the ac inductance is calculated from the following equation:

$$L_f = \frac{\sqrt{3} * M * v_{dc}}{12 * a * f_s * I_{cr(p-p)}} \tag{2.31}$$

Where:

L_f: ac inductance.

M: modulation index and is considered as 1.

v_{dc}: dc bus voltage.

a: over loading factor.

f_s: switching frequency.

$I_{cr(p-p)}$: current ripple.

2.14.3 Hybrid harmonic filtering

Hybrid harmonic filtering is the combination of passive and active harmonic filtering. Hybrid harmonic filtering combines the two solutions in situations where the use of passive harmonic filters can be used reliably for static loads of an electrical installation and a smaller active filter can be used to mitigate harmonics generated by the other variable loads. This solution can is having high cost and application effective.

2.15 Passive filter verses active filter

Use of the passive filters is one of the classic solutions to solve harmonic current problems, but they present several disadvantages, namely: they only filter the frequencies they were previously tuned for; their operation cannot be limited to a certain load; resonances can occur because of the interaction between the passive filter and other loads, with unpredictable results. As a result, conventional solutions that rely on passive filters to perform a harmonic reduction is ineffective. Under these conditions it has been proved that the most effective solutions are active filters which are able to compensate not only harmonics but also asymmetric currents caused by nonlinear and unbalanced loads.

3

CHAPTER THREE

Collecting data and harmonic analysis

3.1 Power Quality Analyzers.

3.2 Data collection.

3.3 Data analysis.

3.1 Power Quality Analyzers

Power Quality Analyzer is a device used to analyze the power on lines and substation. The Analyzer offers an extensive and powerful set of measurements to check power distribution systems. By using Fluke 435 the standard IEC61000-4-30 2003 class A. It is used to obtain data in the form of values and curves such as: voltage, current, frequency, power, energy, power factor (PF), total harmonic distortion (THD) and all harmonics.

Figure 3.1: Power quality analyzer

3.1.1 Examination and installation steps

1) Configuration and programming the device through the substation in terms of voltage, current and the method of connection of the current transformer inside the station.

2) Selecting the scan duration and determine the period between each reading, and select the period 8-hour divided into 1 second to read the data.

3) Connect the device to the feeder and start recording readings.

4) Disconnect the device after finish of the examination period.

5) Collect the reading from the device and transfer to the computer.

6) Analysis the reading data.

3.2 Data collection

The first step after recording the data is to transfer it to the computer, to obtain the required data in this study such as Voltage, current, Frequency, power, energy, power factor (PF), total harmonic distortion voltage (THDV), total harmonic distortion current (THDI), all harmonics from fundamental to the fifteen harmonics.

The electrical compensation of the university consists a 1000 KVA rating transformer, which Feeding from the 11 KV distribution system and feeds the university with its needed energy as. the transformer data sheet is existing in Appendix A. the output of the transformer is feed the main electrical busbar and the main busbar are feed the main four building in the university (A, B, B+, C) and the mosque as shown in the ETAP circuit in figure 3.2.

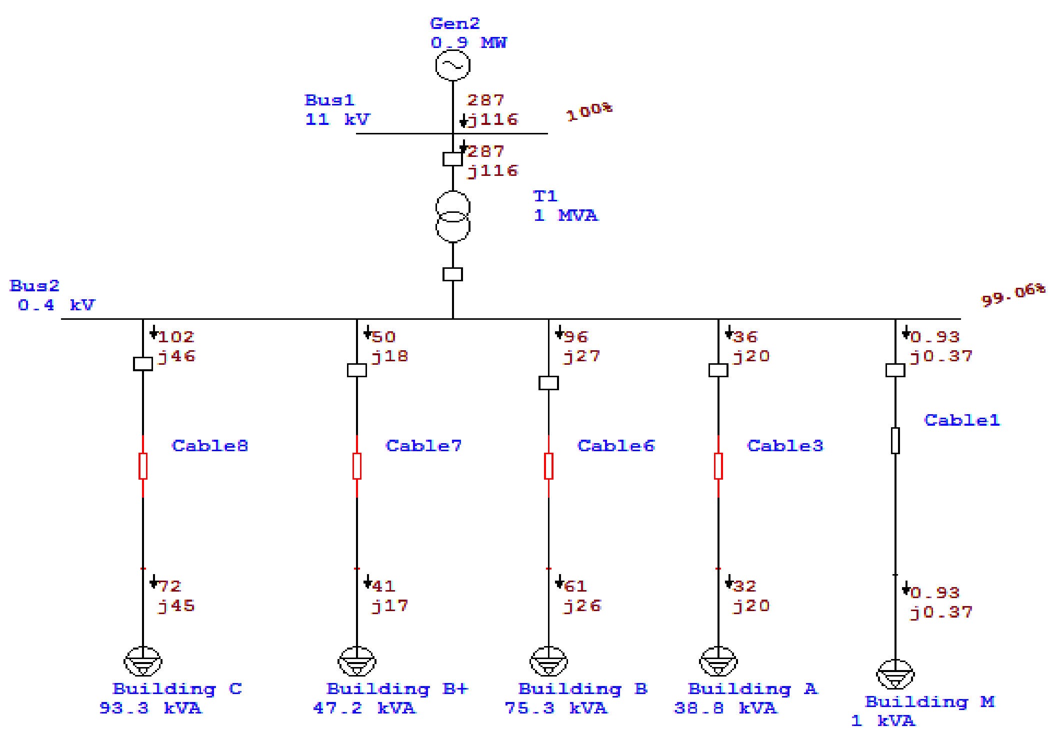


Figure 3.2: ETAP circuit for electrical single line diagram of the Palestine polytechnic university

The data of electrical components are shown in the AutoCAD drawing in the figure 3.3.

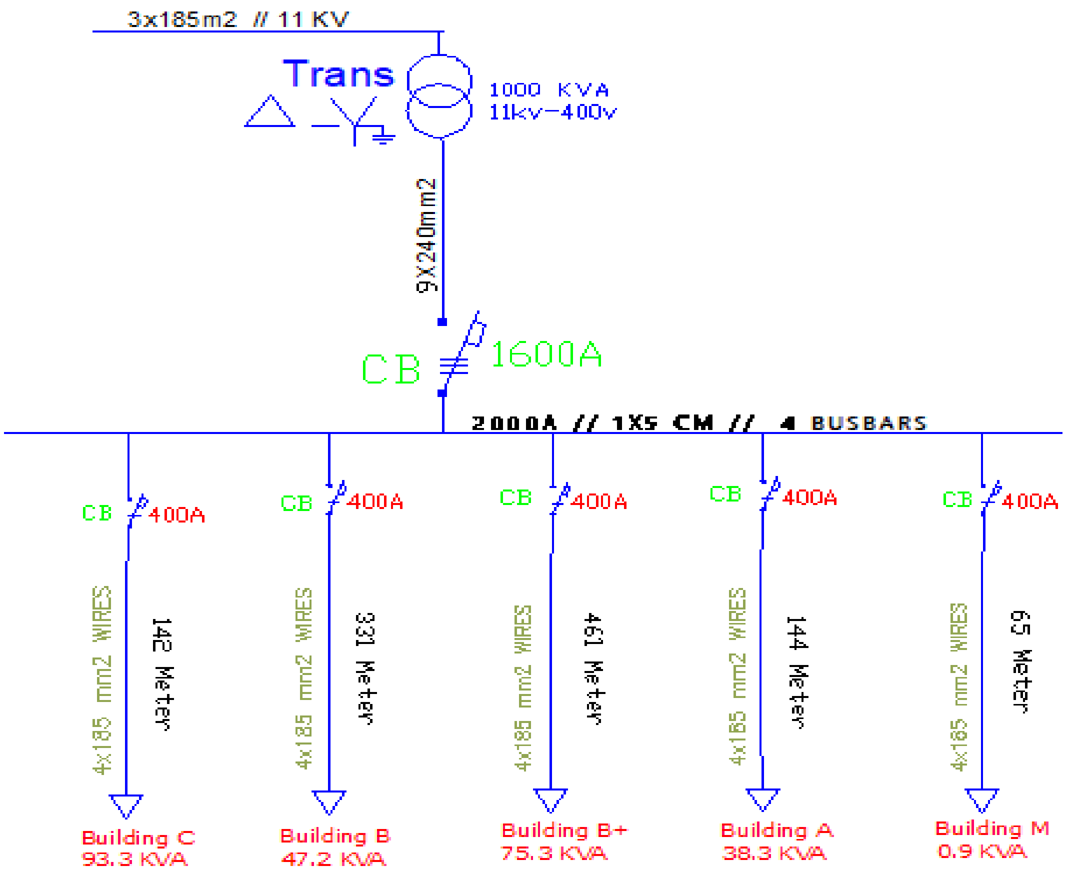


Figure 3.3: AutoCAD drawing for electrical single line diagram of the Palestine polytechnic university.

The information of the transformer, circuit breaker, cables, length of the cables and loads are collect by us.

The collect data in our project are begin to measure the power analysis parameter on the main feeder for a whole week, and then we branch to each sub feeders each one measure it also for a week, the data tables that we are collect are in Appendix B.

3.3 Data analysis

After collection the data that it need to analysis to discover the problem in the system, we begin to classification the harmonics according to the IEEE std 519-1992 and determine if there are a problem or not. We draw the result that we get by using MATLAB and Microsoft excel programs.

3.3.1 Data analysis for main feeder

3.3.1.1 total harmonic distortion(THD) for main feeder

The ratio of the total harmonic distortion in the main feeder which its voltage is below 69 KV according to the Table 2.1 shouldn't exceed for Individual Voltage Distortion (3%), and for Total Voltage Distortion THD shouldn't exceed (5%).

The result that We got are shown in the Figure 3.4 ,3.5 and Table 3.1

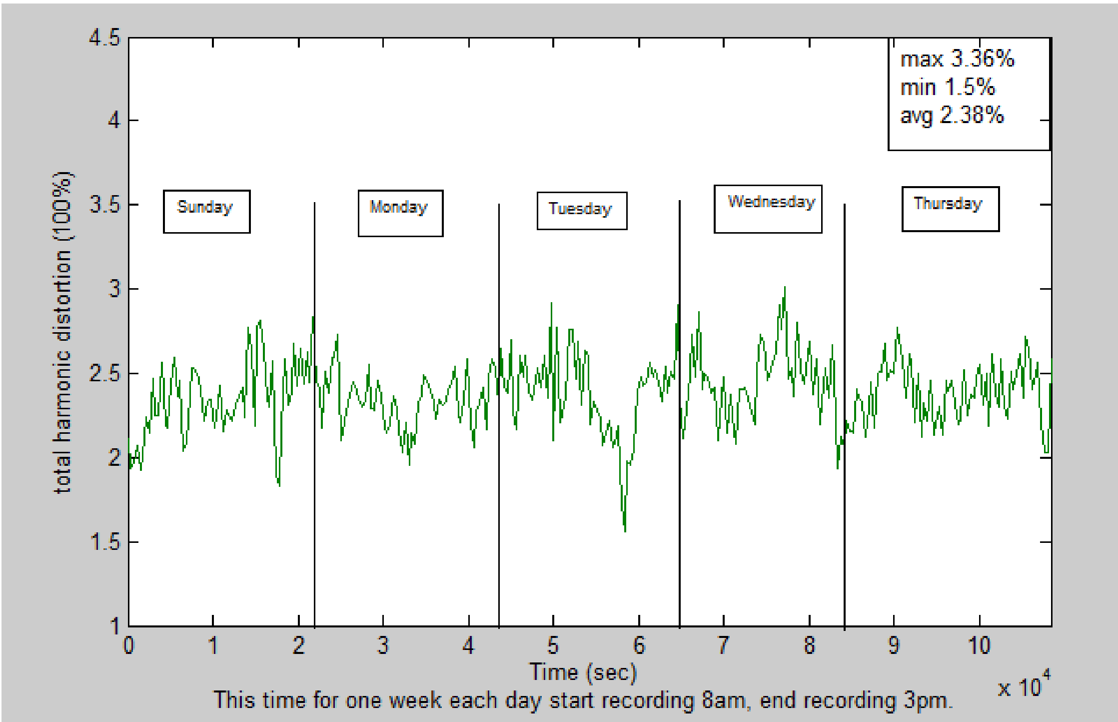


Figure 3.4: total harmonic distortion for main feeder

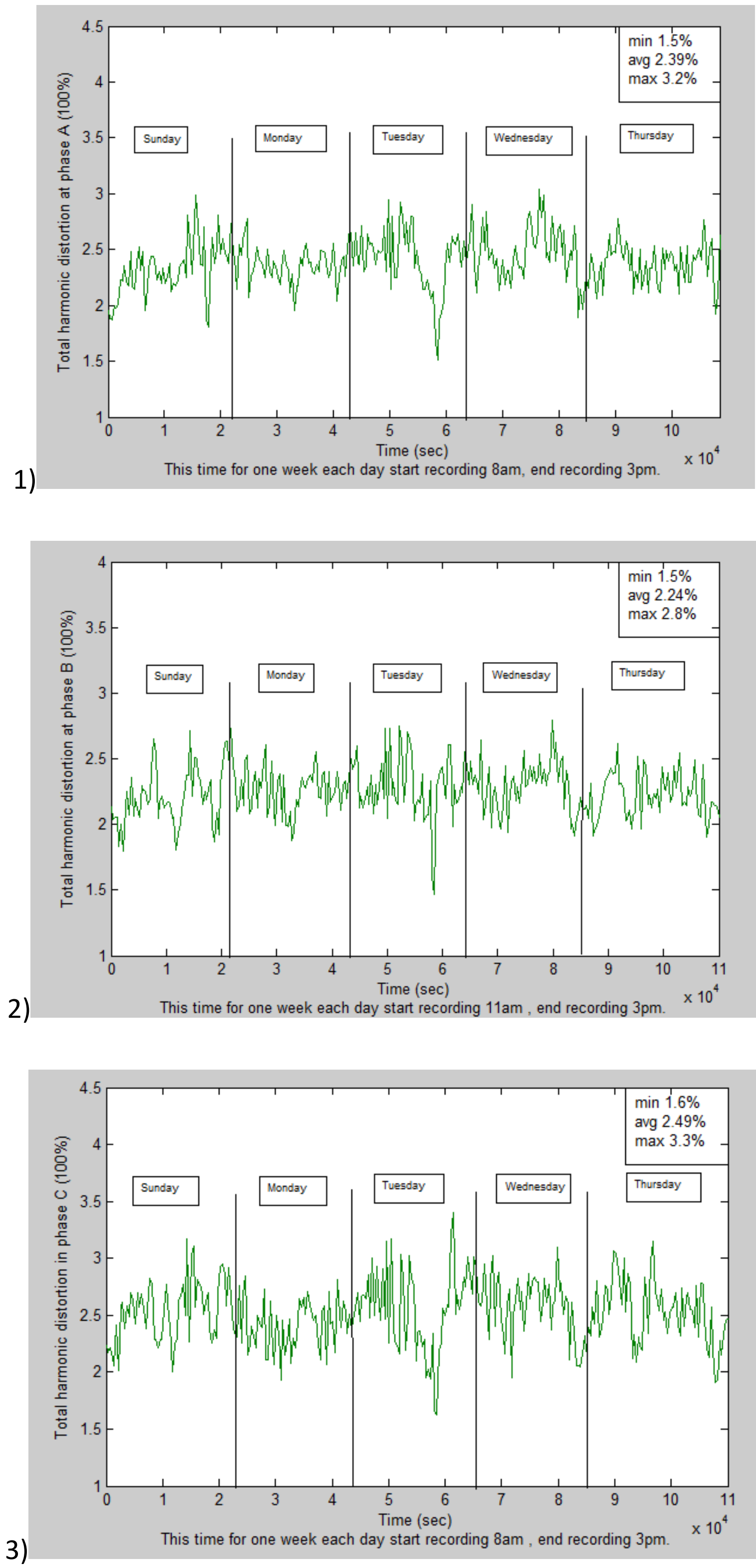


Figure 3.5: total harmonic distortion for main feeder 1) phase A 2) phase B 3) phase C

Table 3.1: Percentage THD (voltage) in main feeder.

Phase / THD %(voltage)	Va	Vb	Vc	total	voltage distortion limits
Maximum THD	3.2	2.8	3.3	3.36	5%
Minimum THD	1.5	1.45	1.6	1.49	5%
Average	2.39	2.24	2.49	2.38	5%

3.3.1.1 total demand distortion(TDD) for main feeder

The value of (TDD) are calculated according to the 2.11 and the average demand current (I_L) for the main feeder can be calculated by using 2.14 and Table 3.2.

Table 3.2: the energy consumed by the university over part of 2016 and 2017 **year**

the monthly bill	energy consumed (KWH)
4-2016	72000
5-2016	57600
6-2016	46400
7-2016	36800
8-2016	60160
9-2016	56320
10-2016	58560
11-2016	64000
12-2016	70400
1-2017	68800
2-2017	90560
3-2017	73600

$$\text{total power consumed yearly} = \begin{matrix}(72000 + 57600 + 46400 + \\ 36800 + 60160 + 56320 + \\ 58560 + 64000 + 70400 + \\ 68800 + 90560 + 73600)\end{matrix} = 755200\ kwh$$

$$\text{power consumed} = \frac{755200kwh/y}{8760h/y} = 86.21kw$$

$$\text{Utilization factor for Palestine polytechnic university} = \frac{(\mathbf{288}\boldsymbol{day/y})*(\mathbf{10}\frac{\boldsymbol{hours}}{\boldsymbol{day}})}{\mathbf{8760}\ \boldsymbol{hours/y}} = 0.329$$

$$I_{L\ average} = \frac{KW}{PF * \sqrt{3} * KV} = \frac{86.21}{0.9 * \sqrt{3} * 400} = 138.25\ A$$

$$I_L\ actual = \frac{I_L}{\text{Utilization factor}} = \frac{138.25}{0.329} = 420\ A$$

The short circuit current (I_{SC})for the main feeder can be calculated by using 2.12.

$$I_{SC} = \frac{1000*MVA}{\sqrt{3}*KV}$$

$$MVA = \frac{MVA_{\ rated}}{z_{pu}} = \frac{1}{0.05} = 20$$

The z_{pu} are obtain from

$$I_{SC} = \frac{1000*MVA}{\sqrt{3}*KV} = \frac{1000*20}{\sqrt{3}*400} = 28.867\text{KA}$$

short circuit ration of the system are calculated from 2.15

$$\text{short circuit ration} = \frac{I_{SC}}{I_L} = \frac{28867}{420} = 68.73$$

According to the Table 2.2 shouldn't exceed (12%).

The result that We got are shown in the Figure 3.6,3.7,3.8 and Table3.3

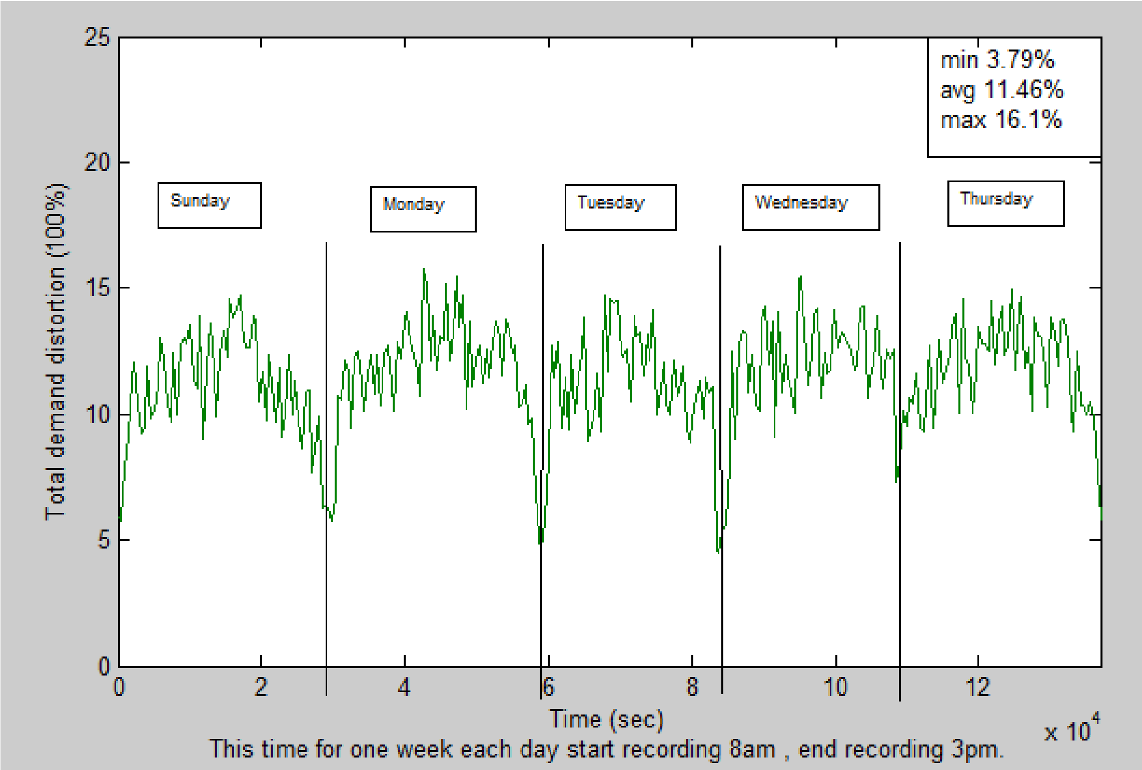
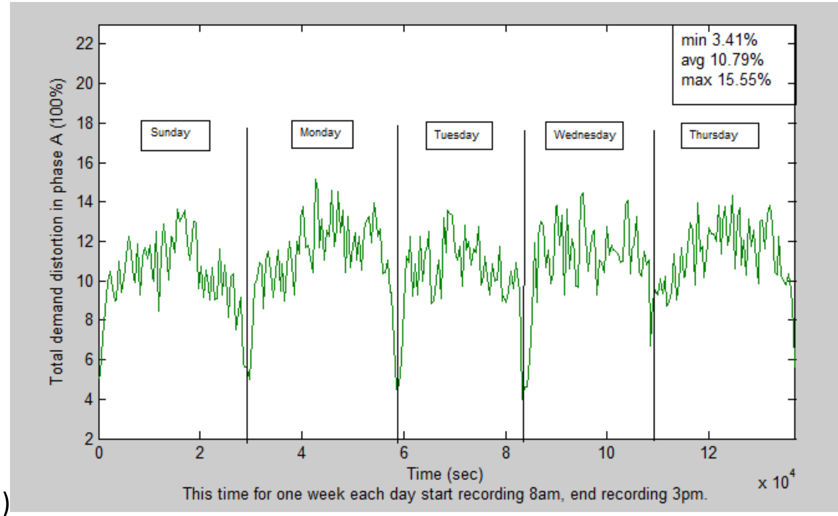
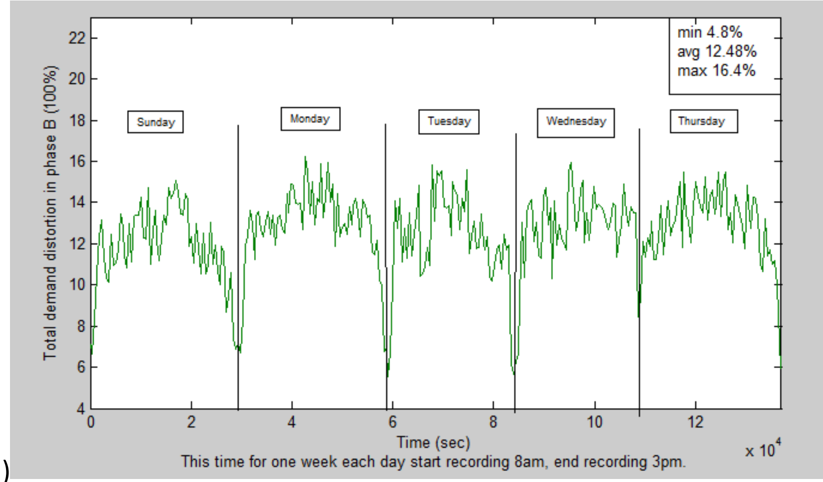


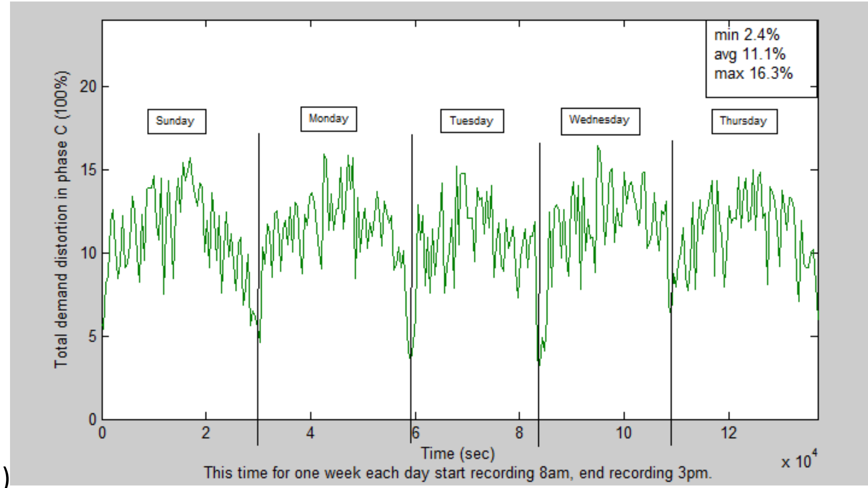
Figure 3.6: total demand distortion for main feeder



1)



2)



3)

Figure 3.7: total demand distortion for main feeder 1) phase A 2) phase B

3) phase C

Table 3.3: Percentage TDD in main feeder.

Phase / TDD %(AMBER)	Ia	Ib	Ic	total	current distortion limits
Maximum TDD	15.5	16.4	16.3	16.3	12%
Minimum TDD	3.41	4.8	2.4	3.79	12%
Average	10.79	12.48	11.1	11.46	12%

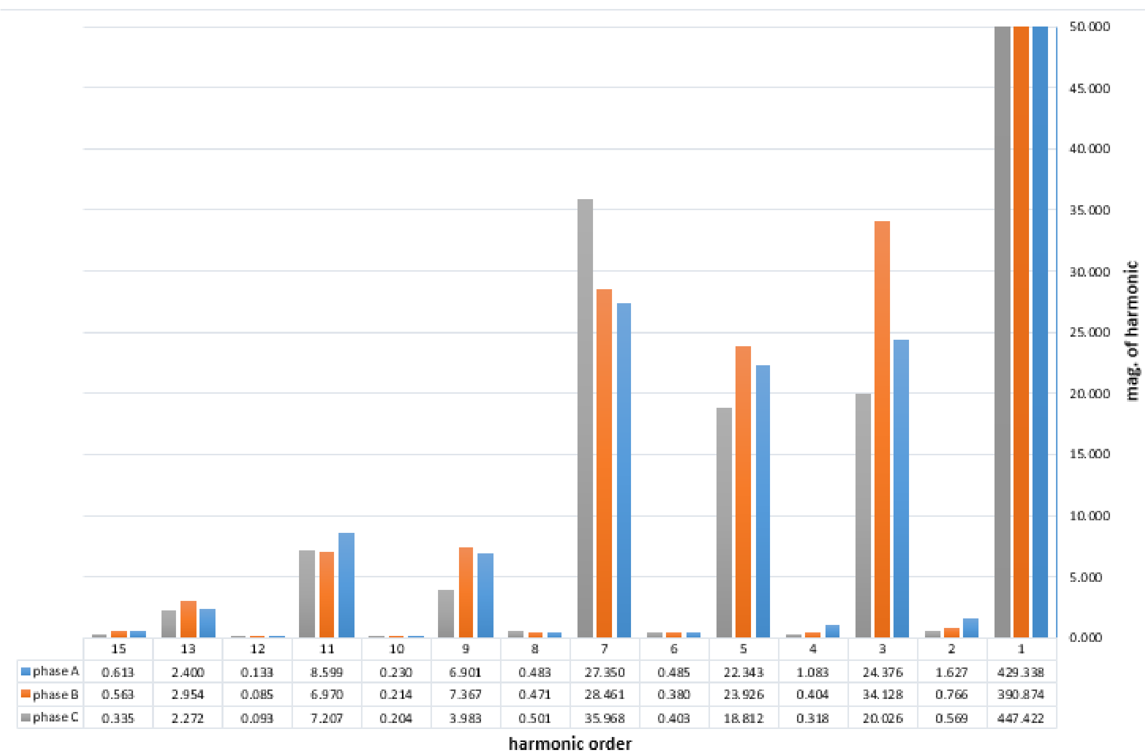


Figure 3.8: The harmonic order according to their magnitude of harmonic for the three phases of main feeder

3.3.2 Data analysis for sub feeders

3.3.2.1 Data analysis for Building A

3.3.2.1.1 total harmonic distortion(THD) for Building A

The ratio of the total harmonic distortion in the main feeder which its voltage is below 69 KV according to the Table 2.1 shouldn't exceed for Individual Voltage Distortion (3%), and for Total Voltage Distortion THD shouldn't exceed (5%).The result that We got are shown in the Figure 3.9 ,3.10 and Table 3.4

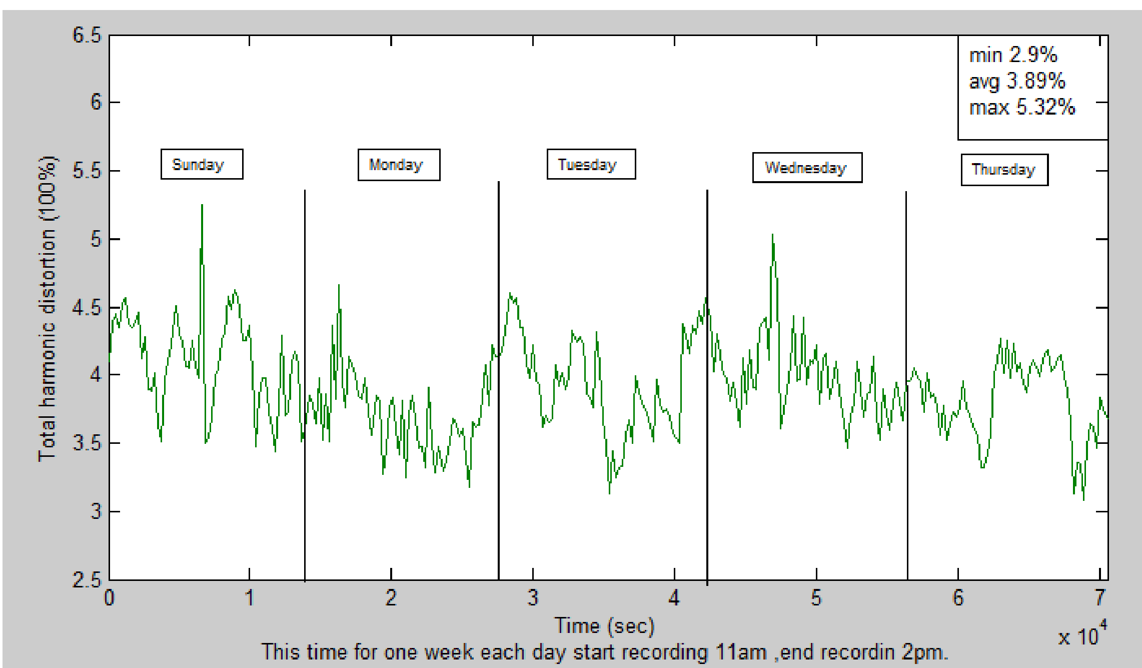


Figure 3.9: total harmonic distortion for Building A

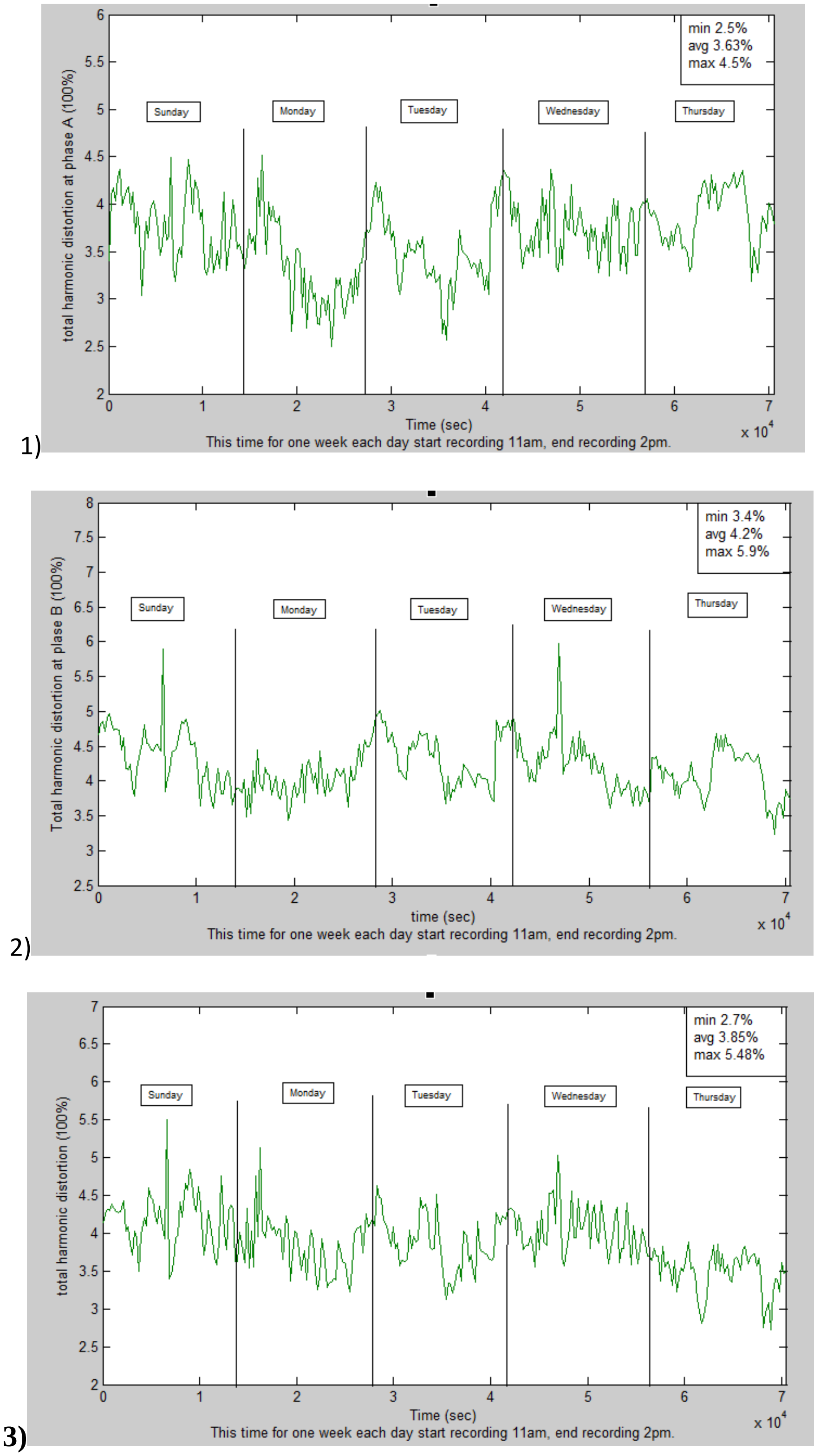


Figure 3.10: total harmonic distortion for building A 1) phase A 2) phase B 3) phase C

Table 3.4: Percentage THD (voltage) in Building A.

Phase / THD %(voltage)	Va	Vb	Vc	total	voltage distortion limits
Maximum THD	4.5	5.9	5.48	5.32	5%
Minimum THD	2.5	3.4	2.7	2.9	5%
Average	3.63	4.2	3.85	3.89	5%

3.3.2.1.2 total demand distortion(TDD) for Building A

The value of (TDD) are calculated according to the 2.11 and the average demand current (I_L) for building A we take it by take the average value of the load current of building A. The ratio of the total demand distortion in the main feeder which its (ISC / I_L) according to the Table 2.2 shouldn't exceed (12%).The result that We got are shown in the Figure 3.11,3.12,3.13,3.14 and Table 3.7

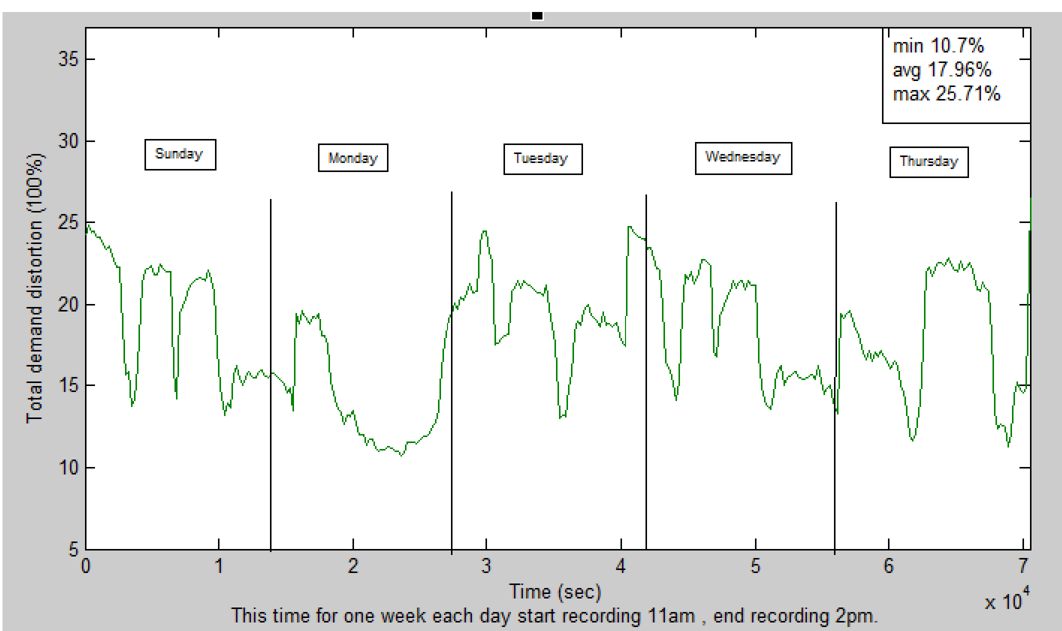
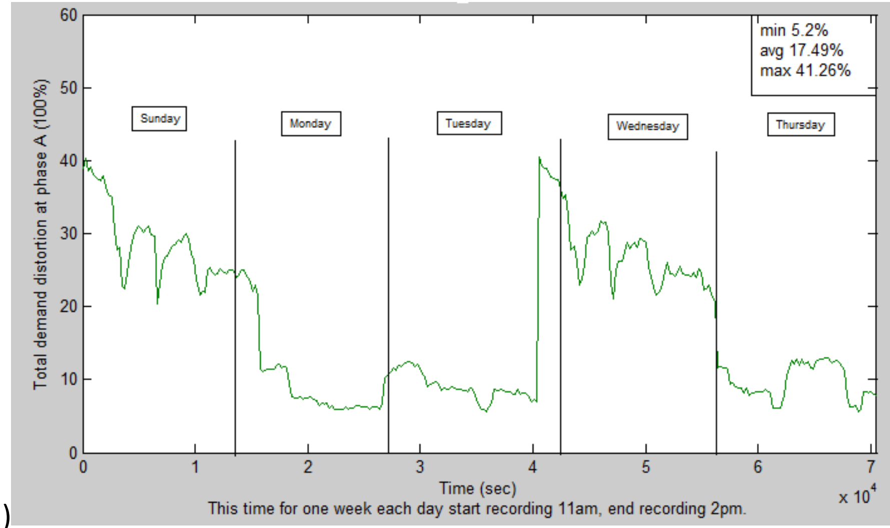
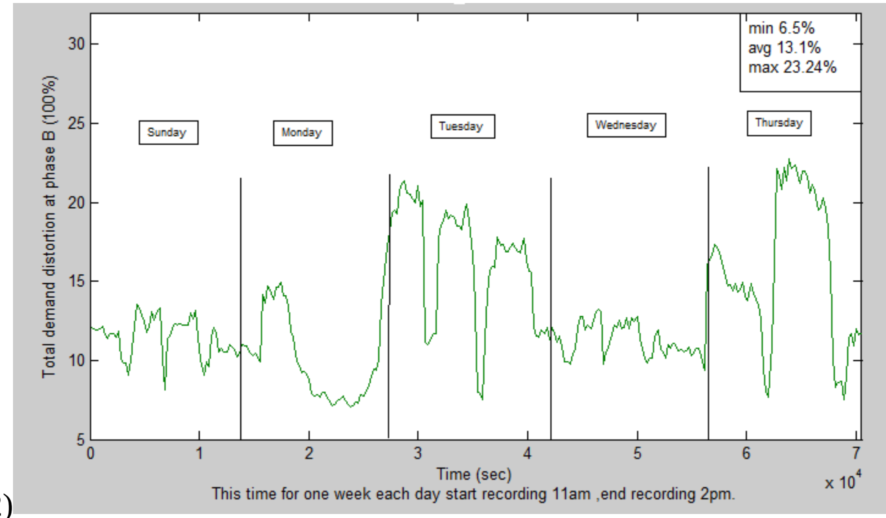


Figure 3.11: total demand distortion for Building A

1) 

2) 

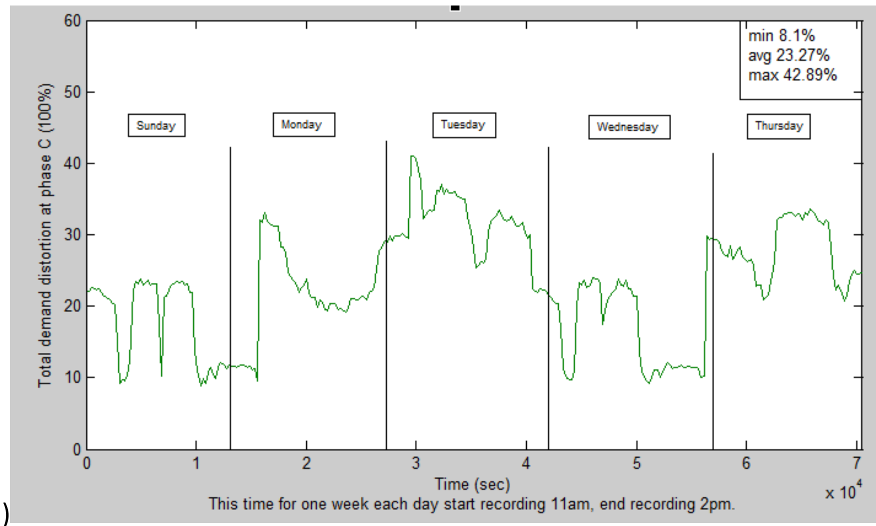
3) 

Figure 3.12: total demand distortion for building A 1) phase A 2) phase B 3) phase C

Table 3.5: Percentage TDD in Building A.

Phase / TDD %(AMBER)	Ia	Ib	Ic	total	current distortion limits
Maximum TDD	41.26	23.24	42.89	25.7	12%
Minimum TDD	5.2	6.5	8.1	10.7	12%
Average	17.49	13.1	23.27	17.9	12%

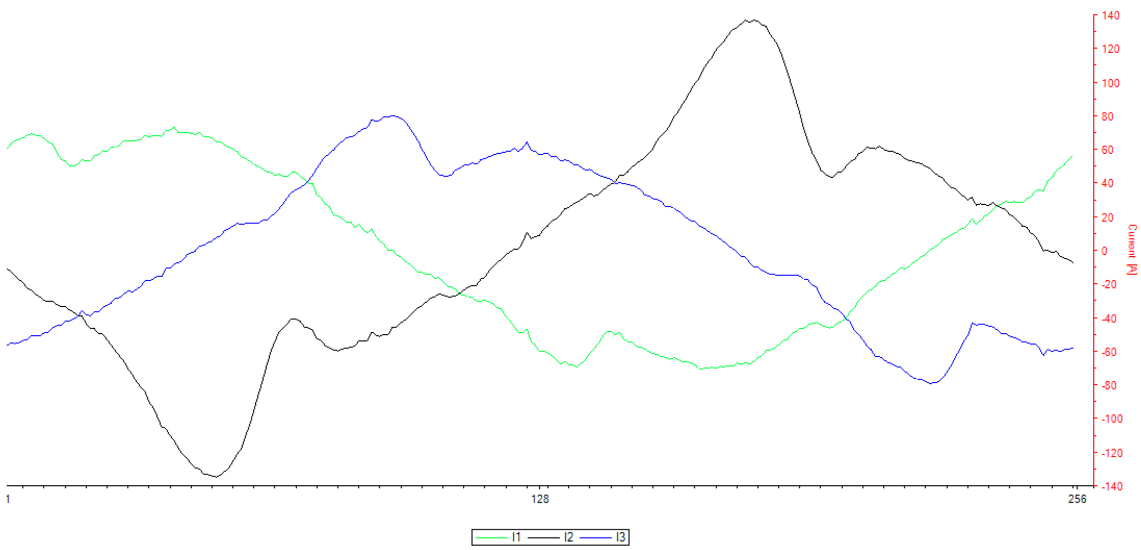
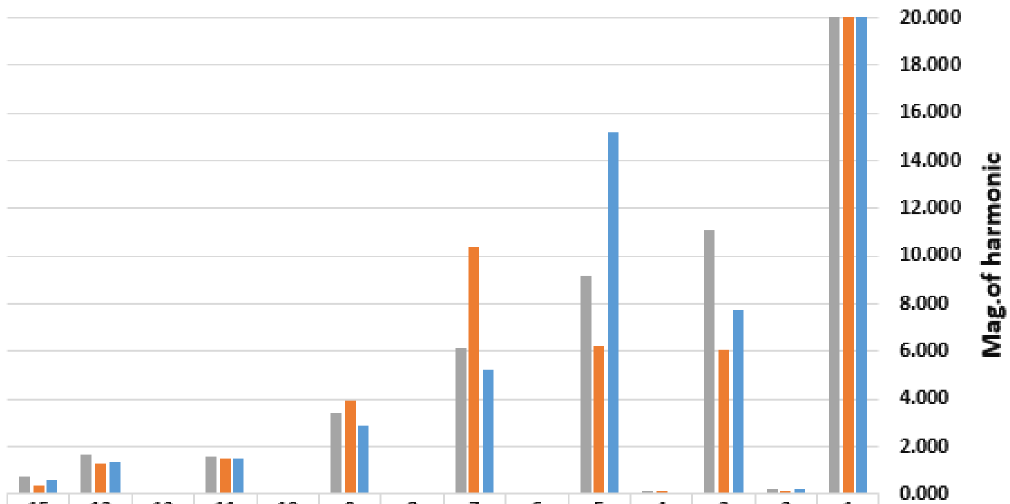


Figure 3.13: The three phases signal for the Building A



	15	13	12	11	10	9	8	7	6	5	4	3	2	1
phase A	0.626	1.355	0.034	1.535	0.041	2.900	0.040	5.216	0.053	15.200	0.082	7.722	0.207	61.512
phase B	0.381	1.276	0.050	1.544	0.057	3.965	0.062	10.421	0.099	6.250	0.148	6.103	0.178	53.497
phase C	0.770	1.694	0.056	1.622	0.075	3.390	0.080	6.124	0.085	9.188	0.121	11.049	0.183	60.449

Harmonic order

Figure 3.14: The harmonic order according to their magnitude of harmonic for the three phases of building A

3.3.2.2 Data analysis for Building B

3.3.2.2.1 total harmonic distortion(THD) for Building B

The ratio of the total harmonic distortion in the main feeder which its voltage is below 69 KV according to the Table 2.1 shouldn't exceed for Individual Voltage Distortion (3%), and for Total Voltage Distortion THD shouldn't exceed (5%).

The result that We got are shown in the Figure 3.15 ,3.16 and Table 3.6

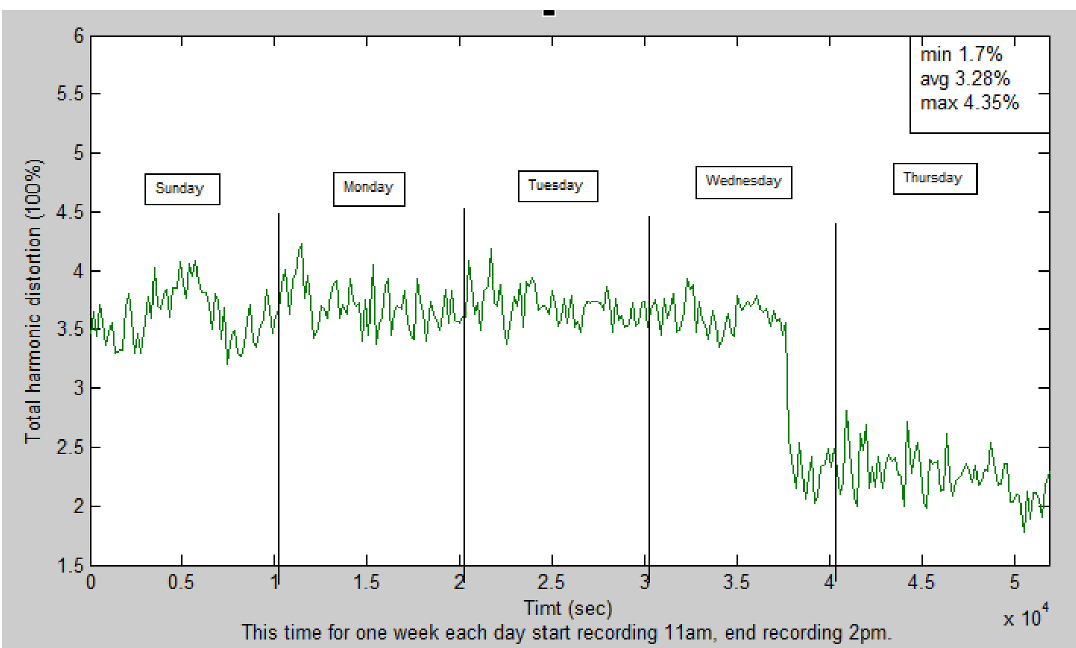


Figure 3.15: total harmonic distortion for Building B

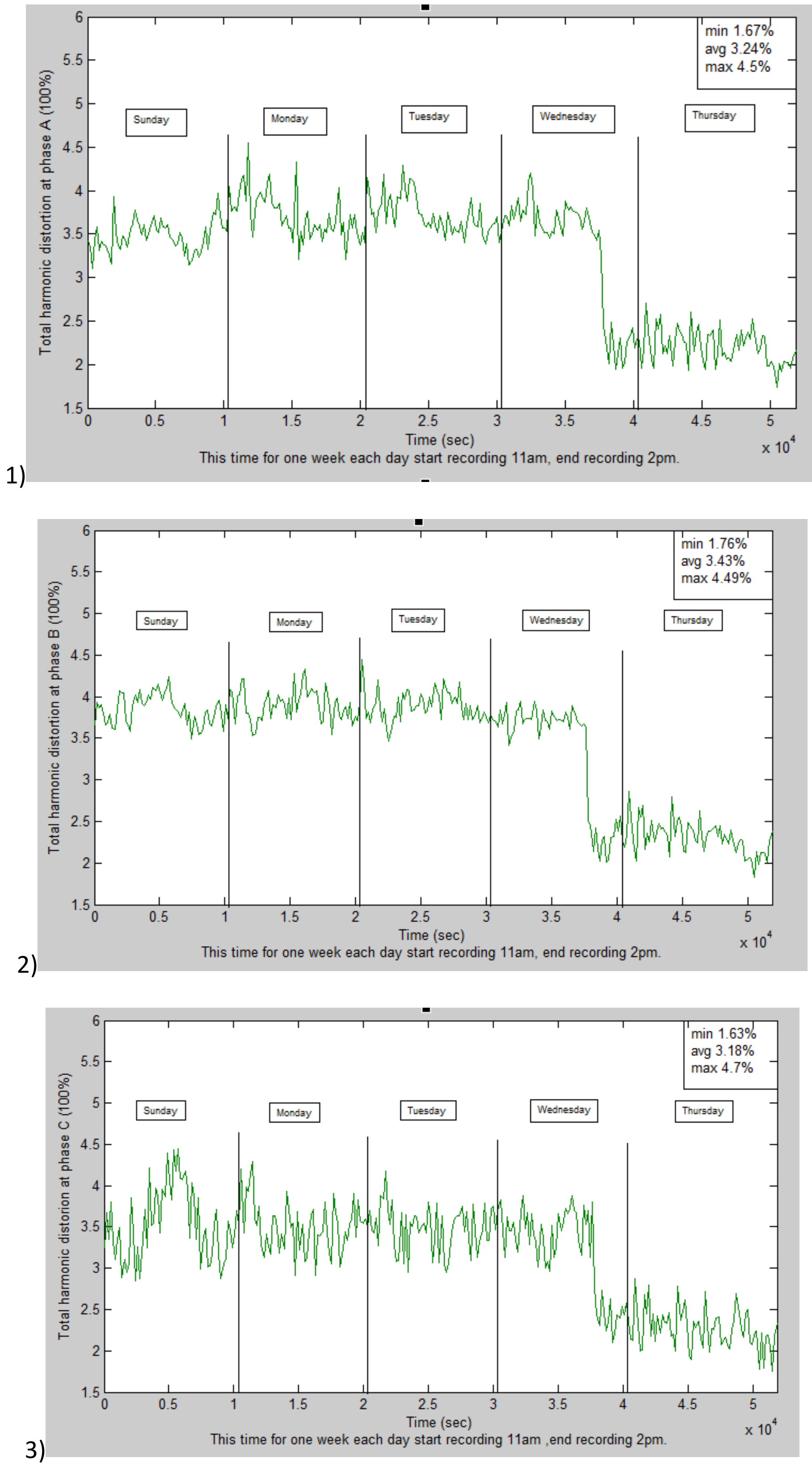


Figure 3.16: total harmonic distortion for building B 1) phase A 2) phase B 3) phase C

Table 3.6: Percentage THD (voltage) in Building B.

Phase THD %(voltage)	Va	Vb	Vc	total	voltage distortion limits
Maximum THD	4.5	4.49	4.7	4.35	5%
Minimum THD	1.67	1.76	1.63	1.70	5%
Average	3.24	3.43	3.18	3.28	5%

3.3.2.2.2 total demand distortion(TDD) for Building B

The value of (TDD) are calculated according to the 2.11 and the average demand current (I_L) for building B we take it by take the average value of the load current of building B. The ratio of the total demand distortion in the main feeder which its (ISC / I_L) according to the Table 2.2 shouldn't exceed (12%).

The result that We got are shown in the Figure 3.17,3.18,3.19,3.20 and Table 3.7

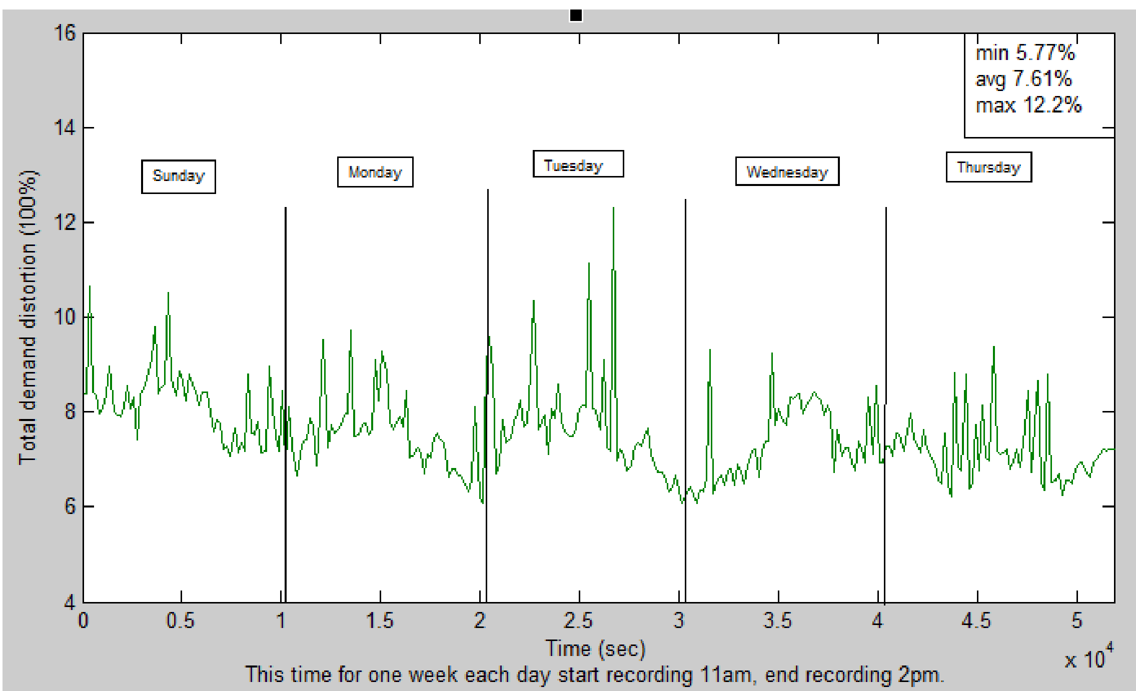


Figure 3.17: total demand distortion for Building B

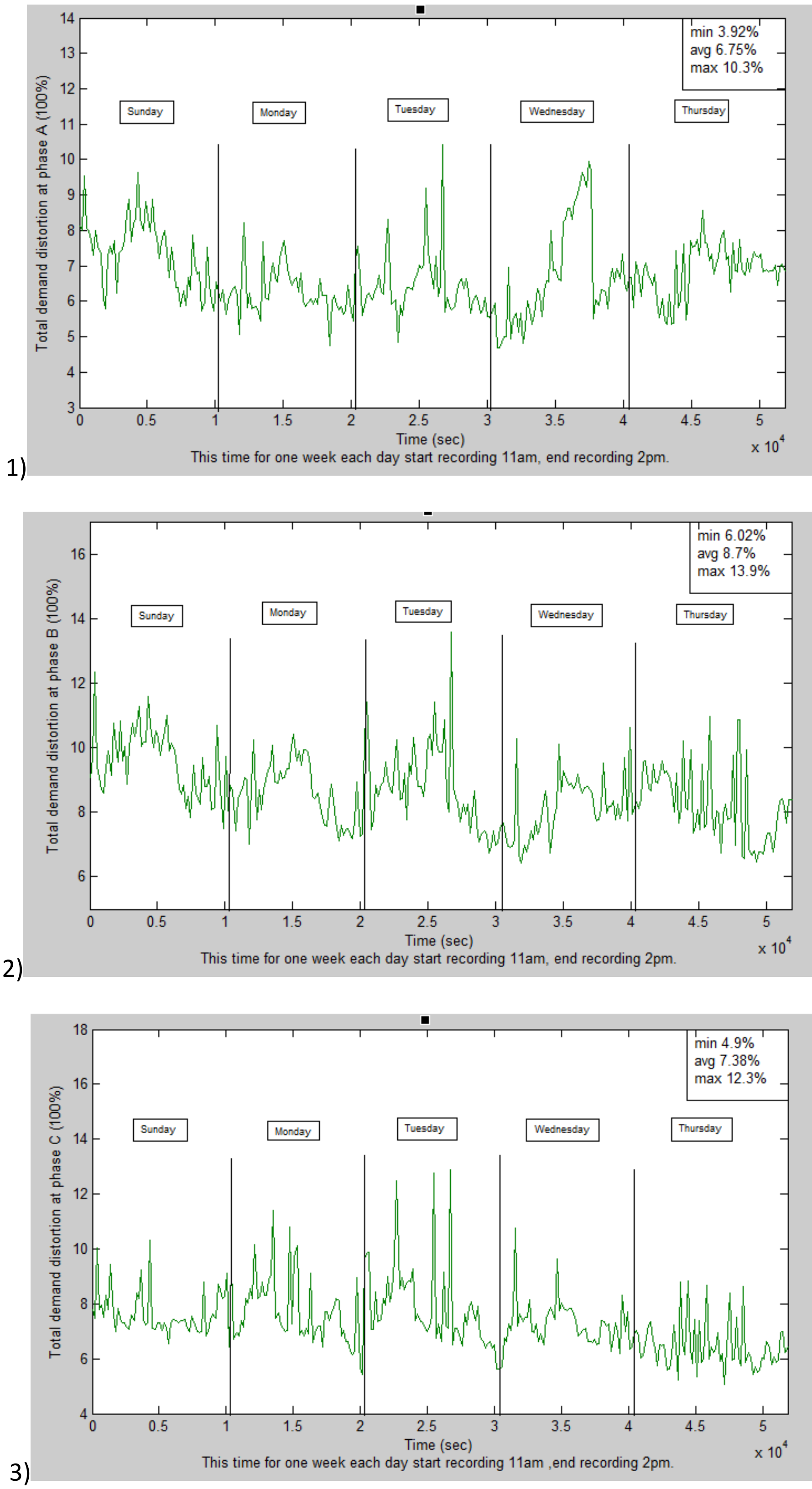


Figure 3.18: total demand distortion for building B 1) phase A 2) phase B 3) phase C

Table 3.7: Percentage TDD in Building B.

Phase TDD %(AMBER)	Ia	Ib	Ic	total	current distortion limits
Maximum TDD	10.3	13.9	12.3	12.2	12%
Minimum TDD	3.92	6.02	4.9	5.77	12%
Average	6.75	8.7	7.38	7.61	12%

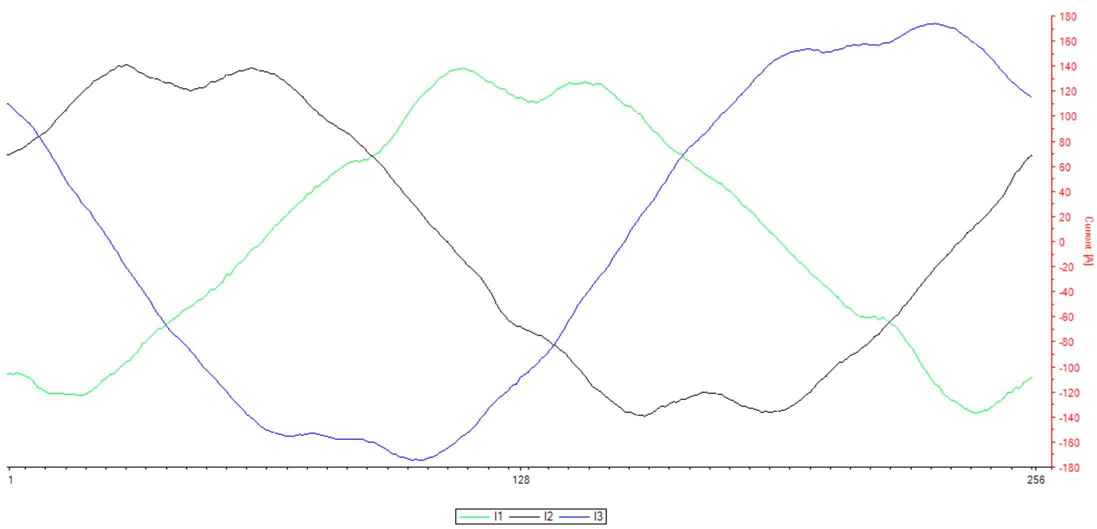
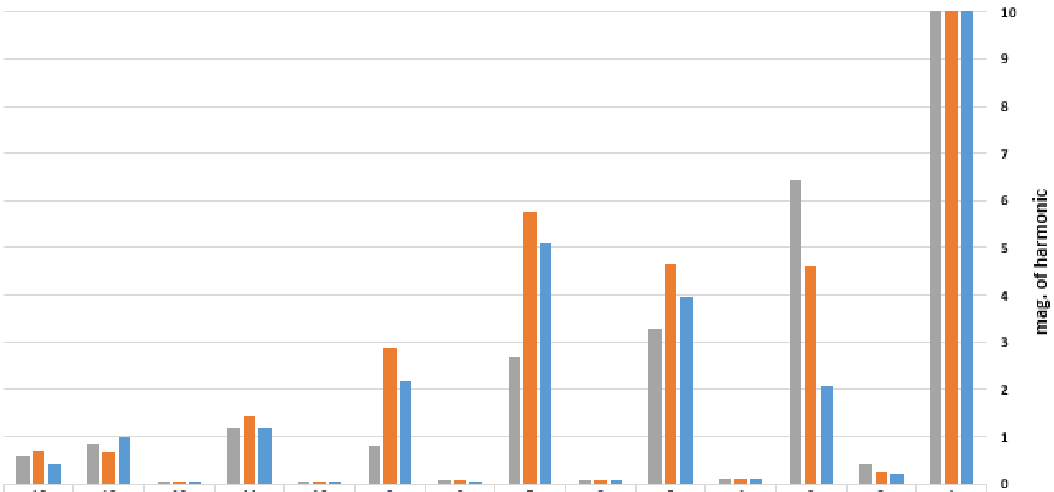


Figure 3.19: The three phases signal for the Building B



	15	13	12	11	10	9	8	7	6	5	4	3	2	1
phase A	0.433168	0.9968319	0.0304087	1.1911805	0.039294	2.1564328	0.0474363	5.0887537	0.0670517	3.9563752	0.1092028	2.0791608	0.2226001	100.63475
phase B	0.6902619	0.6744426	0.0323405	1.446416	0.0599613	2.8772681	0.0772264	5.7664103	0.0762995	4.6471492	0.1045879	4.6102049	0.2496574	99.557829
phase C	0.5890289	0.8442238	0.045755	1.1968639	0.0446983	0.8279566	0.0713416	2.6801144	0.0623832	3.2950325	0.1244907	6.4364831	0.4436953	113.67106

harmonic order

Figure 3.20: The harmonic order according to their magnitude of harmonic for the three phases of building B

3.3.2.3 Data analysis for Building B+

3.3.2.3.1 total harmonic distortion(THD) for Building B+

The ratio of the total harmonic distortion in the main feeder which its voltage is below 69 KV according to the Table 2.1 shouldn't exceed for Individual Voltage Distortion (3%), and for Total Voltage Distortion THD shouldn't exceed (5%).

The result that We got are shown in the Figure 3.21,3.22 and Table 3.8

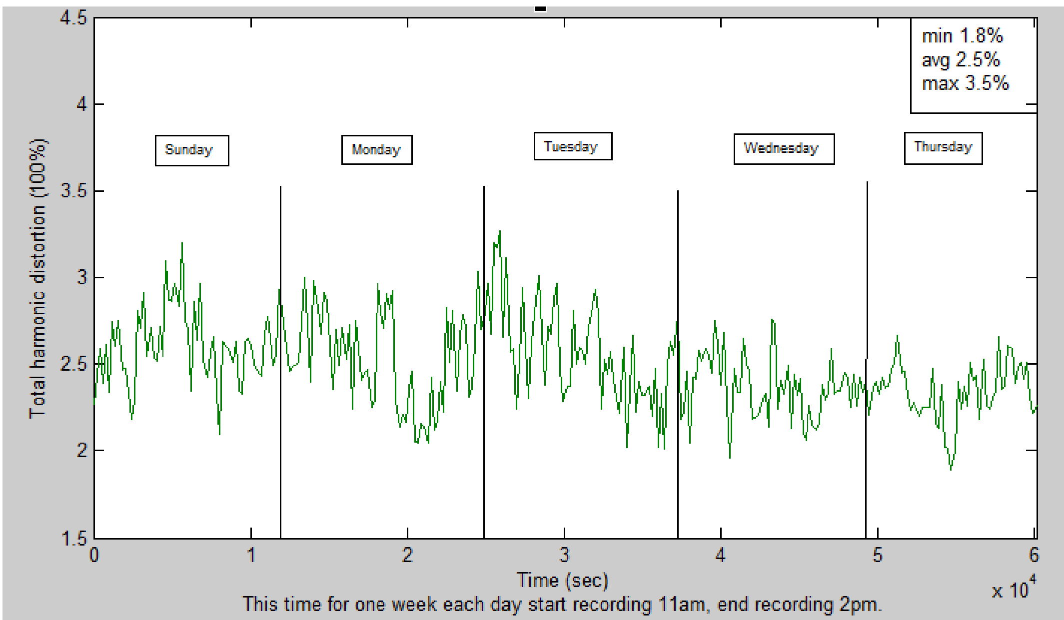


Figure 3.20: total harmonic distortion for Building B+

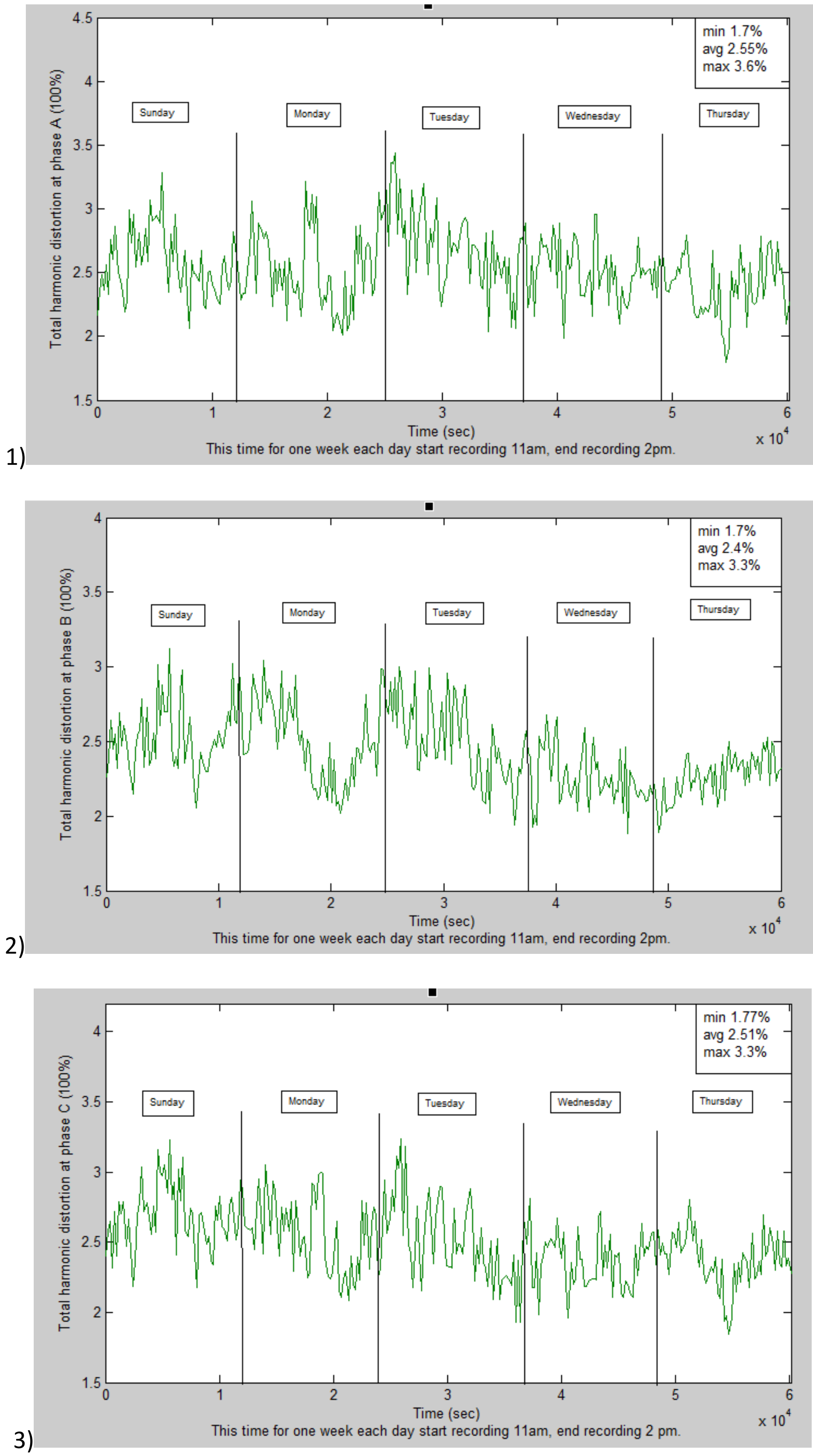


Figure 3.21: total harmonic distortion for building B+ 1) phase A 2) phase B 3) phase C

Table 3.8: Percentage THD (voltage) in Building B+.

Phase / THD %(voltage)	Va	Vb	Vc	total	voltage distortion limits
Maximum THD	3.6	3.3	3.3	3.5	5%
Minimum THD	1.7	1.7	1.77	1.8	5%
Average	2.55	2.4	2.51	2.5	5%

3.3.2.3.2 total demand distortion(TDD) for Building B+

The value of (TDD) are calculated according to the 2.11 and the average demand current (I_L) for building B+ we take it by take the average value of the load current of building B+

The ratio of the total demand distortion in the main feeder which its (ISC / IL) according to the Table (2.2) shouldn't exceed (12%). The result that We got are shown in the Figure 3.22 ,3.23 ,3.24 ,3.25 and Table 3.9

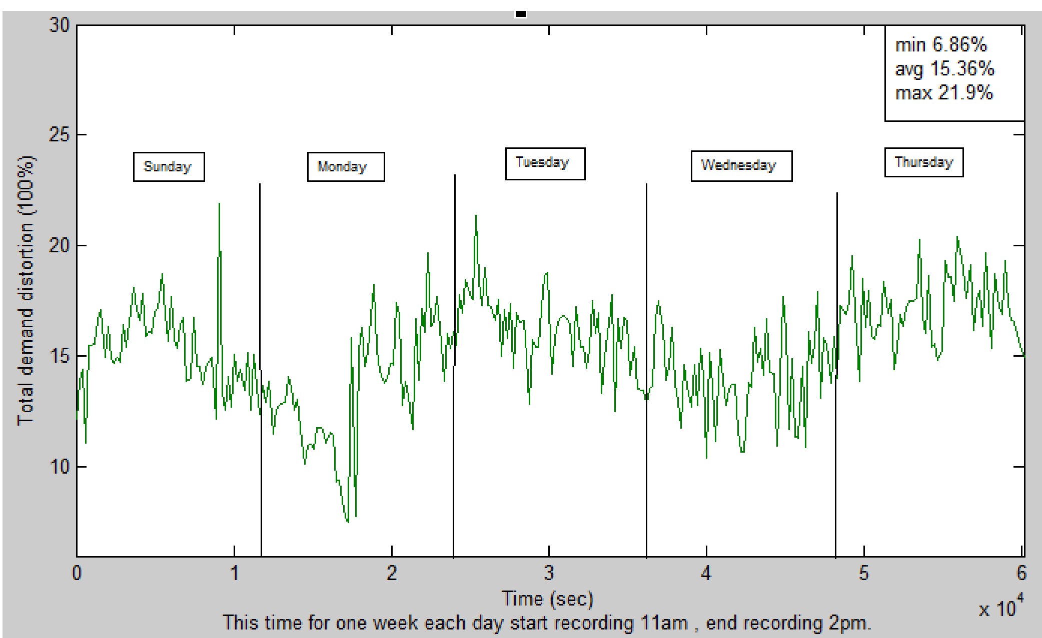


Figure 3.22: total demand distortion for Building B+

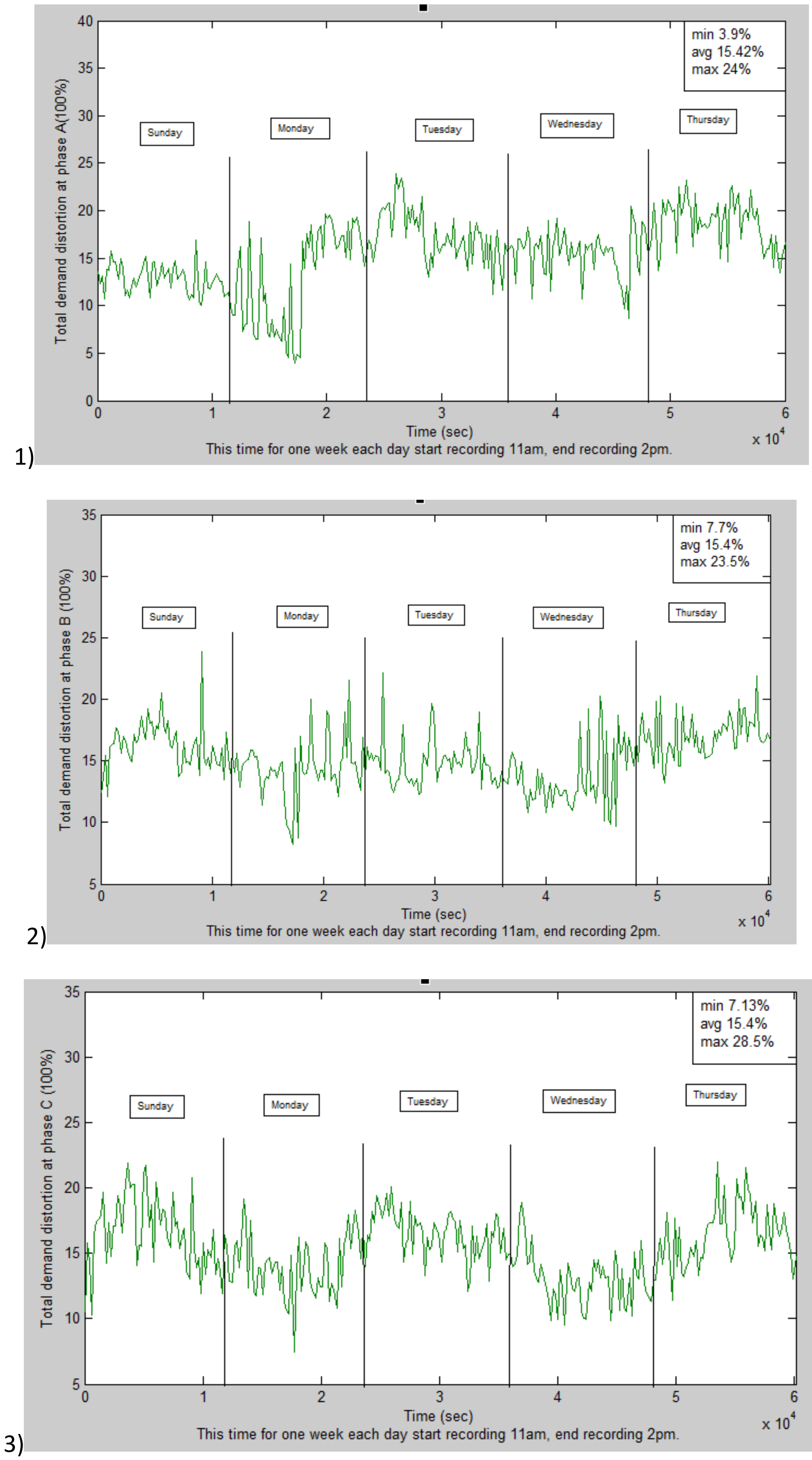


Figure 3.23: total demand distortion for building B+ 1) phase A 2) phase B 3) phase C

Table 3.9: Percentage TDD in Building B+.

Phase / TDD %(AMBER)	Ia	Ib	Ic	total	current distortion limits
Maximum TDD	24	23.5	28.5	21.9	12%
Minimum TDD	3.9	7.7	7.13	6.86	12%
Average	15.42	15.4	15.4	15.3	12%

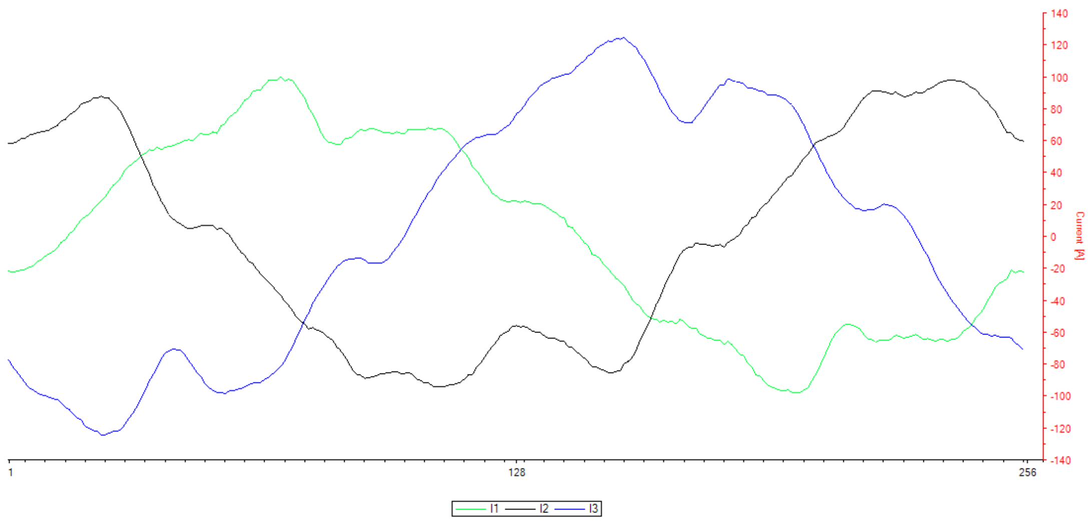
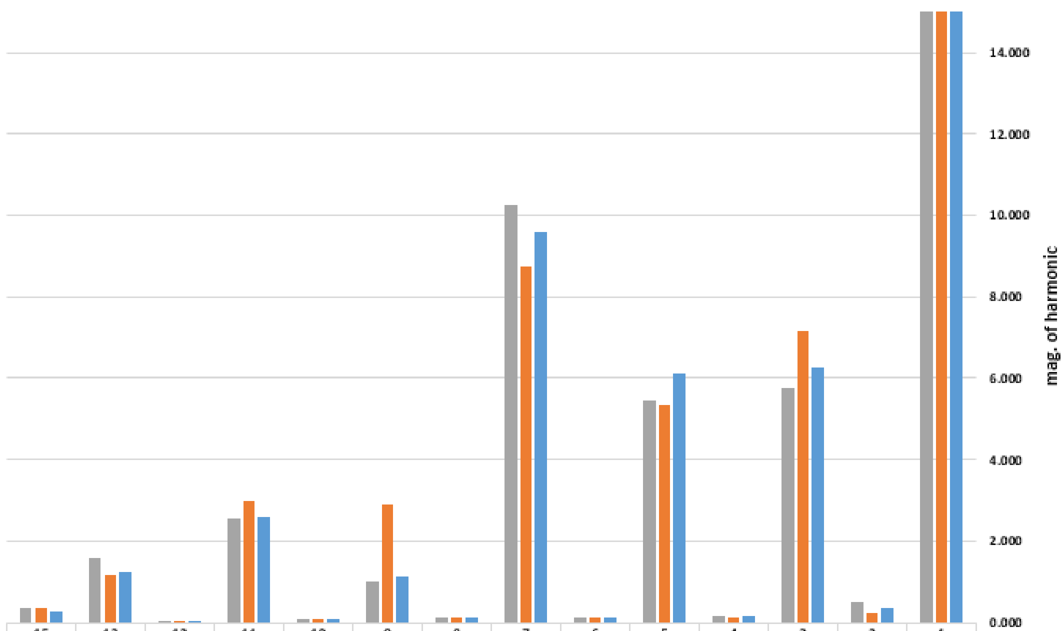


Figure 3.24: The three phases signal for the Building B+



	15	13	12	11	10	9	8	7	6	5	4	3	2	1
phase A	0.281	1.224	0.054	2.597	0.091	1.105	0.136	9.578	0.119	6.115	0.161	6.247	0.342	75.577
phase B	0.335	1.146	0.036	2.966	0.088	2.888	0.105	8.755	0.105	5.346	0.132	7.163	0.232	64.239
phase C	0.330	1.592	0.046	2.535	0.075	0.988	0.134	10.251	0.124	5.442	0.146	5.765	0.487	70.272

Figure 3.25: The harmonic order according to their magnitude of harmonic for the three phases of building B+

3.3.2.4 Data analysis for Building C

3.3.2.4.1 total harmonic distortion(THD) for Building C

The ratio of the total harmonic distortion in the main feeder which its voltage is below 69 KV according to the Table 2.1 shouldn't exceed for Individual Voltage Distortion (3%), and for Total Voltage Distortion THD shouldn't exceed (5%).

The result that We got are shown in the Figure 3.26 ,3.27 and Table 3.10

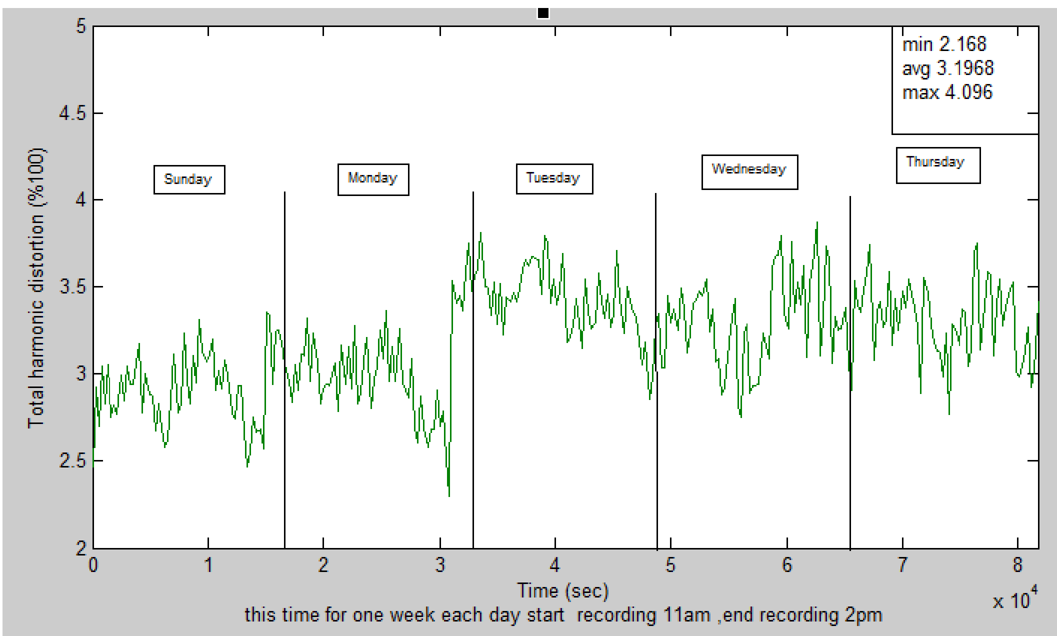


Figure 3.26: total harmonic distortion for Building C

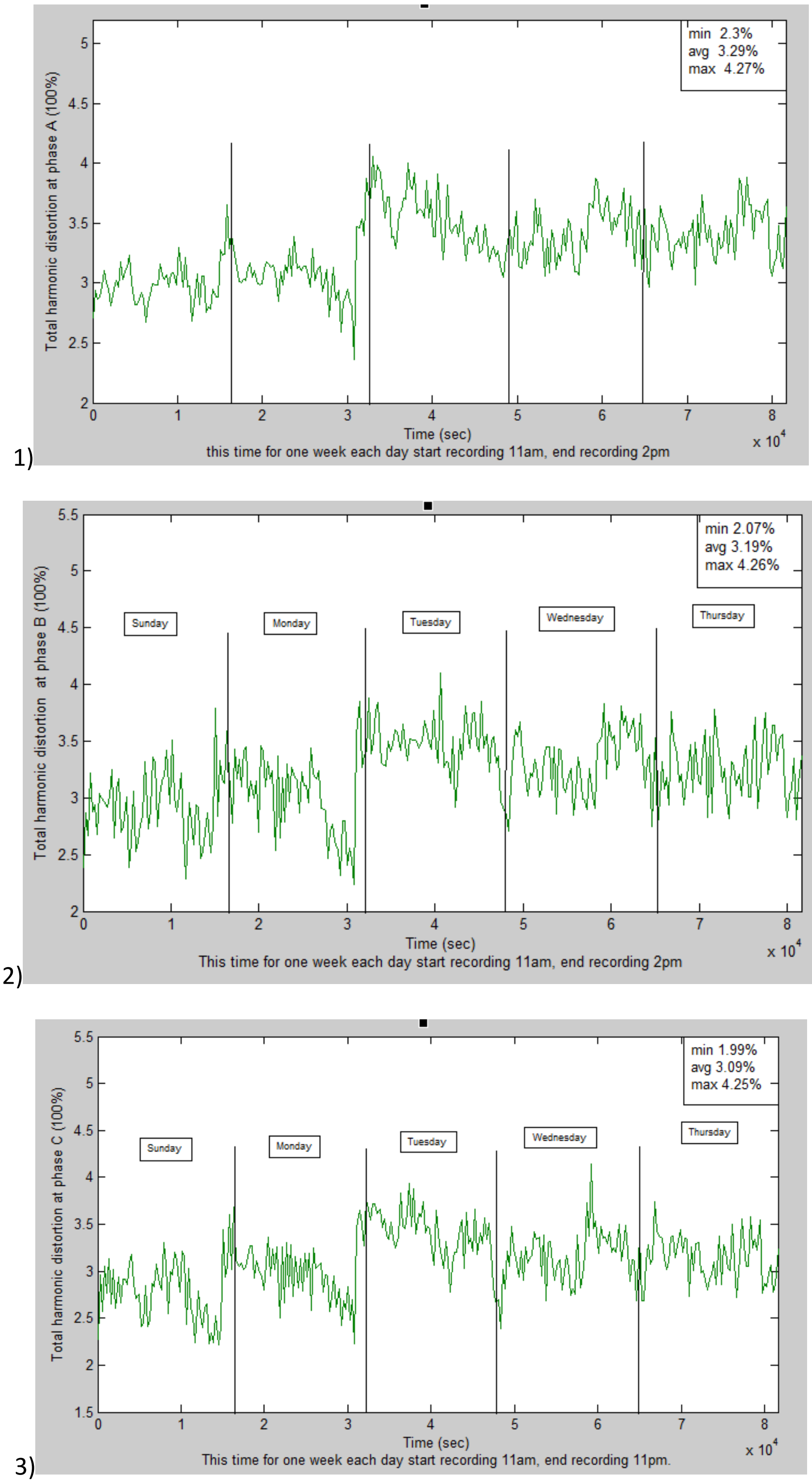
1)
2)
3)


Figure 3.27: total harmonic distortion for building C 1) phase A 2) phase B 3) phase C

Table 3.10: Percentage THD (voltage) in Building C.

Phase / THD %(voltage)	Va	Vb	Vc	total	voltage distortion limits
Maximum THD	4.27	4.26	4.25	4.09	5%
Minimum THD	2.3	2.07	1.99	2.16	5%
Average	3.29	3.19	3.09	3.19	5%

4.3.2.4.2 total demand distortion(TDD) for Building C

The value of (TDD) are calculated according to the 2.11 and the average demand current (I_L) for building C we take it by take the average value of the load current of building C. The ratio of the total demand distortion in the main feeder which its (ISC / I_L) according to the Table 2.2 shouldn't exceed (12%).

The result that We got are shown in the Figure 3.28 ,3.29 ,3.30 ,3.31 and Table 3.11

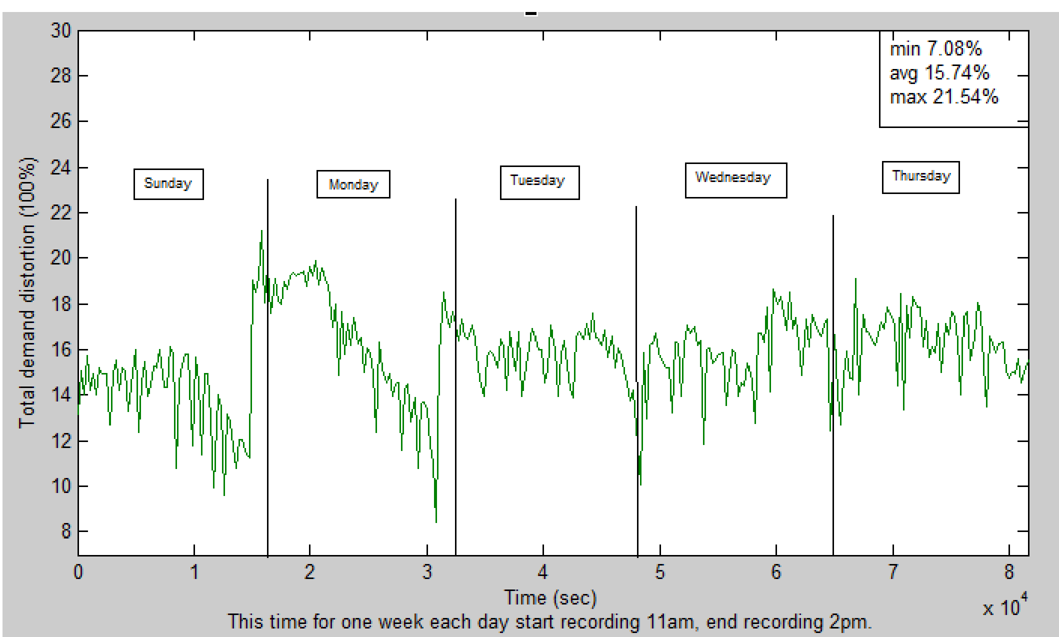
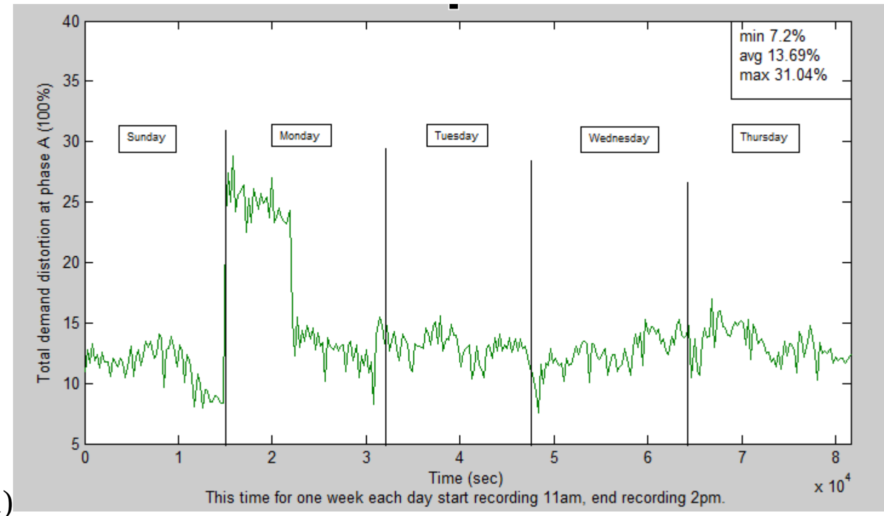
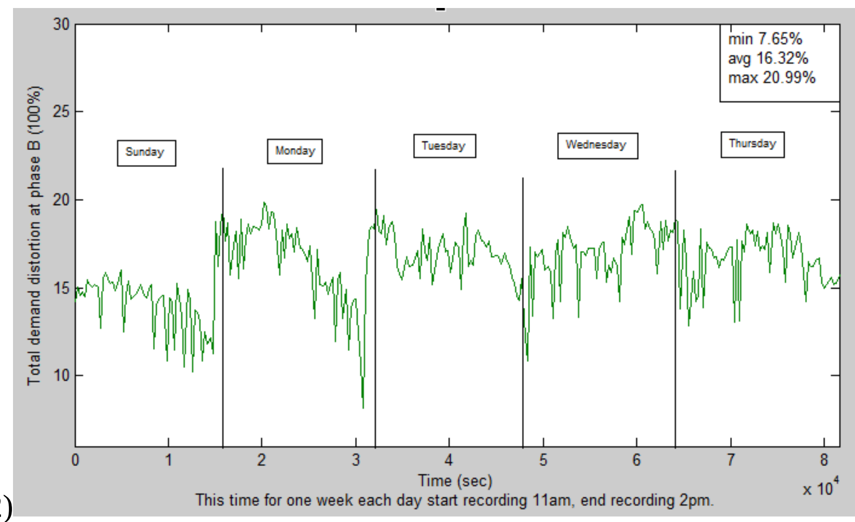


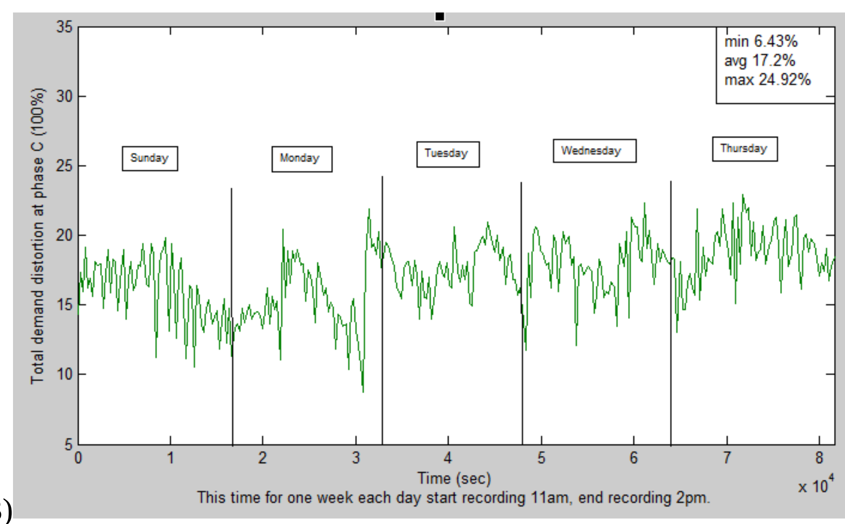
Figure 3.28: total demand distortion for Building C



1)



2)



3)

Figure 3.29: total demand distortion for building C 1) phase A 2) phase B 3) phase C

Table 3.11: Percentage TDD in Building C

Phase / TDD %(AMBER)	Ia	Ib	Ic	total	current distortion limits
Maximum TDD	30.04	20.99	24.92	21.54	12%
Minimum TDD	7.2	7.65	6.43	7.08	12%
Average	13.69	16.32	17.2	15.7	12%

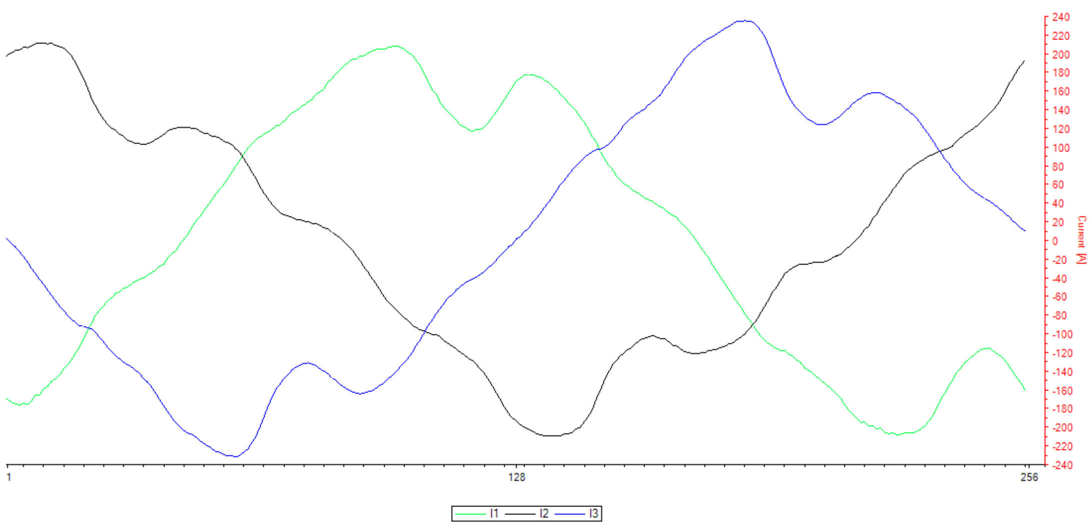
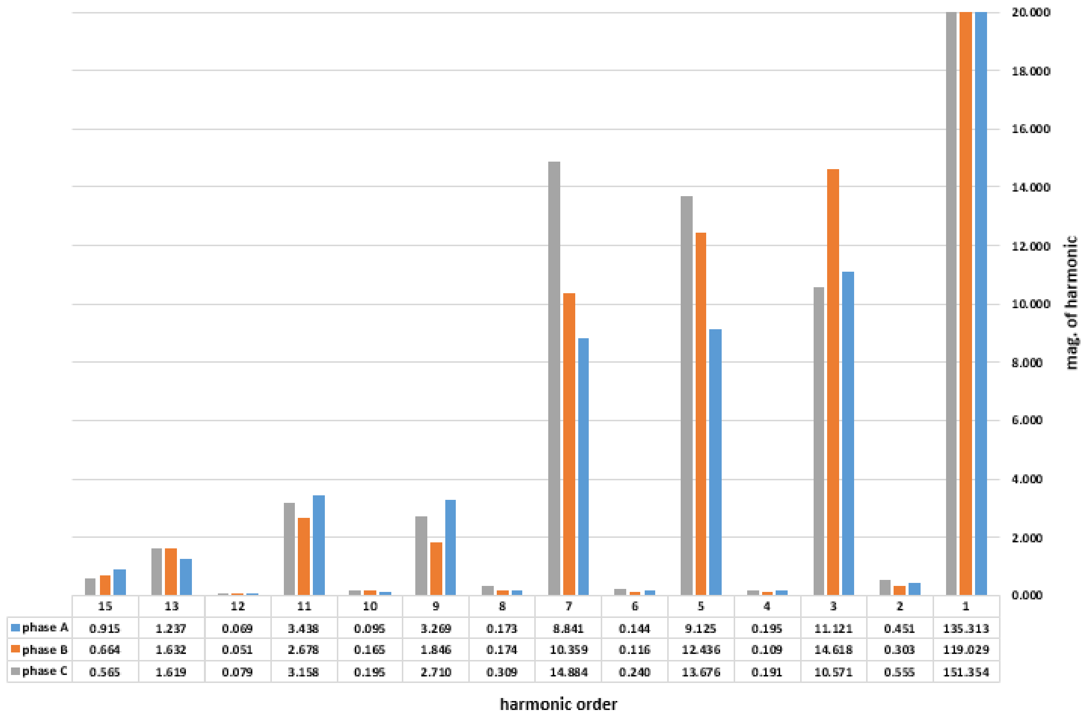


Figure 3.30: The three phases signal for the Building C



	15	13	12	11	10	9	8	7	6	5	4	3	2	1
phase A	0.915	1.237	0.069	3.438	0.095	3.269	0.173	8.841	0.144	9.125	0.195	11.121	0.451	135.313
phase B	0.664	1.632	0.051	2.678	0.165	1.846	0.174	10.359	0.116	12.436	0.109	14.618	0.303	119.029
phase C	0.565	1.619	0.079	3.158	0.195	2.710	0.309	14.884	0.240	13.676	0.191	10.571	0.555	151.354

Figure 3.31: The harmonic order according to their magnitude of harmonic for the three phases of building C

3.3.2.5 Data analysis for Mosque

3.3.2.5.1 total harmonic distortion(THD) for Mosque

The ratio of the total harmonic distortion in the Mosque which its voltage is below 69 KV according to the Table 2.1 shouldn't exceed for Individual Voltage Distortion (3%), and for Total Voltage Distortion THD shouldn't exceed (5%).

The result that We got are shown in the Figure 3.32 ,3.33 and Table 3.12

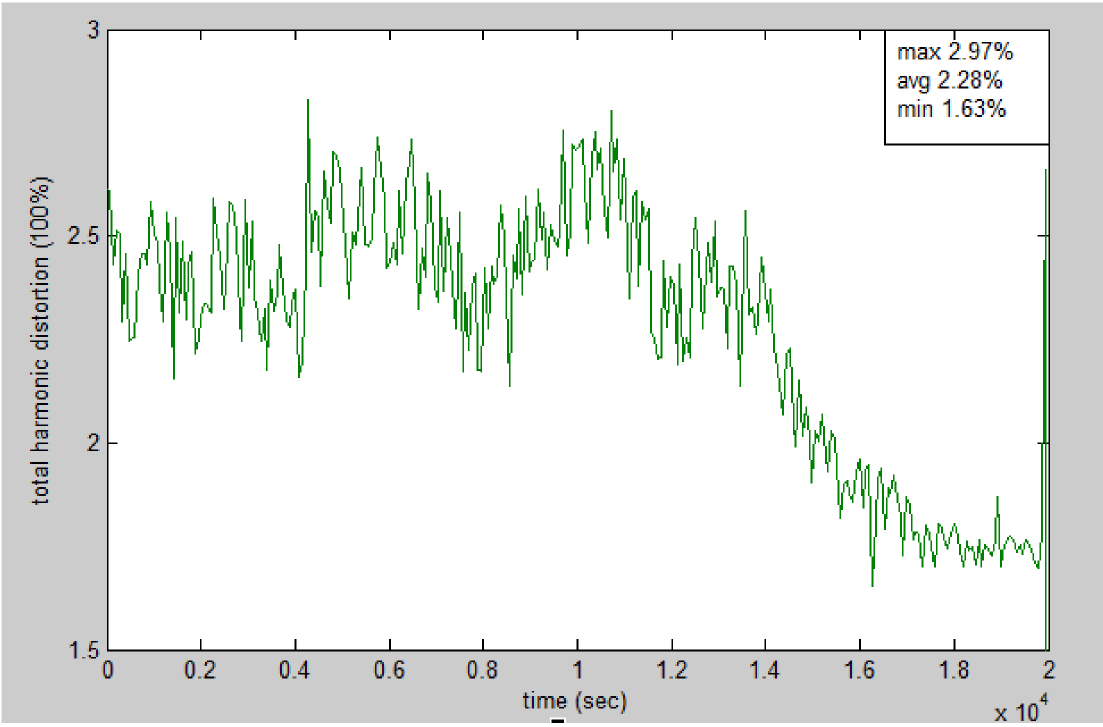
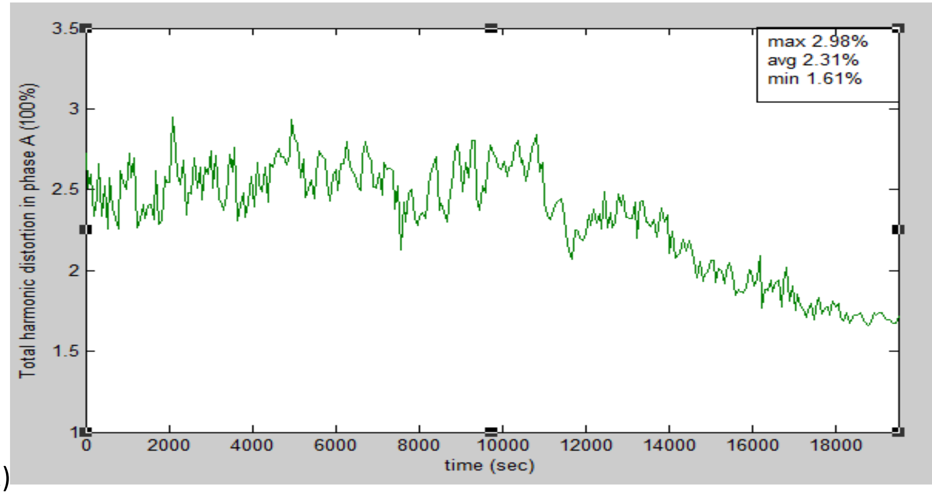
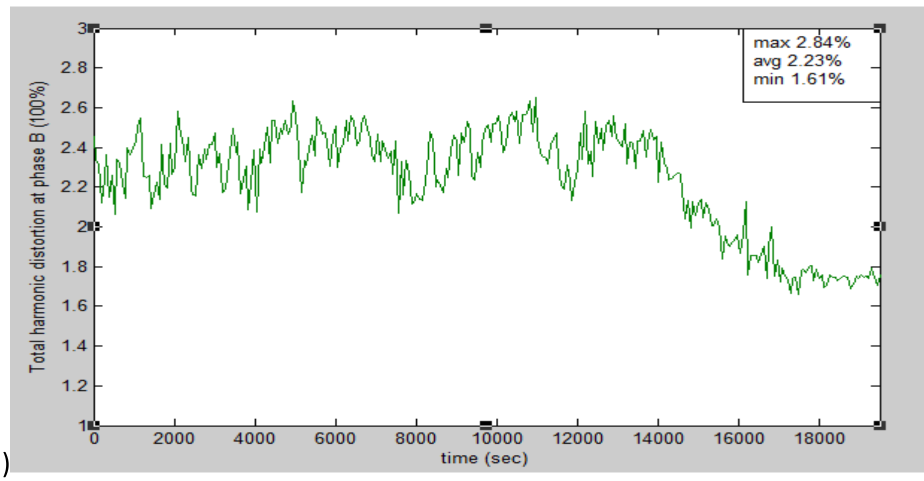


Figure 3.32: total harmonic distortion for Mosque

1)


2)


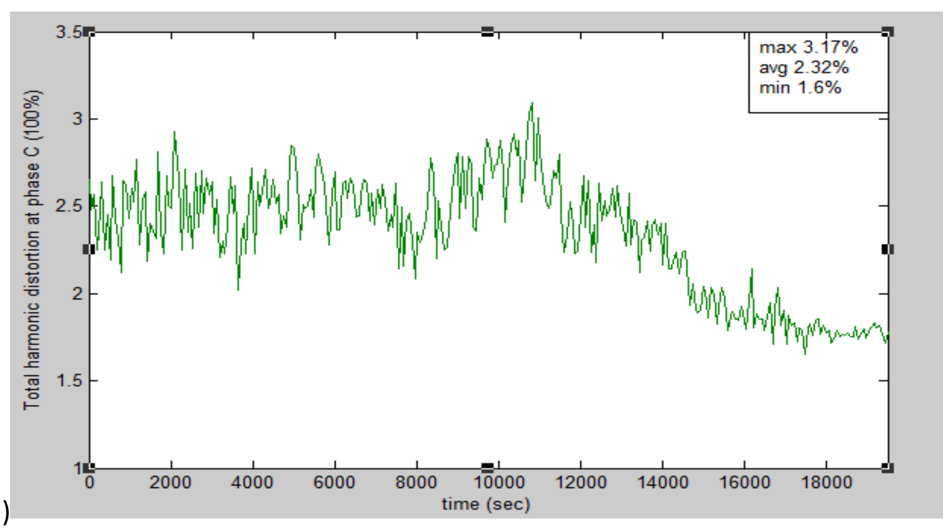
3)


Figure 3.33: total harmonic distortion for mosque 1) phase A 2) phase B 3) phase C

Table 3.12: Percentage THD (voltage) in Mosque.

Phase / THD %(voltage)	Va	Vb	Vc	total	voltage distortion limits
Maximum THD	2.98	2.84	3.17	2.97	5%
Minimum THD	1.61	1.61	1.6	1.6	5%
Average	2.31	2.23	2.32	2.28	5%

3.3.2.5.2 total demand distortion(TDD) for Mosque

The value of (TDD) are calculated according to the 2.11 and the average demand current (I_L) for Mosque we take it by take the average value of the load current of Mosque, The ratio of the total demand distortion in the Mosque which its (ISC / I_L) according to the Table 2.2 shouldn't exceed (12%).

The result that We got are shown in the Figure 3.34,3.35,3.36,3.37 and Table 3.13

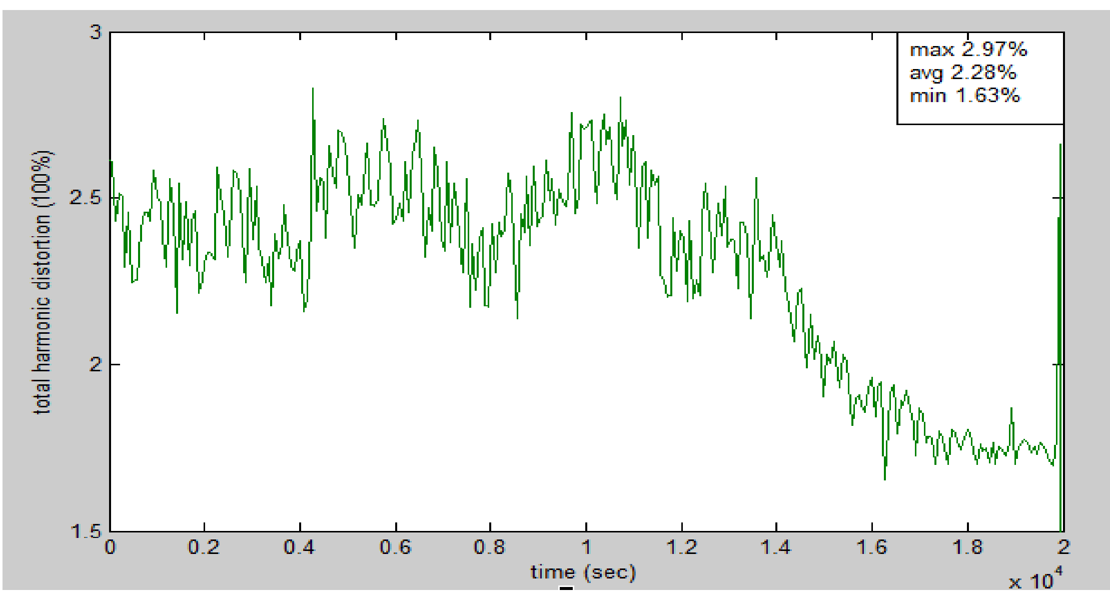
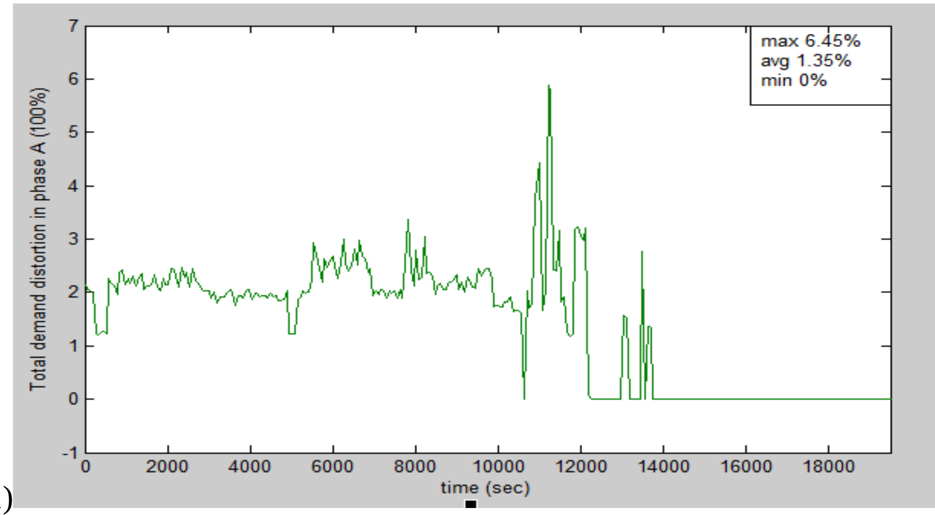
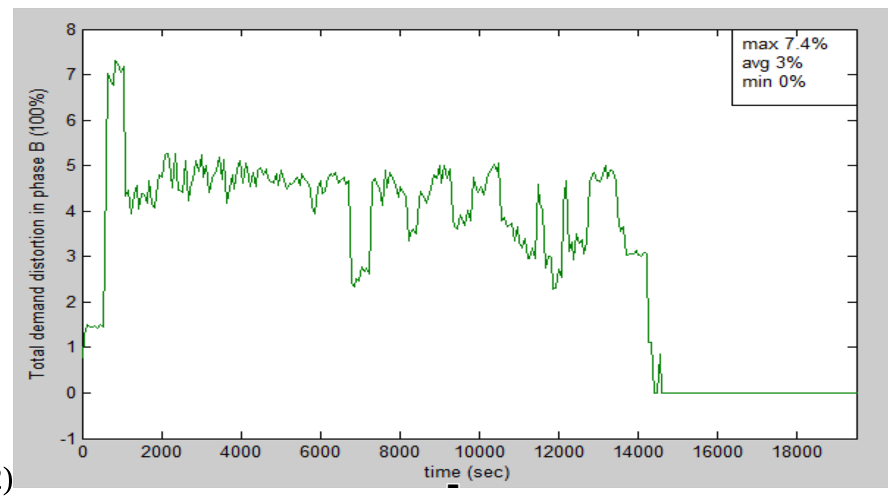


Figure 3.34: total demand distortion for Mosque

1) 

2) 

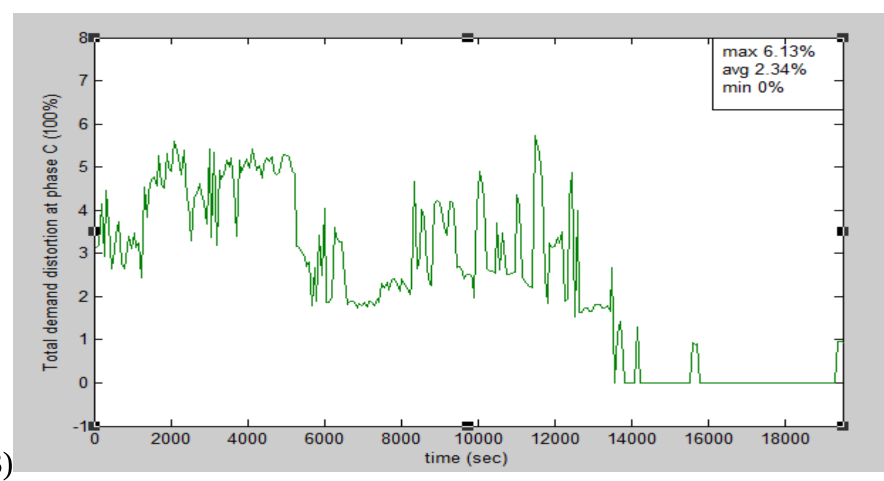
3) 

Figure 3.35: total demand distortion for mosque 1) phase A 2) phase B 3) phase C

Table 3.13: Percentage TDD in Mosque

Phase / TDD %(AMBER)	Ia	Ib	Ic	total	current distortion limits
Maximum TDD	6.45	7.4	6.13	2.97	12%
Minimum TDD	0.00	0.00	0.00	0.01	12%
Average	1.35	3.00	2.34	2.28	12%

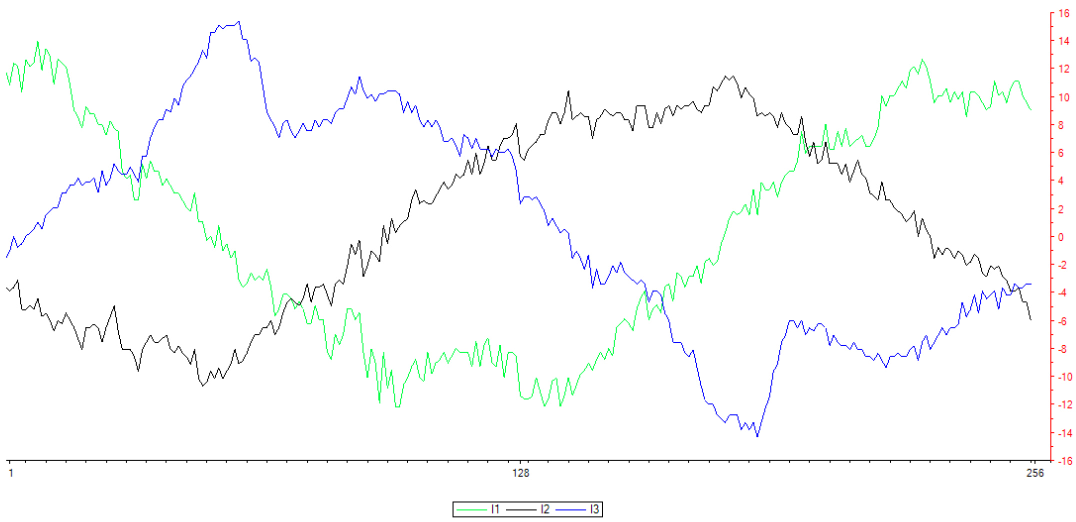
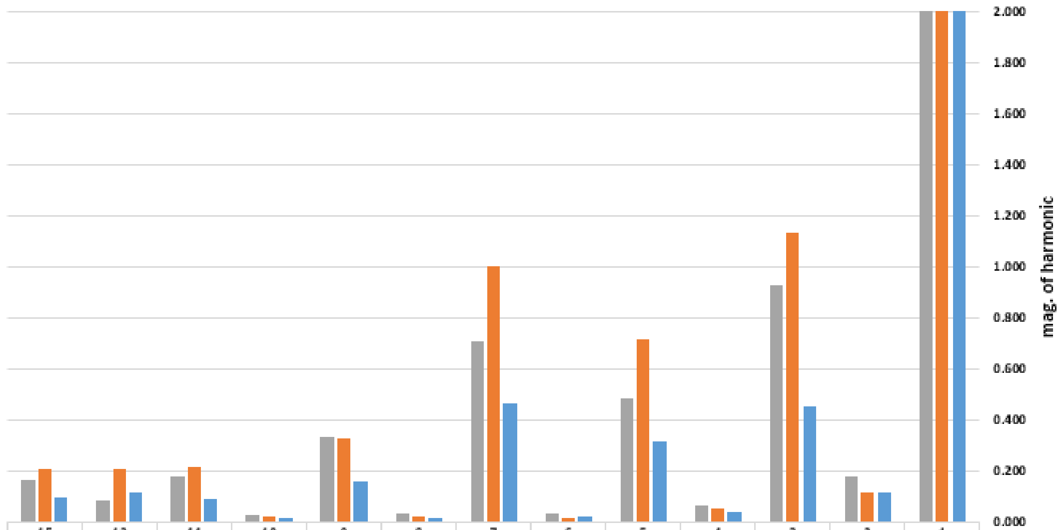


Figure 3.36: The three phases signal for the Mosque



	15	13	11	10	9	8	7	6	5	4	3	2	1
phase A	0.095	0.112	0.087	0.014	0.157	0.015	0.466	0.023	0.317	0.038	0.454	0.113	7.858
phase B	0.206	0.205	0.212	0.022	0.326	0.020	1.002	0.017	0.714	0.049	1.132	0.113	11.993
phase C	0.167	0.085	0.177	0.028	0.332	0.031	0.707	0.034	0.482	0.067	0.930	0.176	11.658

Figure 3.37: The harmonic order according to their magnitude of harmonic for the three phases of Mosque

4

CHAPTER FOUR

Filter design

4.1 Introduction.

4.2 Design the simulation for building A electrical network.

4.3 System simulation after filtration.

4.1 Introduction

According to the data collected in this project for the main feeder and buildings (A,B,B+,C and mosque) and after analyzing it and compare it with the international standards in last chapter, we found that the most building that suffer significantly from the harmonic distortion is building A, and all it is problems are in current so we attempt to build the corresponding real system simulation for electrical network of that building A with the same parameter that it has in practical , after that we design the solution that eliminates the distortion by two methods the first is: adding passive filter to the network, second: adding shunt active filter.

4.2 Design the simulation building A

The whole network for building A is simulated using MATLAB-Simulink. To simulate the filters, we should first simulate the network with the same data that we got. So, we built the simulation before adding a filter as shown in figure 4.1.

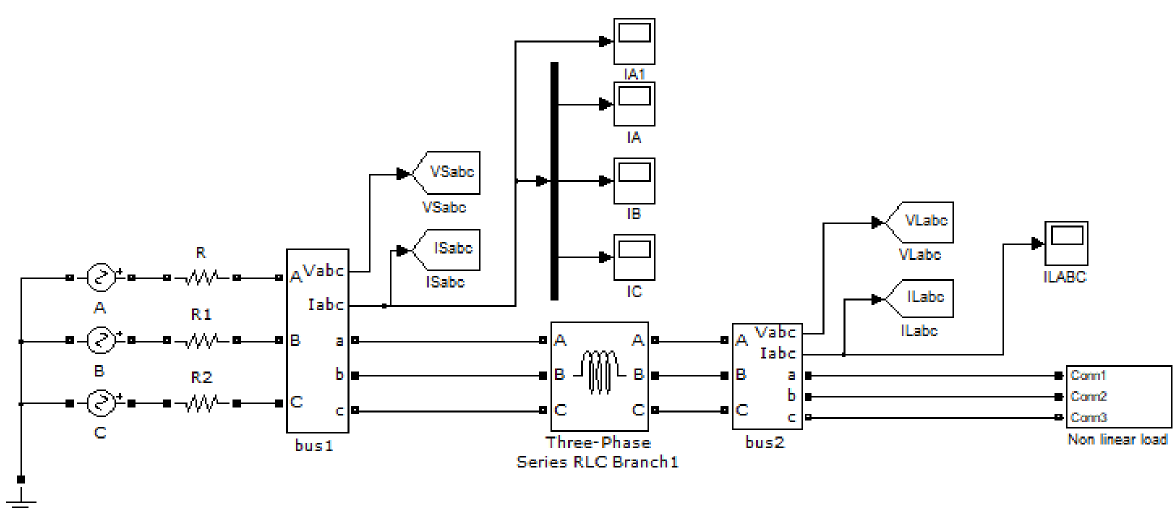


Figure 4.1 simulation design for building A

The result that we got from the simulation is around the result that we measure from the system and it shows in previous chapters.

The distortion signal that we got from the simulation for three phases is shown in figure 4.2, 4.3 and 4.4.

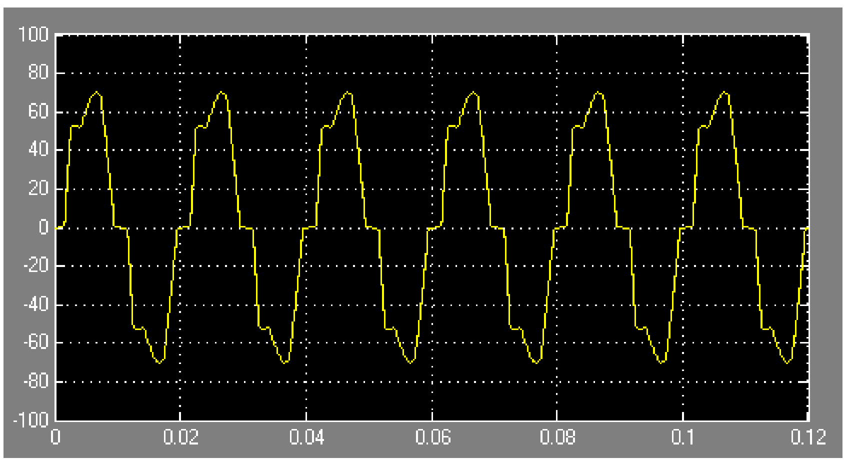


Figure 4.2 distortion signal for phase A before adding filter

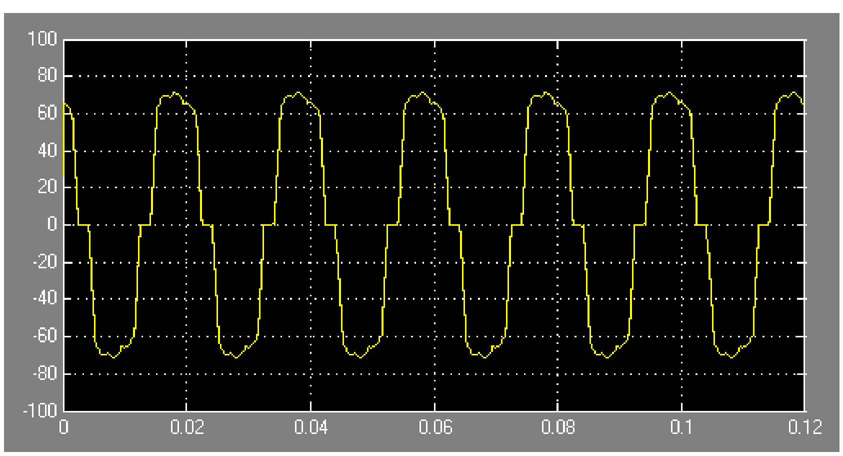


Figure 4.3 distortion signal for phase B before adding filter

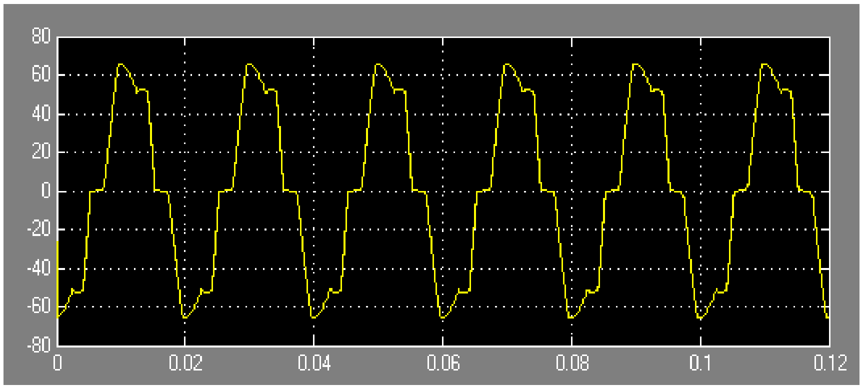


Figure 4.4 distortion signal for phase C before adding filter

By using the FFT analysis tool from MATLAB-Simulink, the harmonic percentage and orders for the current signal for each line are shown in figures 4.5, 4.6 and 4.7.

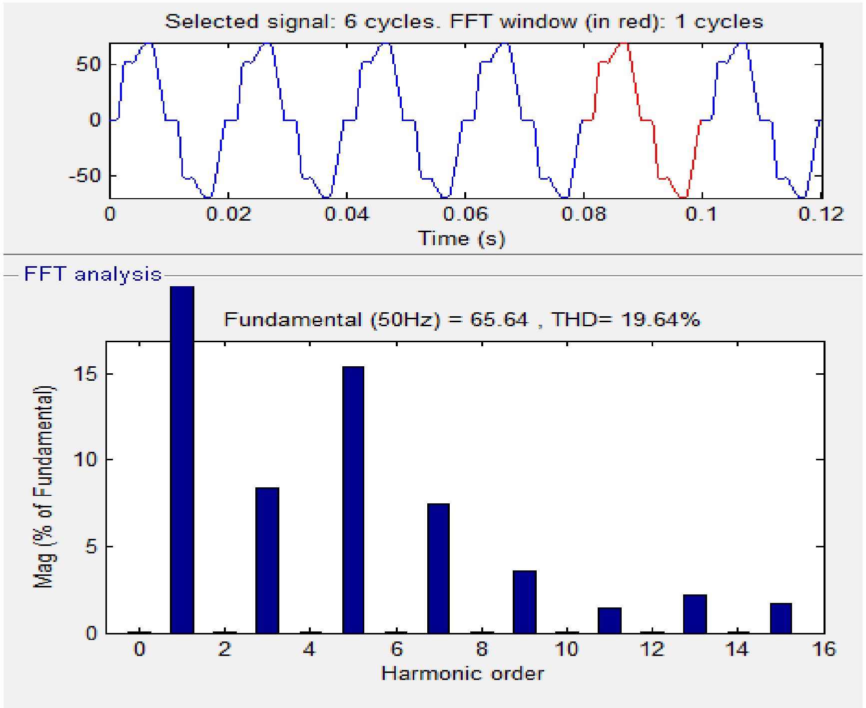


Figure 4.5 FFT Analysis for the phase A before filtration

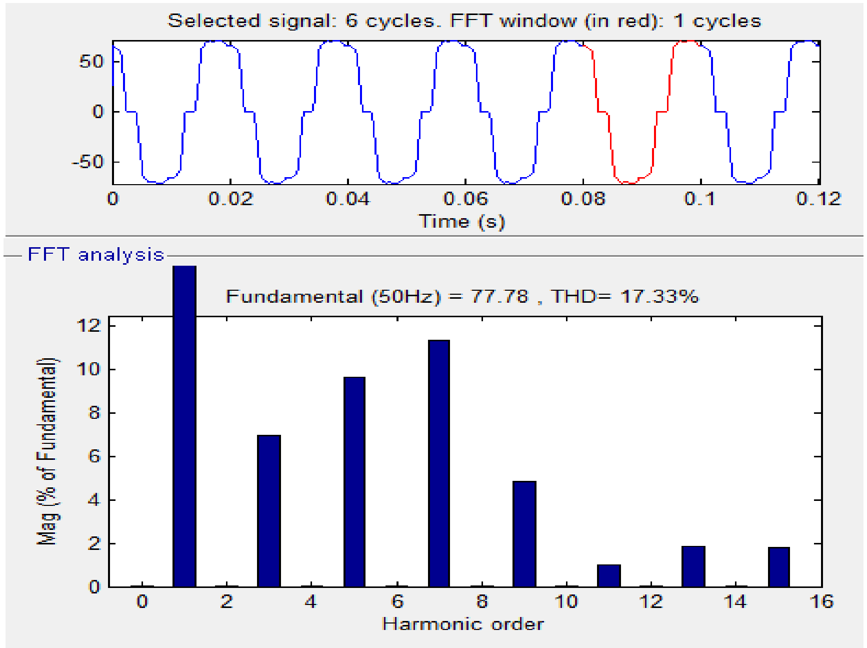


Figure 4.6: FFT Analysis for the phase B before filtration

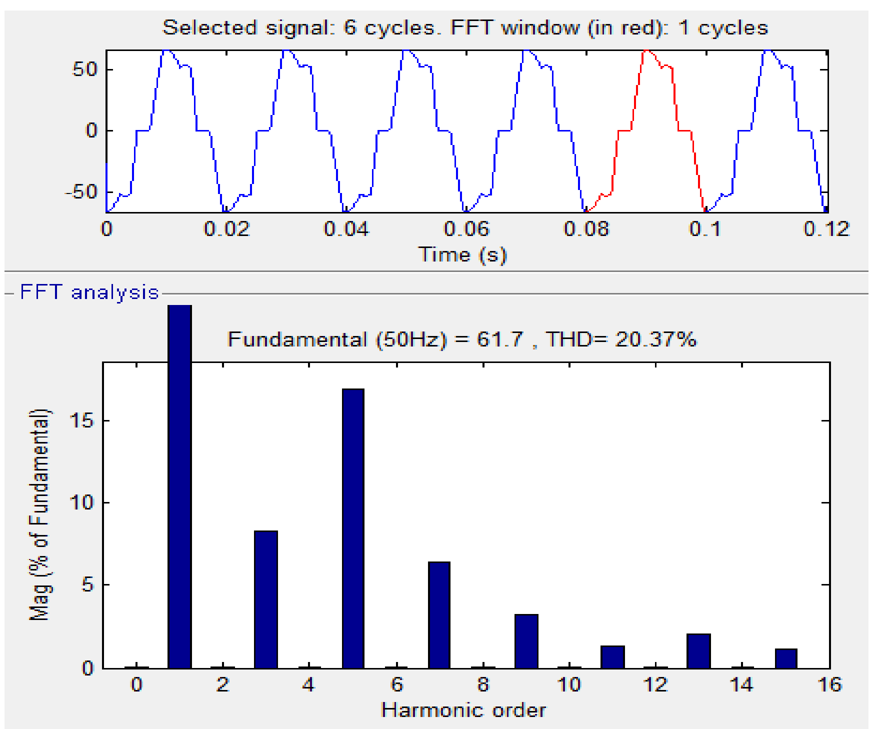


Figure 4.7: FFT Analysis for the phase C before filtration

By comparing the results that we got from the simulation operation with the results that we analyzed from the measurement operation which exist in figure 3.22, we found that the values are almost equal.

4.3 System simulation after filtration

4.3.1 Design passive filter

After simulation the real system with its harmonics, the passive single-tuned filters are designed according to the parameters values found in the previous section. The filter block design is shown in figure 4.8. it shows the three-parallel signal-tuned filter for each line.

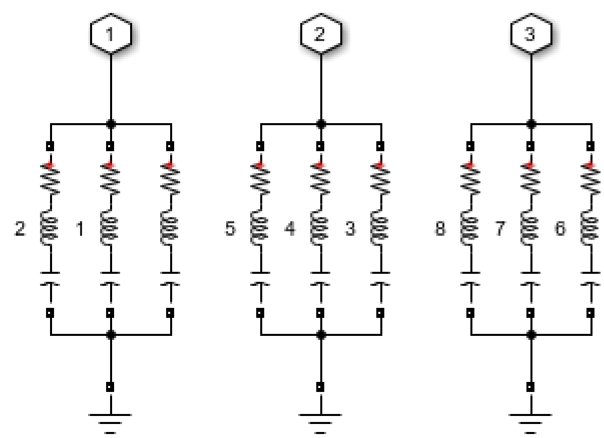


Figure 4.8: single tuned filter design

Parameters of the single-tuned passive filters:

To begin the design and find the parameters of the filter, the capacitor size is to be determined depending on the reactive power requirement Qc, which it is equal 5124 var for the 3^{rd} order, 5344 var for the 5^{th} order and 4806 var for the 7^{th} order and according to 2.16, up to 2.19.

The calculated parameter for the four-single toned filter are shown in table 4.1:

Table 4.1: calculated passive filter parameters

Harmonic order (H)	Reactance (Xc) (Ω)	Capacitance (C) (μf)	Inductance (L) (mh)	Resistance (R) (Ω)
3^{rd} order	63	16	70.4	1.1
5^{th} order	29	36	25.3	0.66
7^{th} order	45	23	7.8	0.36

The electrical network simulation after aiding the calculated passive filter are shown in the figure (4.9)

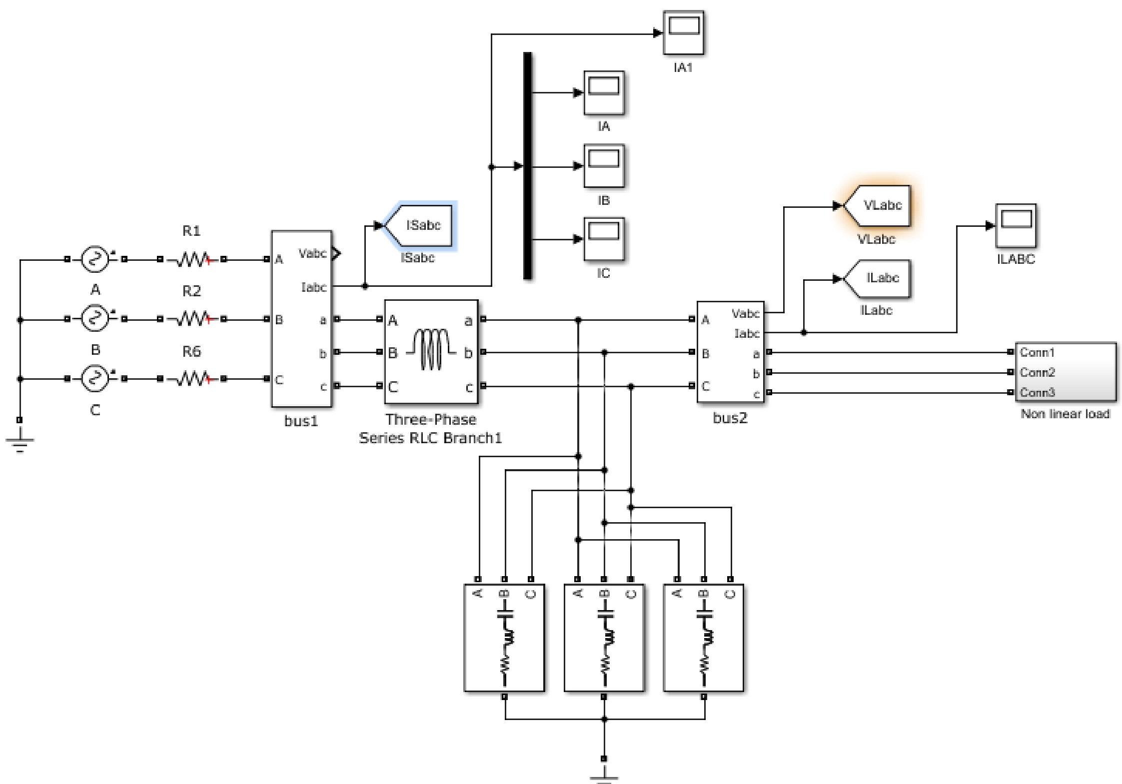


Figure 4.9: simulation design for sub feeder A after adding passive filter

The pure sinusoidal signal for three phases that we got from the simulation are shown in figure 4.10, 4.11 and 4.12.

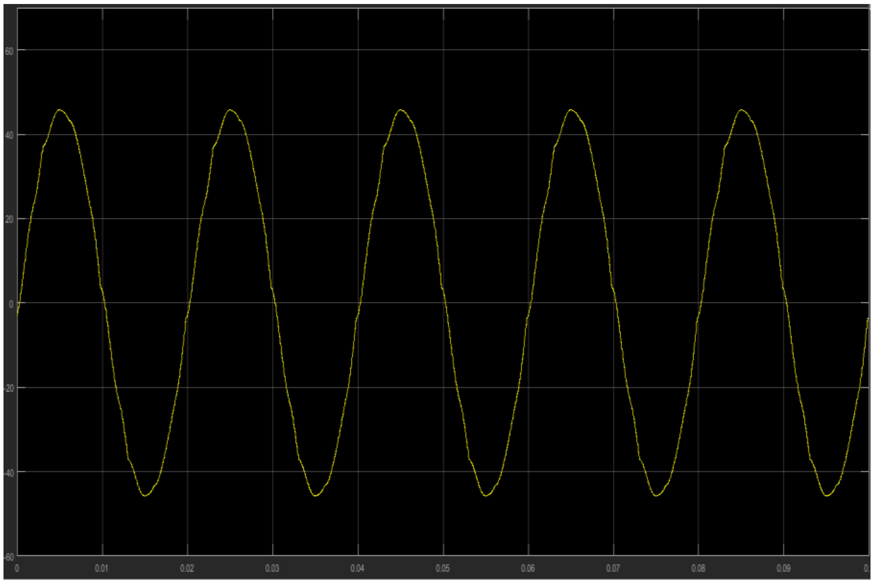


Figure 4.10: signal for phase A after adding passive filter

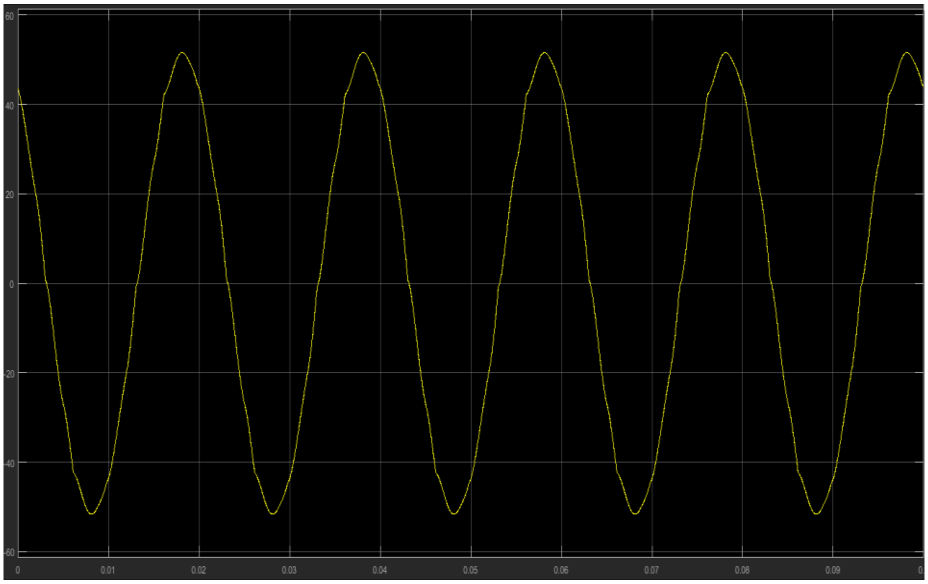


Figure 4.11: signal for phase B after adding passive filter

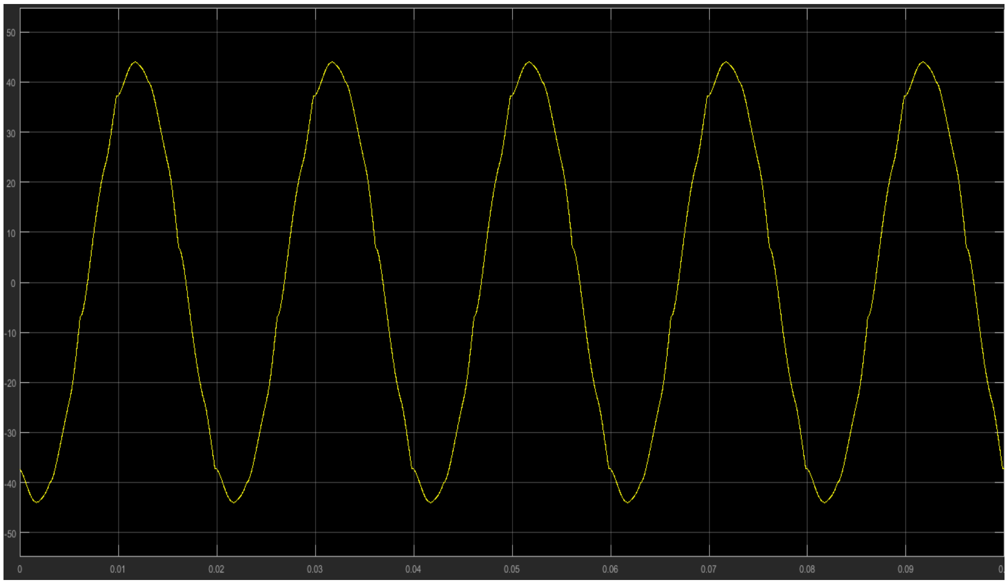


Figure 4.12: signal for phase C after adding passive filter

By using the FFT analysis tool from MATLAB-Simulink, the harmonic percentage and orders for the current signal for each line after adding passive filter are shown in figure 4.13, 4.14 and 4.15.

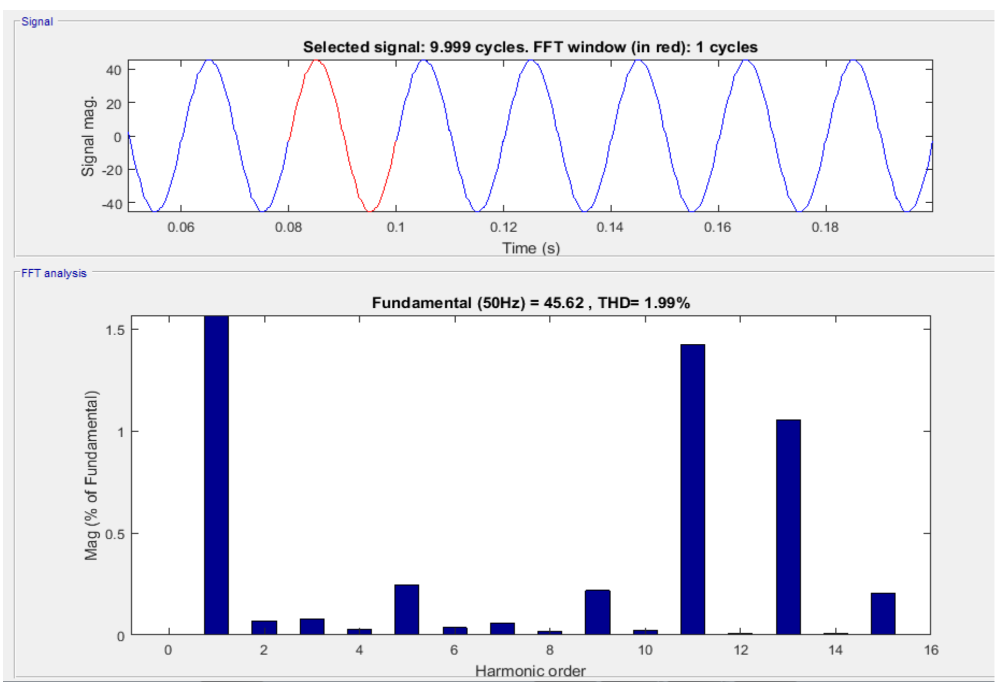


Figure 4.13 FFT Analysis for the phase A after adding passive filter

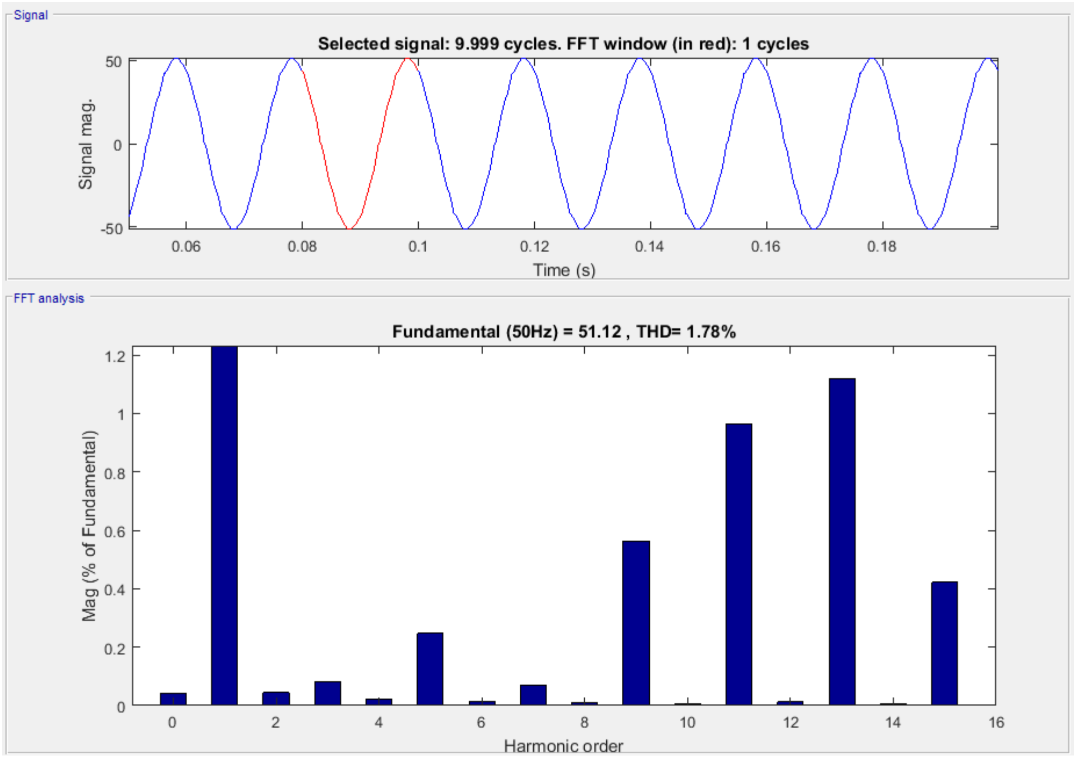


Figure 4.14: FFT Analysis for the phase B after adding passive filter

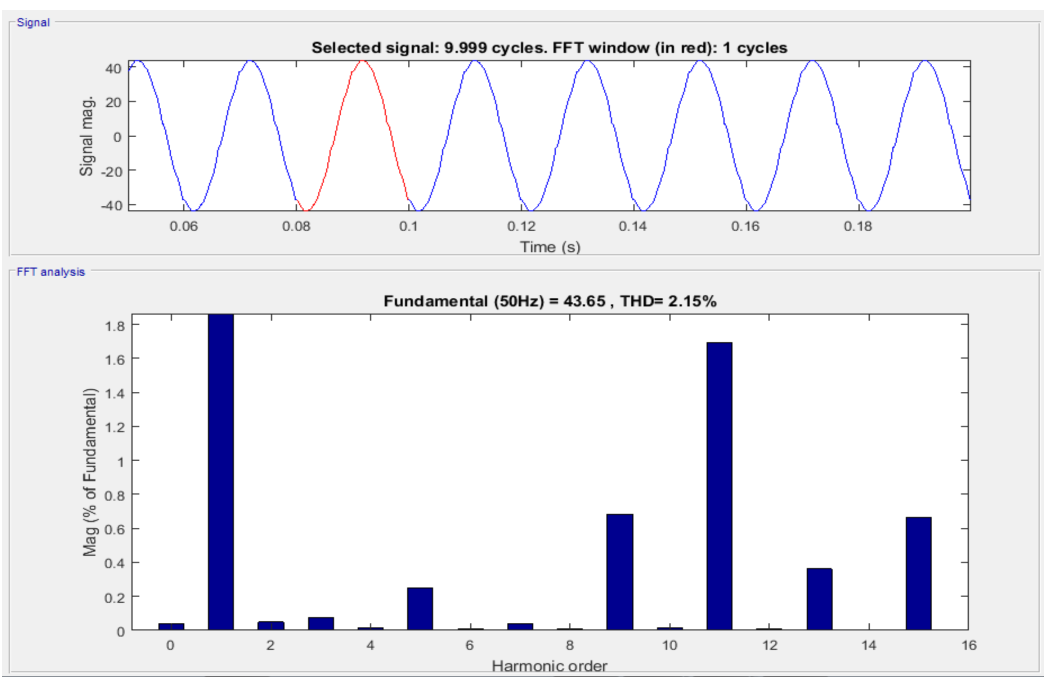


Figure 4.15: FFT Analysis for the phase C after adding passive filter

After converted the THDi to TDD we got from the FFT after filtration by 2.11, we found that the TDD value are as shown in table 4.2.

Table 4.2: Percentage TDD in Building A after adding passive filter

Phase / TDD %(AMBER)	Ia	Ib	Ic	average	current distortion limits
values	2.85	2.37	2.84	2.68	12%

All values are during the acceptable value that in table 2.2 so the distortion problems are solved.

.

4.3.2 Design of shunt active filter

After simulation the system harmonics, the shunt active filters are designed according to the parameters values found in the previous section. The filter block design which contains the power and control circuits are shown in figure 4.16.

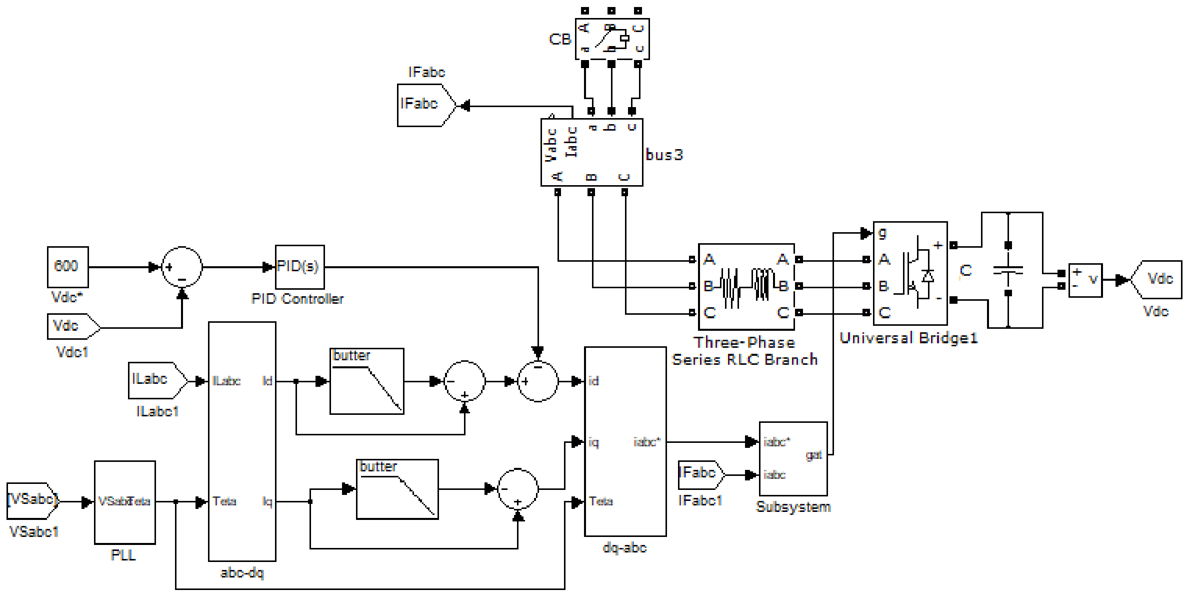


Figure 4.16: shunt active filter

Parameters of the shunt active filters:

The values of parameters are calculated according to 2.29, 2.30 and 2.31,

The calculated parameter for the stunt active filter are shown in the table 4.3:

Table 4.3 Parameters of the System Considered for Shunt Active Filter:

parameter	value
DC capacitor voltage	600 V
DC bus capacitor	1810 uF
AC inductor	150 mH

The electrical network simulation after adding the calculated shunt active filter and the component circuits are shown in figure 4.17.

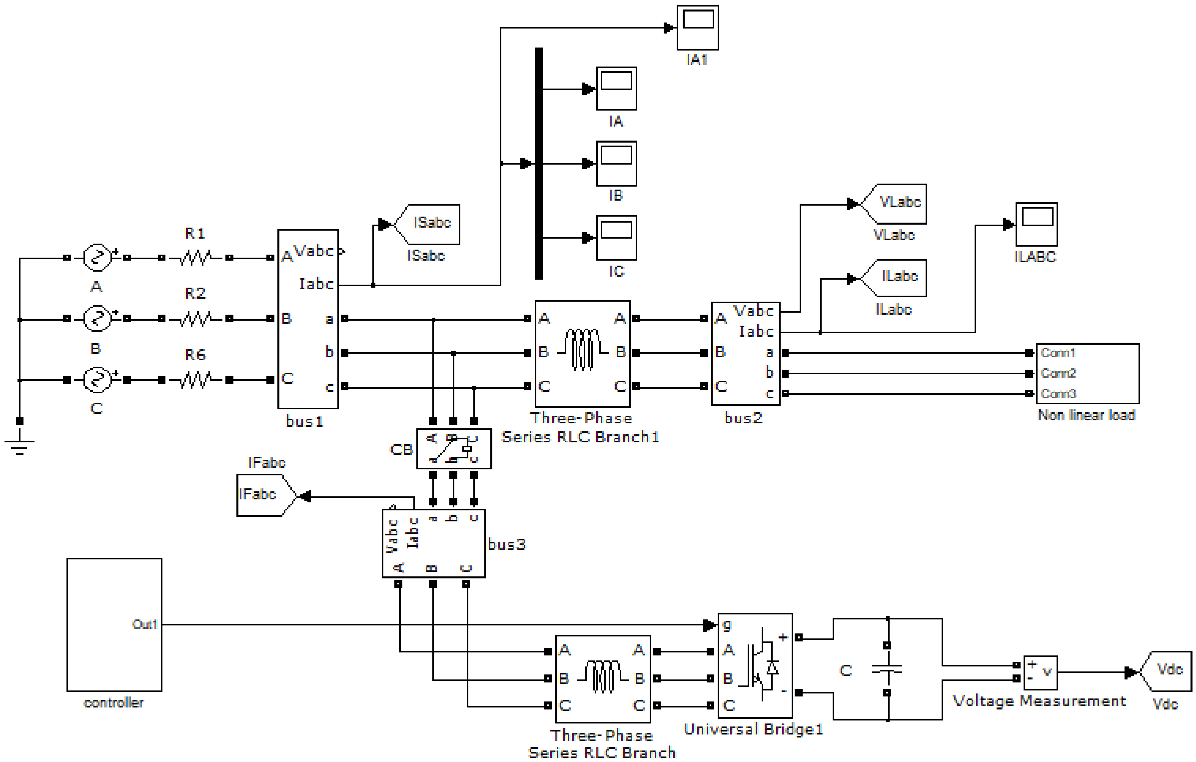


Figure 4.17: simulation design for building A with active filter

The control circuit for the shunt active filter is shown in figure 4.18.

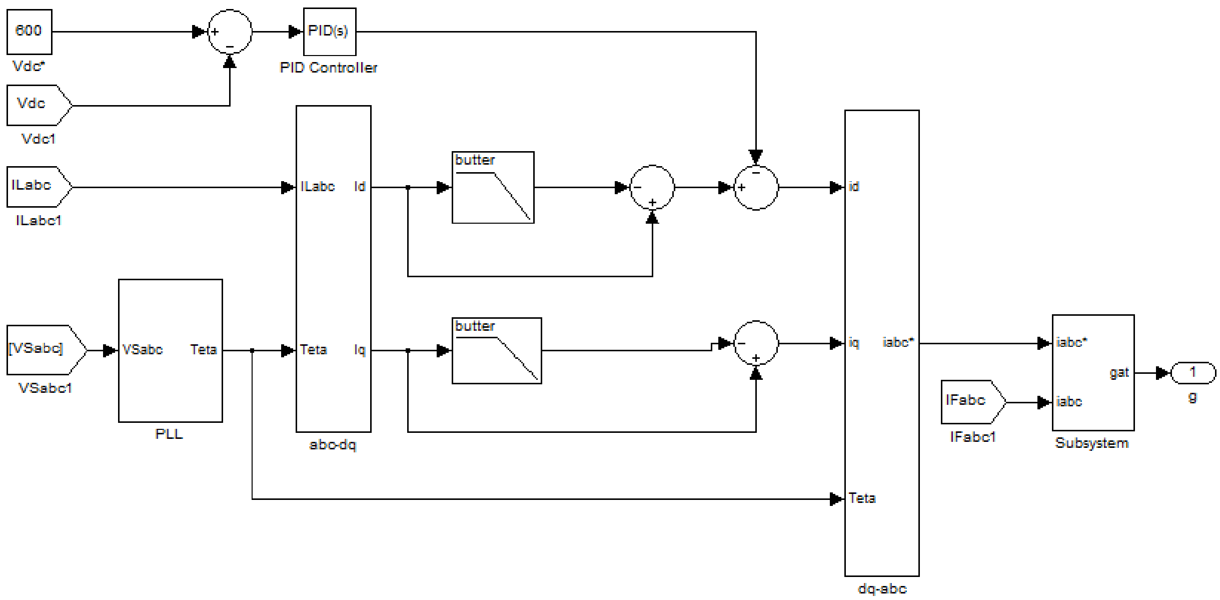


Figure 4.18 control circuit of the filter

The Phase-Locked Loop (PLL) circuit that used to obtain an accurate synchronization to the grid which is built by using equation 2.22 is shown in figure 4.19.

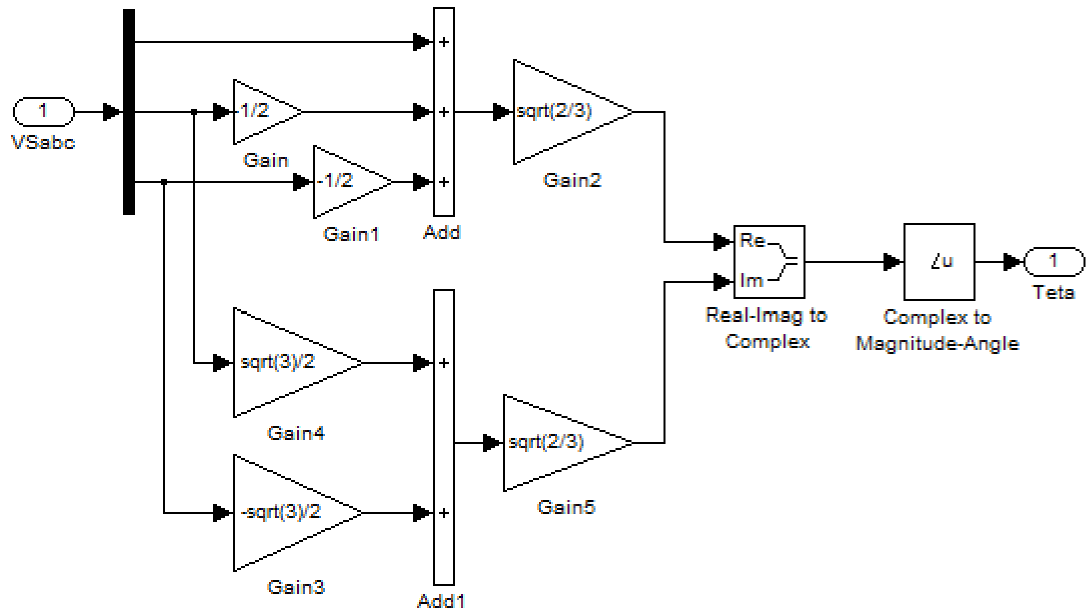


Figure 4.19: PLL synchronization circuit

the circuit that convert the quantities from abc to an arbitrary rotating dq0 reference frame is which is built by using equation 2.21, 2.22 and 2.32 shown in figure 4.20

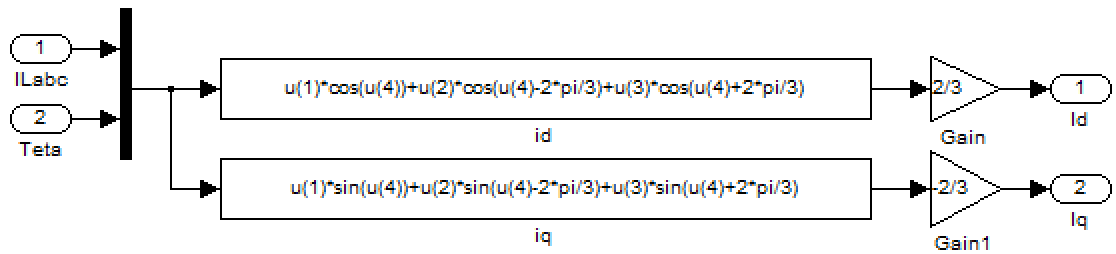


Figure 4.20: convert quantities from abc to an arbitrary rotating dq0 reference frame circuit

the circuit that convert the quantities from dq0 to an arbitrary rotating abc reference frame which is built by using equation 2.28 is shown in figure 4.21

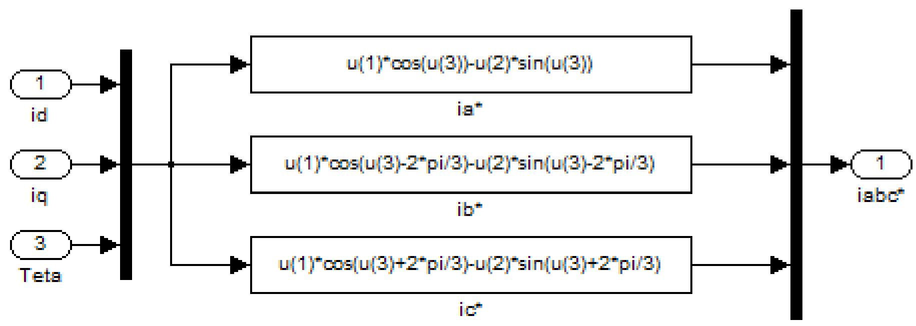


Figure 4.21 convert quantities from dq0 to an arbitrary rotating abc* reference frame circuit

The Performance of Three Phase Three Wire System with Nonlinear Load are shown in figures 4.22, 4.23 and 4.24.

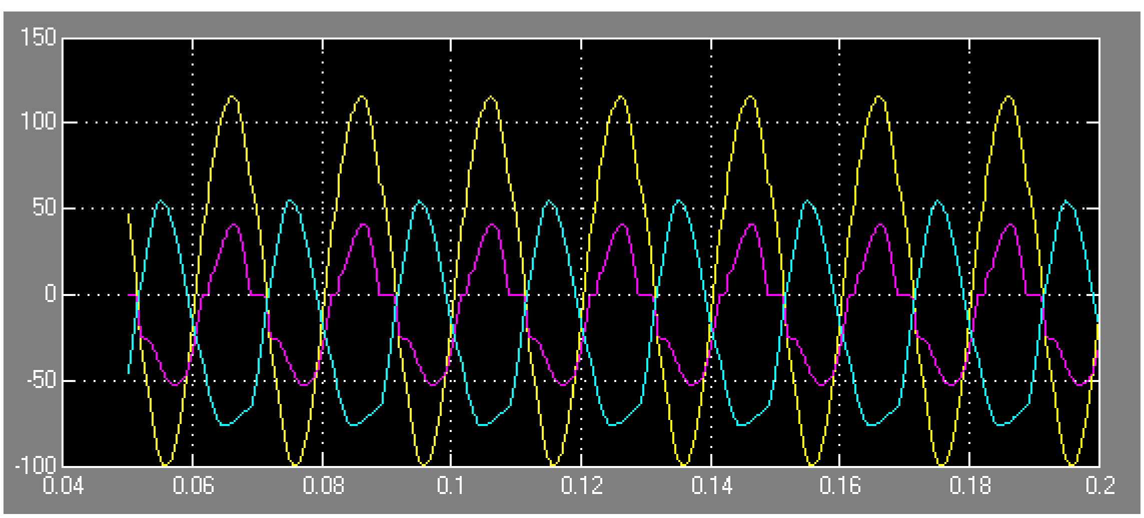


Figure 4.22: The Performance of Phase A with Unbalanced Nonlinear Load (blue: source current, pink: injected current, yellow: load current)

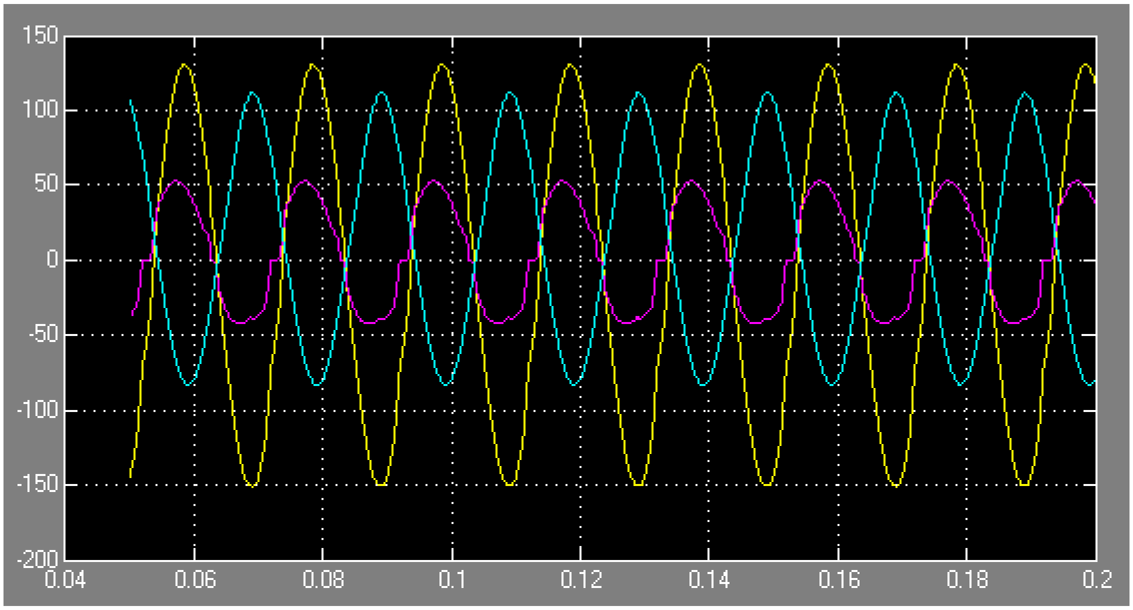


Figure 4.23: The Performance of Phase B with Unbalanced Nonlinear Load (blue: source current, pink: injected current, yellow: load current)

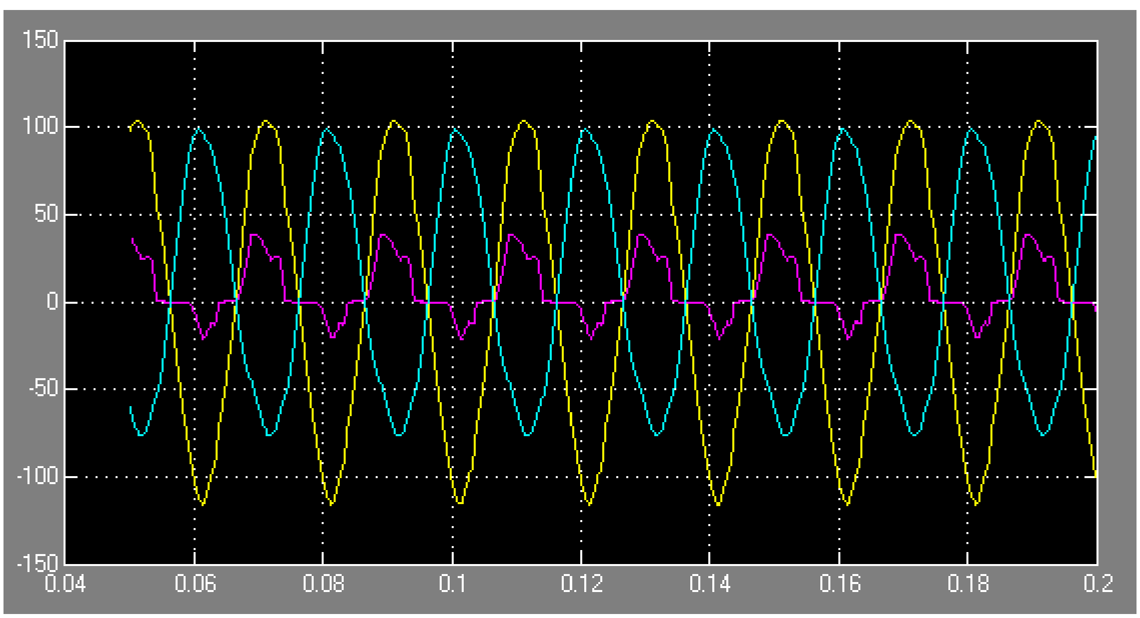


Figure 4.24: The Performance of Phase C with Unbalanced Nonlinear Load (blue: source current, pink: injected current, yellow: load current)

The DC capacitor voltage for the circuit are shown in figure 4.25.

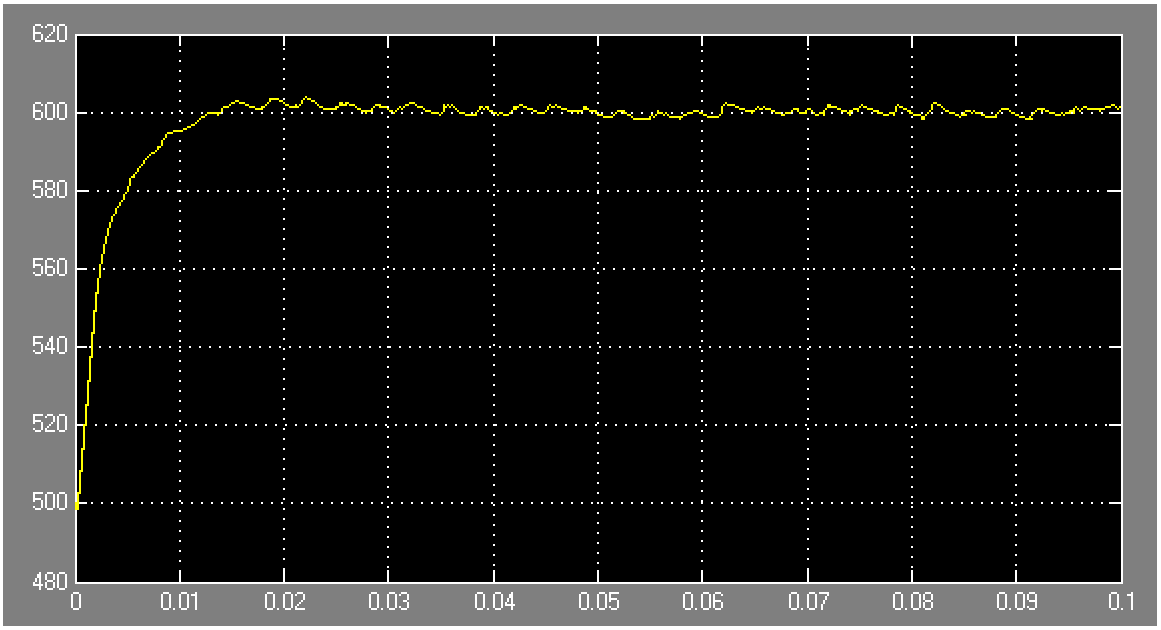


Figure 4.25: DC capacitor voltage

The pure sinusoidal signal for each phase that we got from the simulation are shown in the figure 4.26, 4.27 and 4.28.

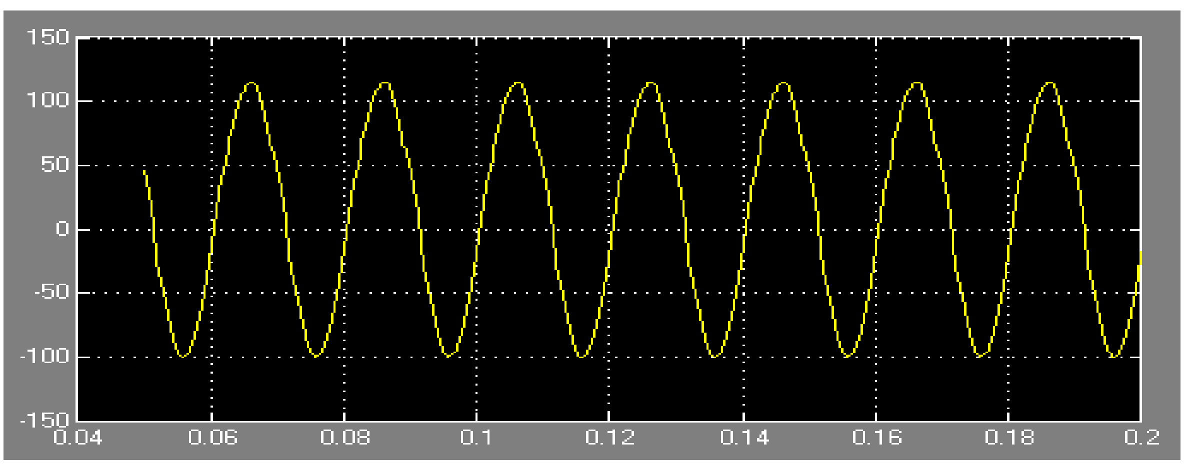


Figure 4.26: signal for phase A after adding active filter

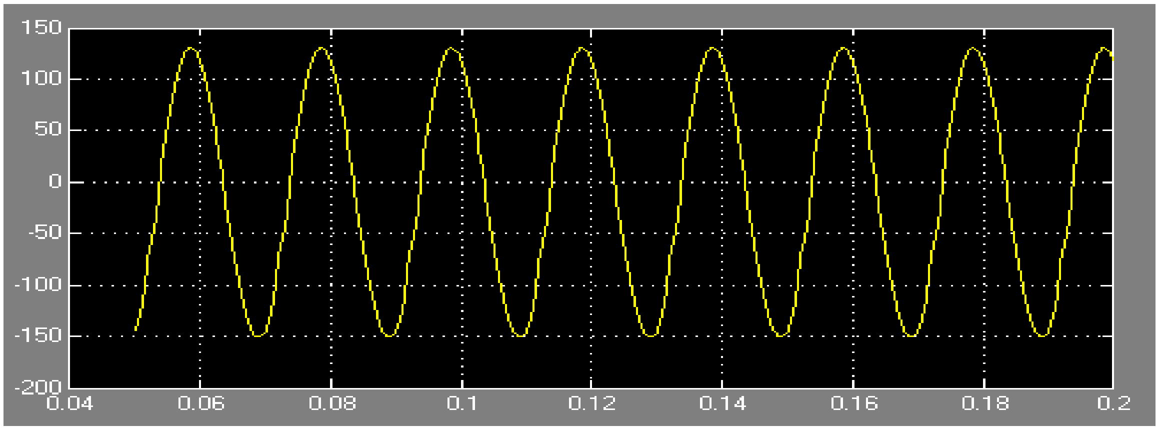


Figure 4.27: signal for phase B after adding active filter

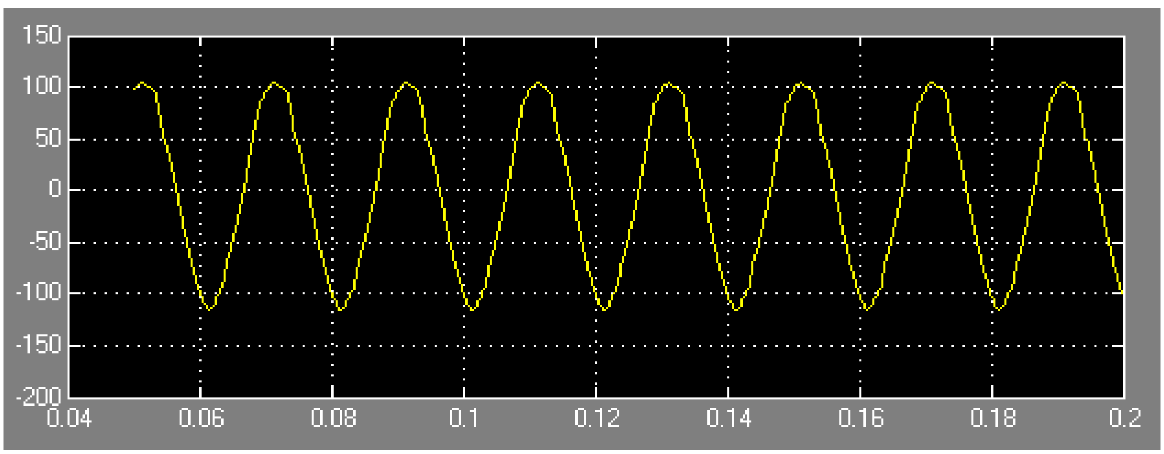


Figure 4.28: signal for phase C after adding active filter

By using the FFT analysis tool from MATLAB-Simulink, the harmonic percentage and orders for the current signal for each line after adding passive filter are shown in figures 4.29, 4.30 and 4.31.

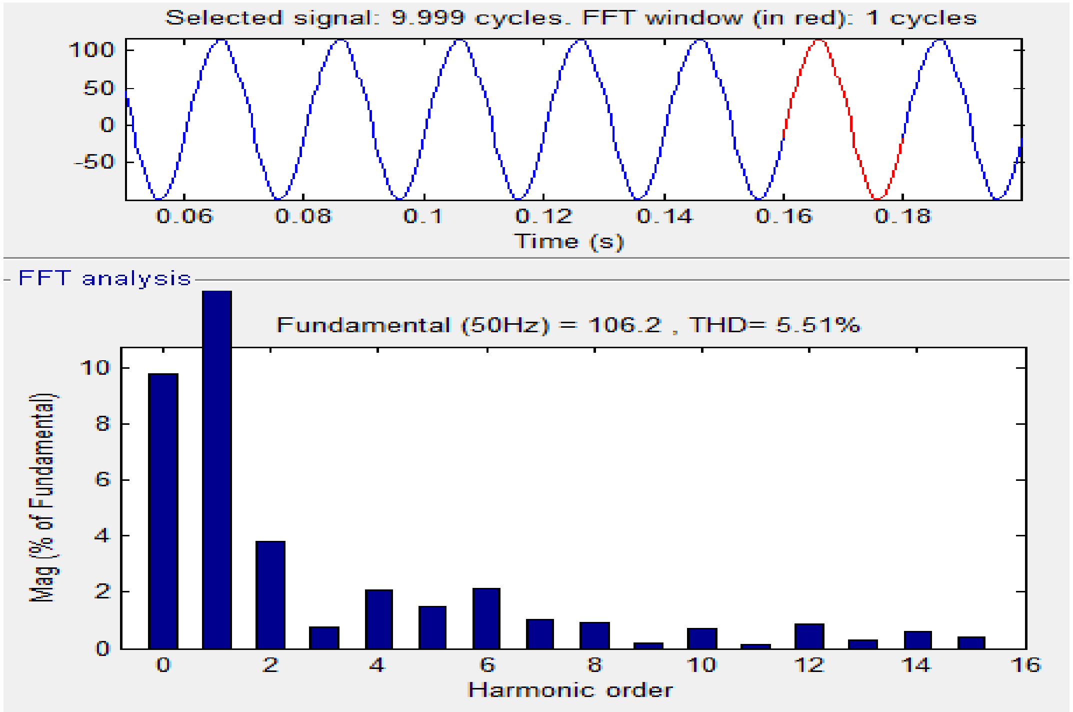


Figure 4.29: FFT Analysis for the phase A after adding active filter

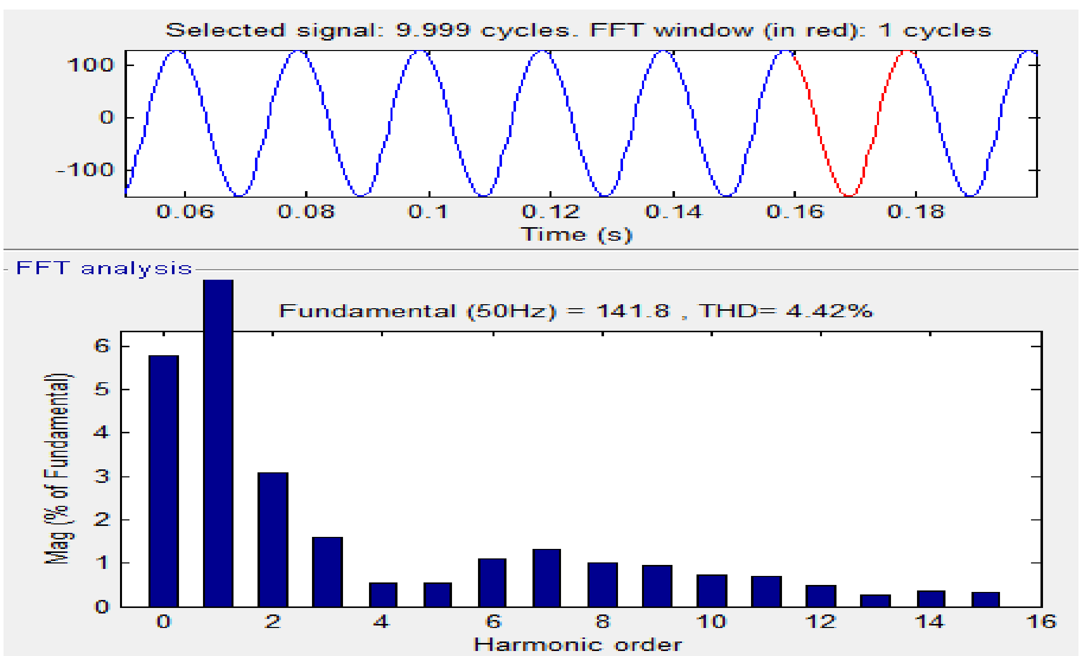


Figure 4.30: FFT Analysis for the phase B after adding active filter

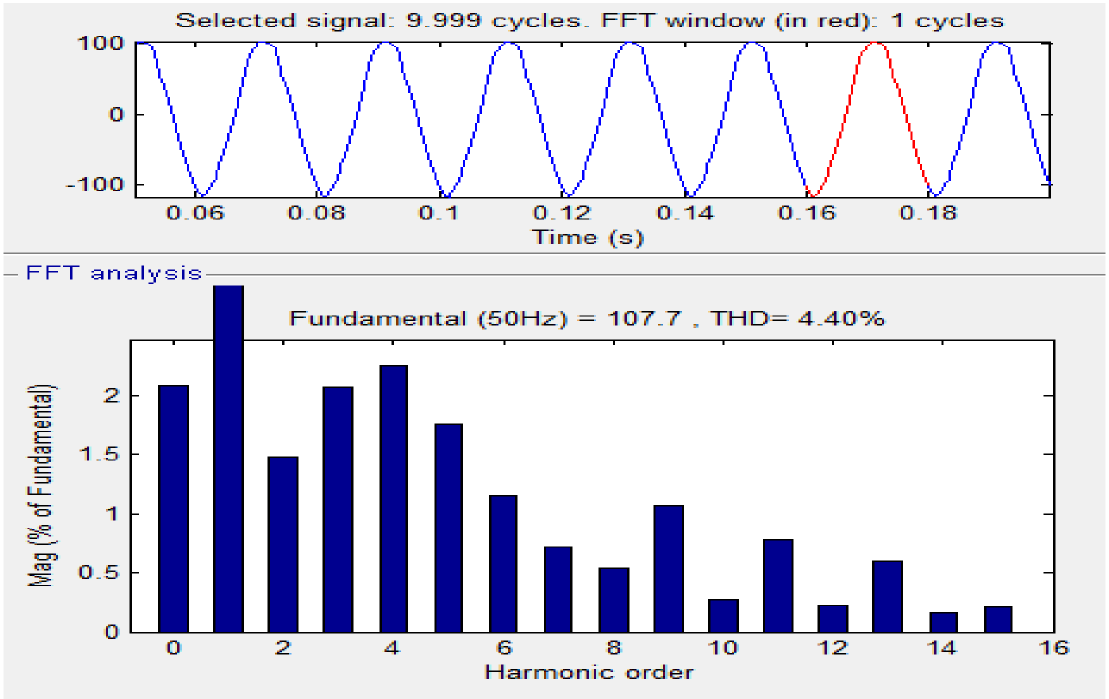


Figure 4.31: FFT Analysis for the phase C after adding active filter

After converted the THDi to TDD we got from the FFT after filtration by using 2.11, we found that the TDD value are as shown in table 4.4.

Table 4.4: Percentage TDD in Building A after adding active filter

Phase / TDD %(AMBER)	Ia	Ib	Ic	average	current distortion limits
values	7.82	6.22	6.43	6.82	12%

All values are during the acceptable value that in table 2.2 so the distortion problems are solved.

5

CHAPTER FIVE

CONCLUSION

5.1 Conclusion

5.2 Future work

5.3 Obstacles

5.1 Conclusion

after design both passive and active harmonic filter and observes there results we found that the Use of the passive filters is one of the classic solutions to solve harmonic current problems, but they present several disadvantages, namely: they only filter the frequencies they were previously tuned for; their operation cannot be limited to a certain load; resonances can occur because of the interaction between the passive filter and other loads, with unpredictable results. As a result, conventional solutions that rely on passive filters to perform a harmonic reduction is ineffective. Under these conditions it has been proved that the most effective solutions are active filters which are able to compensate not only harmonics but also asymmetric currents caused by nonlinear and unbalanced loads.

5.2 Future work

1) make a prototype for the designed shunt active filter

2) improves the power quality and eliminate harmonics in other buildings

5.3 Obstacles

1) Administrative procedures in university are Complex

2) the memory of the Vega 78 device needed to improves.

References

[1] GONEN (2014). Electric-Power-Distribution-Engineering, 3ed (pp. 695)

[2] Paul L. Joskow, Douglas R. Bohi and Frank M. GollopBrookings Papers on Economic Activity. Microeconomics Vol. 1989 (1989), pp. 125

[3] Daniel J. Carnovale P.E. and CEMEaton , Moon Township, PA &Timothy J. Hronek P.E. and CEM , Power Quality Solutions and Energy Savings-What is Real? , 2009, pp . 25

[4] IEEE Recommended Practice for Powering and Grounding Electronic Equipment, 22 March 1999 (pp. 12). IEEE.

[5] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, April 12, 1993 (pp. 63),Eq 8.13. IEEE.

[6] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, April 12, 1993 (pp. 11). IEEE.

[7] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, April 12, 1993 (pp. 58), Table 11.1. IEEE

[8] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, April 12, 1993 (pp. 78), Table 10.3. IEEE

[9] Hebron municipality, Hebron Electric Power Company, archives,ppu building

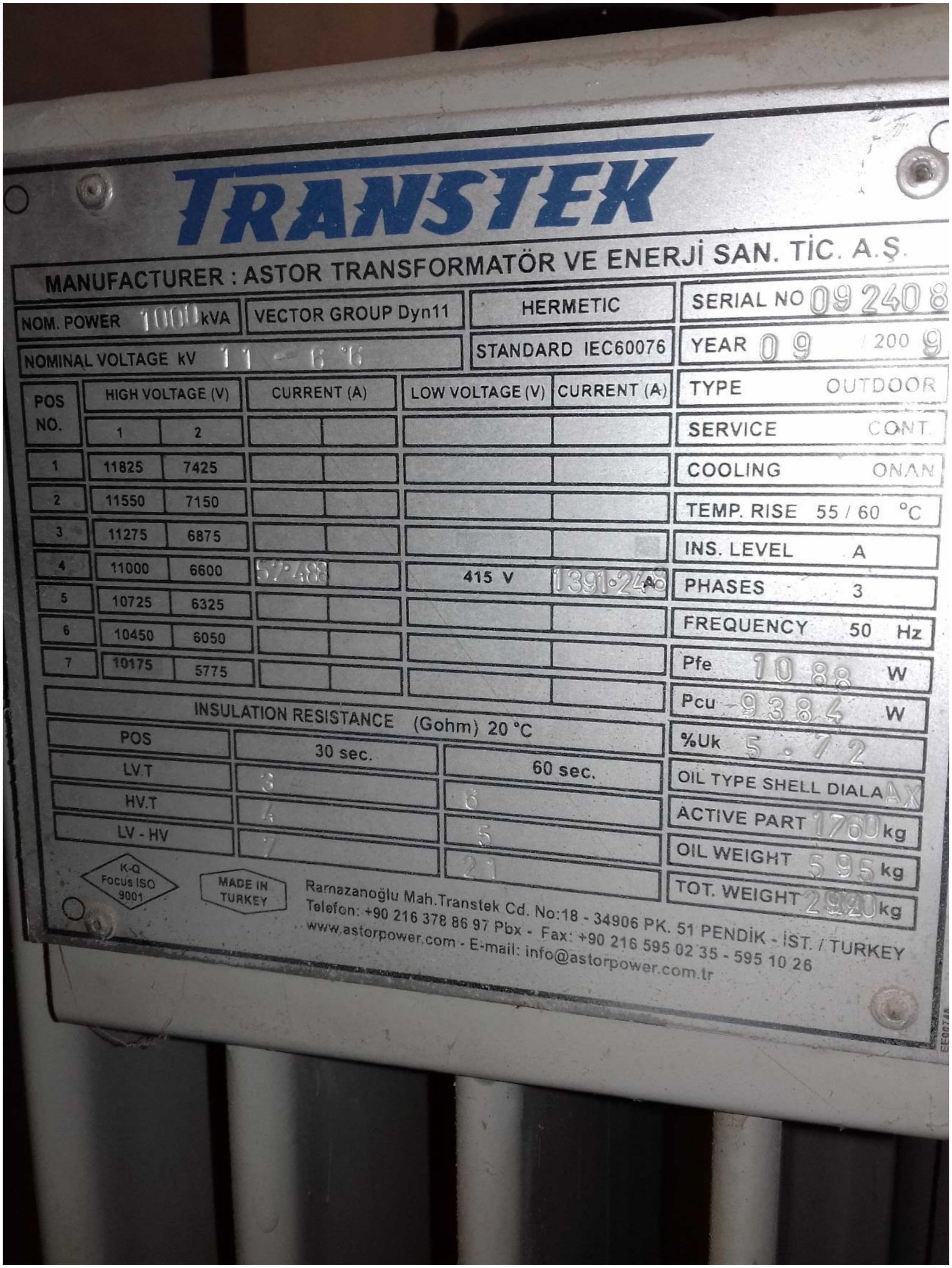
[10] INTERNATIONAL STANDARD IEC 60076-5, JULY, 2000 (pp. 13), Table 1. IEC

Appendices

Appendix A

Appendix B

Appendix A
Data sheet for the university transformer


TRANSTEK
MANUFACTURER : ASTOR TRANSFORMATÖR VE ENERJİ SAN. TİC. A.Ş.
NOM. POWER 1000 kVA
VECTOR GROUP Dyn11
HERMETIC
SERIAL NO 09 240 8
NOMINAL VOLTAGE kV 11 - 6.6
STANDARD IEC60076
YEAR 09 / 2009
POS NO.
HIGH VOLTAGE (V)
CURRENT (A)
LOW VOLTAGE (V)
CURRENT (A)
1 2
1 11825 7425
2 11550 7150
3 11275 6875
4 11000 6600 52.48 415 V 1391.24 A
5 10725 6325
6 10450 6050
7 10175 5775
TYPE OUTDOOR
SERVICE CONT.
COOLING ONAN
TEMP. RISE 55 / 60 °C
INS. LEVEL A
PHASES 3
FREQUENCY 50 Hz
Pfe 1088 W
Pcu 9384 W
%Uk 5.72
OIL TYPE SHELL DIALA AX
ACTIVE PART 1760 kg
OIL WEIGHT 595 kg
TOT. WEIGHT 2990 kg
INSULATION RESISTANCE (Gohm) 20 °C
POS
30 sec.
60 sec.
LV.T
HV.T
LV - HV
K-Q Focus ISO 9001
MADE IN TURKEY
Ramazanoğlu Mah.Transtek Cd. No:18 - 34906 PK. 51 PENDİK - İST. / TURKEY
Telefon: +90 216 378 86 97 Pbx - Fax: +90 216 595 02 35 - 595 10 26
www.astorpower.com - E-mail: info@astorpower.com.tr

Appendix B

List of tables for main feeder and building A parameters values

Data of main feeder										
St [VA]	Pt [W]	Qt [VAR]	TDDa [%]	TDDb [%]	TDDc [%]	TDD total	thdVa [%]	thdVb [%]	thdVc [%]	THDv total
164300	154900	54750	4.94	6.96	5.39	5.76	1.945	2.09	2.2	2.07
165600	156400	54370	4.91	6.81	5.12	5.61	1.925	2.05	2.1	2.03
164700	155400	54480	4.91	6.76	5.04	5.57	1.924	2.04	2.1	2.02
166700	157600	54490	4.79	6.29	4.46	5.18	1.9	1.97	2	1.97
167500	158600	53910	4.73	5.89	4.01	4.88	1.913	1.94	2	1.96
165400	156500	53590	4.83	6.1	4.25	5.06	1.944	1.97	2	1.98
165100	156100	53530	4.9	6.29	4.44	5.21	1.962	1.99	2.1	2
164600	155700	53490	4.96	6.28	4.44	5.23	1.961	1.99	2.1	2
163900	154900	53630	4.98	6.34	4.47	5.26	1.97	1.99	2.1	2.01
163700	154800	53430	5.03	6.19	4.27	5.16	1.983	1.97	2	2
385500	316600	127200	11.8	13.5	13.08	12.8	2.26	2.62	2.4	2.59
391800	316000	126700	11.9	13.5	13.25	12.9	2.259	2.59	2.5	2.57
388400	315900	126600	11.9	13.4	12.97	12.8	2.233	2.57	2.5	2.57
384800	314700	126500	12	13.4	13.16	12.9	2.203	2.59	2.4	2.56
382000	312100	126900	12.4	13.9	14.36	13.5	2.154	2.59	2.5	2.66
378100	314900	127800	12.5	14.1	14.88	13.8	2.188	2.56	2.5	2.69
375000	320600	127600	12.4	13.8	14.41	13.5	2.204	2.52	2.6	2.66
371600	330600	127400	12.3	13.5	13.91	13.2	2.196	2.53	2.5	2.63
368600	324600	127700	11.9	12.7	12.49	12.3	2.223	2.55	2.6	2.57
369400	322300	127700	12.4	13.8	14.52	13.6	2.234	2.58	2.8	2.65
338600	179600	133300	11.4	12.5	10.82	11.6	2.425	2.32	2.9	2.67
340100	181000	133700	11.4	12.5	10.97	11.6	2.512	2.32	2.9	2.66
340700	182000	134000	11.5	12.7	11.15	11.8	2.496	2.36	2.8	2.64
343700	182400	134200	12.9	13.8	13.69	13.4	2.401	2.36	2.8	2.77
341200	182200	133800	13.6	14.2	14.86	14.2	2.476	2.34	2.8	2.87
339700	184700	133700	13.6	14.1	14.71	14.1	2.486	2.31	2.8	2.87
338600	187400	133500	13.5	14.1	14.64	14.1	2.526	2.25	2.7	2.86
337000	196100	133500	13.6	14.2	14.86	14.2	2.496	2.2	2.9	2.85
337200	200300	133600	13.4	14.1	14.65	14	2.455	2.11	2.9	2.83
178300	196600	136000	13.2	14	14.56	13.9	2.442	2.09	2.9	2.83
179000	181300	88160	11	11.8	11.41	11.4	3.057	2.4	3.2	2.43
179100	180500	88000	10.9	11.8	11.4	11.4	3.091	2.39	3.2	2.38
179800	179100	87910	10.9	11.7	11.32	11.3	3.045	2.41	3.2	2.35
180000	179000	88170	10.8	11.5	11.26	11.2	3.082	2.41	3.2	2.33
180800	180000	87830	10.8	11.5	11.27	11.2	3.07	2.37	3.2	2.35
180900	181000	87680	10.8	11.5	11.24	11.2	3.073	2.35	3.2	2.32
178200	180600	87830	10.7	11.5	11.24	11.1	3.094	2.36	3.2	2.33
177800	182900	86820	10.5	11.6	11.29	11.1	3.101	2.41	3.2	2.34
177600	182200	85790	10	11.2	10.66	10.6	3.116	2.41	3.1	2.26
177300	187500	86330	9.89	11.2	10.33	10.5	3.135	2.4	3	2.24

harmonic voltage in phase A													
har15	har13	har12	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.129	0.94	0.021	1.25	0.024	1.076	0.017	1.99	0.033	3.571	0.027	0.705	0.034	235
0.165	0.81	0.017	1.31	0.026	1.146	0.015	1.92	0.032	3.526	0.022	0.726	0.037	235
0.171	0.79	0.023	1.34	0.016	1.181	0.019	1.92	0.028	3.511	0.023	0.724	0.023	235
0.145	0.65	0.022	1.45	0.015	1.316	0.017	1.75	0.03	3.453	0.019	0.755	0.032	235
0.157	0.7	0.015	1.57	0.015	1.309	0.017	1.61	0.027	3.505	0.015	0.744	0.039	235
0.137	0.65	0.022	1.49	0.024	1.401	0.017	1.74	0.027	3.54	0.037	0.76	0.042	235
0.111	0.58	0.016	1.43	0.018	1.433	0.022	1.84	0.028	3.569	0.041	0.745	0.042	235
0.111	0.6	0.025	1.45	0.018	1.427	0.024	1.84	0.028	3.56	0.026	0.743	0.031	235
0.119	0.59	0.016	1.44	0.018	1.414	0.013	1.87	0.029	3.582	0.02	0.762	0.03	235
0.143	0.61	0.021	1.53	0.022	1.464	0.016	1.8	0.027	3.589	0.033	0.783	0.026	235
0.041	0.36	0.004	0.59	0.031	0.943	0.071	3.34	0.078	4.513	0.041	1.672	0.081	231
0.043	0.36	0.005	0.74	0.032	0.856	0.067	3.24	0.075	4.361	0.051	1.672	0.076	231
0.032	0.37	0.004	0.71	0.029	0.867	0.059	3.18	0.068	4.441	0.048	1.695	0.084	231
0.035	0.37	0.007	0.68	0.028	0.878	0.065	3.27	0.07	4.418	0.049	1.706	0.088	231
0.055	0.34	0.008	0.76	0.032	0.902	0.061	3.24	0.07	4.401	0.053	1.749	0.086	231
0.061	0.33	0.004	0.6	0.035	0.994	0.065	3.34	0.082	4.522	0.049	1.74	0.082	231
0.033	0.36	0.005	0.57	0.033	0.955	0.063	3.29	0.08	4.455	0.051	1.747	0.08	231
0.017	0.36	0.013	0.63	0.024	0.903	0.049	3.29	0.075	4.416	0.041	1.729	0.083	231
0.014	0.32	0.013	0.73	0.022	0.862	0.046	3.06	0.073	4.455	0.057	1.787	0.073	231
0.03	0.33	0.013	1.02	0.021	0.794	0.035	2.68	0.075	4.449	0.044	1.878	0.089	231
0.06	0.25	0.016	0.71	0.056	1.021	0.028	3.44	0.089	4.523	0.09	1.593	0.079	236
0.049	0.25	0.01	0.71	0.046	0.982	0.013	3.41	0.049	4.562	0.094	1.558	0.064	236
0.056	0.26	0.016	0.57	0.056	0.984	0.018	3.7	0.079	4.529	0.091	1.488	0.063	236
0.058	0.27	0.019	0.53	0.053	0.983	0.011	3.74	0.095	4.468	0.08	1.468	0.076	236
0.06	0.25	0.014	0.54	0.063	0.997	0.02	3.72	0.104	4.387	0.099	1.472	0.07	236
0.065	0.23	0.019	0.57	0.052	1.008	0.02	3.74	0.091	4.32	0.083	1.465	0.063	236
0.071	0.24	0.018	0.55	0.057	1.007	0.019	3.74	0.074	4.281	0.092	1.463	0.06	236
0.069	0.25	0.017	0.53	0.055	1.001	0.023	3.72	0.08	4.28	0.093	1.444	0.055	236
0.049	0.25	0.019	0.58	0.05	0.93	0.024	3.64	0.072	4.334	0.076	1.469	0.067	236
0.048	0.26	0.018	0.67	0.046	0.891	0.032	3.54	0.067	4.333	0.109	1.462	0.079	236

harmonic current in phase A													
har15	har13	har12	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.423	5.05	0.111	8.85	0.177	5.865	0.189	6.52	0.172	11.12	0.182	11.2	0.349	197
0.592	4.28	0.091	8.93	0.171	6.444	0.164	6.41	0.167	10.51	0.153	11.52	0.5	200
0.632	4.11	0.113	9.02	0.123	6.689	0.22	6.3	0.152	10.36	0.162	11.57	0.472	195
0.505	3.18	0.103	9.45	0.109	7.751	0.196	5.38	0.145	8.41	0.167	12.07	0.435	197
0.429	3.46	0.082	10.2	0.111	7.756	0.187	4.28	0.136	6.743	0.219	12.4	0.34	198
0.436	3.15	0.106	9.78	0.143	8.344	0.18	5.34	0.168	7.429	0.175	12.36	0.557	193
0.403	2.77	0.073	9.42	0.119	8.588	0.319	6.16	0.19	7.853	0.294	12.37	0.885	194

0.408	2.82	0.099	9.54	0.11	8.574	0.24	6.21	0.157	7.882	0.106	12.66	0.542	192
0.44	2.83	0.072	9.44	0.132	8.578	0.198	6.35	0.157	8.07	0.245	12.66	0.548	191
0.491	2.85	0.092	9.94	0.136	8.954	0.191	6.04	0.14	7.499	0.218	12.87	0.356	187
0.462	1.99	0.058	9.15	0.087	6.634	0.381	26.4	0.468	19.55	0.508	29.26	0.754	525
0.361	2.56	0.084	9.37	0.064	6.227	0.314	27.2	0.361	21.21	0.14	28.83	0.547	523
0.388	2.58	0.067	9.12	0.059	6.406	0.359	27.3	0.407	20.95	0.208	28.83	0.413	520
0.391	2.5	0.094	9.27	0.049	6.302	0.409	27.2	0.496	21.21	0.254	28.66	0.446	520
0.31	2.51	0.081	8.93	0.079	6.281	0.39	26.6	0.495	20.91	0.318	28.71	0.459	518
0.3	2.45	0.072	9.13	0.08	6.174	0.402	26.5	0.578	21.42	0.284	28.29	0.396	519
0.331	2.55	0.086	9.14	0.068	6.187	0.348	26.9	0.63	21.38	0.271	28.23	0.474	522
0.422	2.58	0.103	9.37	0.102	6.404	0.345	27.1	0.609	21.73	0.292	28.51	0.471	524
0.425	2.59	0.086	9.05	0.081	6.313	0.311	28	0.5	22	0.195	28.15	0.41	524
0.535	2.56	0.069	8.29	0.079	6.064	0.393	31.9	0.619	25	0.194	27.24	0.452	521
0.864	2.95	0.095	9.56	0.182	7.441	0.154	17	0.365	15.97	0.23	23.69	0.221	341
0.83	2.95	0.09	9.58	0.233	7.574	0.094	17.3	0.352	16.38	0.164	23.76	0.209	340
0.787	2.9	0.099	9.56	0.175	7.386	0.147	17.3	0.304	16.42	0.138	23.77	0.327	340
0.773	2.99	0.042	10	0.137	7.192	0.256	17	0.329	16.4	0.12	23.8	0.212	339
0.826	3.07	0.068	10	0.1	7.246	0.216	16.9	0.345	16.17	0.218	23.79	0.048	340
0.838	3.05	0.095	9.99	0.082	7.31	0.154	17	0.392	16.19	0.12	23.85	1.132	342
0.829	3.06	0.055	9.89	0.073	7.35	0.091	17	0.434	16.45	0.19	23.53	0.41	342
0.777	2.81	0.084	9.49	0.066	7.09	0.147	16.7	0.452	15.85	0.134	22.63	0.315	345
0.799	2.65	0.092	9.24	0.13	7.185	0.264	16.9	0.381	15.4	0.222	22.88	0.078	348
0.726	2.01	0.082	9.24	0.045	6.911	0.186	14.8	0.402	11.18	0.218	23.77	0.28	349

harmonic voltage in phase B													
har15	har13	har12	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.445	0.8	0.012	0.56	0.009	1.28	0.016	2.83	0.009	3.43	0.049	1.286	0.06	236
0.435	0.66	0.009	0.6	0.005	1.29	0.009	2.75	0.01	3.355	0.053	1.325	0.064	236
0.435	0.63	0.012	0.62	0.008	1.29	0.018	2.75	0.012	3.339	0.053	1.313	0.069	236
0.451	0.48	0.008	0.87	0.01	1.273	0.014	2.54	0.01	3.234	0.046	1.304	0.064	236
0.492	0.49	0.011	0.99	0.007	1.267	0.013	2.4	0.01	3.2	0.039	1.326	0.064	236
0.481	0.48	0.013	0.94	0.01	1.279	0.018	2.5	0.013	3.235	0.05	1.312	0.079	236
0.483	0.45	0.013	0.89	0.012	1.292	0.013	2.58	0.02	3.261	0.051	1.311	0.076	236
0.473	0.46	0.014	0.89	0.004	1.287	0.008	2.56	0.007	3.269	0.051	1.297	0.068	236
0.466	0.46	0.01	0.88	0.007	1.298	0.013	2.6	0.01	3.275	0.045	1.249	0.064	236
0.462	0.45	0.011	0.98	0.005	1.289	0.014	2.51	0.011	3.257	0.062	1.225	0.067	236
0.069	0.16	0.005	0.26	0.03	1.128	0.059	2.72	0.037	3.575	0.038	2.154	0.061	236
0.069	0.21	0.004	0.36	0.026	1.094	0.051	2.59	0.028	3.555	0.034	2.188	0.066	236
0.055	0.21	0.006	0.33	0.022	1.072	0.042	2.57	0.026	3.452	0.033	2.166	0.06	236
0.078	0.37	0.005	0.72	0.033	1.069	0.03	1.96	0.023	3.392	0.051	2.294	0.06	236
0.095	0.42	0.008	0.93	0.04	1.16	0.033	1.45	0.023	3.551	0.034	2.458	0.065	236
0.079	0.33	0.003	0.71	0.046	1.151	0.05	1.89	0.022	3.438	0.037	2.353	0.067	236

0.078	0.29	0.007	0.59	0.036	1.034	0.052	2.17	0.025	3.355	0.038	2.272	0.07	236
0.068	0.29	0.007	0.59	0.037	1.045	0.043	2.14	0.02	3.334	0.048	2.289	0.074	236
0.092	0.28	0.006	0.58	0.027	1.029	0.044	2.12	0.021	3.307	0.042	2.299	0.077	236
0.086	0.29	0.011	0.58	0.029	1.059	0.043	2.14	0.022	3.329	0.054	2.32	0.079	236
0.07	0.18	0.007	0.29	0.007	0.809	0.053	3.12	0.047	3.367	0.029	2.228	0.061	236
0.07	0.21	0.008	0.3	0.011	0.803	0.055	3.14	0.058	3.407	0.037	2.219	0.065	235
0.077	0.2	0.008	0.28	0.01	0.804	0.043	3.12	0.056	3.336	0.039	2.22	0.065	235
0.079	0.2	0.007	0.29	0.01	0.786	0.044	3.08	0.065	3.355	0.046	2.187	0.067	235
0.117	0.13	0.01	0.34	0.008	0.903	0.033	2.96	0.067	3.43	0.053	2.276	0.079	236
0.116	0.15	0.007	0.36	0.012	0.915	0.042	3.05	0.078	3.447	0.05	2.256	0.076	236
0.116	0.07	0.012	0.39	0.007	0.931	0.044	2.86	0.07	3.362	0.06	2.3	0.073	236
0.126	0.03	0.013	0.44	0.005	0.94	0.04	2.79	0.072	3.342	0.054	2.325	0.074	236
0.085	0.17	0.011	0.32	0.006	0.841	0.044	3.04	0.075	3.368	0.05	2.267	0.068	236
0.07	0.21	0.009	0.3	0.008	0.784	0.053	3.11	0.074	3.34	0.047	2.225	0.071	236

harmonic current in phase B													
har15	har13	har12	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
1.78	5.17	0.078	4.39	0.07	7.169	0.11	14.8	0.052	15.07	0.139	17.56	0.445	236
1.746	4.33	0.031	3.89	0.044	7.187	0.099	14.5	0.058	14.22	0.128	17.79	0.168	238
1.738	4.07	0.056	3.93	0.044	7.14	0.103	14.4	0.085	14.07	0.173	17.7	0.187	239
1.764	2.91	0.039	5.26	0.048	6.997	0.093	12.9	0.053	11.57	0.151	17.6	0.435	242
1.965	2.69	0.049	6.29	0.04	6.942	0.121	11.2	0.042	8.986	0.103	17.55	0.643	242
1.916	2.76	0.057	5.84	0.039	6.988	0.106	12.2	0.064	10.46	0.13	17.43	0.585	239
1.975	2.69	0.066	5.44	0.075	7.072	0.089	13	0.124	11.56	0.193	17.46	0.593	238
1.947	2.72	0.067	5.45	0.04	7.013	0.075	13	0.031	11.55	0.142	17.43	0.373	238
1.906	2.78	0.039	5.36	0.04	7.046	0.13	13.2	0.057	11.82	0.105	17.45	0.201	237
1.843	2.64	0.061	5.99	0.04	7.007	0.093	12.6	0.059	10.84	0.12	17.47	0.307	238
0.528	3.37	0.072	9.31	0.23	8.399	0.356	19.9	0.358	14.36	0.299	37.98	0.393	485
0.548	3.36	0.096	10	0.224	7.858	0.38	21.6	0.381	18.34	0.268	37.27	0.313	478
0.528	3.33	0.071	9.89	0.23	8.005	0.405	22.2	0.341	18.52	0.201	37.24	0.3	475
0.363	3.4	0.047	9.81	0.215	8.444	0.473	21.8	0.42	17.82	0.226	37.57	0.3	476
0.409	3.31	0.04	9.76	0.273	8.681	0.442	21.7	0.373	17.74	0.235	37.77	0.251	477
0.428	2.74	0.027	9.77	0.23	8.761	0.475	21.2	0.32	15.94	0.161	38.5	0.29	478
0.427	2.08	0.063	9.63	0.214	7.784	0.484	26.7	0.291	21.7	0.169	37.17	0.343	470
0.611	2.53	0.038	7.32	0.156	7.791	0.471	31.9	0.372	28.24	0.178	35.55	0.303	464
0.665	3.06	0.041	6.42	0.133	7.62	0.374	33.6	0.315	30.91	0.228	34.77	0.308	464
0.657	2.8	0.054	6.25	0.119	7.576	0.366	33.4	0.348	30.35	0.189	35.2	0.308	466
0.7	3.74	0.1	7.19	0.052	5.548	0.586	31.3	0.409	29.17	0.351	32.92	0.526	376
0.768	3.23	0.088	7.6	0.144	6.07	0.729	30.9	0.397	27.89	0.287	33.39	0.473	378
0.792	3.03	0.119	7.96	0.198	6.05	0.748	30.4	0.431	27.11	0.303	33.43	0.514	379
0.671	2.04	0.117	9.32	0.163	5.911	0.721	27.1	0.369	22.2	0.232	34.38	0.495	386
0.663	1.87	0.126	10.2	0.139	5.693	0.646	24.8	0.447	17.78	0.283	34.95	0.503	398

0.716	2.15	0.104	9.35	0.076	5.877	0.477	25.3	0.316	20	0.383	34.72	0.463	396
0.712	2.21	0.113	9.13	0.062	5.79	0.532	26.3	0.416	21.18	0.324	34.45	0.597	393
0.738	2.18	0.102	9.02	0.111	5.958	0.546	26.1	0.353	21.02	0.33	34.55	0.544	396
0.699	2.12	0.092	9.58	0.174	5.599	0.526	25.3	0.396	19.49	0.341	34.67	0.494	398
0.698	2.35	0.11	9.43	0.204	5.824	0.545	25.7	0.452	19.28	0.326	34.94	0.451	398

harmonic voltage in phase C													
har15	har13	har12	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.237	0.7	0.014	1.3	0.015	1.106	0.022	3.07	0.01	3.638	0.077	0.294	0.044	236
0.174	0.52	0.008	1.22	0.009	1.082	0.026	3.02	0.01	3.589	0.073	0.264	0.047	236
0.165	0.46	0.009	1.2	0.012	1.078	0.029	3	0.013	3.555	0.075	0.272	0.055	236
0.233	0.32	0.011	1.31	0.013	0.992	0.031	2.85	0.015	3.451	0.065	0.256	0.055	236
0.287	0.4	0.009	1.44	0.013	0.947	0.031	2.67	0.011	3.467	0.068	0.282	0.046	236
0.255	0.34	0.012	1.37	0.016	0.967	0.033	2.76	0.015	3.454	0.083	0.27	0.065	236
0.237	0.3	0.006	1.32	0.019	0.988	0.04	2.85	0.014	3.47	0.073	0.284	0.07	236
0.243	0.31	0.008	1.31	0.016	0.994	0.034	2.85	0.012	3.492	0.073	0.318	0.052	236
0.23	0.3	0.009	1.28	0.017	1.008	0.032	2.86	0.007	3.503	0.074	0.33	0.043	236
0.248	0.33	0.01	1.36	0.012	0.976	0.024	2.77	0.011	3.467	0.081	0.343	0.057	236
0.157	0.34	0.008	1.05	0.028	0.696	0.041	2.79	0.015	4.563	0.008	1.279	0.054	236
0.133	0.26	0.005	1	0.027	0.863	0.04	2.62	0.017	4.785	0.015	1.285	0.055	236
0.134	0.27	0.008	1.01	0.024	0.854	0.046	2.7	0.025	4.781	0.018	1.322	0.056	236
0.178	0.32	0.005	1.08	0.02	0.787	0.063	2.81	0.046	4.656	0.024	1.336	0.054	236
0.181	0.32	0.007	1.08	0.021	0.757	0.063	2.84	0.045	4.642	0.023	1.357	0.061	236
0.18	0.36	0.007	1.03	0.024	0.707	0.065	3.08	0.043	4.608	0.02	1.363	0.05	236
0.177	0.35	0.005	1.04	0.03	0.674	0.033	3.09	0.022	4.711	0.026	1.333	0.054	236
0.16	0.32	0.009	0.8	0.026	0.713	0.043	3.67	0.027	4.699	0.033	1.348	0.049	236
0.157	0.29	0.006	0.66	0.025	0.803	0.049	4.08	0.013	4.691	0.034	1.331	0.046	236
0.156	0.29	0.007	0.62	0.025	0.829	0.048	4.08	0.016	4.689	0.027	1.345	0.037	236
0.116	0.33	0.008	1.03	0.014	0.8	0.053	2.9	0.028	5.367	0.017	1.162	0.053	236
0.123	0.35	0.01	1	0.013	0.834	0.044	3.03	0.022	5.421	0.025	1.143	0.063	237
0.14	0.36	0.014	0.98	0.016	0.879	0.031	3.07	0.019	5.393	0.02	1.16	0.085	237
0.14	0.37	0.01	1	0.018	0.886	0.03	3.04	0.014	5.427	0.014	1.18	0.081	237
0.142	0.37	0.015	1.01	0.017	0.88	0.028	3.04	0.008	5.414	0.011	1.196	0.084	237
0.133	0.36	0.008	0.89	0.023	0.916	0.042	3.27	0.025	5.372	0.011	1.185	0.076	237
0.11	0.35	0.016	0.67	0.021	1.033	0.054	3.69	0.027	5.426	0.024	1.17	0.055	236
0.109	0.35	0.013	0.67	0.021	1.023	0.056	3.82	0.033	5.434	0.029	1.167	0.061	237
0.108	0.34	0.011	0.69	0.021	1.029	0.06	3.76	0.038	5.427	0.044	1.201	0.06	237

0.106	0.34	0.01	0.69	0.027	1.039	0.07	3.73	0.043	5.471	0.025	1.194	0.067	237

harmonic current in phase C													
har15	har13	har12	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.254	3.51	0.08	9.12	0.111	6.317	0.123	14.9	0.125	9.931	0.241	7.625	0.399	260
0.134	2.45	0.046	8.15	0.092	5.924	0.147	14.4	0.141	9.571	0.199	7.373	0.491	261
0.194	2.08	0.049	7.95	0.076	5.92	0.174	14.3	0.175	9.341	0.249	7.27	0.378	261
0.372	0.88	0.064	7.49	0.043	4.983	0.186	12.9	0.153	7.544	0.205	6.697	0.618	265
0.499	1.06	0.045	8.14	0.036	4.528	0.213	11	0.133	5.512	0.228	6.672	0.774	269
0.43	0.86	0.061	7.72	0.087	4.643	0.207	12.1	0.134	6.627	0.227	6.741	0.935	267
0.385	0.83	0.043	7.44	0.082	4.774	0.259	12.9	0.165	7.447	0.205	6.774	0.919	266
0.441	0.85	0.054	7.38	0.077	4.81	0.213	12.9	0.15	7.513	0.216	6.741	0.761	266
0.41	0.85	0.034	7.26	0.08	4.876	0.215	13.1	0.138	7.689	0.23	6.66	0.357	264
0.45	0.79	0.051	7.46	0.069	4.55	0.182	12.4	0.143	6.96	0.174	6.445	0.395	266
0.388	1.34	0.03	7.73	0.14	3.448	0.353	23.9	0.136	14.09	0.36	21.83	0.479	517
0.416	1.29	0.05	7.94	0.156	3.43	0.359	24.4	0.19	13.87	0.365	22.1	0.907	513
0.433	1.98	0.046	8.43	0.078	3.125	0.461	28.3	0.234	14.57	0.389	22.75	0.625	506
0.466	2.02	0.052	8.5	0.116	2.79	0.443	28.8	0.171	14.88	0.367	22.85	0.314	507
0.379	2.34	0.048	8.08	0.085	2.539	0.482	32.8	0.151	17.04	0.367	23.26	0.376	505
0.366	2.46	0.036	8.35	0.207	2.282	0.279	33	0.19	18.11	0.266	22.99	0.379	507
0.291	2.8	0.065	6.89	0.177	2.683	0.313	39.9	0.251	21.95	0.236	23.56	0.949	502
0.246	3.16	0.04	6.2	0.139	3.365	0.394	44	0.12	23.81	0.13	23.76	0.779	500
0.32	3.25	0.041	6.06	0.133	3.688	0.391	44.4	0.167	24.61	0.132	23.92	0.446	500
0.348	3.47	0.034	5.87	0.111	4.126	0.454	46.2	0.188	24.72	0.107	24.15	0.665	501
0.148	1.94	0.027	7.43	0.092	5.402	0.563	22.5	0.767	13.98	0.118	19.21	0.468	351
0.21	2.07	0.04	7.39	0.105	5.648	0.505	22.4	0.652	14.17	0.23	19.22	0.252	352
0.202	2.37	0.058	7.56	0.113	5.619	0.535	23.1	0.397	14.41	0.138	19.45	0.38	351
0.183	2.4	0.047	7.54	0.11	5.461	0.613	23.1	0.488	14.48	0.112	19.32	0.436	351
0.184	2.44	0.035	7.83	0.084	5.59	0.517	22.6	0.747	14.48	0.194	19.61	0.258	349
0.196	2.52	0.038	7.9	0.085	5.393	0.438	22.5	0.608	14.08	0.23	19.62	0.312	349

0.198	2.47	0.016	7.79	0.128	5.543	0.649	22.2	0.465	14.09	0.156	19.63	0.556	349
0.229	2.41	0.021	7.8	0.077	5.495	0.631	21.9	0.582	14.17	0.106	19.56	0.448	349
0.194	1.92	0.042	7.58	0.076	4.953	0.539	21.6	0.723	13.41	0.236	19.63	0.296	350
0.149	1.71	0.071	7.47	0.073	4.882	0.49	21.5	0.589	12.96	0.282	19.55	0.269	350

Data of building A

harmonic voltage in phase A												
har15	har13	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.141	0.253	0.954	0.018	0.851	0.049	2.106	0.021	3.805	0.015	1.29	0.025	234
0.14	0.243	0.959	0.011	0.845	0.052	2.075	0.021	3.699	0.022	1.25	0.026	234.1
0.157	0.186	1.072	0.012	1.006	0.052	1.589	0.028	3.783	0.029	1.255	0.029	234.2
0.149	0.189	1.061	0.007	1.014	0.048	1.539	0.03	3.891	0.026	1.256	0.018	234.1
0.173	0.217	1.079	0.011	0.945	0.056	1.594	0.025	3.856	0.018	1.219	0.022	234
0.169	0.209	1.081	0.011	0.939	0.058	1.607	0.032	3.816	0.019	1.216	0.024	234
0.163	0.155	0.893	0.005	1.014	0.061	2.164	0.041	3.847	0.016	1.202	0.027	234
0.163	0.12	0.78	0.004	1.081	0.062	2.513	0.036	3.82	0.013	1.181	0.023	234.1
0.157	0.132	0.749	0.004	1.109	0.054	2.612	0.038	3.773	0.011	1.209	0.019	234
0.161	0.143	0.742	0.004	1.119	0.048	2.636	0.047	3.753	0.016	1.209	0.02	234.1
0.109	0.386	1.187	0.015	1.117	0.053	1.617	0.088	3.697	0.064	2.124	0.088	235.7
0.131	0.323	1.223	0.018	1.112	0.044	1.621	0.088	3.8	0.083	2.131	0.071	235.5
0.127	0.327	1.24	0.015	1.089	0.048	1.622	0.08	3.789	0.066	2.1	0.078	235.6
0.134	0.319	1.236	0.013	1.092	0.037	1.65	0.083	3.766	0.072	2.106	0.052	235.6
0.11	0.329	1.187	0.011	1.028	0.047	1.759	0.093	3.704	0.074	2.106	0.072	235.6
0.109	0.327	1.167	0.014	1.026	0.064	1.934	0.111	3.71	0.075	2.113	0.097	235.6
0.096	0.335	0.908	0.019	1.06	0.069	2.704	0.095	3.694	0.068	1.979	0.096	235.7
0.1	0.236	0.708	0.018	1.172	0.061	3.232	0.099	3.707	0.064	1.936	0.066	235.7
0.107	0.146	0.527	0.012	1.281	0.049	3.815	0.092	3.799	0.07	1.855	0.05	235.7
0.134	0.162	0.492	0.009	1.378	0.055	3.981	0.108	3.794	0.082	1.885	0.08	235.7
0.209	0.222	0.404	0.023	0.889	0.028	3.241	0.037	4.139	0.068	1.363	0.046	235.3
0.21	0.174	0.417	0.015	0.897	0.031	3.109	0.036	4.153	0.066	1.368	0.045	235.3
0.208	0.149	0.669	0.017	0.863	0.026	2.428	0.032	3.969	0.052	1.427	0.036	235.2
0.218	0.156	0.705	0.031	0.846	0.026	2.299	0.047	3.958	0.046	1.442	0.033	235.2
0.192	0.153	0.438	0.033	0.837	0.039	2.993	0.044	4.107	0.04	1.351	0.052	235.2
0.188	0.156	0.413	0.031	0.86	0.017	2.985	0.071	3.999	0.039	1.325	0.067	235.1

0.19	0.133	0.459	0.009	0.846	0.022	2.903	0.053	3.959	0.042	1.315	0.054	235.1
0.187	0.122	0.477	0.012	0.865	0.031	2.875	0.059	4.012	0.041	1.358	0.055	235.1
0.2	0.179	0.598	0.028	0.835	0.04	2.544	0.047	3.91	0.035	1.414	0.041	235.1
0.209	0.237	0.771	0.025	0.835	0.03	2.097	0.056	3.864	0.038	1.513	0.029	235.1

harmonic current in phase A												
har15	har13	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.083	1.023	2.265	0.039	2.21	0.046	4.097	0.043	3.915	0.063	3.548	0.162	52.17
0.116	1.005	2.296	0.025	2.21	0.029	4.136	0.043	3.927	0.072	3.503	0.175	51.99
0.261	0.876	2.404	0.034	2.487	0.032	4.02	0.039	3.878	0.074	3.687	0.17	52.16
0.245	0.838	2.371	0.016	2.438	0.03	3.9	0.036	3.907	0.056	3.676	0.168	52.22
0.184	0.961	2.346	0.028	2.359	0.034	3.949	0.039	3.908	0.095	3.607	0.182	52.22
0.2	0.926	2.342	0.043	2.366	0.029	3.909	0.047	3.898	0.081	3.613	0.193	52.44
0.14	0.88	2.199	0.032	2.385	0.025	4.188	0.029	3.99	0.071	3.57	0.19	52.42
0.119	0.835	2.075	0.034	2.405	0.034	4.382	0.024	4.015	0.076	3.513	0.173	52.43
0.15	0.848	2.013	0.022	2.376	0.03	4.421	0.029	4.018	0.083	3.531	0.178	52.23
0.154	0.882	1.939	0.026	2.394	0.02	4.428	0.032	4.028	0.068	3.521	0.186	52.07
0.421	0.964	1.054	0.049	1.207	0.037	4.094	0.111	5.293	0.069	3.166	0.237	80.62
0.441	1.032	1.193	0.039	1.245	0.032	3.941	0.122	5.252	0.061	3.303	0.247	80.52
0.453	0.994	1.253	0.063	1.261	0.033	3.923	0.115	5.204	0.08	3.283	0.212	80.53
0.391	1.063	1.282	0.047	1.265	0.028	3.875	0.131	5.155	0.071	3.341	0.213	80.6
0.367	1.039	1.342	0.043	1.283	0.039	3.874	0.129	5.147	0.063	3.292	0.265	80.56
0.453	0.956	1.193	0.025	1.254	0.031	4.024	0.131	5.233	0.084	3.229	0.23	80.71
0.445	0.88	1.157	0.031	1.268	0.015	4.171	0.103	5.327	0.081	3.281	0.239	80.83
0.439	0.869	1.114	0.045	1.279	0.022	4.239	0.141	5.336	0.092	3.143	0.24	80.84
0.45	0.9	1.078	0.024	1.271	0.008	4.272	0.106	5.312	0.079	3.144	0.237	80.84
0.396	0.893	1.103	0.04	1.268	0.024	4.277	0.102	5.328	0.103	3.17	0.213	80.57
0.121	0.741	1.064	0.022	1.645	0.029	2.883	0.029	2.897	0.101	2.045	0.179	37.59
0.079	0.751	1.091	0.025	1.628	0.022	2.825	0.029	2.894	0.127	2.042	0.179	37.72
0.118	0.755	1.112	0.037	1.676	0.034	2.816	0.041	2.862	0.096	2.052	0.226	37.77
0.105	0.8	1.176	0.034	1.629	0.023	2.732	0.087	2.83	0.033	2.076	0.228	37.76
0.145	0.865	1.2	0.036	1.585	0.014	2.634	0.086	2.82	0.019	2.103	0.276	37.64
0.137	0.81	1.248	0.025	1.59	0.016	2.566	0.041	2.796	0.079	2.146	0.221	37.54
0.14	0.848	1.218	0.022	1.566	0.023	2.581	0.032	2.76	0.103	2.103	0.195	37.52
0.124	0.853	1.229	0.031	1.563	0.015	2.609	0.028	2.783	0.096	2.127	0.164	37.56
0.175	0.834	1.213	0.042	1.601	0.016	2.657	0.013	2.801	0.111	2.121	0.155	37.62
0.145	0.852	1.224	0.011	1.594	0.019	2.637	0.028	2.792	0.106	2.116	0.166	37.59

harmonic voltage in phase B												
har15	har13	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.165	0.247	0.73	0.014	0.709	0.05	1.578	0.04	3.487	0.04	2.201	0.08	234.3

0.161	0.295	0.78	0.012	0.653	0.05	1.393	0.05	3.534	0.035	2.247	0.069	234.4
0.169	0.276	0.93	0.017	0.669	0.06	0.806	0.04	3.646	0.036	2.416	0.073	234.4
0.169	0.277	0.92	0.012	0.683	0.05	0.816	0.05	3.643	0.044	2.432	0.063	234.4
0.189	0.258	0.93	0.012	0.656	0.06	0.892	0.04	3.661	0.042	2.377	0.067	234.4
0.192	0.251	0.93	0.013	0.666	0.06	0.913	0.03	3.643	0.045	2.373	0.076	234.4
0.156	0.225	0.76	0.017	0.651	0.06	1.261	0.04	3.75	0.056	2.324	0.081	234.4
0.128	0.162	0.64	0.02	0.687	0.06	1.516	0.04	3.767	0.054	2.304	0.08	234.5
0.111	0.13	0.6	0.021	0.711	0.05	1.613	0.05	3.768	0.058	2.262	0.07	234.4
0.115	0.122	0.6	0.02	0.711	0.04	1.631	0.04	3.732	0.059	2.29	0.071	234.5
0.078	0.154	0.72	0.042	0.666	0.02	2.184	0.09	4.113	0.091	1.973	0.037	233.3
0.058	0.101	0.6	0.035	0.537	0.02	2.61	0.09	4.035	0.081	1.907	0.027	233.3
0.008	0.15	0.3	0.027	0.506	0.02	3.288	0.08	4.057	0.096	1.787	0.035	233.3
0.003	0.186	0.34	0.025	0.486	0.01	3.354	0.09	4.071	0.109	1.769	0.03	233.2
0.006	0.175	0.34	0.02	0.491	0.02	3.373	0.09	4.046	0.093	1.793	0.044	233.3
0.007	0.175	0.35	0.02	0.501	0.03	3.343	0.07	4.123	0.09	1.815	0.045	233
0.008	0.174	0.36	0.03	0.515	0.03	3.23	0.06	4.159	0.062	1.828	0.064	233.3
0.016	0.209	0.34	0.031	0.491	0.02	3.345	0.05	4.144	0.057	1.76	0.065	233.5
0.014	0.213	0.35	0.029	0.436	0.03	3.364	0.07	4.238	0.065	1.707	0.05	233.4
0.019	0.201	0.34	0.028	0.476	0.02	3.363	0.06	4.266	0.071	1.755	0.046	233.2
0.167	0.266	0.43	0.043	0.265	0.09	3.129	0.09	4.158	0.053	1.62	0.01	235.7
0.161	0.273	0.4	0.045	0.265	0.1	3.196	0.1	4.226	0.041	1.619	0.008	235.7
0.177	0.254	0.5	0.049	0.224	0.1	3.057	0.11	4.188	0.058	1.605	0.016	235.7
0.205	0.219	0.67	0.045	0.207	0.1	2.788	0.1	4.035	0.041	1.696	0.01	235.7
0.173	0.282	0.46	0.038	0.287	0.11	3.229	0.12	4.197	0.079	1.674	0.015	235.7
0.17	0.287	0.41	0.034	0.325	0.1	3.367	0.14	4.213	0.1	1.635	0.017	235.8
0.166	0.255	0.39	0.037	0.316	0.11	3.295	0.14	4.165	0.098	1.582	0.018	235.7
0.174	0.199	0.4	0.04	0.313	0.11	3.173	0.14	4.111	0.093	1.614	0.012	235.7
0.187	0.086	0.51	0.033	0.289	0.1	2.727	0.14	4.09	0.085	1.709	0.017	235.7
0.172	0.243	0.43	0.036	0.322	0.1	3.186	0.14	4.083	0.093	1.618	0.013	235.7

harmonic current in phase B												
har15	har13	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.625	0.902	1.98	0.075	3.713	0.06	6.52	0.07	11.24	0.113	13.14	0.24	80.44
0.68	0.825	1.86	0.056	3.579	0.04	6.611	0.07	11.76	0.113	12.79	0.246	78.97
0.72	1.046	2.07	0.074	3.825	0.04	6.611	0.06	11.65	0.104	12.27	0.296	82.38
0.668	0.996	1.94	0.054	3.83	0.04	6.221	0.08	11.42	0.106	13.49	0.231	81.04
0.713	1.022	1.99	0.061	3.726	0.06	6.204	0.06	11.42	0.113	13.47	0.208	80.76
0.739	0.98	1.96	0.079	3.718	0.06	6.246	0.06	11.44	0.098	13.48	0.208	80.68
0.707	0.959	1.88	0.053	3.733	0.06	6.454	0.04	11.51	0.108	13.36	0.238	80.59
0.648	1.018	1.84	0.078	3.764	0.06	6.635	0.07	11.56	0.104	13.32	0.236	80.66
0.657	1.076	1.89	0.061	3.827	0.03	6.816	0.06	11.58	0.092	13.17	0.233	78.36
0.656	1.107	1.89	0.071	3.832	0.03	6.747	0.05	11.53	0.098	13.28	0.224	75.83

1.03	1.466	1.64	0.093	4.215	0.07	7.405	0.12	13.16	0.397	17.7	0.397	96.77
1.03	1.413	1.6	0.109	4.201	0.08	7.736	0.12	13.15	0.327	17.52	0.442	96.66
1.034	1.422	1.58	0.112	4.21	0.05	7.699	0.1	13.12	0.359	17.56	0.395	96.6
1.041	1.508	1.68	0.057	4.243	0.05	7.902	0.08	13.14	0.195	17.46	0.29	95.49
1.025	1.553	1.7	0.026	4.262	0.04	7.986	0.04	13.17	0.191	17.35	0.286	94.3
1.025	1.514	1.69	0.053	4.254	0.03	8.073	0.05	13.17	0.18	17.35	0.248	94.36
1.036	1.523	1.73	0.033	4.272	0.06	8.059	0.03	13.11	0.184	17.4	0.236	94.59
1.031	1.551	1.7	0.036	4.293	0.03	8.064	0.04	13.1	0.185	17.4	0.3	94.36
1.043	1.536	1.71	0.028	4.321	0.05	8.058	0.04	13.11	0.165	17.37	0.301	94.55
1.029	1.55	1.74	0.031	4.302	0.07	8.053	0.05	13.12	0.2	17.39	0.255	94.46
1.026	1.246	1.38	0.05	3.002	0.08	5.878	0.06	9.21	0.151	11.81	0.361	43.94
1.03	1.264	1.39	0.044	3.036	0.09	5.873	0.05	9.241	0.163	11.83	0.371	43.95
1.045	1.25	1.38	0.051	3.015	0.09	5.881	0.05	9.251	0.18	11.82	0.352	44
1.049	1.264	1.38	0.061	3.019	0.09	5.936	0.05	9.316	0.169	11.91	0.383	44.15
1.031	1.268	1.36	0.059	3.019	0.09	5.898	0.04	9.255	0.15	11.85	0.396	44.04
1.025	1.272	1.36	0.035	3.017	0.07	5.867	0.05	9.222	0.163	11.84	0.38	43.95
1.044	1.26	1.36	0.029	2.975	0.07	5.844	0.07	9.215	0.136	11.83	0.414	43.92
1.067	1.231	1.38	0.049	2.984	0.09	5.799	0.06	9.215	0.132	11.87	0.431	43.87
1.091	1.206	1.42	0.039	2.878	0.09	5.575	0.05	9.194	0.137	11.93	0.416	43.72
1.165	1.251	1.49	0.064	2.675	0.09	5.227	0.07	9.056	0.121	11.99	0.439	43.72

harmonic voltage in phase C												
har15	har13	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.063	0.337	0.902	0.037	1.266	0.039	2.206	0.014	4.224	0.15	1.808	0.024	233.1
0.051	0.352	0.895	0.034	1.348	0.044	2.138	0.017	4.211	0.147	1.809	0.026	233.2
0.031	0.308	1.033	0.038	1.284	0.039	1.634	0.023	4.419	0.151	1.94	0.014	233.3
0.028	0.297	1.022	0.035	1.271	0.034	1.573	0.029	4.445	0.144	1.931	0.011	233.2
0.04	0.349	1.022	0.036	1.264	0.045	1.6	0.013	4.45	0.142	1.933	0.018	233.2
0.045	0.344	1.031	0.037	1.263	0.044	1.611	0.015	4.449	0.141	1.949	0.017	233.2
0.046	0.297	0.872	0.041	1.348	0.055	2.001	0.016	4.437	0.14	1.82	0.016	233.2
0.062	0.254	0.793	0.044	1.38	0.061	2.303	0.013	4.395	0.137	1.775	0.019	233.2
0.055	0.256	0.774	0.047	1.379	0.046	2.412	0.015	4.329	0.128	1.775	0.023	233.1
0.059	0.26	0.784	0.043	1.378	0.045	2.428	0.009	4.303	0.134	1.75	0.019	233.2
0.1	0.166	0.484	0.065	1.223	0.009	4.248	0.078	5.368	0.168	1.78	0.072	232.7
0.102	0.176	0.498	0.066	1.193	0.033	4.222	0.086	5.402	0.154	1.759	0.077	232.7
0.096	0.17	0.515	0.069	1.177	0.011	4.054	0.072	5.457	0.169	1.758	0.067	232.7
0.096	0.159	0.513	0.073	1.169	0.012	4.114	0.06	5.48	0.18	1.791	0.074	232.6
0.092	0.152	0.517	0.064	1.221	0.019	4.222	0.057	5.514	0.173	1.809	0.077	232.7
0.094	0.145	0.501	0.07	1.268	0.008	4.347	0.055	5.546	0.173	1.841	0.083	232.6
0.1	0.148	0.495	0.064	1.266	0.012	4.404	0.06	5.562	0.184	1.787	0.082	232.7
0.107	0.134	0.489	0.068	1.285	0.01	4.421	0.063	5.531	0.176	1.748	0.091	232.7
0.098	0.14	0.498	0.07	1.305	0.012	4.315	0.055	5.535	0.173	1.791	0.073	232.6

0.106	0.127	0.501	0.067	1.315	0.023	4.392	0.051	5.482	0.173	1.785	0.079	232.8
0.174	0.262	0.997	0.053	1.522	0.047	3.391	0.04	4.927	0.125	1.708	0.028	235.9
0.161	0.265	0.743	0.054	1.688	0.018	3.963	0.049	5.028	0.108	1.649	0.039	235.9
0.161	0.264	0.748	0.053	1.666	0.022	3.974	0.068	5.035	0.098	1.642	0.04	235.9
0.164	0.257	0.779	0.05	1.643	0.025	3.939	0.059	4.986	0.104	1.669	0.046	236
0.158	0.26	0.751	0.059	1.643	0.037	3.859	0.051	5.041	0.135	1.694	0.038	235.9
0.16	0.265	0.746	0.045	1.681	0.066	3.97	0.039	5.144	0.154	1.684	0.04	235.9
0.163	0.273	0.689	0.044	1.676	0.047	4.053	0.048	5.041	0.133	1.646	0.036	235.9
0.161	0.279	0.69	0.056	1.7	0.062	4.046	0.03	4.983	0.146	1.683	0.031	235.9
0.155	0.273	0.703	0.063	1.686	0.041	4.029	0.048	4.97	0.141	1.681	0.032	235.9
0.181	0.21	0.683	0.049	1.722	0.023	3.951	0.056	4.936	0.143	1.707	0.031	235.9

harmonic current in phase C												
har15	har13	har11	har10	har9	har8	har7	har6	har5	har4	har3	har2	har1
0.209	1.411	1.083	0.051	1.431	0.105	3.396	0.103	3.999	0.156	3.676	0.11	43.31
0.316	1.488	1.134	0.067	1.447	0.112	3.418	0.105	4.103	0.153	3.687	0.111	43.4
0.303	1.374	1.125	0.041	1.342	0.079	3.067	0.108	4.098	0.168	3.909	0.12	43.39
0.275	1.323	1.118	0.039	1.425	0.084	3.028	0.103	4.101	0.166	3.876	0.116	43.21
0.249	1.442	1.163	0.041	1.373	0.103	3.011	0.102	4.127	0.142	3.858	0.127	43.2
0.287	1.433	1.165	0.037	1.362	0.105	3.028	0.103	4.145	0.142	3.852	0.118	43.2
0.357	1.406	1.046	0.039	1.529	0.095	3.303	0.089	4.155	0.149	3.724	0.13	43.24
0.344	1.324	0.93	0.045	1.644	0.121	3.544	0.097	4.152	0.145	3.617	0.132	43.27
0.348	1.265	0.861	0.052	1.623	0.125	3.595	0.118	4.156	0.172	3.641	0.104	43.23
0.341	1.268	0.915	0.046	1.688	0.109	3.565	0.115	4.083	0.159	3.611	0.135	43.25
0.225	1.341	2.101	0.016	1.86	0.118	6.809	0.111	8.275	0.12	5.992	0.083	69.23
0.179	1.262	1.95	0.025	1.94	0.117	6.886	0.125	8.306	0.116	6.017	0.08	69.15
0.18	1.3	1.972	0.014	1.886	0.12	6.833	0.124	8.289	0.1	6.078	0.083	69.13
0.142	1.194	1.982	0.025	1.984	0.124	7.122	0.113	8.341	0.114	6.005	0.088	69.18
0.169	1.334	2.064	0.016	1.93	0.119	6.731	0.13	8.245	0.106	6.138	0.061	69.24
0.318	1.388	2.055	0.033	2.083	0.127	6.227	0.118	8.079	0.111	6.275	0.081	68.89
0.25	1.416	2.09	0.031	2.002	0.142	6.229	0.114	8.162	0.109	6.1	0.038	69.86
0.271	1.467	2.044	0.029	1.905	0.135	6.214	0.124	8.423	0.089	6.08	0.064	74.59
0.28	1.442	2.07	0.014	1.826	0.139	6.339	0.117	8.493	0.132	5.635	0.046	76.13
0.269	1.441	2.1	0.029	1.954	0.161	6.34	0.125	8.496	0.104	6.087	0.09	76.28
0.037	1.116	1.598	0.084	1.908	0.058	3.481	0.115	3.868	0.133	3.41	0.137	33.9
0.029	1.059	1.434	0.07	2.007	0.069	3.642	0.101	3.865	0.132	3.338	0.162	32.35
0.033	1.072	1.406	0.078	1.998	0.071	3.652	0.126	3.843	0.118	3.344	0.12	32.45
0.044	1.073	1.416	0.078	2.035	0.072	3.709	0.118	3.923	0.124	3.403	0.151	32.47
0.061	1.013	1.333	0.083	2.048	0.072	3.788	0.123	3.977	0.122	3.434	0.156	32.52
0.069	1	1.303	0.062	2.029	0.075	3.803	0.127	3.945	0.147	3.406	0.137	32.5
0.062	0.988	1.328	0.058	2.054	0.065	3.808	0.113	3.983	0.13	3.424	0.131	32.48
0.092	0.987	1.381	0.091	2.023	0.074	3.735	0.109	3.964	0.14	3.439	0.154	32.46

0.046	1.03	1.34	0.075	2.061	0.07	3.766	0.108	3.967	0.138	3.429	0.123	32.46
0.056	1.089	1.509	0.066	2.011	0.077	3.55	0.111	3.868	0.133	3.449	0.145	32.51