An-Najah National University
Faculty of Graduate Studies

Modeling the Effect of Total Harmonic Distortion on Power Quality of Supply

(Case Study- Hisham Hijjawi College of Technology)

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Dr. Imad Ibrik / Internal Examiner	....

Dedication

To the spirit of our leader and teacher Mohammed Blessings and Peace be upon him

To my mother, and father

To my wife Ala'a Yadak

To my brothers, and sisters

To my big family to my teachers

To all friends and colleagues to all of them,

I dedicate this work

Acknowledgments

Initially, I would like to thank Allah for blessing me with the opportunity to contribute to the research community through this research thesis.

I would like to thank my university supervisor Dr.Walid Kukhon for giving me strong support, encouragement and guidance during the thesis.

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Also big thanks to my family that has been very understanding and supportive during this thesis.

Finally, I would like to thank everybody who was important to the successful realization of thesis, as well as expressing my apology that I could not mention personally one by one.

الإقرار

أنا الموقع أدناه، مقدم الرسالة التي تحمل عنوان:

Modeling the Effect of Total Harmonic Distortion on Power Quality of Supply

(Case Study- Hisham Hijjawi College of Technology)

بناء نموذج رياضي محوسب لتقييم أثر تشويش توافقيات الموجات على جودة الطاقة الكهربائية

(دراسة حالة – كلية هشام حجاوي التكنولوجية)

أقر بأن ما اشتملت عليه هذه الرسالة هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the research's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: **اسم الطالب:**

Signature: **التوقيع:**

Date: **التاريخ:**

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List of Abbreviations

AC	Alternative current
KVA	Kilo volt ampere
KWh	Kilo watt hour
VA	Volt ampere
THD	Total Harmonic Distortion
THDi	Total Harmonic Current Distortion
THDv	Total Harmonic Voltage Distortion
PWM	Pulse Width Modulation
SAPF	Shunt Active Power Filter
R	Resistance
I	Current
DV	Distortion Voltage
Vph	Phase Voltage
Ih	Magnitude of Harmonic Current
Iavg	Average current
THDi avg	Average total Harmonic Distortion for Current wave
THDv avg	Average total Harmonic Distortion in Voltage wave
P.F true	True power factor
P.F dis	Distortion power factor
P.F disp	Displacement power factor
Rms	Route mean square
Ro	The resistance per unit length
Qc	The reactive power capacity of the capacitor
Q	Reactive power
S	Apparent power
P	Real power
MDB	Main distribution board
DB	Distribution board
Ps.c	Full load losses in watt
Pt	Total losses in transformer in watt
Pnl	No-load losses of the transformer in watt

Prat	Rated power of transformer in KVA
Pact	Actual power of transformer in KVA
L.F	Load factor
P.F	Power factor
Ps.c	Full load losses in watt
E	Efficiency
Pout	Output power
Pin	Input power
Ih avg	Average value of the magnitude of harmonic current during the day
I avg	Average value of the magnitude of the current during the day
I1 avg	Average current during the day in phase A.
I2 avg	Average current during the day in phase B.
I3 avg	Average current during the day in phase C
THD I1%	Percentage of the total harmonic current distortion in phase A.
THD I2%	Percentage of the total harmonic current distortion in phase B.
THD I3%	Percentage of the total harmonic current distortion in phase C.
THD v1	Total harmonic voltage distortion in phase A.
THD v2	Total harmonic voltage distortion in phase B.
THD v3	Total harmonic voltage distortion in phase C.

Modeling the Effect of Total Harmonic Distortion on Power Quality of Supply (Case Study- Hisham Hijjawi College of Technology)

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Abstract

This research analyzed the impacts of total harmonic distortion on the power quality in the College. The College fed by 6.6KV line from Northern Electrical Distribution Company 'NEDCO'. It purchases the electricity bill at the low voltage side, the rate is “0.7"NIS for each kWh consumed, the college transformer capacity 1000KVA and, the college using one diesel generator with 130 KVA as standby supply, and The power factor in the College changing from 0.83 to 0.94 .

The objective of this research is to estimate the impacts of the THD on the electrical including ,cable losses, transformer losses, the effect of THD on the power factor, how we can reduce THD, environmental impact of low power quality in the College, and to find answers to the main question ‘why do we have harmonic distortion in the College?’.

Total harmonic current distortion THDi changes during the day from (8%-24%).we can note that the worst case of the THDi occurs in the night due to discharging lamps, which act as a non-linear load.

The electrical energy saving will be around 74 kWh/year by improving the power factor from 0.89 to 0.98 through installing variable capacitor bank with capacity QC=25KVAR.

The electrical energy losses due to THDi increase the electrical energy losses in the transformer by 41KWh/year, and also increase the electrical energy losses in cable by 68KWh / year.

From other side the low load factor of the transformer in the college increased the electrical losses of the transformer by 7230KWh/year, as its effects on energy efficiency.

Through the analysis of THD we found that the useful capacity of the transformer in the college decreases from 1000KVA to 887KVA due to harmonic losses.

The low load factor of the transformer in the college, affecting on the level of the THDi, we also found out that when the load factor of the transformer in the college changes from (10% - 100%) the THDi decrease from (15%-5%).

We used MATLAB/SIMULINK to show the impacts of the THD on the power factor as well as to reduce the THD using "Passive Filter, Shunt Active Filter, and Pulse Width Modulation "PWM".

By using, Pulse Width Modulation "PWM" we noted that the THDi decreases (26%-3.7%) when the carrier frequency increases from (50-

2000Hz), also we found out that THDi's decreases from (185%-4%) when the modulation index increases from (0.1-0.9) and a passive filter the THDi reduces from (30%-3.6%), and shunt active filter which reduce THDi from (21%-2.8%).

The electrical energy losses due to low power quality lead to more coal combustion, which in turn leads to increase environmental impacts.

We found out that the electrical energy saving is 7900KWh/year when improving low power quality in the College which in turn saves 4.3 tons of coal per year, and 7.5 tons of carbon dioxide per year.

Intrduction:

One of the main issues that facing the electrical energy is low power quality, which affecting on the performance and lifespan of the electrical equipments, more electrical losses as well.

One of those main affecting factors on the power quality is the level of the total harmonic distortion, which reduces the lifetime of the electrical equipment because the harmonic distortion yields more current which in turn increases each the operating temperature, drop voltage, and the electrical losses in the cables and transformers, as well as it reduces each power factor, and the stability of the electric power system.

IEEE determine the acceptable value of the THD for current and voltage is not exceed 5% from the value of cuurent and voltage waves.

Problem Statement:

1- The importance of power quality in power system.

2- Analysis the effect of the THD on the power system.

3- Design suitable method to reduce THD.

4- The energy losses by low power quality.

Research Objectives:

1- Study the power quality condition at the college.

2- Study the Total Harmonic Distortion condition at the college.

3- Study the effect of the Total Harmonic Distortion on the power factor.

4- Study the effect of the load factor of the transformer on the Total Harmonic Distortion and electrical energy losses.

5- Study the effect of the Total Harmonic Distortion on the power losses

6- Reduce THD by using some methods tested by MATLAB/SIMULIINK.

7- Find the environmental impact of the low power quality at the college.

Thesis Structure:

The work carried out in this thesis has been summarized in eight chapters.

Chapter One: Introduction to Electric power Quality:

In this chapter we will provide some basic information about the power quality and harmonic distortion.

Chapter Two: Overview for the Electrical Energy in Hisham Hijjawi College of Technology:

This chapter describes the electricity condition at the college such as The Electrical installation at the college, Type of loads use at the college, daily utilization of electrical energy, the harmonic distortion at the college, and the power factor at the college.

Chapter Three: Total Harmonic Distortion Standard "IEEE Std. 519":

This chapter goes over the IEEE standards that related to the acceptable level of the Total Harmonic Current and Voltage Distortion**.**

Chapter Four: The Effect of Total Harmonic Distortion on Power Factor:

This chapter shows the effect of THD on the power factor and the relationship between power factor and THD using MATLAB/SIMULINK, the improvement of the power factor at the college, and calculations of the electrical energy losses due to low power factor at the college.

Chapter Five: The Effect of the Total Harmonic Distortion on the Electrical Energy losses and Energy Conservation:

This chapter shows the calculations of the losses produced by THD in cable and transformer, the effect of low load factor of the transformer on the electrical power losses, the effect of low load factor of the transformer on the THD level, and the effect of the THD on the useful capacity of the transformer.

Chapter Six: Methods to Reduce Total Harmonic Distortion:

In this chapter, MATLAB/SIMULINK has been used to test different method such as, PWM, shunt active filter, passive filter to reduce THDi.

Chapter Seven: The Environmental Impact Assessment for reduction Total Harmonic Distortion in Hisham Hijjawi College:

This chapter shows the effect of the electrical energy losses due to low power quality on the environment.

Chapter Eight: Discussion, Conclusion and Recommendations:

This chapter summarizes what mentioned in the formers chapters.

Chapter one

Introduction to Electric power Quality

Chapter one

Introduction to Electric power Quality

1.1 What Is Power Quality?

There can be completely different definitions for power quality, depending on one’s frame of reference. For example, a utility may define power quality as reliability and show statistics demonstrating that its system is 99.98 percent reliable. Criteria established by regulatory agencies are usually in this vein. A manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly. These characteristics can be very different for different criteria.

There are many misunderstandings regarding the causes of power quality problems. While surveys of other market sectors might indicate different splits between the categories. The utility’s and customer’s perspectives are often much different.

It must be realized that there are many events resulting in end-user problems that never show up in the utility statistics. One example is capacitor switching, which is quite common and normal on the utility system, but can cause transient overvoltage's that disrupt manufacturing machinery. Another example is a momentary fault elsewhere in the system that causes the voltage to sag briefly at the location of the customer in question. This might Cause an adjustable-speed drive or a distributed generator to trip off, but the utility will have no indication that anything was amiss on the feeder unless it has a power quality monitor installed. [1]

1.2 Electric Power Quality:

Electric Power Quality (EPQ) is a term that refers to maintaining the near sinusoidal waveform of power distribution bus voltages and currents at rated magnitude and frequency. Thus EPQ is often used to express voltage quality, current quality, reliability of service, quality of power supply, etc.

1.3 Classification of Power System Disturbances:

Power quality problems occur due to various types of electrical disturbances. Most of the EPQ disturbances depend on amplitude or frequency or on both frequency and amplitude. Based on the duration of existence of EPQ disturbances, events can divided into short, medium or long type. The disturbances causing power quality degradation arising in a power system and their classification mainly include:

1. **Interruption/under voltage/over voltage**: these are very common type disturbances. During power interruption, voltage level of a particular bus goes down to zero. The interruption may occur for short or medium or long period. Under voltage and over voltage are fall and rise of voltage levels of a particular bus with respect to standard bus voltage. Sometimes under and over voltages of little percentage is allowable; but when they cross the limit of desired voltage level, they are treated as disturbances.

Such disturbances are increasing the amount of reactive power drawn or deliver by a system, insulation problems and voltage stability.

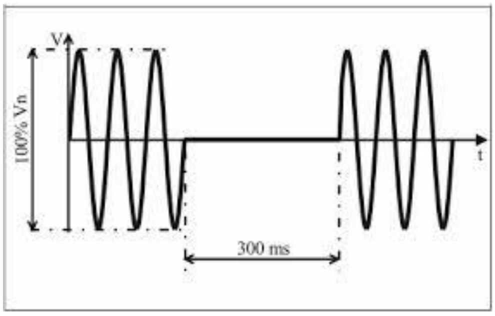


Figure 1.1: Interruption/under voltage/over voltage

2. **Voltage/Current unbalance**: voltage and current unbalance may occur due to the unbalance in drop in the generating system or transmission system and unbalanced loading. During unbalance, negative sequence components appear. T hampers system performance may change loss and in some cases it may hamper voltage stability.

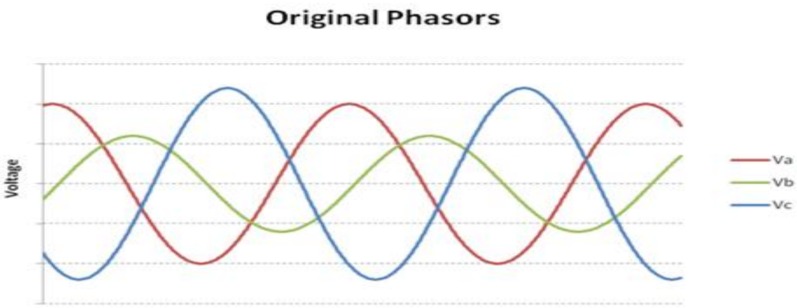


Figure 1.2: Voltage unbalance

3. **Harmonics**: harmonics are the alternating components having frequencies other than fundamental present in voltage and current signals. There are various reasons for harmonics generation like non linearity, excessive use of semiconductor based switching devices, different design constrains, etc. Harmonics have adverse effects on generation, transmission and distribution system as well as on consumer equipments

also. Harmonics are classified as integer harmonics, sub harmonics and inter harmonics.

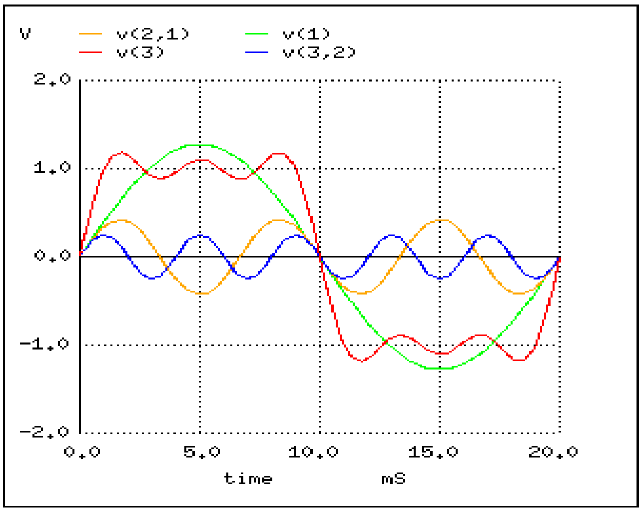


Figure 1.3: Harmonics Distortion in the sine wave

4. **Transients**: may generate in the system itself or may come from the other system. Transients are classified into two categories: dc transient and ac transient. AC transients are further divided into two categories: single cycle and multiple cycles.

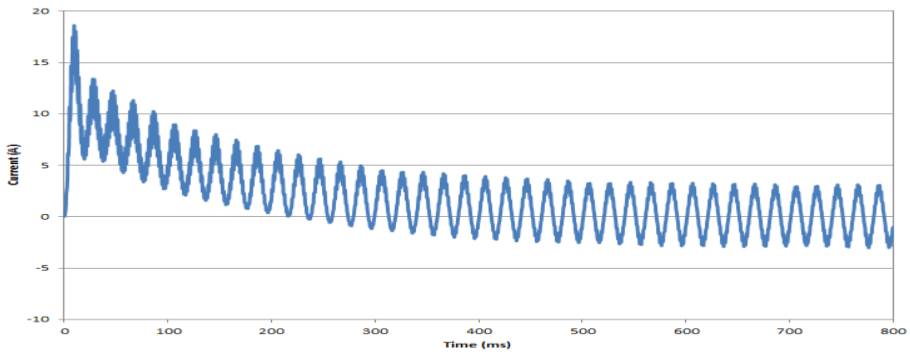


Figure 1.4: Transients with respect to time

5. **Voltage sag:** it is a short duration disturbance. During voltage sag, r. m. s. voltage falls to a very low level for short period of time.

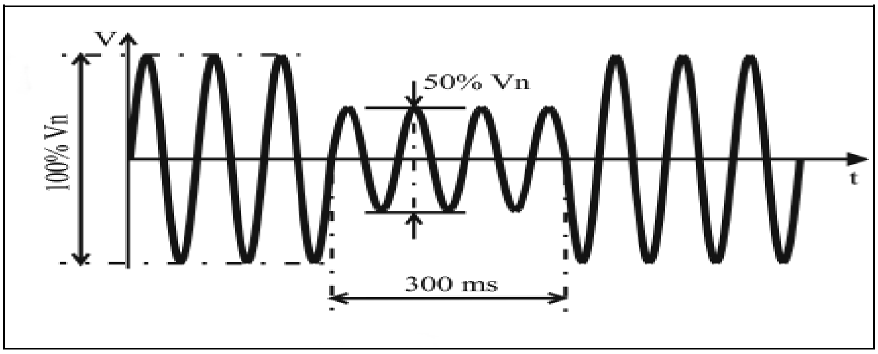


Figure 1.5: Voltage sag

6. **Voltage swell***:* it is a short duration disturbance. During voltage sag, r. m. s. voltage increases to a very high level for short period of time.

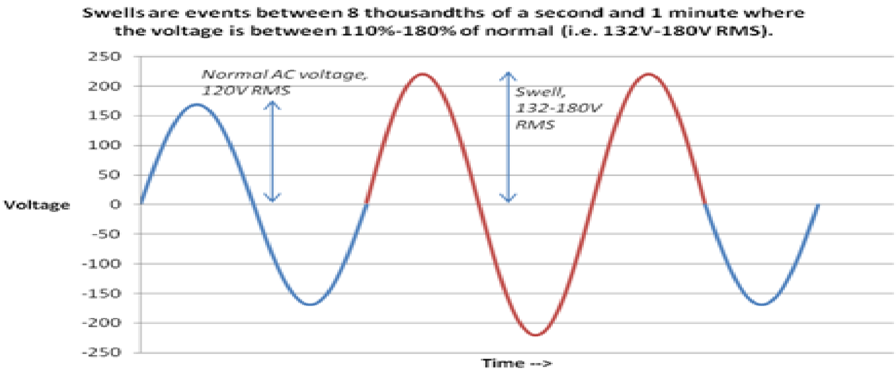


Figure 1.6: Voltage swell

7. **Flicker:** it is undesired variation of system frequency.

8. **Ringing waves***:* oscillatory disturbances of decaying magnitude for short period of time are known as ringing wave. It may be called a special type transient. The frequency of a flicker may or may not be same with the system frequency.

9. **Outage***:* it is special type of interruption where power cut has occurred for not more than 60 s. [2]

1.4 Why Are We Concerned about Power Quality?

Both electric utilities and end users of electric power are becoming increasingly concerned about the quality of electric power. The term *power quality* has become one of the most prolific buzzwords in the power industry since the late 1980s. It is an umbrella concept for a multitude of individual types of power system disturbances.

The quality of power can have a direct economic impact on many industrial consumers. There has recently been a great emphasis on revitalizing industry with more automation and more modern equipment. This usually means electronically controlled, energy efficient equipment that is often much more sensitive to deviations in the supply voltage than were its electromechanical predecessors. Thus, like the blinking clock in residences, industrial customers are now more

1.5 The Power Quality Evaluation:

Power quality problems encompass a wide range of different phenomena. Each of these phenomena may have a variety of different causes and different solutions that can be used to improve the power quality and equipment performance. However, it is useful to look at the general steps that are associated with investigating many of these problems, especially if the steps can involve interaction between the utility supply system and the customer facility.

The general procedure must also consider whether the evaluation involves an existing power quality problem or one that could result from a new design or from proposed changes to the system. [1]

1.6 The Effect of Power Factor on PQ

Power Factor: is the ratio between the KW (Kilo-Watts) and the KVA (Kilo-Volt Amperes) drawn by an electrical load where the KW is the actual load power and the KVA is the apparent load power or its the cosine angle between current sine wave and voltage sine wave.

The circuit current *I* can be resolved into two perpendicular components, namely;

(a) I cos φ in phase with *V*

(b) I sin φ 90o out of phase with *V*

A power factor less than unity results in the following disadvantages:

(*i*) **Large kVA rating of equipment.** The electrical machinery (e.g., alternators, transformers, switchgear) is always rated in kVA.

kW = kVA.cos φ

It is clear that kVA rating of the equipment is inversely proportional to power factor. The smaller the power factor, the larger is the kVA rating. Therefore, at low power factor, the kVA rating of the equipment has to be made more, making the equipment larger and expensive.

(*ii*) **Greater conductor size**. To transmit or distribute a fixed amount of power at constant voltage, the conductor will have to carry more current at low power factor. This necessitates

The electrical machinery is rated in kVA because the power factor of the load is not known when the machinery is manufactured in the factory.

(*iii*) **Large copper losses.** The large current at low power factor causes more *(I* ^2 * *R)* losses in all the elements of the supply system. This results in poor efficiency.

(*iv*) **Poor voltage regulation.** The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors. This results in the decreased voltage available at the supply end, thus impairing the performance of utilization devices. In order to keep the receiving end voltage within permissible limits, extra equipment (*i.e.*, voltage regulators) is required.

(*v*) **Reduced handling capacity of system.** The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilization of installed capacity.

Causes of Low Power Factor:

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system in lower than 0.8.

The following are the causes of low power factor:

(*i*) Most of the A.C. motors are of induction type (1φ and 3φ induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0·2 to 0·3) and rises to 0·8 or 0·9 at full load.

(*ii*) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

(*iii*) The load on the power system is varying; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetization current.

Power Factor Improvement:

Normally, the power factor of the whole load on a large generating station is in the region of 0·8 to 0·9. However, sometimes it is lower and in such cases it is generally desirable to take special steps to improve the power factor. This can be achieved by the following equipment:

1- **Static capacitor.** The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor.

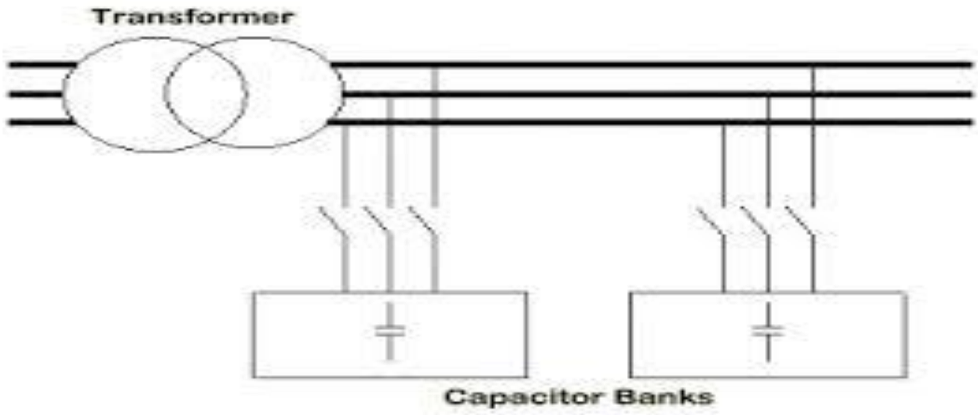


Figure 1.7: Static capacitor connected to the load

2- **Synchronous condenser.** A synchronous motor takes a leading current when over-excited and, therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved.

Figure 1.8: Synchronous condenser photo

3- **Phase advancers.** Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags be- hind the supply voltage by 90o. If the exciting ampere turns can be provided from some other A.C. source, then Static Capacitor the stator winding will be relieved of exciting current and the power factor of the motor can be improved. This job is accomplished by the phase advancer which is simply an A.C. exciter. The phase advancer is mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor. It provides exciting ampere turns to the rotor circuit at slip frequency. By providing more ampere turns than required, the induction motor can be made to operate on leading power factor like an over-excited synchronous motor.

Phase advancers have two principal **advantages**. Firstly, as the exciting ampere turns are supplied at slip frequency, therefore, lagging kVAR drawn by the motor are considerably reduced. Secondly, phase advancer can be conveniently used where the use of synchronous motors is inadmissible.

However, the major **disadvantage** of phase advancers is that they are not economical for motors below 200 H.P.

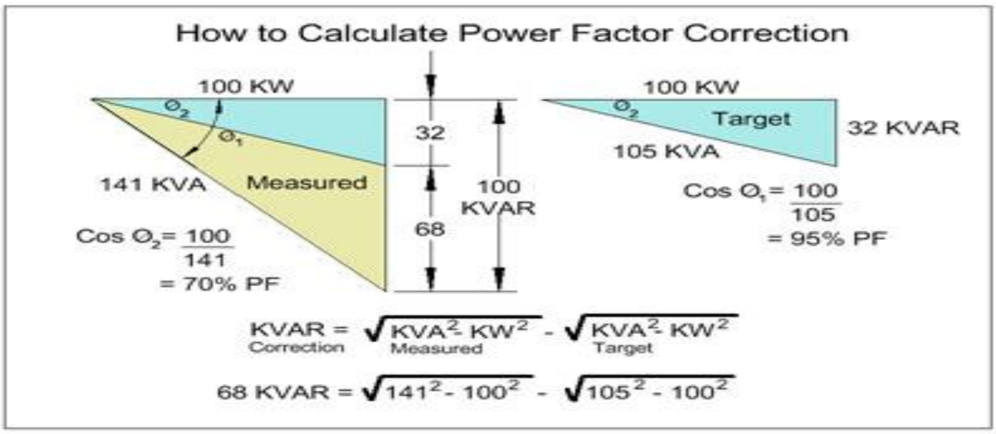


Figure 1.9: power triangle for improvement power factor

Capacitance required in kVAR= Average Max. Demand * Average P.F.*($\tan\Phi_1$ – $\tan\Phi_2$). [3]

1.7 The Effect of Drop Voltage on PQ:

When discussing the effects of voltage drop on industrial circuits it is important to realize that changes in technology have changed the way this anomaly has manifested itself while at the same time has had no effect on the resulting condition. Voltage drop affects the different components in different ways requiring separate analysis in order to understand the overall resulting condition.

1. Low Voltage effect on power supply.
2. Thermal transfer.
3. Low voltage effect on control systems.
4. Low voltage effects on power components.
5. Low voltage effects on motors.

Devices for Voltage Regulation:

There are a variety of voltage regulation devices in use on utility and industrial power systems. We have divided these into three major classes:

1- Tap-changing transformers

2- Isolation devices with separate voltage regulators

3- Impedance compensation devices, such as capacitors

There are both mechanical and electronic tap-changing transformers. Tap-changing transformers are often autotransformer designs, although two- and three-winding transformers may also be equipped with tap changers. The mechanical devices are for the slower-changing loads, while the electronic ones can respond very quickly to voltage changes. [1]

1.8 The effect of Total Harmonic Distortion on power system:

1.8.1 Harmonic generation:

Conversion from AC to DC, DC to DC, DC to AC and AC to AC; and constitute the largest nonlinear loads connected to the electric power systems. These converters are used for various purposes in the industry, such as adjustable speed (or variable frequency) drives, uninterruptable power supplies, switch-mode power supplies etc. These static power converters used in a variety of applications draw non-linear (i.e. non-sinusoidal) currents and distort the supply voltage waveform at the point of common coupling (PCC).

Figure 1.10 shows the single-phase full wave diode bridge rectifier supplying a load containing an inductance (Ldc) and a resistance (Rdc). The impedance of the AC power supply is represented by the inductance (Lac).

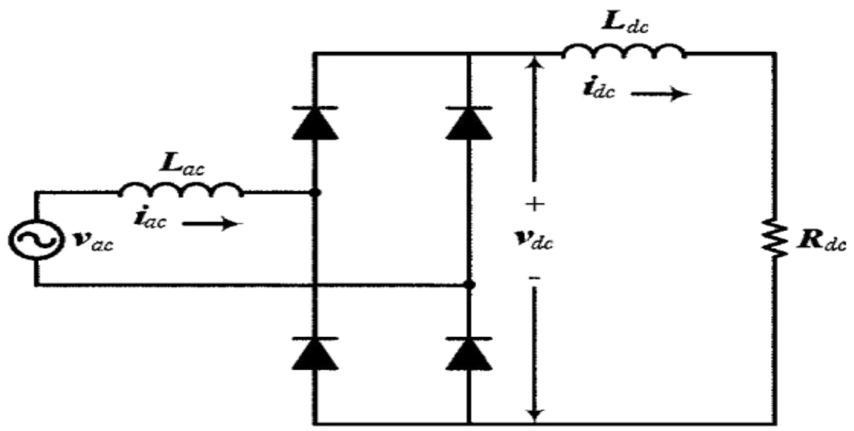


Figure 1.10: Single phase full wave rectifier

Figure 1.11 shows the distortion in the waveform of vPCC due to the flow of non-linear current through the finite system impedance. The notches in the voltage wave are caused by the commutating action of the rectifier. As explained above, ideally, when the rectifier is fed from an infinite source, the current wave shape is rectangular and in this case voltage notching does not occur.

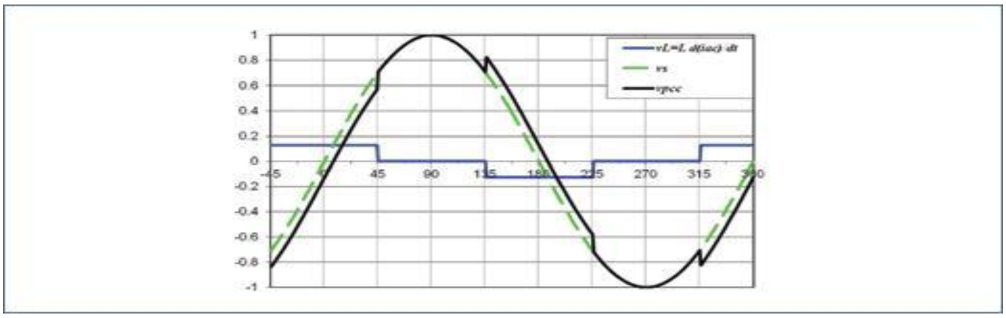


Figure 1.11: Distorted voltage waveform at the PCC

These non-sinusoidal quantities (voltages and currents) can be divided into sinusoidal components, the fundamental frequency (i.e. 50 or 60 Hz) component and the harmonic components. Figure 1.12 shows the harmonic spectrum up to the 50th order of the “Trapezoid” shape AC current of Figure 1.11 as a percentage of fundamental current. The fundamental component, I1 (i.e. 100% component) is intentionally omitted in Figure 1.12, for the clarity.

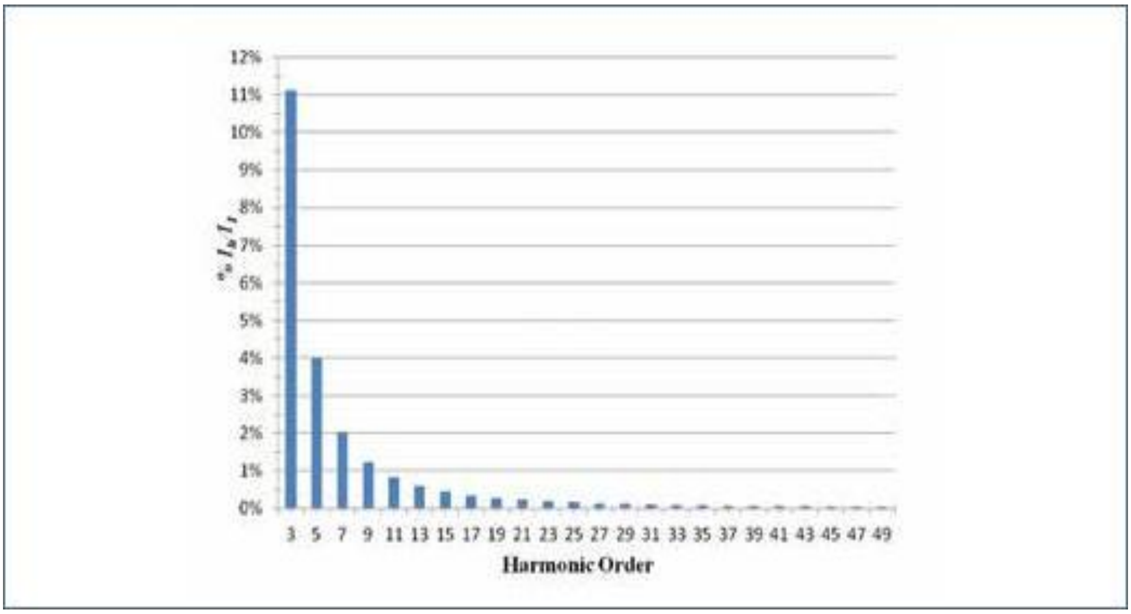


Figure 1.12: Harmonic spectrum of a “rapezoid” shape AC current shown in Figure1.11

The higher the harmonic components of a quantity, the larger the distortions of this quantity; in other words, the larger the deviations of this quantity from the sinusoidal fundamental frequency. Moreover, the harmonic components of the voltages and currents are integer multiples of the fundamental frequency. For example on 60Hz supply, the 3rd harmonic is 3 x 60Hz (=180Hz); the 5th harmonic is 5 x 60Hz (=300Hz), and so forth. When all harmonic currents are added to the fundamental a waveform known as complex wave is formed. An example of complex wave consisting of the fundamental (1st harmonic), 3rd harmonic and 5th harmonic is illustrated in Figure 1.13. [4]

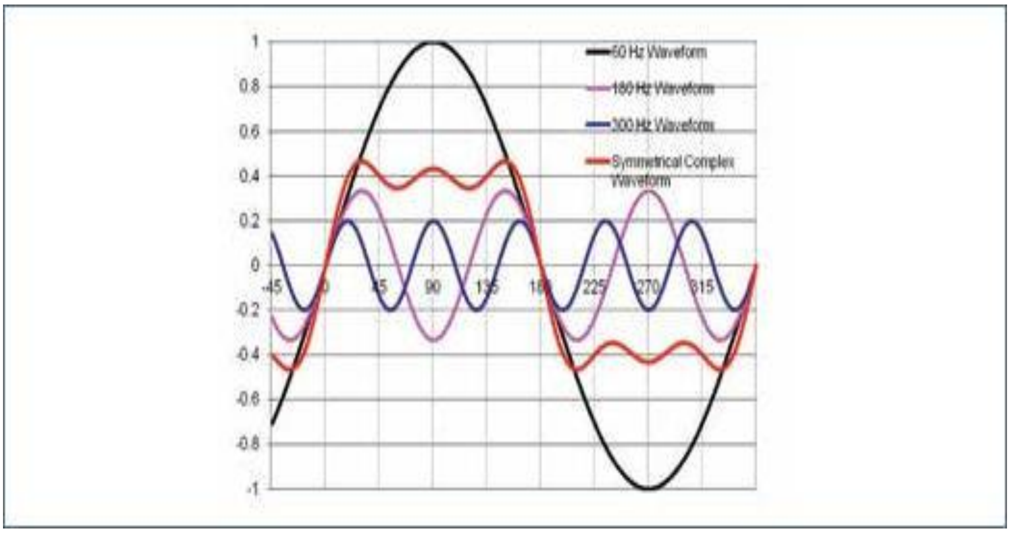


Figure 1.13: Production of a symmetrical complex waveform

1.8.2 Harmonic spectrum and distortion factor:

Ideally, the harmonics produced by the semiconductor converter equipment in steady state condition of operation are called characteristic harmonics of the converter and are expressed as:

$$h = np \pm 1$$

Where:

h = order of harmonics n = an integer 1, 2, 3,….

p = number of pulses per cycle

For a single phase bridge rectifier, the number of pulses p = 2 for one cycle of line frequency and therefore the characteristic harmonics are:

$$h = n .2 \pm 1 = 1 \text{ (fundamental)}, 3 , 5 , 7 , 9 , 11 \ldots..$$

The characteristic or dominant harmonics are:

$$h = n \cdot 6 \pm 1 = 5, 7, 11, 13, 17, 19, 23, 25, 35, 37\ldots$$

Similarly, the characteristic harmonic currents for a 12-pulse rectifier will be: $h = n \cdot 12 \pm 1 = 11, 13, 23, 25, 35, 37\ldots$

Abovementioned characteristic harmonics are for an ideal steady state operation of the converter and assuming the AC power supply network is symmetrical and the AC supply is pure sinusoidal (free from harmonics). Any divergence from the abovementioned hypothesis will introduce "non-characteristic" harmonics including possibly DC component. In practical situation, the supply networks or connected equipment's never follow the abovementioned ideal condition and therefore, the actual measured harmonics will not be exactly as calculated from the equation.

Moreover, it should be noted that in four-wire distribution systems (three-phase and neutral), the currents in the three phases return via the neutral conductor, the 120-degree phase shift between respective phase currents causes the currents to cancel out in the neutral, under balanced loading conditions. However, when nonlinear loads are present, any "Triplen" (3rd, 9th…) harmonics in the phase currents do not cancel out but add cumulatively in the neutral conductor, which can carry up to 173% of phase current at a frequency of predominately 180 Hz (3rd harmonic).

The amount of distortion in the voltage or current waveform is quantified by means of an index called (THD) total harmonic distortion.

According to IEEE 519-1992, it is defined as a ratio of the root-mean-square of the harmonic content to the root-mean-square value of the fundamental quantity and expressed as a percent of the fundamental.

$$\%THD_{Vpcc} = \frac{\sqrt{\sum_{h=2}^{\infty} {V_{pcch}}^{2}}}{V_1} \text{ x } 100 \qquad -$$

Similarly, total harmonic distortion of current,

$$\%THD_{I} = \frac{\sqrt{\sum_{h=2}^{\infty} {I_{h}}^{2}}}{I_1} \text{ x } 100 \qquad -$$

Typically, the harmonics up to the 50th order are used to calculate the THD; however, the harmonic components of order greater than 50 may be included when necessary. [4]

1.8.3 The Effects of Harmonics Distortion:

Figure 1.14 shows in detail the effect individual harmonic currents have on the impedances within the power system and the associated voltages drops for each. Note that the “total harmonic voltage distortion”, %THDV (based on the vector sum of all individual harmonics), is reduced at source as more impedance is introduced between the nonlinear load and source.

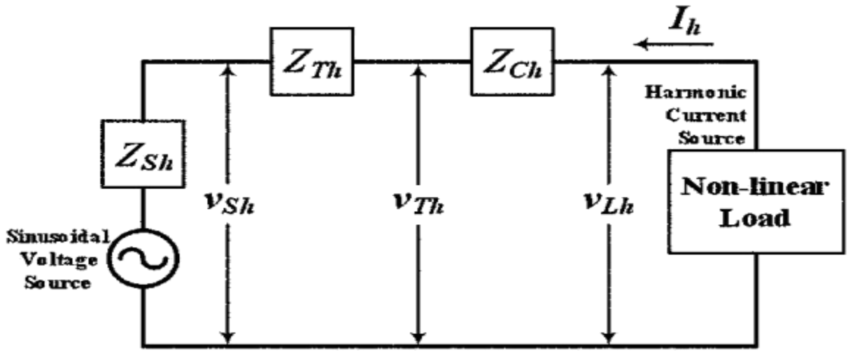


Figure 1.14: Individual harmonic voltage drops across system impedances

$$Vh = Ih \times Zh \quad \text{(Ohm's Law)}$$

At load:

$$VLh = Ih \times (ZCh + ZTh + ZSh)$$

At transformer:

$$VTh = Ih \times (ZTh + ZSh)$$

At source:

$$VSh = Ih \times (ZSh)$$

Where:

Zh = Impedance at frequency of harmonic (e.g., for 5th harmonic, 5x60=300 Hz)

Vh = Harmonic voltage at hth harmonic (e.g. 5th)

Ih = Harmonic current at hth harmonic (e.g. 5th)

ZCh= Impedance of common connected harmonic load. [4]

Generators:

In comparison with utility power supplies, the effects of harmonic voltages and harmonic currents are significantly more pronounced on generators (esp. stand-alone generators used a back-up or those on the ships or used in marine applications) due to their source impedance being typically three to four times that of utility transformers. The major impact of voltage and current harmonics is to increase the machine heating due to increased iron losses, and copper losses, since both are frequency dependent and increase with increased harmonics. To reduce this effect of harmonic heating, the generators supplying nonlinear loads are required to be derated. In addition, the presence of harmonic sequence components with nonlinear loading cause's localized heating and torque pulsations with torsion vibrations. [5]

Transformers:

The effect of harmonic currents at harmonic frequencies causes increase in core losses due to increased iron losses (i.e., eddy currents and hysteresis) in transformers. In addition, increased copper losses and stray flux losses result in additional heating, and winding insulation stresses, especially if high levels of dv/dt (i.e., rate of rise of voltage) are present. Temperature cycling and possible resonance between transformer winding inductance and supply capacitance can also cause additional losses. The small laminated core vibrations are increased due to the presence of harmonic frequencies, which can appear as an additional audible noise. The increased rms current due to harmonics will increase the (I^2 * R) (copper) losses.

The distribution transformers used in four-wire (i.e., three-phase and neutral) distribution systems have typically a delta-wye configuration. Due to delta connected primary, the Triplen (i.e. 3rd, 9th, 15th…) harmonic currents cannot propagate downstream but circulate in the primary delta winding of the transformer causing localized overheating. With linear loading, the three-phase currents will cancel out in the neutral conductor. However, when nonlinear loads are being supplied, the triplen harmonics in the phase currents do not cancel out, but instead add cumulatively in the neutral conductor at a frequency of predominately 180 Hz (3rd harmonic), overheating the transformers and occasionally causing overheating and burning of neutral conductors. Typically, the uses of appropriate "K factor" rated units are recommended for non-linear loads. [5]

Cables:

Cable losses, dissipated as heat, are substantially increased when carrying harmonic currents due to elevated (I^2 * R) losses, the cable resistance, R, determined by its DC value plus skin and proximity effect. The resistance of a conductor is dependent on the frequency of the current being carried. Skin effect is a phenomenon whereby current tends to flow near the surface of a conductor where the impedance is least. An analogous phenomenon, proximity effect, is due to the mutual inductance of conductors arranged closely parallel to one another. Both of these effects are dependent upon conductor size, frequency, resistivity and the permeability of the conductor material. At fundamental frequencies, the skin effect and proximity effects are usually negligible, at least for smaller conductors. The associated losses due to changes in resistance, however, can increase significantly with frequency, adding to the overall ($I^2 * R$) losses. [5]

Circuit Breakers and Fuses:

The vast majority of low voltage thermal-magnetic type circuit breakers utilize bi-metallic trip mechanisms which respond to the heating effect of the rms current. In the presence of nonlinear loads, the rms value of current will be higher than for linear loads of same power. Therefore, unless the current trip level is adjusted accordingly, the breaker may trip prematurely while carrying nonlinear current. Circuit breakers are designed to interrupt the current at a zero crossover. On highly distorted supplies which may contain line notching and/or ringing, spurious “zero crossovers” may cause premature interruption of circuit breakers before they can operate correctly in the event of an overload or fault. However, in the case of a short circuit current, the magnitude of the harmonic current will be very minor in comparison to the fault current.

Fuse ruptures under over current or short-circuit conditions is based on the heating effect of the rms current according to the respective I2t characteristic. The higher the rms current, the faster the fuse will operate. On nonlinear loads, the rms current will be higher than for similarly-rated linear loads, therefore fuse derating may be necessary to prevent premature opening. In addition, fuses at harmonic frequencies, suffer from skin effect and more importantly, proximity effect, resulting in non-uniform current distribution across the fuse elements, placing additional thermal stress on the device. [5]

Lighting:

One noticeable effect on lighting is the phenomenon of "flicker" (i.e., repeated fluctuations in light intensity). Lighting is highly sensitive to rms voltage changes; even a slight deviation (of the order of 0.25%) is perceptible to the human eye in some types of lamps. [5]

Chapter Two

Overview for the Electrical Energy

in Hisham Hijjawi College of Technology

2.1 Introduction about Hisham Hijjawi College

2.2 The Electrical installation at the college

2.3 Type of the used loads at the college

2.4 Daily Utilization of the Electrical Energy at the college

2.5 The Harmonic Distortion at the college

Chapter Two

Overview of the Electrical Energy

in Hisham Hijjawi College of Technology

Electricity is one of the major problems facing the Palestine Authority specially as the PA satisfies the majority of its electricity depending mainly on Israel. The Palestine utility of electrical energy increasing rapidly. The electrical load in Palestine include domestic, commercial and industrial load.

One of the main problem facing the electricity is low power quality .in this thesis we study the effect of the low power quality (specially Harmonic Distortion) in Palestine (case study Hisham Hijjawi College) on the electrical energy losses and reliability of the electrical system.

Figure 2.1: The building of the College.

2.1 Introduction about Hisham Hijjawi College:

The college locates in the east of the Nablus city, have around 2000 student in different academic programs such as, computer, communication, auto Mechatronics, electric programs…… etc..

The college is fed with 6.6KV line by the northern electrical distribution company 'NEDCO', the bill for the electrical energy consumed at the low voltage side "0.7"NIS for each kWh, it has an internal transformer 1000KVA "1M VA" transformer, it has one diesel generator with capacity 130 KVA as standby power supply.

2.2 The Electrical installation at the college:

The following figure shows the main electrical board at the college.

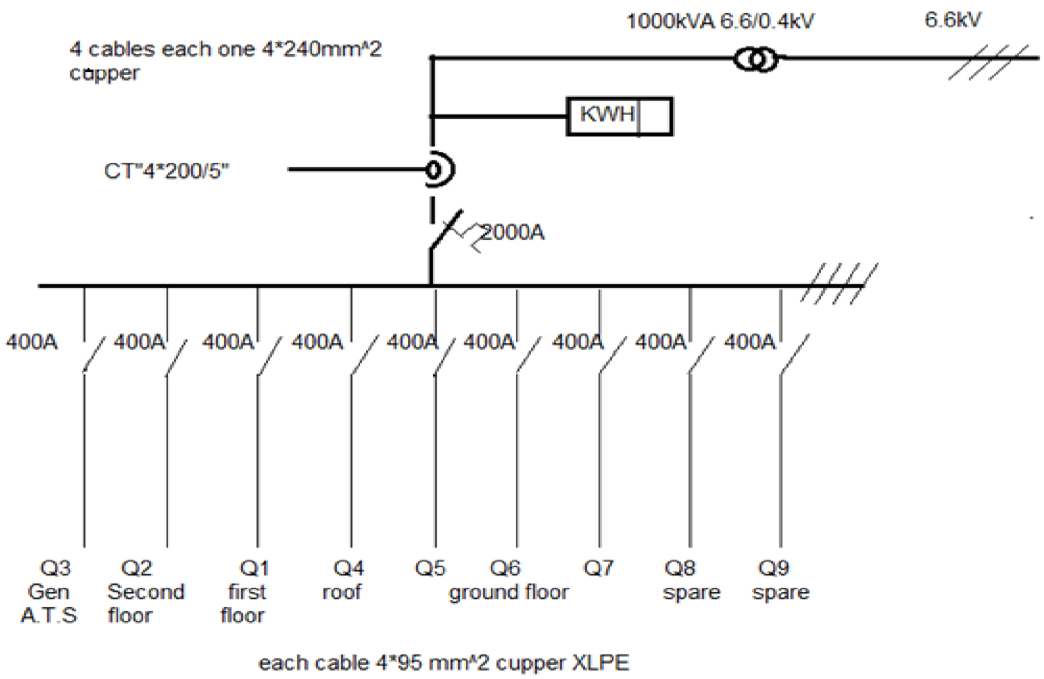


Figure 2.2: The main electrical board for the college.

From the above figure we have one internal transformer with capacity 1MVA, and 7 sub-distribution boards (Q1-Q7), another two spares (Q8 and Q9). Each sub-distribution board is fed by copper cable (4*95mm^2). We have four cables from the transformer to the main circuit breaker each one (4*240mm^2 XLPE copper cable). The rating of the main circuit breaker is 2000A. The rating of the circuit breaker for the sub-distribution boards is 400A.

The following figure shows the photo of the main electrical distribution board 'MDB' at the college.

Figure 2.3: The photo of the main electrical distribution board at the college.

The following table shows some information about the distribution boards at the college such as the type of conductor cable, length of cable, cross sectional area.

Table 2.1: Information about the electrical distribution boards at the college.

<table>
<tr><th>From MDB to</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q5</th><th>Q6</th><th>Q7</th><th>T</th></tr>
<tr><td>Length “m”</td><td>50</td><td>60</td><td>15</td><td>90</td><td>95</td><td>95</td><td>95</td><td>20</td></tr>
<tr><td>Cross sectional area mm^2</td><td colspan="7">4*95</td><td>4 cables each one 4*240</td></tr>
<tr><td>Type of conductor</td><td colspan="8">Copper</td></tr>
<tr><td>Type of insulator</td><td colspan="8">XLPE</td></tr>
</table>

From the above table, we have seven distribution boards at the college (Q1-Q7), and two spares (Q8-Q9). Each distribution board fed by cable (4*95 mm^2, copper, XLPE cable). The length of the cable between main electrical distribution boards and sub-distribution boards changes from sub-distribution board to another, depending on the location of the sub-distribution board. We have four cables between the transformer and main distribution board each one (4*240mm^2, copper, XLPE cable) with length 20 meters.

We used clamp meter and energy analyzer for recording the current consumed from the main electrical distribution board and each sub-distribution board.

The following table shows some reading for the distribution boards, to see other reading see the appendix (B).

Table 2.2: Some reading for the current consume from main and each distribution boards at the college.

Distribution boards	Phase 1	Phase 2	Phase 3	Neutral
Q1	26	50	36	16
Q2	35	27	27	21
Q3	75	68	64	23
Q4	3.5	9	2	2.3
Q5	8	18	7	13
Q6	8	1	1.5	2
Q7	64	75	56	34
MDB	219.5	248	193.5	95.3

*to see the more result and reading see the appendix ’B’

Where:

Q1-Q7: sub-distribution board at the college.

MDB: Main electrical distribution board.

From the previous table, the current consumed from the sub-distribution boards are varied from one sub-distribution board to another. The most sub-distribution boards consume current is Q3, which connecting to important loads A.T.S, and Q7, which connecting to the ground floor which has the most electrical load.

2.3 Type of the used loads at the college:

1- Lab loads (power and light).

2- Welding machines, Motors, Turning machines and compressors

3- Lighting loads such as fluorescent lamp, discharging lamp.... etc.

4- Air conditioning loads, computers, printers, elevator, heating load…. etc.

2.4 Daily Utilization of the Electrical Energy at the college:

This section shows the characteristic of the electrical energy consumed during the day at the college. The energy analyzer has been used to record some electrical reading from the main distribution board such as, the real power, reactive power, apparent power and power factor…. etc.

The following table shows the daily Readings of the real power, reactive power, apparent power, and power factor during the day at the college.

Table 2.3: daily utilization of real power, reactive power, apparent power and power factor during the day

P.F=P/S	S	Q	P	Time (clock)
0.83453237	27,800	14,600	23,200	00:00:00
0.83512545	27,900	14,600	23,300	01:00:00
0.83277592	29,900	15,900	24,900	02:00:00
0.8490566	26,500	13,500	22,500	03:00:00
0.84269663	26,700	13,700	22,500	04:00:00
0.84528302	26,500	13,500	22,400	05:00:00
0.84790875	26,300	13,300	22,300	06:00:00
0.92528736	17,400	3,700	16,100	07:00:00
0.97847358	51,100	10,400	50,000	08:00:00
0.95083682	95,600	28,800	90,900	09:00:00
0.9391435	133,100	45,700	125,000	10:00:00
0.94629349	132,200	42,500	125,100	11:00:00
0.94569758	119,700	38,500	113,200	12:00:00
0.94164456	113,100	37,900	106,500	13:00:00
0.95363636	110,000	32,700	104,900	14:00:00
0.95327103	107,000	32,400	102,000	15:00:00
0.94130435	92,000	31,100	86,600	16:00:00
0.93760832	57,700	19,900	54,100	17:00:00
0.90547264	60,300	24,300	54,600	18:00:00
0.90689013	53,700	21,900	48,700	19:00:00
0.83985765	28,100	14,600	23,600	20:00:00
0.83098592	28,400	15,100	23,600	21:00:00
0.83275261	28,700	15,300	23,900	22:00:00
0.8410596	30,200	15,300	25,400	23:00:00

The following figure shows daily utilization of the real power, reactive power, and apparent power during the day.

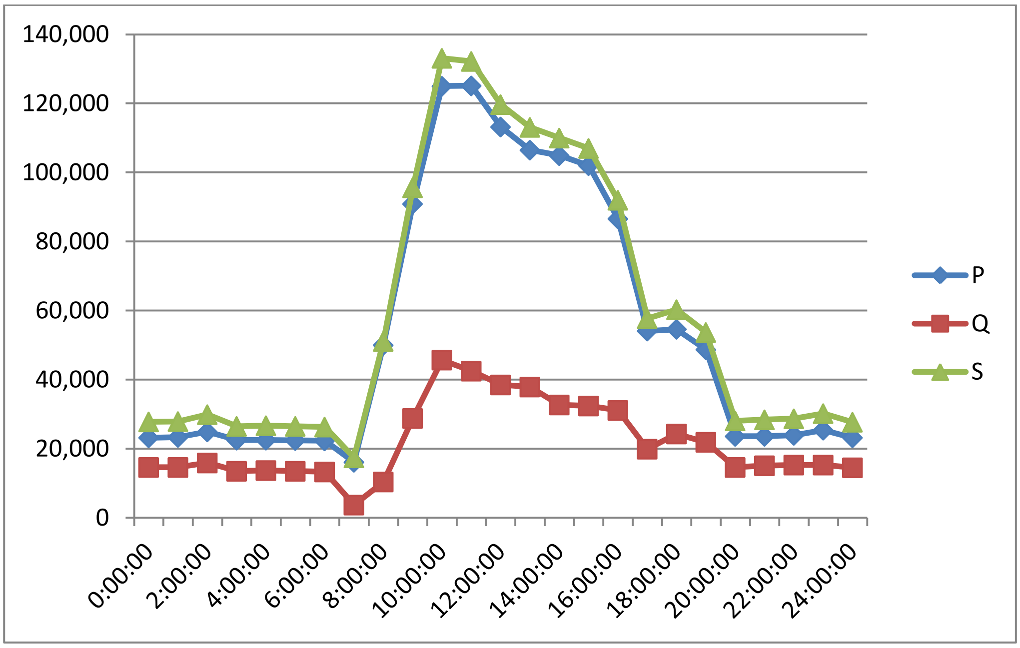


Figure 2.4: Daily utilization of the real power, reactive power, and apparent power during the day at the college.

Where:

P: real power in Watt.

Q: reactive power in VAR

S: apparent power in VA

From the previous figure, the electrical energy consumed from the college changes during the day .The peak load occurs at 11:00AM, P=125.1Kw, Q=42.5Kvar, S=132.2Kva. Based on the previous results as the average load, daily load factor, and transformer load factor have been calculated:

$$\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{\text{24 hour}} = 56.6\text{KW}$$

$$\text{Daily load factor} = \frac{\text{Average Load}}{\text{Max.Demand}}$$

$$= \frac{\text{Average Load}*24\text{h}}{\text{Max.demand}*24\text{h}} = 0.45$$

$$\text{Transformer load factor} = \frac{\text{Max.demand}}{\text{capacity of the transformer}}$$

$$= \frac{133\text{KVA}}{1000\text{KVA}} = 0.133 \qquad [6].$$

From the previous results, the load factor L.F is 0. 133 and the maximum demand of the college is 133KVA where the installed capacity of the transformer at the college is 1MVA.

The power factor changes during the day due to the changing the type of the electrical loads.

The following figure shows the power factor changing during the day at the college

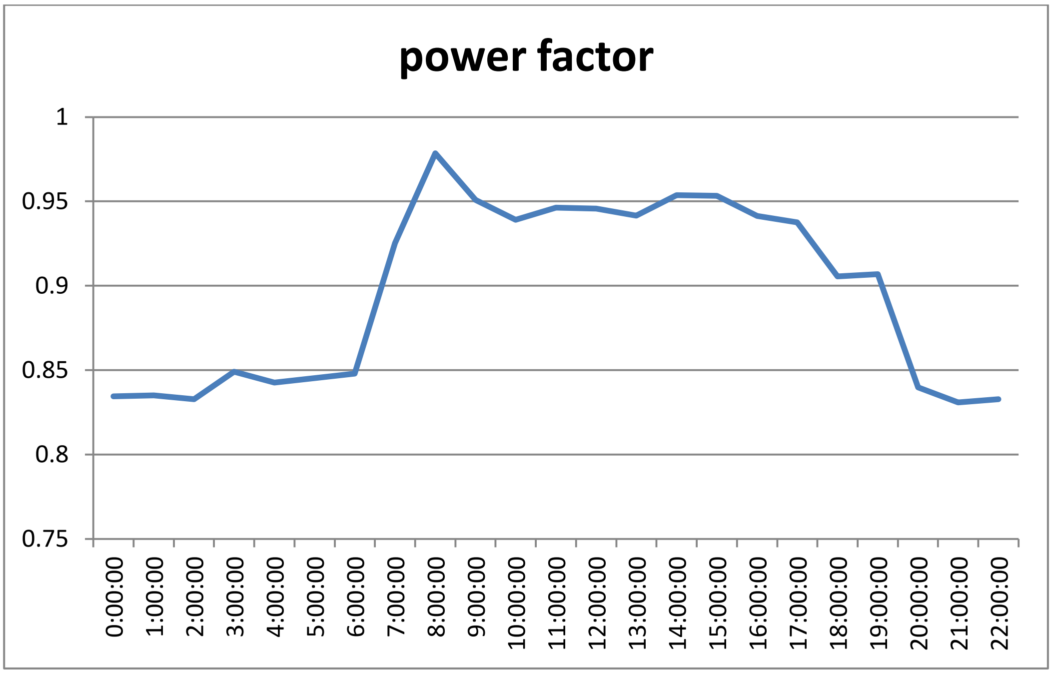


Figure 2.5: The daily power factor

The low power factor occurs in the night and it reaches to 0.83 because the most loads in the night are discharging lamps which operate at low power factor.

To calculate the average power factor at the college during the day

Average P.F=$\sum \frac{P}{S} = 0.89$ **.** [6]

The power factor at the college changes during the day from the worst case in the night P.F =0. 83 to the best condition in the morning P.F =0. 97. The average power factor during the day at the college, it equals 0.89.

2.5 The Harmonic Distortion at the college:

We have two types of Harmonic Distortion:

1- Harmonic voltage Distortion.

2- Harmonic current Distortion.

In this section shows the calculations of the average total harmonic current distortion and the average total harmonic voltage distortion at the college.

The following figure shows the readings of the total harmonic voltage distortion during the day at the college.

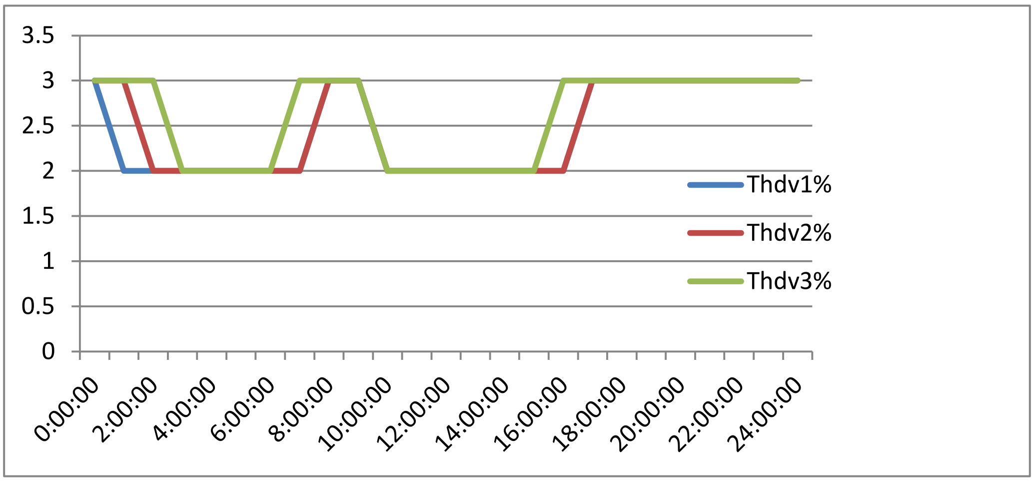


Figure 2.6: The daily total harmonic voltage distortion.

From the previous figure, the total harmonic voltage distortion changes during the day from (2-3%).

Where:

THDv1%: percentage of the total harmonic voltage distortion in phase A.

THDv2%: percentage of the total harmonic voltage distortion in phase B.

THDv3%: percentage of the total harmonic voltage distortion in phase C.

The following figure shows the total harmonic current distortion in the three phases at the college during the day.

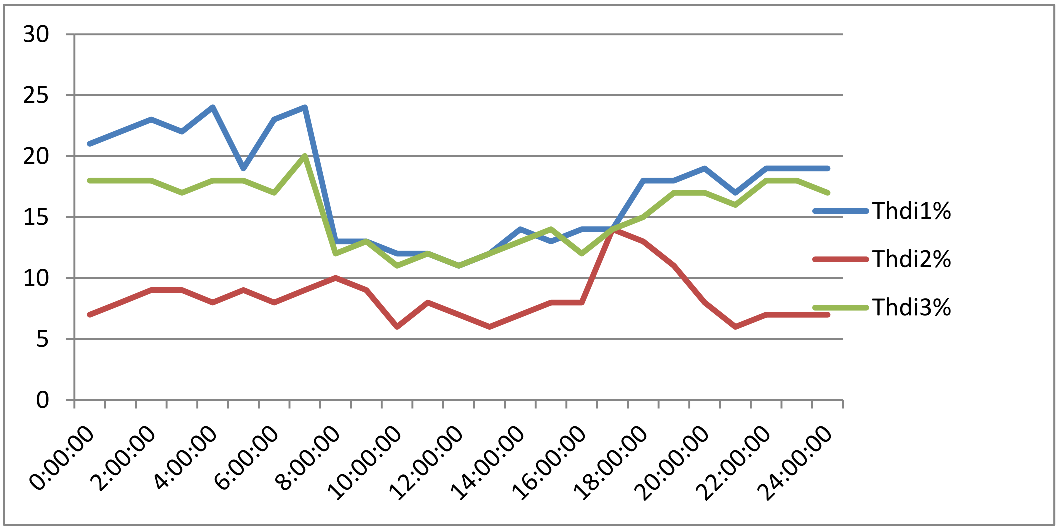


Figure 2.7: daily harmonic current distortion.

Where:

THDI1%: percentage of the total harmonic current distortion in phase A.

THDI2%: percentage of the total harmonic current distortion in phase B.

THDI3%: percentage of the total harmonic current distortion in phase C.

The following table shows the magnitude of the harmonic current distortion for the three phases during the day at the college.

Table 2.4: The magnitude of the harmonic current distortion.

Time	I1	I2	I3	Thdi1%	Thdi2%	Thdi3%	Ih1	Ih2	Ih3
00:00:00	40	61	20	21	7	18	8.4	4.27	3.6
01:00:00	40	61	19	22	8	18	8.8	4.88	3.42
02:00:00	40	57	20	23	9	18	9.2	5.13	3.6
03:00:00	43	59	23	22	9	17	9.46	5.31	3.91
04:00:00	39	59	20	24	8	18	9.36	4.72	3.6
05:00:00	39	59	25	19	9	18	7.41	5.31	4.5
06:00:00	38	58	20	23	8	17	8.74	4.64	3.4
07:00:00	31	55	20	24	9	20	7.44	4.95	4
08:00:00	79	68	58	13	10	12	10.27	6.8	6.96
09:00:00	111	102	89	13	9	13	14.43	9.18	11.57
10:00:00	149	217	175	12	6	11	17.88	13	19.25
11:00:00	168	208	164	12	8	12	20.16	16.6	19.68
12:00:00	175	210	171	11	7	11	19.25	14.7	18.81
13:00:00	165	194	165	12	6	12	19.8	11.6	19.8
14:00:00	137	164	153	14	7	13	19.18	11.4	19.89
15:00:00	149	180	170	13	8	14	19.37	14.4	23.8
16:00:00	123	148	147	14	8	12	17.22	11.8	17.64
17:00:00	74	78	97	14	14	14	10.36	10.9	13.58
18:00:00	71	80	78	18	13	15	12.78	10.4	11.7
19:00:00	86	90	65	18	11	17	15.48	9.9	11.05
20:00:00	58	65	32	19	8	17	11.02	5.2	5.44
21:00:00	47	64	25	17	6	16	7.99	3.8	4
22:00:00	44	59	22	19	7	18	8.36	4.1	3.96
23:00:00	44	59	22	19	7	18	8.36	4.1	3.96

*to see more result in the appendix ‘C’

Where:

Ih1: magnitude of the harmonic current distortion in phase A.

Ih2: magnitude of the harmonic current distortion in phase B.

Ih3: magnitude of the harmonic current distortion in phase C.

Thdi1%: Total harmonic current distortion in phase A.

Thdi2%: Total harmonic current distortion in phase B.

Thdi3%: Total harmonic current distortion in phase C.

I1: magnitude of the current that record at phase one from MDB

I2: magnitude of the current that record at phase one from MDB

I3: magnitude of the current that record at phase one from MDB

The following table shows the magnitude of the harmonic voltage distortion for the three phases during the day at the college. This reading measure from main distribution board

Table 2.5: Magnitude of the harmonic voltage distortion.

Time	V1	V2	V3	Thdv1 %	Thdv2 %	Thdv3 %	Vh1	Vh2	Vh3
00:00:00	230	229	231	3	3	3	6.9	6.87	6.93
01:00:00	232	232	233	3	3	2	4.64	6.96	6.99
02:00:00	233	233	234	3	2	2	4.66	4.66	7.02
03:00:00	231	231	232	2	2	2	4.62	4.62	4.64
04:00:00	229	229	230	2	2	2	4.58	4.58	4.6
05:00:00	230	230	231	2	2	2	4.6	4.6	4.62
06:00:00	229	228	229	2	2	2	4.58	4.56	4.58
07:00:00	228	228	229	3	2	2	4.56	4.56	6.87
08:00:00	226	227	227	3	3	3	6.78	6.81	6.81
09:00:00	224	224	224	3	3	3	6.72	6.72	6.72
10:00:00	226	226	226	2	2	2	4.52	4.52	4.52
11:00:00	225	225	225	2	2	2	4.5	4.5	4.5
12:00:00	225	224	225	2	2	2	4.5	4.48	4.5
13:00:00	223	223	224	2	2	2	4.46	4.46	4.48
14:00:00	223	223	223	2	2	2	4.46	4.46	4.46
15:00:00	224	223	224	2	2	2	4.48	4.46	4.48
16:00:00	226	226	226	3	2	2	4.52	4.52	6.78
17:00:00	229	229	229	3	3	3	6.87	6.87	6.87
18:00:00	228	228	229	3	3	3	6.84	6.84	6.87
19:00:00	225	225	226	3	3	3	6.75	6.75	6.78
20:00:00	228	228	229	3	3	3	6.84	6.84	6.87
21:00:00	228	228	229	3	3	3	6.84	6.84	6.87
22:00:00	232	231	232	3	3	3	6.96	6.93	6.96
23:00:00	230	230	231	3	3	3	6.9	6.9	6.93

*to see more result in the appendix. ‘C’

Where:

Vh1: magnitude of the harmonic voltage distortion in phase A.

Vh2: magnitude of the harmonic voltage distortion in phase B.

Vh3: magnitude of the harmonic voltage distortion in phase C.

Thdv1: total harmonic voltage distortion in phase A.

Thdv2: total harmonic voltage distortion in phase B.

Thdv3: total harmonic voltage distortion in phase C.

V1: magnitude of the voltage in phase one measured from MDB

V2: magnitude of the voltage in phase two measured from MDB

V3: magnitude of the voltage in phase three measured from MDB

To calculate the average total harmonic voltage distortion during the day at the college:

Vh1 =THDv1*V1

Vh2 =THDv1*V2

Vh3 =THDv1*V3

Vh=V*THDv

THDv avg = $\frac{\text{Vh avg}}{\text{V avg}}$

V1 avg =$\frac{\sum V1}{24h} = 227.7$V

V2 avg =$\frac{\sum V2}{24h} = 227.5$V

V1 avg =$\frac{\sum V3}{24h} = 228.3$

$$V\ avg = \frac{(V1\ avg + V2\ avg + V3\ avg)}{3}$$

$$Vavg = \frac{(227.7+227.5+228.3)}{3} = 227.8\ Volt$$

$$Vh1\ avg = \frac{\sum Vh1}{24h} = 5.5\ Volt$$

$$Vh2\ avg = \frac{\sum Vh2}{24h} = 5.6\ Volt$$

$$Vh3\ avg = \frac{\sum Vh3}{24h} = 5.9\ Volt$$

$$Vh\ avg = \frac{(Vh1\ avg + Vh2\ avg + Vh3\ avg)}{3}$$

$$Vh\ avg = \frac{(5.5+5.6+5.9)}{3} = 5.67\ Volt$$

$$THDv\ avg = \frac{Vh\ avg}{Vavg} = \frac{5.67\ Volt}{227.8\ Volt} = 2.5\%$$

To calculate the average total harmonic current distortion during the day at the college:

Ih=I*THDi

$$THDi\ avg = \frac{Ih\ avg}{I\ avg}$$

Where:

THDi avg : average total harmonic current distortion during the day.

Ih avg: average value of the magnitude of harmonic current during the day.

Iavg: average value of the magnitude of the current during the day.

I1avg: average current during the day in phase A.

I2avg: average current during the day in phase B.

I3avg: average current during the day in phase C.

It’s noted that the magnitude of the current consumes at the college changes during the day, so that we need to calculate the average current during the day.

$$I\ avg = \frac{(\text{I1 avg} + \text{I2 avg} + \text{I3 avg})}{3}$$

$$I1\ avg = \frac{\sum I1}{24h} = 83A$$

$$I2\ avg = \frac{\sum I2}{24h} = 102A$$

$$I1\ avg = \frac{\sum I3}{24h} = 75A$$

$$I\ avg = \frac{(\text{I1 avg} + \text{I2 avg} + \text{I3 avg})}{3}$$

$$I\ avg = \frac{(83+102+75)}{3} = 87A$$

$$Ih\ avg = \frac{(\text{Ih1 avg} + \text{Ih2 avg} + \text{Ih3 avg})}{3}$$

$$Ih1\ avg = \frac{\sum Ih1}{24h} = 12.5A$$

$$Ih2\ avg = \frac{\sum Ih2}{24h} = 8.2A$$

$$Ih3\ avg = \frac{\sum Ih3}{24h} = 10A$$

$$\text{Ih avg} = \frac{(\text{Ih1 avg} + \text{Ih2 avg} + \text{Ih3 avg})}{3}$$

$$\text{Ih avg} = \frac{(12.5+8.2+10)}{3} = 10.23\text{A}$$

$$\text{THDi avg} = \frac{\text{1h avg}}{\text{Iavg}} = \frac{10.23\text{A}}{87\text{A}} = 11.8\%$$

From the above calculations we noted that THDi avg at the college equals 11.8%, THDv avg at the college equals 2.5%.

Chapter Three

Total Harmonic Distortion Standard “IEEE Std. 519”

Chapter Three

Total Harmonic Distortion Standard "IEEE Std. 519"

Unfortunately, the Palestinian or Israeli standards about the total harmonic distortion are rare to find, instead of that, IEEE standards taken into considerations.

IEEE Std. 519-1992 is a standard developed for utility companies and their customers in order to limit harmonic content and provide all users with better power quality. Some of the key areas of the standard are detailed in the below tables (3.1) and (3.2).

Bear in mind that dealing with harmonics may still be required, whether or not the goal is to meet IEEE 519 standards. In low-voltage systems (600 V or less), capacitors are typically the lowest impedance at harmonic frequencies, and experience very high RMS currents and increased heat which causes them to fail.

Table 3.1: Voltage Distribution limits.

Bus Voltage	Individual voltage distortion	Total voltage distortion
69 kV and below	3.0%	5.0%
69.001 kV through 161 Kv	1.5%	2.5%
161.001 kV and above	1.0%	1.5%

Table 3.2: Maximum Harmonic Current Distortion in percentage

I_{sh}/I_l ratio	< 11	11≤ h < 17	17≤h < 23	23≤ h 35	35 ≤ h	THD-I Limit
< 20*	4.0	2.0	1.5	0.6	0.3	5%
20 - 50	7.0	3.5	2.5	1.0	0.5	8%
50 – 100	10.0	4.5	4.0	1.5	0.7	12%
100 -1000	12.0	5.5	5.0	2.0	1.0	15%
1000 up	15.0	7.0	6.0	2.5	1.4	20%

Where:

ISC = maximum short-circuit current at PCC* (Point of Common Coupling)

IL = maximum demand load current (fundamental frequency component) at PCC*

*All power generation equipment is limited to these values of current I_{sh}/I_l distortion, regardless of actual I **PCC is Point of Common Coupling

Table 3.3: low voltage system classification and distribution limits.

	Special Applications*	General System	Dedicated System
Notch Depth	10%	20%	50%
THD (Voltage)	3%	5%	10%

Chapter Four
The effect of Total Harmonic Distortion on the Power Factor

4.1 Introduction

4.2 Power Factor with Non-Linear Loads

4.3 The effect of Harmonic Distortion on the Power Factor by using SIMULINK

4.4 The Effect of Resistive load with switching device on the Power Factor and Harmonic Distortion.

4.5 The Relationship between the Power Factor Non-linear loads, inductive load with switching device:

4.6 Power factor improvement in Hisham Hijjawi College

Chapter Four

The Effect of Total Harmonic Distortion on the Power Factor

4.1 Introduction:

One of the main factors that effecting on the power quality is the condition of the power factor. In this chapter shows how the power factor affecting on the power quality and electrical energy losses, and how the total harmonic distortion affecting on the value of the power factor.

The power factor depends on the type of the load resistive and reactive (inductive or capacitive) loads, which will present varying phase angles between the sinusoidal voltages applied to the load and the current flowing in it. With a purely resistive load the current and voltage are in phase, so the real power consumed is just the product of Voltage and Current. However, with reactive elements there will be a phase shift between the current and voltage. For a pure capacitive load the current will lead the voltage by 90 degrees and for a pure inductive load the current will lag the voltage by 90 degrees. With a mixture of resistive and reactive loads the phase angle will be somewhere between +90 and -90 degrees, either leading or lagging. Figure 4.1 presents a typical reactive load current.

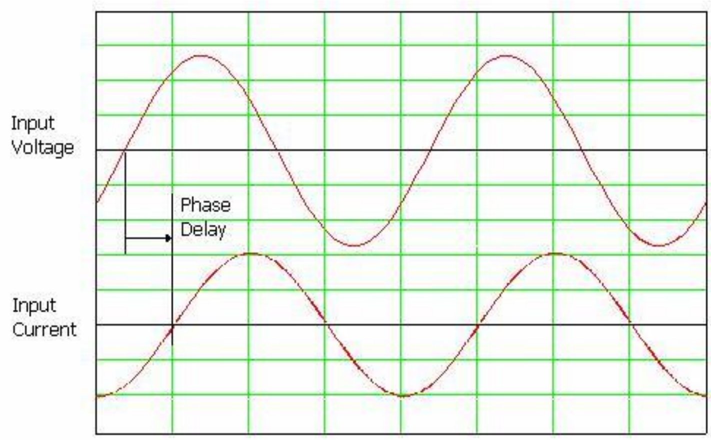


Figure 4.1: Reactive Phase Delay

Definition of Power Factor:

For a linear load, Power factor is defined as follows:

Power Factor (PF) = Real Power / (RMS Voltage x RMS Current). [7]

Power Factor is described as leading for capacitive loads (i.e., current builds up faster than voltage) and lagging for inductive loads (i.e., current builds up slower than voltage). [7]

4.2 Power Factor with Non-Linear Loads:

Voltage and current harmonics produced by nonlinear loads increase power losses and, therefore, have a negative impact on the electric utility distribution systems and components. [7]

The true power factor at the load is defined as the ratio of average power to apparent power, or

$$P.F = P_{avg}/S \qquad (2)$$

$$P.F_{true} = P.F_{dis} = P_{avg}/V_{rms}.I_{rms} = \cos(\delta_1 - \theta_1) \qquad (3)$$

For sinusoidal situations, unity power factor corresponds to zero reactive power Q, and low power factors correspond to high Q. Since most loads consume reactive power, low power factors in sinusoidal systems can be corrected by simply adding shunt capacitors.

Now, consider no sinusoidal situations, where network voltages and currents contain harmonics. While some harmonics are caused by system nonlinearities such as transformer saturation, most harmonics are produced by power electronic loads such as adjustable-speed drives and diode-bridge rectifiers. The significant harmonics (above the fundamental, i.e., the first harmonic) are usually the 3rd, 5th, and 7th multiples of 50/60 Hz, so that the frequencies of interest in harmonics studies are in the low-audible range. [7].

A frequently-used measure of harmonic levels is total harmonic distortion (or distortion factor), which is the ratio of the rms value of the harmonics (above fundamental) to the rms value of the fundamental, times 100%, or

$$THD_v = \frac{\sqrt{(\sum (V_{krms})^2)}}{V_{1rms}}$$ [7].

Obviously, if no harmonics are present, then the *THD*s are zero.), we find that

$V_{rms} = V_{1rms} + (THD_V/100)^2$ [7].

$I_{rms} = I_{1rms} + (THD_I/100)^2$ [7].

$$PF_{true} = \frac{P_{avg}}{V1_{rms} . I1_{rms}} * \frac{1}{\sqrt{1 + (THDv/100)^2} * \sqrt{1 + (THDi/100)^2}}$$

$$PF_{true} = \frac{P_{avg1}}{V1_{rms} . I1_{rms}} * \frac{1}{sqrt(1+(THDI/100)^2)} = PF_{disp}.PF_{dist} \quad [7].$$

Where:

P.F disp: displacement power factor.

P.F dist: distortion power factor.

P.F true: true power factor. [7]

4.3 The effect of Harmonic Distortion on the Power Factor

This section shows the effect of the total harmonic distortion on the power factor.

The following table shows the relationship between the total harmonic current distortion and power factor. In this table, we fixed the value of the total harmonic voltage distortion at 3% and change the value of the total harmonic current distortion from 10% to 100%. In this table, we use the last equation:

$$PF_{true} = \frac{P_{avg}}{V1_{rms} . I1_{rms}} * \frac{1}{\sqrt{1 + (THDv/100)^2} * \sqrt{1 + (THDi/100)^2}} \quad [7].$$

By making the following two assumptions:

1. In most cases, the contributions of harmonics above the fundamental to average power are small, so that Pavg =P1avg.
2. Since THDV is usually less than 10%, then Vrms = V1rms.

$$PF_{true} = \frac{P_{avg1}}{V1_{rms} . I1_{rms}} * \frac{1}{sqrt(1+(THDI/100)^{\wedge}2)} = PF_{disp}.PF_{dist} \quad [7]$$

Table 4.1: The effect of harmonic distortion on the power factor

THDV%	THDI%	P.Fdisp	P.Fdist	P.Ftrue
3	10	0.999	0.9868	0.9868
3	20	0.999	0.98	0.98
3	30	0.999	0.957	0.957
3	40	0.999	0.928	0.928
3	50	0.999	0.89	0.89
3	60	0.999	0.857	0.857
3	70	0.999	0.819	0.819
3	80	0.999	0.78	0.78
3	90	0.999	0.74	0.74
3	100	0.999	0.7	0.7

The following figure shows the relationship between the total harmonic current distortion and power factor.

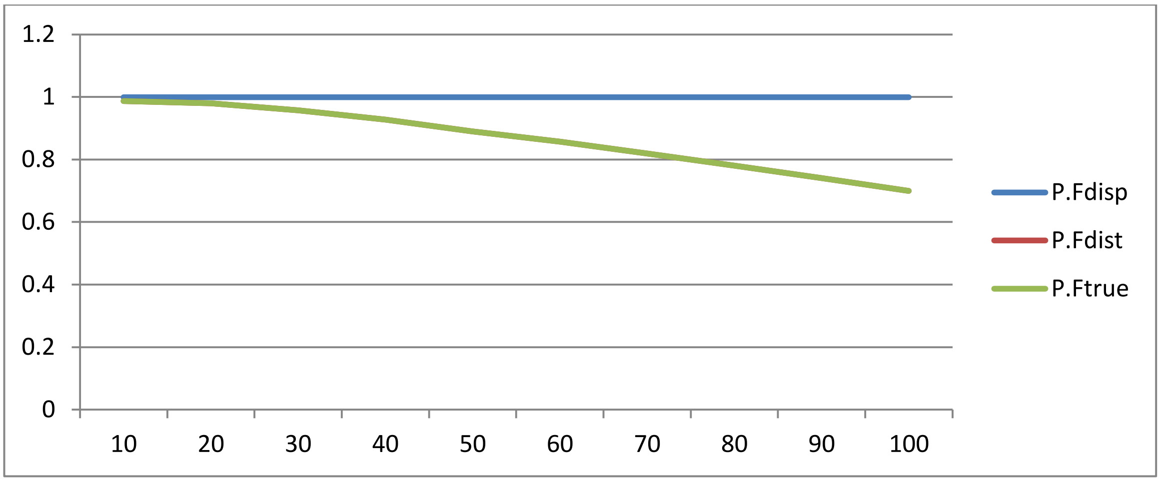


Figure 4.2: The relationship between the harmonic distortion and power factor at given values

Where:

P.F disp: displacement power factor.

P.F dist: distortion power factor.

P.F true: true power factor.

It is noted when the total harmonic current distortion increases the power factor decreases.

4.4 The Effect of Resistive load with switching device on the Power Factor and Harmonic Distortion:

This section shows the effect of the resistive load with switching device 'non-linear load' on the power factor and total harmonic current distortion. The following SIMULINK block diagram describes the effect of Non-linear load on the power factor, real and apparent power. We use resistive load 10Ω with the switching device to represent the Non-linear load.

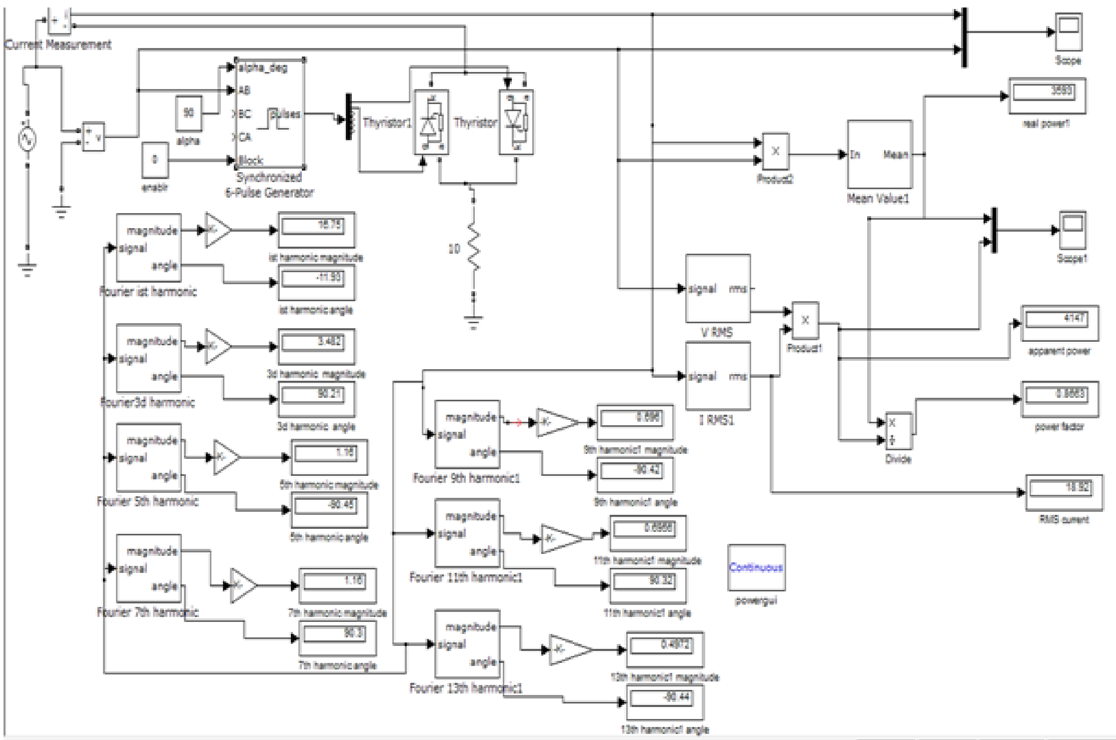
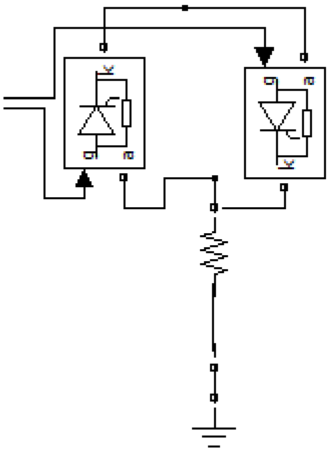
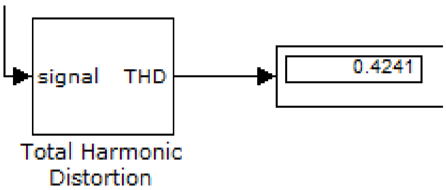


Figure 4.3: block diagram for the effect of resistive load with switching device on the power factor and harmonic distortion. [8]

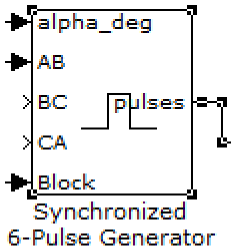
Where:



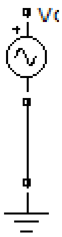
Resistive load with thyristor to represent the non-Linear load .we use R=10Ω



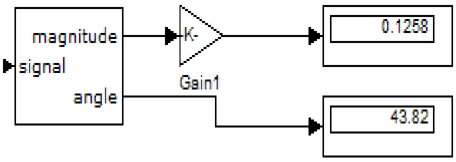
Block diagram to calculate the total harmonic distortion in the circuit, we set frequency on 50Hz.



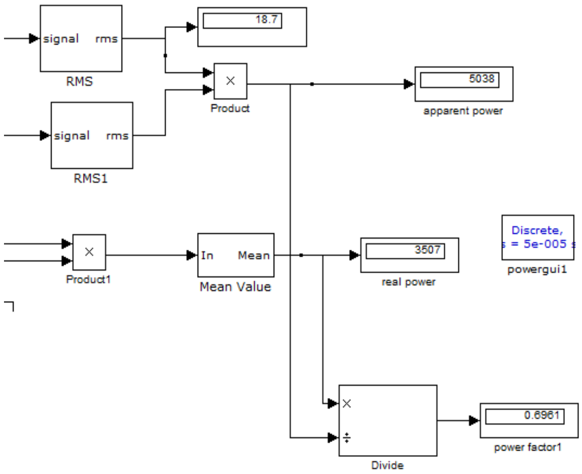
6-pulse generator to provide the needed pulses to thyristor, to operate the load as non-linear load



AC power supply, we set the AC voltage on 220 Vrms



Block diagram to display the magnitude and the angle of the harmonic order.



Block diagram to calculate the actor in the circuit.

The result of magnitude and angle of the odd number harmonic for the non-linear load

Table 4.2: The odd number harmonic for the non-linear load

Harmonic no	Current harmonic mag.	Angle	P.F	0.866
1	16.75A	-11.93	P(W)	3593W
3	3.48A	90.2	S(VA)	4147VA
5	1.16A	-90.45		
7	1.16A	90.3		
9	0.696A	-90.4		
11	0.696A	90		
13	0.497A	-90		

The following figure shows the magnitude current for each odd harmonic order. The x-axis represents the odd harmonic order and the y-axis represents the magnitude of the harmonic current distortion in Ampere.

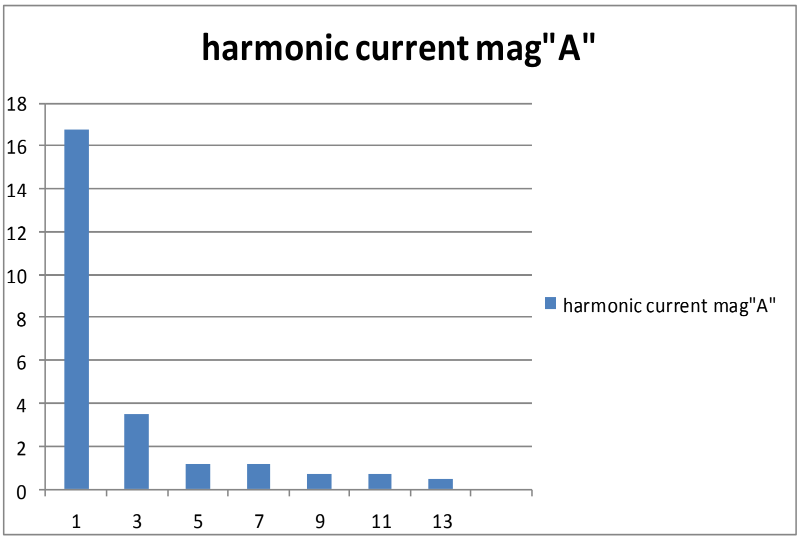


Figure 4.4: The Fourier series for the resistive load with switching device.

The previous table shows that the power factor measured by the Simulink block diagram equal 0.866 at that harmonic condition. To calculate the value of the power factor and to see the effect of the total harmonic distortion on the power factor as the following equation which describes the relationship between the total harmonic distortion and power factor.

From the result of the previous block diagram it's noted that:

I_{rms} =18.92A

I1: rms fundamental magnitude =16.75A

ØI1 = fundamental angle =-11.93

Distortion factor = $\frac{I1}{Is} = \frac{16.75}{18.92}$ =0.885

Displacement factor =cos (-11.93) =0.9816

Overall power factor =0.885*0.9816=0.868 [7].

It's also noted, the overall power factor calculated from the above equation equal to 0.868, but the measure one is equal to 0.866. Both values measured and calculated are converging and how the power factor in the power system is dependent on the level of the total harmonic distortion.

Power factor = $\frac{\text{real power}}{\text{apparent power}} = \frac{3593}{4147}$= 0.866 [7].

4.5 The Relationship between the Power Factor Non-linear loads, inductive load with switching device:

This section shows the effect of the non-linear inductive load on the power factor and total harmonic current distortion. The following figure shows the block diagram for the effect of the inductive non-linear load on the power factor and total harmonic current distortion. By using R= 10 **Ω**, and inductor L=30*mH.

The RMS current values =14. 06 A.

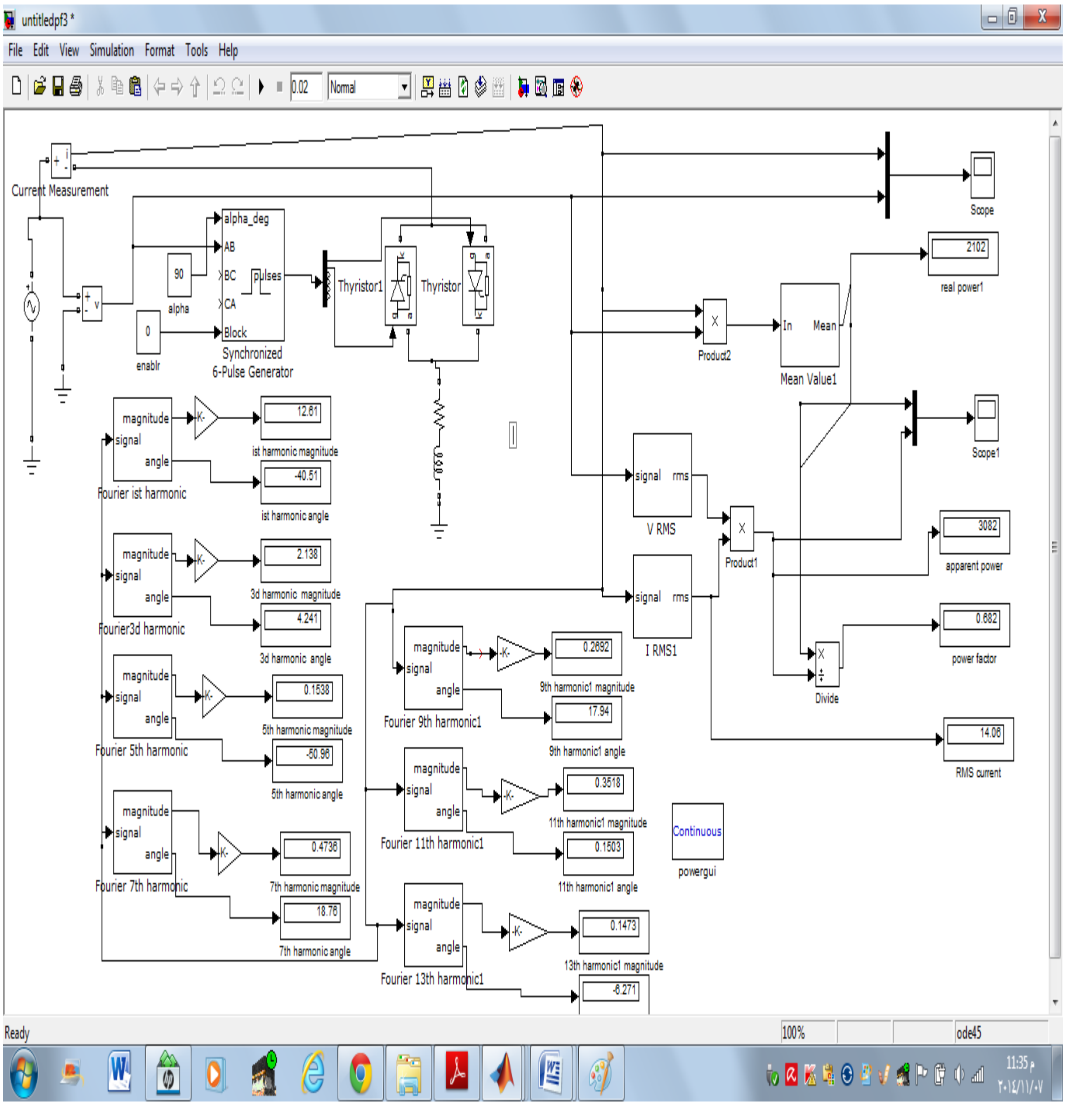
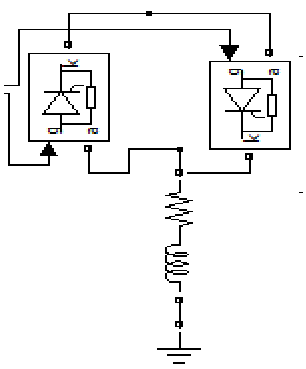
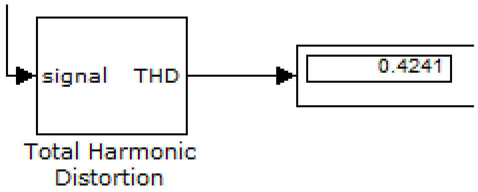


Figure 4.5: block diagram that show the effect of the Non-linear inductive load on the power factor and harmonic distortion. [9]

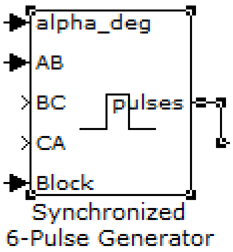
Where:



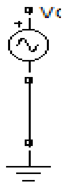
Inductive load with thyristor to represent the non-linear load .We set R=10Ω and L=30mH



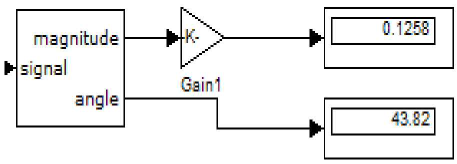
Block diagram to calculate the total harmonic distortion in the circuit. We set the fundamental frequency equal 50Hz



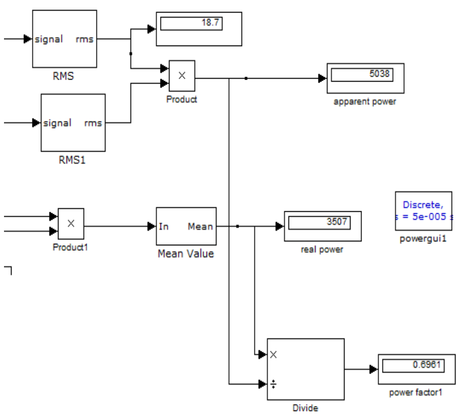
6-pulse generator to provide the needed pulses to thyristor, to operate the load as non-linear load



AC power supply. We set the AC voltage on 220 Vrms



Block diagram to display the magnitude and the angle of the harmonic



Block diagram to calculate the power factor.

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The following table shows the odd number harmonic distortion for the inductive Non -linear load.

Table 4.3: The harmonic order for the Non -linear load inductive load with switching devices.

Harmonic no	Current harmonic mag.	Angle	P.F	0.682
1	12.61A	-40.5	P(W)	2102
3	2.138A	4.241	S(VA)	3082
5	0.1538A	-50.9		
7	0.474A	18.76		
9	0.269A	17.9		
11	0.352A	0.15		
13	0.147A	-6.27		

Irms =14.06A

I1rms fundamental magnitude =12.61A

ØI1 = fundamental angle =-40.51

Distortion factor = $\frac{\text{I1}}{\text{Is}} = \frac{12.61}{14.06}$ =0.8968

Displacement factor =cos (-40.51) =0.76

Overall power factor =0.76*0.8968=0.6816

Its noted that the overall power factor calculated from the above equation is approx. 0.6816. And the measured one is 0.682 both values are close; this means the power factor is mostly dependent on the total harmonic distortion.

Power factor = $\frac{\text{real power}}{\text{apparent power}} = \frac{2102}{3082}$=0.682

The following figure shows Fourier series for the inductive Non-linear load.

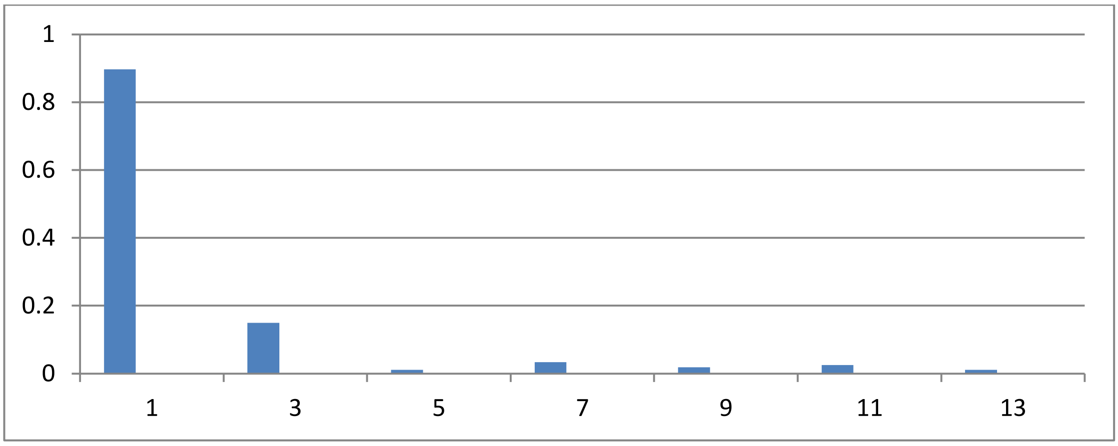


Figure 4.6: Fourier series for the inductive Non- linear load.

4.6 Power factor improvement in Hisham Hijjawi College:

This section shows the effect of the Low power factor on the electrical energy losses at the college .The average power factor in the college equals 0.89.This section also shows the calculations of saved losses through improving the power factor to 0.98 using the needed variable capacitor bank .

The following table shows changing power factor at the college during the day.

Table 4.4: power factor changing during the day

P.F=P/S	S	Q	P	TIME
0.83453237	27,800	14,600	23,200	00:00:00
0.83512545	27,900	14,600	23,300	01:00:00
0.83277592	29,900	15,900	24,900	02:00:00
0.8490566	26,500	13,500	22,500	03:00:00
0.84269663	26,700	13,700	22,500	04:00:00
0.84528302	26,500	13,500	22,400	05:00:00
0.84790875	26,300	13,300	22,300	06:00:00
0.92528736	17,400	3,700	16,100	07:00:00
0.97847358	51,100	10,400	50,000	08:00:00
0.95083682	95,600	28,800	90,900	09:00:00
0.9391435	133,100	45,700	125,000	10:00:00
0.94629349	132,200	42,500	125,100	11:00:00
0.94569758	119,700	38,500	113,200	12:00:00
0.94164456	113,100	37,900	106,500	13:00:00
0.95363636	110,000	32,700	104,900	14:00:00
0.95327103	107,000	32,400	102,000	15:00:00
0.94130435	92,000	31,100	86,600	16:00:00
0.93760832	57,700	19,900	54,100	17:00:00
0.90547264	60,300	24,300	54,600	18:00:00
0.90689013	53,700	21,900	48,700	19:00:00
0.83985765	28,100	14,600	23,600	20:00:00
0.83098592	28,400	15,100	23,600	21:00:00
0.83275261	28,700	15,300	23,900	22:00:00
0.8410596	30,200	15,300	25,400	23:00:00

The following figure shows changing power factor at the college during the day.

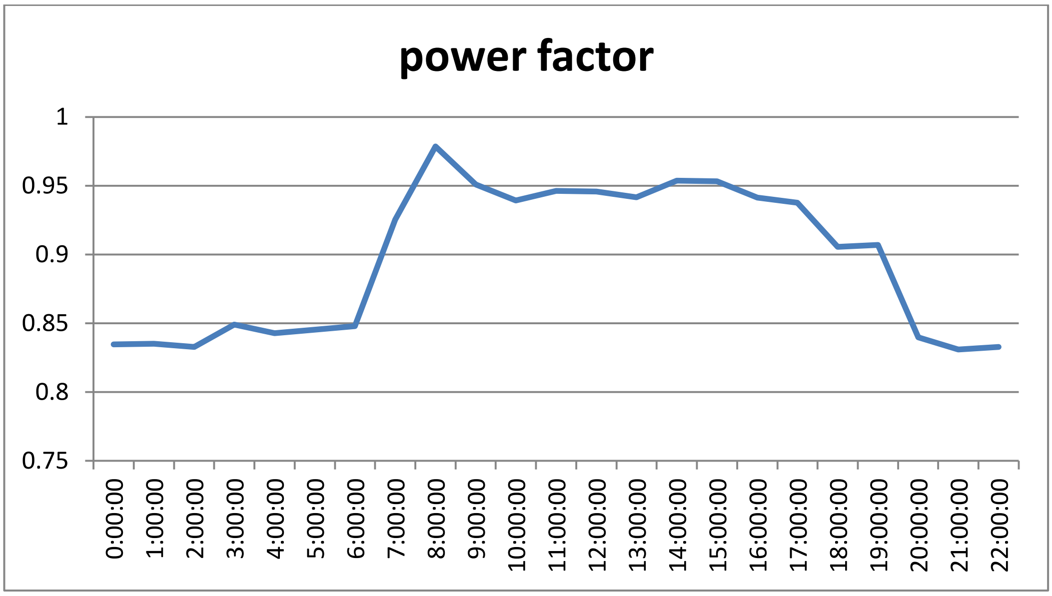


Figure 4.7: changing power factor in the college during day.

Average power factor = 0.89

To improve the power factor from (0.89 to 0.98) to decrease the losses that produced from low power factor as possible, from other side no problem to reach this value P. F=0. 98 because of using a variable capacitor bank not are overcompensating.

To increase power factor from 0.89 to 0.98, so the capacitor bank needed to improve power factor.

$QC = P * (Tan(\theta_{old}) - Tan(\theta_{new}))$ [10].

$\theta_{old} = \cos^{-1} 0.89 = 27$ degree

$\theta_{new} = \cos^{-1} 0.98 = 11$ degree

We take P as the maximum total real power, at peak load we have S=133KVA and P.F =0.94

P=S*P.F =133KVA *0.94 =125kw [10].

QC =P *(Tan (θ_{old}) –Tan (θ_{new}))

QC =125KW *(Tan (27) –Tan (11))

Qc =25 kVAR .

The saving for improvement power factor divides into:

1-Saving in penalty

2-Saving in energy losses in the cable

3-Saving in energy losses in the transformer

1-Saving in penalty

Fortunately, the college fed the electricity from the NEDCO "northern electricity distribution company" which use only fixed rate tariff for energy consumption at commercial side 0.7NIS for each kWh consumed. No penalty for low power factor.

2-Saving in the electrical energy losses in the cable:

This section shows the calculation of electrical energy losses in the cable due to low power factor. The cables have been taken between each distribution board and main distribution board, and the cables from the transformer to the main distribution board.

The following table shows the length, cross sectional area, type of conductor, type of insulation for the cables between each distribution boards and main distribution board, and the cables from transformer to the main distribution board.

Table 4.5: data for the distribution board at the college

From MDB	Q1	Q2	Q3	Q4	Q5	Q6	Q7	T
Length "m"	50	60	15	90	95	95	100	20
Area mm^2	4*95	4*95	4*95	4*95	4*95	4*95	4*95	4cables 4*240
Type of conductor	copper	copper	Copper	Copper	Copper	Copper	Copper	Copper
Type of insulator	XLPE	XLPE	XLPE	XLPE	XLPE	XLPE	XLPE	XLPE
Ro(Ω/Km)	0.247	0.247	0.247	0.247	0.247	0.247	0.247	0.062

Where:

Q1……Q7: the name of the distribution board.

T: Transformer.

Ro(Ω/Km):resistance per kilometer.

The following table shows the readings of the current for each distribution board at the college at power factor =0.89.

Table 4.6: The current reading for the distribution boards at power factor =0.89.

DB	Phase1(A)	Phase2(A)	Phase3(A)	Neutral(A)
Q1	26	50	36	16
Q2	35	27	27	21
Q3	75	68	64	23
Q4	3.5	9	2	2.3
Q5	8	18	7	13
Q6	8	1	1.5	2
Q7	64	75	56	34
MDB	220	248	193.5	95.3

*To see more result see appendix ‘B’

$P= 3*V_{ph}*I_{ph} *\cos(\theta_{old})$ [10].

The following table shows the power consumes for each distribution board at the college.

Table 4.7: the real power for the distribution boards at the college

Distribution Board	Power1(W)	Power2(W)	Power3(W)
Q1	5322.2	10235	7369.2
Q2	7164.5	5526.9	5526.9
Q3	15352.5	13919.6	13100.8
Q4	716.45	1842.3	409.4
Q5	1637.6	3684.6	1432.9
Q6	1637.6	204.7	307.05
Q7	13100.8	15352.5	11463.2
MDB	45034	50765.6	39609.45

After compensation of power factor the total power remains constant.

$P_{old} = P_{new} = \text{constant}$

$P= 3*V_{ph} * I_{ph} *p.f$ >>>>> $I_{new} = \dfrac{P}{3*V_{ph}*P.F_{new}}$

Saving in power losses per phase = $(I_{old} - I_{new})^2 * R$

P saving = $(I_{old} - I_{new})^2 * R$ [10].

The following table shows the magnitude of the current reduction by improvement power factor from 0.89-0.98.

Table 4.8: The reduction in current due to the improvement of the power factor

DB	Ph1(A)	Ph2(A)	Ph3(A)
Q1	2.387755	4.591837	3.306122
Q2	3.214286	2.479592	2.479592
Q3	6.887755	6.244898	5.877551
Q4	0.321429	0.826531	0.183673
Q5	0.734694	1.653061	0.642857
Q6	0.734694	0.091837	0.137755
Q7	5.877551	6.887755	5.142857
MDB	20.20408	22.77551	17.77041

But R = Ro * length of cable

The following table shows per phase resistance of the each distribution boards at the college.

Table 4.9: cable resistance between MDB and SDB's and from MDB to transformer.

DB	R per phase
Q1	0.01235
Q2	0.0148
Q3	0.00371
Q4	0.0222
Q5	0.0235
Q6	0.0235
Q7	0.0247
MDB	0.00124

The following table shows per phase the power saving due to the improvement of the power factor at the college.

Table 4.10: saving losses per phase in the cable due to low power factor

Distribution board	**PL1(W)**	**PL2 (W)**	**PL3 (W)**	**ΔP(W)**
Q1	0.070412	0.260399	0.134991	0.465802
Q2	0.152908	0.090996	0.090996	0.3349
Q3	0.176007	0.144685	0.128164	0.448856
Q4	0.002294	0.015166	0.000749	0.018209
Q5	0.012685	0.064216	0.009712	0.086613
Q6	0.012685	0.000198	0.000446	0.013329
Q7	0.853276	1.171797	0.65329	2.678363
MDB	0.506174	0.643218	0.391576	1.540968
Total power losses in cable due low power factor equal				5.6W

Yearly saving in energy losses = P saving *8760h

Yearly saving in energy losses=49kwh/year

It’s noted the power losses in the cables due to low power factor are very

Small because of, the cables are under loading, it's design to 95mm^2

“Copper” whereas the current pass through it is small.

3-Saving in energy losses in transformer

In our case study the transformer with delta star connection, have the following data:

Rating:1,000KVA

$I=\frac{1000KVA}{(\sqrt{3}*400\ )}$ = 1443.5 A at low voltage side [10].

$Kv=\frac{6600}{400}=$ 16.5

$I=\frac{1443.5A}{16.5}$ = 87.48A at high voltage side

At maximum current consumed from main electrical distribution board I=400A

P =$\sqrt{3}$*Vl *Il * P.F old =$\sqrt{3}$*400*400*0.89=246.64 Kw [10].

P_{old} =P_{new} =constant =246.64 Kw

After improving power factor

$I_{new}=\frac{246.64Kw}{\sqrt{3}*400*0.98}$ =363A at the low voltage side

At low voltage side ‘secondary coil’ the power losses calculated as the following:

P_L=3*(I_{old}-I_{new})^2 *R_y= 3*(400-363)^2 *0.00055=2.26watt [10].

Where:

R_y: the per phase secondary coil resistance of the transformer star connection.

To find the primary current when the secondary its 400A

$$Kv=\frac{Vp}{Vs}=\frac{Is}{Ip}=\frac{6600}{400}=16.5=\frac{400}{X}$$

I_P=24.24A Line current before improvement of power factor.

The primary phase current $=\frac{IL}{\sqrt{3}}=\frac{24.24}{\sqrt{3}}$=14 A

Where:

I_P:The primary current of the transformer.

The power at primary side equal

P=$\sqrt{3}$*6600*24.24*0.89= 246.62Kw

$I_{new} = \frac{246.62}{6.6*0.98*\sqrt{3}}$ =22A

The new current for the primary side of the transformer after improving power factor calculate as the following:

$\frac{IL}{\sqrt{3}}=\frac{22}{\sqrt{3}}$=12.7 A

R_Δ =0. 318Ω

To calculate the power losses at primary side “delta connection” we convert delta to star as the following equation

$R_Y = \frac{R\Delta}{3} = \frac{0.318}{3} = 0.106\ \Omega$ [11].

P_L=3*(I_{old}-I_{new})^2 *R_Y=3*(14-12.7)^2 *0.106 =0.54 Watt [10].

Where:

R_Δ = primary transformer branch resistance which is connected as delta connection.

Total power losses in transformer due to low power factor =power losses at low voltage side +power losses at high voltage side=2.8watt.

The total power losses at the college due to low power factor =losses in cables + losses in transformer =8.4 Watt.

The yearly energy losses due to low power factor =73.6Kwh/year

Total money losses per year due to low power factor =14$/year

It's noted the power losses due to low power factor is small because of the transformer with low load factor.

Chapter Five

The Effect of the Total Harmonic Distortion on the Electrical Energy losses and Energy Conservation

5.1 Introduction:

5.2 Transformer Losses in Harmonic Loads:

5.3 Calculation the useful Capacity of the Transformer under Harmonic loads

5.4 The effect of Harmonic Distortion on the Cable Losses:

5.5 The effect of low Load Factor of the Transformer on the transformer efficiency and Energy Losses in the transformer.

5.6 The effect of low load factor of transformer on harmonic current distortion

Chapter Five

The Effect of the Total Harmonic Distortion on the Electrical Energy losses and Energy Conservation

5.1 Introduction:

In recent years, there has been an increased concern about the effects of nonlinear loads on the electric power system. Nonlinear loads are any loads which draw current which is not sinusoidal and include such equipment as fluorescent lamp, gas discharge lighting, solid state motor drives, diodes, transistors and the increasingly common electronic power supply causes generation of harmonics [9]. Harmonics are voltages and currents which appear on the electrical system at frequencies that are integral multiples of the generated frequency. It results in a significant increase in the level of harmonics and distortion in power system.

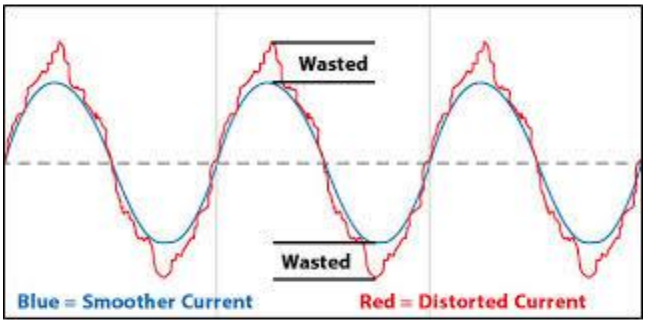


Figure 5.1: Fundamental wave and distortion wave**.**

Transformers are one of the component and usually the interface between the supply and most non-linear loads. They are usually manufactured for operating at the linear load under rated frequency.

Nowadays the presence of nonlinear load results in production of harmonic load [10].

Increasing in harmonic currents causes extra loss in transformer winding and thus, leads to increase in temperature, reduction in insulation life, Increase to higher losses and finally reduction of the useful life of transformer . Harmonic voltage increase losses in its magnetic core while harmonic currents increased losses in its winding and structure. In general, harmonics losses occur from increased heat dissipation in the windings and skin effect both are a function of the square of the rms current, as well as from eddy currents and core losses. This extra heat can have a significant impact in reducing the operating life of the transformer insulation the increased of eddy current losses that produced by a non-sinusoidal load current can cause abnormal temperature rise and hence excessive winding losses.

Therefore the influence of the current harmonics is more important. A lot of works have been done to shows that effect of harmonics on losses and life time of distribution transformer and other equipment of power system.

To estimate the costs of harmonics is much more difficult than these of other power quality costs. People usually have a good picture about the economic impact of harmonics like:

1- Loss of production

2- Unrecoverable downtime and resources

3- Process restart costs

4- Equipment damage

5- Increased troubleshooting

5.2 Transformer Losses in Harmonic Loads:

Transformer manufacturers usually try to design transformers in a way that their minimum losses occur in rated voltage, rated frequency and sinusoidal current. However, by increasing the number of non-linear loads in recent years, the load current is no longer sinusoidal. This non-sinusoidal current causes extra loss and temperature in transformer [12].

Transformer loss is divided into two major groups,

No load losses

Load loss as shown in (1)

$$\mathbf{P_T = P_{NL} + P_{LL}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad \mathbf{(1)}$$ [13, 14].

Where:

P_{NL}: No load loss.

P_{LL}: Load loss.

P_T: total loss.

5.3 Calculation the effect of the harmonic distortion on the useful Capacity of the Transformer:

In this section we study the effect of the total harmonic current distortion and total harmonic voltage distortion on the useful capacity of the transformer and the electrical energy losses due to harmonic distortion in the college.

5.3.1 The transformer useful capacity reduction due to harmonic load

The harmonic current distortion and harmonic voltage distortion affecting on the useful capacity of the transformer .when the total harmonic current distortion and total harmonic voltage distortion increase the useful capacity of the transformer decrease, due to additional harmonic losses.

In Hisham Hijjawi College we have one transformer with installed capacity 1000kVA.

$S=1000KVA = \sqrt{3} * V * I = \sqrt{3} * 400 * I$ [10].

…IL =1443A Iph=IL =1443A

Under the harmonic current and, the useful capacity of the transformer reduce as the following:

$Ih = THDi * IL = 0.12 * 1443 = 173A$

$IL_{new} = IL - Ih = 1443 - 173 = 1270A$

$I_{ph\ new}$=IL new =1270A star connection.

V_{ph} =240volt

V_h=THDv * Vph = 0.03*240=7.2 volt

$V_{ph\ new}$ = V_{ph} – V_h =240-7.2 = 232.8 volt.

S =1000KVA.

S_{new} =3*Iph new *Vph new = 3*1270*232.8 =887KVA

Where:

Ih: The magnitude of the current distortion by harmonic.

Vh: The magnitude of the voltage distortion by harmonic.

Iph new: The magnitude of the phase current due to harmonic.

Vph new: The magnitude of the phase voltage due to harmonic.

S: The capacity of the transformer “apparent power “without harmonic.

S new: The capacity of the transformer “apparent power “with harmonic.

It’s noted that the useful capacity of the transformer reduction due to total harmonic voltage and current distortion by 113KVA, from 1000KVA to 887KVA.

5.3.2 The losses of the transformer due to harmonic load:

In this section we study the effect of the total harmonic current distortion on the transformer losses and electrical energy losses.

In Hisham Hijjawi College the transformer has the following data:

S= 1,000 KVA, 6.6/0.4 KV

IL =Iph $=\frac{1000KVA}{(\sqrt{3}*400\ )}$ = 1443.5 A at low voltage side, star connection

Kv= $\frac{\text{Vp}}{\text{Vs}} = \frac{6600}{400}$ = 16.5; conversion ratio for the transformer.

IL = $\frac{1443.5\text{A}}{16.5}$ = 87.48A at high voltage side, at full load.

No load losses PNL=1074.4 watt

To find harmonic losses at the low voltage side

At maximum current reading in the winter I_{ph}= 400A

P_{hl}=3*Ih^2 *R_Y

RY for low voltage side per branch =0.00055Ω

Ih=Iph *THDi =400*0.12 =48A

P_{hl}= 3*I^2 *R = 3*48^2 *0.00055=3.8Watt

To find the primary current when the secondary its 400A

$$\text{Kv} = \frac{\text{Vp}}{\text{Vs}} = \frac{\text{Is}}{\text{Ip}} = \frac{6600}{400} = 16.5$$

I_p=24.24A Line current for the primary side of the transformer.

The primary phase current = $\frac{IL}{\sqrt{3}} = \frac{24.24}{\sqrt{3}}$ =14A

$I_h=I_{ph}$ *THDi =14*0.12 =1.68A

RY: the primary side resistance of transformer that converted from delta to star connection =0.106Ω

The power losses due to harmonic current distortion in the primary side of the transformer P_{h2}= 3* I_h^2 * R = 0.9 Watt

Total power losses in transformer due to THDi =losses in primary +losses in secondary=4.7 Watt

Total energy losses in the transformer due to THDi in the transformer per year equals 41Kwh/year.

At full load factor the transformer losses due to harmonic load will be as the following:

Rating: S=1,000kVA.

Iph = IL =$\frac{1000KVA}{(\sqrt{3}*400\ )}$ = 1443.5 A at low voltage side, star connection.

Kv=$\frac{6600}{400}$ = 16.5

IL= $\frac{1443.5A}{16.5}$ = 87.48A at high voltage side

Ih =Iph*THDi=1443.5*0.12 =173.2A at secondary.

$I_h = I_{ph} * THDi = \frac{87.48}{\sqrt{3}} * 0.12 = 6.06A$ at primary.

To find harmonic losses at low voltage side

$P_h = 3 * Ih^2 * R_y$

R_y for low voltage side =0.00055Ω

$P_h = 3 * I_h^2 * R = 3*3*173.2^2 * 0.00055 = 49.5$Watt

To find harmonic losses at high voltage side

The phase primary current for the transformer

$Phl = 3 * Ih^2 * R_y = 3 * 6.06^2 * 0.106 = 11.7$ Watt

Total transformer losses due to harmonic at full load = harmonic losses at high voltage side+ harmonic losses at low voltage side=61.2Watt

The yearly energy losses in transformer due to harmonic will be equal =536Kwh/year.

It's noted that the electrical energy losses in the transformer that produce from harmonic distortion increases as the transformer load increases ,because of the power losses depends on the current square. When the load factor of the transformer increases the current consumption and the power losses increase.

5.4 The effect of Harmonic Distortion on the Cable Losses:

Harmonics in power systems are increasingly at high level. Also, there has been an incredible growth in the use of cross linked polyethylene (XLPE) cables in distribution systems. Harmonics cause additional power loss/temperature rise; causing premature failure of cables. Catastrophic failure of power cables leads to great inconvenience to consumers and loss of system reliability and money. To avoid the overheating of power cables; the additional power loss due to harmonics should be accurately calculated and properly accommodated by rating the cable. [15]

The power losses in the cable due to harmonic distortion can be calculated by the following equation:

$Pl = I_h^2 * R$

Where:

Pl: the power losses in the cable due to harmonic distortion in current wave.

I_h: the harmonic current.

I_h =%THD for current * total current pass through cable.

R: the resistance of the cable, which depends on:

Cable length

Type of insulation

Type of conductor

Resistance per unit length

The following table shows some information about distribution boards at the college such as the type of cable, length of cable, cross sectional area…….etc

Table 5.1: Data for the distribution board at the college

From MDB To	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**T**
Length 'm'	50	60	15	90	95	15	15	20
Cross sectional area mm^2	4*95	4*95	4*95	4*95	4*95	4*95	4*95	4cable Each one 4*240
Type of conductor	Copper	Copper	Copper	Copper	Copper	Copper	Copper	Copper
Type of insulator	XLPE	XLPE	XLPE	XLPE	XLPE	XLPE	XLPE	XLPE
Ro	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.062
R	0.0123	0.0148	0.0037	0,0222	0.0235	0.0037	0.0037	0.00124
THDI	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%
Reading current	50A	35A	75A	9A	18A	8A	75A	250A
PhL	1.33w	0.78w	0.9w	0.1w	0.33w	0.01w	0.9w	3.35w
Power losses due to the harmonic losses in cable = 7.7w								
Total energy losses due harmonic in the cable	= 68Kwh/year							
Total money saving	13$/year							

From the above table its noted that the electrical energy losses due to harmonic distortion in the cable are small because of, the cable is low loading.

5.5 The effect of low Load Factor of the Transformer on the transformer efficiency and Energy Losses in the transformer.

This section shows the effect of load factor of the transformer on the transformer efficiency and energy losses in the transformer.

In this section we discus two method used to draw the efficiency curve of the transformer, the first one is theoretically method, we use the rated capacity of the transformer, no-load losses and the value of primary and secondary resistance to calculate the efficiency of the transformer at different load factor, then calculate the energy losses due to low load factor of the transformer.

The second is practically method, we used the reading of the energy analyzer (apparent power, real power, reactive power, and power factor), no-load losses and the value of primary and secondary resistance to calculate the daily efficiency curve of the transformer in the college, and then calculate the energy losses due to low load factor of the transformer.

5.5.1 Theoretically The effect of low Load Factor of the Transformer on the transformer efficiency and Energy Losses in the transformer.

This section shows the effect of the load factor of transformer on the transformer efficiency and energy losses in the transformer ,by calculate theoretical efficiency at different load factor of the transformer depending on the capacity ,the resistance of the primary ,the resistance of the secondary and no-load losses of the transformer.

Then using the calculation result to draw theoretically efficiency curve of the transformer, and calculate theoretically the electrical energy losses due to low load factor of the transformer.

The following table shows the daily utilization of the real power, reactive power, apparent power and power factor during the day.

Table 5.2: The daily utilization of the real power, reactive power, apparent power and power factor in the college.

P.F=P/S	S	Q	P	Time
0.83453237	27,800	14,600	23,200	00:00:00
0.83512545	27,900	14,600	23,300	01:00:00
0.83277592	29,900	15,900	24,900	02:00:00
0.8490566	26,500	13,500	22,500	03:00:00
0.84269663	26,700	13,700	22,500	04:00:00
0.84528302	26,500	13,500	22,400	05:00:00
0.84790875	26,300	13,300	22,300	06:00:00
0.92528736	17,400	3,700	16,100	07:00:00
0.97847358	51,100	10,400	50,000	08:00:00
0.95083682	95,600	28,800	90,900	09:00:00
0.9391435	133,100	45,700	125,000	10:00:00
0.94629349	132,200	42,500	125,100	11:00:00
0.94569758	119,700	38,500	113,200	12:00:00
0.94164456	113,100	37,900	106,500	13:00:00
0.95363636	110,000	32,700	104,900	14:00:00
0.95327103	107,000	32,400	102,000	15:00:00
0.94130435	92,000	31,100	86,600	16:00:00
0.93760832	57,700	19,900	54,100	17:00:00
0.90547264	60,300	24,300	54,600	18:00:00
0.90689013	53,700	21,900	48,700	19:00:00
0.83985765	28,100	14,600	23,600	20:00:00
0.83098592	28,400	15,100	23,600	21:00:00
0.83275261	28,700	15,300	23,900	22:00:00
0.8410596	30,200	15,300	25,400	23:00:00

Transformer load factor = $\frac{\text{Max.Demand}}{\text{Installed capacity}} = \frac{133\text{kVA}}{1000\text{kVA}}$ =0.133 [10].

In our case study the transformer has the following data:

S Rating: 1,000 KVA

I=$\frac{1000KVA}{\sqrt{3}*400}$

The full load current at low voltage=1443.4A…….Iph=1443.4A

The full load current at high voltage=87.48A ……..Iph =50A

Power factor =0.89

No load losses =1074.4watt

R branch at low voltage star connection= 0.00055Ω

R branch at high voltage side delta connection=0.318 Ω

The following figure shows the delta star conversion for the primary resistance of the transformer.

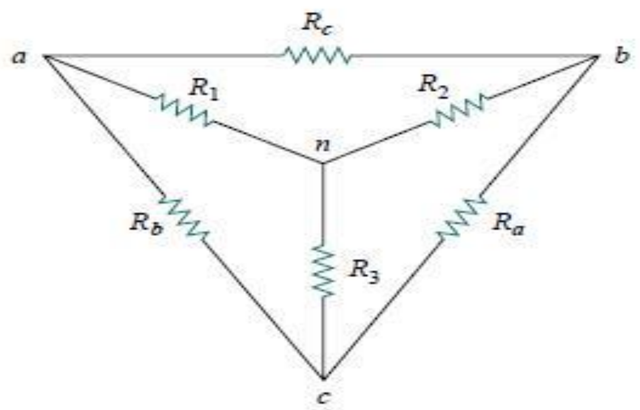


Figure 5.2: Delta /star conversion for the resistance of the transformer primary.

$\mathbf{R}_Y = \frac{\mathbf{R}\Delta}{3} = \frac{0.318}{3} = 0.106\ \Omega$ [11].

Where:

I: The phase current of the primary or secondary connection of the transformer at variable load factor

$\mathbf{P}_o=\sqrt{3}*\mathbf{I}_L*\mathbf{V}_L*\mathbf{P.F}$, use power factor =0.89

$\mathbf{I}_L$=the line current of the transformer at variable load factor

$I_{ph}=\frac{IL}{\sqrt{3}}$, for delta connection

$I_{ph}=I_L$, for star connection

The transformer power losses at given load factor = on-load losses at primary +on-load losses at secondary + no-load losses

PNL=1074.4watt.

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Output power+power losses}}$$ [16].

Ps.c=**Ps.c** for primary + **Ps.c** for secondary.

Ps.c for primary = $3*\mathbf{I}^{\wedge 2}*\mathbf{R}_Y + 3*\mathbf{I}^{\wedge 2}*\mathbf{R}_\Delta$

Ps.c=3*(1443^2)*0.00055+3(50^2)*0.106 =3436+2407=4230 watt

$$\mathbf{Pt=Pnl + (\frac{Pac}{Prat})^{\wedge}2 * P\ s.c}$$

Pin = Pout +Pt [16].

Pout =S (installed capacity)*L.F*P.F [16].

Where:

Ps.c =full load losses in watt

Pt=total losses in transformer in watt

Pnl: no-load losses of the transformer in watt

Prat: rated power of transformer in KVA

Pact : actual power of transformer in KVA

L.F: Load factor

P.F: power factor

To draw the efficiency curve of the transformer we want to calculate the efficiency at different load factor from (0.01-1.3) as the following:

At load factor =0.1

Pt=1074 + $(\frac{100KVA}{1000KVA})$^2 * 4230 =1116 Watt

Efficiency = $\frac{\text{Output power}}{\text{Output power+power losses}}$ = $\frac{89KW}{90.116KW}$ =98.76%.

*The result of the calculation put in the next table (table 5.3)

The following table shows the theoretical calculation of the efficiency of the transformer with variable load factor:

Table 5.3: Theoretical efficiency calculation for the transformer in the college.

L.F	Pnl (w)	Ps.c (w)	Pt(w)	cupper losses(w)	Pin (w)	Pout (w)	Efficiency
0.01	1074	4230	1074.4	0.423	9974	8900	0.8923
0.1	1074	4230	1116	42	90116	89000	0.9876
0.13	1074	4230	1148	74	119518	118370	0.9904
0.2	1074	4230	1243	169	179243	178000	0.9931
0.3	1074	4230	1454	380	268454	267000	0.9946
0.4	1074	4230	1750	676	357750	356000	0.9951
0.5	1074	4230	2131	1057	447131	445000	0.9952
0.6	1074	4230	2596	1522	536596	534000	0.9952
0.7	1074	4230	3146	2072	626146	623000	0.9950
0.8	1074	4230	3781	2707	715781	712000	0.9947
0.9	1074	4230	4500	3426	805500	801000	0.9944
1	1074	4230	5304	4230	895304	890000	0.9941
1.1	1074	4230	6192	5118	985192	979000	0.9937
1.2	1074	4230	7165	6091	1075165	1068000	0.9933
1.3	1074	4230	8222	7148	1165223	1157000	0.9929

The following figure shows the no-load losses and on-load losses at different load factor of the transformer.

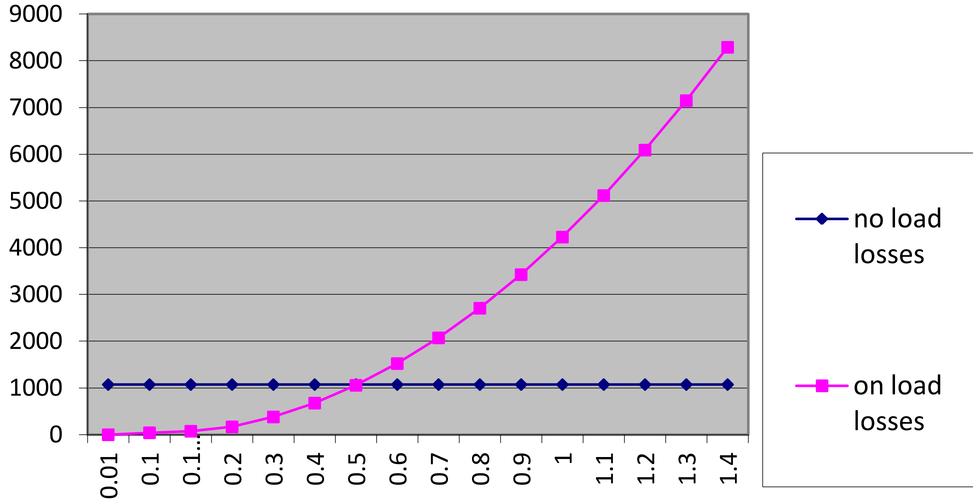


Figure 5.3: No-load and on-load losses with changing load factor for the transformer.

The previous curve shows maximum efficiency occur at 50% of load factor which equal 99.52%, at this point the no-load losses approximately equal to on-load losses.

The following figure shows the theoretical calculation of the transformer efficiency with variable load factor

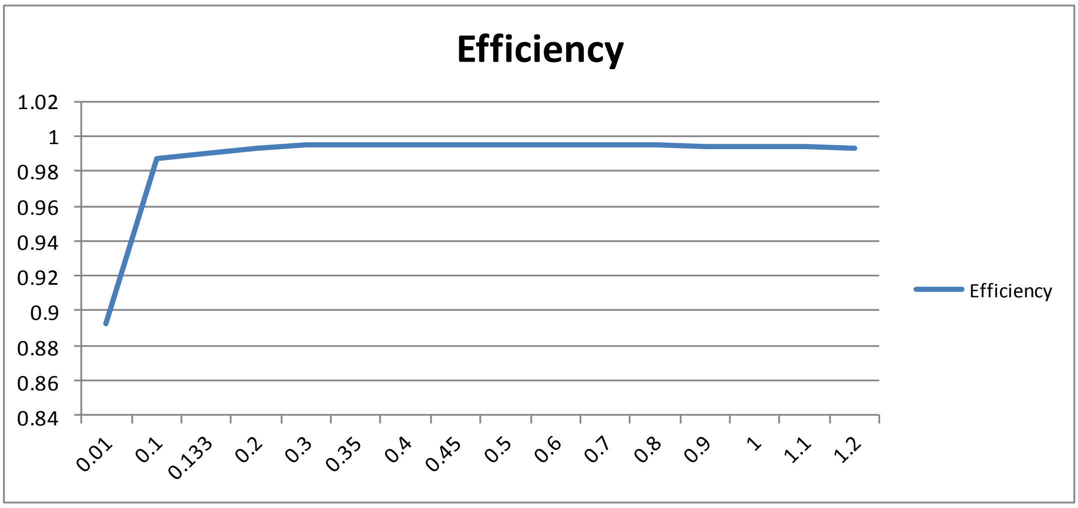


Figure 5.4: Theoretically efficiency curve of the transformer.

The previous curve shows the efficiency of the transformer changes during variable load factor of the transformer .when the load factor of the transformer equal 0.01 ,the transformer efficiency equal to 0.89 .in our case study the load factor of the transformer equal to 0.13 ,the efficiency equal to 99%. The maximum efficiency of the transformer occurs at 50% of load factor, which the efficiency reaches to 99.52%.

The electrical energy losses due to low load factor of the transformer calculate theoretically as the following:

EL=ΔPin*Time

$$\Delta Pin = \frac{P\ out}{\Delta efficiency}$$ [16].

At best condition with load factor 0.50, which the efficiency =99.5%.

Pout =445000 w, Pin =447132 w

At actual condition at load factor 0.133, which the efficiency =99%

Pout=118370w, Pin=119519w

So that:

Pout=118370w

$$Pin\ 1 = \frac{Pout}{E1} = 119519W$$

$$Pin2 = \frac{Pout}{E2} = 118937W$$

ΔPin=Pin 2-Pin 1= 582watt

Where:

EL=electrical energy losses due to low load factor in the transformer

Pout: output power at given load factor.

Pin: input power at giver load factor

E1: The efficiency at maximum load factor recorded in the college (0.13)

E2: The maximum efficiency of the transformer at 50% of load factor (99.5%).

ΔPin: the power losses due to low load factor of the transformer.

Time =8760hour

The yearly electrical energy losses in the transformer due to low load factor of the transformer calculate as the following equation:

EL= 582w*8760h=5097Kwh/year

Money saving by improvement load factor of the transformer=EL*0.185$=917$ per year.

5.5.2 Practically The effect of low Load Factor of the Transformer on the transformer efficiency and Energy Losses in the transformer.

This section shows the effect of load factor of the transformer on the transformer efficiency and energy losses in the transformer .we calculate the practical efficiency of the transformer at different load factor depends on reading of the energy analyzer, capacity, the resistance of the primary, the resistance of the secondary, no-load losses of the transformer.

Then use the calculation result to draw the practically efficiency curve of the transformer, and calculate practically the electrical energy losses due to low load factor of the transformer.

To draw the practically efficiency curve of the transformer we want to calculate the hourly efficiency during the day ,then draw the daily efficiency curve of the transformer, and using the result to calculate the (hourly, daily ,yearly) electrical energy losses due to low load factor of transformer.

Using the following equation in calculation:

PNL=1074.4watt.

Ps.c=**Ps.c** for primary + **Ps.c** for secondary.

Ps.c for primary = $3*\mathbf{I}^{\wedge 2}*\mathbf{R}_{Y} + 3*\mathbf{I}^{\wedge 2}*\mathbf{R}_{\Delta}$

Ps.c=3*(1443^2)*0.00055+3(50^2)*0.106 =3436+2407=4230 watt

$$\mathbf{Pt=Pnl + (\frac{Pac}{Prat})^2 * P\,s.c}$$

Pin = Pout +Pt

Pout =S (installed capacity)*L.F*P.F

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Output power+power losses}}$$

EL=ΔPin*Time

$$\Delta Pin = \frac{\text{P out}}{\Delta \text{efficiency}}$$

The following table shows the daily efficiency curve of the transformer in the college.

Table 5.4: The daily actual efficiency of transformer in the college.

Time	S avg	S	L.F	Pnl	Ps.c	Pcu	Po	Pin	Efficiency
0	28583	1000000	0.03	1074	4230	3	25439	26517	0.959
1	27916.7	1000000	0.03	1074	4230	3	24846	25923	0.958
2	28050	1000000	0.03	1074	4230	3	24965	26042	0.959
3	27400	1000000	0.03	1074	4230	3	24386	25463	0.958
4	27300	1000000	0.03	1074	4230	3	24297	25374	0.958
5	27000	1000000	0.03	1074	4230	3	24030	25107	0.957
6	26666.7	1000000	0.03	1074	4230	3	23733	24810	0.957
7	20150	1000000	0.02	1074	4230	2	17934	19009	0.943
8	53566.7	1000000	0.05	1074	4230	12	47674	48760	0.978
9	110217	1000000	0.11	1074	4230	51	98093	99218	0.989
10	128783	1000000	0.13	1074	4230	70	114617	115761	0.990
11	129500	1000000	0.13	1074	4230	71	115255	116400	0.990
12	123850	1000000	0.12	1074	4230	65	110227	111365	0.990
13	107717	1000000	0.11	1074	4230	49	95868	96991	0.988
14	111150	1000000	0.11	1074	4230	52	98924	100050	0.989

15	108350	1000000	0.11	1074	4230	50	96432	97555	0.988
16	81816.7	1000000	0.08	1074	4230	28	72817	73919	0.985
17	56566.7	1000000	0.06	1074	4230	14	50344	51432	0.979
18	55900	1000000	0.06	1074	4230	13	49751	50838	0.979
19	54216.7	1000000	0.05	1074	4230	12	48253	49339	0.978
20	29216.7	1000000	0.03	1074	4230	4	26003	27080	0.960
21	29000	1000000	0.03	1074	4230	4	25810	26888	0.960
22	29316.7	1000000	0.03	1074	4230	4	26092	27169	0.960
23	28700	1000000	0.03	1074	4230	3	25543	26620	0.960

The following figure shows the transformer load factor during the day

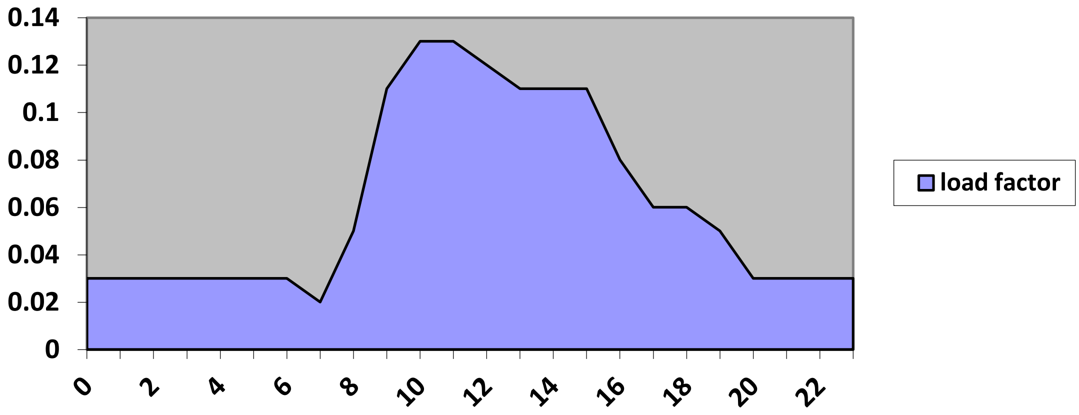


Figure 5.5: The actual daily transformer load factor in the college.

The previous figure shows the load factor of the transformer changes during the day, the highest load factor of the transformer in the college is 13% at 11:00 AM.

The following figure shows the daily efficiency curve of transformer in the college.

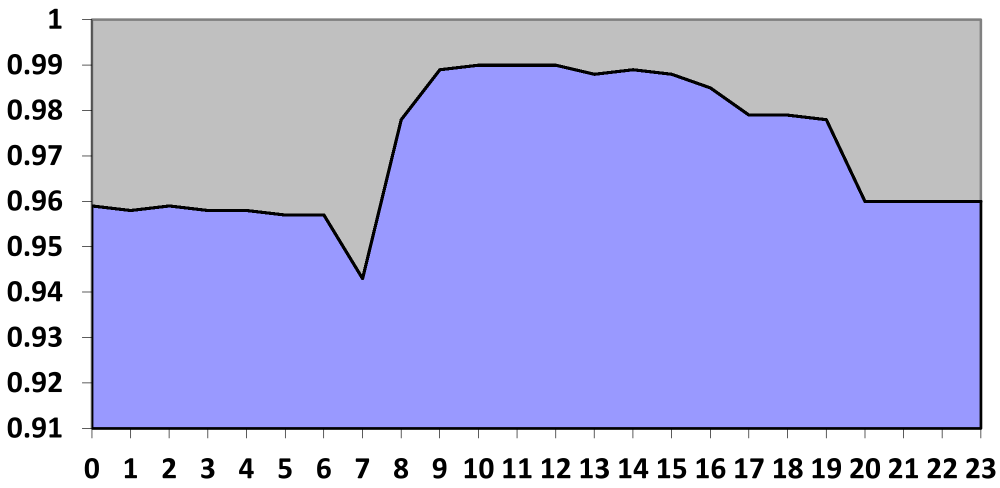


Figure 5.6: The actual daily transformer efficiency in the college.

The previous curve shows the efficiency of the transformer changes during day the, from 0.959 to 0.99.

The maximum efficiency of the transformer occurs at 50% of transformer load factor, which reach's to 99.5%

The electrical energy losses due to low load factor of transformer in the college calculated as the following equation:

EL=ΔPin*Time

$$\Delta Pin = \frac{P\ out}{\Delta efficiency}$$

At actual condition the daily load factor of the transformer changes from 3% to 13%. So that the power losses due to low load factor of the transformer is changes as the following.

Pin 1= Pout / E1

Pin2= Pout /E2

ΔPin=Pin 2-Pin 1

Where:

E1: the efficiency at each hour

E2: the maximum efficiency at 50% load factor 99.5%

The following table shows the efficiency of the transformer at each hour, the maximum efficiency of the transformer, hourly input power, hourly output power and hourly power losses due to low load factor of the transformer.

Table 5.5: Hourly power losses due to low load factor of the transformer in college.

Time	**E2**	**E1**	**Pin1**	**Po**	**ΔPin**
0	0.995	0.959	26517	25439	950
1	0.995	0.958	25923	24846	952
2	0.995	0.959	26042	24965	952
3	0.995	0.958	25463	24386	955
4	0.995	0.958	25374	24297	955
5	0.995	0.957	25107	24030	956
6	0.995	0.957	24810	23733	958
7	0.995	0.943	19009	17934	986
8	0.995	0.978	48760	47674	847
9	0.995	0.989	99218	98093	632

10	0.995	0.990	115761	114617	568
11	0.995	0.990	116400	115255	566
12	0.995	0.990	111365	110227	585
13	0.995	0.988	96991	95868	641
14	0.995	0.989	100050	98924	629
15	0.995	0.988	97555	96432	639
16	0.995	0.985	73919	72817	736
17	0.995	0.979	51432	50344	835
18	0.995	0.979	50838	49751	837
19	0.995	0.978	49339	48253	844
20	0.995	0.960	27080	26003	947
21	0.995	0.960	26888	25810	948
22	0.995	0.960	27169	26092	947
23	0.995	0.960	26620	25543	949

The daily energy losses during low load factor in transformer calculated as the following equation

E=ΔP*Time= 19800wh/day.

The yearly energy losses due to load factor of the transformer calculated as the following equation:

E yearly =E daily *365 day =19800wh/day *365day =7232kwh/year

Money saving by improvement load factor of the transformer=EL*0.185$=7232kwh/year *0.18$ = 1300$ per year.

5.6 The effect of low load factor of transformer on harmonic current distortion:

This section shows the effect of the low load factor of the transformer on the Harmonic Current Distortion by using SIMULINK/Matlab program**.**

The following figure shows the block diagram for the effect of low load factors of the transformer on the level of the harmonic current distortion. We use transformer 1mVA 6.6/0.4 KV. The non-linear load expresses by R-L load with Thyristors. The value of the load R-L load is changeable to provide variable load factor.

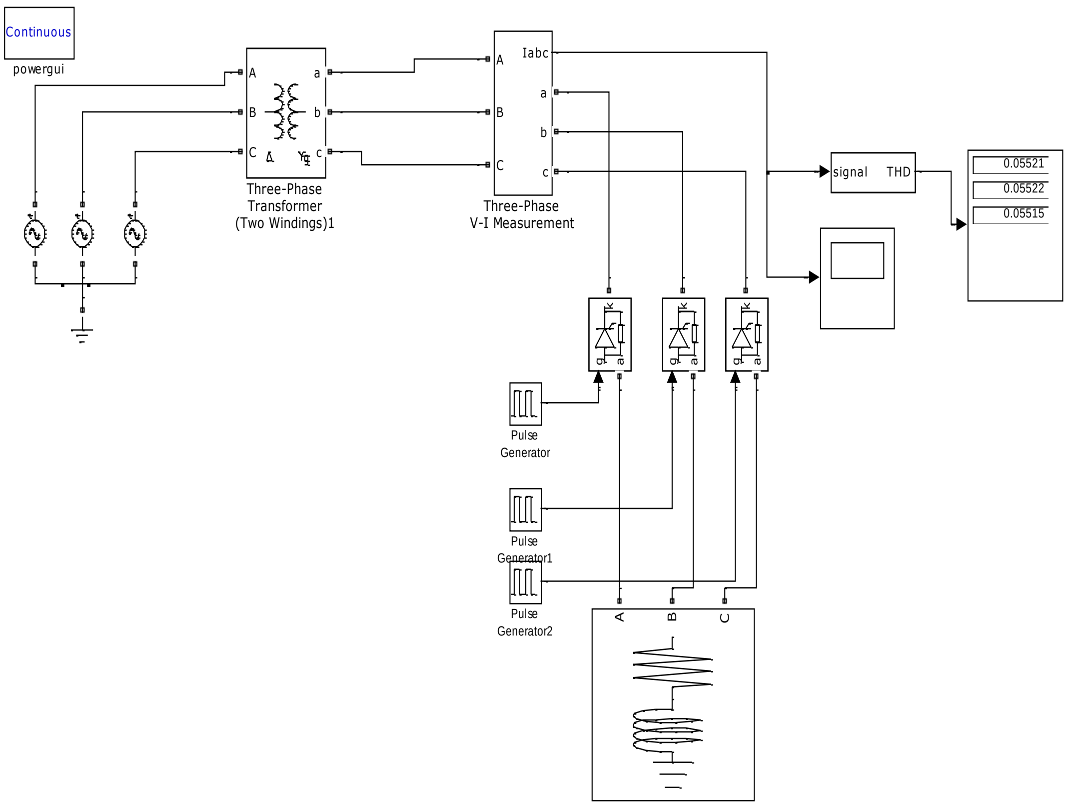
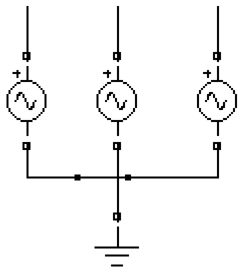


Figure 5.7: Simulink block diagram showing the effect of load factor of the transformer on the harmonic current distortion.

Where:

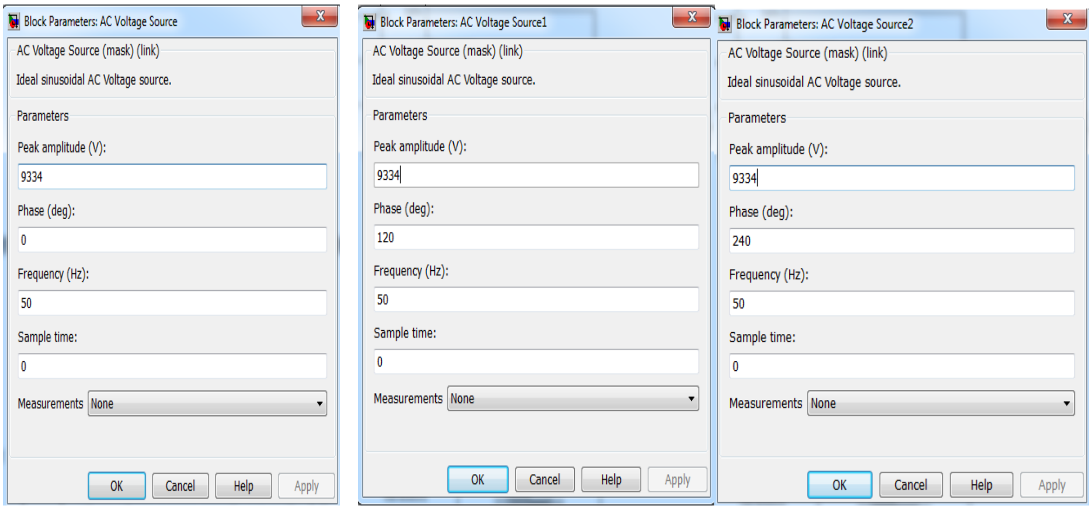


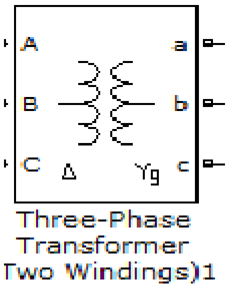
Three phase power supply set as the following

Peak amplitude =sqrt(2)*Vrms=1.41*6600=9334volt

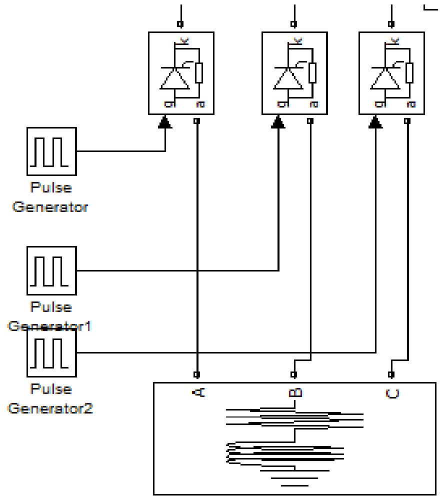
Frequency =50Hz,phase(deg) =0 for phase one,120 for phase two,240 for the phases three.

The following figure shows the setting for the power supply in the previous Simulink block diagram.

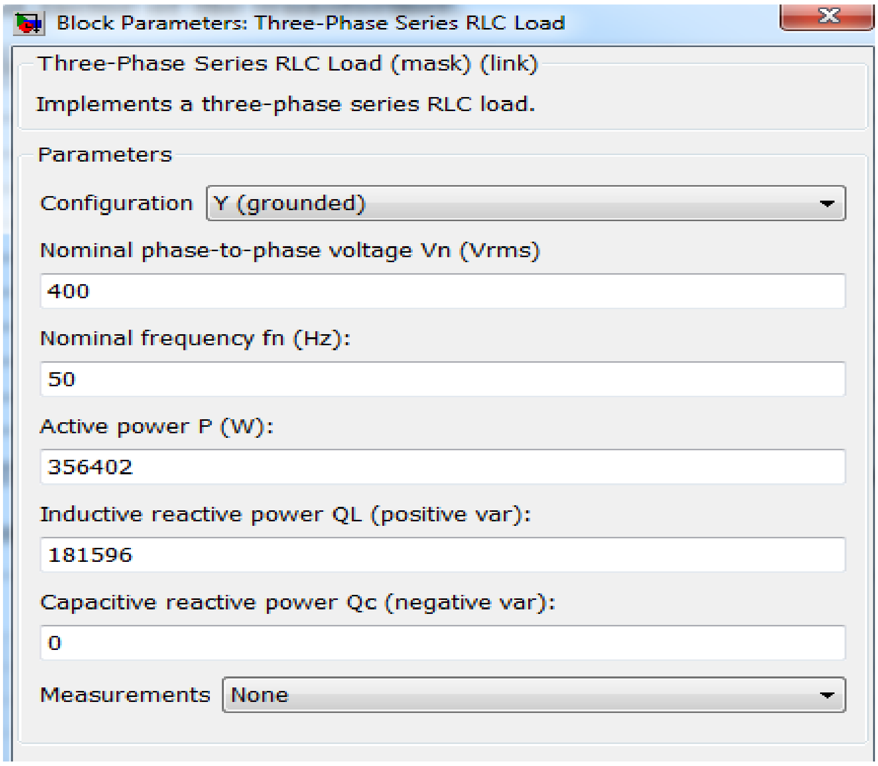


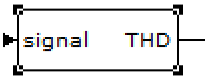


Three phase transformer, the primary connects as delta connection, and the secondary connects as the star connection .The setting for the transformer as the following

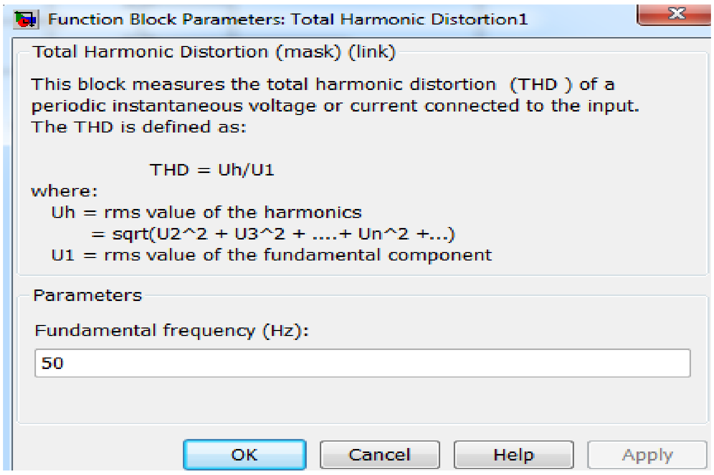


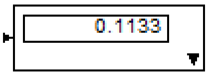
R-L loads with thyrisors to represent the non-linear load. The variable load sets as the following figure.



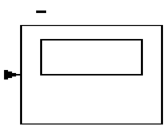


Total harmonic distortion in the signal, set as the following

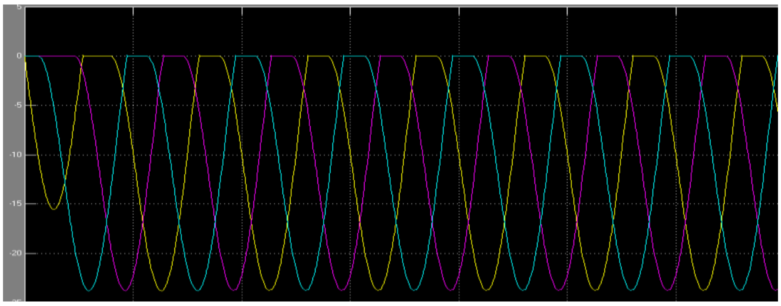




Display the percentage of the total harmonic distortion for the load



Display the graph of the current or the voltage sine wave as the following figure



The following table 5.6 shows the result of the effect of the load factor of the transformer on the total harmonic current distortion. This value was taken from the previous Simulink block diagram.

Table 5.6: The Relationship between harmonic current distortion and the load factor of the transformer.

load factor	S(VA)	P.F (0.89)	P(W)	Q(VAR)	THDi
0.1	100000	0.89	89100	45400	22%
0.2	200000	0.89	178200	90798	16.2%
0.3	300000	0.89	267300	136197	13.2%
0.4	400000	0.89	356402	181596	11.3%
0.5	500000	0.89	445503	226995	10%
0.6	600000	0.89	534604	272394	9%
0.7	700000	0.89	623705	317793	8.3%
0.8	800000	0.89	712805	363192	7.7%
0.9	900000	0.89	801906	408591	7.2%
1	1000000	0.89	891006	453990	6.8%

The previous table shows the effect of the load factor of the transformer on the total harmonic current distortion. The total harmonic current distortion decrease as the load factor of the transformer increase.

The following figure shows the effect of the load factor of the transformer on the total harmonic current distortion.

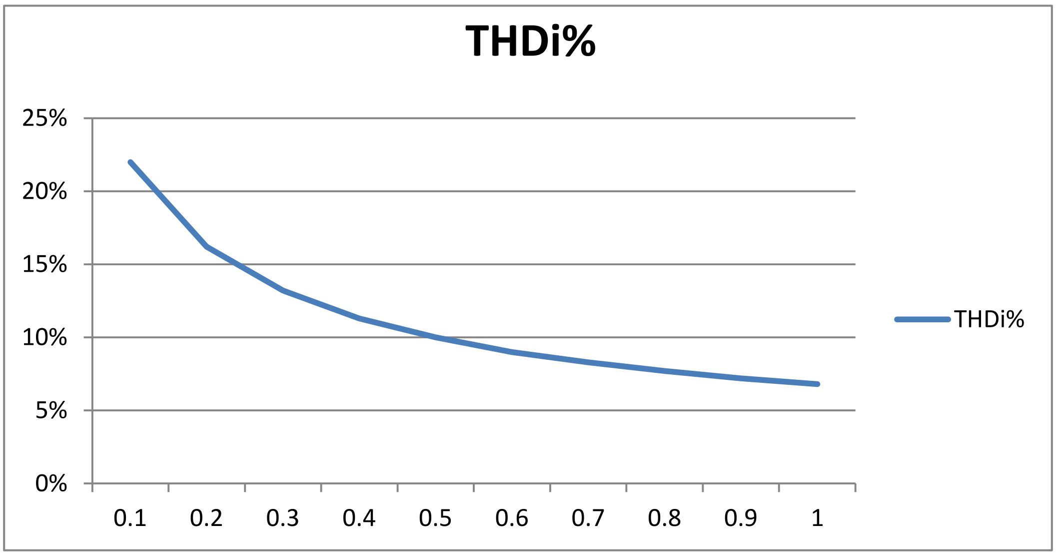


Figure 5.8: The effect of load factor of the transformer on the harmonic current distortion at the college.

It's noted that the total harmonic current distortion affected by the load factor of the transformer when the load factor of the transformer increases from 10% to 100%, the total harmonic current distortion decreases from 15% to 5%. So, we can consider that the low load factors of the transformer in the college as one of reasons of the high value of the total harmonic current distortion.

Chapter Six

Modeling to Reduce Total Harmonic Distortion

6.1 Introduction:

6.2 Reduce Total Harmonic Distortion by using Passive Filter

6.2.1 Total Harmonic Distortion of the load without passive filter:

6.2.2 Total Harmonic Distortion of the load With Passive Filter:

6.3 Reduce Total Harmonic Distortion by using pulse width modulation "PWM"

6.4 Reduce Total Harmonic Distortion by using Shunt Active Filter

Chapter Six

Modeling to Reduce Total Harmonic Distortion

6.1 Introduction:

The harmonic distortion generated from non-linear load Produce electrical losses in the electrical equipment as transformer, cable. From other side the harmonic distortion in the power system destroys the insulation of the electrical equipment by increasing thermal losses therefore it reduces the life time of the electrical equipments, increases the drop voltage , reduces the power factor ,other economic and technical problems .For this reasons we must find the solution for harmonic distortion. Unfortunately, we don't have the needed harmonic reduction filters to test the affecting on the harmonic, and due some limitation to do this actual tests in this case study we tended to using MATLAB/SIMULINK to design the needed filters, and how the non-linear load affecting by this filters.

There are some methods used to mitigate the effect of harmonic distortion (for example “passive filter combined of the series and Active power filters shunt active filter, PWM").

6.2 Reduce Total Harmonic Distortion by using Passive Filter:

The first methods to mitigate total harmonic distortion, it's by using Passive filter, which is very much helpful for mitigation of harmonic component, and used traditionally. Passive filter is used for the mitigation of harmonic in the electrical society for the last three decades, and there is a continuous development has been reported in this technique for the better use of filter, and converts the filter more useful to achieve the optimum approach to utilization with reduced rates, and cost. The use of passive filter in the mitigation of harmonic in three phase system uses the utilizing with thyristor controlled reactor, and thyristor switched capacitor is the most significant development in the field of harmonic distortion mitigation. Passive filter is used for the mitigation of the harmonic component in six pulse converter, and also provide the reactive power compensation in the system to improve the power quality, so by men of this power filter helps the system by two minus one is to improve the system power quality and improve reactive power problem so reduced the need of capacitor for supplying extra needed KVAR. The performance of passive filter depends mainly on the system source impedance. [17]

Classification of Passive filter:

We have two types of passive filter as the following:

1. Passive Series Filter
2. Passive Shunt Filter

Passive series filter:

The system which comes with the voltage source type harmonic, which are the product of the diode rectifier with R-L connected load (Figure 6.1) it is preferred to use the series type passive filter as considered as a potential remedy of harmonic mitigation. A passive type series filter has a property of purely inductive type or LC tuned characteristics. The main component of passive series filter is an AC line reactor, and a DC link filter. The operating principle of series passive filter is given by these two components connected in series that AC line reactor improves system magnitude of inductance in a system that alters the path of current drawn in the rectifier circuit. [17]

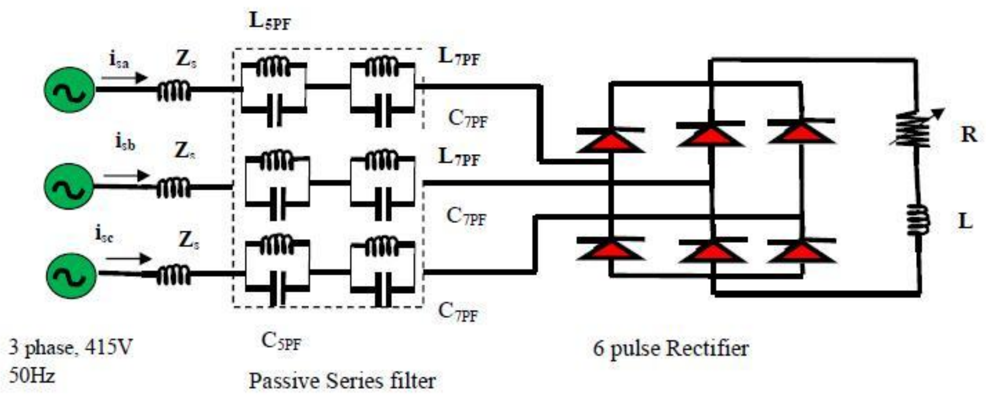


Figure 6.1: Schematic diagram of series connected passive filter with six pulse rectifier filters with six pulse rectifier

Passive shunt filter:

It is the most common method for the cancellation of harmonic current in the distribution system. The passive harmonic filter is basically designed on principle of either single tuned or band pass filter technology.

As the name suggests shunt type filter are connected to system parallel with the load. Passive filter offers very low impedance in the network at the tuned frequency to divert all the related current, and at given tuned frequency. Because of passive filter always have the tendency of offering some reactive power in the circuit so the design of passive shunt filter takes place for the two purposes one is the filtering purposes, and another one is to provide reactive compensation purpose of correcting power factor in the circuit at desired level. The advantage with the passive shunt type filter is that it only carries a fraction of current so the whole system AC power losses are reduced compared to series type filter. [17]

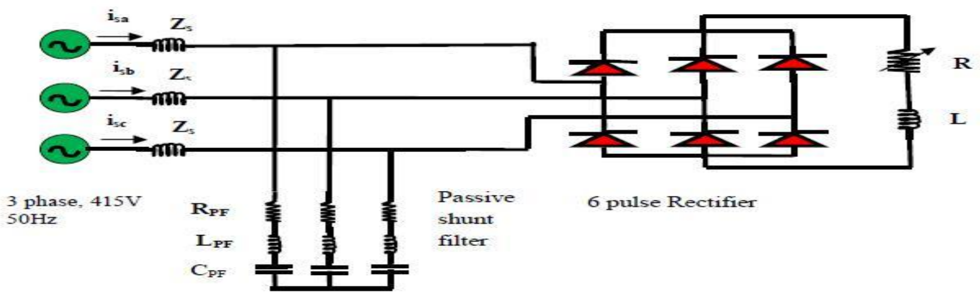


Figure 6.2: Shunt filter connection with six pulse rectifier circuit at input. [17]

6.2.1 Total Harmonic Distortion of the load without passive filter:

This section shows the effect of non-linear load on the total harmonic current distortion.We used inductive load with R=5Ω, L=5mH, the following block diagram design by MATLAB/SIMMULINK shows the effect of non-linear load on the total harmonic current distortion without using passive filter.

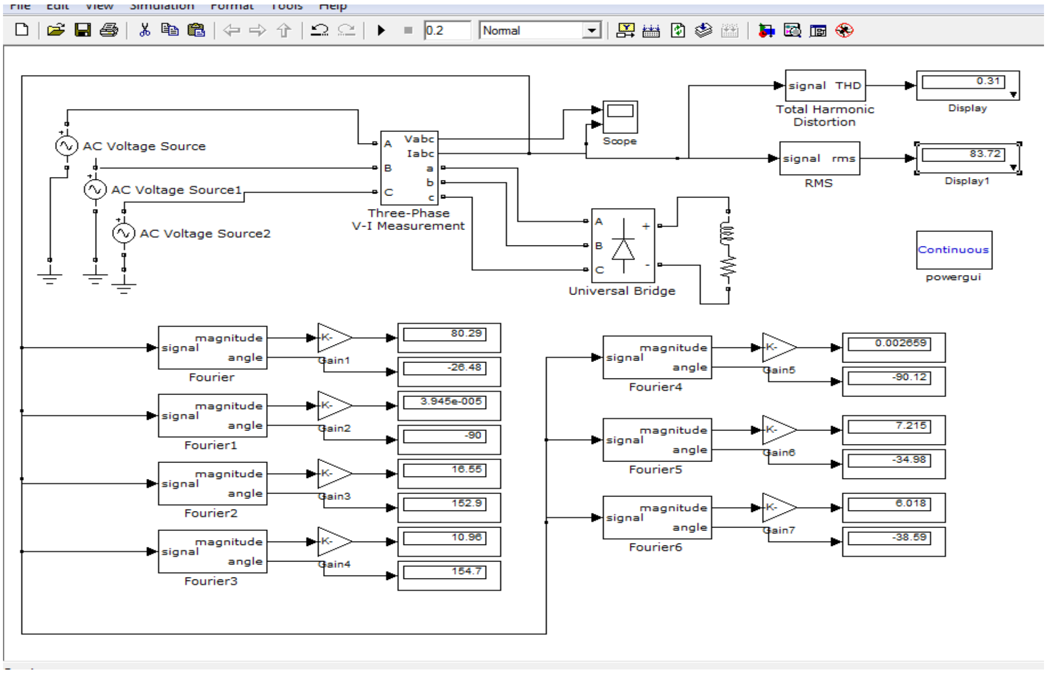
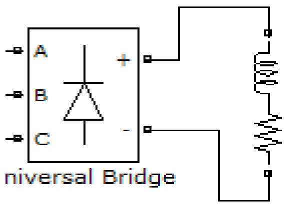


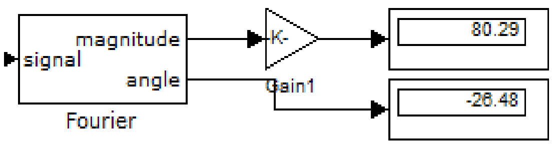
Figure 6.3: block diagram of the non-linear load without using passive filter. [17]

The following table shows the odd number harmonic order for the non-linear load with R=5Ω,L=5mH.

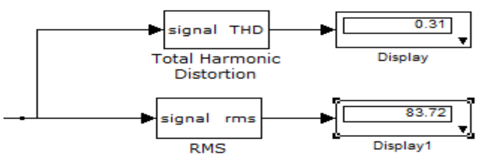
Where:



Represent nonlinear load



Represent the harmonic order magnitude and angle.



Represent the magnitude of the current and the total harmonic current distortion.

Table 6.1: The percent of the harmonic current distortion due to non-linear load without passive filter

Harmonic order	Percent of harmonic order
1	0.9563
3	0.00001
5	0.198
7	0.13
9	0.00038
11	0.086
13	0.07

The following table shows the magnitude of current contribute to the odd harmonic order.

Table 6.2: The harmonic distortion due to non-linear load without using passive filter

Harmonic order	Magnitude	Angle	THDI%=31%
1	80.3A	-27	
3	0.0004A	-90	
5	16.55A	153	
7	10.96A	155	
9	0.003A	-90	
11	7.2A	-34	
13	6A	-38	

From the above table that represents the result of the previous block diagram we noted that the total harmonic current distortion of the system without using a passive filter equals 31%.

The following figure shows the Fourier series for the non-linear load without using Passive Filter.

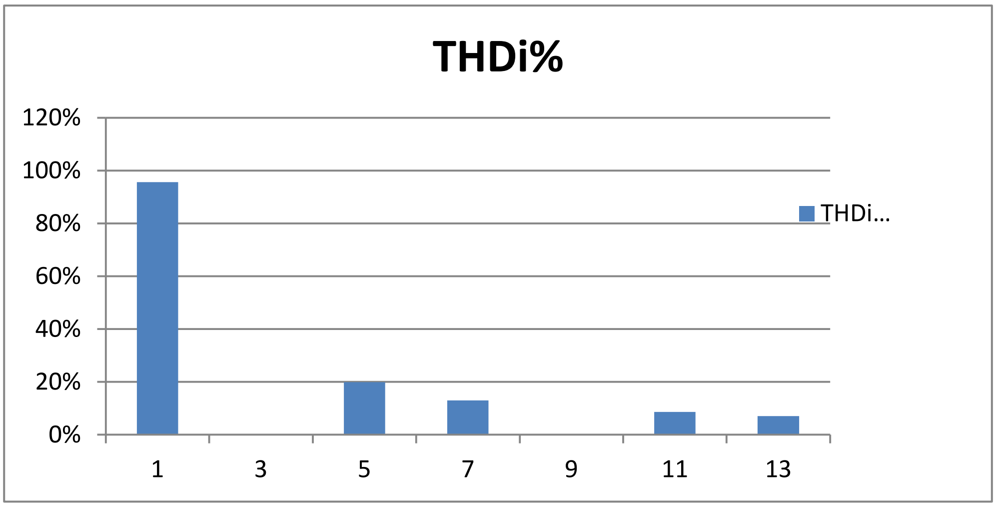


Figure 6.4: Fourier series for the non-linear load without using Passive Filter.

The following figure shows the output voltage and current for the non-linear load without using passive filter.

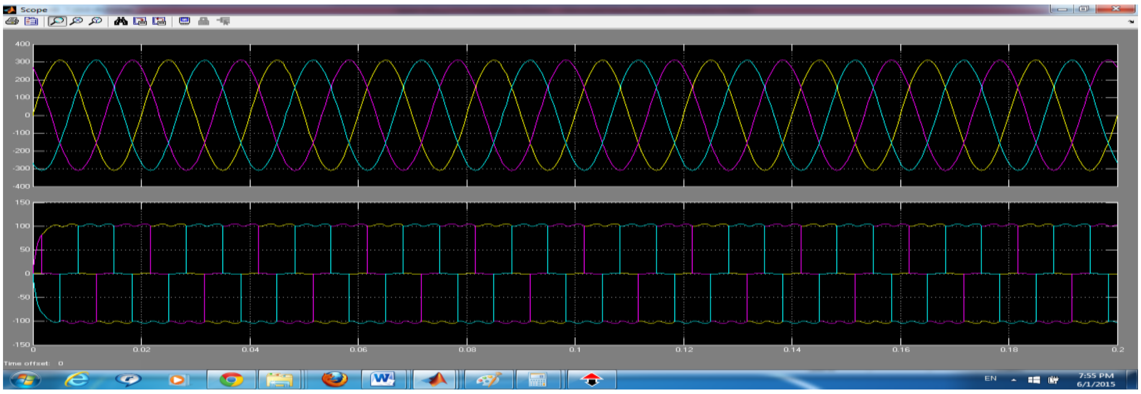


Figure 6.5: Voltage and current wave due to non-linear load without using Passive Filter.

6.2.2 Total Harmonic Distortion of the load With Passive Filter:

This section shows the effect of using the passive filter on the total harmonic current distortion that produces from the non-linear load. We used to load R=5Ω, L=5mH.

The following figure shows the Simulink block diagram for the effect of the using passive filter with nonlinear load on the total harmonic current distortion.

Using passive filters with L=15mH, C=0. 625mF.

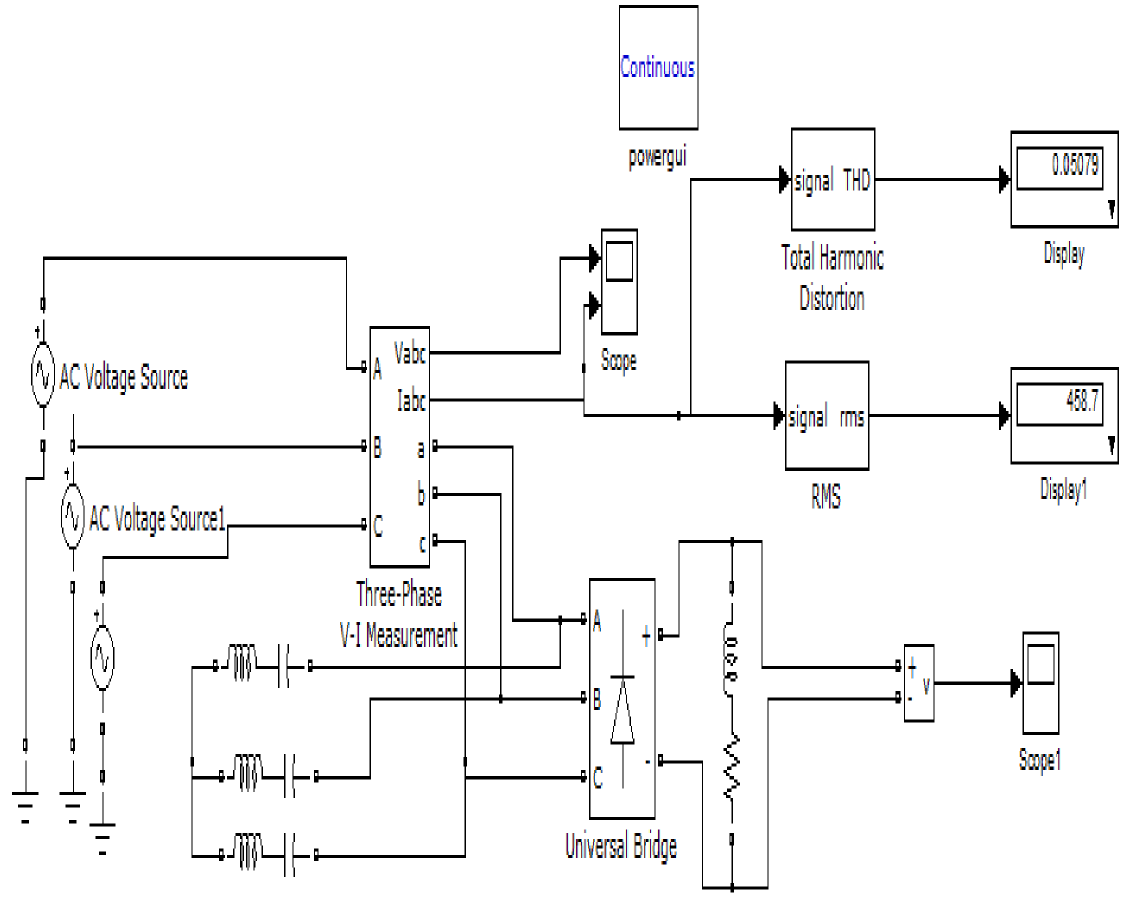
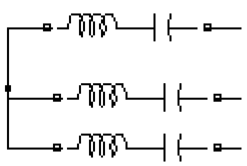


Figure 6.6: block diagram of the mitigation total harmonic current distortion by using Passive filter. [17]

Where:



Represent the passive filter.

With L=15Mh, C=0. 625Mf

The passive filter reduces total harmonic current distortion from 31% to 4 %.

The following figure shows the output voltage and current that consumes from load with using passive filter.

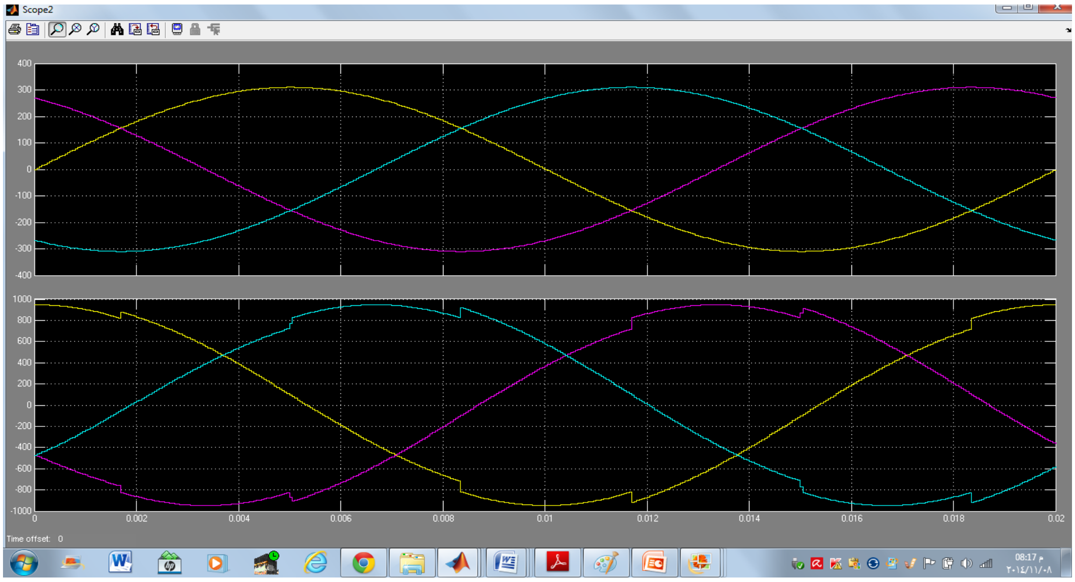


Figure 6.7: Voltage and current wave for non-linear load after using Passive Filter**.**

From above figure we noted that how the output current wave becomes most approaches to the sine wave.

6.3 Reduce Total Harmonic Distortion by using pulse width modulation "PWM":

This section shows the effect of using PWM on the total harmonic current distortion.We used load R=1Ω,L=50mH.

The following figure shows the block diagram designed to see the effect of PWM on the total harmonic current distortion.

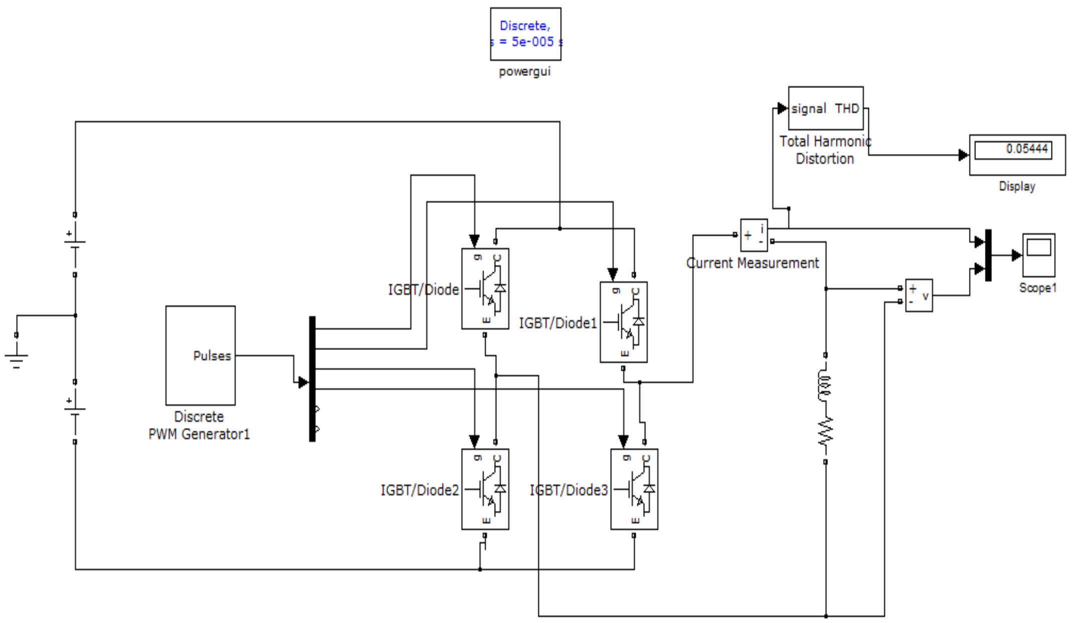
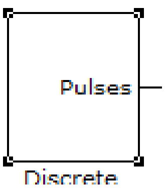
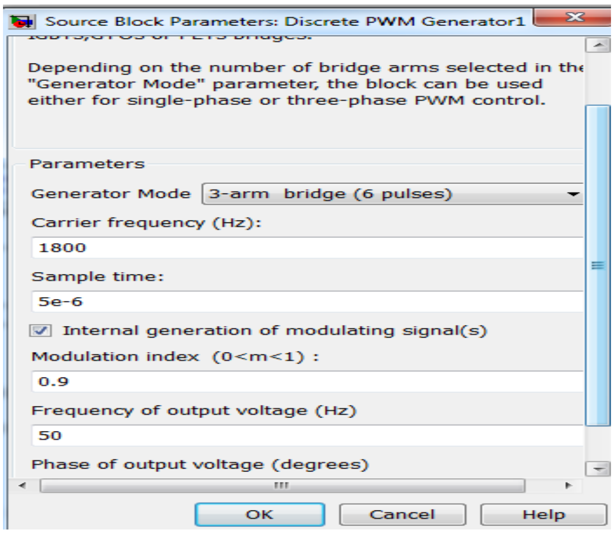


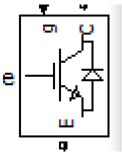
Figure 6.8: Block diagram of PWM. [18]

Where:

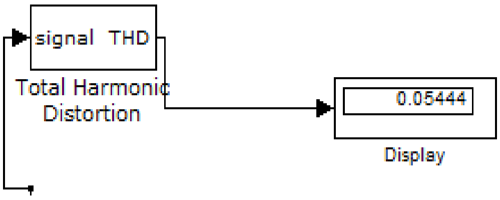


PWM generator, the modulation index changes from (0.1 to 0.9); the carrier frequency changes from 0-2000Hz as the following figure



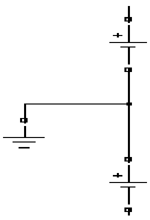


IGBT/diode



Total harmonic current distortion measurement

R-L load with R=1Ω, L=50mH



DC power supply with 100V set as magnitude

The first step we shows the effect of the carrier frequency in PWM on the total harmonic current distortion.

The following table shows the effect of Carrier frequency in PWM on the total harmonic current distortion.

Table 6.3:The effect of carrier frequency of the PWM on the THDi

Modulation index	Carrier frequency	THD I%
0.9	50	26%
0.9	100	16.4%
0.9	150	11%
0.9	200	10.8%
0.9	300	7%
0.9	500	5%
0.9	1000	4%
0.9	2000	3.7%

From the above table it’s noted that the total harmonic current distortion decreases from 26% to 3.7% when the carrier frequency increases from 50 Hz to 2000Hz.

The following figure shows the effect of the carrier frequency that use in PWM on the total harmonic current distortion.

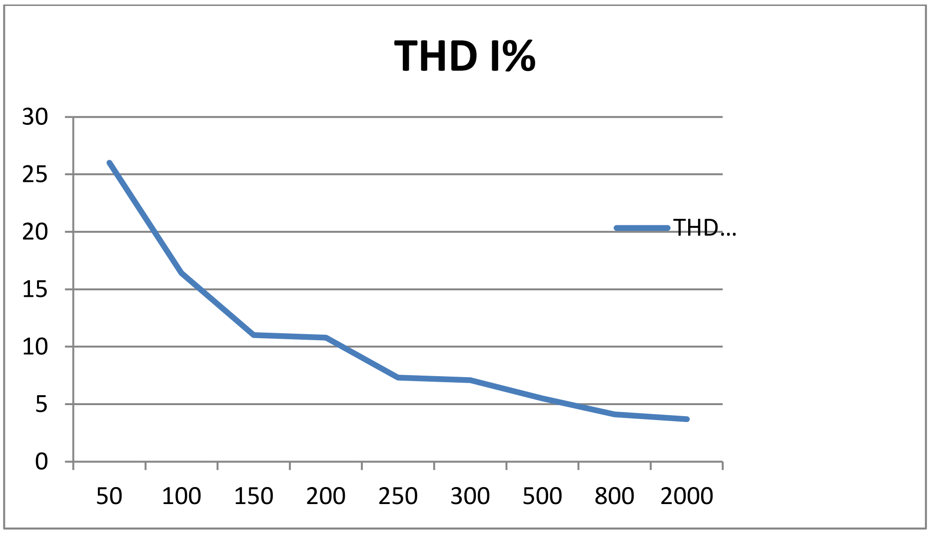


Figure 6.9: The effect of the carrier frequency that use in PWM on the total harmonic current distortion**.**

From the above figure it's noted that the total harmonic current distortion decreases when the carrier frequency increases.

The second step in using PWM for reduction THDi shows the effect of the modulation index in PWM method on the total harmonic current distortion.

The following table shows the effect of the modulation index in PWM on the total harmonic current distortion.

Table 6.4:The effect of the modulation index of the PWM on the THDi

Modulation index	Carrier frequency	THD I%
0.1	800	185%
0.2	800	130%
0.3	800	86.6%
0.4	800	56.5%
0.5	800	23.6%
0.6	800	15.1%
0.7	800	9.6%
0.8	800	6.5%
0.9	800	4%

From the above table we noted that the total harmonic current distortion decreases from 185% to 4% when the modulation index increases from 0.1 to 0.9.

The following figure shows the effect of the modulation index of the PWM on the total harmonic current distortion.

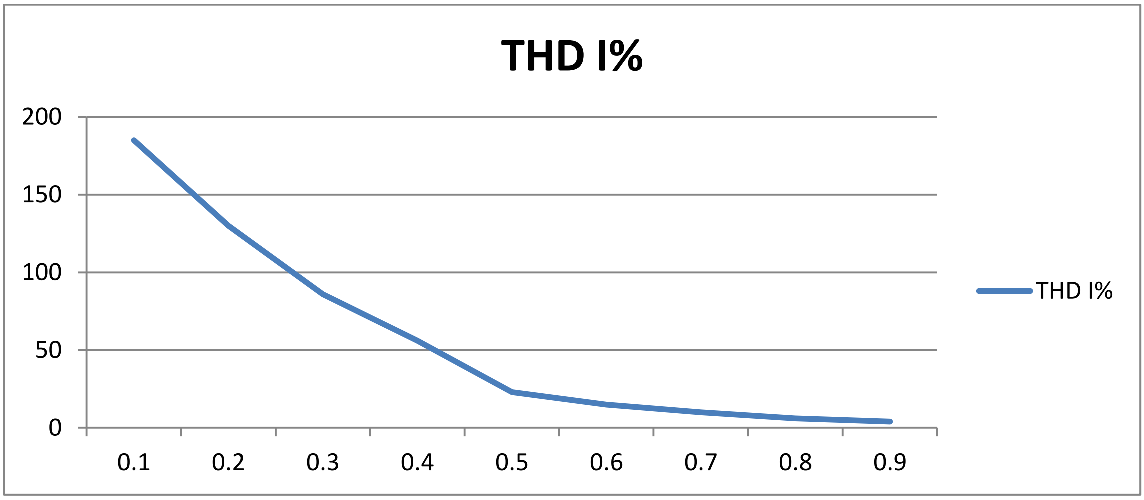


Figure 6.10: The effect of the modulation index that use in PWM on the total harmonic current distortion.

From the above figure it's noted that the total harmonic current distortion decreases when the modulation index increases.

6.4 Reduce Total Harmonic Distortion by using Shunt Active Filter:

This method use of the large scale use of the power electronics equipment has led to increase in harmonics in the power system. The nonlinear loads generate harmonic current which distorts the voltage waveform at PCC. These current harmonics will result in a power factor reduction, decrease in efficiency, power system voltage fluctuations and communications interference. So harmonics can be considered as a pollutant which pollutes the entire power system. Traditionally a bank of tuned LC filters was used as a solution for the problems caused by the system harmonics, since they are easy to design, have simple structure, low cost and high efficiency. Phase advances, synchronous capacitors, etc. were also employed for the power system quality enhancement. However, traditional controllers have many drawbacks. It provides only fixed compensation, generates resonance problems and is bulky in size. To overcome these disadvantages, active power filters are introduced which compensate for the current harmonics and reduces the total harmonic distortion.[19]

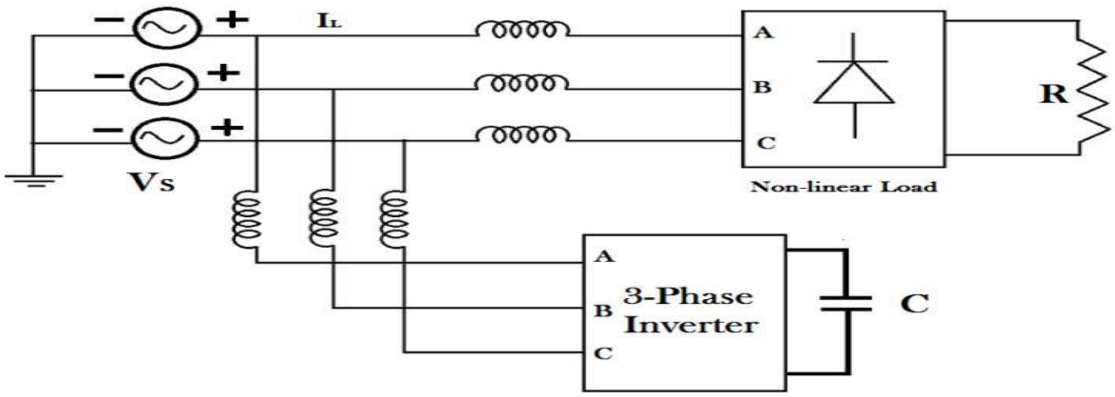


Figure 6.11: Three phase shunt active power filter. [19]

The following table shows the parameter that used in Simulink block diagram to see the effect of the non-linear load without using shunt active filter.

Table 6.5: Simulation Parameters.

Parameters	**Value**
Line inductance	1Mh
Filter inductance	1mH
DC link capacitor	1000µF
Load inductance	5mH
Load resistance	5Ω

The following figure shows the block diagram of the non-linear load without using a shunt active filter

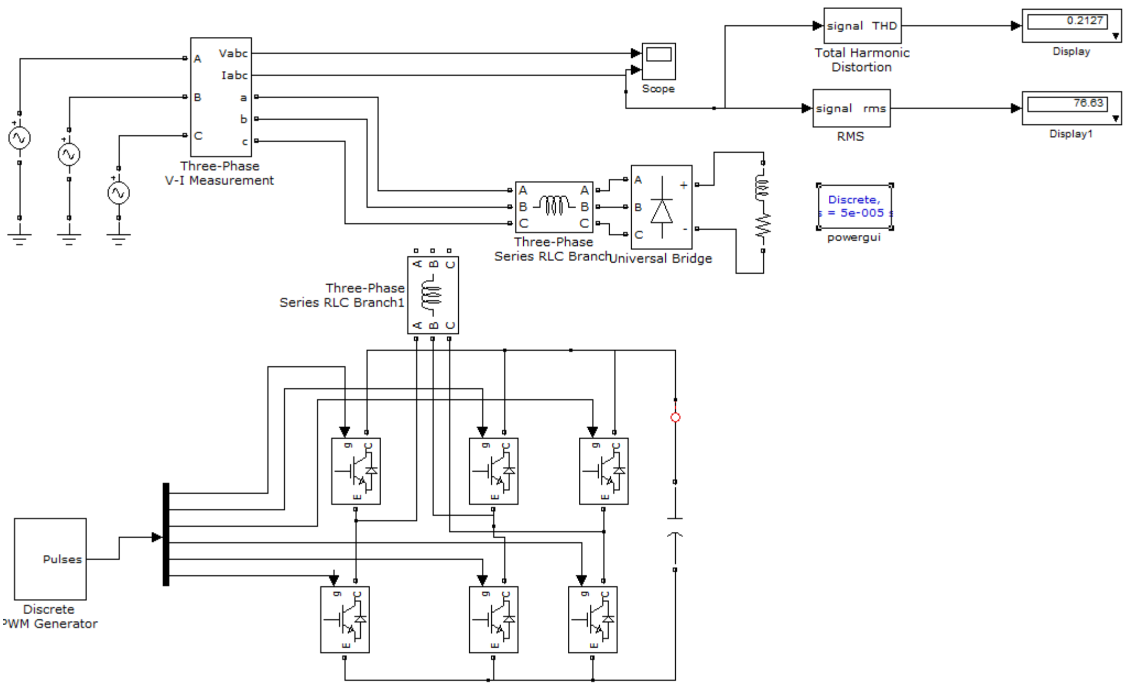
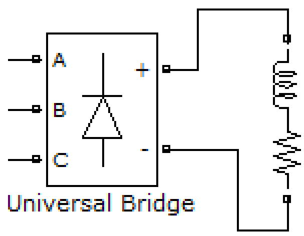
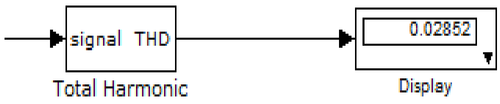


Figure 6.12: The block diagram of the non-linear load without using shunt active filter [19].

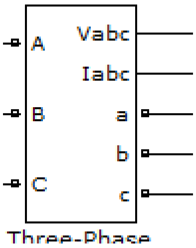
Where:



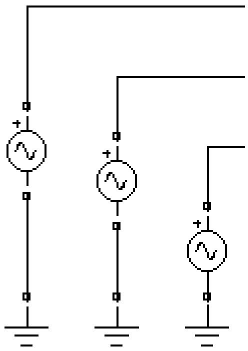
Represent non-linear load



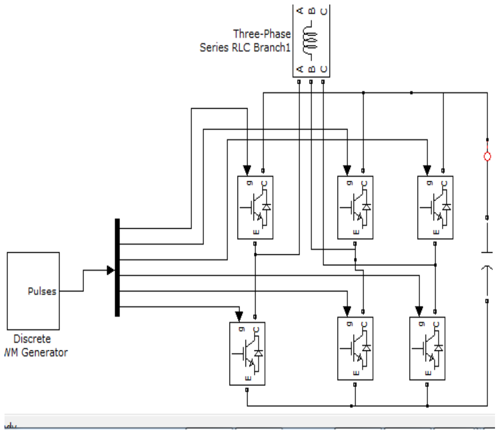
Total harmonic current distortion



Three phase current and voltage measurement



Three phase power supply



Shunt active filter

The following figure shows the output voltage and current for the non-linear load without using shunt active power filter.

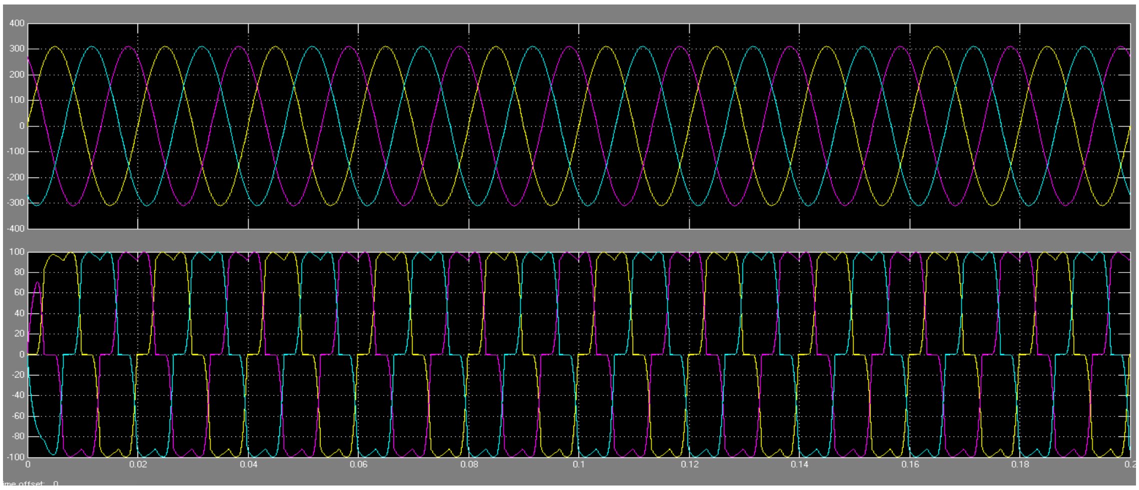


Figure 6.13: The voltage and wave current of non-linear load without using shunt active power filter.

From the above figure it's noted that the total harmonic current distortion measured without using shunt active filter equals 21%.

The following figure showing the block diagram for the non-linear load with using shunt active power filter

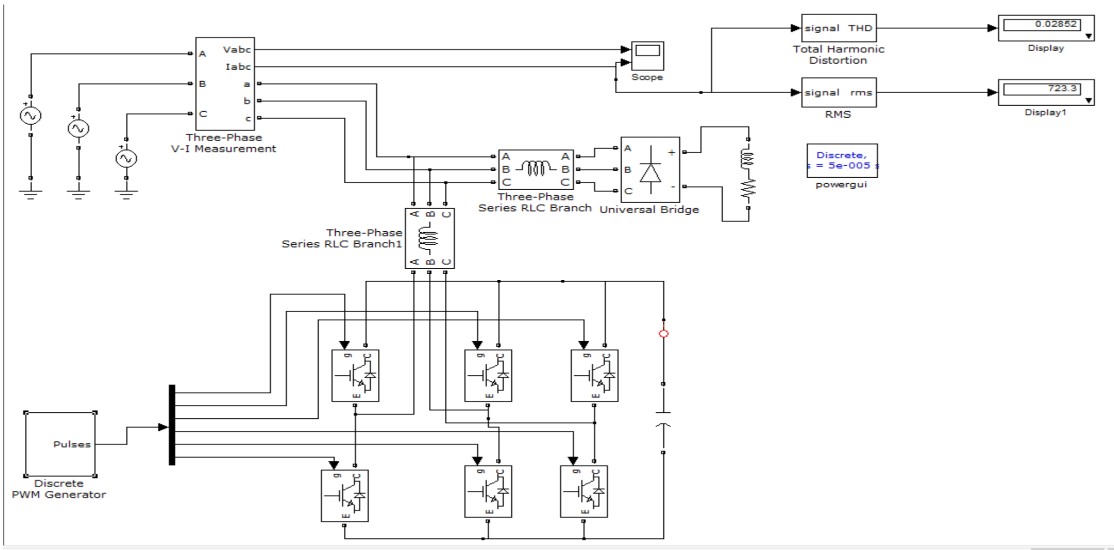


Figure 6.14: Simulink block diagram for the shunt active power filter [19].

The following table shows the harmonic current distortion for the non-linear load after using shunt active power filter.

Table 6.6: parameter using shunt active filter

Carrier frequency	500HZ
Modulation index	0.9
THD i%	2.8%
Line inductance	1mH
Filter inductance	1mH
DC link capacitor	1000μF
Load inductance	5mH
Load resistance	5Ω

From the above table it's noted that shunt active filter reduces the total harmonic current distortion from 21% to 2.8%.

Chapter Seven

The Environmental Impact Assessment for Reduction Total Harmonic Distortion

7.1 Introduction

7.2 The pollution produces due to coal combustion:

7.3 The coal combustion condition in Israel:

7.4 The coal and pollutant saving due to Reduce Total Harmonic Distortion at the college

Chapter Seven

The Environmental Impact Assessment for Reduction Total Harmonic Distortion

7.1 Introduction:

The losses produces from the harmonic distortion, low power factor and low load factor of transformer increases the energy losses, which increases the energy demand that led to more coal combustion to cover the energy losses, which produce more pollutants to the environment.

This chapter shows the effect of the electrical energy losses due to low power quality in the college on the environment and carbon dioxide emissions.

7.2 The pollution produces due to coal combustion:

Coal plants are the nation’s top source of carbon dioxide (CO_2) emissions, the primary cause of global warming. In 2011, utility coal plants in the United States emitted a total of 1.7 billion tons of CO21. A typical coal plant generates 3.5 million tons of CO_2 per year.

Burning coal is also a leading cause of smog, acid rain, and toxic air pollution. Some emissions can be significantly reduced with readily available pollution controls, but most U.S. coal plants have not installed these technologies.

Sulfur dioxide (SO_2): Coal plants are the United States' leading source of SO_2 pollution, which takes a major toll on public health, including by contributing to the formation of small acidic particulates that can penetrate into human lungs and be absorbed by the bloodstream. SO_2 also causes acid rain, which damages crops, forests, and soils, and acidifies lakes and streams. A typical uncontrolled coal plant emits 14,100 tons of SO_2 per year. A typical coal plant with emissions controls, including flue gas desulfurization (smokestack scrubbers), emits 7,000 tons of SO_2 per year.

Nitrogen oxides (NO_x): NO_x pollution causes ground level ozone, or smog, which can burn lung tissue, exacerbate asthma, and make people more susceptible to chronic respiratory diseases. A typical uncontrolled coal plant emits 10,300 tons of NO_x per year. A typical coal plant with emissions controls, including selective catalytic reduction technology, emits 3,300 tons of NO_x per year.

Particulate matter: Particulate matter (also referred to as soot or fly ash) can cause chronic bronchitis, aggravated asthma, and premature death, as well as haze obstructing visibility. A typical uncontrolled plan emits 500 tons of small airborne particles each year.

Mercury: Coal plants are responsible for more than half of the U.S. human-caused emissions of mercury, a toxic heavy metal that causes brain damage and heart problems. Just 1/70th of a teaspoon of mercury deposited on a 25-acre lake can make the fish unsafe to eat. A typical uncontrolled coal plants emits approximately 170 pounds of mercury each year. [20]

7.3 The coal combustion condition in Israel:

Due to the electricity that we use is generated from Israel, so that we based on the data that related to coal consumption, pollution from Israel studies.

In Israel the Fuel Oil and Coal Consumption for Electricity in Israel (1980-2001) (1000 Tons). [21]

The following figure shows the fuel oil and coal consumption that used in Israel to generate electricity

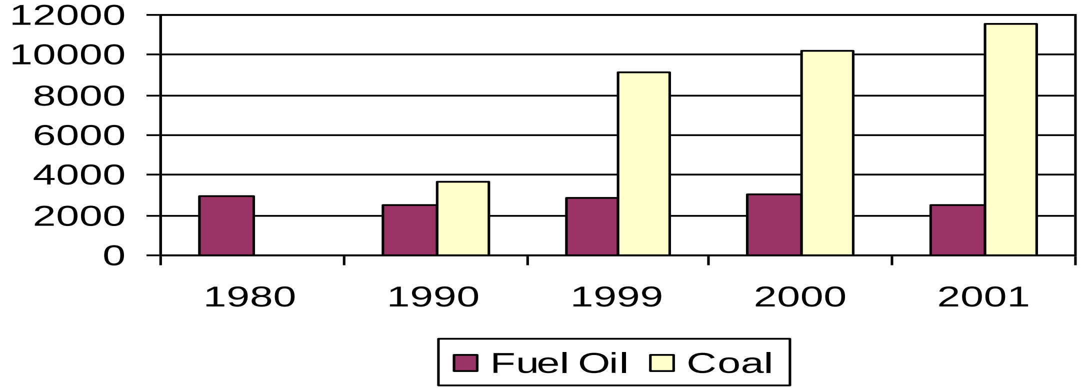


Figure 7.1: In Israel the Fuel Oil and Coal Consumption for Electricity in Israel (1980-2001) (1000 Tons).[21]

The following figure showing the Fuel Combustion Emissions in Israel by Fuel, 2002

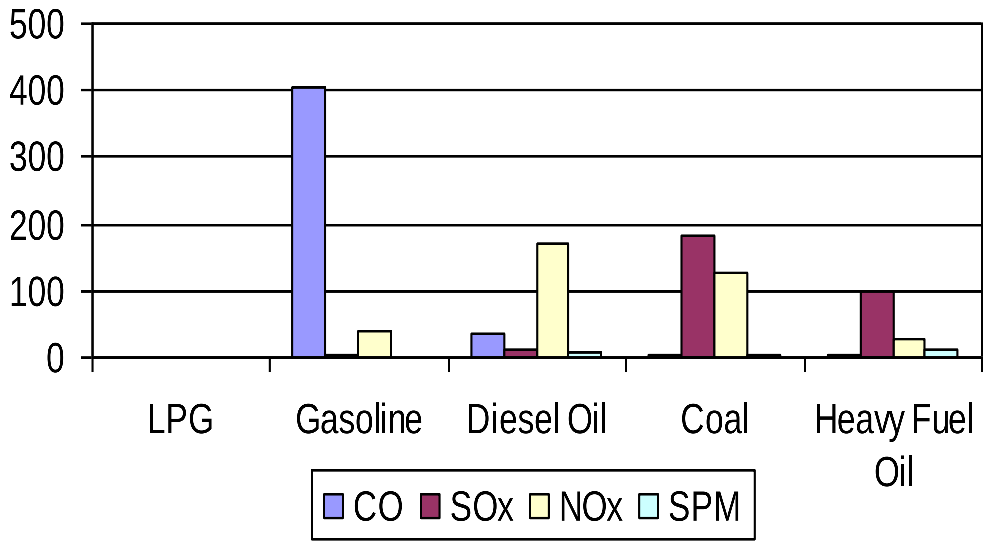


Figure 7.2: Fuel Combustion Emissions in Israel by Fuel, 2002 (1000 Tons) [22].

The following figure showing The Co2 pollutant that produces in Israel due to fuel combustion

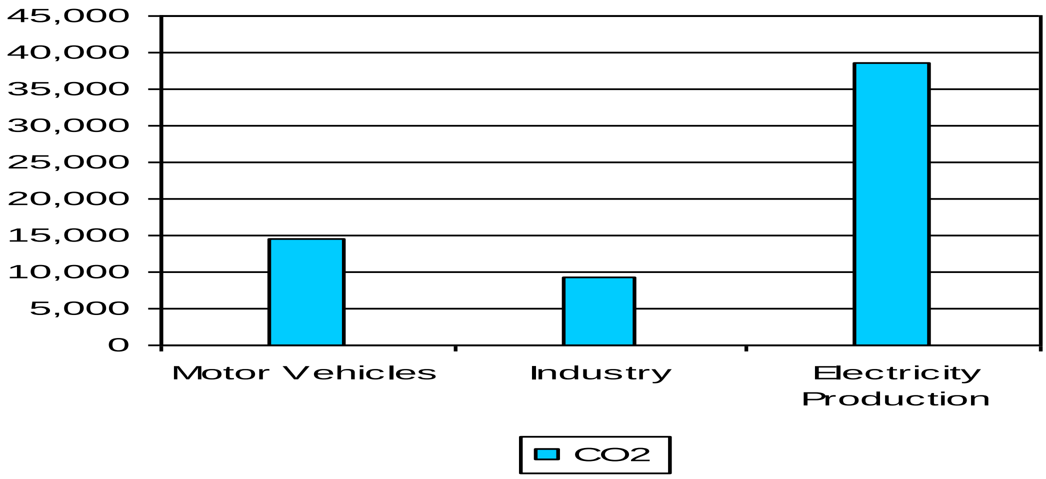


Figure 7.3: The Co2 pollutant that produce in Israel due to fuel combustion

Coal combustion in Israel has tripled since 1990. Almost all of coal use is for electricity production.

Coal combustion emissions in Israel:

1- 71% of total SO_2 emissions.

2- 62% of total CO_2 emissions.

3- 39% of total NOx emissions.

4- 38% of total SPM emissions.

5- 1% of total CO emissions. [23]

7.4 The coal and pollutant saving due to Reduce Total Harmonic Distortion at the college:

The amount of fuel used to generate electricity depends on the efficiency or heat rate of the generator (or power plant) and the heat content of the fuel. Power plant efficiencies (heat rates) vary by types of generators, power plant emission controls, and other factors. Fuel heat contents also vary.

Two formulas for calculating the amount of fuel used to generate a kilowatt-hour (kWh) of electricity:

Amount of fuel used per kWh = Heat rate (in Btu per Kwh) / Fuel heat content (in Btu per physical unit)

Kilo watt hour generated per unit of fuel used =

$$= \frac{\text{Fuel heat content (in Btu per physical unit)}}{\text{Heat rate (in Btu per Kwh)}} \ . \quad [24]$$

The price of one metric ton of coal is from 70 to80 $ per metric ton[25].

1,842 kWh per ton of Coal or 0.9 kWh per pound of Coal

Coal = 10,498 Btu/kWh

Pollutant produces from coal power plant that used to generate electricity;

0.95 kg CO_2 for Kwh [26].

To calculate the electrical energy losses due to low power quality at the college as the following:

Total electrical energy losses at the college = electrical energy losses due to low power factor + electrical energy losses due to harmonic distortion + electrical energy losses due to low load factor of the transformer=7910Kwh/year.

The following table shows the carbon dioxide that can be saving by improvement power quality at the college.

Table 7.1: The carbon dioxide emission saving by removes THD at the college.

Total energy saved per year	**Total coal saved per year**	**Total CO2 saved per year**
7910Kwh/year	4.3 tons of coal saved per year	7.5 tons per year

Chapter Eight

Discussion, Conclusion and Recommendation

8.1 Discussion and Conclusion:

8.2: Recommendation:

Chapter Eight

Discussion, Conclusion and Recommendation

8.1 **Discussion and Conclusion**:

THDi at the college changes during the day from (8%-24%) with average 12%, but the THDv changes during the day from (2-3%). The power factor is also changing during the day from (0.83 -0.94). The lowest reading of the power factor is (P. F=0. 83), and the highest value of the (THDi=24%) that recorded at night because the most load use in the night are discharging lamps which have high harmonic distortion and low power factor. We found that the electrical energy saving by improving the power factor from (0.89 to 0.98) equals 122 kWh/year this amount will be save if we installed variable capacitor bank with Qc=25KVAR.

THDi affecting on the power factor we noted that when the THDi increases the power factor decreases.

The THDi Level effects on the electrical losses as electrical losses in transformer and cables. We found that the electrical energy losses due to THDi increase the electrical energy losses in transformer by 74KWh/year, and increase the electrical energy losses in the cables by 68KWh / year.

The low load factor of the transformer affecting on the electrical losses of the transformer because low load factor means lower efficiency.

We found that the electrical energy losses due to low load factors of the transformer at the college equals 7230KWh/year.

The THDi effects on the useful capacity of the transformer it decreases the useful capacity of the transformer when the THD increases.

We found that the exist condition of the harmonic current and voltage distortion reduce the transformer useful capacity from 1000KVA to 887KVA.

The load factor of the transformer affecting on the THDi we found that when the load factor of the transformer increases the THDi decreases as the following when the transformer load factor at the college increase from (10% -100%), the THDi decrease from (15%-5%).

We noted that the standby diesel generator size is small to cover the loads at the college it only 130KVA.

We use modeling to reduce THDi at the college by using the MATLAB / SIMULINK program. The first one its PWM ‘pulse width modulation’, we found that the THDi decreases from (26%-3.7%) when the carrier frequency increase from (50-2000Hz), also we found that, the THDi decreases from (185%-4%) when the modulation index increase from (0.1-0.9).

Second one it’s by using passive filter which reduces THDi from (30%-3.6%). The third one it’s by using shunt active filter which reduces THDi from (21%-2.8%).

The electrical energy losses due to low power quality increase the environmental impact, because additional losses mean more coal combustion on power plant which increases the pollutant emission.

We noted that the electrical energy saving by improving low power quality at the college equal to 7900KWh/year will save 4.3 tons of coal per year, 7.5 tons of carbon dioxide per year.

8.2: Recommendation:

From this thesis at the college we provide some recommendation:

1- Change the type of lamps or Installing capacitors with discharging lamps to improve losses, low power factor and high harmonic distortion in the night.

2- Establish standard for harmonic distortion in Palestine.

3- Increase the awareness of the people about the power quality.

4- Using shunt active filters to reduce the THDi to be under the standard limit.

5- We noted that, the losses produce by THD is still small in our case study due to low load, we recommend to make another study at substations to show the THD at that location, and improve THD at that location, which improve the power quality of the power system, make a huge energy conservation in the cables and transformers, and increase the capacity of cables and transformer.

6- Replace the transformer with large capacity and low load factor to another suitable size transformer 400KVA to reduce the transformer losses due to the low load factor.

7- Improve the low power factor at the college by using a variable capacitor bank with QC =25KVAR.

8- Replacement the small size standby diesel generator with another one 400kVA.

References

[1] Ruger C. Dugan. **Electrical Power System Quality**. Second edition.

[2] S. Chattopadhyay et al. **Electric Power Quality, Power Systems**,

[3] K. R. Govindan Kavoori consultants**. POWER FACTOR IMPROVEMENT**

[4] Nikunj Shah. **Harmonics in power systems Causes, effects and control**. Siemens Industry.

[5] Wagner, V.E et al. "***Effects of harmonics on equipment***", Power Delivery, **IEEE Transactions** on Volume 8, Issue 2, Apr 1993 Page(s):672 – 680.

[6] vk mehta ,rohit mehta ,Principles of power system

[8] https://www.youtube.com/watch?v=9UqvXuKtpCo

[9] https://www.youtube.com/watch?v=dnlywfOktJE

[10] Makarov, S.N. and A.E. Emanuel, 2000. ***Corrected Harmonic Loss Factor For Transformers supplying Non-sinusoidal Load current***. In the Proceedings of IEEE 9th International conference on **Harmonics and Power Quality**, vol. 1, Oct.2000, pp.87-90.

[11] Version 2 EE IIT, Kharagpur, Wye (Y) - Delta (Δ) OR Delta (Δ)-Wye (Y) Transformations

[12] IEEE Standard C57.110-1998. ***IEEE Recommended Practice for Establishing Transformer Capability when Supplying Non-sinusoidal Load Currents***. **IEEE Standards**.

[13] Sadati, S.B., A. Tahani, B. Darvishi, M. Dargahi and H. Yousefi, 2008. ***Comparison of Distribution Transformer Losses and Capacity under Linear and Harmonic Loads***. In the proceedings of the **IEEE 2nd International Power and Energy Conference**, 2008, PP: 1265-1269.

[15] W. Z. Gandhare1, K. D. Patil2. **Effects of Harmonics on Power Loss in XLPE Cables.**

[16] Kenneth Duane Harden, OPTIMIZING ENERGY EFFICIENCY STANDARDS FOR LOW VOLTAGE DISTRIBUTION TRANSFORMERS

[17] Kuldeep Kumar Srivastava, Saquib Shakil, Anand Vardhan Pandey. ***Harmonics & Its Mitigation Technique by Passive Shunt Filter***, **International Journal of Soft Computing and Engineering** (IJSCE) ISSN: 2231-2307, Volume-3, Issue-2, May 2013

[18] S. Jeevananthan1 , R. Nandhakumar1 , P. **Dananjayan Inverted Sine Carrier for Fundamental Fortification in PWM Inverters and FPGA Based Implementations.**

[19] Radmehr, M.; Farhangi, S.; Nasiri, A. (2006). **Effect of Power Quality Distortion on Electrical Drives and Transformer Life** in Paper Industries: Simulation and Real Time.

[20] A Girgis, E. Makram, J. Nims. ***Evaluation of temperature rise of distribution transformer in the presence of harmonic distortion***. **Electric Power Systems Research**, vol. 20, no.1, Jan 1990, pp.15-22.

[19] Rejil C1, AnzariM2 and Arun Kumar R3. ***Design and Simulation of Three Phase Shunt Active Power Filter Using SRF Theory***. 2,3 **School of Electrical Engineering**, VIT University Chennai Campus

[20] Nescaum. "**Control Technologies to Reduce Conventional and Hazardous Air Pollutants from Coal-Fired Power Plants.**" March 31, 2011.

[21] Israeli CBS, 2001

[22] Israeli Central Bureau Statistics (CBS), 2002

[23] Israel Central Bureau of Statistics, Shanton 54, 2003 (http://www.cbs.gov.il).

[24] http://www.eia.gov/tools/faqs/faq.cfm?id=667&t=2

[25] http://www.answers.com/Q/How_much_CO2_is_produced_from_burning_coal

[26] http://www.infomine.com/investment/metal-prices/coal/5-year/

APPENDICES

Appendix (A): the resistance of the copper cable various cross sectional area of the cable

Appendix (B): some current reading for the distribution board in Hisham Hijjawi College.

Appendix (C): some reading of the energy analyzer in Hisham Hijjawi College

Appendix (A) :the resistance of the copper cable various cross sectional area of the cable

5 CURRENT CARRYING CAPACITY

Table 18 : Single core cables with conductors PVC 70 °C insulated and PVC Sheathed. 0.6/1 KV

Conductor	Conductor Resistance			Current Carrying Capacity					
				In Ground			In Air		
Cross Sectional Area mm²	DC at 20°C Maximum ohm/km	AC at 70°C in Flat Formation Approx ohm/km	AC at 70°C in Trefoil Formation Approx ohm/km	Direct Laid (Flat) Approx Amps	Direct Laid (Trefoil) Approx Amps	In Duct Approx Amps	Free (Flat) Approx Amps	Free (Trefoil) Approx Amps	In Pipes Approx Amps
1.5	12.1	14.5	14.5	25	24	18	20	18	15
2.5	7.41	8.87	8.87	33	31	24	27	23	19
4	4.61	5.52	5.52	42	41	31	36	31	25
6	3.08	3.69	3.69	53	51	39	46	40	32
10	1.83	2.19	2.19	70	68	52	62	54	43
16	1.15	1.38	1.38	91	87	67	83	71	56
25	0.727	0.870	0.870	116	112	87	109	94	73
35	0.524	0.627	0.627	140	134	104	135	116	89
50	0.387	0.463	0.464	166	158	125	164	141	107
70	0.268	0.321	0.322	204	194	154	208	179	134
95	0.193	0.232	0.232	245	233	186	259	222	163
120	0.153	0.184	0.185	279	264	212	301	258	188
150	0.124	0.150	0.151	313	296	238	345	296	213
185	0.0991	0.1200	0.1215	354	334	270	399	343	243
240	0.0754	0.0922	0.0941	412	385	313	476	407	285
300	0.0601	0.0743	0.0767	466	433	353	551	469	324

Appendix (B): some current reading for the distribution board in Hisham Hijjawi College.

Time	DB	Phase1(A)	Phase2(A)	Phase3(A)	Neutral(A)
Time Tuesday 11/11/2014 9:30 AM	Q1	12.8	44	30	16
	Q2	17.6	16.2	16.4	4
	Q3	61	44	64	21
	Q4	3.5	2	2	1.3
	Q5	7	14	5	3
	Q6	3	1	1.5	2
	Q7	63	46	49	20
Time Tuesday 11/11/2014 11:00 AM	Q1	12.6	24	15	7
	Q2	6.5	10	8.4	3.6
	Q3	38	40	33	15.6
	Q4	3.2	2	2	1
	Q5	8	4	2	2.5
	Q6	.5	0.6	0.7	0.5
	Q7	52	48	35	28
Time Wednesday 12/11/2014 9:30 AM	Q1	24	40	33	12
	Q2	22	21	26	11
	Q3	53	55	47	21
	Q4	3	2	2	1
	Q5	6	7	6	4
	Q6	8	1	1	2
	Q7	62	56	53	25
Time Wednesday 12/11/2014 10:00 AM	Q1	25	47	34	13
	Q2	27	27	20	7
	Q3	53	59	45	20
	Q4	3	2	2	1
	Q5	2	18	6	13
	Q6	0.9	0.4	0	0.5
	Q7	49	61	55	33
Time Wednesday 12/11/2014 10:30 AM	Q1	26	46	35	14
	Q2	18	24	23	10
	Q3	55	68	52	20
	Q4	3	2	2	2
	Q5	2	15	6	10
	Q6	2	0.1	0.1	0.4
	Q7	58	75	56	34
Time Wednesday 12/11/2014 11:00 AM	Q1	23	45	34	13
	Q2	31	25	18	8
	Q3	66	61	47	13
	Q4	3	9	2	2
	Q5	3	4	2	3
	Q6	0.4	0	0	0.4
	Q7	58	68	53	21

Time Wednesday 12/11/2014 11:30 AM	DB	Phase1(A)	Phase2(A)	Phase3(A)	Neutral(A)
	Q1	24	44	35	10
	Q2	31	22	14	15
	Q3	65	50	49	23
	Q4	3	2	2	1
	Q5	7	9	8	3
	Q6	0.4	0	0	0.4
	Q7	64	38	44	25
Time Wednesday 12/11/2014 12:00 AM	Q1	24	38	36	8
	Q2	33	19	17	19
	Q3	75	47	46	23
	Q4	3	2	2	1
	Q5	2	5	3	3
	Q6	0.4	0.2	0	0.5
	Q7	55	54	46	24
Time Wednesday 12/11/2014 12:30 AM	Q1	22	50	29	15
	Q2	35	23	25	21
	Q3	56	49	54	21
	Q4	3	2	2	1
	Q5	2	5	7	6
	Q6	0.7	0.3	0	0.8
	Q7	53	65	52	29
Time Wednesday 12/11/2014 13:00 AM	Q1	21	42	28	13
	Q2	30	21	27	5

	Q3	56	57	51	18
	Q4	3.2	0.5	0.5	2.3
	Q5	2.3	3.2	5.3	5
	Q6	0.7	0.2	0.1	0.7
	Q7	39	54	37	33
Time Wednesday 12/11/2014 13:30 AM	Q1	22	44	31	11
	Q2	23	17	21	4
	Q3	49	50	47	17
	Q4	3	0.5	0.1	2.3
	Q5	1.4	3.5	4	3.8
	Q6	0.8	0.1	0.3	0.4
	Q7	38	40	38	18
Time Wednesday 12/11/2014 14:00 AM	Q1	26	40	27	10
	Q2	13	16	18	8
	Q3	52	57	46	16
	Q4	3	0.4	0.1	2
	Q5	0.9	3	2	2
	Q6	0.6	0.1	0.3	0.4
	Q7	39	35	40	14

Appendix (C): some reading of the energy analyzer in Hisham Hijjawi College

Date	Time	Ave Freq	AveUrms1	AveUrms2	AveUrms3	AveIrms1	AveIrms2	AveIrms3	AveIrms4
27/10/2014	10:40:00	50	224	223	224	166	205	167	60
27/10/2014	10:50:00	50	223	223	223	168	213	182	57
27/10/2014	11:00:00	50	223	222	223	153	211	176	64
27/10/2014	11:10:00	50	225	225	225	150	220	181	73
27/10/2014	11:20:00	50	224	224	224	148	219	178	75
27/10/2014	11:30:00	50	225	224	225	147	232	180	83
27/10/2014	11:40:00	50	224	223	224	149	232	179	83
27/10/2014	11:50:00	50	224	223	223	167	239	196	75
27/10/2014	12:00:00	50	224	224	224	159	214	179	65
27/10/2014	12:10:00	50	224	223	224	136	204	176	67
27/10/2014	12:20:00	50	224	223	223	136	211	178	70
27/10/2014	12:30:00	50	223	223	223	144	211	181	63
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AveP1	AveP2	AveP3	AvePsum	AveS1	AveS2	AveS3	AveSsum
35,550	42,730	35,900	114,200	37,150	45,790	37,520	120,500
36,010	43,790	39,180	119,000	37,610	47,330	40,740	125,700
32,800	44,110	37,990	114,900	34,100	46,920	39,360	120,400
32,450	46,620	39,150	118,200	33,670	49,390	40,680	123,700
31,870	46,210	38,090	116,200	33,110	49,060	39,840	122,000
31,580	49,000	38,670	119,300	33,040	51,910	40,480	125,400
31,810	48,650	38,220	118,700	33,280	51,870	40,130	125,300
35,870	50,480	41,820	128,200	37,310	53,200	43,790	134,300
34,600	45,460	38,310	118,400	35,750	47,880	40,060	123,700
29,500	43,080	37,630	110,200	30,470	45,570	39,250	115,300
29,230	44,250	37,950	111,400	30,410	46,900	39,650	117,000
30,850	44,290	38,840	114,000	32,050	46,880	40,410	119,300
30,470	41,360	37,070	108,900	31,540	43,940	38,760	114,200
30,460	42,170	37,340	110,000	31,420	44,720	39,280	115,400
33,360	42,730	39,240	115,300	34,270	45,270	41,010	120,500
34,920	44,750	42,280	122,000	36,240	47,580	44,010	127,800
34,600	45,910	36,330	116,800	36,070	48,370	38,050	122,500
33,880	44,360	33,650	111,900	35,460	47,050	35,390	117,900

31,710	44,110	35,150	111,000	33,110	46,780	36,830	116,700
33,620	45,510	36,180	115,300	35,190	48,170	37,840	121,200
34,790	44,450	35,110	114,400	36,290	46,720	36,560	119,600
36,660	45,580	36,360	118,600	38,400	47,990	37,890	124,300
34,980	46,740	35,230	117,000	37,040	50,150	37,010	124,200
34,750	47,250	35,650	117,700	37,040	50,850	37,720	125,600
33,480	44,680	32,260	110,400	35,510	48,080	34,090	117,700
31,800	43,420	30,510	105,700	33,580	46,670	32,120	112,400
30,440	41,710	29,710	101,900	31,980	44,690	31,190	107,900
30,330	37,690	32,480	100,500	32,030	40,430	34,680	107,100
31,330	36,910	35,330	103,600	33,270	39,580	37,370	110,200
29,500	36,250	34,830	100,600	31,170	38,840	36,570	106,600
30,630	35,700	33,870	100,200	32,440	38,240	35,520	106,200
29,260	35,060	33,420	97,700	31,100	37,590	35,490	104,200
29,220	32,820	31,690	93,700	31,050	34,890	33,070	99,000
30,320	32,240	31,630	94,200	32,200	34,140	32,790	99,100
26,760	29,730	30,420	86,900	28,360	31,150	31,440	91,000
25,410	26,670	25,880	78,000	26,810	28,120	26,810	81,700
20,800	22,720	20,370	63,900	22,050	23,760	21,180	67,000
18,530	19,110	18,720	56,400	19,520	19,920	19,520	59,000
18,350	19,670	18,170	56,200	19,270	20,840	19,190	59,300
17,530	17,490	15,490	50,500	18,360	18,610	16,300	53,300
18,230	18,240	16,880	53,400	19,440	19,660	17,760	56,900
15,950	17,840	15,090	48,900	17,000	18,950	15,830	51,800
15,610	16,890	15,650	48,200	16,590	17,550	16,320	50,500
15,640	16,200	12,920	44,800	16,560	16,720	13,320	46,600
14,970	15,480	11,750	42,200	15,980	16,200	12,090	44,300
16,330	16,650	11,390	44,400	18,440	18,330	11,820	48,600
19,010	19,020	12,930	51,000	21,060	21,290	13,380	55,700
18,860	18,990	13,250	51,100	20,770	21,250	13,720	55,700
19,630	18,480	12,740	50,800	21,360	20,960	13,210	55,500
17,470	17,730	11,470	46,700	19,140	20,030	11,820	51,000
16,850	17,480	11,360	45,700	18,540	19,800	11,690	50,000
17,030	17,150	11,130	45,300	18,790	19,510	11,490	49,800
13,480	14,160	7,910	35,500	14,920	16,990	8,220	40,100
8,510	10,590	4,600	23,700	9,590	13,710	4,870	28,200
8,330	10,250	4,290	22,900	9,290	13,190	4,460	26,900
8,170	10,240	4,910	23,300	9,140	13,180	5,070	27,400
8,200	10,760	5,240	24,200	9,190	14,020	5,380	28,600
8,640	11,240	4,700	24,600	9,700	14,580	4,950	29,200
8,590	10,970	4,590	24,100	9,740	14,350	4,900	29,000
8,310	10,750	4,340	23,400	9,330	14,020	4,510	27,900
9,510	10,900	4,410	24,800	10,440	14,240	4,600	29,300
8,300	10,700	4,300	23,300	9,300	13,860	4,470	27,600
8,700	11,050	4,740	24,500	9,760	14,310	4,970	29,000

8,550	10,970	4,620	24,100	9,700	14,400	4,880	29,000
8,350	10,820	4,360	23,500	9,380	14,050	4,540	28,000
8,300	10,900	4,360	23,600	9,320	14,280	4,520	28,100
8,310	10,660	4,350	23,300	9,330	13,910	4,520	27,800
8,690	11,130	4,720	24,500	9,780	14,450	4,940	29,200
8,680	10,990	4,700	24,400	9,830	14,410	4,980	29,200
8,440	10,860	4,950	24,200	9,500	14,060	5,100	28,700
8,340	10,890	5,270	24,500	9,400	14,160	5,430	29,000
8,290	10,810	4,360	23,500	9,330	14,110	4,530	28,000
8,480	10,830	4,560	23,900	9,520	14,060	4,770	28,400
8,620	10,880	4,700	24,200	9,780	14,360	5,000	29,100
8,220	10,960	4,310	23,500	9,240	14,410	4,470	28,100
8,260	10,880	4,330	23,500	9,280	14,240	4,500	28,000
8,100	10,510	4,280	22,900	9,060	13,700	4,430	27,200
8,250	10,490	4,380	23,100	9,270	13,690	4,560	27,500
8,830	11,050	4,960	24,800	10,010	14,520	5,260	29,800
8,260	10,520	4,330	23,100	9,290	13,740	4,490	27,500
8,220	10,600	4,340	23,200	9,230	13,980	4,500	27,700
8,270	10,600	4,360	23,200	9,300	13,990	4,530	27,800
8,340	10,510	4,750	23,600	9,400	13,810	4,910	28,100
9,090	11,430	6,260	26,800	10,380	15,170	6,540	32,100
8,290	10,580	4,370	23,200	9,310	13,950	4,530	27,800
8,310	10,670	4,330	23,300	9,360	14,110	4,490	28,000
8,320	10,640	4,340	23,300	9,370	14,060	4,500	27,900
8,320	10,660	4,360	23,300	9,350	14,060	4,520	27,900
9,060	11,070	5,040	25,200	10,340	14,590	5,420	30,400
8,300	10,230	4,370	22,900	9,340	13,340	4,540	27,200
8,330	10,190	4,390	22,900	9,380	13,300	4,570	27,200
8,120	10,250	4,400	22,800	9,070	13,270	4,570	26,900
8,250	10,110	4,420	22,800	9,250	13,180	4,610	27,000
8,890	10,880	5,120	24,900	10,070	14,340	5,490	29,900
8,230	10,490	4,430	23,100	9,200	13,840	4,620	27,700
8,270	10,670	4,470	23,400	9,270	14,050	4,660	28,000
8,210	10,250	5,330	23,800	9,180	13,390	5,480	28,100
8,020	10,370	4,930	23,300	8,930	13,540	5,090	27,600
8,800	10,500	5,030	24,300	9,950	13,620	5,370	28,900
8,100	10,060	4,320	22,500	9,040	13,000	4,500	26,500
7,950	10,060	4,280	22,300	8,840	13,020	4,450	26,300
8,020	10,280	4,320	22,600	8,940	13,220	4,500	26,700
7,950	10,350	4,320	22,600	8,840	13,390	4,500	26,700
8,700	10,780	5,030	24,500	9,820	14,050	5,400	29,300
7,980	10,480	4,330	22,800	8,890	13,570	4,510	27,000
7,950	10,230	4,330	22,500	8,840	13,340	4,510	26,700
8,030	10,330	4,340	22,700	8,960	13,390	4,520	26,900
7,980	10,340	4,340	22,700	8,890	13,380	4,520	26,800

8,700	10,800	5,030	24,500	9,820	14,060	5,380	29,300
8,010	10,380	4,480	22,900	8,920	13,540	4,660	27,100
7,990	10,430	5,670	24,100	8,900	13,480	5,810	28,200
7,930	10,190	4,270	22,400	8,810	13,240	4,440	26,500
7,920	10,060	4,270	22,200	8,810	12,980	4,440	26,200
8,610	10,750	4,970	24,300	9,700	13,910	5,300	28,900
7,970	10,020	4,360	22,400	8,860	12,880	4,550	26,300
7,970	9,800	4,310	22,100	8,870	12,500	4,490	25,900
7,900	10,330	4,310	22,500	8,760	13,280	4,490	26,500
7,940	10,080	4,310	22,300	8,830	12,990	4,480	26,300
8,600	10,760	5,010	24,400	9,650	14,020	5,380	29,100
7,830	10,040	4,280	22,200	8,690	13,010	4,450	26,100
7,880	10,040	4,280	22,200	8,750	12,970	4,460	26,200
7,680	9,910	4,290	21,900	8,490	12,810	4,460	25,800
6,590	9,710	4,320	20,600	7,050	12,510	4,540	24,100
4,520	6,570	5,040	16,100	4,690	7,320	5,350	17,400
6,710	5,520	6,780	19,000	6,770	5,970	7,030	19,800
6,720	5,430	6,090	18,200	6,770	5,850	6,370	19,000
7,380	5,030	5,890	18,300	7,440	5,280	6,120	18,800
8,170	6,130	6,790	21,100	8,310	6,430	7,080	21,800
16,990	14,930	12,510	44,400	17,770	15,400	13,100	46,300
18,170	16,890	14,940	50,000	18,690	17,160	15,260	51,100
14,810	15,080	12,620	42,500	15,390	15,420	13,000	43,800
17,160	19,540	14,770	51,500	17,740	20,410	15,160	53,300
18,230	22,230	15,340	55,800	18,780	23,350	15,750	57,900
22,880	24,520	18,890	66,300	23,620	25,920	19,410	69,000
23,970	21,400	19,330	64,700	24,710	22,930	19,980	67,600
31,380	30,050	29,480	90,900	32,350	32,300	30,920	95,600
36,500	45,310	41,450	123,300	37,850	48,380	43,640	129,900
32,350	44,510	40,990	117,800	33,780	47,780	43,150	124,700
31,290	42,330	38,950	112,600	32,830	45,730	41,360	119,900
32,150	44,110	39,290	115,500	33,840	47,900	41,850	123,600
32,050	45,720	37,210	115,000	33,750	48,930	39,590	122,300
36,010	49,330	39,640	125,000	38,350	52,550	42,220	133,100
35,710	48,170	40,000	123,900	37,770	51,650	42,460	131,900
36,910	44,680	39,180	120,800	38,910	48,620	41,880	129,400
38,140	44,630	36,380	119,100	40,270	48,940	39,130	128,300
37,840	44,980	36,340	119,200	39,660	48,910	39,140	127,700
35,740	42,670	34,230	112,600	37,810	46,670	36,840	121,300
39,410	46,530	39,120	125,100	41,170	50,030	40,990	132,200
39,260	47,700	39,980	126,900	41,330	51,390	42,340	135,100
35,740	45,860	38,270	119,900	38,020	49,600	40,920	128,500
35,130	46,110	39,090	120,300	37,500	50,150	41,980	129,600
36,020	46,490	38,720	121,200	38,220	50,540	41,510	130,300
37,660	44,440	36,630	118,700	39,350	47,200	38,330	124,900

34,740	41,380	37,130	113,200	36,370	44,430	38,910	119,700
33,860	44,020	40,470	118,400	35,520	47,020	42,970	125,500
38,600	43,950	41,330	123,900	40,520	46,770	43,890	131,200
35,710	42,200	39,160	117,100	37,250	44,970	41,910	124,100
32,850	40,680	35,560	109,100	34,810	44,300	38,640	117,700
35,180	40,640	34,750	110,600	36,810	43,330	36,850	117,000
34,250	39,280	32,940	106,500	35,940	42,020	35,130	113,100
32,330	37,470	32,630	102,400	33,890	39,970	34,640	108,500
31,460	37,950	32,430	101,800	32,860	40,620	34,300	107,800
30,270	34,300	31,330	95,900	31,450	36,630	33,010	101,100
29,030	32,400	32,470	93,900	30,080	34,420	34,350	98,800
29,390	34,470	32,270	96,100	30,470	36,650	34,100	101,200
31,840	36,860	36,250	104,900	32,940	38,560	38,500	110,000
33,460	38,440	40,910	112,800	34,840	40,460	43,330	118,600
30,120	36,870	39,380	106,400	31,430	38,710	41,880	112,000
30,400	37,310	38,840	106,500	31,770	39,600	41,190	112,600
30,370	38,940	37,340	106,600	31,740	41,500	39,270	112,500
32,000	37,980	36,290	106,300	33,410	40,260	38,070	111,700
29,750	36,540	35,680	102,000	31,200	38,580	37,260	107,000
31,420	37,140	38,740	107,300	33,120	39,580	40,900	113,600
30,790	37,880	36,130	104,800	32,450	40,350	38,390	111,200
30,250	33,580	35,310	99,200	31,810	35,900	37,810	105,500
26,690	33,930	34,560	95,200	27,930	36,230	36,930	101,100
26,400	31,270	31,040	88,700	27,720	33,460	33,270	94,400
25,740	29,230	31,590	86,600	27,020	31,130	33,890	92,000
24,500	26,680	32,150	83,300	25,630	28,430	34,700	88,800
22,560	23,770	29,870	76,200	23,740	25,190	32,320	81,200
18,540	22,320	28,280	69,100	19,600	23,820	30,310	73,700
16,530	18,750	22,100	57,400	17,470	20,080	23,260	60,800
16,080	16,720	21,120	53,900	16,920	17,930	22,240	57,100
16,090	16,580	21,480	54,100	17,020	17,770	22,890	57,700
17,230	17,420	21,860	56,500	18,380	18,840	23,360	60,600
15,820	16,420	20,350	52,600	16,810	17,740	21,760	56,300
15,910	16,340	18,940	51,200	16,970	17,680	20,160	54,800
15,400	16,790	17,420	49,600	16,400	18,110	18,380	52,900
15,350	16,980	17,090	49,400	16,290	18,220	17,890	52,400
17,600	18,020	19,010	54,600	19,460	20,880	19,960	60,300
18,830	19,350	16,130	54,300	20,360	22,590	16,740	59,700
18,600	17,480	15,690	51,800	19,950	20,200	16,240	56,400
16,300	16,580	14,290	47,200	17,640	19,190	14,760	51,600
17,510	17,970	14,580	50,100	19,310	20,580	15,110	55,000
17,390	17,510	14,280	49,200	19,330	20,190	14,770	54,300
17,380	17,140	14,190	48,700	19,290	19,750	14,680	53,700
17,730	16,690	14,280	48,700	19,740	19,340	14,790	53,900
18,530	17,060	15,050	50,600	20,750	19,940	15,700	56,400

17,840	16,470	14,340	48,700	19,910	19,210	14,860	54,000
17,710	16,420	13,630	47,800	19,690	19,230	14,110	53,000
11,860	11,770	6,930	30,600	13,220	14,910	7,230	35,400
8,950	9,970	4,650	23,600	10,020	13,210	4,890	28,100
8,830	10,080	4,660	23,600	9,870	13,370	4,880	28,100
8,760	9,570	4,940	23,300	9,800	12,630	5,160	27,600
8,750	9,520	5,790	24,100	9,790	12,560	5,970	28,300
8,850	9,800	4,670	23,300	9,920	12,990	4,900	27,800
9,550	10,810	5,320	25,700	10,810	14,530	5,710	31,000
8,840	10,010	4,750	23,600	9,980	13,380	5,010	28,400
8,800	10,020	4,720	23,500	9,930	13,400	4,950	28,300
8,930	10,160	4,780	23,900	10,100	13,570	5,030	28,700
8,920	10,210	4,750	23,900	10,100	13,730	4,990	28,800
8,940	10,210	4,770	23,900	10,110	13,700	5,030	28,800
9,000	10,170	4,790	24,000	10,190	13,650	5,030	28,900
8,940	10,160	4,750	23,900	10,110	13,630	4,990	28,700
9,650	10,130	4,740	24,500	10,750	13,600	4,970	29,300
8,900	10,110	4,760	23,800	10,050	13,570	5,010	28,600
9,710	10,690	5,470	25,900	11,120	14,390	5,920	31,400
9,040	10,150	4,770	24,000	10,250	13,740	5,030	29,000
8,870	10,140	4,750	23,800	10,020	13,680	4,980	28,700
8,970	10,020	6,410	25,400	10,150	13,490	6,600	30,200
8,980	10,160	4,780	23,900	10,170	13,690	5,020	28,900
8,950	10,040	4,750	23,700	10,110	13,550	4,980	28,600
8,710	9,730	4,650	23,100	9,810	12,990	4,870	27,700
8,830	9,890	4,680	23,400	9,960	13,220	4,900	28,100
8,810	9,860	4,680	23,400	9,950	13,050	4,890	27,900
9,550	10,660	5,410	25,600	10,910	14,460	5,870	31,200
8,900	9,980	4,740	23,600	10,060	13,490	4,970	28,500
8,860	9,980	4,710	23,600	10,000	13,430	4,930	28,400
8,880	10,030	4,730	23,600	10,030	13,470	4,960	28,500
8,930	10,020	4,770	23,700	10,100	13,500	5,000	28,600
8,920	10,070	4,740	23,700	10,080	13,630	4,970	28,700
8,940	10,150	4,740	23,800	10,110	13,670	4,970	28,800
8,860	10,100	4,760	23,700	10,020	13,670	5,000	28,700
8,800	10,070	4,800	23,700	9,930	13,640	5,050	28,600
8,870	9,780	6,100	24,800	10,020	13,050	6,330	29,400
9,430	10,710	6,030	26,200	10,720	14,450	6,510	31,700
8,630	9,890	4,820	23,300	9,690	13,240	5,090	28,000
8,500	9,760	4,760	23,000	9,520	12,960	5,000	27,500
8,480	9,750	4,740	23,000	9,500	12,950	4,980	27,400
8,400	9,590	4,700	22,700	9,410	12,690	4,910	27,000
8,360	9,250	4,700	22,300	9,350	12,190	4,930	26,500
8,460	9,300	4,720	22,500	9,500	12,270	4,940	26,700
8,400	9,600	4,710	22,700	9,400	12,580	4,940	26,900

8,430	10,150	4,710	23,300	9,450	13,530	4,940	27,900
9,190	10,510	5,440	25,100	10,430	14,050	5,900	30,400
8,490	9,770	4,750	23,000	9,540	12,940	4,980	27,500
8,440	9,820	4,740	23,000	9,450	13,040	4,970	27,500
8,500	9,860	4,740	23,100	9,550	13,170	4,970	27,700
8,570	9,760	4,790	23,100	9,630	12,970	5,030	27,600
8,460	9,750	4,750	23,000	9,480	12,940	4,980	27,400
8,530	9,810	5,560	23,900	9,580	13,030	5,760	28,400
8,500	9,940	5,570	24,000	9,540	13,300	5,780	28,600
8,510	9,780	4,740	23,000	9,560	13,050	4,980	27,600
8,530	9,710	4,760	23,000	9,600	12,850	5,010	27,500
9,180	10,370	5,380	24,900	10,410	13,860	5,800	30,100
8,420	9,790	4,710	22,900	9,420	13,050	4,940	27,400
8,530	9,860	4,790	23,200	9,580	13,160	5,040	27,800
8,470	9,720	4,700	22,900	9,500	12,870	4,920	27,300
8,430	9,690	4,710	22,800	9,440	12,850	4,940	27,200
8,430	9,720	4,710	22,900	9,430	12,920	4,950	27,300
8,460	9,730	4,720	22,900	9,470	12,940	4,950	27,400
8,430	9,690	4,710	22,800	9,450	12,860	4,950	27,300
8,720	9,720	4,730	23,200	9,690	12,920	4,970	27,600
9,190	10,450	5,420	25,100	10,400	13,850	5,850	30,100
7,480	9,900	4,670	22,100	8,130	13,100	4,900	26,100
7,190	9,930	6,190	23,300	7,720	13,240	6,370	27,300
5,750	8,210	4,050	18,000	6,110	10,520	4,250	20,900
3,120	5,230	2,810	11,200	3,210	5,780	3,080	12,100
4,810	5,060	3,780	13,700	4,900	5,610	4,030	14,500
7,280	5,050	6,600	18,900	7,320	5,610	6,880	19,800
8,180	4,990	6,170	19,300	8,230	5,530	6,470	20,200
8,570	6,660	7,490	22,700	8,730	7,200	7,850	23,800
16,760	16,110	12,780	45,600	17,490	16,710	13,390	47,600
18,040	16,640	13,240	47,900	18,660	17,310	13,800	49,800
17,870	20,130	16,700	54,700	18,430	20,870	17,180	56,500
17,020	19,620	16,530	53,200	17,570	20,240	16,960	54,800
19,790	23,250	19,930	63,000	20,370	23,880	20,370	64,600
17,310	21,560	20,100	59,000	17,930	22,610	20,540	61,100
20,590	23,070	22,000	65,700	21,390	24,650	22,680	68,700
30,710	28,750	33,520	93,000	32,060	31,010	34,800	97,900
38,420	39,920	41,790	120,100	40,090	42,670	43,930	126,700
40,320	43,610	41,820	125,700	42,040	46,010	43,880	131,900
37,930	46,950	43,060	128,000	39,690	49,370	45,390	134,400
35,510	45,640	43,190	124,300	37,240	48,080	45,720	131,000
33,000	41,610	40,600	115,200	34,820	44,430	43,390	122,600
34,250	43,800	40,810	118,900	36,220	46,870	43,770	126,900
37,230	44,760	41,280	123,300	39,220	48,170	44,200	131,600
39,120	44,750	39,910	123,800	41,260	48,600	42,720	132,600

AveQ1	AveQ2	AveQ3	AveQsum	AveUthd1	AveUthd2	AveUthd3	AveIthd1	AveIthd2	AveIthd3
10,760	16,440	10,900	38,100	2	2	2	11	8	12
10,810	17,920	11,140	39,900	2	2	2	11	7	11
9,280	15,970	10,270	35,500	2	2	2	13	8	11
8,960	16,290	11,020	36,300	2	2	2	13	7	11
8,990	16,450	11,670	37,100	2	2	3	13	7	12
9,690	17,110	11,940	38,700	2	2	3	14	6	12
9,780	17,990	12,200	40,000	2	2	3	13	6	12
10,240	16,780	12,960	40,000	2	2	2	12	6	10
8,970	15,000	11,660	35,600	2	2	2	12	6	10
7,590	14,830	11,130	33,600	2	2	2	11	6	11
8,360	15,540	11,470	35,400	2	2	2	12	6	11
8,670	15,350	11,140	35,200	2	2	2	11	6	10
8,150	14,840	11,290	34,300	2	2	2	11	8	12
7,700	14,870	12,170	34,700	2	2	3	11	8	13
7,840	14,910	11,860	34,600	2	2	2	10	8	11
9,630	16,140	12,150	37,900	2	2	2	10	7	10
10,180	15,210	11,290	36,700	2	2	3	11	8	11
10,460	15,680	10,950	37,100	2	2	3	10	9	11
9,540	15,560	10,960	36,100	2	2	3	11	9	11
10,360	15,790	11,060	37,200	2	2	3	12	7	11
10,290	14,290	10,150	34,700	3	2	3	11	6	12
11,390	14,980	10,620	37,000	3	2	3	10	6	11
12,180	18,150	11,330	41,700	2	2	3	11	7	11
12,790	18,760	12,300	43,900	2	2	3	11	7	11
11,840	17,740	11,000	40,600	2	2	3	12	7	12
10,780	17,100	10,030	37,900	3	2	3	14	8	12
9,800	16,030	9,490	35,300	3	2	3	15	8	12
10,240	14,590	12,110	36,900	3	2	3	15	7	12
11,180	14,280	12,140	37,600	3	2	3	14	7	12
10,060	13,940	11,100	35,100	3	2	3	15	7	11
10,650	13,680	10,680	35,000	3	2	3	14	7	11
10,530	13,540	11,870	35,900	3	2	3	14	7	12
10,470	11,820	9,390	31,700	3	2	3	15	7	11
10,790	11,200	8,610	30,600	3	2	3	14	6	11
9,410	9,320	7,930	26,700	3	2	3	14	6	11
8,540	8,900	6,970	24,400	3	2	3	12	6	14
7,290	6,920	5,800	20,000	3	2	3	13	7	16
6,120	5,630	5,530	17,300	3	3	3	13	9	15
5,830	6,830	6,150	18,800	3	3	3	13	8	15

5,460	6,330	5,060	16,900	3	3	3	14	9	17
6,720	7,290	5,450	19,500	3	3	3	12	8	13
5,870	6,360	4,780	17,000	3	3	3	12	8	15
5,600	4,750	4,610	15,000	3	2	3	12	8	14
5,390	4,090	3,220	12,700	3	2	3	13	8	15
5,550	4,710	2,810	13,100	2	2	2	14	8	15
8,460	7,190	3,030	18,700	2	2	2	15	8	16
9,050	9,540	3,420	22,000	2	2	2	16	8	16
8,670	9,510	3,530	21,700	3	2	2	15	8	16
8,370	9,880	3,460	21,700	3	2	2	15	8	16
7,810	9,310	2,820	19,900	3	2	2	16	10	17
7,740	9,300	2,780	19,800	3	2	2	16	10	17
7,930	9,290	2,850	20,100	3	3	3	17	11	18
6,380	9,280	2,200	17,900	3	3	3	16	8	19
4,420	8,700	1,550	14,700	3	3	3	15	6	21
4,110	8,310	1,220	13,600	3	3	3	16	7	22
4,080	8,290	1,230	13,600	3	3	3	17	7	20
4,130	8,980	1,190	14,300	3	3	3	17	6	19
4,380	9,280	1,480	15,100	3	3	3	17	6	21
4,550	9,250	1,610	15,400	3	3	3	17	6	21
4,240	9,000	1,230	14,500	3	3	3	18	6	22
4,270	9,160	1,280	14,700	3	3	3	16	6	22
4,210	8,810	1,190	14,200	3	3	3	18	6	22
4,420	9,100	1,450	15,000	3	3	3	18	6	21
4,560	9,330	1,520	15,400	3	3	3	18	6	20
4,280	8,950	1,240	14,500	3	3	3	19	7	22
4,240	9,230	1,210	14,700	3	3	3	19	7	22
4,240	8,930	1,230	14,400	3	3	3	19	7	22
4,470	9,220	1,420	15,100	3	3	3	18	7	21
4,600	9,320	1,590	15,500	3	3	3	18	7	20
4,350	8,930	1,220	14,500	4	3	3	19	7	20
4,330	9,060	1,240	14,600	3	3	3	19	7	18
4,270	9,070	1,210	14,600	3	3	3	19	7	22
4,330	8,960	1,340	14,600	3	3	3	18	7	21
4,590	9,350	1,610	15,600	3	3	3	18	7	21
4,200	9,360	1,170	14,700	3	3	3	19	6	22
4,230	9,180	1,210	14,600	3	3	3	18	6	22
4,050	8,780	1,150	14,000	3	3	3	18	7	21
4,200	8,790	1,240	14,200	3	3	3	18	7	21
4,690	9,410	1,680	15,800	3	3	3	16	7	19
4,250	8,850	1,200	14,300	3	3	3	18	7	21
4,200	9,110	1,190	14,500	3	3	3	18	7	21
4,250	9,130	1,220	14,600	3	3	3	18	7	21
4,330	8,950	1,210	14,500	3	3	3	18	8	20
4,990	9,950	1,820	16,800	3	3	3	16	7	16

4,250	9,100	1,200	14,500	3	3	2	18	7	22
4,300	9,230	1,180	14,700	3	3	2	18	7	22
4,300	9,190	1,190	14,700	3	3	2	18	8	22
4,270	9,180	1,190	14,600	3	2	2	18	8	22
4,950	9,490	1,880	16,300	3	2	2	16	8	20
4,290	8,560	1,210	14,100	3	2	2	17	8	22
4,300	8,540	1,250	14,100	3	2	2	18	8	22
4,040	8,420	1,240	13,700	3	2	2	19	9	22
4,160	8,450	1,280	13,900	3	2	2	18	9	23
4,710	9,330	1,900	15,900	3	2	2	17	8	21
4,110	9,030	1,290	14,400	2	2	2	18	8	23
4,170	9,140	1,300	14,600	3	2	2	18	8	23
4,100	8,620	1,270	14,000	3	2	2	19	9	20
3,930	8,700	1,220	13,900	3	2	2	19	8	21
4,610	8,650	1,810	15,100	2	2	2	17	9	22
4,000	8,230	1,220	13,500	3	2	2	19	9	24
3,850	8,260	1,210	13,300	2	2	2	19	9	24
3,940	8,320	1,240	13,500	2	2	2	18	8	24
3,850	8,490	1,230	13,600	2	2	2	18	8	24
4,520	9,000	1,860	15,400	2	2	2	17	8	22
3,910	8,620	1,240	13,800	2	2	2	18	8	24
3,860	8,550	1,260	13,700	2	2	2	18	9	24
3,970	8,520	1,250	13,700	2	2	2	18	9	24
3,890	8,500	1,270	13,700	2	2	2	18	9	24
4,540	8,990	1,820	15,300	2	2	2	17	8	22
3,920	8,690	1,270	13,900	2	2	2	18	8	24
3,920	8,540	1,220	13,700	2	2	2	18	9	19
3,850	8,440	1,210	13,500	2	2	2	18	8	24
3,850	8,200	1,210	13,300	2	2	2	18	9	24
4,440	8,800	1,760	15,000	2	2	2	16	8	22
3,850	8,090	1,270	13,200	2	2	2	17	9	24
3,880	7,760	1,230	12,900	2	2	2	17	9	23
3,780	8,340	1,250	13,400	2	2	2	17	8	23
3,870	8,190	1,230	13,300	2	2	2	17	8	23
4,350	8,990	1,860	15,200	2	2	2	16	7	21
3,760	8,270	1,210	13,200	2	2	2	17	8	23
3,810	8,200	1,220	13,200	2	2	2	17	8	23
3,590	8,110	1,210	12,900	2	2	2	18	9	24
2,380	7,850	1,100	11,300	3	2	2	20	9	24
510	3,190	20	3,700	3	3	2	18	15	26
-20	2,230	1,830	4,000	3	3	3	11	17	14
130	2,130	1,870	4,100	3	3	3	11	16	15
-510	1,580	1,650	2,700	3	3	3	10	17	15
660	1,870	1,980	4,500	3	3	3	11	15	15
5,130	3,700	3,800	12,600	3	3	3	12	10	13

4,360	3,010	3,080	10,400	3	3	3	12	8	11
4,180	3,170	3,110	10,500	3	3	3	15	9	13
4,490	5,870	3,370	13,700	3	3	3	13	7	12
4,500	7,140	3,540	15,200	3	3	3	13	7	11
5,870	8,340	4,440	18,600	3	3	3	13	8	12
5,990	8,210	4,970	19,200	3	3	3	13	9	13
7,800	11,800	9,230	28,800	2	2	3	11	10	12
9,980	16,940	13,630	40,500	2	3	3	10	7	10
9,690	17,350	13,440	40,500	3	2	3	12	6	11
9,900	17,290	13,890	41,100	2	2	3	12	6	11
10,570	18,670	14,400	43,600	2	2	3	12	7	11
10,530	17,400	13,500	41,400	2	2	2	11	6	12
13,160	18,090	14,480	45,700	2	2	2	11	6	11
12,300	18,620	14,240	45,200	2	2	3	12	6	12
12,310	19,150	14,800	46,300	2	2	2	12	6	11
12,910	20,070	14,390	47,400	2	2	2	12	7	12
11,860	19,170	14,490	45,500	2	2	2	12	7	12
12,320	18,890	13,580	44,800	2	2	2	12	8	12
11,880	18,370	12,230	42,500	2	2	2	11	8	10
12,880	19,090	13,880	45,900	2	2	2	11	8	11
12,950	18,870	14,460	46,300	2	2	2	12	8	11
13,100	19,720	15,260	48,100	2	2	2	11	8	11
12,720	19,790	14,890	47,400	2	2	2	11	7	11
11,360	15,860	11,260	38,500	2	2	2	11	7	11
10,750	16,170	11,600	38,500	2	2	2	12	7	11
10,720	16,520	14,420	41,700	2	2	2	11	6	12
12,280	15,950	14,690	42,900	2	2	2	10	6	11
10,540	15,510	14,840	40,900	2	2	2	12	7	12
11,480	17,510	15,090	44,100	2	2	2	13	7	13
10,790	14,940	12,160	37,900	2	2	2	12	6	12
10,830	14,870	12,180	37,900	2	2	2	12	6	12
10,130	13,880	11,590	35,600	2	2	2	12	7	12
9,450	14,450	11,160	35,100	2	2	2	12	6	12
8,530	12,820	10,370	31,700	2	2	2	13	7	13
7,850	11,610	11,220	30,700	2	2	2	14	8	14
8,010	12,440	11,000	31,400	2	2	2	13	7	14
8,430	11,290	12,940	32,700	2	2	3	13	8	13
9,650	12,580	14,220	36,400	2	2	3	13	8	12
8,960	11,770	14,210	34,900	2	2	3	15	8	13
9,230	13,260	13,700	36,200	2	2	3	14	9	13
9,220	14,330	12,150	35,700	2	2	3	14	8	13
9,620	13,350	11,460	34,400	2	2	3	14	8	13
9,390	12,350	10,670	32,400	2	2	3	14	7	12
10,460	13,660	13,120	37,200	2	2	3	13	8	12
10,210	13,880	12,940	37,000	2	2	3	14	7	12

9,810	12,670	13,480	36,000	2	2	3	14	7	13
8,200	12,680	12,990	33,900	2	2	3	15	7	13
8,450	11,880	11,950	32,300	2	2	3	12	8	14
8,200	10,680	12,260	31,100	2	2	3	12	8	14
7,520	9,820	13,040	30,400	2	2	3	13	8	13
7,370	8,300	12,330	28,000	2	2	3	14	9	14
6,300	8,300	10,870	25,500	2	2	3	13	10	13
5,630	7,170	7,240	20,000	2	2	3	13	12	14
5,250	6,480	6,970	18,700	2	2	3	14	14	14
5,550	6,400	7,900	19,900	3	3	3	14	13	15
6,350	7,120	8,220	21,700	3	3	3	13	12	13
5,690	6,710	7,710	20,100	3	3	3	15	13	16
5,920	6,730	6,880	19,500	2	2	3	15	14	17
5,640	6,770	5,830	18,200	3	2	3	15	14	17
5,460	6,590	5,260	17,300	3	3	3	15	13	18
8,140	10,210	6,000	24,300	3	3	3	15	12	16
7,750	11,670	4,470	23,900	3	3	3	17	12	18
7,200	10,120	4,190	21,500	3	3	3	17	11	19
6,720	9,670	3,670	20,100	3	3	3	16	11	18
8,130	10,030	3,960	22,100	3	2	2	16	11	18
8,440	10,050	3,790	22,300	3	3	3	17	11	18
8,370	9,820	3,760	21,900	3	3	3	17	11	18
8,670	9,760	3,840	22,300	3	3	3	17	12	17
9,320	10,320	4,440	24,100	3	3	3	16	11	16
8,820	9,880	3,900	22,600	3	3	3	17	12	18
8,610	10,000	3,640	22,300	3	3	3	17	12	18
5,840	9,090	2,060	17,000	3	3	3	17	8	19
4,490	8,660	1,490	14,600	3	3	3	16	6	20
4,420	8,790	1,460	14,700	3	3	3	17	6	19
4,370	8,240	1,440	14,100	3	3	3	18	7	18
4,380	8,180	1,430	14,000	3	3	3	18	7	16
4,470	8,530	1,470	14,500	3	3	3	18	7	19
5,050	9,690	1,990	16,700	3	3	3	16	6	17
4,610	8,880	1,570	15,100	3	3	3	18	7	19
4,600	8,890	1,490	15,000	3	3	3	18	7	19
4,710	9,000	1,550	15,300	3	3	3	18	7	19
4,730	9,170	1,520	15,400	3	3	3	18	7	19
4,700	9,140	1,560	15,400	3	3	3	18	7	19
4,780	9,110	1,550	15,400	3	3	3	18	7	19
4,720	9,080	1,520	15,300	3	3	3	18	7	19
4,690	9,080	1,500	15,300	3	3	3	17	7	19
4,670	9,060	1,540	15,300	3	3	3	18	7	19
5,400	9,620	2,180	17,200	3	3	3	16	7	17
4,830	9,250	1,550	15,600	3	3	3	18	7	19
4,660	9,180	1,500	15,300	3	3	3	18	7	19

4,760	9,040	1,540	15,300	3	3	3	18	7	15
4,780	9,170	1,530	15,500	3	3	3	18	7	19
4,690	9,090	1,500	15,300	3	3	3	17	7	19
4,500	8,600	1,410	14,500	3	3	3	17	7	19
4,600	8,780	1,450	14,800	3	3	3	17	7	19
4,620	8,540	1,420	14,600	3	3	3	17	7	19
5,230	9,750	2,140	17,100	3	3	3	16	7	18
4,680	9,080	1,470	15,200	3	3	3	17	7	19
4,630	8,980	1,450	15,100	3	3	3	17	7	19
4,660	8,990	1,470	15,100	3	3	3	17	7	19
4,700	9,050	1,500	15,300	3	2	2	16	7	19
4,700	9,170	1,480	15,300	3	3	2	17	7	20
4,720	9,160	1,470	15,400	3	2	2	16	7	20
4,680	9,210	1,510	15,400	2	2	2	16	7	20
4,590	9,200	1,530	15,300	2	2	2	16	7	20
4,660	8,650	1,570	14,900	2	2	2	17	8	16
5,070	9,690	2,300	17,100	2	2	2	16	8	18
4,400	8,800	1,600	14,800	2	2	2	18	8	20
4,300	8,530	1,520	14,400	2	2	2	17	8	20
4,280	8,520	1,510	14,300	2	2	2	17	8	20
4,240	8,310	1,420	14,000	3	3	2	18	8	19
4,180	7,930	1,450	13,600	3	3	2	19	8	19
4,310	8,010	1,450	13,800	3	2	2	18	9	19
4,220	8,130	1,460	13,800	3	2	2	18	8	19
4,280	8,950	1,450	14,700	3	2	2	19	7	19
4,900	9,320	2,150	16,400	3	2	2	17	7	18
4,330	8,490	1,470	14,300	3	2	2	19	8	19
4,250	8,580	1,480	14,300	3	2	2	19	8	19
4,340	8,730	1,470	14,500	3	2	2	18	8	19
4,390	8,540	1,520	14,500	3	2	2	18	8	19
4,290	8,500	1,480	14,300	3	2	2	19	8	19
4,360	8,570	1,490	14,400	3	2	2	18	8	17
4,340	8,830	1,470	14,600	3	2	2	19	8	17
4,340	8,630	1,500	14,500	3	2	2	19	8	19
4,390	8,420	1,510	14,300	3	2	2	18	8	19
4,890	9,180	2,080	16,100	2	2	2	17	7	18
4,230	8,630	1,450	14,300	2	2	2	18	8	19
4,350	8,710	1,550	14,600	2	2	2	18	8	19
4,300	8,430	1,450	14,200	2	2	2	18	8	19
4,240	8,420	1,470	14,100	2	2	2	18	8	19
4,220	8,510	1,490	14,200	2	2	2	17	8	19
4,250	8,530	1,490	14,300	2	2	2	17	8	19
4,250	8,460	1,480	14,200	2	2	2	17	8	19
4,210	8,510	1,510	14,200	2	2	2	17	8	19
4,850	9,070	2,120	16,000	2	2	2	15	7	17

3,160	8,570	1,450	13,200	2	2	2	18	8	19
2,810	8,760	1,460	13,000	2	2	2	19	8	15
1,810	6,500	860	9,200	3	2	2	19	10	24
-280	2,460	-980	1,200	3	3	3	18	16	31
-250	2,400	-430	1,700	3	3	3	14	16	26
-220	2,430	1,910	4,100	3	3	3	9	15	12
-210	2,370	1,930	4,100	3	3	3	8	15	13
740	2,690	2,290	5,700	2	2	2	10	14	14
4,980	4,390	3,950	13,300	2	2	2	12	9	13
4,700	4,740	3,840	13,300	2	2	2	12	8	12
4,480	5,470	4,000	13,900	2	2	2	12	6	10
4,300	4,940	3,740	13,000	2	2	2	12	7	12
4,770	5,430	4,180	14,400	2	2	2	11	6	10
4,640	6,770	4,200	15,600	2	2	2	13	8	11
5,760	8,640	5,460	19,900	2	2	2	13	9	12
9,200	11,560	9,280	30,000	2	2	2	13	9	11
11,420	15,050	13,520	40,000	2	2	2	11	8	10
11,840	14,650	13,260	39,800	2	2	2	10	8	10
11,650	15,240	14,310	41,200	2	2	3	11	7	10
11,230	15,080	14,980	41,300	2	2	2	12	7	10
11,090	15,550	15,310	42,000	2	2	2	12	7	11
11,710	16,640	15,780	44,100	2	2	2	12	7	11
12,320	17,780	15,750	45,800	2	2	2	12	7	11
13,020	18,940	15,210	47,200	2	2	2	11	8	11

جامعة النجاح الوطنية
كلية الدراسات العليا

بناء نموذج رياضي محوسب لتقييم أثر تشويش توافقيات الموجات على جودة الطاقة الكهربائية

(دراسة حالة – كلية هشام حجاوي التكنولوجية)

إعداد
عبد اللطيف فواز عبد اللطيف يدك

إشراف
د. وليد الكخن

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة وإستراتيجية الترشيد بكلية الدراسات العليا في جامعة النجاح الوطنية نابلس فلسطين.

2015م

بناء نموذج رياضي محوسب لتقييم أثر تشويش توافقيات الموجات على جودة الطاقة الكهربائية (دراسة حالة – كلية هشام حجاوي التكنولوجية)

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الملخَص

تعتبر الكهرباء عصب الصناعة الحديثة فهي تزود المصانع والمعامل والمنشآت العامة، كالمستشفيات والمستوصفات والجامعات والمؤسسات والشركات المختلفة بالطاقة الكهربائية . إن أسواق الكهرباء تتطلب أن يكون أداء شبكات الكهرباء بأقصى جودة و كفاءة فنية و اقتصادية ممكنة.

مع تزايد استخدام المعدات والأجهزة فى الشبكات الكهربائية، ومع تعدد واختلاف المستهلكين، واللذين يتم تغذيتهم من شبكة توزيع كهرباء معقدة يتسبب ذلك كله في حدوث اضطرابات في الطاقة الكهربائية وتكون النتيجة فى النهاية إختلال عمليات التشغيل للمعدات أو انقطاع الكهرباء أو انهيار بعض المعدات.

الهدف الرئيسي من هذا البحث هو تقدير تأثير التشوه في الموجات الكهربائية على خسائر الكابلات الكهربائية والمحولات ،كذلك على عامل القدرة ، وكذلك على العمر التشغيلي للمعدات الكهربائية.

هذا البحث يحقق في تأثير التشوه التوافقي في الموجات الكهربائية على نوعية وجودة الطاقة الكهربائية في فلسطين وتم اخذ كلية هشام حجاوي التكنولوجية كدراسة حالة وجدنا أن مقدار التشوه في موجة التيار يساوي 11.7% من الموجة الاصلية وهذه القيمة هي في المعدل، لان القيمة تتغير خلال اليوم من(8%–22 %) واما بالنسبة للتشوه الموجود في موجة الفولطية فتساوي 3% من الموجة الاصلية. ونحن وجدنا أنه في الليل لدينا قيمة عالية من التشوه (23%) في الموجات، لأن معظم الاحمال هي عبارة عن مصابيح التفريغ التي تتميز بتدني

معامل القدرة(0.83) ومساهمتها في تشوه الموجات بشكل. وجدنا أنه في حالة رفع معامل القدرة في كلية هشام حجاوي هذا سيوفر طاقة كهربائية بمعدل 122كيلو واط ساعة في السنة .

رأينا كيف أن معامل القدرة المنخفض تؤثر على قيمة التشوه في الموجات ، فكلما انخفض معامل القدرة زاد التشوه في الموجات الكهربائية.

وجدنا ان التشوه الموجود في الموجات الكهرباية في كلية هشام حجاوي يساهم بخسائر في المحولات الكهربائية وفي الكابلات. في المحولات بمقدار 74كيلو واط ساعة في السنة. وفي الكابلات بمقدار 68كيلوا واط ساعة في السنة.

معامل الحمولة المنخفض للمحول في كلية هشام حجاوي تؤثر على خسائر الكهربائية للمحول ،لأن عامل الحمل منخفض يعني انخفاض الكفاءة، حيث أن الفاقد من الطاقة الكهربائية بسبب انخفاض عامل الحمولة للمحول يساوي 7230كيلو واط ساعة في السنة.

وجدنا أن التشوه الموجود في الموجات في كلية هشام خجاوي تؤثر على السعة الفعالة للمحول حيث تقلل من سعته الفعالة بمقدار 113 كيلو فولت امبير .

استخدمنا برنامج الماتلاب/ السيميولينك لرؤية تأثير التشوه الموجود في الموجات الكهربائية على معامل القدرة، وكذلك اثر استخدام الفلاتر في تقليل قيمة التشوه في الموجات الكهربائية. و من هذه الطرق "فلتر السلبي، هجين من فلتر سلبي و نشط، فلتر نشط، وطريقة النبض وتعديل العرض" التي تقلل التشوه بشكل كبير جدا.

الفاقد من الطاقة الكهربائية بسبب انخفاض نوعية الطاقة تزيد من التأثير السلبي على البيئة، لأن خسائر إضافية تعني المزيد من احتراق الفحم في محطة توليد الكهرباء مما يزيد من انبعاث الملوثات. وجدنا أن توفير الطاقة الكهربائية من خلال تحسين جودة الطاقة في كلية هشام حجاوي يساوي 7900 كيلو واط ساعة في السنة سيوفر 4.3 طن من الفحم سنويا، 7.5 طن من ثاني أكسيد الكربون سنويا وبالتالي الحد من ظاهرة الانحباس الحراري والامراض الناتجة عن الغازات المنبعثة من محطات توليد الطاقة الكهربائية .