Palestine Polytechnic University

College of Engineering and Technology

Electrical and Computer Engineering Department

Graduation Project

Study and Implementation of Energy Saving Techniques & Power Factor Correction in Industrial Plants in Hebron District

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Abstract

Due to the continuous incremental usage of electric energy in Hebron district for beyond values than that of other places in the west bank, it is considered to be a national objective from the highest priority to conserve this energy and use it as wisely as possible to achieve the common welfare.

This scheme manipulates the previous problem of incremental demand, and low power factor for industrial plants through considerations and practical issues, starting with data collection and walk-through surveys for houses and industrial plants in whole the district, determination of the targeted equipments that cause the problem, determination the core of the problem, data analysis and engineering calculations with curves and graphs to make the study more convenient to be established, and finally providing advices to include the responsibility of personnel, and suggestions of practical circuits for achieving the previous target in all aspects of the daily life.

تعتبر محافظة الخليل المحافظة الأكثر استهلاكا للطاقة الكهربائية على مستوى الضفة الغربية، لذلك؛ فإن المحافظة على معدلات الطاقة الكهربائية وترشيد استهلاك المصانع والمنشآت والمساكن لها يعتبر من أهم الأولويات الوطنية.

هذا البحث يعرض لمشكلة المعدلات المتزايدة لاستهلاك الطاقة الكهربائية وتدني مستويات معاملات القدرة للمنشآت والمساكن، وتحديد أسباب هذه المشكلة، والتركيز على أساسها، واستخدام وسائل البحث العلمي، من أجل إيجاد حلول علمية وعملية للمشكلة. وفي النهاية استغلال مادة البحث لوضعها بين يدي الباحثين من أجل تطوير الفكرة ووضع المقترحات المستقبلية اللازمة لحل مشكلة استهلاك الطاقة الكهربائية في محافظة الخليل.

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CHAPTER ONE

INTRODUCTION

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1.1 Introduction

Electrical energy has become the most important part of human life aspects. It provides comfort to every side of life, lighting, conditioning, industrial applications, medical care, even the life of human itself.

Electrical energy effect has taken its place since the twenty first of October eighteen seventy nine, when the first idea of lighting the world had been a real thing; the first lamp was invented by Edison and the life had its special eyes.

A few years later, electrical energy affected all life sides, and became the most important, appreciated, valuable phenomenon. Simply, it is appeared to be not only the spirit of the human beings life, but also the spirit of all creatures' life.

Now, electrical energy is as important as water or air, and no one can ignore its effects and wide applications, in factories, homes, streets, everywhere on earth, even on moon, in space stations. Electrical energy now is the soul of any application that could be imagined, and the last century is the most real, obvious, and strongest evidence on those facts.

Everywhere, there are very large amounts of losses in electrical energy. The more critical problem is the high rates of consumption, and the lack of information about electrical energy saving techniques. In Palestine the problem is said to have its importance from the fact that all Palestinian municipalities and electricity companies provide their customers with large amount of electricity by buying it from the company of electricity of Israel. For this reason, the problem of obtaining electricity is said to be so complicated and dependent.

Palestinian territories are dependent of Israeli electricity suppliers. In Hebron, electricity has its privacy; since it is the largest industrial region in whole Palestine.

This leads everyone to pay attention to the problem of electrical consumption, and let all specialists and electrical engineers find their way to put rules for electrical energy saving, and seek for new techniques to realize this objective.

From the all forgoing, electrical energy saving is important for Palestinian territories, especially Hebron governorate, and this will help Palestinian economy to improve and develop.

1.2 Literature review

- The first two researchers are engaged now on a sponsored project (final stage) sponsored by AED (total amount of $15000), entitled " Design of wind energy station", for further details see the site: http://pesp.ppu.edu/. (two publications have been formed).

- The first researcher worked a sponsored project sponsored by AUL (total amount of $ 7500), entitled "design of two – phase brushless motor with asymmetrical magnetization", for further details, see he site: http://pesp.ppu.edu/. (One publication has been formed).

1.3 Overview

Hebron, the most populated city in Palestinian territories, the center of Hebron governorate, the most populated of all Palestinian governorates too, located in the southern part of West Bank, 36 kilometers to the south of Jerusalem, embosom all types of industry and have the largest number of factories and industrial plants.

FIGURE 1.1 Hebron governorate

Hebron governorate is the most industrial multifarious zone in Palestine. When visiting Hebron, a very large number of industries will be watched. Marble manufactories and quarries are wide-spreading. Also nylon and plastic industry is one of the most important industries in this region.

Some other industries are wide-spreading too, but not as important as the previous two ones. These industries are not only existed to cover the necessity of the Palestinian local market, but also some cargo like shoes, leather, sponge bedplates, and cartoon can be exported to neighboring countries.

The large number of factories in Hebron governorate causes a very large amount of consumption in electrical energy. The invoices of electricity of most of these factories and industrial plants are relatively very high, which leads to the fact that these industrial plants consume electrical energy in very high rates. Moreover, a large number of these factories do not apply the techniques of Power Factor Correction, taking into account the bad idea about the new techniques of lighting.

Applying the techniques of electrical energy saving can help this governorate to develop and go on. Otherwise, it will be a serious problem for the next 50 years, which no one can imagine what will happen after.

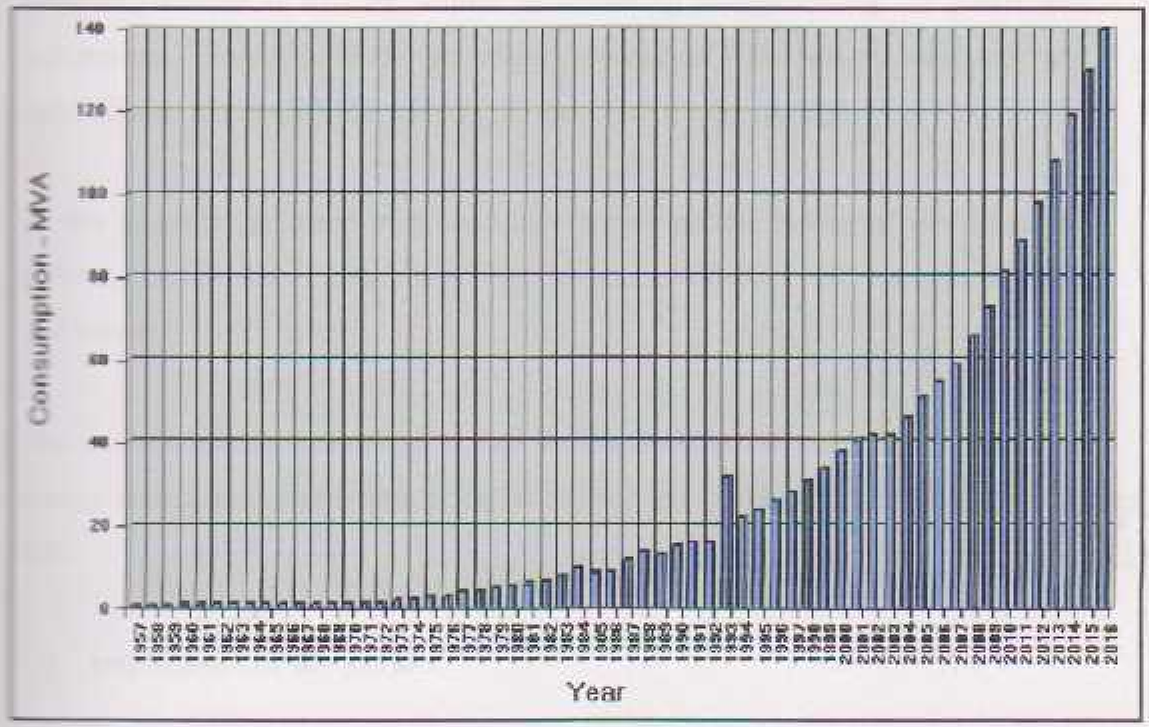


FIGURE 1.2 History and expected rates of total apparent power consumption in MVA unit's in Hebron district between the years 1957 – 2016

1.4 Problem description

Electrical energy saving has become as important as the search for alternative power resources, this importance arises from the fact that electrical energy is used in all life aspects.

In Hebron, the rates of power consumption reach a level higher than the rates in some regions, and it is the highest in Palestine. So, it is important to work on the energy saving methods in one of the most important industrial zones in Palestine.

Power factor correction is considered to be the most important objective of this research; because it will be helpful in achieving energy saving for power and equipments, moreover, there are many approaches like using condensers and synchronous motors, which will help in electrical energy saving.

In this research, the team will conduct a survey on the industrial institutions in Hebron, through distributing questionnaires and conducting field visits to factories and homes

The purpose of this research is to find out facts about the status of the electrical energy consumption, and then work on solving the problems in the best way we can.

1.5 Importance of the project

According to its wide and important applications, electrical energy is set to be the first of all energy resources to deal with. In other words, it is important to find solutions for electrical energy serious problems.

Electrical energy consumption is one of the most critical and serious problems electrical engineers have ever faced; due to the importance of electrical energy on a hand, and to the high rates of consumption on the other hand.

Moreover, electrical energy cost is not low. All countries all over the world produce electricity themselves, but in Palestine; we buy our amounts from Israel, and that makes electrical energy cost higher than if we produce it ourselves.

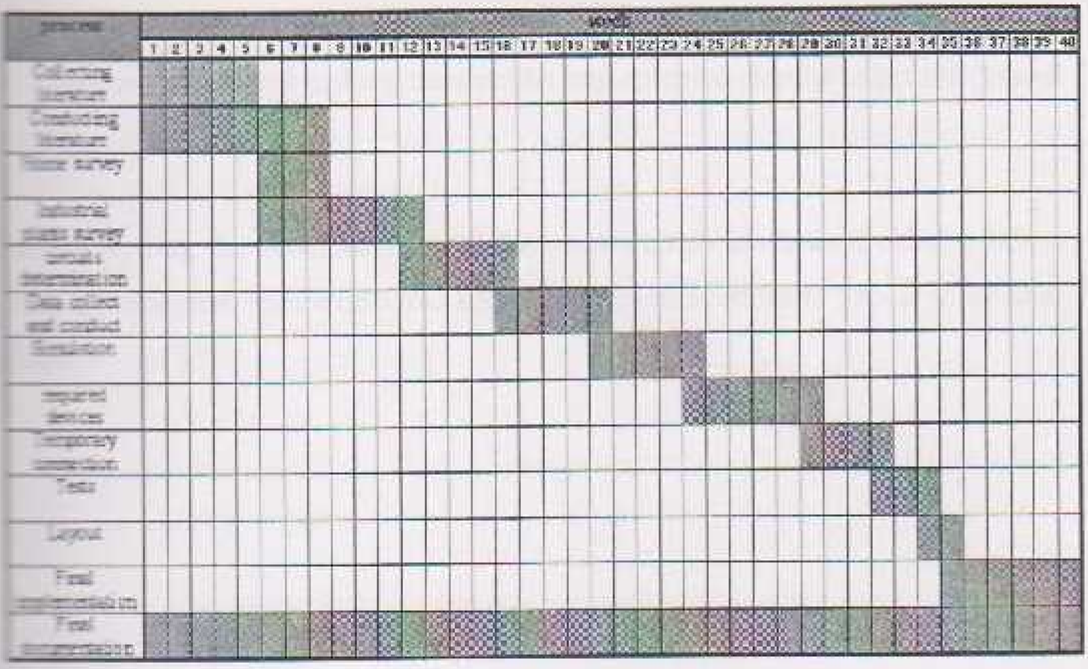
On the other side, Palestine can not ensure electrical energy supply forever, because of political situation and other accounts. In other words, Israel, the occupier, has another way to practice pressure on Palestinians, to lead their situation to a worse case.

Producing our own electricity seems to be very difficult. So, now it is very important -as engineers- to find our way to save the available electrical energy, and seek what new technologies are useful and how to improve old technologies to be efficient and helpful in electrical energy saving.

1.6 Project schedule

This project passed thirteen successful stages facing many problems during work as shown in table (1.1).

Table 1.1 Project time-schedule



Collecting and conducting previous studies and literatures were the first two stages, which started early and passed within eight weeks. Here, resources, literatures, and researches were carefully studied, discussed, and analyzed.

Home survey then took a place as the third step, and started just after finishing collecting and analyzing data. Our team evenly distributed to cover the whole targeted area. Despite it was not a very large sample, it perfectly described the real situation in Hebron district, and surveys different levels of life.

However, the most important part of this project was the survey of the industrial plants and homes in Hebron governorate, through distributing questionnaires, which was our way to get the needed information.

Home survey and questionnaire results need to be analyzed using suitable software programs and theoretical data and equations. On the other hand suggested circuits and elements are to be implemented and simulated through other engineering software programs, and making tests on the implemented circuits to get the desired results.

Finally, writing the documentation of the research. this has been divided within a full academic year, then with some editions and modifications to appear in its final shape.

1.7 The cost of the project

Table 1.2 Cost of the project

Field	Cost (NIS)
Printing	380.00
Transportations	290.00
Communications	100.00
Practical Circuits (Not exact)	890.00
Total	**1660.00**

1.8 contents and description

This project has three main phases to work on; each one is described solely in a single chapter. For instance, the field work and survey deserves a chapter to be discussed in a comprehensive form, and so are the other ideas and applications. These chapters construct all chapters of the final report, and they will be reviewed as follows:

Chapter 1: where in we are now, discusses the whole project in general, arrangements and topics distribution.

Chapter 2: questionnaire and survey analysis and results. Describes analyzing of questionnaire and home survey results, taking into account the equations and theoretical background of calculating the consumption amounts of electrical energy, then making comparison between these theoretical analysis results and questionnaire results.

Chapter 3: energy saving. The different technologies for many applications are to be mentioned in this chapter. The discussion will go through every side of life. For instance, lighting, air conditioning, heating…, etc.

Chapter 4: Power Factor and power factor correction. Describes the idea of Power Factor Correction (PFC) in energy saving. Because it is very important for industrial applications, theoretical equations and practical implementation for (PFC) techniques are mentioned and analyzed.

Chapter 5: Proposed practical design. Illustrates the designing criteria and implementation of a single phase Boost PFC circuit, three phase Boost PFC circuit, and a single phase AC Buck-Boost voltage regulator.

Chapter 6: Tests and results. Describes the practical circuits behaviors, compared with the theoretical results achieved by simulation and mathematical analysis, with results and conclusions as they were found.

CHAPTER TWO

QUESTIONNAIRE AND SURVEY

2.1 Introduction

2.2 History of electrical consumption in Hebron district

2.3 Questionnaire, results and analysis

2.4 Home survey

2.1 Introduction

In order to give a real estimation for the situation of energy consumption in Hebron governorate, a scientific analysis for the questionnaire and home survey results achieved by working group during field visits must be done.

The more you analyze, the more accuracy you get for your results, this is the rule. So, to accomplish this part, one or more suitable software programs must be chosen to achieve the desired analysis.

Excel, the engineering and mathematician software will be helpful, according to its smart possibilities. SPSS also gives a hand in this analysis. It is an accountancy software that uses probability and statistics equations to analyze results and give a future assumption and anticipation.

On the other hand, the history of electrical energy consumption will give a very important background about the real fact before many years. It is not considered to stop only at a discussion of the results taken about consumption rates in Hebron; on the contrary, these results are to be analyzed carefully.

However, this is the first time to go on such a survey by the students, in which, an comprehensive questionnaire was distributed and covered a large area in Hebron governorate. This questionnaire was carefully analyzed, so that, a lot of facts about the situation of electrical energy consumption and electrical energy saving in Hebron district has to be clear.

2.2 History of electrical consumption in Hebron district

According to Hebron municipality, Hebron district has three main substations for electrical distribution, Al-Fahs Substation, Abu Ayyash Substation and Al-Haryeq Substation. However, these substations are distributed in various locations in the region to achieve electrical distribution to different areas.

Each area has a number of facilities, some may close, others may be established, and so, there may be variable consumption rates up to a point. However; usually the case is gradually incrementing.

Data on daily and annually electrical consumption, average Power Factor and average electric Tariff were collected by Hebron municipality between 2002 and 2007. Those data were manipulated and analyzed individually to get the required calculations; analysis and graphs. Data and values are arranged in the following tables.

Table 2.1 illustrates data including power consumption, power factor and tariff for Al-Fahs substation.

Table 2.1 Al-Fahs Substation electricity consumption for the years 2002 – 2007

Year	Consumption kWh/year	Consumption kVARh/year	Consumption kWh/Day	PF	Electric Tariff NIS/100
2002	41225280	19646400	112946	0.9062	27.84167
2003	41855760	21227520	114673	0.8909	29.01
2004	46213440	23157600	126612	0.8952	31.43833
2005	57668880	22770000	157997	0.9290	34.87083
2006	52978800	17682000	145147	0.9433	34.02667
2007	57822720	17304960	158418	0.9577	32.92

Figure 2.1 compares between the annual active and reactive power consumptions for Al-Fahs Substation in Giga units for the years 2002 – 2007

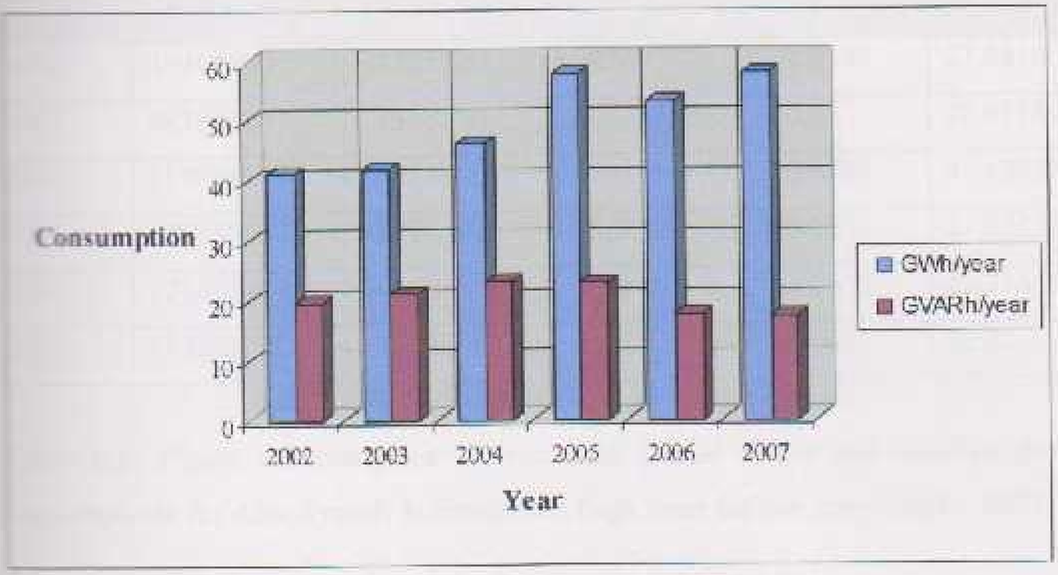


FIGURE 2.1 Al-Fahs Substation Active and Reactive Power Consumptions per year

As it is clear in figure 2.1, that the rate of active power consumption increases gradually, whereas; reactive power fluctuates between increase and decrease.

Table 2.2 contains data including power consumption, power factor and tariff for Abu Ayyash substation.

Table 2.2 Abu Ayyash Substation electricity consumption for the years 2002-2007

Year	Consumption kWh/year	Consumption kVARh/year	Consumption kWh/Day	PF	Electric Tariff NIS/100
2002	88947600	38325120	243692	0.9147	27.841667
2003	98262720	23988240	269213	0.97	26.611667
2004	117964080	24273600	323189	0.9795	31.438333
2005	129850800	18471840	355756	0.9871	31.978333
2006	121868400	19160160	333886	0.9872	25.256667
2007	153558720	17523840	420709	0.9936	32.92

Following, Figure 2.2 compares between the annual active and reactive power consumptions for Abu Ayyash Substation in Giga units for the years 2002 – 2007.

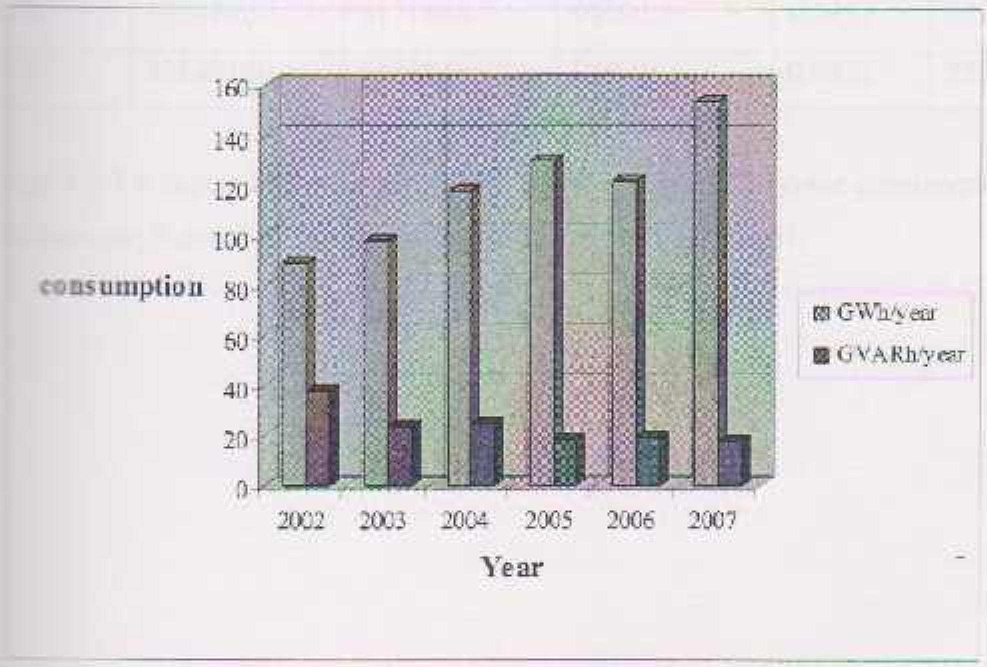


FIGURE 2.2 Abu Ayyash Substation Active and Reactive Power Consumptions per year

It is noted that the rate of active power consumption increases gradually, whereas; reactive power consumption decreases, both with slight fluctuations due to some political and environmental circumstances.

Table 3 contains data including power consumption, power factor and tariff for Al-Harayeq substation.

Table 2.3 Al-Harayeq Substation electricity consumption for the years 2002 – 2007

Year	Consumption kWh/year	Consumption kVARh/year	Consumption kWh/Day	PF	Electric Tariff NIS/100
2002	35451000	6873840	97126	0.9822	27.84167
2003	34166760	6720840	93608	0.9812	26.57917
2004	33248160	6171840	91091	0.9832	31.43833
2005	33248160	6171840	91091	0.9832	31.97833
2006	33248160	6171840	91091	0.9832	25.25667
2007	33248160	6171840	91091	0.9832	32.92

Figure 2.3 compares between the annual active and reactive power consumptions for Al-Harayeq Substation in Giga units for the years 2002 – 2007.

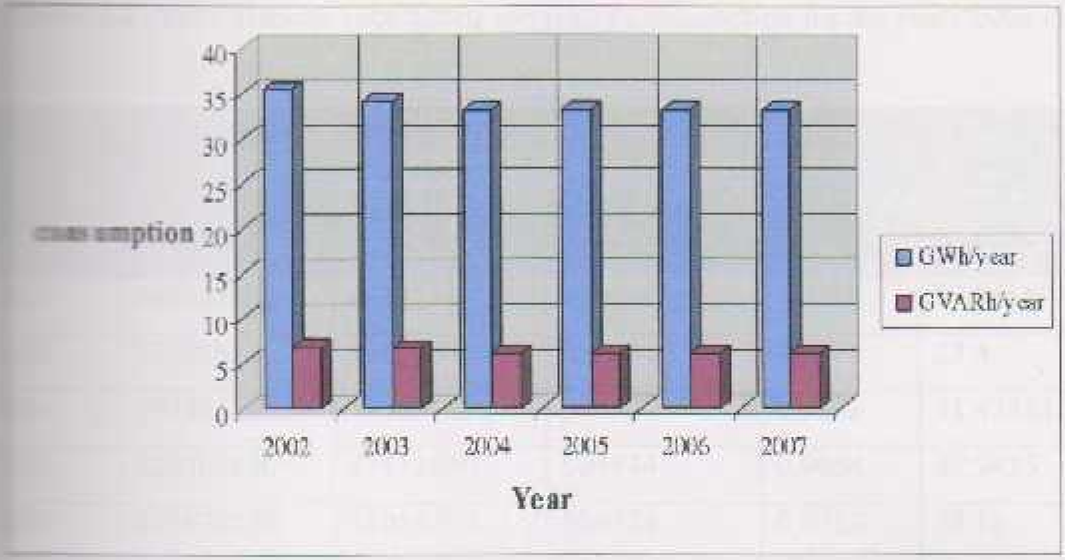


FIGURE 2.3 Al-Harayeq Substation Active and Reactive Power Consumptions per year

From the previous graph (Figure 2.3), it is noted that both active and reactive power consumption decreases between the years 2002-2003 and then goes at a constant rate between the years 2004-2007, due to some problems of consumption reading meters in that area.

Table 2.4 contains data including power consumption, power factor and tariff for total Hebron substations.

Table 2.4 Total Hebron Substations electricity consumption for the years 2002 - 2007

Year	Consumption kWh/year	Consumption kVARh/year	Consumption kWh/Day	PF	Electric Tariff NIS/100
2002	165623880	64845360	453764	0.9344	27.84167
2003	174285240	51936600	477494	0.9474	27.4
2004	197425680	53603040	540892	0.9526	31.43833
2005	220767840	47413680	604844	0.9664	32.9425
2006	239870520	43014000	570124	0.9712	28.18
2007	244629600	41000640	670218	0.9782	32.92

The following figure (Figure 2.4) compares between the total annual active and reactive power consumptions for Hebron district in Giga units for the years 2002 – 2007.

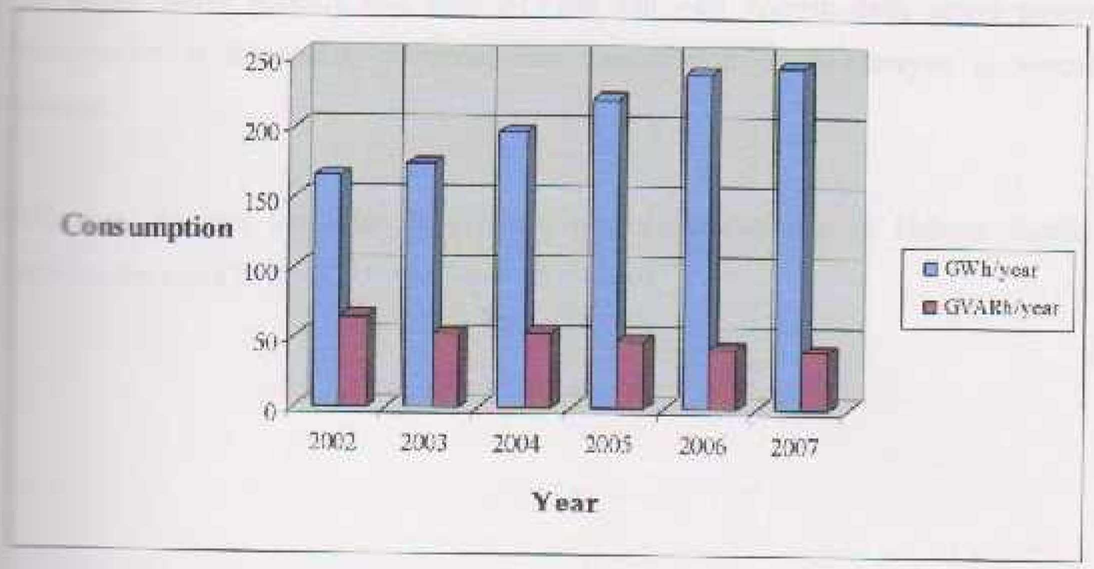


FIGURE 2.4 Total Hebron Active and Reactive Power Consumptions per year

The previous graph illustrates an increase in active power consumption against a decrement in reactive power consumption.

Figure 2.5 next, compares between the daily active and reactive power consumptions for Al-Fahs, Abu Ayyash and Al-Harayeq Substations in Mega units for the years 2002 - 2007, conducted from the previous tables.

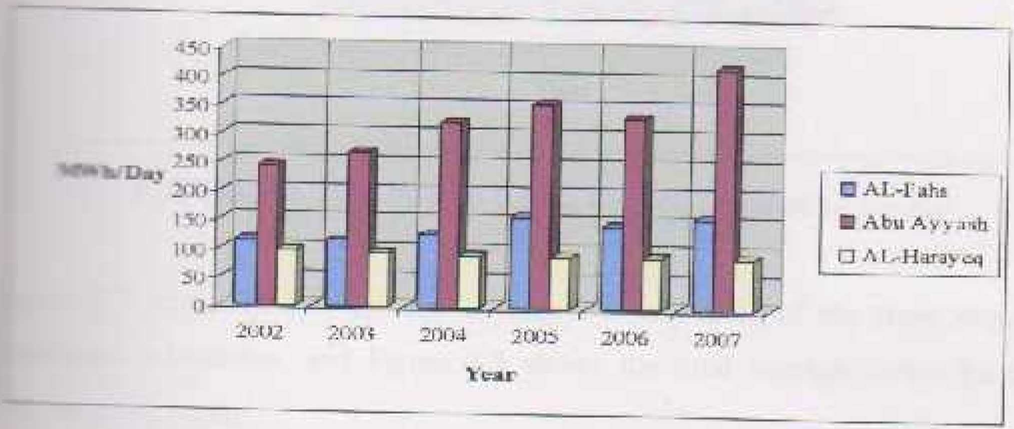


FIGURE 2.5 Daily consumption of Al-Fahs, Abu Ayyash & Al-Harayeq

The figure above appears that both Al-Fahs and Abu Ayyash daily active power consumption is increasing, whereas; the consumption of Al-Harayeq is almost constant.

Following, appears the total daily active power consumption of Hebron district between the years 2002-2007. See Figure 2.6 below.

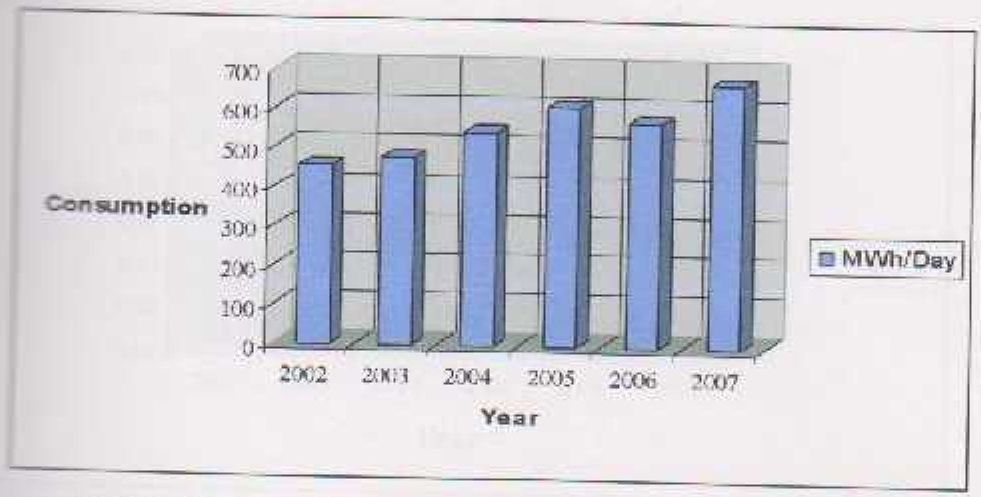


FIGURE 2.6 Total Hebron Active Power Consumption per day

Figure 2.7 compares between the average Power Factor of the three previously mentioned substations, and Figure 2.8 shows the total average Power Factor of Hebron governorate.

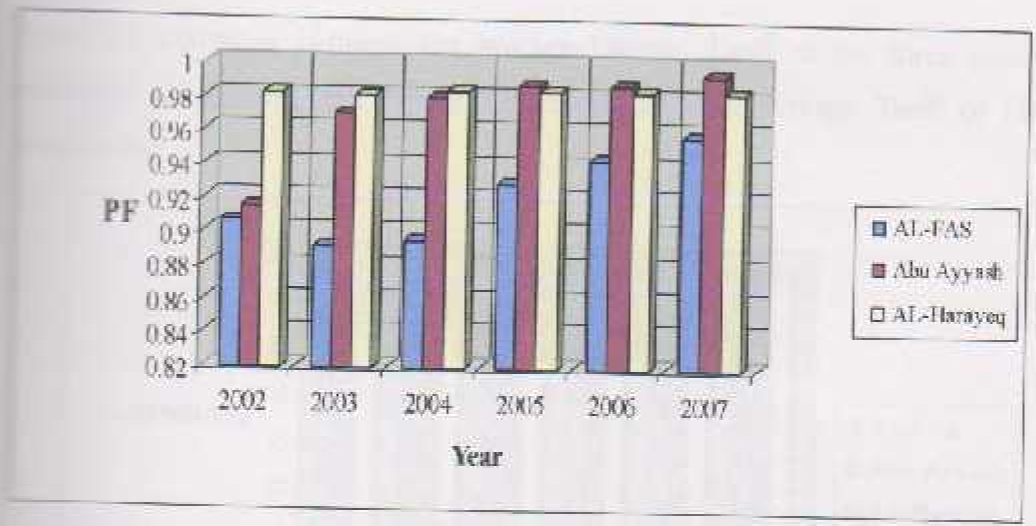


FIGURE 2.7 Comparison of Al-Fahs, Abu Ayyash & Al-Harayeq Power Factors

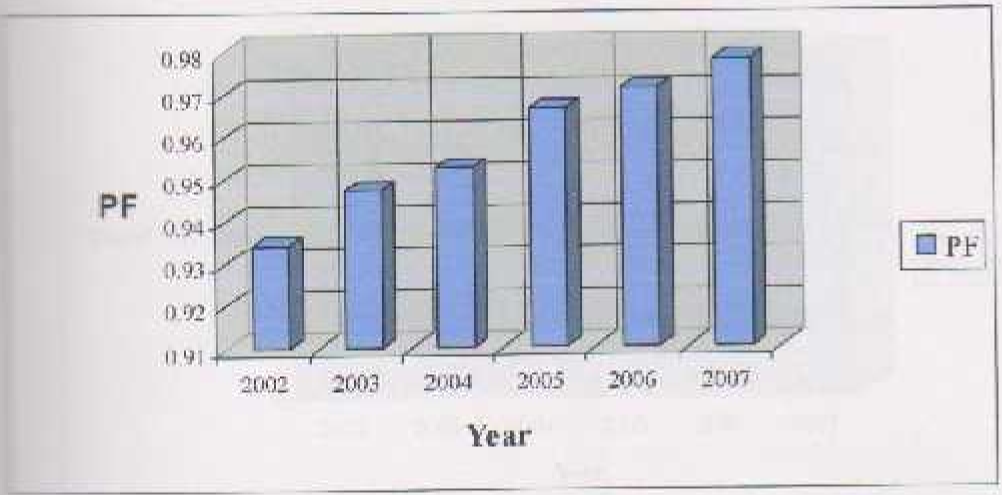


FIGURE 2.8 Average Hebron Substations Power Factor for the years 2002 – 2007

From Figure 2.7 and Figure 2.8, generally it is concluded that Power Factor is increasing proportionally with the year, taking in consideration some slight unexpected variations of Al-Fahs substation due to certain issues.

Figure 2.9 compares between the average Electric Tariff of the three previously mentioned substations, and Figure 2.8 shows the total average Tariff of Hebron governorate.

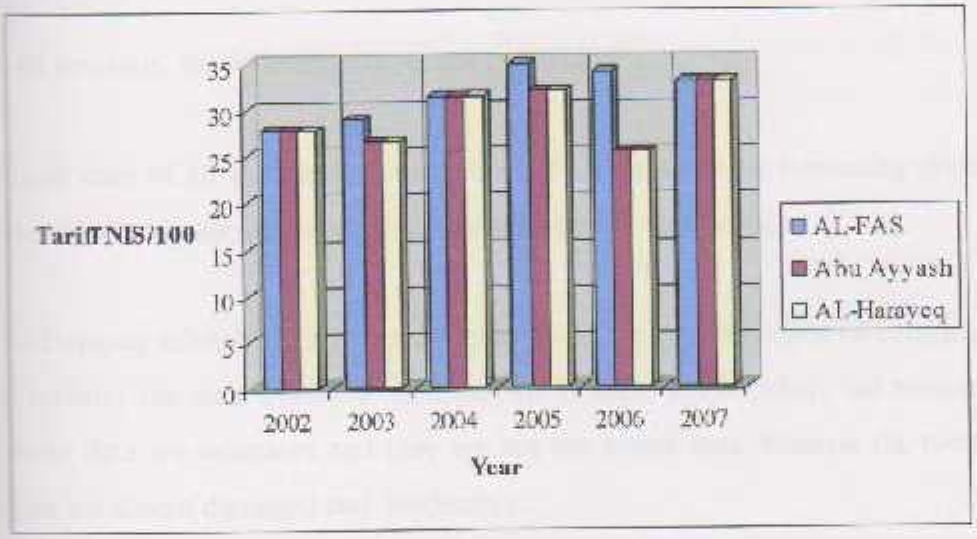


FIGURE 2.9 Comparison of Al-Fahs, Abu Ayyash & Al-Harayeq Electric Tariffs

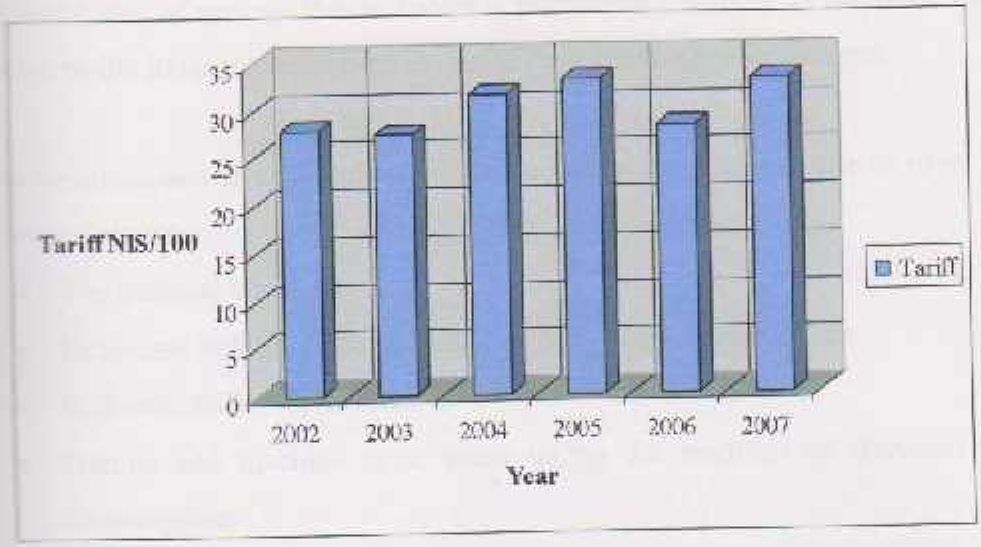


FIGURE 2.10 Average Hebron Substations Electric Tariffs per kWh

From the previous two figures, it is noticed that the rate of electric tariff always fluctuate, unstable and unexpected, due to the political considerations at the first level, because, the electricity consumed in Hebron like other areas of west bank, is basically provided by the Israeli company of electricity, which in turn determines the cost of each consumed kWh of energy to serve their welfare ignoring the bad economical situation of the people of Palestine.

From all previous, the following issues are concluded.

The usual case of all electrical consumption of active power is increasing gradually with the time, whereas; reactive power consumption is decreasing.

For Al-Harayeq substation, it is noticed that there are constant rates of consumption when revising the data available, referring to Hebron municipality; the reason was that those data are estimated and they are not the actual data, because the meters in that area are almost damaged and ineffective.

The usual case of average Power Factor is increasing gradually by the time. Rates of electric tariffs have no stable manner and always fluctuate with the time.

Any variations and unexpected values of electricity rates refer to one or more of the following reasons:

- The political situation.
- Increment in loads at some period of time to unexpected rates.
- Bad economical situations.
- Human and machine error when taking the readings of electrical power consumption.
- Natural and environmental circumstances at a certain period of time.

2.3 Questionnaire

The distributed questionnaire consists of four parts. The first part aims to have the real number of industrial plants that use power factor correction technique, and to have a general idea about how this technique is useful.

The second part aimed to figure out the effect of the use of power factor correction technique on electrical energy consumption, and to achieve the real values of the power factor before and after choosing the correction technology.

The types of used motors in industrial plants were the third target, so that the third part of the questionnaire was founded. Also the average power factor of these motors, especially induction ones was an important objective.

Lighting, its types, standards, and the ability of the industrial institutions to use the new lighting technologies were the reasons for which the fourth part, lighting, was founded. So lighting is really causing a big problem for those who are not taking care of their lighting devices and ignore the new saving technologies of lighting.

2.3.1 Partitions of surveyed plants

Regional partition: Hebron district was divided into three main regions, middle, north and south; to cover the whole district factories and industrial plants. However, a chosen sample for one region was in respect with it's size.

Industry type partition: Hebron governorate contains a lot of different types of industry. So when choosing our sample of factories, this partition was taken into account, if the industry is heavy or light.

2.3.2 Analysis of questionnaire results

2.3.2.1 Part one

This part includes 13 important questions, the most important one was the first, do you use PFC technique? The answers were as follows:

There are 63% only of the whole Hebron district industrial plants use the technique of compensating capacitors, whereas 37% do not. Figure 2.11 shows these results.

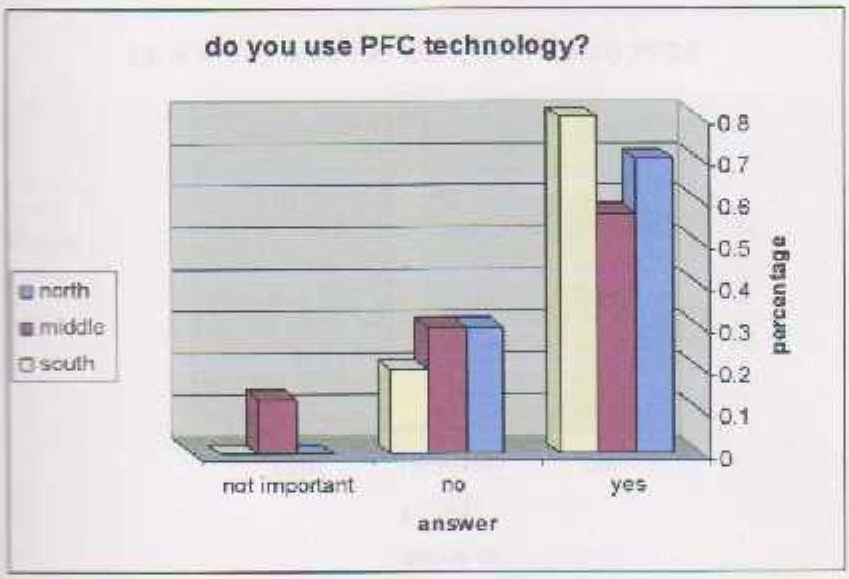


FIGURE 2.11 (Questionnaire) percentage use of PFC, Q1 - Part 1

It is clear that the highest percentage of users was in the southern part, and reached 80% of total factories there, where it was 70% in north of Hebron. The least percentage was in the middle of the district.

The other important question in this part was about the benefit after using this technique, comparing with its cost. 69% of the middle region see that the benefit was unchallenging. This is a real disaster, and the benefit will not take a place until the meters read the reactive and apparent power .Figure 2.12 illustrates the results of this question.

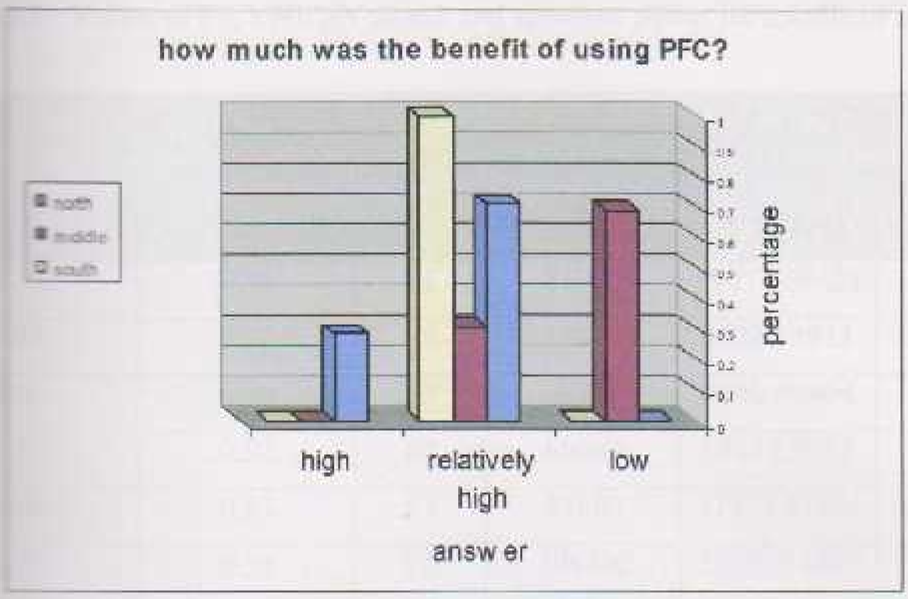


FIGURE 2.12 (Questionnaire) percentage values of answers of Q 5 - Part 1

2.3.2.2 Part two

The second part of the questionnaire was about the electrical energy consumption in the three regions of Hebron district, middle, north and south of Hebron.

Here in table 2.5 are the results of the middle of Hebron for factories and industrial plants that already have the power factor correction technique.

The results of the 12-factory sample illustrated in table 2.5 are analyzed using Excel software. Here is the diagram.

Table 2.5 Values of PF, kWh per month and apparent power for middle of Hebron

Power factor		factory	kWh/month	Apparent power (kVA)	
before correction	after correction			With correction	Without correction
0.75	0.95	F1	85000	89473.68421	113333.3333
0.85	0.92	F2	14000	15217.3913	16470.58824
0.8	0.99	F3	4000	4040.40404	5000
0.75	0.92	F4	60000	65217.3913	80000
0.65	0.92	F5	25000	27173.91304	38461.53846
0.75	0.96	F6	208300	216979.1667	277733.3333
0.78	0.93	F7	5000	5376.344086	6410.25641
0.78	0.90	F8	15000	16666.66667	19230.76923
0.78	0.93	F9	16400	17634.4086	21025.64103
0.8	0.94	F10	26000	27659.57447	32500
0.75	0.94	F11	10000	10638.29787	13333.33333
0.78	0.93	F12	9300	10000	11923.07692

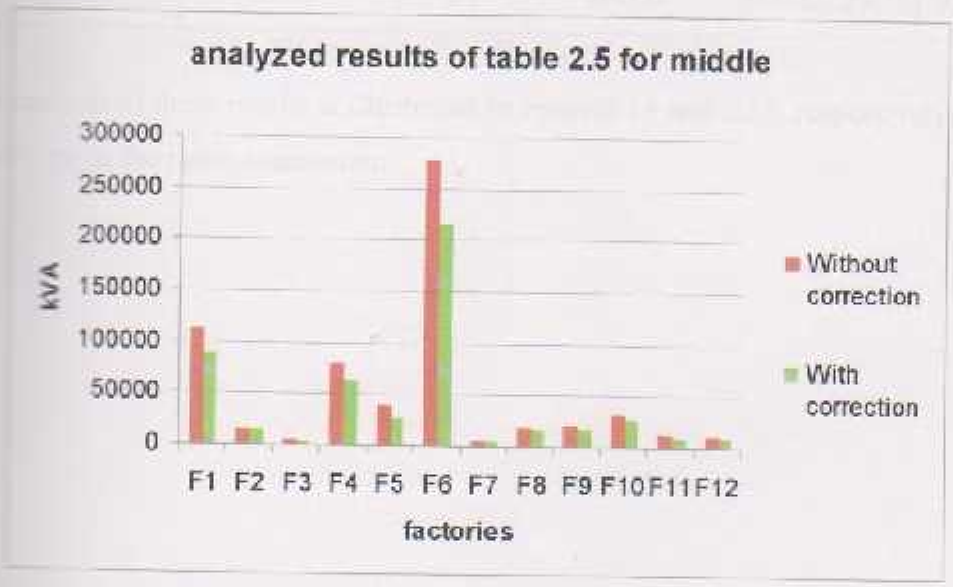


FIGURE 2.13 Analyzed results of table 2.5

It is clear that when using the power factor correction, the consumption of the apparent power will decrease.

Now, table 2.6 and 2.7 list the results taken from the north and south of Hebron, respectively. Results also describe the consumption for those factories use power factor correction techniques.

Table 2.6 Values of PF, kWh per month and apparent power for north of Hebron

Power factor		Factory	kWh/month	Apparent power (kVA)	
before correction	after correction			With correction	Without correction
0.6	0.96	F1	14000	14583.33333	23333.33333
0.65	0.94	F2	40000	42553.19149	61538.46154
0.76	0.95	F3	80000	84210.52632	105263.1579
0.78	0.95	F4	30000	31578.94737	38461.53846
0.65	0.95	F5	20000	21052.63158	30769.23077
0.75	0.94	F6	20000	21276.59574	26666.66667
0.65	0.93	F7	60000	64516.12903	92307.69231

The analysis of these results is illustrated in figure 2.14 and 2.15, respectively, which exactly go to the same conclusion.

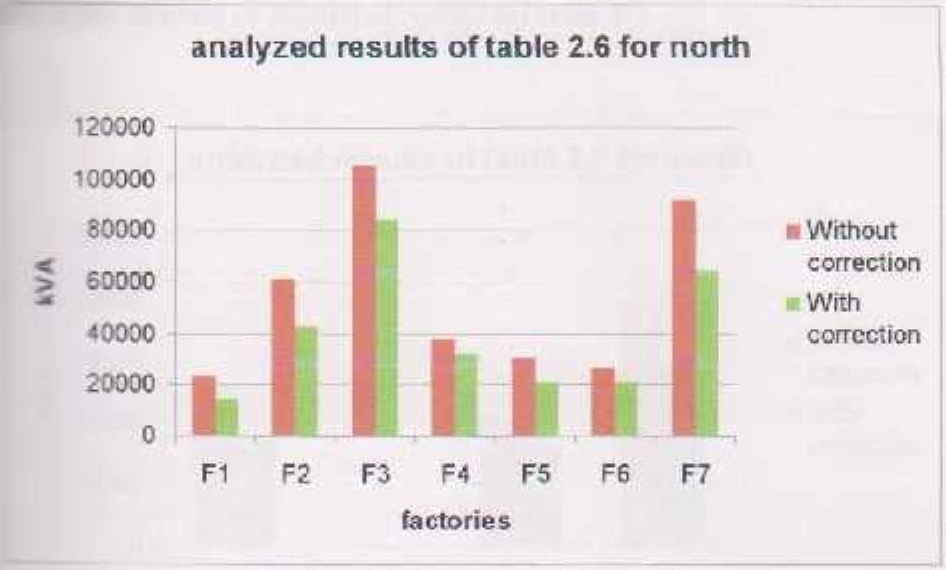


FIGURE 2.14 Analyzed results of table 2.6

Table 2.7 Values of PF, kWh per month and apparent power for south of Hebron

Power factor		factory	kWh/month	Apparent power (kVA)	
before correction	after correction			With correction	Without correction
0.7	0.95	F1	9090	9568.421053	12985.71429
0.8	0.95	F2	140	147.3684211	175
0.75	0.95	F3	8000	8421.052632	10666.66667
0.7	0.95	F4	14000	14736.84211	20000

And here is the diagram of illustrated results for table 2.7

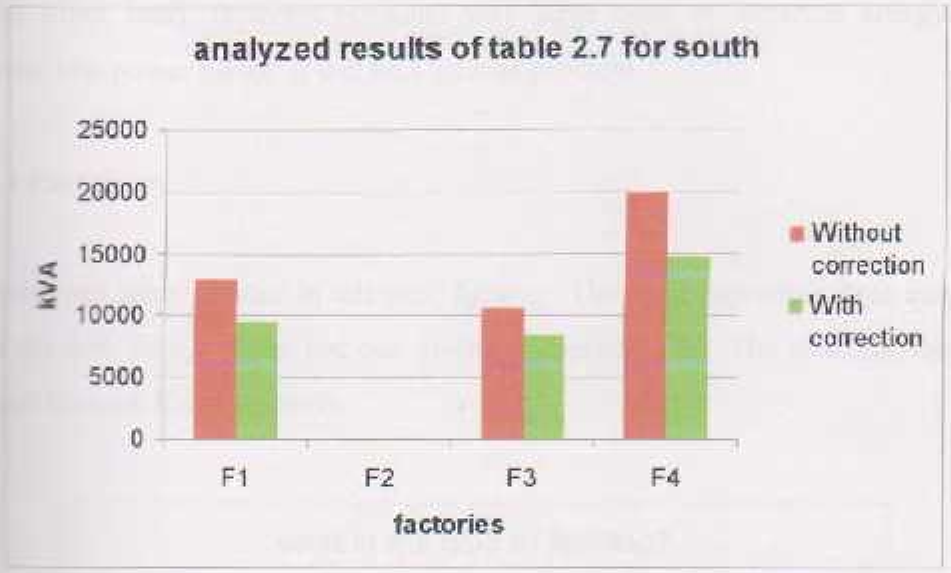


FIGURE 2.15 Analyzed results of table 2.7

From the previous analysis, here are some illustrations of the expectations.

As the history says, power factor increases with years, from 2002 when it was about 97% until 2007 when reached 97.5%. Also the future agrees with this fact. According to SPSS software, the power factor will rise up to 99.75% at 2009; this seems to be almost ideal, but this is just a future assumption. Also the rates of reactive power consumption at 2010 will be close to half its value when being in the year of 2006.

2.2.2.3 Part three

Part three aimed to achieve a real view about the motors used in industry in Hebron district, according to type, power rating and power factor. The collected data was referred to an average, in other words, no certain numbers achieved for this part.

About 95% of motors are induction, which means that the total power factor of a machine that uses 10 motor for instance is 75% to 85%, and so the efficiency is low. On the other hand, factories consume very large rates of electrical energy, with relatively low power factor; it will be a serious problem.

2.3.2.4 Part four

Ten questions were situated in this part, lighting. The most important three questions where the first, fifth, and the last one, (refer to appendix A1). The collected data was analyzed through Excel software.

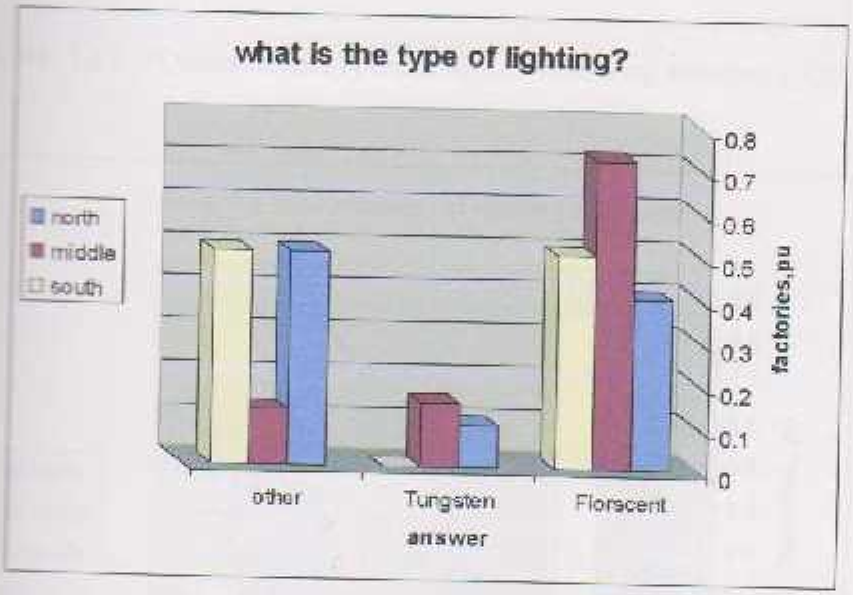


FIGURE 2.16 (Questionnaire) percentage use of the 3 types of lighting, Q1-Part 4

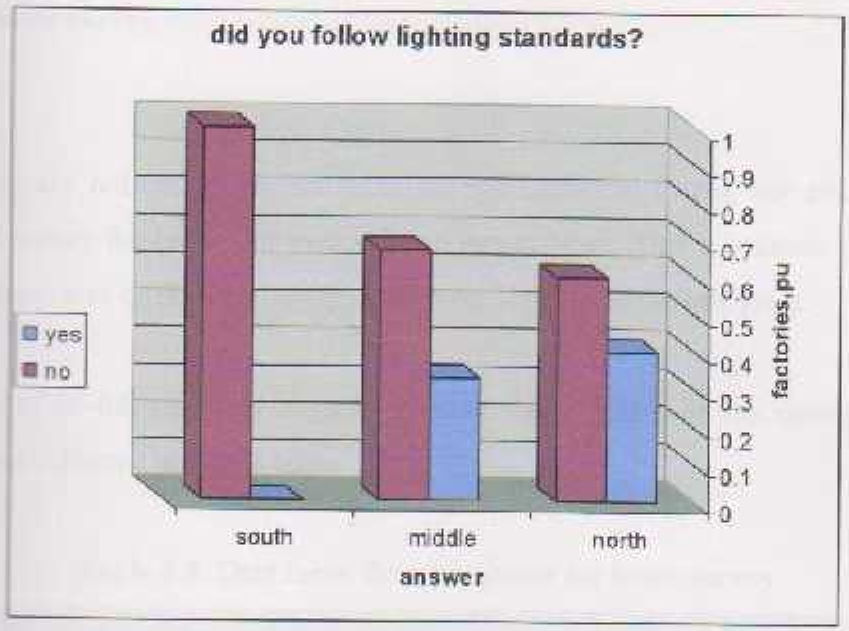


FIGURE 2.17 (Questionnaire) percentage of following standards, Q5-Part 4

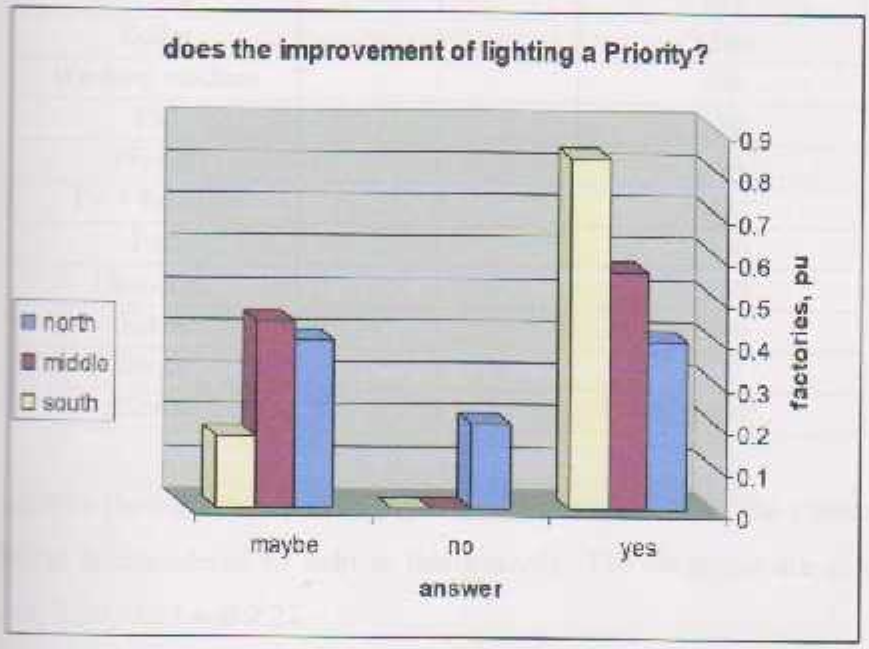


FIGURE 2.18 (Questionnaire) percentage of factories assume lighting improvement as a priority, Q10-Part 4

[illegible] Home survey

Field visits are not only done for factories and industrial plants, but also included visits and survey for homes all over Hebron governorate. This is because of the high consumption rates of electrical energy had been noticed for the last years.

A sample of 20-full electrical elements houses was included in this survey, and the sample was collected in such a table:

Table 2.8 Data taken from one home for home survey

Device	#	Wattage
Tungsten bulbs	3	100
Florescent	12	40
Fridge	1	165
Boiler	1	1200
Washing machine	1	400
Fan	1	120
PC-full	1	150
TV + Receiver	2	30
Iron	1	1200
Hair dryer	1	1200
Kettle	1	2000
Blender	1	400
Heater	1	1800

So as to analyze the collected data and to have a good view about the consumption in houses, Excel is considered to help in this analysis. The diagrams are as shown in figures 2.19, 2.20, 2.21 and 2.22.

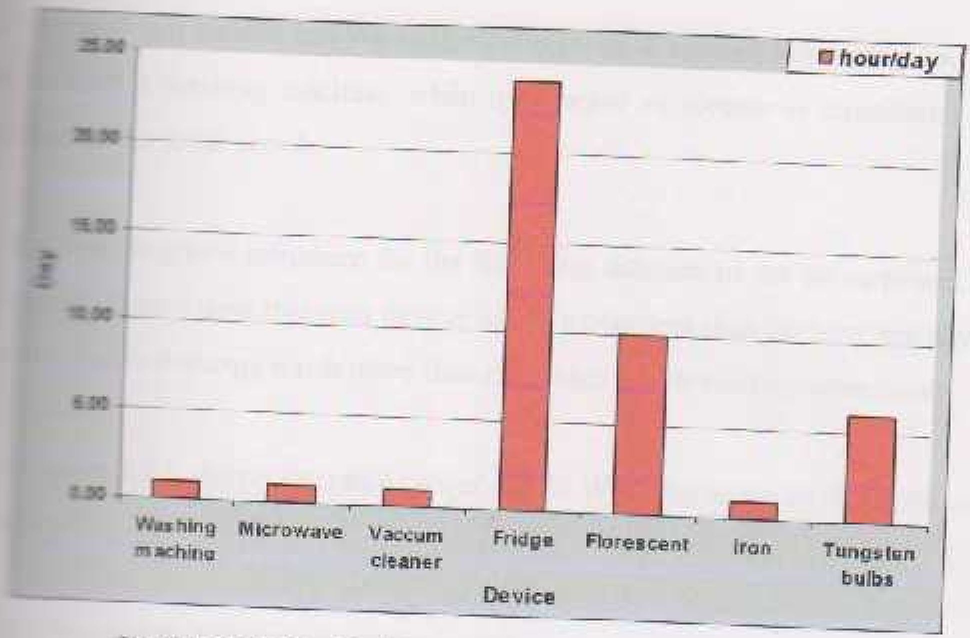


FIGURE 2.19 Device average working hours per day

time, with excessively high rated power, works for excessive low time, while fridge
to work all the time.

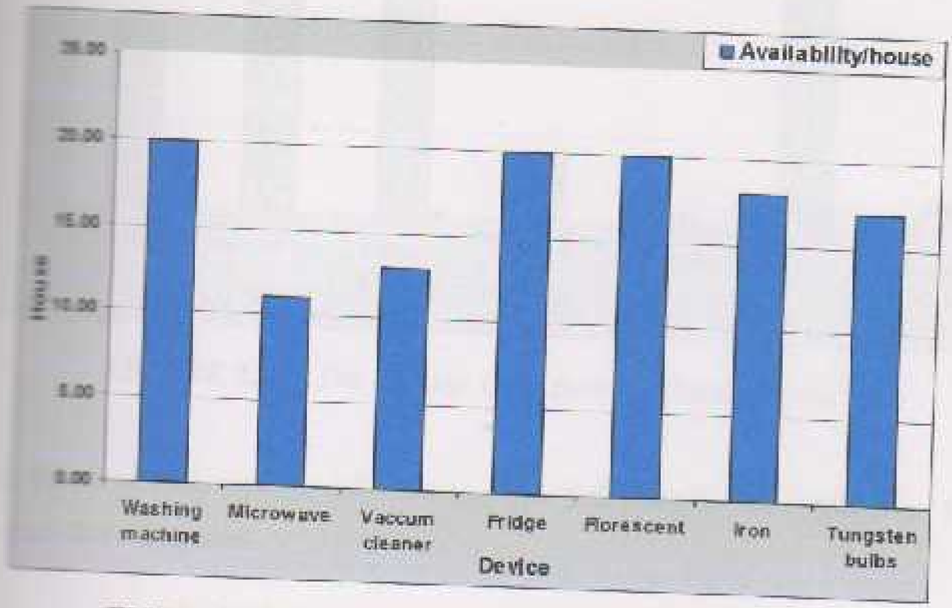


FIGURE 2.20 Availability of home devices per house

It appeared that no one can live without fridges or florescent lamps, and any house need to have a washing machine, while microwave or cleaner is considered to be perfectionism to some people.

The first two diagrams introduce for the following diagram to not be surprised. That will happen if you know that iron device which works less than an hour per day, can consume electrical energy much more than the fridge which works continuously.

Here is figure 2.21, shows the rated power in kilo Watts for every device achieved by the survey.

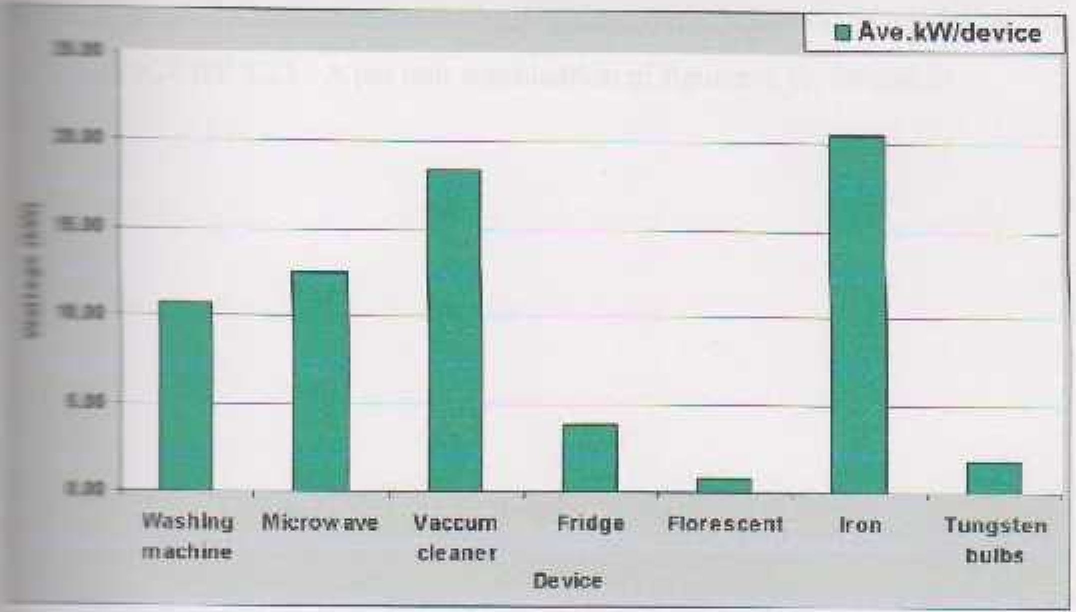


FIGURE 2.21 The average rated power of home devices

Finally, the three diagrams are collected together and can give the explanation for all of the past three diagrams.

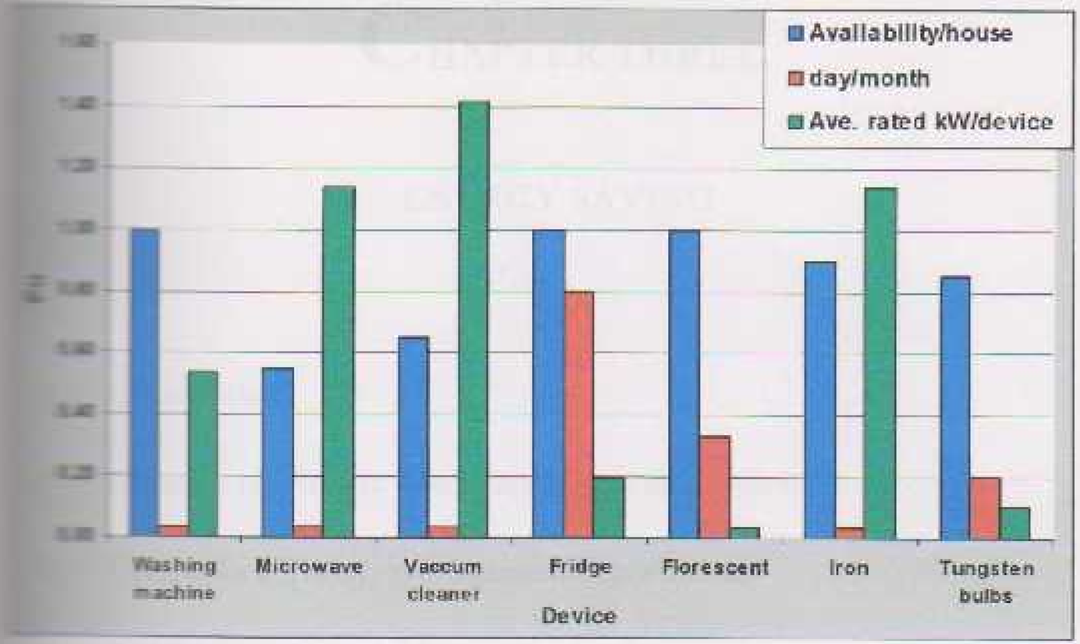


FIGURE 2.22 A per unit combination of figures 2.19, 20 and 21

Chapter Three

ENERGY SAVING

[illegible] **Introduction**

[illegible] **Elements of effective energy management program**

[illegible] **Categories of energy management opportunities**

[illegible] **Building envelope and Energy Saving**

[illegible] **Lighting and Energy Saving**

[illegible] **HVAC Systems and Energy Saving**

[illegible] **Electric Power Systems and Energy Saving**

[illegible] **Renewable energy sources and energy saving**

Introduction

Improved energy use efficiency has become a national objective of highest priority. To evaluate the success of programs aimed at improvements in efficiency, a target is needed against which actual performance can be compared. That target is an estimate of the savings in energy use that are sound economically and technically.

Many energy saving methods for which the necessary technology is at hand are simply too expensive to implement at the current price of energy. Many other methods of improving energy efficiency save both energy and money.

Efficient technology alone is not enough to accomplish energy savings. Technological solutions must be economic, understandable, and acceptable. Certain national and local codes and standards create difficulties since they restrict efficient energy use. These institutional barriers will require resolution if efficient energy use options are to be fully implemented. Furthermore, special skills, new materials and equipment, capital investment, and time are also necessary for improving energy use efficiency. [1]

The time span is important because while some improvements can be made immediately, most require a certain amount of time.

The time span has been divided into the following categories:

- Immediate savings, are those which can accomplished in one year or less and involve modified methods of operation or housekeeping improvements and little or no capital expenditure. The same equipment and processes are employed but methods are modified to improve efficiency.

- Near-term savings, a slightly longer period of two to five years, additional improvements can be gained but generally only with capital expenditure. An example might be improved insulation of residences or insulation of more efficient lighting. Not only is time required to make these changes but a certain period must pass before the changes are made in a sufficient number of facilities or installations to have a significant effect.
- Long-term savings, which have been arbitrarily defined as five to twenty-five years, additional improvements are possible but nearly all require capital expenditures for new equipment, new facilities, or changed technology.

There are, however, valid technical reasons why the electricity growth rate is expected to continue to exceed that of non-electrical energy forms, as follows:

- Practical efficiency of electricity generation is high, that the central generating station is actually a highly efficient device for recovering the work potential of fuels. Electricity generation produces a high quality energy form and recovers most of the available work of the fuel.
- Better control permits efficient use, that is electricity is easily controlled with inexpensive equipment as compared to all other energy forms. This means that waste is reduced; energy is used only when and where it is needed. A switch costing less than a dollar can control an electric heater; compare this to the valves, piping, insulation, steam traps, and noise and leaks associated with a steam heating system.
- Electricity is environmentally clean, that is fuel is burned whereas electricity is generated. [1]

Energy efficiency can be improved in two ways:

- Reducing the amount of energy that we need to support our economy (our energy demand) through technological improvements.
- Changing our behaviors to reduce the amount of energy that we waste.

Programs to improve energy use efficiency could be implemented on several levels (in industry and commerce, in homes, and by governments). Programs could be initiated by managers, corporations, local and municipal authorities, state and federal agencies, and even by private citizens.

In each case it is important to recognize the three critical elements involved:

- Awareness of the need.
- Access to solutions.
- Visibility of economic benefits.

The last point is most important. It is vital to recognize that the economic payoff must be there before a significant savings can result.

In general approach, energy management programs will bring immediate payoffs. In many cases just an awareness of energy use can lead to savings of a few percent. When housekeeping improvements and other steps to improve operational efficiency, are added to this awareness, savings in the range of 5 to 10 percent with little financial expenditures are commonly reported.

After this, further savings are more difficult and generally require concerted effort, capital expenditure, and the use of efficient technologies.

There are three main concepts related to energy:

- Energy quality: can be measured by the ability of the system to perform work, and it can be characterized quantitatively by a thermodynamic concept called availability.
- Energy efficiency: refers to the ratio of work or heat output to energy input.
- Effectiveness: the ratio of the theoretical minimum work needed for a given process and the actual useful work required.

The fact that a more efficient technology has been found of value in certain applications does not mean it will be appropriate in all applications.

Obviously, conservation practices in industry will depend heavily on the cost and availability of energy. In many cases increased energy costs will simply be passed onto the consumer in the price of the product. [1]

[illegible] Elements of effective energy management program

Any successful energy management plan should be held in the recourse with the [illegible] mentioned in Table 3.1.

Table 3.1 Elements of effective energy management program

Phase 1	Management commitment
Commitment by management plan to an energy management program.	
Phase 2	**Audit and analysis**
Review of historical patterns of energy use.	
Facility walk-through survey.	
Preliminary analysis, review of drawings, data sheets, equipment specifications.	

Development of energy audit plans.	
Conduct facility energy audit, covering: • Processes. • Facilities and equipment.	
Calculation of annual energy use based on audit results.	
Comparison with historical records.	
Analysis and simulation step (engineering calculations, theoretical efficiency calculations, computer analysis and simulation).	
Phase 3	*Implementation*
Establish energy effectiveness goals for the organization and individual plants.	
Determine capital investment requirements and priorities.	
Promote continuing awareness and involvement of personnel.	

3.2.1 Phase 1 - Management Commitment

A commitment by the directors of a company to initiate and support a program is essential.

A plan is formulated to set up the program with a commitment of funds and personnel.

3.2.2 Phase 2 - Audit and Analysis

Historical data for the facility should be collected, reviewed, and analyzed.

The review should identify gross energy use, fiscal year effects, dependence on work load, and minimum and maximum energy use ratios.

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A plan is formulated to set up the program with a commitment of funds and personnel.

Phase 2 - Audit and Analysis

Historical data for the facility should be collected, reviewed, and analyzed.

The review should identify gross energy use, fiscal year effects, dependence on work load, and minimum and maximum energy use ratios.

Objectives of the audit

- To determine how, where, when, and how much energy is used in the facility.
- Helps to identify opportunities to improve the energy use efficiency of the facility and its operations.

Often the energy audit will identify immediate energy management's opportunities, such as unoccupied areas which have been inadvertently illuminated 24 hours a day, equipment operating needlessly, etc.

Corrective housekeeping and maintenance action can be insulated to achieve short term savings with little or no capital investment.

Phase 3 - Implementation

At this point goals of saving energy can be established more firmly and priorities set on the modifications and alterations to equipment and the process.

Effective measurement and monitoring procedures are essential in evaluating progress in the energy management program.

Routine reporting procedures between management and operations should be established to accumulate information on plant performance and to inform plant supervisors of the effectiveness of their operations.

Involvement of employees and recognizing their contributions facilitate the achievement of objectives.

Finally the program must be continually reviewed and analyzed with regard to established goals and procedures.

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3.3 Categories of energy management opportunities

- Operational and maintenance strategies.
- Retrofit or modification strategies.
- New design strategies.

Experience has shown that a minimum of 5 to 10 percent improvement in energy utilization can be achieved through effective housekeeping measures.

Table 3.2 Plant systems to be reviewed for energy management opportunities

System	Typical opportunities
Building envelop	Reduce infiltration, improve insulation, modify paint colors, etc.
Lighting	Task lighting, more efficient lamps, improved controls.
HVAC systems	Heat recovery, better controls use of outside air, modified ventilation.
Electric power systems	Reduce I^2R losses; modify power factor, reduce peak demand, decrease losses.

3.4 Building envelope and Energy Saving

Energy requirements to heat and cool buildings depend on two major factors. The first is the building envelope (roof, walls, windows, doors, and the floor of the building).

The second is the installation and operation of the building's mechanical and electrical equipment to provide a proper indoor environment.

The function of any building is to provide heated or cooled space away from the wind and the weather. The building envelope is what separates you from the wind and the weather outside

From the housekeeping view point, the most essential aspect is to provide a tight envelope to reduce heating and cooling losses.

Skylights and window areas can save energy by providing natural light, while in another they would represent a heat loss.

Infiltration is often an important cause of excess energy use; it can be controlled by upgrading weather-stripping, using door closers, and sealing piping penetrations.

Insulation can be installed in some situations; in other cases it may be very costly. Site considerations are sometimes helpful.

Efficient designs seek to maximize the heating potential of the site in winter, and minimize it during summer.

However, there are some factors affecting energy use in buildings, as follows.

2.4.1 Building users

Larger volume or space than actually required for the functional needs of the occupants increases costs as increases energy use.

3.4.2 Climate and geographical location

Climate is defined as the average condition of weather at a particular location over a period of years.

It includes temperature averages, changes in temperature extremes, the temperature difference between day and night, humidity, infiltration, snowfall and its distribution, sky conditions, and hail.

3.4.3 Window efficiency

For achieving energy saving by means of window efficiency, there are several things to consider, as follows:

- Do the windows seal tightly when closed?
- Are they easy to open and close so that you take advantage of natural ventilation?
- Are the frames in good condition?
- Are they the right type of windows for the climate (double-pane in warmer climates, insulated air spaces in colder climates)?

3.4.4 Air barrier systems

Uncontrolled air leakage through the building envelope is typically responsible for up to 33 per cent of the total heat loss of smaller buildings, such as detached houses.

Air leakage out of the building is called exfiltration and air leakage into the building is called infiltration. The common term to describe both is simply infiltration.

Air leakage can affect moisture accumulation in the walls and ceiling, building temperature control and energy consumption.

Buildings have an air barrier system to reduce uncontrolled air leakage. The air barrier system is the most important part of the building envelope. It literally separates the indoor from the outdoor.

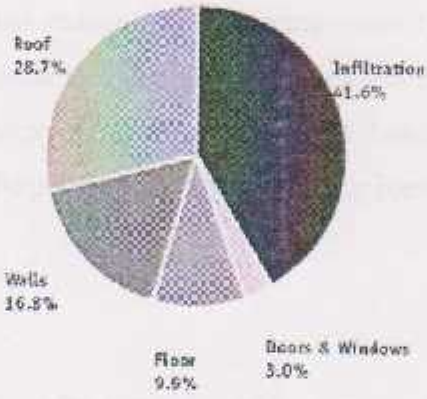


FIGURE 3.1 Building heat loss

3.4.5 Insulation

Insulation is installed to control heat conduction through the building envelope. It is rated according to its resistance to conduction. This is commonly called its R-value. If two different types of insulation have the same R-value, they will perform the same.

Heating costs decrease as the amount of insulation increases.

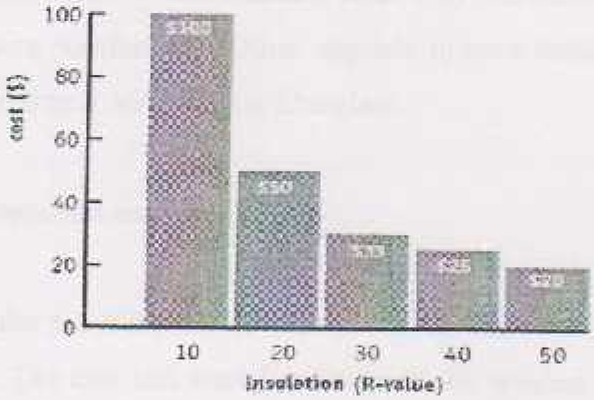


FIGURE 3.2 Costs versus R-values

Insulation must be held in place in the walls and ceilings so that it is not blown out by the wind.

Compressed insulation also reduces its insulating value (R-value) by reducing the size and number of air pockets. All types of insulation must be carefully cut and closely fitted around obstacles, such as electrical boxes or structural supports. Insulation should always be placed tight against the air barrier system.

3.4.6 Insolation

The amount of radiation from the sun received by a surface. The exception to radiant barriers is windows. Making the window opaque or reflective to heat radiation decreases the amount of heat transmission through the window and increases the comfort level next to the window.
The R-value of windows has improved over the years with common upgrades such as low emissivity coating on the glass, inert gas fill (argon or krypton) between glass layers, and insulating spacers between panes of glass. All of these are designed to reduce heat transfer from the warmest to the coldest parts of the window.

This also helps reduce window condensation caused by increased humidity, allowing the space to be more comfortable. Other upgrade options include additional glass layers and improved frame design using fiberglass.

3.4.7 Sitting, orientation and shape

For simple rectangular plans the most effective shapes will be those elongated in the east-west direction. The east and west faces receive the greatest amount of summer radiation and therefore should be reduced in area.

The south-west face receives radiation in the winter, but not so much in the summer and, thus, should be increased in size.

Buildings can also be shaded to prevent solar radiation from reaching each surface, particularly the windows.

The absorption or reflection of heat is also affected by the colors of the buildings it faces; for example, light colors, particularly for roofs, are effective in reducing heat gain.

In summary, each surface of a building is subjected to different environmental influences, depending upon the geographical location, climate, insolation, siting, orientation, and building shape.

3.4.8 Configuration

Besides its orientation and envelope, a buildings configuration also determines the amount of energy used. If energy can be saved by use of natural illumination, the building perimeter should be increased and its interior space proportionately decreased.

Configurations that resist unwanted heat gains and losses result in less energy use.

With low buildings, a square configuration has less surface than a rectangular one of equal area and so experiences less thermal effect due to the environment.

Tall buildings have a proportionately smaller roof and are less affected by solar gains on the surface, on the other hand, tall buildings generally are subjected to greater wind velocities which increase infiltration and heat losses.

3.4.9 Waterproofing

Waterproof the roof with shingles or a membrane. Membrane systems are commonly used on flat roofs, however no roof should be built totally flat. The more slope, the less chance there is for accumulation of water on the roof, which can eventually lead to leaks and further damage.

3.4.10 Moisture Handling

If buildings have an enemy it can be defined in one word: moisture. Moisture problems in buildings can cause energy losses as well as construction material deterioration.

Moisture affects the thermal performance of the building envelope by reducing the resistance of insulation. A small amount of moisture in the insulation cuts the R-value considerably. This costs extra heating and cooling costs.

Moisture can get into the materials and assemblies of the building from the outside and from the inside. Rain or snow can infiltrate from the outside. Interior humidity can infiltrate from the inside, which can condense in the walls and ceiling spaces.
The most effective strategy is to prevent moisture from accumulating in the first place. However, almost all buildings have some form of moisture deposition or accumulation and it is impossible to achieve a 100 per cent perfect building. As a result, there has to be some consideration for handling the moisture.

A number of approaches are used to minimize condensation in buildings, including some unique ones in rinks and arenas.

In retrofit situations, these basically involve:

- Reducing the amount of airflow through cracks and openings.

- Reducing the humidity level of indoor air.
- Using ventilation fans to exhaust moist air from the building and bring in cold dry air.
- Passive (natural) ventilation, using the wind to induce airflow through ducts and planned openings.

3.5 Lighting and Energy Saving

Industrial lighting needs range from low level requirements for assembly and welding of large structures to the high levels needed for manufacture of precision mechanical and electronic components.

3.5.1 Optimum lighting sources

Good quality and effective lighting systems are necessary to create a pleasant functional indoor and outdoor environment. This part outlines some of the design concepts for achieving the most effective use of electricity for lighting.
Lighting must be considered as a system: an efficient lamp must also be used with an efficient luminaire (light fixture). It is also important that the luminaire perform effectively for the intended environment.

Lighting must be reasonably uniform for specific applications, Good color rendering may be necessary, so lamp selection is critical.

Lamp output is measured in lumens. For example, a 23 watt compact fluorescent lamp delivers about 1,450 lumens of light.

Reducing lighting energy consumption in locations where heat from the lighting helps warm an area will increase the annual heating costs.

3.5.2 Lighting study fundamentals

The study of lighting aims to determine the type, the number, and the method of distribution of lighting devices; in order to get a comfortable and suitable lighting for the desired place nature. This can be done by:

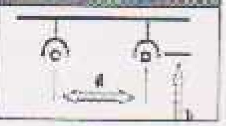
Suitable lighting intensity: describes the amount of light in a certain area.
Target dimensions: the light when reborn is divided into two parts: the first one lies directly on the room ground, whereas the other lies on the roof and walls, then reverberates on ground.

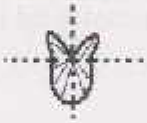
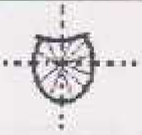
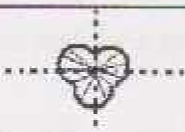
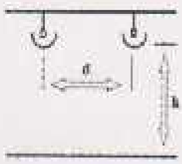
Lighting devices shape and distribution: lighting may be direct, half-direct, homologous, indirect, or half-indirect.

Table 3.3 shows light distribution for each method, usage factor, and the height of the device over workbench, so as to have perfect lighting.

The type of used lamps: there are many types of lamps. However there are mainly two types, filament and gas discharge.

Table 3.3 Light distribution ratios and distances between lighting devices according to lighting method

Methods of lighting	Light distribution percentage		$d_{max}\backslash h$	Lighting shape
Direct lighting	$\frac{0-10}{90-100}$		0.5-0.8	

Half-direct lighting	$\frac{10-40}{60-90}$		0.8-1.1	
Homologous lighting	$\frac{40-60}{40-60}$		1.0-1.8	
Half-indirect lighting	$\frac{60-90}{10-40}$		1.0-1.2	
Indirect lighting	$\frac{90-100}{0-10}$		1.1-1.4	

3.5.3 Considerations when choosing lamp type

- Color appearance: describes the combination of color rendering and how warm or cool would you want the light to appear.
- Switch on times: for high pressure lamps, like sodium or metal halide may take a while to reach full output levels and will not usually switch on when they are warm. These are unsuitable for switching on and off too often during a day.
- Flicker: some lamps flicker on and off at high speeds e.g. fluorescents. The eye cannot see this, but it may cause rotating machinery to appear to be running faster or slower or even in a different direction.

  Ballasts are used to start and operate such lamps correctly, and high frequency ballasts are available which overcome the problem of flicker and use less energy.
- Lamp life: Where maintenance is problematic, for example where lights are mounted high up or over delicate areas such as food preparation, long-life lamps should be used.

3.5.5.1 Filament lamps

Filament lamps are widely used everywhere. Another partition is included in filament lamps, incandescent and tungsten halogen lamps. The following explanation briefly mentions these two types.

- **Incandescent**

An incandescent bulb is usually made of clear or frosted glass, screws into a medium base socket, generally lasts from 750 to 1000 hours, and emits a warm white light. Light is produced when the electric current heats the bulb's filament; 90 percent of the energy is used to heat the filament and only 10 percent goes into making light. Therefore, most of the energy used by the bulb is given off as waste heat, not light.

- **Tungsten Halogen Lamps**

This type produces a bright, white light. Moreover, it has longer life and provides more light (lumens) per watt than regular incandescent bulbs.
Another advantage over this, it maintains maximum efficiency throughout life of bulb, and available in both lines (120 volts) and low-voltage (12 volts). [6]

3.5.5.2 Gas-discharge lamps

- **Fluorescent lamps (Tubular fluorescent and Compact fluorescent lamps)**

Fluorescent lamps are very efficient for areas where lighting is required for long periods of time. They are between two and ten times the price of a light bulb, but have ten times the life.
They last between 8000–16000 hours. Fluorescent lamps use about 70% less electricity than incandescent lamps of similar output.

All fluorescent lamps require ballast, which is an electric device that starts and regulates power to the lamp. Electronic high frequency ballasts are now standard equipment for most fluorescent sources.

Compact fluorescent lamps (CFL) are smaller versions of standard fluorescent lamps. They consume much less energy but provide light that is comparable to incandescent lights. CFL's provide 75-80% energy savings.

Compact fluorescent lamps have all the energy saving benefits of standard fluorescent tubes, but can be used to replace incandescent lamps.
A 20W compact fluorescent lamp will provide the same amount of light as a 100W incandescent globe. See Table 3.4.

Table 3.4 Comparison between 20W CFL and 100W incandescent lamp

Cost Comparison	Compact Fluorescent	Incandescent
Power (Watt)	20	100
Lifetime (hour)	1000	1000
Comparison period (hour)	10000	10000
Number of lamps	1	10
Cost of Lamps (NIS)	60	1.5
cost of Current (NIS)	0.58	0.58
Cost of lamps (NIS)	60	15
Electrical consumption during Comparison period (NIS)	116	580
Total cost (cost of Current + Cost of lamps) for 10000 hour of use (NIS)	176	595
Saving due to the use of *CFL* (NIS)	595 - 176 = 419	

- **Low Pressure Sodium (LPS)**

Low pressure sodium (LPS) lamps are closely related to the fluorescent lamp, since they have a low-pressure, low intensity discharge source and a linear lamp shape.

It can be used in applications where color rendition is not critical. A large variety of wattages are available, from 18 to 180 watts.

This source has the highest efficiency of all sources, ranging from 100-180 lumens per watt.

Rated life is 18,000 hours. Wattage increases 7 per cent, and lumen output 5 per cent, by the end of lamp life.

- **High Pressure Sodium (HPS)**

The HPS lamp has gained popularity in both indoor and outdoor applications because of its efficiency, low cost and excellent lumen maintenance.

FIGURE 3.3 Outdoor HPS luminaire

The average rated life of HPS lamps is about 24,000 hours. A loss of about 20 per cent of initial lumen output can be expected at the end of its life. The color of light is accepted in all applications where color rendition is not critical.

- **Low pressure mercury lamps (LPM)**

Rising concern over mercury disposal has in turn increased the importance of using low mercury content lamps.

- **High pressure mercury lamps (HPM)**

Mercury high discharge lamps are widely used in warehouses and factories with high efficiency overall. They have a low initial cost but poor disposal problems as a result of their use of the heavy metal mercury.

In most situations, mercury lamps can be replaced by metal halide lamps with much improved efficiency.

- **Metal halide (MH)**

This source is effectively the same lamp type as mercury vapour (MV), except that metallic salts (scandium and sodium) have been added for extra efficiencies.

In spite of higher starting voltages; however as an energy conservation retrofit, some MH lamps are designed as direct replacements for MV lamps.

FIGURE 3.4 Enclosed metal halide luminaire

A lumen loss of about 30 per cent can be expected at the end of life. Rated life is about 10,000 to 20,000 hours.

- **Light emitting diode (LED) lighting**

The LED is an electro-chemical light source. When the diode is forward-biased, light is generated.

The color is dependent on the materials used. White light can be produced by using phosphors similar to those used in fluorescent.

Light emitting diodes are becoming more common in commercial and residential lighting because they are extremely durable and produce a much more intense light.

LED systems last up to 100,000 hours, based on the fact that when the light output has depreciated to less than 50 per cent of initial output, then the light source has effectively expired.

LED typically has the following advantages:

- Low power consumption and low heat generation.

- Extremely long life.
- Negligible early failures.
- High color efficiency.
- Very small.
- Resistant to damage from shock and vibration.
- No infrared or ultra-violet energy is emitted.

The use and applications of this light source will continue to increase now and into the future.

Table 3.5 Comparisons of energy use, extended life, capital investment, and annual energy operating costs associated with the LED and incandescent lamp

Factor	LED	Incandescent Lamp
Energy use (Watts)	0.7 to 6.4	23 to 40
Extended life (hours)	218,000	1,000
Capital investment (NIS)	120 to 400	160 to 700
Annual energy operating costs (NIS)	4 to 14	56 to 98

3.5.6 Lighting Control

Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Control techniques ranges from simple to extremely sophisticate.

Lighting control strategies are most successful when people can easily understand their operating characteristics. Another critical factor is the proper commissioning of lighting control systems so that they operate according to design intent.

Finally, regularly scheduled maintenance of control equipment will improve the long-term success of the system.

3.5.6.1 Control using switches

Manual switches are the simplest form of user-accessible lighting control. Minimal compliance requires individual manual switching for each separate building space. Bi-level switching is now required in almost every space.

Manual switches should also be installed in spaces with occupancy sensors to increase the energy savings by allowing people to turn off the lights when they are not needed.

3.5.6.2 Occupancy Sensors control

Occupancy sensors employ motion detectors to shut lights off in unoccupied spaces. The primary detection technology can be either passive infrared (PIR) or ultrasonic. Some sensors employ both passive infrared and either ultrasonic detection. Occupancy sensors are most effective in spaces that are intermittently occupied, or where the lights are likely to be left on when unoccupied.

3.5.6.3 Time Controls

Time controls save energy by reducing lighting time of use through preprogrammed scheduling. Time control equipment ranges from simple devices designed to control a single electrical load to sophisticated systems that control several lighting zones.

Time controls make sense in applications where the occupancy hours are predictable, and where occupancy sensor automatic control is either impractical or undesirable.

3.5.6.4 Manual Dimmers control

Next to standard wall switches, manual dimmers are the simplest of lighting control devices. With incandescent and halogen sources, there is the additional benefit of extended lamp life. However, more importantly, dimmers allow people to tune the lights to optimum levels for visual performance and comfort.

3.5.6.5 Photo-sensor controls

Photo-sensor control systems are used to control electric illumination levels in day lit spaces. A photo-sensor detects the daylight illumination level and sends a signal to a logic controller to switch off or dim the electric lights in response.

In open-loop systems, the sensor is placed so that it sees a representative daylight level, such as looking up into a skylight or out a window. In a closed-loop system, the sensor is placed so that it sees both the daylight and electric illumination level combined.

3.5.7 Light pollution

Light pollution is light that shines where it is not needed or wanted. It is easily recognized as light that is poorly aimed and too bright for its surroundings.

What causes light pollution is the use of artificial over-lighting with poorly designed aimed outdoor lighting fixtures.

Lighting only what is actually needed, when it is needed and to the required minimum lighting levels will help to reduce your electrical costs and help reduce the expanding problem of light pollution.

3.5.8 Re-lamping Opportunities

Re-lamping to a lower wattage can save substantial amounts of energy.
For example, re-lamping from a 150 watt to a 75 watt bulb saves 50 percent of previous use, or re-lamping fluorescents to smaller wattages will save energy.

Re-lamping two Lamps with one can save also. For example, replacing two 60 watt lamps with one 100 watt will save 12 percent of previous usage and will normally provide the same amount of Light as before.

Table 3.6 some illustrative examples of changes lade in installed lighting systems

Common Replacements		
Pole-mounted fixtures to replace older mercury vapor heads		
Mercury vapor	HPS Light	Output (Lumens)
250 watt	150 watt	14400
175 watt	100 watt	8850

100 watt	50 or 75 watt	3600-5600
Replacements for entrance, wall-mounted, or decorative post-top lighting		
Incandescent	HPS Light	Output (Lumens)
500 watt	100 watt	8850
300 watt	70 watt	5600
200 watt	50 watt	3600
135 watt	35 watt	2000

3.5.9 De-lamping Opportunities

De-lamping is a simple and effective method of reducing your lighting costs in over-lit areas. It involves removing one or more fluorescent tubes from existing fluorescent fittings where levels are higher than required.

When de-lamping, ensure that lighting remains uniform throughout rooms or work areas. Lighting levels should be measured at the place where work is performed and should not include ambient daylight.

The measurement method is fairly simple. The following example supports this claim. Each 40 W fluorescent tube removed will save about 48–60 (NIS) a year, based on usage of approximately 40 hours a week.

Savings can be calculated by using this equation:

$$\text{Annual savings (NIS)} = \frac{N * P * H * T}{1000} \quad \text{..........(3.1)}$$

Where:

N = number of lamps removed.

P = power rating of lamps (W).

H = number of hours of usage per year.

T = electricity charge per kWh (tariff).

3.5.10 Indirect Impact of Lighting on Heating and Cooling

Electrical equipment and appliances, from lighting systems and office equipment to motors and water heaters, produce useful services. But the electrical energy they use also appears as heat within the building, which can either be useful or detrimental to the building's heating, ventilating and air conditioning systems, depending on the season.

In cold weather, heat produced by the electrical equipment can help reduce the load on the building's heating system. In contrast, during warm weather, this heat adds to the building's air conditioning load.

Energy efficient equipment and appliances consume less energy to produce the same useful work, but they also produce less heat. As a result, efficient equipment increases the load on the heating systems in winter and reduces the load on your air conditioning systems in summer.

The impacts of energy efficient electrical equipment and appliances on the energy use for building heating and air conditioning systems are commonly called interactive effects or cross effects.

When considering the overall net savings of an energy efficient product it is very important to consider the interactive effects of the product on building heating, cooling and refrigeration systems. Weighing the interactive effects will result in better informed decisions and realistic expectations of savings.

3.5.11 Indoor Lighting Calculations

The accurate calculations for lighting is not a simple operation, it is so complicated taking into account the effect of desired place; its dimensions, reflection factor of services, type of used lamps, and the architecture of the building.

Here, an interesting, simple method for the calculations of lighting is to be explained, called usage factor method.

In this method, the suitable brightness is to be calculated firstly, then the determination of the needed total light flux, and the number of lighting devices then is calculated after choosing suitable lamp and device.

The light flux is calculated by

$$\phi_{total} = \frac{1.25 * E * A}{\eta} \quad \text{............(?.2)}$$

Where:

ϕ_{total}: total light flux [Lumen].

E: lighting intensity measured by [Lux].

A: the area [m^2].

1.25: Factor.

η: usage factor.

Suitable devices and lamps are to be determined. By knowing the per-lamp luminous flux, and number of lamps per device, then the number of devices can be calculated by:

$$N = \frac{\phi_{total}}{n * \phi_{per-lamp}} \quad ....(3.3)$$

N: number of lamps.

$\phi_{per-lamp}$: total luminous flux for one lamp.

n: number of lamps per device.

Example on determining number, type and distribution of lighting devices required for a lecture hall:

Length of the hall: 12m.

Width of the hall: 6m.

Type of required lighting device: Florescent – 40W * 2.

Suggested lighting intensity (E): 500 Lux – referring to Appendix C (Table C.1).

Usage factor (η): 0.45, Appendix C (Table C.5).

Area = Length * Width = 12 * 6 = 72 m^2.

Total Luminous flux =

$$\phi_{total} = \frac{1.25 * E * A}{\eta} = \frac{1.25 * 500 * 72}{0.45} = 100{,}000 - Lumen.$$

$\phi_{per-lamp} = 2000$, referring to Appendix C (Table C.3)

Required number of devices = $N = \frac{\phi_{total}}{n * \phi_{per-lamp}} = \frac{100{,}000}{2 * 2{,}000} = 25 - lighting - devices$

3.4 HVAC Systems and Energy Saving

There are an unlimited variety of ways to heat and ventilate buildings. The choice of systems is based on a number of factors:

- Energy source (electricity).
- Heat transfer medium (air, water, or steam).
- Heat delivery system (pipes and ducts).

Typically air or water is used as the heat transfer medium because both are in abundant supply.

Heat flow is always from warm to cool. The rate is based on the temperature differences between the hot side and the cool side, as well as the resistance to flow created by walls, insulation, air films, and other building components).

The basic heating and ventilation system takes the heat from the heat source and distributes it to the places that need it, using fans and ducts for air-based systems or pumps and pipes for water-based systems.

There are two main techniques of Heating and Ventilation:

- Natural Techniques: Using sunshine for natural heating, and wind, air flow for natural ventilation.
- Artificial Techniques: Furnaces, infrared radiant heaters, water heaters, air conditioners, fans and filters.

[illegible] Furnaces

A furnace is a typical inexpensive heating unit. Furnaces come in various configurations to suit various applications. They are inexpensive to own, operate and maintain.

Their efficiencies vary depending on type and operation.

An electric furnace has annual fuel utilization efficiency (AFUE) of 100 per cent meaning that essentially 100 per cent of the electrical energy supplied to the furnace is converted to heat in the building.

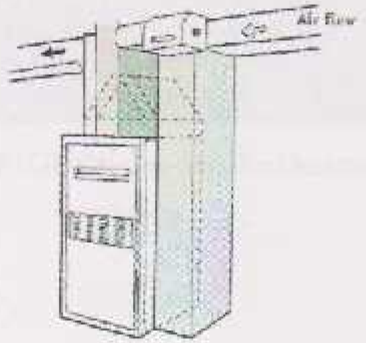


FIGURE 3.5 Typical forced-air furnace

Infrared radiant heaters

Infrared heaters use a different principle than furnaces, unit heaters, or boilers to warm occupants and rooms. The method is similar to sunshine.

Radiant heaters use electricity to produce a high temperature radiating body. Heat is radiated via infrared rays from the heater to any object visible to the heater.

These heaters heat objects, not the air. They may reduce heating costs since the air does not have to be heated to keep occupants comfortable.

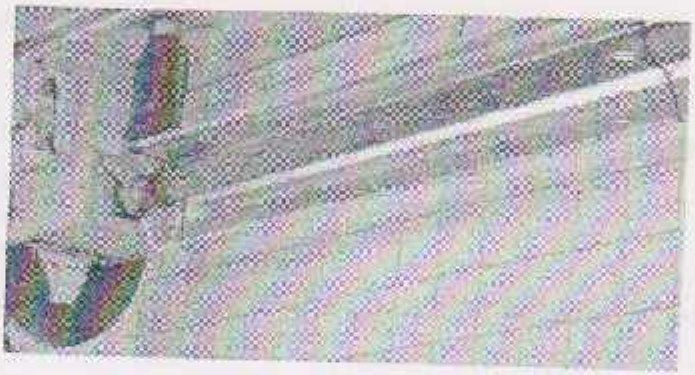


FIGURE 3.6 Radiant heater

3.6.3 Water heaters

Water heaters must be maintained in a manner similar to any other appliance. In addition, flush and drain the hot water storage tanks once a year to remove scale deposits. Flush more often in areas with very hard water.

FIGURE 3.7 Typical water heater

3.6.4 Air conditioners

Air conditioning is normally used in summer when outdoor temperatures and humidity exceed comfort levels.

Air conditioners are rated in Btu/h. They may also be rated in tons. One ton of cooling is equal to 12,000 Btu/h.

Cooling systems should be checked annually by an authorized refrigeration mechanic to help ensure long trouble-free operations.

3.6.5 Electric Fans

A more commonly used devices for ventilating spaces, can be in more than one shape, can also be located in various places distributed wherever it is recommended.

Electric fans have the following advantages:

- Availability.
- Ease of use.
- Typically inexpensive.
- At most they have low power consumption.
- Provide suitable and fair ventilation.
- Can be located in various locations.
- Ease of implementation.

Fans and their associated motors should be checked annually and lubricated as directed by the equipment manufacturer.

Belts should be checked for wear and deterioration. If belts are questionable, they should be replaced rather than risking a break down of the heat distribution or exhaust systems.

3.6.6 Filters

Dirty filters waste energy and reduce air flow in buildings. Air filters should be cleaned regularly. If you have permanent filters they should be cleaned and replaced. Throw-away filters should be replaced with new filters of the same type and style.

3.6.7 Factors for determination of heating and ventilation rates

- The rate of heating and ventilation is a function of activity.
- The number of people in the room.
- The odors and gases associated with the activity (unhealthy atmosphere).

3.6.8 Energy Saving Suggestions

The operation of mechanical systems and equipment is ultimately what uses energy. The following are energy-saving suggestions on the operation of heating and ventilation systems.

- Shut off ventilation systems during unoccupied times.
- Install low flow shower heads to save domestic hot water and heating costs.
- Insulate hot and cold water lines, as well as domestic hot water tanks, to prevent heat loss.
- Provide timed shut-off shower heads to eliminate the possibility of leaving showers running, which wastes water and heat energy; infrared sensors for starting and stopping showers are also gaining popularity.

- Keep room temperatures at a reasonable level; excessive room temperatures add to heat loss and energy consumption.
- Building heating and cooling controls should be examined and preset.
- Ventilation, air, and building exhaust requirements should be examined. A reduction in air flow will result in a saving of electrical energy to motor drives and additionally reduce the energy requirements for space heating and cooling.
- Review air conditioning and heating operations, seal off sections of plant operations which do not require environmental conditioning, and use air conditioning equipment only when needed.
- During non working hours the environmental control equipment should be shut down or reduced, automatic timer can be effective.
- Insure that all equipment is operating efficiently; filter, fan belts, and bearings should be in a good condition.

Heating and ventilation control

- Programmable Thermostats.
- Time Clocks.
- Equipment Efficiency.
- When process is needed.
- Lot controllers.

Impacts of appliances locations on energy consumption

It is highly recommended that household appliances and electric equipments should be placed at suitable locations within proper distribution. For example; the fridge should not be located in narrow and limited sites, also not so near to walls, in fear

The walls and other house envelopes may affect the performance of the operated machine, and may increase their power consumption to achieve their targeted tasks.

Also, taking in consideration, that also air leakage has a powerful influence on their characteristics, so choosing a proper place is as important as energy saving itself.

[illegible] Old vs. New appliances and power consumption

It has been noticed that old equipments usually consume more power, due to their degree of complexity and variable internal connections, therefore; when someone wants to buy a fridge for instance, it is recommended that he buy's a new one.

Another important thing that should be taken into account, the economical view, meanwhile; if you have an old fridge that consumes 300 kWh, and you wanna replace it with a 180 kWh new one, you should take in consideration is how wise you are in your choice, is that step achieves a real progress in energy saving align with your pocket? And how much time is still required to recover the initial cost to start earning profits ?

[illegible] Electric Power Systems and Energy Saving

In order to keep the manufacturing cost of a product minimum, and make its price competitive in the market, it is necessary to minimize energy consumption at all stages of the manufacturing process including electrical drives.

Energy conservation is also necessary because with the ever increasing demand, need for electrical power can only be met by conserving electrical power in addition to installation of new generating units. [7]

Guidelines for achieving Energy Saving in Power Systems

- Eliminate unnecessary transformers.
- Reduce Energy losses which are an inherent part of electric power distribution systems.
- The overall power factor of electrical systems should be checked for low power factor.
- Check load factors.
- Reduce peak loads wherever possible.
- Provide improved monitoring capability, sub-meters, or demand recorders.
- Avoid operation of equipment above its rated voltage.
- Minimize operation of idling or lightly loaded motors.
- Replace standard motors as they burn out with energy-efficient motors.
- Install capacitors in your AC circuit to decrease the magnitude of reactive power.

Measures for energy conservation in electrical drives

The following measures can be adopted:

- Use of efficient semiconductor converters.
- Use of efficient motors.
- Use of variable speed drives.
- Energy efficient operation of drives.
- Improvement of power factor.

- Using a motor of right rating.
- Improvement of quality of supply.
- Use of single to three phase semiconductor converters in rural applications.
- Regular and preventive maintenance of motors, transformers and coupled equipment.

3.8 Renewable energy sources and energy saving

It is hard to feed oneself, keep warm, get around, build or produce without energy. A source of innovation and progress, energy is one of the keys to development.

Energy consumption, which has increased thirteen-fold in a century, reflects the vitality of a country's economy and is one of the most reliable indicators of growth. In developing countries, where work stops at sunset, health, social and economic developments are hard to imagine.

A quarter of the global population consumes three-quarters of the energy produced. Fossil fuels still account for almost 80% of the energy used worldwide.

These finite resources are also responsible for the latest massive oil spills, problems of deforestation and soil erosion and, more importantly, air pollution.

On a global scale, fossil fuels generate almost 60% of carbon dioxide emissions, the most widespread of the greenhouse gases. Scientists and ecologists alike have repeatedly sounded the alarm to alert political and economic decision-makers to the problem of global warming.

Since then, multiple initiatives have been taken to develop new and sustainable energies using the wind, oceans, earth and sun.

Uncertainty about the future of fusion research has increased the importance of renewable energy sources.

Renewable energy sources main assets are their environmental cleanliness and their virtual inexhaustibility. Major drawbacks, however, are limited energy production (in most cases not suitable for large-scale power generation) as well as relative costliness to build and maintain.

[illegible] Wind Energy

Mankind has made use of wind power since ancient times. Wind has powered boats and other sea craft for years. Further, the use of windmills to provide power for the accomplishment of agricultural tasks has contributed to the growth of civilization.

This important renewable energy source is starting to be looked at again as a possible source of clean, cheap energy for years to come.

On the same principle as the windmill, revolving propellers drive a rotor that is connected to a generator which converts mechanical energy to electrical energy.

Whether on land (fields, farms, parks, wind farms) or offshore, all winds have the potential to generate energy, and thus decreasing the consumption rates of electricity generated from other finite sources.

FIGURE 3.8 A Typical Wind Turbine

One of the main problems with wind power is the space that is used up by the so-called wind farms. In some cases, the space taken up can seriously alter the environment.

FIGURE 3.9 A Typical Wind Farm

Another problem with wind power is that relatively speaking, it does not generate very much energy for the price.

Biomass Energy

This consists in the transformation of renewable organic matter (plant or animal) into energy.

Biomass energy provides agriculture with new outlets and is a means of recycling waste. Various processes exist for producing heat, electricity or fuel.

Solar Power

Solar energy reaches the atmosphere in the form of electromagnetic rays that produce light and heat. Photovoltaic cells convert this energy directly to electricity.

However, this is the most practical and applicable source to implement in our country, but with a typically high initial cost; but can retrofit a pay pack in almost a short period of time

FIGURE 3.10 Discreetly blending in with roof tiles, solar panels

[illegible] Channel Light

Channeling light from its natural source to then diffuse it inside an old or new building is a simple way to save energy.

The system, which comprises a dome on the roof of the building and an optical channel made up of micro-prisms, concentrates light irrespective of the angle of the sun

This light is then channeled along an aluminum-lined pipe, up to 20 m in length. Up to 80% of this light is released via an optical diffuser into any room and at any time of day or night.

FIGURE 3.11 A Typical Channel Light

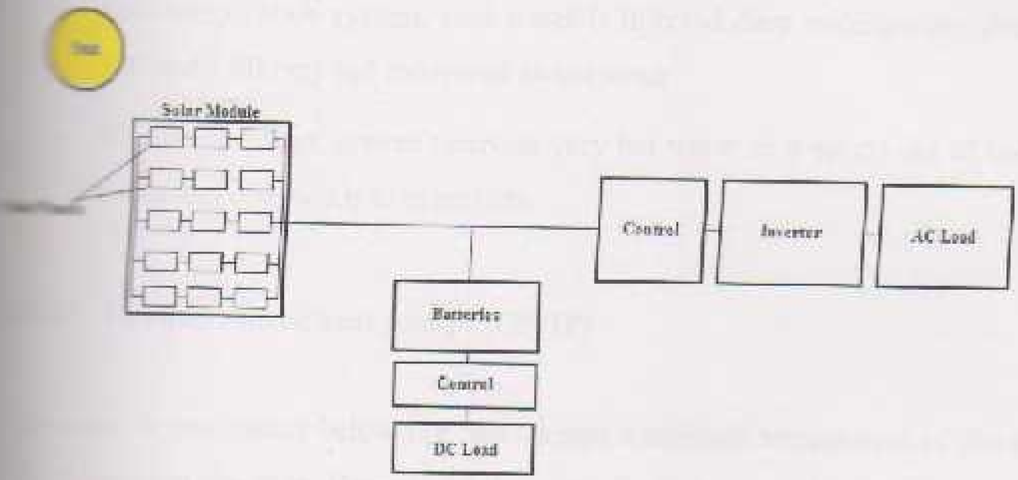


FIGURE 3.12 Typical Design of a Solar Energy System Block Diagram

3.8.3.2 Factors affecting on radiation:

- Radiation received per unit area perpendicular to the incoming radiation is greater than that received per unit area on a horizontal surface due to the earth's curvature and the tilt of its axis. It is for this reason that solar collectors are generally placed on an angle.
- Atmospheric conditions, its purity, vapor, dust, and smoke contents.
- Length of daylight period, which is dependent upon the day of the year.
- Siting, orientation and shape: for simple rectangular plans, the most effective shapes will be those elongated in the east west direction.

3.8.4 Geothermal Energy

The center of the earth can reach **12,000** degrees Fahrenheit. Just imagine if we could tap that heat for our own use. Well, geothermal systems do just that.

This energy is produced by recovering heat from underground sources.

Two techniques exist to produce energy:

- Low-temperature system, cold water is injected deep underground (between 500 and 1,500 m) and recovered as hot water.
- High-temperature system recovers very hot water as it spurts out of volcanic zones and converts it to electricity.

3.8.4.1 Ground source heat pumps (GSHP)

The earth - a few meters below our feet - keeps a constant temperature of about 11-13C throughout the year. Because of the ground's high thermal mass, it stores heat from the sun during the summer.

Ground source heat pumps (GSHP) can transfer this heat from the ground into a building to provide space heating and, in some cases, pre-heating domestic hot water.

For every unit of electricity used to pump the heat, 3-4 units of heat are produced.

[illegible] Components and Principle of Operation

There are three important elements of a GSHP:

- Ground loop - comprises lengths of pipe buried in the ground, either in a borehole or a horizontal trench. The pipe is usually a closed circuit and is filled with a mixture of water and antifreeze.
- Heat pump - fridges and air conditioners are both examples. A heat pump has three main components:

  Evaporator: takes the heat from the water in the ground loop.

  Compressor: compresses the gaseous refrigerant to the temperature needed for the heat distribution circuit.

  Condenser: gives up heat to a hot water tank which feeds the distribution system.

- Heat distribution system - consists of under floor heating or radiators for space heating and in some cases water storage for hot water supply.

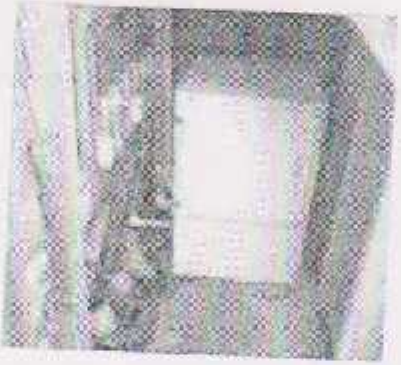


FIGURE 3.13 8kW heat pump unit connected to the ground loops via the red manifolds

4

3.4.3 Cost

- Installation costs: The installed cost of a GSHP, for a professional installation, ranges from about 3000 NIS – 6000 NIS per kW of peak heat output, excluding the cost of the distribution system.

- Running costs: The efficiency of a GSHP system is measured by the Coefficient of Performance (COP). This is the ratio of the number of units of heat output for each unit of electricity input used to drive the compressor and pump for the ground loop. Typical COP's range between 2.5 - 4.

3.4.4 Considerations when installing a GSHP

- The type of heat distribution system. GSHP's can be combined with radiators but under floor heating is better as it works at a lower temperature.
- Availability of the required space.
- Suitability of the ground type for digging.

- Looking toward to have a combinational system, install solar PV or some other form of renewable electricity generating system to power the compressor.

CHAPTER FOUR

POWER FACTOR AND POWER FACTOR CORRECTION

4.14. Types of Power Factor Correction

4.15. Equipments for Solving the Problem of Phase Lag

4.16. Power Capacitors for Power Factor Correction

4.17. Synchronous Motors for Power Factor Correction

4.18. Power Factor Correction vs. Harmonics

4.1 Introduction

The power factor is the percentage of current in an alternating current circuit which can be used as energy for the intended need. For example, a power factor of 0.75 indicates that 75% of the current supplied is usefully employed.

Power factor is a unit-less number between 1 and 0, where a power factor of 1 would indicate the current and voltage are exactly in phase, which is seemed to be difficult practically.

Low power factor has to be improved (corrected); since it is a desirable situation to have a relatively high power factor. Massive factories and industrial plants should have a technology to improve their power factor. Most of them have to pay for municipalities and electricity companies according to the S reading meters. Moreover, their consumed energy will be much more effective.

In this chapter, many power factor correction methods are to be mentioned and extensively discussed. Capacitors are the most important and most used technique, due to its relative low cost and high efficiency.

Other new and future techniques for power factor correction are to be discussed briefly, and one or more designs are to be put forward as a future design for this graduation-project.

4.2 Power types

4.2.1 Active Power

Pure resistive loads convert the Electrical Power to another form such as Heat, Light or Mechanical Power. For these types of loads which have no Inductive or capacitive components, the voltage and current waveform intersect the Zero coordinate at the same point.

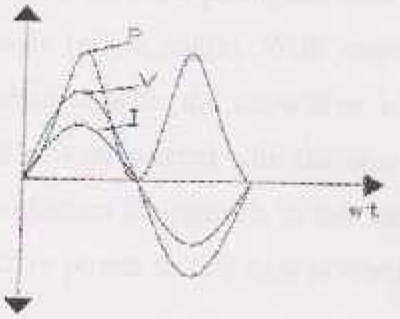


FIGURE 4.1 P, V, and I waveforms when phase shift is zero.

For such Resistive loads, the voltage and current are set to be In-Phase. The active Power (P) measured in Watt units, is calculated as the Product of voltage and current and it is entirely on the positive area.

$$P = V \times I \Leftrightarrow [PF = 1] ....(4.1)$$

In practice, it is unusual to find purely resistive loads, since most of the electrical equipments have Inductive components and they operate in the presence of magnetic field like Motor, Transformer etc. The current which is used to create and reverse the magnetic field is not dissipated, but flows as Reactive Current between the Source and the Load.

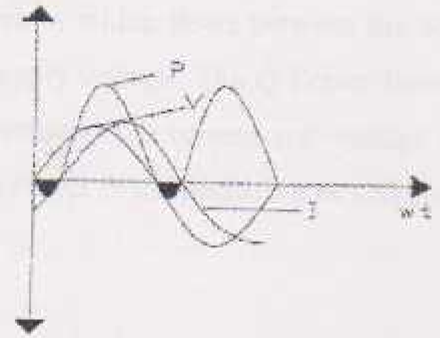


FIGURE 4.2 P, V, and I waveforms when phase shift is not zero

As illustrated in the figure above, the voltage and current waveform no longer intersect the Zero Coordinate at the same point, but with the displacement normally referred as displacement angle (phase angle). With magnetic / inductive loads, the current lags the voltage whereas with the capacitive loads the current leads the voltage. If the Power (P) is now calculated with the above formula, negative value obtained with one of the two factors is negative. In this case, part of the power (P) is in the negative area. The active power in this case is computed as per the following formula:

$$P = V \times I \times Cos\theta ....(4.2)$$

A new parameter $Cos\theta$ is added in effective value computation for active power and this parameter is referred to as Power Factor (PF) in all electrical power computations.

Reactive Power

Electrical machines work on the principle of conversion of electromagnetic energy (e.g. electric motors, transformers). A part of input energy is consumed for creating and maintaining the magnetic field. This part of the input energy cannot be converted into active energy and is returned to the electrical network on removal of the magnetic field. This power is known as Reactive power (Q), measured in VARs.

Reactive Power is the power, which flows between the Source and the Load at the same frequency as the supply voltage. The Q Power flows back and forth, causing 90° Out of phase shift between the current and voltage waveform. This Reactive Power has one half of the Power in the positive area and the other half in the negative area.

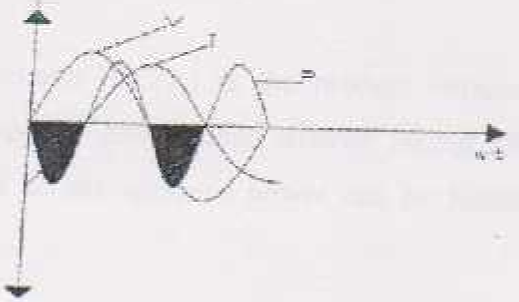


FIGURE 4.3 P, V, and I waveforms when phase shift is not zero

In this case, the Reactive Power is computed as:

$$Q = V \times I \times Sin\theta ....(4.3)$$

As shown in Figure 4.4, reactive power (measured in kVARs) caused by inductance always acts at a 180-degree angle to reactive power from capacitors.

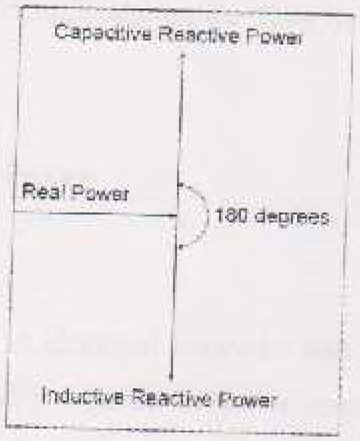


FIGURE 4.4 Capacitive Reactance/Inductive Reactance

4.2.3 Apparent Power

Applications of Electrical equipment are based on the conversion of Electrical energy into some other form of energy. The Electrical energy drawn by an equipment from the Source is termed as Apparent Power (S) and it consists of Active and Reactive Power.

Apparent Power (measured in VA) is the product obtained by multiplying the effective values of voltage and current without taking into account the Phase displacement (θ). And so the apparent power can be found using the following formula:

$$S = V \times I \text{............(4.4)}$$

Also

$$S = \sqrt{P^2 + Q^2} \text{............(4.5)}$$

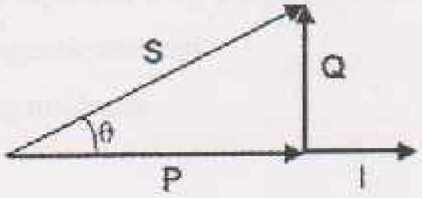


FIGURE 4.5 Power Triangle relating the three types of power; P, Q, and S

4.3 Sources of Reactive Power

Most devices and machines in electrical networks and industrial plants operate on lagging PF, which means that it requires inductive reactive power so as to achieve electromagnetic flux needed for their operations, those machines are known as reactive power consuming devices, whereas, devices operating on leading PF are known as reactive power supplying devices. As a result, connecting reactive power supplying devices with those consuming devices leads to PF improvement or PF correction (PFC).

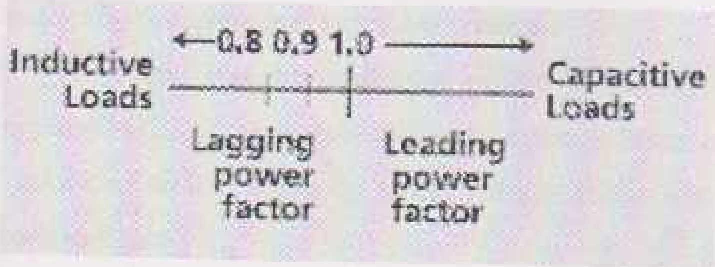


FIGURE 4.6 Leading and Lagging reactive power consumers or suppliers

Reactive Power Consuming Devices

- Induction motors, especially when they are operated with less than their full loads.
- Transformers, they represent a very high inductance due to their large coils, and iron core of magnetic material.
- Electric arc welding machines.
- Electric furnaces.
- Electronic devices in general which is widely used in control.
- Gas discharge lamps.
- Rectifiers.

Reactive Power Supplying Devices

- Capacitors.
- Synchronous Condensers.

Exact Meaning of Power Factor

Power Factor (PF) is usually defined as $Cos\theta$, also known as displacement power factor (DPF). This conventional definition is only valid when considering ideal sinusoidal signals for both current and voltage waveforms.

But the reality is something else, because most offline power supplies (switched-mode power supplies-SMPS) draw a non-sinusoidal current. Many off-line systems have a typical front-end section made by a rectification bridge and an input filter capacitor as shown in figure 4.7.

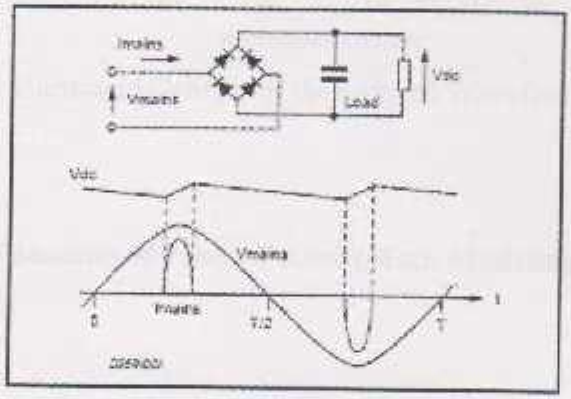


FIGURE 4.7 Full Wave Bridge Rectifier Waveforms

A current flows to charge the capacitor only when the instantaneous AC voltage exceeds the voltage on the capacitor. The load draws the energy stored inside the input capacitor. The phase lag θ, also the harmonic content of such a typical pulsed current waveform produce non-efficient extra RMS currents, affecting then the real power available from the mains.

So, PF is much more than simply $Cos\theta$. The PF value measures how much the mains efficiency is affected by both, phase lag θ and harmonic content of the input current, meanwhile; the purpose of the power factor correction circuit is to minimize the input current distortion and make the current in phase with the voltage.

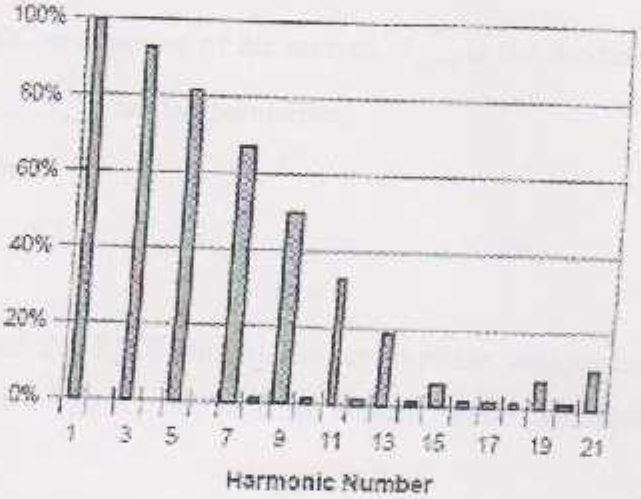


FIGURE 4.8 Harmonic Content of the Current Waveform in Figure 4.7

Theoretical Meaning of Power Factor (Math Modeling)

The power factor (PF) is simply defined by:

$$PF = \frac{P}{S} = \frac{real.power}{total.apparent.power} \text{...........(4.6)}$$

From the previous illustration, it is concluded that there are two cases for finding an exact formula of PF, non-ideal sinusoidal, and ideal sinusoidal current waveforms.

If the current has a periodic non-ideal sinusoidal waveform, the Fourier transform can be applied to get the following formula:

$$I_{RMS-total} = \sqrt{I^2_0 + I^2_{1RMS} + I^2_{2RMS} + ... + I^2_{nRMS}} ....(4.7)$$

Where I_0 is the DC component of the current, I_{1RMS} is the fundamental of the RMS current, and $I_{2RMS} .....I_{nRMS}$ are the harmonics.

For a pure AC signal:

$$I_0 = 0$$

The fundamental of the RMS current has an in-phase component I_{1RMS} P and a quadrature component I_{1RMS} Q. So, the RMS current can be expressed as:

$$I_{RMS-total} = \sqrt{I^2_{1RMS-P} - I^2_{1RMS-Q} + \sum_{n=2}^{\infty} I^2_{nRMS}} ....(4.8)$$

Then, the Real Power is given by:

$$P = V_{RMS} \times I_{1RMS-P} ....(4.9)$$

and is the displacement angle between the input voltage and the in-phase component of the fundamental current:

$$I_{1RMS-P} = I_{1RMS} \times Cos\theta ....(4.10)$$

and

$$P = V_{RMS} \times I_{1RMS} \times Cos\theta ....(4.11)$$

$$S = V_{RMS} \times I_{RMS-total} ....(4.12)$$

Then, the Power Factor can be calculated as:

$$PF = \left(\frac{I_{1RMS}}{I_{RMS-total}} \right) . Cos\theta ....(413)$$

We can introduce the k_d factor by:

$$k_d = \frac{I_{1RMS}}{I_{RMS-total}} = Cos\varphi ....(4.14)$$

φ is the distortion angle. The k_d factor is linked to the harmonic content of the current. If the harmonic content of $I_{RMS\,(total)}$ is approaching zero, then, $k_d \approx 1$.

High power factor and low harmonics go hand-in-hand. There is not a direct correlation however, the following equations link total harmonic distortion to power factor.

$$k_d = \frac{1}{\sqrt{1 + \left(\frac{THD(\%)}{100} \right)^2}} = Cos\varphi ....(4.15)$$

Where THD is the total harmonic distortion factor (distortion factor).

Finally PF can be expressed by:

$$PF = Cos\varphi \times Cos\theta ....(4.16)$$

And since

$$k_{\theta} = Cos\theta \text{............}(4.17)$$

Then,

$$PF = k_d \times k_{\theta} \text{............}(4.18)$$

Which is known as the true power factor (TPF).

However, the modern definition of power factor uses only the first or fundamental harmonic of the line current for the real power calculation (PF = k_{θ} only).

The Reactive component is a measure of the Power Factor. If the Reactive component is small, the Phase angle θ is small and hence the Power Factor $Cos\theta$ will be high. Therefore, a circuit having small reactive current will have high Power Factor and vice versa.

The Power Factor at full load is normally given on the nameplates of the electrical machines.

Average Power Factor

The Power Factor discussed above is Instantaneous Power Factor. However, the invoicing in all the Utility companies is based on the Power Factor on monthly average basis. Average Power Factor is a time integrated quantity and is defined as:

$$PF = \frac{kWh}{kVAh} \text{............}(4.19)$$

Since the kVAh includes both lagging Reactive Power and Leading Reactive Power. This effectively implies, whenever the Reactive Power flows to and fro, the source kVAh is counted irrespective of the direction of the Reactive Power flow. For effective average Power Factor improvement, it may not be just sufficient to maintain instantaneous Power Factor at healthy levels during loaded conditions, but also to maintain the instantaneous Power Factor at healthy levels during lightly loaded conditions and jerking load operations.

Reactive Factor

As mentioned before, the current can be divided into two components, the active component which does the useful work, and the reactive component which does no work. The sum of the two components is the apparent current, in other words; apparent power, combining active and apparent components results in the concept of Power Factor (PF), whereas combining the reactive and apparent components together results in what is known as Reactive Factor (RF); which in turn leads to the following formula:

$$\text{Reactive.Factor}(RF) = \frac{\text{Reactive.Power}(Q)}{\text{Apparent.Power}(S)} \text{............}(4.20)$$

Power Factor Measurement

The most convenient and easiest method of measuring power factor at any point in a circuit or installation is by means of a power factor indicator. Where an instrument of this type is not available, accurate calculation for three phase systems can be made by taking Watt, Volt and Ampere measurements, and using these values in the following equation:

$$PF = \frac{Watts \times 1{,}000}{\sqrt{3} \times V \times I} \quad \text{..........(4.21)}$$

Bad Effects of Low Power Factor

- **Higher Apparent Current**

Low Power Factor causes higher Apparent Current in any Load Centre. For example, if the required Active Current is 10 A, and the prevailing Reactive Current is 10 A, the Apparent Current will be 14.14 A, while drawing at a power factor of 0.71 lag. Hence,
To operate an equipment with 10 A active Current, the Apparent current drawn will be 14.14 A.

- **Higher Losses in the Electrical Distribution System**

The loss in the Cables, Switches, Motors etc., are in square proportion of the Active Current. i.e., 14.14 A leads to higher losses in the electrical systems. The higher

Active Current passing through all electrical circuits, cables, bus-bars, switches, motors etc., reduces the life of the components and also leads to more break-downs.

The electrical losses at a higher level will lead to higher resistive loss in square proportion of the Active Current, in turn leading to higher monthly consumption bills.

- **Low Voltage in the System (voltage clipping)**

The low power factor leads to low voltage which leads to motor winding burn-outs, repetitive fuse failure etc., which in turn lead to production down time.

- **Low Plant Load Factor**

The low power factor reduces the capacity of the distribution network. Low Power Factor increases the maintenance cost of the Power Distribution System, in addition to the stiff power tariffs being paid to the distribution authorities.

- **Reduces an electrical system's distribution capacity**

Uncorrected power factor will cause increased losses in your electrical distribution system and limit capacity for expansion due to the increasing of the loading.

- **Oversized transformers, cables, and utility devices**

To maintain the amount of power required, due to the increment of drawn current by the facility.

- **Presence of harmonics**

These two harmonics travel down the neutral line and disrupt other devices connected to the line. One is the low efficiency of transmission networks and distribution transformers. Effects on the lighting lamps performance in general, lighting intensity could be decreased as the incandescent lamps, whereas others cannot operate as gas discharge lamps (Florescent, mercury, and sodium lamps).

4.20 Governmental Limitations for Low Power Factor

Governments took in consideration some limits to increase the electricity tariffs for those factories and companies who have power factor less than a reference value, due and economical view, and installed meters to record the consumption of reactive power in kVAh in addition to meters of active power in kWh, and those factories are forced to pay additional amount of money as a punishment, additional cost can be found as follows:

Let the reference power factor ordered is 0.90, and the plant's power factor is 0.75, and let the kWh consumed monthly is about 100000 kWh.

$$Active.Power.Cost = kWh \times Tariff = 100,000 \times 0.5 = 50,000 - NIS \quad (4.22)$$

$$Reactive.Power.Cost = \left[\left(\frac{PF_{REF.}}{PF_{ACT.}}\right) - 1\right] \times kWh \times Tariff \Leftrightarrow$$

$$\Leftrightarrow \left[\left(\frac{0.90}{0.75}\right) - 1\right] \times 100,000 \times 0.5 = 10,000 - NIS$$

$$Total.Cost = Active.Power.Cost + Reactive.Power.Cost = 50,000 + 10,000 = 60,000 - NIS$$

All previously mentioned devices and machines operate at lagging PF, which means that they are inductive loads. Their PF is usually between 0.3-0.8. Engineers responsible of operating those machines, tries to improve their PF to about unity, by means of inductive reactive power compensation by providing capacitive reactive power suppliers.

4.2.1 Power Factor Improvement (Power Factor Correction-PFC)

The power factor at which consumers take their electricity is outside the control of the electricity board. It is governed entirely by the electrical plant and equipment which is installed and operated within the consumers building.

As illustrated previously, power factor correction should deal with two different phenomena, phase shift (phase angle θ), and harmonic content (distortion angle φ).

4.2.2 Savings from Improving Power Factor

4.2.2.1 Direct Savings

- Reduction in Maximum Demand of kVA and so reduces kVAh charges.
- Reduction in kW and kWh Consumption.
- Reduced (I^2R) losses in the total Distribution Network and reduced voltage drop. To calculate loss reduction, the following formula is used:

$$\%Reduction = 100 - 100\left(\frac{PF_{ORIGINAL}}{PF_{NEW}}\right)^2 \quad ....(4.23)$$

- Improved Voltage at the point of use, leading to enhanced life of the transformer, cables, switchgear, motors, etc.
- Increase internal electrical system capacity and so increasing available power.
- Reduction in the size of transformers, cables, switches, etc.

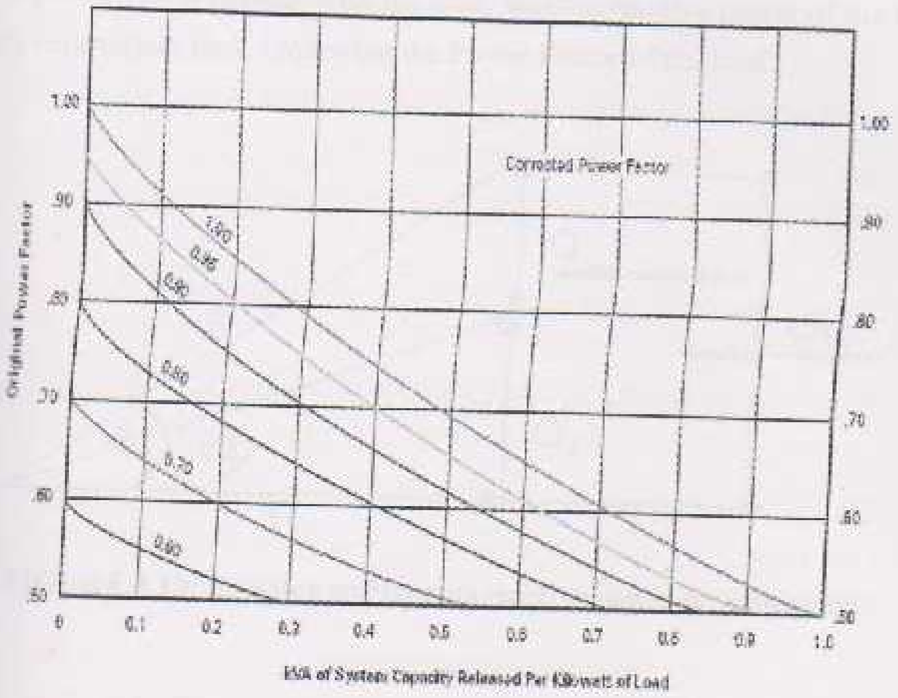


FIGURE 4.9 Corrected Power Factor Releases System kVA

4.22.2 Indirect Savings

- Reduction in Maintenance Cost.
- Reduction of Burn-outs due to reduced Apparent Current Flow.
- Improved performance and efficiency of operating machines due to healthy voltage.

4.13 Power Factor Correction vs. Phase Shift

Phase shift is measured in degrees, but it is equivalent to time (where 360 degrees equals the time required for one full AC cycle).

As the Power distribution system must be dimensioned to carry the apparent power, efforts are made to keep this as low as possible. If a device taking leading reactive power is connected in parallel with the load, lagging reactive power of the load will be partly neutralized, thus, improving the Power Factor of the load.

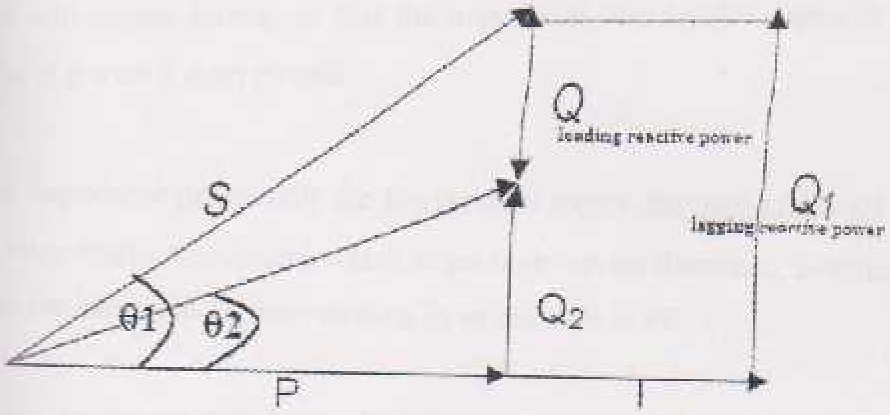


FIGURE 4.10 Leading and lagging reactive power neutralization

Where,

$$Q_{Leading} = Q_{1-Lagging} - Q_{2-Lagging} \qquad (4.24)$$

4.14 Types of Power Factor Correction

There are mainly two types of power factor correction; active and passive. However these two methods are not only dependent of the point where the PFC unit is located, but also depend on the applied frequency.

4.14.1 Passive Power Factor Correction

This technique is simply done by adding passive elements such as capacitors, inductors & resistors to provide a resonant circuit that should together connected on parallel with mains source, so that the impedance seen by the source is so small, acting as if it were a short circuit.

That low impedance passes only the fundamental source frequency (50 / 60 Hz) and kills all other higher frequencies which attain high current distortion, in other words, it absorbs the harmonic content resulting in an improve in PF.

Hence; this technique will be studied in more details in the following sections (section 4.18.4 – Harmonic filters).

4.14.2 Active Power Factor Correction

4.14.2.1 Active Low Frequency Power Factor Correction

This method is simply done by locating the PFC unit before the rectifying converter of the power supply (between the mains and the rectifier).

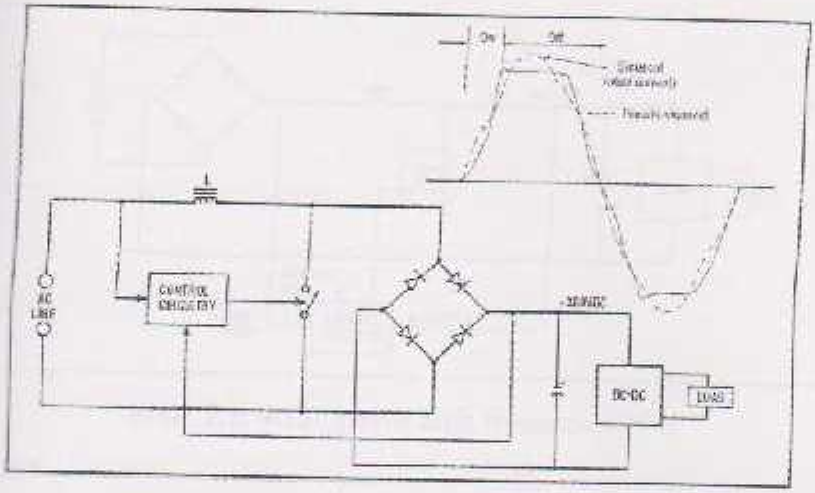


FIGURE 4.11 Active low frequency PFC

Advantages of Active low PFC can be summed in:

- It is more reliable.
- Inexpensive.
- Typically corrects to about 0.9.
- Can achieve a 0.7 power factor for power levels below 500 watts.

Disadvantages of Active low PFC can be summed in:

- The bulkiness of the inductor restricts its usability in many applications.
- A passive filter would be too large and heavy for most designs.

4.14.2.2 Active High Frequency Power Factor Correction

This is done by using active elements such as transistors, thyristors, IC's. This method is simply done by connecting the PFC unit after the rectifying converter (between the rectifier and other side of the electric circuit).

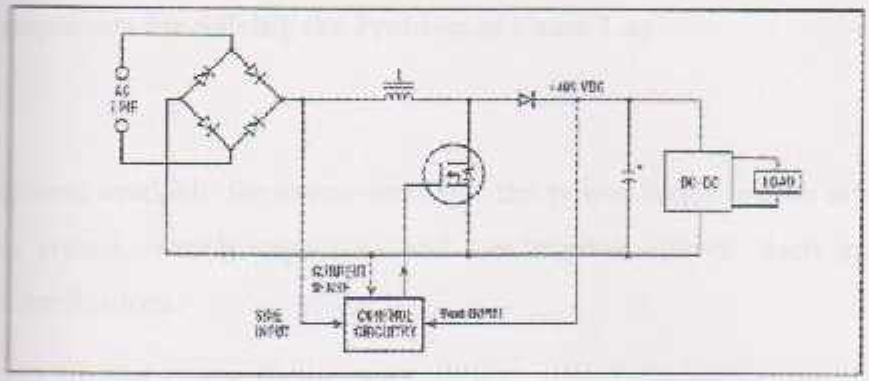


FIGURE 4.12 Active high frequency PFC

Specifications of Active high PFC:

- It is more effective.
- More expensive.
- Generally integrated with the switch-mode power supply, and can achieve about 0.98 PF.
- Wide input voltage range.
- Regulated dc bus.
- Small size.

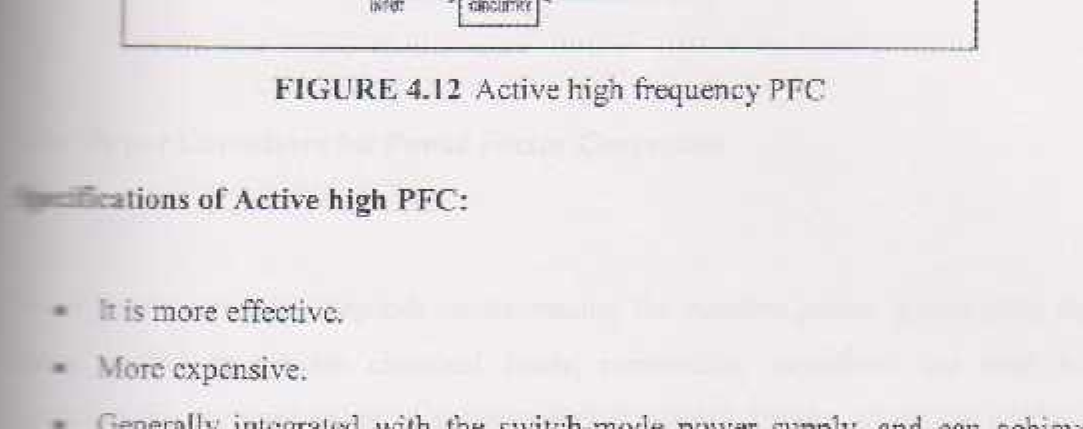


FIGURE 4.13 Input Characteristics of power supplies with Different PFC Types (None, Passive, and Active)

Hence; this technique will be studied more firmly in chapter five

4.15 Equipments for Solving the Problem of Phase Lag

The equipment available for improvement of the power factor can be divided into two main groups, namely capacitors and synchronous motors. Each system has particular applications.

4.16 Power Capacitors for Power Factor Correction

Power factor correction depends on decreasing the reactive power drawn from the mains needed to operate electrical loads; meanwhile, capacitors are used for providing the required value of reactive power needed for the operation of those loads.

For power factor correction in industrial plants, most loads requires a group of capacitors known as Automatic self regulating capacitor bank, which is a group of capacitors, fuses, contactors, circuit breaker, and a controller, all connected on parallel with the electrical load. that group adjusts its value automatically as required value of reactive power, that adjustment depends on the value of the reactive load and the required value of power factor.

The use of capacitors for improvement of the power factor is reliable, economical and practical for a wide variety of commercial and industrial applications. Capacitors for low voltage are designed for connecting either to individual items of equipment or to distribution centers, alternatively, banks of capacitors may be connected to main bus-bars. High voltage capacitors available for individual correction of large motors offer many advantages and the rating of a capacitor used for the purpose should provide as high a power factor as possible without exceeding 85% of the nomagnetizing kVA of the machine. Leading power factor should not be obtained under any circumstances.

4.26.1 Advantages of Capacitors

- Capacitors have no moving parts.
- They require very little or no maintenance.
- No special structural work or foundations are required for installation.
- Capacitors are flexible and additional units can be installed as a project or system is extended.
- Correction equipment can invariably be installed adjacent to the machine concerned.

4.26.2 Disadvantages of Capacitors

- They have a short service life ranging from 8 to 10 years.
- They are easily damaged if the voltage exceeds the rated value.
- Once the capacitors are damaged, there repair is uneconomical.

4.26.3 Types of Power Factor Correction Capacitors

There are mainly two types of power capacitors used for PFC. depending on the ratings of the desired application:

1. Low voltage capacitors.
   - Low voltage capacitors units.
   - Low voltage capacitor bank.
2. High voltage capacitors.
   - High Voltage Capacitors units.
   - High Voltage Capacitors Banks.

4.26.4 Effects of Capacitors

There are many effects caused by capacitors. First, capacitors consume energy at the rate of about one Watt per kVAR installed. More efficient capacitors have been developed to reduce this rate to about 0.5 Watt per kVAR. Another effect is a slight increase in voltage can be expected. And so, there is a chance that resonance may occur between the capacitors and other circuit elements in the system.

4.26.5 Capacitors for PFC in Non-Linear, Non-Sinusoidal Loads

Until recently, almost all loads were linear, such as motors, incandescent lighting and heating loads, with the current waveform closely matching sinusoidal voltage waveform and changing in proportion to the load. Lately, non-linear loads, such as DC drives, variable frequency drives (VFD), programmable controllers, induction furnaces and personal computers, which draw current at frequencies other than 50-60 Hz, have increased dramatically.

The increase in non-linear loads has led to harmonic distortion in electrical distribution systems. Although capacitors do not cause harmonics, they can aggravate existing conditions. Because harmonic voltages and currents are affected by all of the equipment in a facility, they are sometimes difficult to predict and model.

4.26.6 Determination of Required Capacitor Rating

There are three methods used to determine the required capacitor rating. The measurement method, multiplier method and curves method. However the multiplier method is mostly used.

4.16.6.1 Measurement methods

Capacitors value in kVAR's required for power factor correction are determined by one of the following three measurement methods:

- **Measurement with Current and Power Factor**

The active power P is calculated from the measured voltage V, apparent current I_S and Power Factor as follows:

$$P = \sqrt{3} \times V \times I \times 10^{-3} \text{.......................} (4.25)$$

If the desired $Cos\theta$, (PF), has been specified, the capacitor power rating can be calculated from the following formula:

$$Q_C = P \times F \text{.......................................} (4.26)$$

Where,

$$F = Tan\theta_{ACT} - Tan\theta_{Desired} \text{...........} (4.27)$$

- **Measurements with recordance of Active and Reactive power**

More reliable results can be obtained by recording all Parameters including Peak values for a longer duration. With the recorded parameters, the required KVAR can be arrived as per the formula given below:

Q_c = required capacitor rating.

Q_m = measured reactive power.

P = measured active power.

$Tan\theta_{Desired}$ = the corresponding value of $Tan\theta$ at the desired $Cos\theta$

$$Q_C = Q_M - (P \times Tan\theta_{Desired}) \qquad (4.28)$$

- **Measurement by Reading Meters**

For a period of total 8 hours, the active and reactive energy needs to be measured and the initial and final readings shall be noted for calculating the required kVAR.

RM_1 = Initial Reactive Energy Reading.

RM_2 = Final Reactive Energy Reading.

AM_1 = Initial Active Energy Reading.

AM_2 = Final Active Energy Reading.

$$Tan\theta_{ACT.} = \frac{RM_2 - RM_1}{AM_2 - AM_1} \qquad (4.29)$$

With the calculated Tan θ and the desired $Cos\theta$, we can derive the capacitor requirement as given below:

$$Q_C = \frac{AM_2 - AM_1}{8} \times K \times F \qquad (4.30)$$

Where:

K = Multiplication Factor

$F = Tan\theta_{ACT.} - Tan\theta_{Desired}$

This method is only for instantaneous values. The loading pattern may vary from time to time. Hence, care shall be taken while extrapolating these data. A simple method is to take several measurements at different times to have accurate selection.

4.16.6.2 Multipliers method

Referring to Appendix D (Table D.7), do the following:

(1) Find the present power factor in column 1.

(2) Read across to optimum power factor column.

(3) Multiply that number by kW demand.

So as to make it easier to understand, an example is enough to illustrate the case.

Example:

If your plant consumed 450 kW, was currently operating at 70% power factor and you wanted to correct power factor to 95%, you have to:

(1) Find 0.70 in column 1.

(2) Read across to 0.95 column, you will find 0.691 which is called the multiplier.

(3) Multiply 0.691 by 400 kW to get 310.95 (round to 311).

(4) You need 311 kVAR to bring your plant to 95% power factor.

4.16.6.3 Curves method

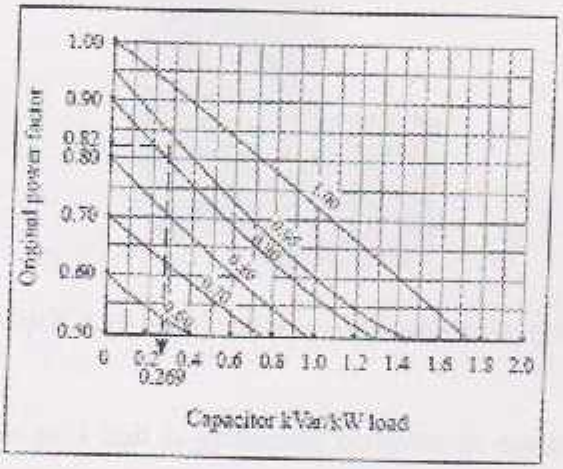


FIGURE 4.14 Curve for determining required kVARs of capacitor per kW for PFC

4.26.7 Types of Reactive Power Compensation Systems using Capacitors

Power factor correction is a frequently misunderstood topic. Improper techniques can result in over-correction, under-correction, and harmonic resonance, so it is necessary to Select the correct System and sizing for Reactive Power Compensation. Following loading patterns are considered for the selection of Suitable Capacitor/Reactive Power Compensation System.

4.26.7.1 Steady Loads

- **Fixed Capacitors**

For Steady Loads, the Capacitors can be connected across the terminals. A correctly sized Capacitor installed in parallel to each Individual Inductive Loads like Motor etc., improves the Power Factor. When load levels are high, a shunt capacitor system is highly beneficial. However, when the load drops off, the capacitor poses more harm to the System compared to its benefits. An excess of capacitance in service can lead to higher than desired voltages, excessively leading power factors, and resonance phenomena.

FIGURE 4.15 Fixed-value compensation capacitors

Since Fixed Capacitor as a unit is extremely compact in design and non-polluting because of the dry type design. Another advantage, fixed capacitor is easy to install and it is maintenance-free. Also it can be used for a wide number of applications like wind turbine applications, Harmonic Filter technology etc. And so it reduces the Apparent Power on the cabling including cable feeding the Motors.

- **Banked Capacitors**

Banked Capacitors are used wherever the kVAR Requirement is high and loading pattern is constant like in a Spinning Mill.

- **Manual Switched Banked Capacitors**

Manually switched Banked Capacitors are used wherever it is necessary to operate each step of the Capacitor bank individually in a manual fashion depending on the kVAR requirement like in an Industry where the machines are operated based on 25%, 50%, and 100% loading. Each capacitor circuitry pertaining to the particular loading pattern can be operated individually through Capacitor Duty contactors and push buttons for switching on and off.

- **Auto Switched Banked Capacitors**

These types of Capacitor Banks are commonly used for Individual Motor Compensation, wherein the Capacitor is switched ON after a period of delay from the Switching ON of the Motor. The delay is basically introduced, since the Inrush current of Induction Motor is usually 7 to 8 times higher than the rated current. Hence, to avoid such higher magnitude currents through the capacitor, time delay is introduced through a timer circuit. Auto switching on and off is controlled through Control Contactor energized through the Motor Controls along with provision for Auto Manual Selector Switch.

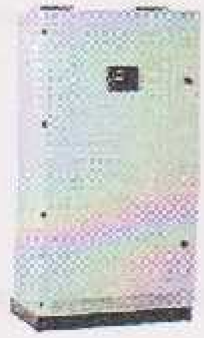


FIGURE 4.16 Automatic-compensation-regulating equipment

4.16.7.2 Varying Loads

Automatic Power Factor Correction Systems (APFC)

The present day electrical networks cater to a variety of loads like UPS, Soft Starter etc which dynamically fluctuates and creates waveforms distortion thereby necessitating an APFC System, which is self adaptable with short reaction times for extremely fluctuating power levels.

Benefits of an APFC System

- To minimize line losses, thus saving power consumption
- Improvement in Voltage Regulation
- Avoid manual disruptions
- Longer life for all electrical circuits, cables, bus-bars, switches, motors etc.
- Avoidance of motor winding failure and end termination darkening or burn outs.

Types of switching in APFC System

- Contactor Switching.
- Thyristor Switching.

Basic Principle of Operation of an APFC System

Power Factor sensing is done by the APFC Relay (Reactive Power Controller), which sends the control signal to the switching device (Contactor/Thyristor). The switching device senses the command from the relay and switches the required Capacitor stages.

Total System Response Time

This is the time taken from the moment when PF is changed from unity to poor, to the time System brings it back to near unity.

The total delay can be divided into two parts:

- Delay in the APFC Relay (the time taken to sense the PF Changes and to deliver suitable output commands to the Switches)
- Delay in the Switching Device (the time taken to receive the command from the APFC Relay to the time when the capacitor is brought in and out from the circuit)

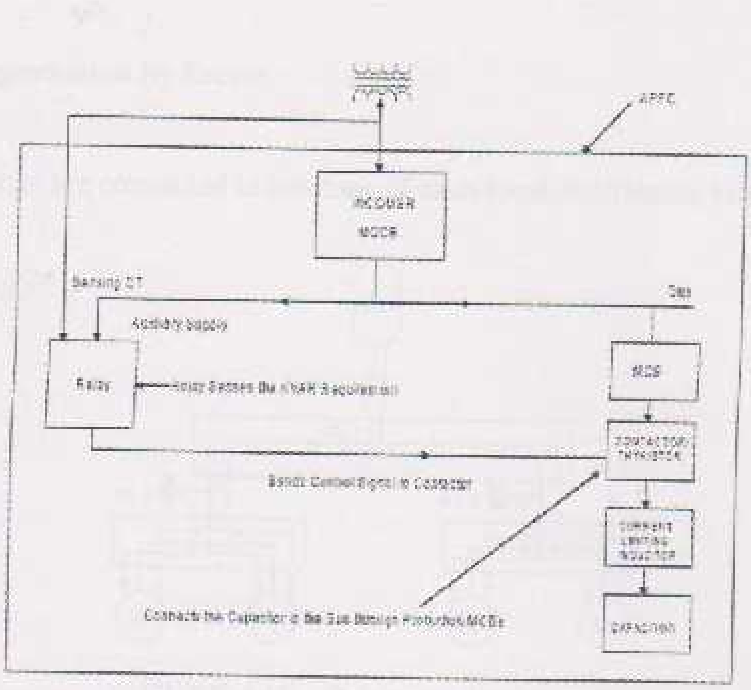


FIGURE 4.17 Basic principle of operation of an APFC system

4.16.8 Where to Install Correction Capacitors

- **Global Compensation**

The capacitor bank is connected to the bus-bars of the main distribution board for the installation, and remains in service during the period of normal load.

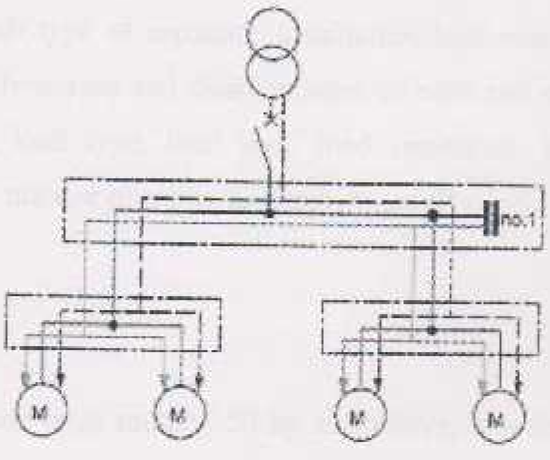


FIGURE 4.18 Global compensation

- **Compensation by Sector**

Capacitor banks are connected to bus-bars of each local distribution board.

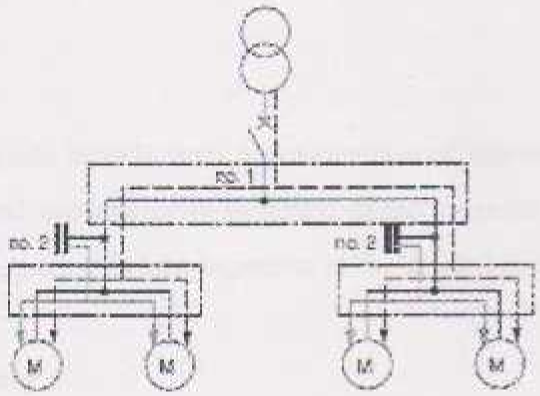


FIGURE 4.19 Compensation by sector

- **Individual Compensation**

Capacitors are connected directly to the terminals of inductive circuit. The kVAR rating of the capacitor bank is in the order of 25% of the kW rating of the motor.

4.26.9 Considerations Taken when Installing PFC Capacitors

When deciding which type of capacitor installation best meets your needs, you'll have to weigh the advantages and disadvantages of each and consider several plant variables, including load type, load size, load constancy, load capacity, motor starting methods and manner of utility billing.

- **Load Type**

If your plant has many large motors, 50 hp and above, it is usually economical to install one capacitor per motor and switch the capacitor and motor together. If your plant consists of many small motors, 0.5-25 hp, you can group the motors and install one capacitor at a central point in the distribution system. Often, the best solution for plants with large and small motors is to use both types of capacitor installations.

- **Load Size**

Facilities with large loads benefit from a combination of individual load, group load and banks of fixed and automatically-switched capacitor units. A small facility, on the other hand, may require only one capacitor at the control board.

- **Load Constancy**

If your facility operates around-the-clock and has a constant load demand, fixed capacitors offer the greatest economy. If load is determined by eight-hour shifts six days a week, you'll want more switched units to decrease capacitance during times of reduced load.

- **Load Capacity**

If your feeders or transformers are overloaded, or if you wish to add additional load on already loaded lines, correction must be applied at the load. If your facility has surplus amperage, you can install capacitor banks at main feeders. If load varies a great deal, automatic switching is probably the answer.

- **Utility Billing**

The severity of the local electric utility tariff for power factor will affect your payback. In many areas, an optimally designed power factor correction system will pay for itself in less than two years.

4.17 Synchronous Motors for Power Factor Correction (Condensers)

Synchronous motors can be operated at power factors from unity to 20 leading and are sometimes used for plant power factor correction. The motors are usually designed to operate at a particular power factor, often between 100 per cent and 90 per cent leading. When the over-excited synchronous motor is used only for power factor improvement is it is known as a synchronous condenser.

Condenser is an older word for capacitor. It has been shown an overexcited synchronous motor draws leading power factor from the line. When there is no mechanical *load* on the motor, the *AC* input power is only enough to supply the losses of the motor (friction, windage, core losses, and copper losses). These losses are quite small, and the machine power factor is practically zero. The power angle $\delta = 0$ and $\theta \approx \pm 90°$. When I_f is adjusted so that E_f is greater than the terminal phase voltage, $\theta \approx \pm 90°$, the machine acts very much like a capacitor bank. Control of the field current provides smooth control of the leading VARs. A synchronous machine designed for this kind of service is called a synchronous condenser. Synchronous condensers are usually totally enclosed. The shaft does not extend outside the case of the machine. It is often found that, when a large number of VARs needs to be supplied to a power system, a synchronous condenser is more economical than ordinary capacitors. [6]

Synchronous condensers are generally used at major bulk supply substation for power factor improvement.

Large synchronous motors are used on systems with long transmission lines for power factor correction, and hence voltage regulation. In industrial practice, the synchronous motor has been largely superseded by the capacitor, the cost of which, in relation to rotating plant, is very low.

4.27.1 Advantages

- By varying the field excitation, the magnitude of current drawn by the motor can be changed by any amount. This helps in achieving step-less control power factor.
- The motor windings have high thermal stability to short circuit currents.
- The faults can be removed easily.

4.27.2 Disadvantages

- There are considerable losses in the motor.
- The maintenance cost is high.
- It produces noise.
- Except in size above 500 kVA, the cost is greater than that of static capacitor of the same rating.
- As a synchronous has no self-starting torque, therefore, an auxiliary equipment has to be provided for this purpose.

4.28 Power Factor Correction vs. Harmonics

4.28.1 Harmonics

Harmonic distortion is a specific type of dirty power that is usually associated with an industrial plant's increased use of adjustable speed drives, power supplies and other devices using solid-state switching. However, harmonic distortion can be generated by any of a variety of non-linear electrical devices existing within a manufacturing plant or within nearby plants.

A harmonic is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency of 50 Hz. For example, 250 Hz is a fifth order harmonic of the fundamental frequency as shown in Figure 4.20. Figure 4.21 shows the resultant wave when the fundamental and fifth harmonics are combined. The result is harmonic distortion of the power waveform.

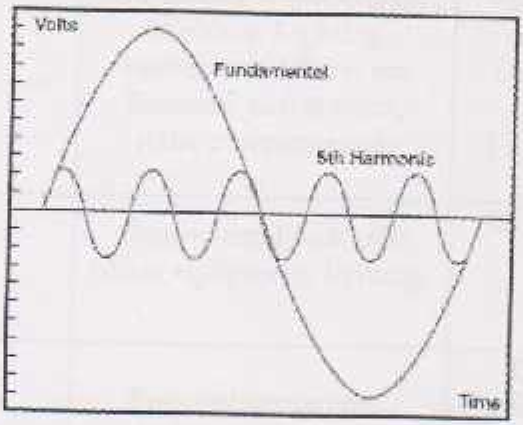


FIGURE 4.20 Fundamental and 5th Harmonic

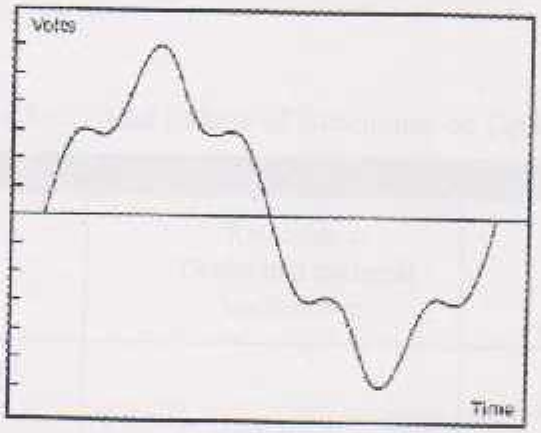


FIGURE 4.21 Fundamental and 5th Harmonic Combined

4.18.2 Types of Harmonics

- Current Harmonics, which means a distorted current waveform. Usually it is of most concern when improving power factor.

- Voltage Harmonics, which means a distorted voltage waveform. This one is almost negligible in contrast with the current waveform harmonics.

Table 4.1 Common sources and problems of harmonics

Sector	Sources	Common problems
Industrial	Adjustable speed drives, Welders, Lighting systems, rectifiers, arc furnaces, soft starters, static compensators.	Over-heating and fuse blowing of power factor correction capacitors. Over-heating of supply transformers. Tripping of over-current protection.
Commercial	Computers, Electronic office equipment, lighting.	Over-heating of neutral conductors and transformers. Interference.
Residential	Personal computers, lighting, electronic devices.	Generally not a big problem, however, high density of electronic loads could cause over-heating of utility transformers.

Table 4.2 Bad Effects of Harmonics on Equipments

Equipment	Harmonic effect	Results
Capacitors	Resonance. Dielectric material breakdown.	Heating. Short circuits. Fuse failure. Capacitor explosion.
Transformers	Current harmonics cause higher transformer losses.	Heating. Increased copper and core losses. Insulation stress. Noise. Reduced life. Skin effect.
Motors	Increased losses. Harmonic voltages produce magnetic field rotating at a speed	Heating. Vibration and noise. Increased copper and iron losses in stator

	corresponding to the harmonic frequency.	and rotor. Reduced efficiency. Reduced life. Voltage stress on insulation of motor windings.
Circuit breakers	Blowout coils may not operate properly.	Failure to interrupt currents.
Electro-mechanical induction disk relays	Additional torque produced and alters the time delay characteristics of the relay.	Incorrect tripping of relays.
Watt-hour meters	Additional torque on the induction disk causing improper operation	Incorrect readings.
Lines	Inductive coupling interference.	Inductive coupling between power and telephone lines. Telephone Influence Factor (TIF). Additional losses.

4.28.3 Solution for the Problem of Harmonics

When power factor correction is required in the presence of non-linear loads, or the amount of harmonic distortion must be reduced to solve power quality problems or avoid penalties, the most reliable, lowest cost solution is often realized with the use of harmonic filters.

4.28.4 Harmonics Filters

A number of harmonic mitigation techniques can be mentioned as follows:

4.18.4.1 Passive Techniques

Shunt connected harmonic filter or harmonic-suppression reactors. This is achieved by the addition of a harmonic-suppression inductor connected in series with the capacitor bank.

1. **Passive Filters**

Passive filters are often employed to reduce the current harmonics generated by rectifiers. The filter network is designed to pass the fundamental frequency component and to attenuate other frequencies, based on the principle of tuned resonance. Tuned resonance referred to insertion of RLC circuits into the network for the purpose of providing a low impedance path at harmonic frequencies.

Passive filters can be of three main approaches as shown in figures 4.22(a), 4.22(b), and 4.22(c).

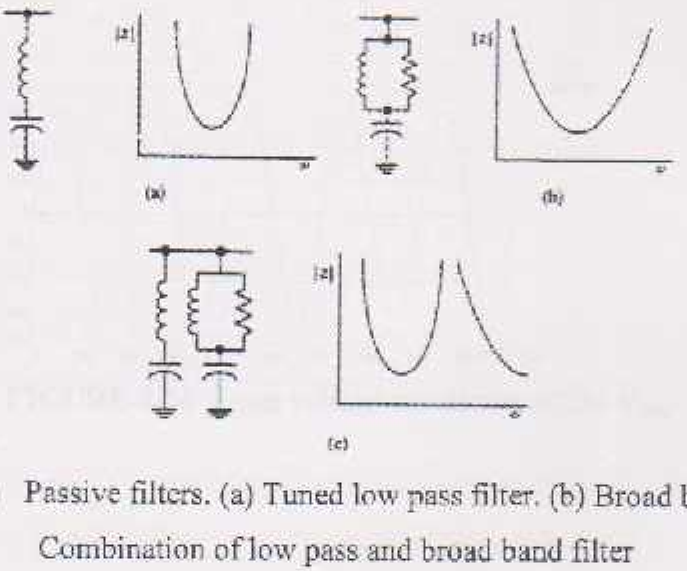


FIGURE 4.22 Passive filters. (a) Tuned low pass filter. (b) Broad band filter. (c) Combination of low pass and broad band filter

The following figure (FIGURE 4.23) shows an off-line power supply without input current harmonic filtration.

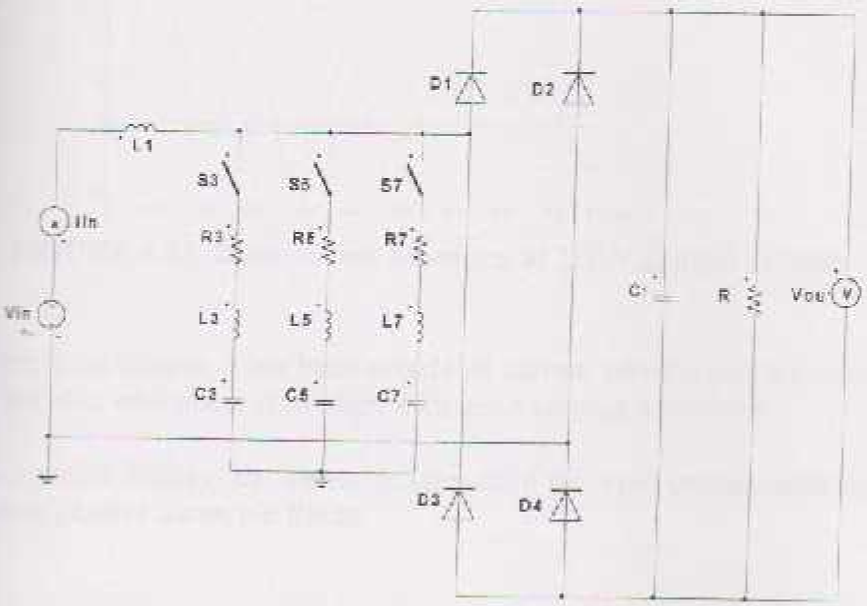


FIGURE 4.23 Without harmonic filtration, switches S3, 4 & 5 are opened

Following are the simulation results generated using SIMPLORER software, showing input voltage & current.

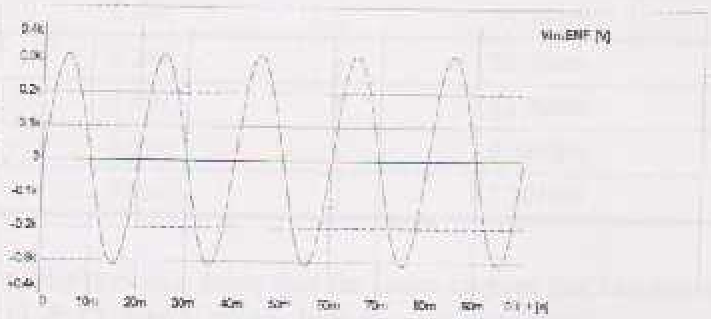


FIGURE 4.24 Input voltage waveform at 220 V_{rms}

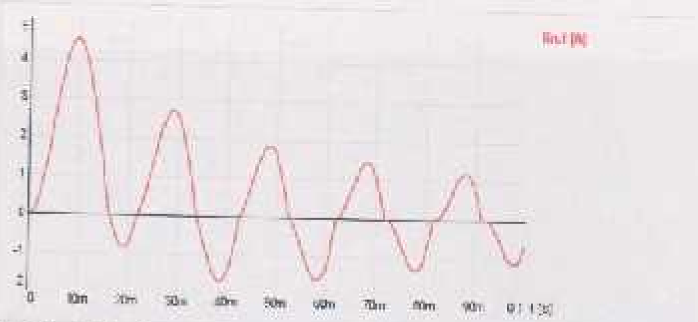


FIGURE 4.25 Input current waveform at 220 V_{rms} input voltage

From the previous figures, it has been noted that current waveform is not only highly distorted, but also with phase shift align with input voltage waveform.

The following table displays the harmonic content of the input current numerically before adding passive harmonic filters.

Table 4.3 Current harmonic distortion at 220 V_{rms} input voltage

f [Hz]	Iin.I [A]
0.5	7.2079m
0.65k	0.70802
50	0.70802
0.15k	0.1845
0.25k	54.151m
0.35k	22.258m
0.45k	12.289m
0.55k	9.2483m
0.65k	7.2079m

It is appeared from the previous table that the input current has harmonic content of orders 3, 5, 7, 9, 11 & 13, which means high current distortion.

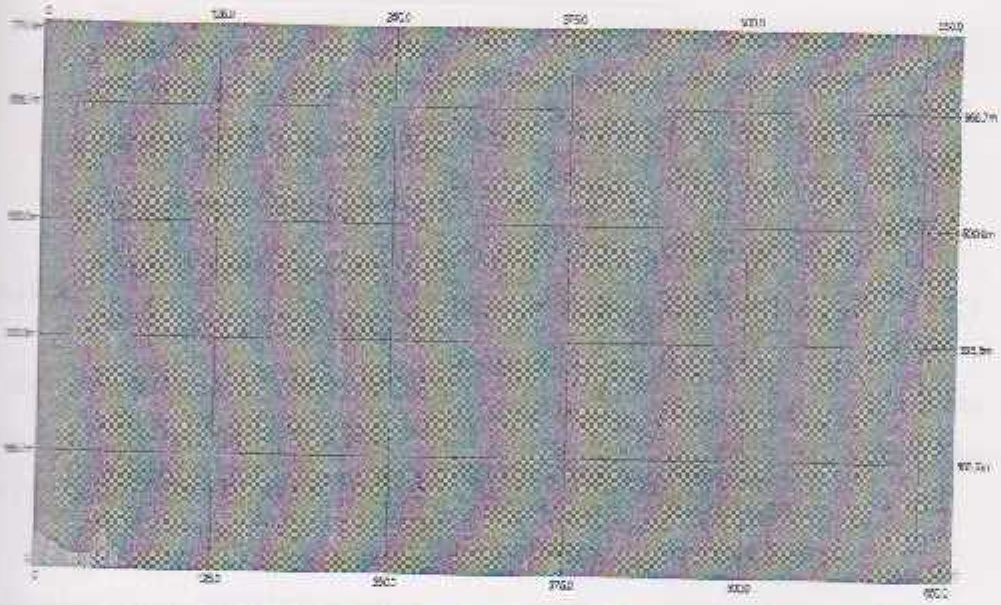


FIGURE 4.26 Graphical display of Input current harmonic content

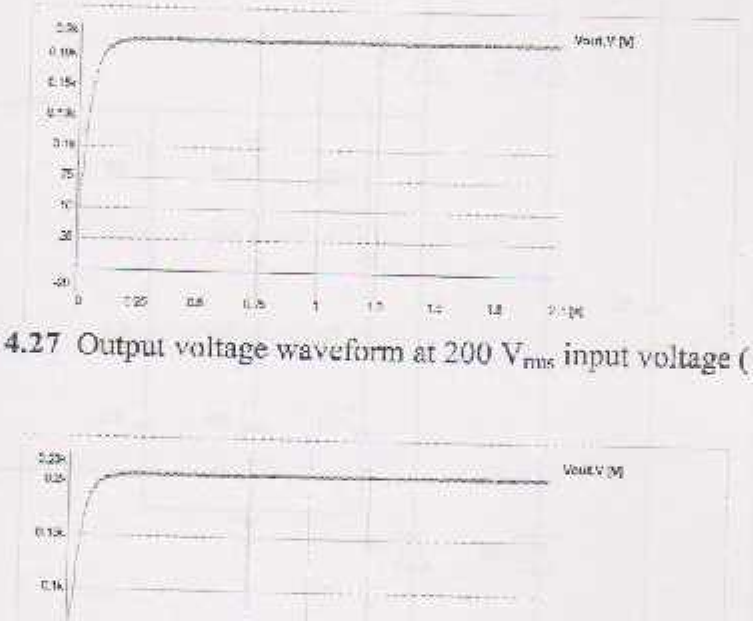


FIGURE 4.27 Output voltage waveform at 200 V_{rms} input voltage (190 VDC)

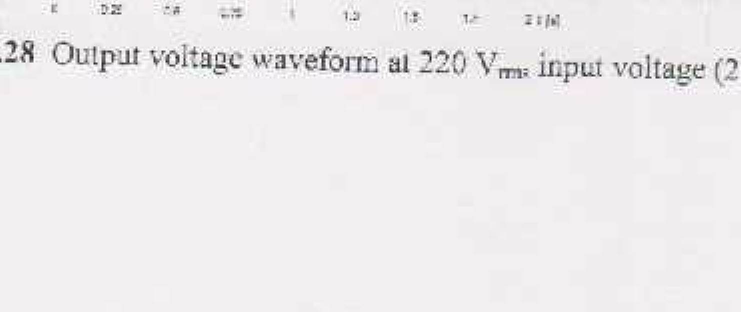


FIGURE 4.28 Output voltage waveform at 220 V_{rms} input voltage (210 VDC)

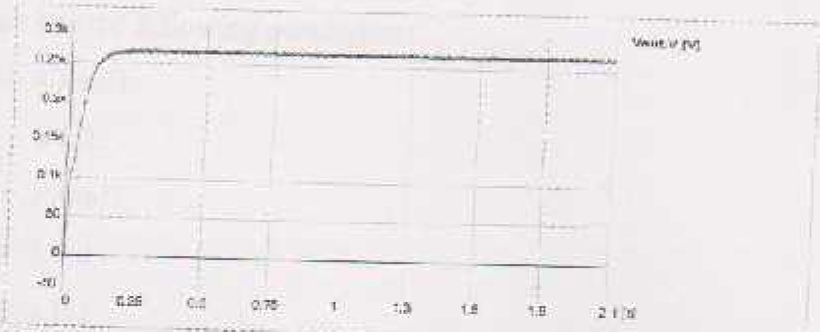


FIGURE 4.29 Output voltage waveform at 240 V_{rms} input voltage (270 VDC)

From the previous figures (4.27, 28 & 29) it is clear that output DC voltage is variable and increases with the increase of input voltage, meanwhile; unregulated output DC voltage.

The following figure (FIGURE 4.30) shows an off-line power supply with input current harmonic filtration.

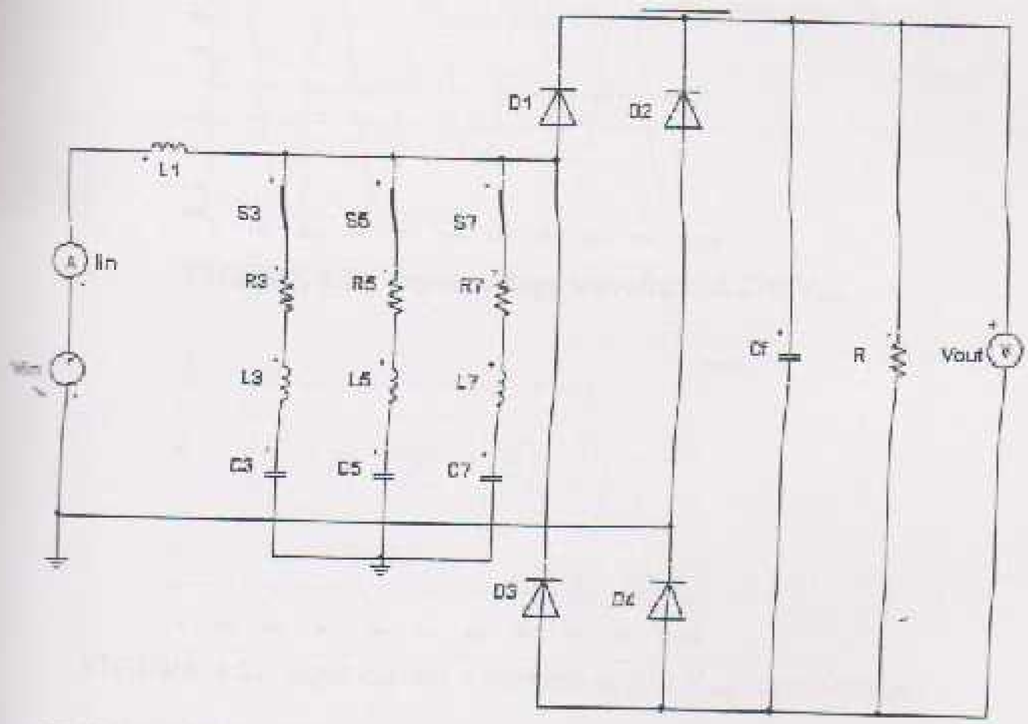


FIGURE 4.30 With harmonic filtration, switches S3, 4 & 5 are closed

Filter circuit has the following parameters:

- L1 = 400mH.
- R3 = 0.1Ω.
- L3 = 200mH.
- C3 = 5.6μF.
- R5 = 0.1Ω.
- L5 = 100mH.
- C5 = 4.04μF.

Following are the simulation results generated using SIMPLORER software, showing input voltage & current.

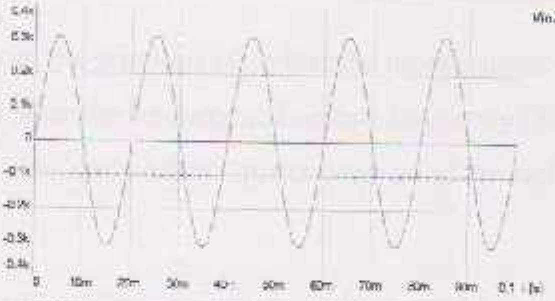


FIGURE 4.31 Input voltage waveform at 220 V_{rms}

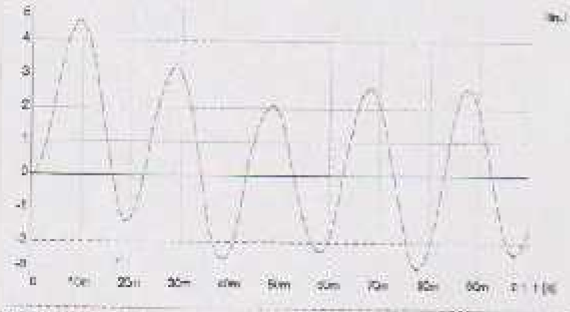


FIGURE 4.32 Input current waveform at 220 V_{rms} input voltage

From the previous figures, it has been noted that current waveform now has no harmonic content as in the case without a harmonic trap filter, but still there is a phase shift align with input voltage waveform.

The following table displays the harmonic content of the input current numerically after adding a passive harmonic filter.

Table 4.4 Current harmonic distortion at 220 V_{rms} input voltage

f [Hz]	lin.1 [A]
0.5	7.2078m
0.65k	0.70802
50	2.4859
0.15k	–
0.25k	–
0.35k	–
0.45k	–
0.55k	–
0.65k	–

It is appeared from the previous table that the input current only has the fundamental harmonic which is on the fundamental source frequency (50Hz), and the other harmonics were absolutely killed, that is because of the well chosen harmonic filter's parameters.

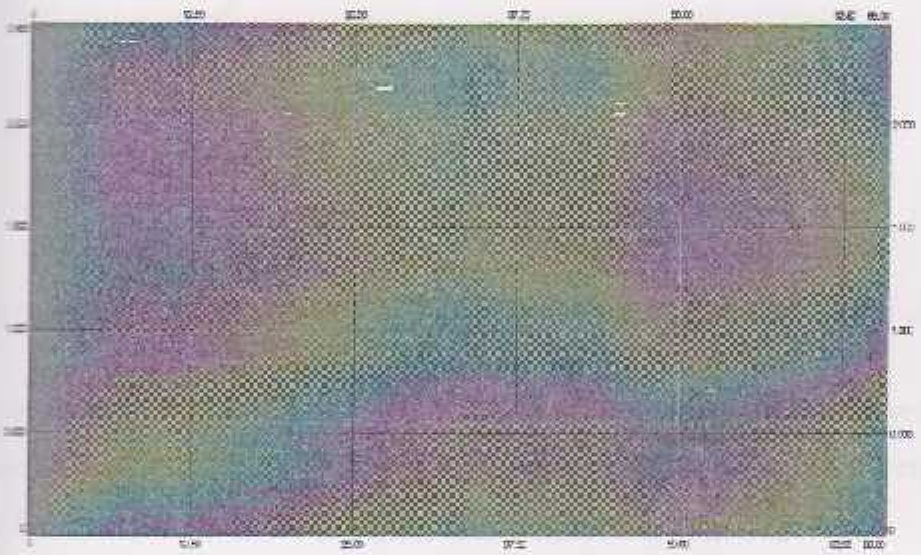


FIGURE 4.33 Graphical display of Input current harmonic content

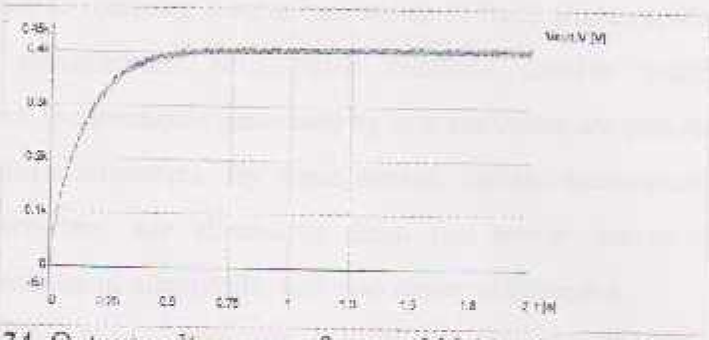


FIGURE 4.34 Output voltage waveform at 200 V_{rms} input voltage (400 VDC)

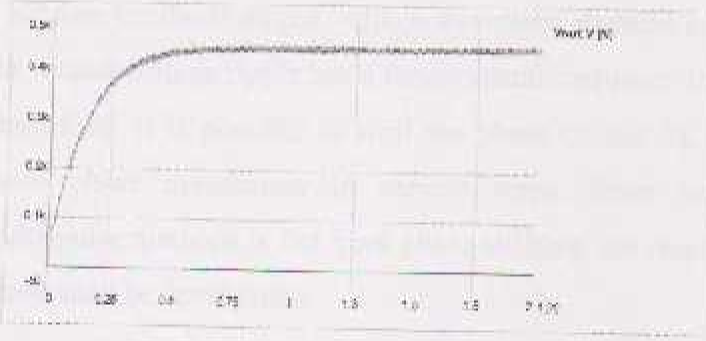


FIGURE 4.35 Output voltage waveform at 220 V_{rms} input voltage (420 VDC)

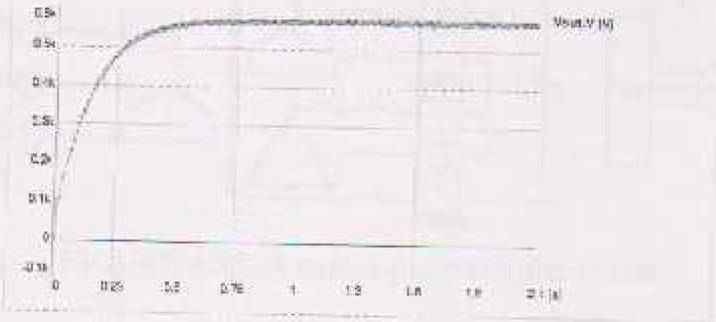


FIGURE 4.36 Output voltage waveform at 240 V_{rms} input voltage (580 VDC)

From the previous figures (4.34, 35 & 36) it is clear that output DC voltage is variable and increases with the increase of input voltage, meanwhile; unregulated output DC voltage.

2. **Multi-Pulse Method**

Another approach to reducing current harmonics of three phase rectifiers is the use of phase-shifting transformers. Multi-pulse methods involve multiple converters connected so that the harmonic generated by one converter are canceled by harmonic produced by other converters. By these means, certain harmonics, related to the number of converters, are eliminated from the power source. The remaining harmonics are smaller in magnitude, and also easier to filter out.

The three phase rectifier circuit with three phase Diode Bridge is known as a six pulse rectifier because the diode output voltage waveform contains six pulses per AC line period. The output voltage ripple has a fundamental frequency that has six times the AC line frequency. It is possible to shift the phase of the AC line voltage by configuring three phase transformer in various ways. Since harmonic current reduction in multi-pulse methods is fed from phase shifting, the resulting phase shift by the transformer must be appropriate.

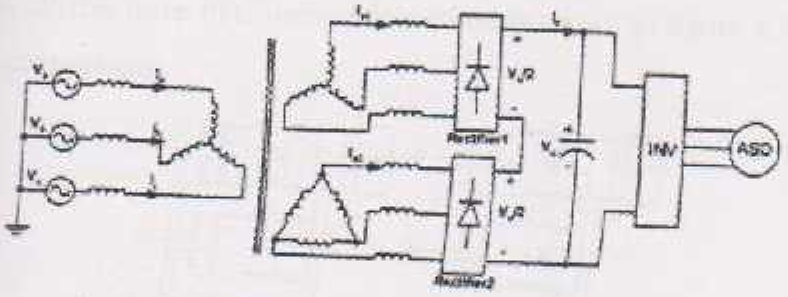


FIGURE 4.37 A twelve-pulse rectifier circuit

In general, the phase shift required for cancellation of current harmonics in converters with six-pulse waveforms is given by:

$$Phase.Shift = \frac{60}{Number.of.Converters} \text{............} (4.31)$$

For example, twelve-pulse scheme requires two six-pulse converters, which results in 30° phase shift. Since passive methods of harmonic mitigation are usually bulky and operate only at a specific design point, active methods are employed at low and medium power applications. A simple way to obtain high power factor for three phase is to use three single-phase power factor correction circuits, one per phase.

4.18.4.2 Active Techniques

Active filters are based on power electronic technology. They are generally installed in parallel with the non linear load. Active filters analyze the harmonics drawn by the load and then inject the same harmonic current to the load with the appropriate phase. As a result, the harmonic currents are totally neutralized at the point considered. Active filters may provide also power factor correction.

1. Combining Three Single-Phase PFC Stages

The scheme utilizes three PFC units; this method is shown in figure 4.38, connected in Δ and Y-connections.

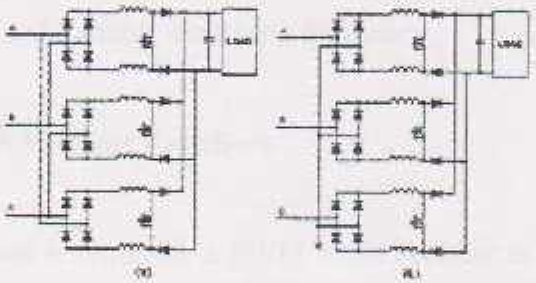


FIGURE 4.38 Combining three single-phase PFC stages. (a) Δ-connection. (b) Y-connection

The previous method has several disadvantages:

- The number of components required is three times the single phase AC-DC converter.

- The interaction among phases severely affects the current quality.
- Complete elimination of harmonics from the input line current can not be achieved.

2. **Single-Switch Boost PFC for Three Phase**

The circuit diagram of this method is shown in figure 4.39.

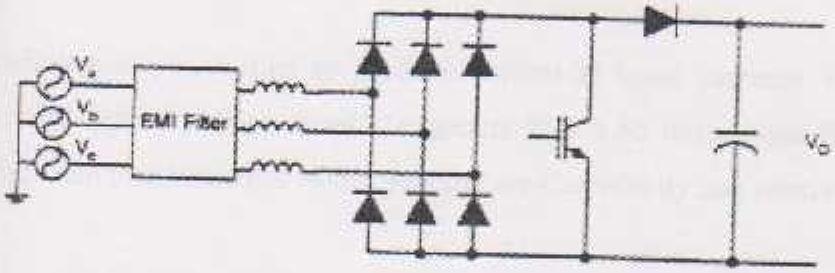


FIGURE 4.39 Single-Switch Boost PFC for Three Phase

Since this rectifier has a single active switch without a need for a complex control circuitry, it is suitable for low-cost-low-power three-phase AC-DC applications.

The input current THD can be reduced to a certain degree by modified model, such as variable duty cycle and variable switching frequency.

3. **Six-Switch PWM Boost Rectifiers**

When high performance is required, a PWM boost rectifier is used due to its good current quality. The circuit diagram of this method is shown in figure 4.40.

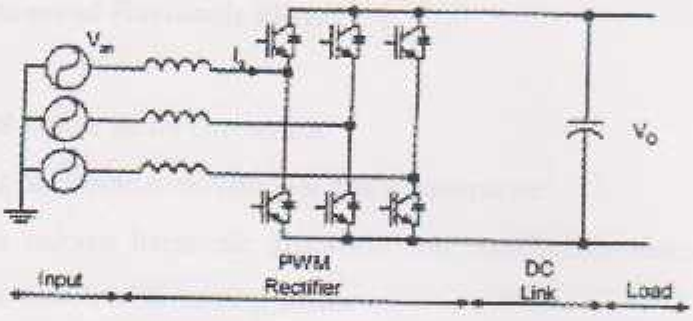


FIGURE 4.40 Six-Switch PWM Boost Rectifier

The six switches are controlled to produce sinusoidal input currents. For proper control, the DC output voltage should be greater than 1.65 times input line to line voltage. The main disadvantages of this scheme are Complexity and relatively higher cost.

4.18.4.3 Hybrid Techniques

This type of filter combines advantages of passive and active filter. One frequency can be filtered by passive filter and all the other frequencies are filtered by active filter.

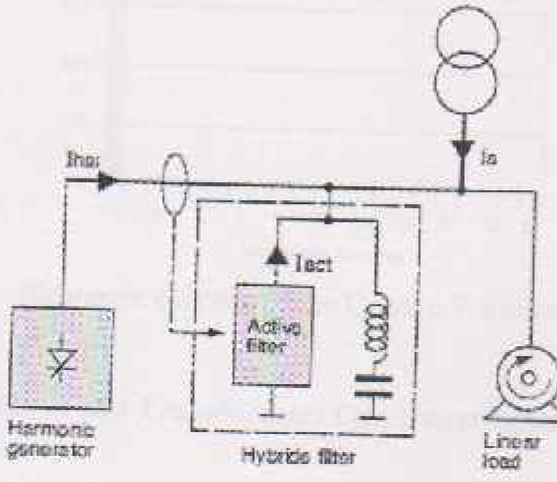


FIGURE 4.41 Operation Principle of Hybrid Filters

4.18.5 Advantages of Harmonic Filters

- Provides power factor correction.
- Prevents harmonic over-voltages due to resonance.
- Reduces voltage harmonic distortion and transformer harmonic loading at frequencies above its turning-point.

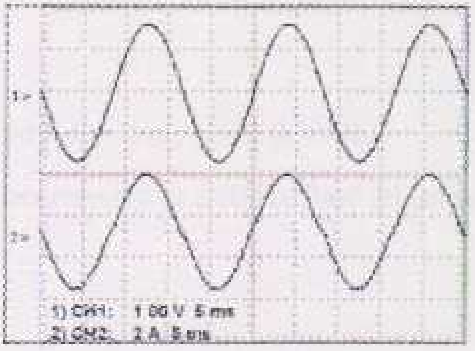


FIGURE 4.42 Input Characteristics of a Power Supply with PFC

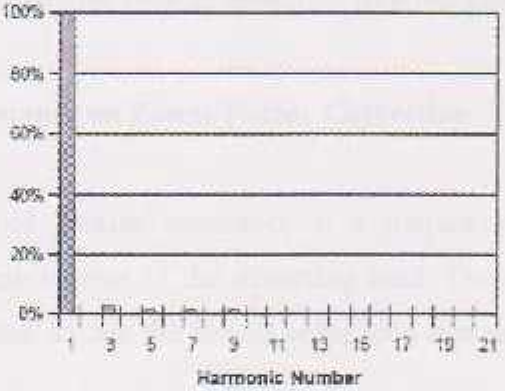


FIGURE 4.43 Harmonic Content of the Current Waveform in Figure 4.42

4.18.6 Capacitor Banks and Transformers Can Cause Resonance

Capacitors and transformers can create dangerous resonance conditions when capacitor banks are installed at the service entrance.

Under these conditions, harmonics produced by non-linear devices can be amplified many fold.

Resonant harmonic (harmonic order) can be estimated using the following formula:

$$n = \sqrt{\frac{S_{FL}}{S_C}} \text{...........}(4.32)$$

Where:

S_{FL} = fault level at the costumers entry point (kVAR).

n = The Harmonic Number referred to a 50 Hz Base (Harmonic order).

S_C = Capacitor kVAR.

If (n) is near the values of the major harmonics generated by a non-linear device (3, 5, 7) then the resonance circuit will greatly increase harmonic distortion. In this case the capacitors should be applied only as harmonic filtering assemblies.

4.18.7 Effect of Resonance on Power Factor Correction

It is important to avoid parallel resonance at a frequency which is close to a frequency of a harmonic current of the distorting load. The common practice is to tune the capacitor bank so that the lowest order load current harmonic sees a very small impedance.

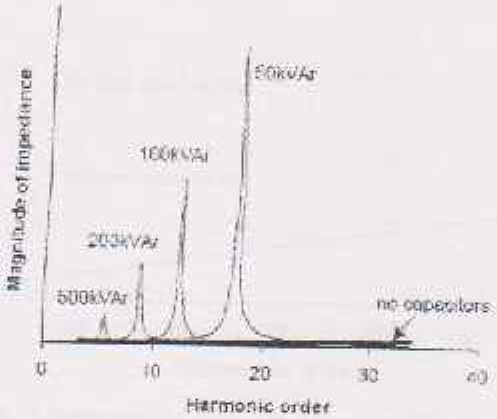


FIGURE 4.44 Variation of the impedance with harmonic order for different capacitor banks

This could be achieved by adding an inductor in series with the power factor correction capacitor leading to a situation commonly known as series resonance.

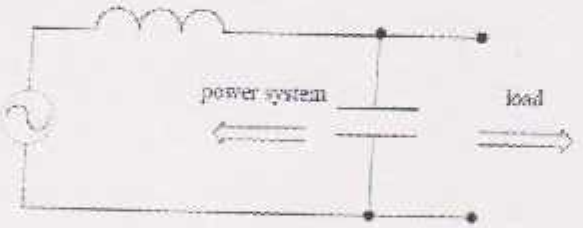


FIGURE 4.45 Parallel combination of power system impedance with power factor correction impedance

At the frequency where series resonance takes place the impedance seen by the harmonic current is small as shown in figure 4.46.

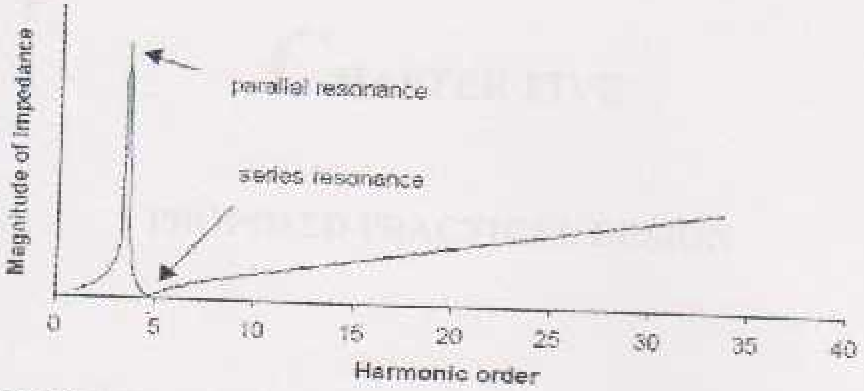


FIGURE 4.46 Variation of the impedance with detuning inductor

And hence, the power factor correction capacitors together with the detuning inductor work as a harmonic filter reducing the voltage distortion.

It has been noted that the capacitor still provides the fundamental reactive power while working as a harmonic filter.

CHAPTER FIVE

PROPOSED PRACTICAL DESIGN

5.1 Introduction

5.2 High Boost Power Factor Correction pre-regulator circuit

5.3 Basic principle of operation

5.4 Design of a single phase High Boost PFC ore-regulator

5.5 Calculations

5.6 Simulation

5.1 Introduction

Boost converter topology is used to accomplish active power-factor correction in many discontinuous/continuous modes. The boost converter is used because it is easy to implement and works well. It is also considered as the heart of power factor correction.

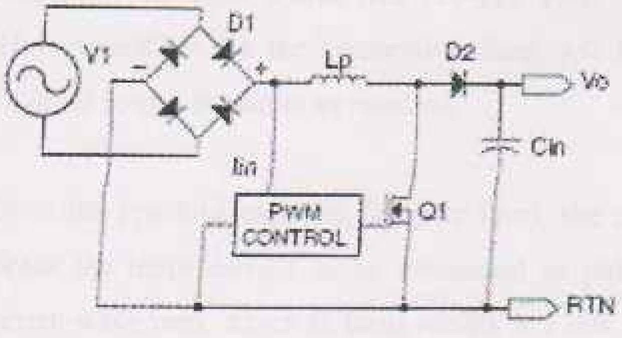


FIGURE 5.1 Single stage Active Boost Power Factor correction pre-regulator

In this project, it is intended to provide a comprehensive switched mode power supply (SMPS) with resulting in PFC for the mains source and a high regulated DC output voltage.

This chapter discusses the designing issues of a single and three phase Boost PFC circuit, supplied with mathematical analysis of used electric circuits (power & control), align with simulation opportunities, and finally provides brief results and conclusions *of the whole work from the theoretical side.*

Hence; the implemented practical circuit is just for a single phase criteria, whereas for three phase, it is the same principle but with modifications and certain additional circuitry, multiplied by three times than that of a single phase one.

5.2 High Boost Power Factor Correction pre-regulator circuit

Most of the electric equipments today, weather used in industry or as home appliances, contains a fixed form of power supplies, those power supplies are naturally known as off-line power supplies (switched mode power supplies – SPMP's).

These SMPS's contain an AC input source (US 110-115 VAC / 60 Hz or UK 220-230 VAC / 50 Hz), a rectifier for the conversion from AC into DC voltage, a capacitor, and then other circuit elements as required.

As discussed early in the previous chapters (chapter four), the occurrence of such power supplies forces the input current to be consumed as pulses, which means highly distorted current waveform, which in turns results in a low PF and affects the whole operational efficiency of the whole system, and many other problems as stated in chapter four.

The target here, is to provide an additional circuitry for controlling PF and leads it to be near unity. Also to provide a high regulated DC output voltage that can be then transformed in an AC source by means of an inverter circuit to give a regulated and stable output AC voltage under any transient cases or variations in the main input source or in loads connected to the mains.

The control circuit main goal is to force the current follow the shape of the input voltage waveform. This idea is called average current mode control.

Boost PFC circuit is an active technique for achieving PFC, it's simple configuration is a SMPS followed by a DC-DC converter (step up DC chopper), filtering capacitor & a PWM controller for the chopping process.

Features of the high Boost PFC pre-regulator circuit

- An active technique for PFC activities.
- Deals with both phase shift and harmonic content of the input current.
- Control Boost PWM to 0.99 Power Factor.
- Limit Line Current Distortion To <5%.
- World-Wide Operation Without Switches.
- Feed-Forward Line Regulation.
- Average Current-Mode Control.
- Low Noise Sensitivity.
- Low Start-Up Supply Current.
- Fixed-Frequency PWM Drive.
- Low-Offset Analog Multiplier/Divider.
- 1A Totem-Pole Gate Driver.
- Precision Voltage Reference.
- Lower costs.
- Lower losses.
- Fast response.
- Lower maintenance.
- Quiet operation.

Basic principle of operation

A power factor corrector is basically an AC to DC converter, and is usually based on an SMPS structure. The basic functional blocks of a Power Factor Corrector are shown in figure 5.3.

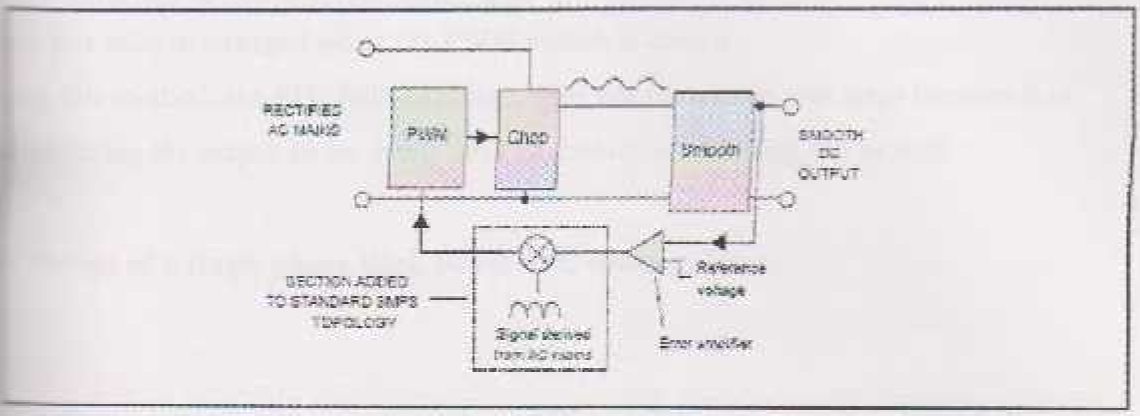


FIGURE 5.2 Simplified block diagram of a Power Factor Corrector (PFC)

A standard SMPS uses Pulse Width Modulation (PWM) to adjust the amount of power it supplies to the attached equipment. The Pulse Width Modulator controls the power switch, which chops the DC input voltage into a train of pulses. This train of pulses is then smoothed, producing the DC output voltage.

The output voltage is then compared with a voltage reference representing the voltage desired by the equipment being supplied, and the resulting voltage difference (the error voltage) is fed back to the input of the PWM, which varies the width of the pulses it supplies accordingly, if the output voltage is too high, the pulse width is reduced, and thus less power is supplied, and vice versa.

The error voltage is modulated with a signal derived from the rectified AC mains, before being fed to the PWM input. This means that the width of the power pulse supplied to the output device depends both on the basic error voltage and also on the instantaneous value of the mains voltage. The PFC thus draws more power from the mains when the level of the mains voltage is high, and less when it is low, which results in a reduction of the harmonics in the drawn current.

Every time this cycle is repeated, the PFC bulk capacitor has to be fully charged since it is fully discharged when the PWM switch is closed.

Using this method, the PFC bulk capacitor does not have to be that large because it is not powering the output all by itself; the PFC inductor is helping out as well.

Design of a single phase High Boost PFC ore-regulator

Following is the Block diagram of the Boost PFC circuit implemented with power simulation software (PSIM).

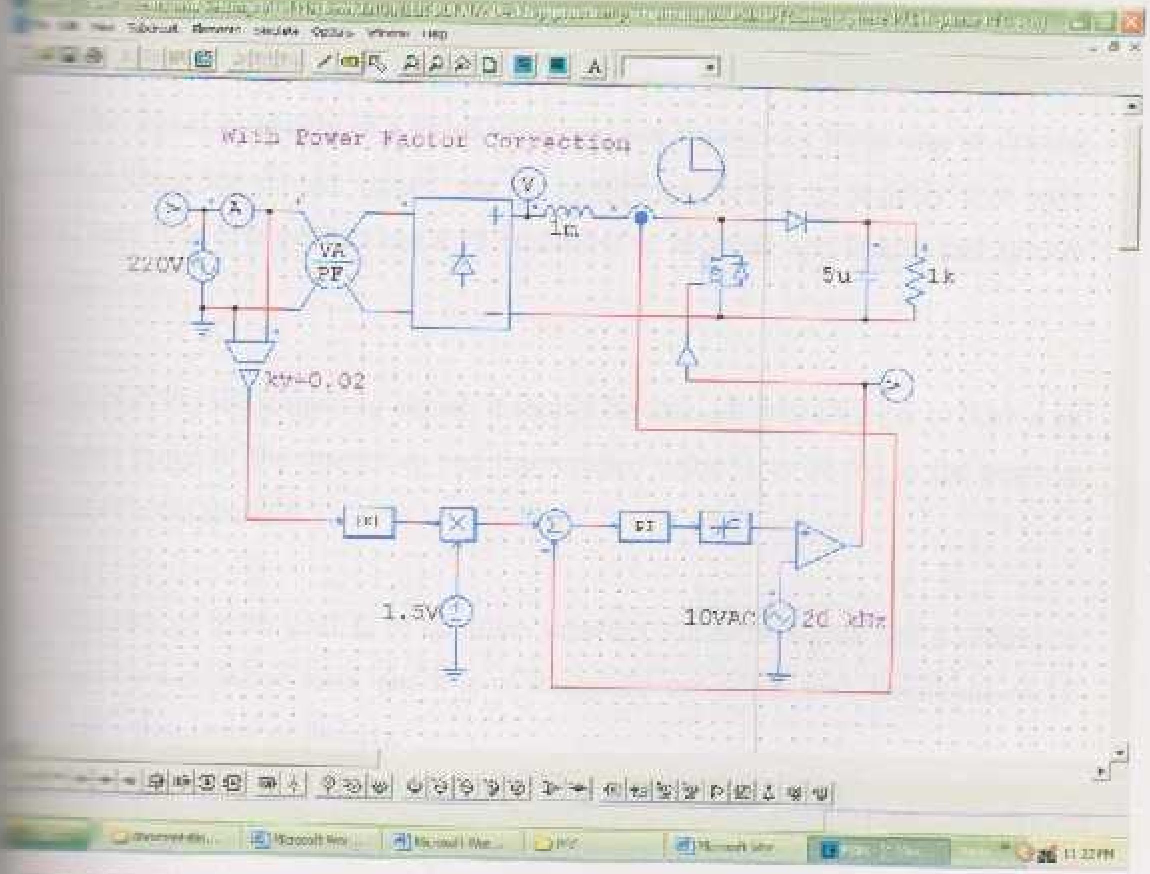


FIGURE 5.3 Comprehensive Block diagram of the Boost PFC circuit on PSIM

From the block diagram, the simple principle of operation is that the circuit corrects the PF according to the consumed current, it is known that when consuming more current from the supply, the PF is going down and down, meanwhile; low PF, due to the presence of inductive loads that consume reactive power which in turn result in phase shift between current and voltage, or because of the occurrence of current harmonics due to the presence of non-linear loads such as rectifiers for example.

The circuit senses the input voltage, multiplies with a gain of about 0.02 to attenuate it, takes the absolute value, multiplies with a reference voltage, and subtracts the sensed value of the boost current in terms of voltage.

This operation results in an error signal which may increase or decrease due to the increment or decrement of sensed voltages and currents.

That error signal is usually of a small value and not enough for triggering or driving activities, thus; the circuit should use an amplifying device to amplify that error signal, here it is preferred to use a PI controller to increase amplitudes and system response time.

After amplifying the triggering signal, it should be then get into a limiter to limit a an acceptable range of the operation, and the resulted value is to be fed to the positive terminal of a comparator.

The comparator main goal is to compare between the error signal and a reference signal set by simulation tests, and it is of triangular waveform with amplitude of 10 VAC and a frequency of 20 kHz.

If the error signal is larger than the reference one, the output of the comparator is high, which in turn drives the gate of the MOSFET to prevent the current from passing to the output.

The duty cycle of the gating of MOSFET is absolutely dependent on how much current is consumed in terms of volts. If it exceeded the reference value the MOSFET is on, if not; the MOSFET is off, and so on.

The design of a full practical single phase Boost PFC circuit was designed using PSIM software. The following figure shows the whole circuit arrangements.

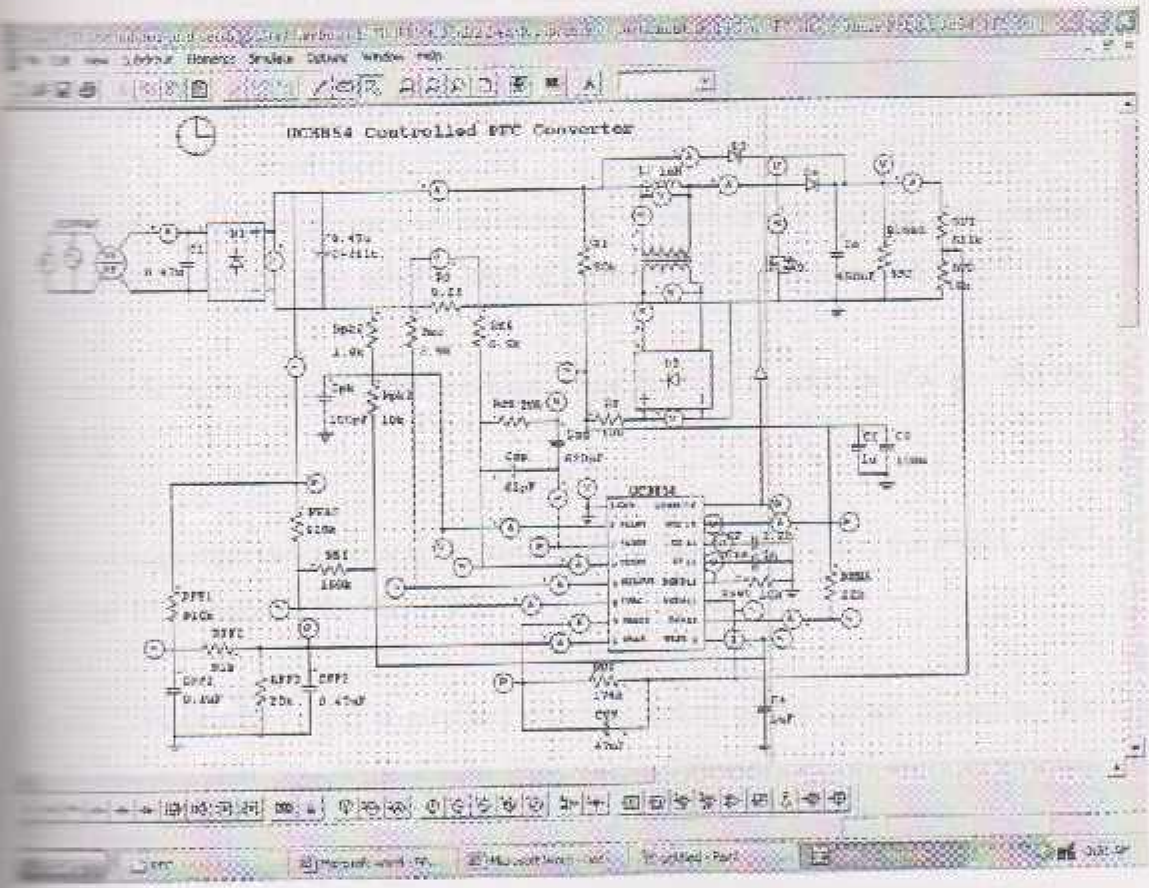


FIGURE 5.4 Complete single phase Boost PFC circuit implemented on PSIM software

The circuit contains various hardware with various parameters, containing the following:

- AC source with any range between 80 & 260 VAC, and frequencies between 50 & 400 Hz.
- Bridge rectifier for the conversion from AC into DC voltage.
- Filtering capacitor to filter the output DC voltage of the rectifier (0.47μF).
- Boost inductor with rating of about 1mH.
- MOSFET (IRF840).
- Inrush diodes to prevent the effect of reverse currents that may damage the hardware such as MOSFET and other components as a protective step.
- High voltage electrolytic output capacitor of about 450-470 μF / 450 V for regulating the output DC voltage to about 400 VDC.
- PWM / PFC controller (UC2854).
- Various values of various resistors & capacitors for voltage and current division activities to achieve kind of protection for the controlling IC.

For further information about the previous elements, refer to APPENDIX B – DATA SHEETS.

The most important two elements of this project is the MOSFET and the PWM / PFC controller IC that drives the MOSFET.

The UC2854 (PWM / PFC controller) provides active power factor correction for power systems that otherwise would draw non-sinusoidal current from sinusoidal power lines.

This device implements all the control functions necessary to build a power supply capable of optimally using available power-line current while minimizing line-current distortion. To do this, the UC2854 contains a voltage amplifier, an analog multiplier/divider, a current amplifier, and a fixed-frequency PWM.

In addition, the UC2854 contains a power MOSFET compatible gate driver, 7.5V reference, line anticipator, load-enable comparator, low supply detector, and over-current comparator.

The UC1854 uses average current-mode control to accomplish fixed frequency current control with stability and low distortion.

Average current control accurately maintains sinusoidal line current without slope compensation and with minimal response to noise transients. The UC2854's high reference voltage and high oscillator amplitude minimize noise sensitivity while fast PWM elements permit chopping frequencies above 200kHz.

The UC2854 can be used in single and three phase systems with line voltages that vary from 80 to 270 volts and line frequencies across the 50Hz to 400Hz range. To reduce the burden on the circuitry that supplies power to this device, the UC2854 features low starting supply current.

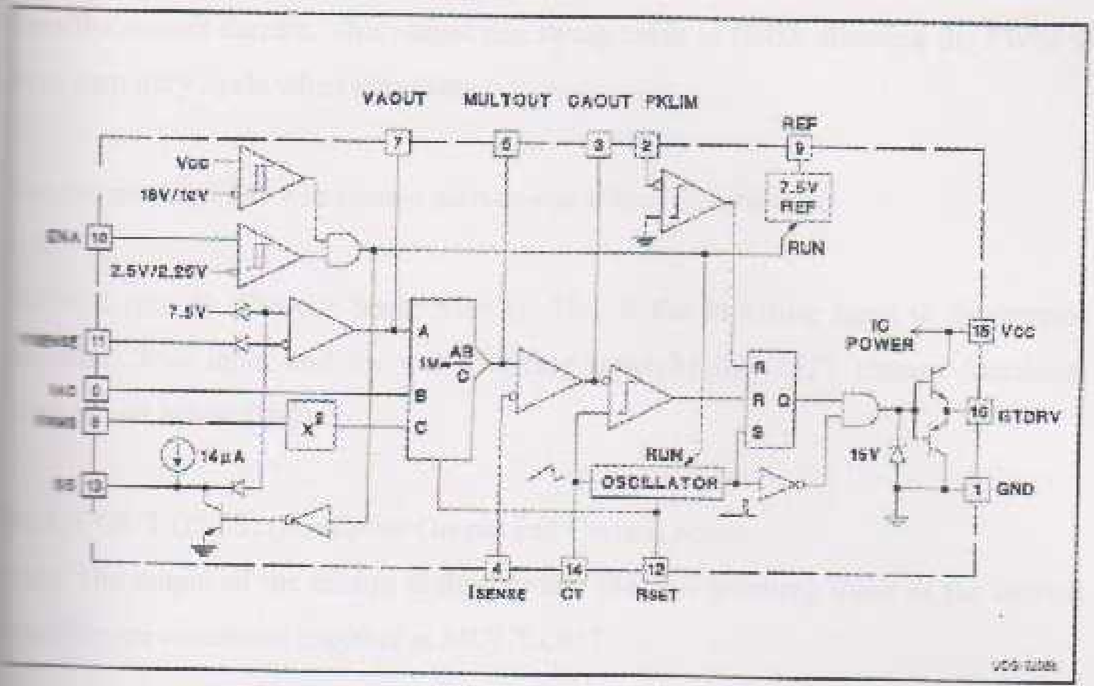


FIGURE 5.5 Data sheet block diagram of the UC2854

5.4.1 PIN configuration of the UC2854

GND (Pin 1) (Ground): All voltages are measured with respect to GND. VCC and REF should be bypassed directly to GND with an 0.1µF or larger ceramic capacitor.

The timing capacitor discharge current also returns to this pin, so the lead from the oscillator timing capacitor to GND should also be as short and as direct as possible.

PKLMT (Pin 2) (Peak Limit): The threshold for PKLMT is 0.0V. this input is to be connected to the negative voltage on the current sense resistor RS.

CA Out (Pin 3) (Current Amplifier Output): This is the output of a wide-bandwidth op amp that senses line current and commands the pulse width modulator (PWM) to force the correct current. This output can swing close to GND, allowing the PWM to force zero duty cycle when necessary.

The current amplifier will remain active even if the IC is disabled

ISENSE (Pin 4) (Current Sense Minus): This is the inverting input to the current amplifier. This input and the non-inverting input MULT OUT remain functional down to and below GND.

MULT OUT (Pin 5) (Multiplier Output and Current Sense pins): The output of the analog multiplier and the non-inverting input of the current amplifier are connected together at MULT OUT.

IAC (Pin 6) (Input AC Current): This input to the analog multiplier is a current. The multiplier is tailored for very low distortion from this current input (IAC) to MULT OUT, so this is the only multiplier input that should be used for sensing instantaneous line voltage. The nominal voltage on IAC is 6V.

VA Out (Pin 7) (Voltage Amplifier Output): This is the output of the op amp that regulates output voltage. Like the current amplifier, the voltage amplifier will stay active even if the IC is disabled with either ENA or VCC.

This means that large feedback capacitors across the amplifier will stay charged through momentary disable cycles. The voltage amplifier output is internally limited to approximately 5.8 V to prevent overshoot.

VRMS (Pin 8) (RMS Line Voltage): The output of a boost PWM is proportional to the input voltage, so when the line voltage into a low-bandwidth boost PWM voltage regulator changes, the output will change immediately and slowly recover to the regulated level.

For best control, the VRMS voltage should stay between 1.5V and 3.5V.

REF (Pin 9) (Voltage Reference Output): REF is the output of an accurate 7.5 V voltage reference. This output is capable of delivering 10mA to peripheral circuitry and is internally short circuit current limited.

REF is disabled and will remain at 0V when VCC is low or when ENA is low.

ENA (Pin 10) (Enable): ENA is a logic input that will enable the PWM output, voltage reference, and oscillator.

ENA also will release the soft start clamp, allowing SS to rise

VSENSE (Pin 11) (voltage amplifier inverting input): This is normally connected to a feedback network and to the boost converter output through a divider network.

RSET (Pin 12) (oscillator charging current and multiplier limit set): A resistor from RSET to ground will program oscillator charging current and maximum multiplier output.

Multiplier output current will not exceed 3.75V divided by the resistor from RSET to ground.

SS (Pin 13) (soft start): SS will remain at GND as long as the IC is disabled or VCC is too low. SS will pull up to over 8 V by an internal 14μA current source when both VCC becomes valid and the IC is enabled, SS will act as the reference input to the voltage amplifier if SS is below REF.

CT (Pin 14) (oscillator timing capacitor): A capacitor from CT to GND will set the PWM oscillator frequency according to this relationship:

$$f = \frac{1.25}{RSET \times CT} \text{ ....(5.1)}$$

VCC (Pin 15) (Positive Supply Voltage): this Pin should be connected to a stable source of at least 20mA above 17V for normal operation. To prevent inadequate GT DRV signals, these devices will be inhibited unless VCC exceeds the upper under-voltage lockout threshold and remains above the lower threshold.

GT DRV (Pin 16) (Gate Drive): This output is internally clamped to 15 V so that the IC can be operated with VCC as high as 35 V.

5.4.2 Principle of operation

The UC2854 controller receives four main sensing signals: VSENSE, IVAC, VRMS & ISENSE.
With the internally built in multiplier / divider, the UC2854 multiplies both VSENSE & IVAC, then the result is divided by the VRMS square.

The result is in fact a current, now this current is compared with the ISENSE, whether there was a difference or not, that controls the PWM signal to be generated or not and how much pulses required to compensate for incremental drawn mains current.

5.5 Calculations

$$I_{MULTOUT} = \frac{K \times I_{VAC} \times (VA_{OUT} - 1)}{{V_{RMS}}^{2}} \text{ ....(5.2)}$$

$$=\frac{-1\times0.42\times10^{-3}\times(4.56-1)}{3.31^2}$$

$$=-0.137mA$$

$$I_{MULT_{MAX.}}=\frac{-3.75}{R_{SET}}\text{..............(5.3)}$$

$$=\frac{-3.75}{10k}$$

$$=-375\mu A$$

$$I_{MAX}=\frac{-I_{MULT_{MAX}}\times3.9k}{0.25\Omega}\text{..................(5.4)}$$

$$=\frac{-375\mu A\times3.9k}{0.25\Omega}$$

$$=-5.85A$$

$$C_T=\frac{1.25}{f\times R_{SET}}\text{...................(5.5)}$$

$$=\frac{1.25}{200kHz\times10k}$$

$$=625pF$$

$$R_{AC}=\frac{V_{PK}}{I_{ACPK}}\text{.................(5.6)}$$

$$=\frac{220\times\sqrt{2}}{420\mu A}$$

$$=741k$$

$$R_{REF} = \frac{R_{AC}}{4} \text{ ....(5.7)}$$

$$= \frac{741k}{4}$$

$$= 185k$$

5.6 Simulation

5.6.1 Single phase Power Factor Correction

The following figure shows an SMPS circuit without the usage of PFC technique.

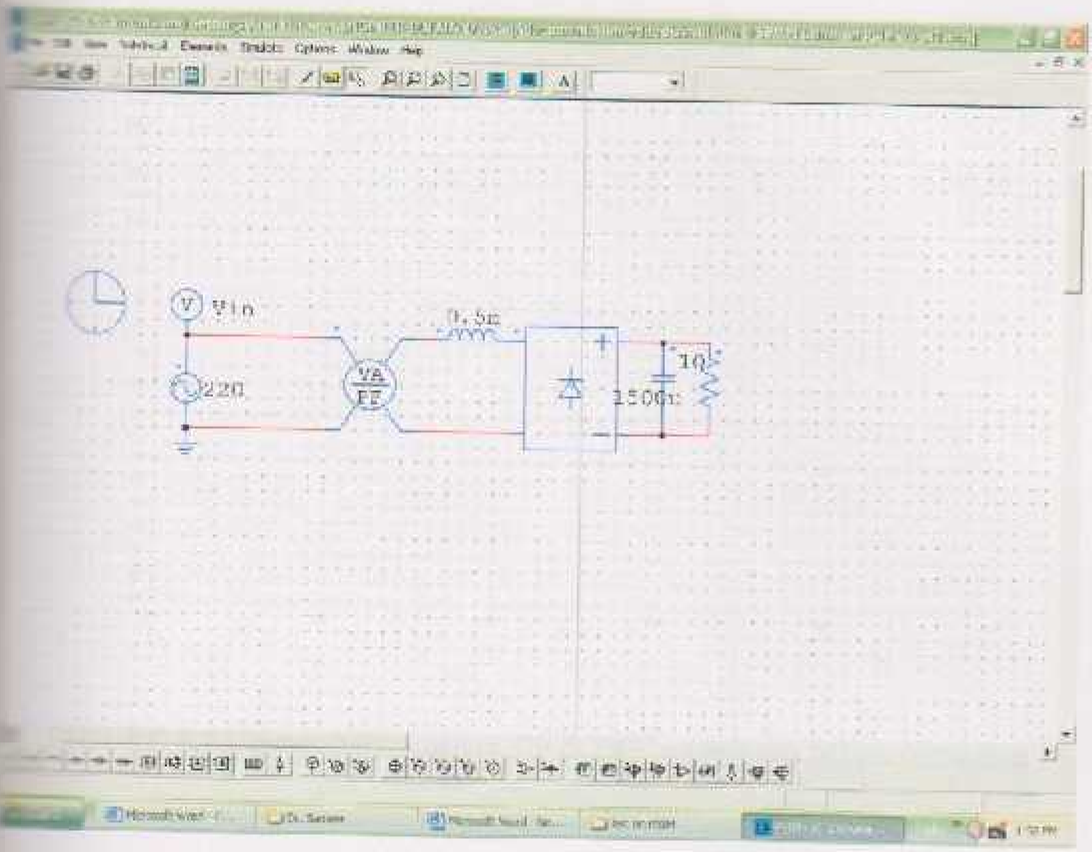


FIGURE 5.6 Single phase circuit without PFC

Following, the simulation results are represented with PSIM software for input voltage, current, PF, DPF and input current harmonic content waveforms.

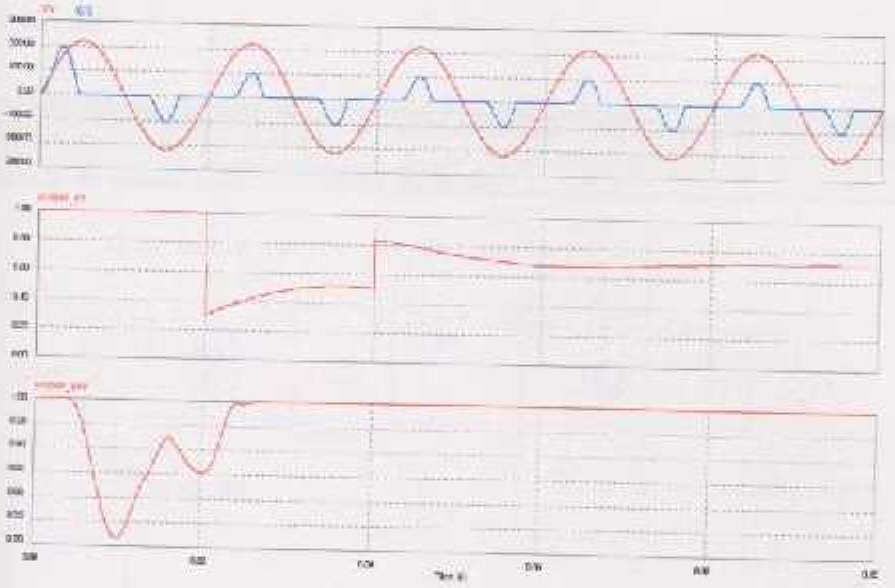


FIGURE 5.7 Input voltage, current, PF & DPF waveforms before correction

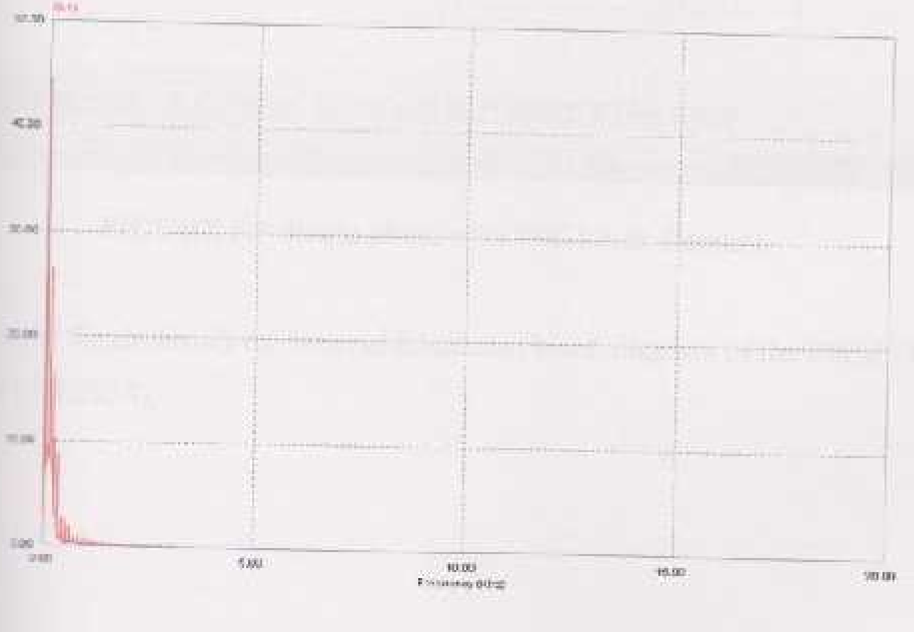


FIGURE 5.8 Input current harmonics content before correction

Figure 5.9 summarizes the functional block diagram of an active high boost PFC pre -regulator circuit.

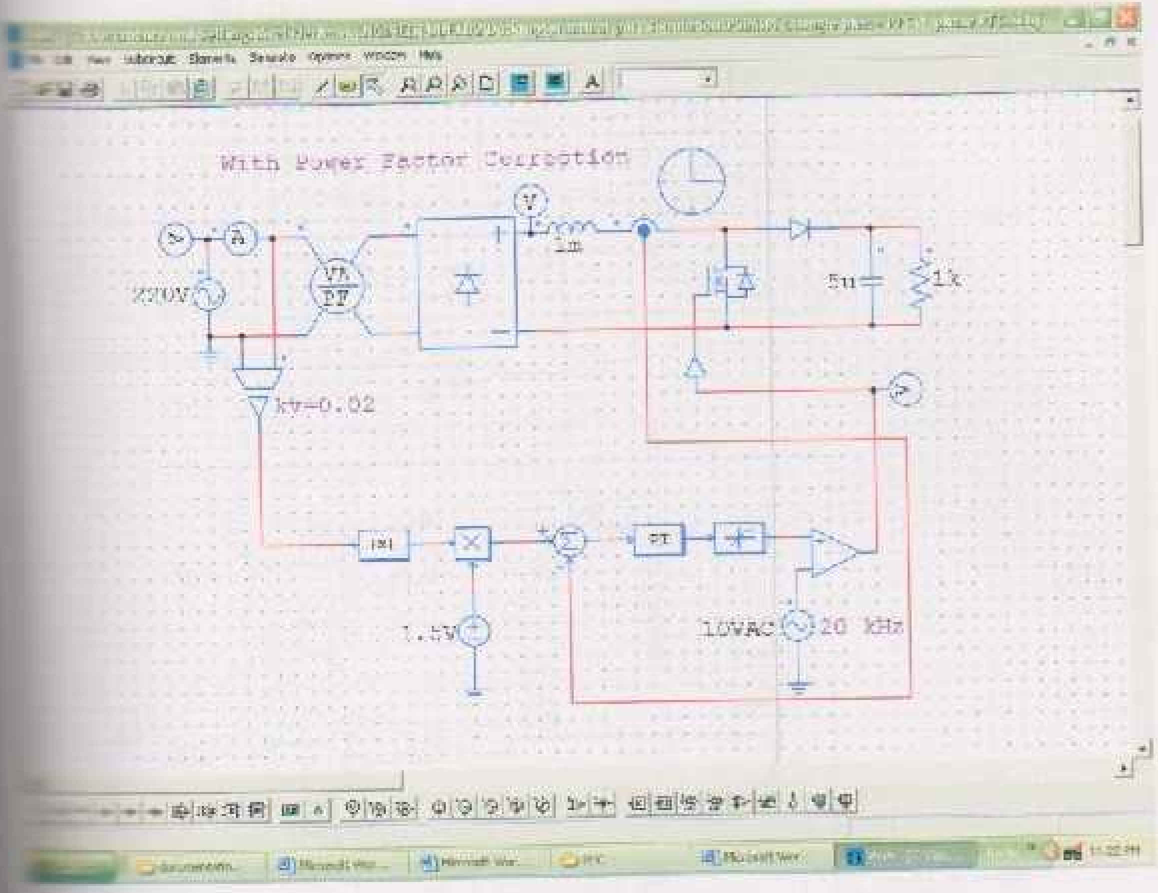


FIGURE 5.9 Single phase with PFC block diagram

The following figure shows the internal functional block diagram of the PWM \ PFC controller (UC2854).

Internal Connection of the UC3854A

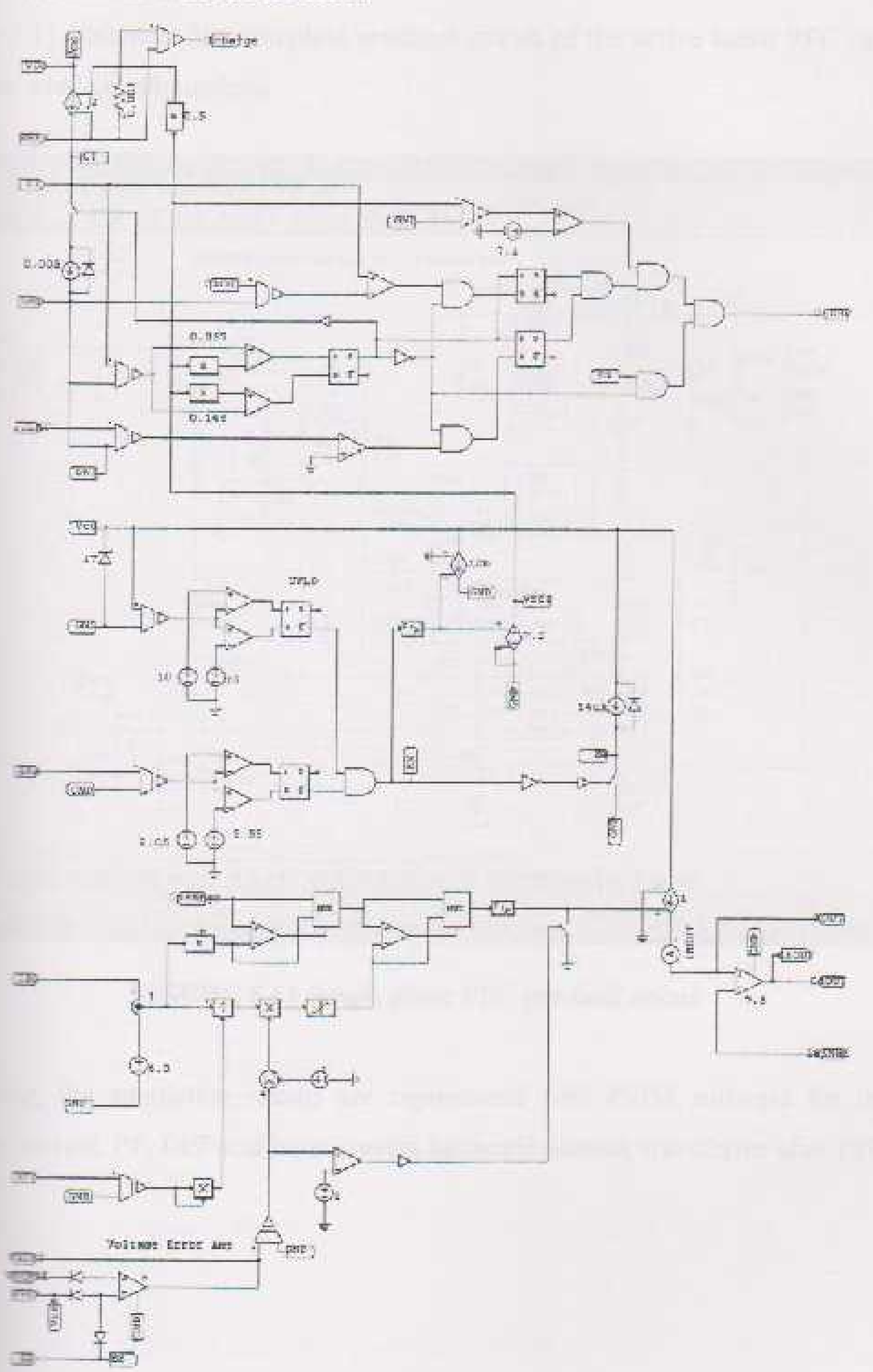


FIGURE 5.10 Internal connection of the UC3854

Figure 5.11 illustrates the complete practical circuit of the active boost PFC circuit with the whole configurations.

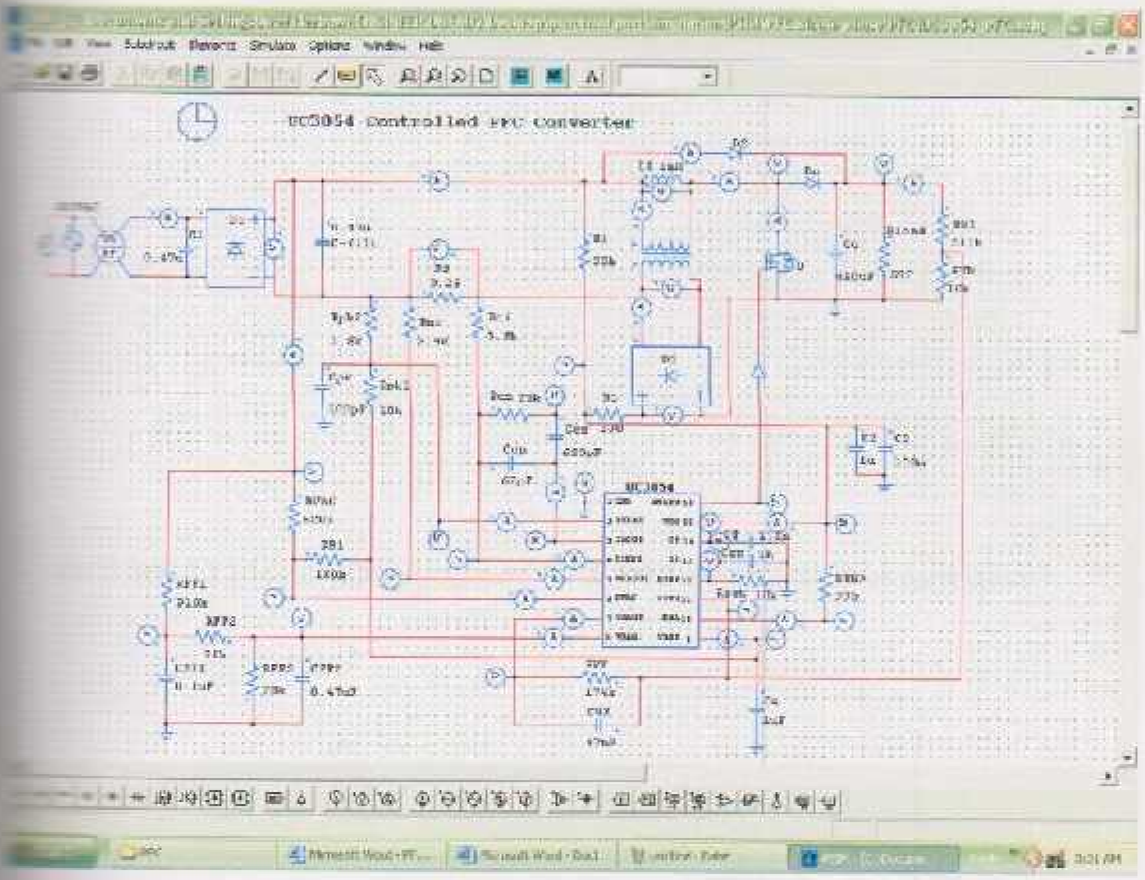


FIGURE 5.11 Single phase PFC practical circuit

Following, the simulation results are represented with PSIM software for input voltage, current, PF, DPF and input current harmonic content waveforms after PFC.

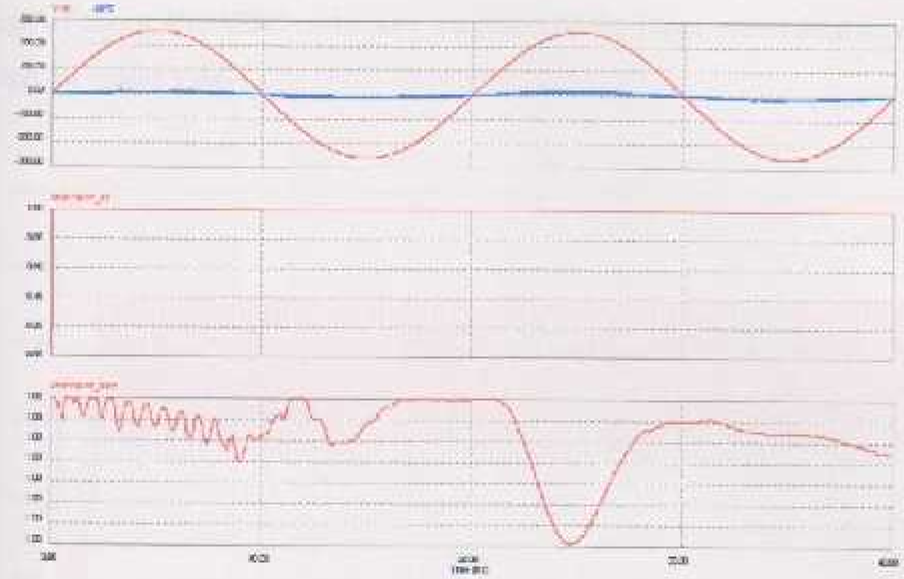


FIGURE 5.12 Input voltage, current, PF & DPF waveforms after correction

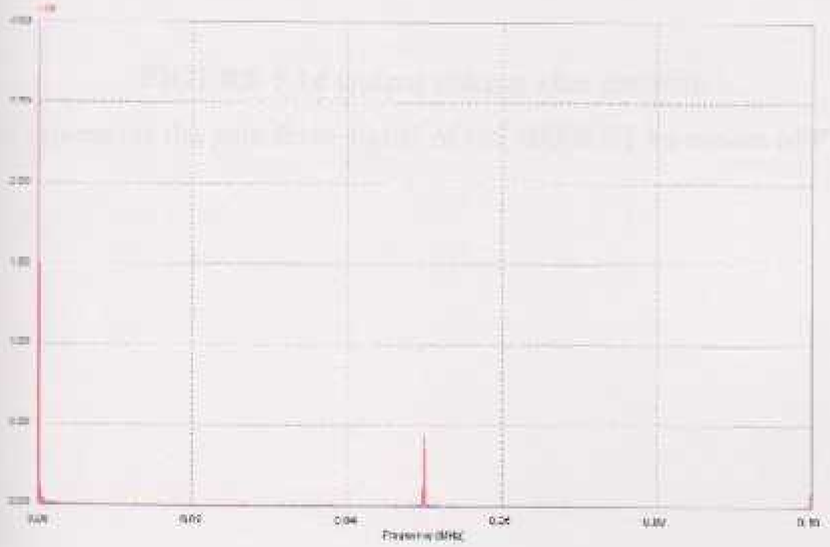


FIGURE 5.13 Input current harmonics content after correction

The high active boost PFC pre – regulator circuit results in a high regulated output DC voltage of about 400 VDC under any variation of the input mains source voltage in the range 80 – 260 VAC.

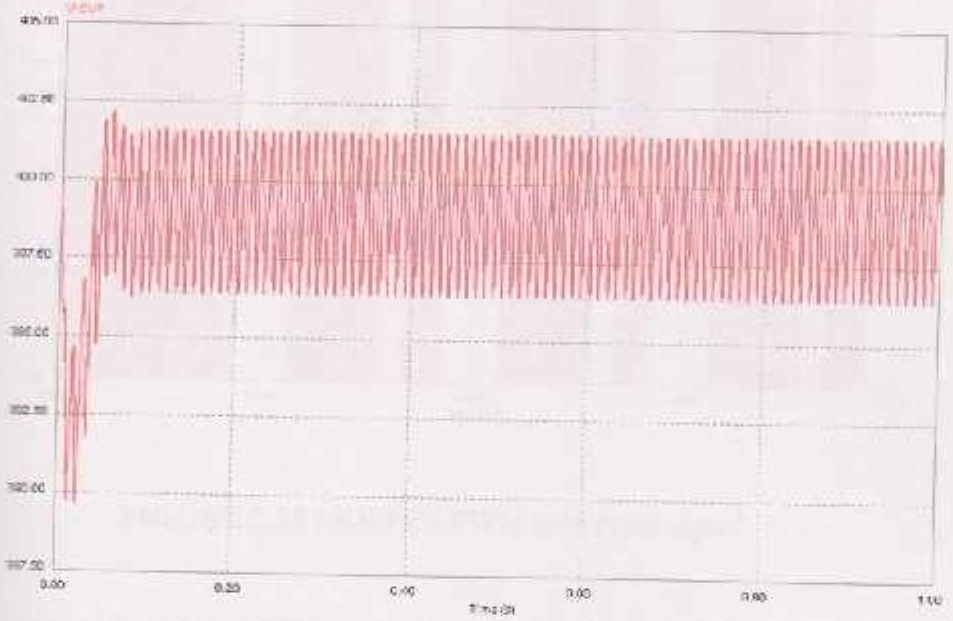


FIGURE 5.14 Output voltage after correction

Following represents the gate drive signal of the MOSFET by means of PWM

FIGURE 5.15 MOSFET PWM gate drive signal

Since the single phase boost PFC results in a regulated output DC voltage, there is a great chance to utilize that voltage by converting it into a regulated AC voltage using an ideal PWM inverter followed by a transformer with a suitable ratio to get 220 regulated AC voltage along any technological process. And figure 5.17 appears the regulated output 220 VAC.

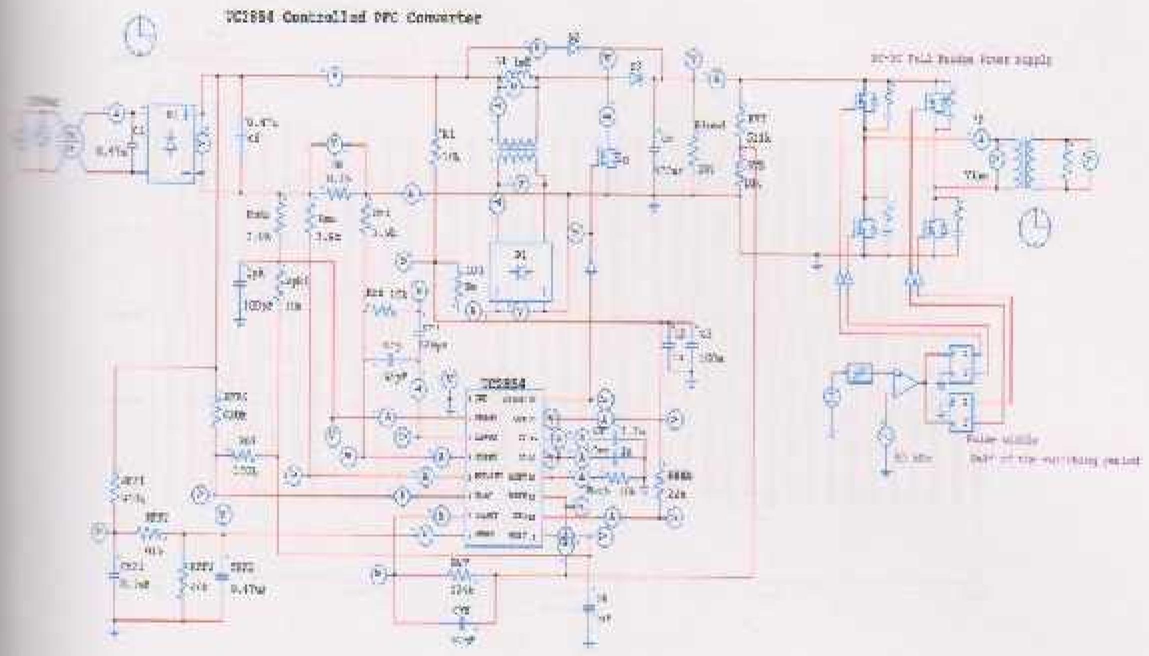


FIGURE 5.16 Complete single phase Boost PFC with regulated AC output circuit

Hence, this part is discussed only from a theoretical view, not to be implemented practically.

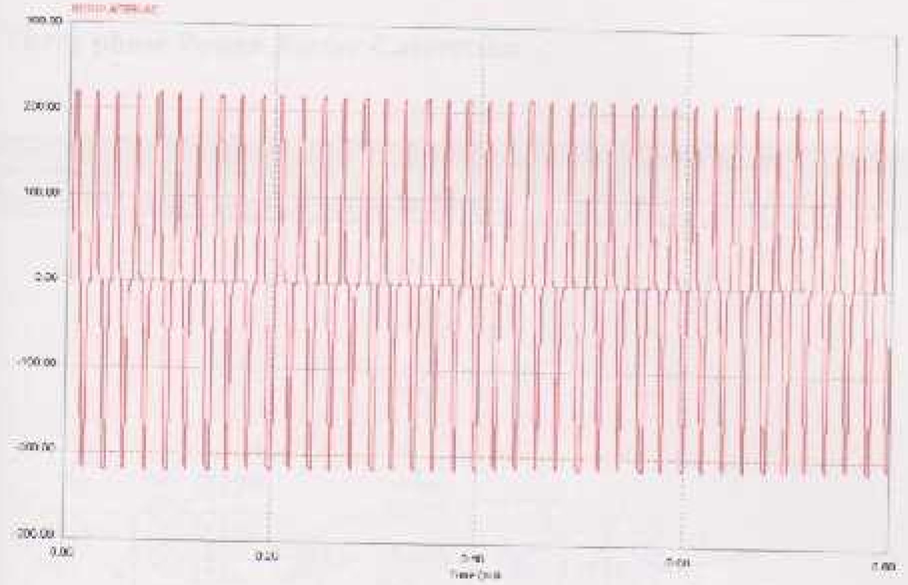


FIGURE 5.17 Regulated output AC voltage of the complete high Boost PFC pre-regulator

5.6.2 Three phase Power Factor Correction

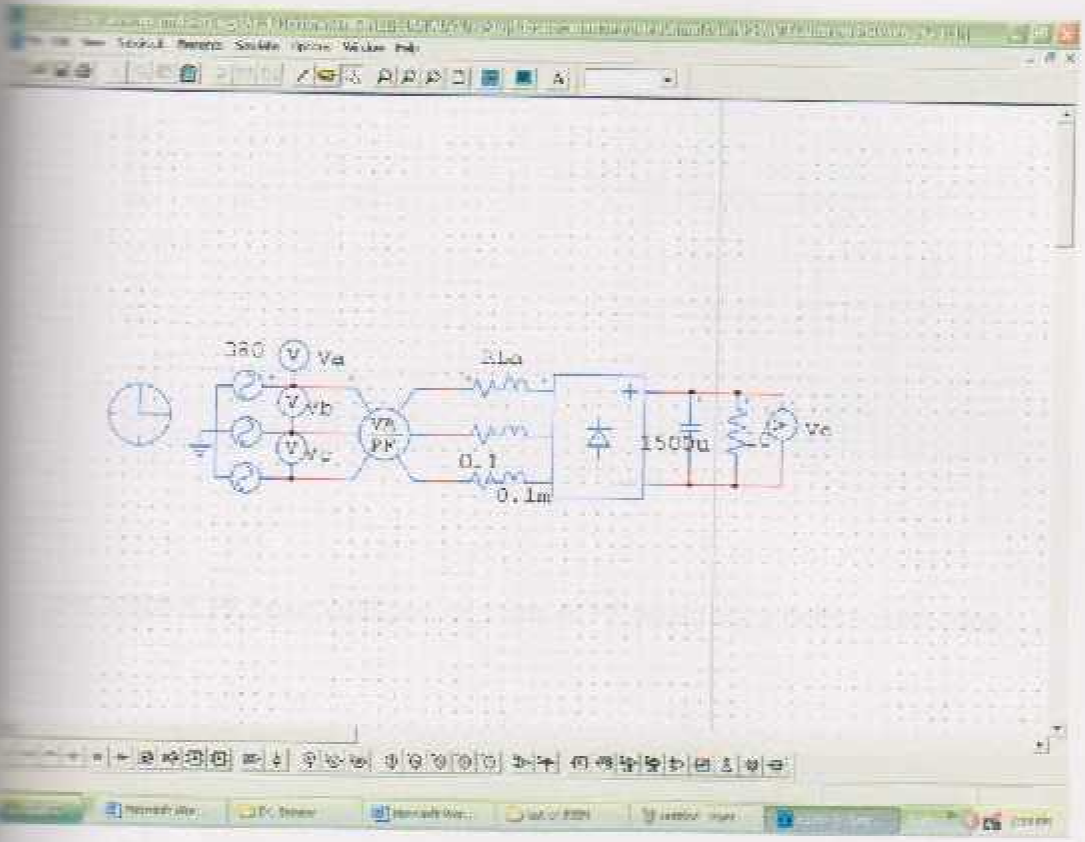


FIGURE 5.18 Three phase circuit without PFC

The previous figure implements simple configuration of a SMPS without PFC, while the following figures show its input phase voltages, currents, PF, DPF and harmonic content of the input phase currents waveforms.

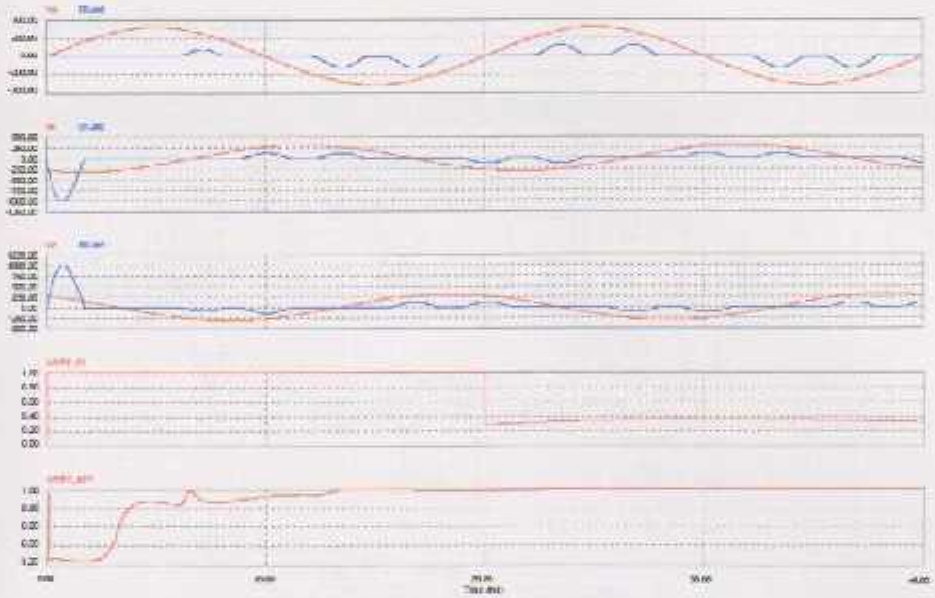


FIGURE 5.19 Input voltages, currents & PF waveforms before correction

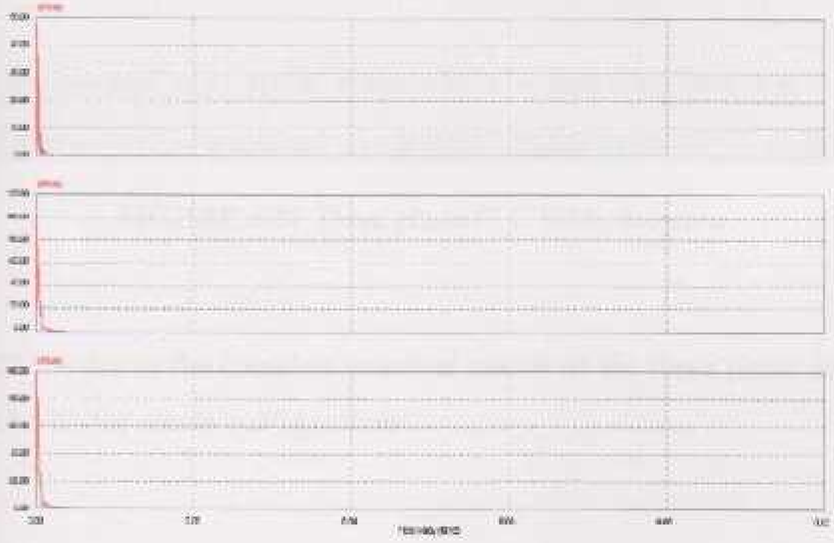


FIGURE 5.20 Input current harmonic content of the three phases before correction

Figure 2.21 summarizes the functional block diagram of a three phase active high boost PFC pre - regulator circuit.

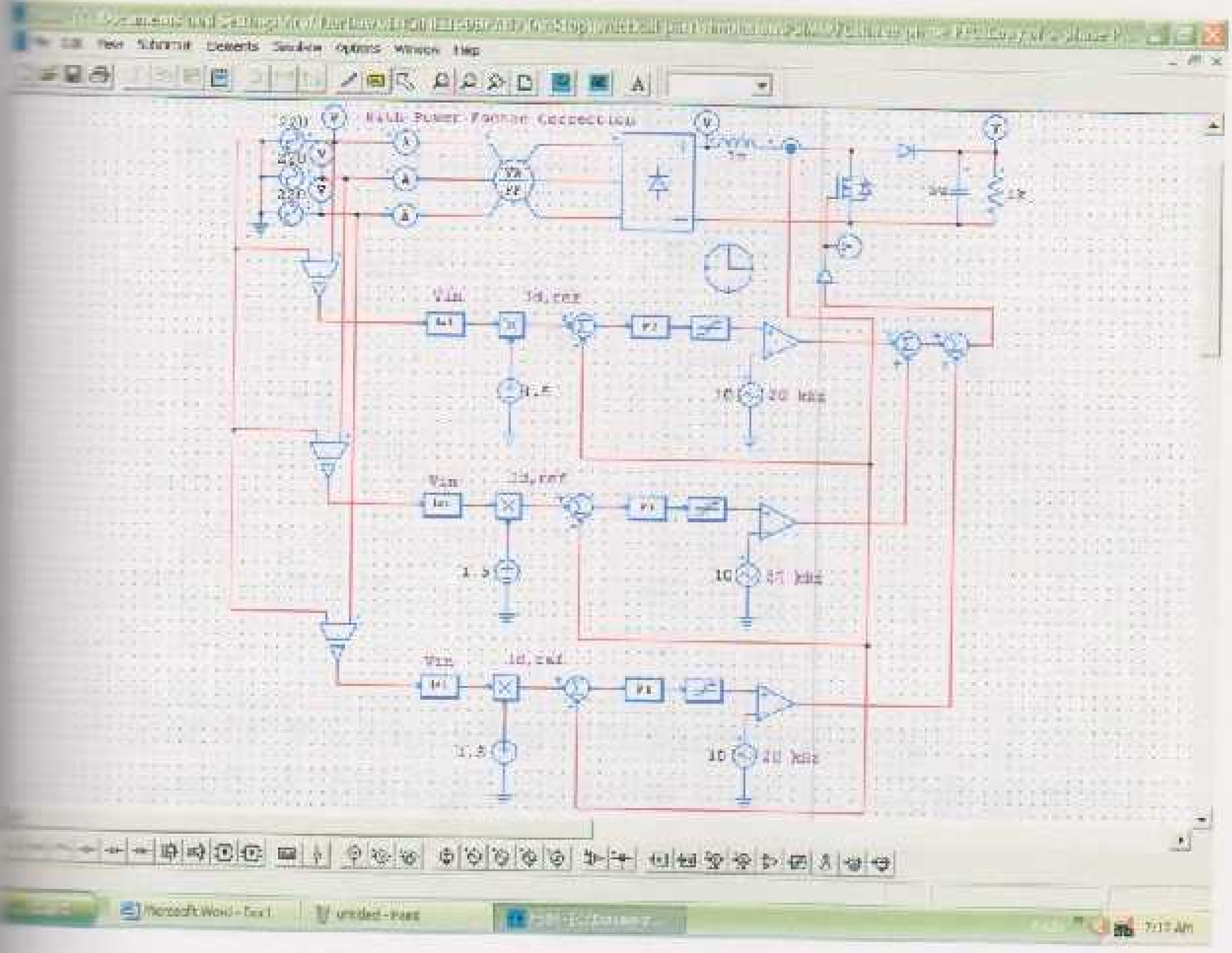


FIGURE 5.21 Three phase PFC block diagram

Figure 5.22 illustrates the complete practical circuit of the three phase active boost PFC circuit with the whole configurations.

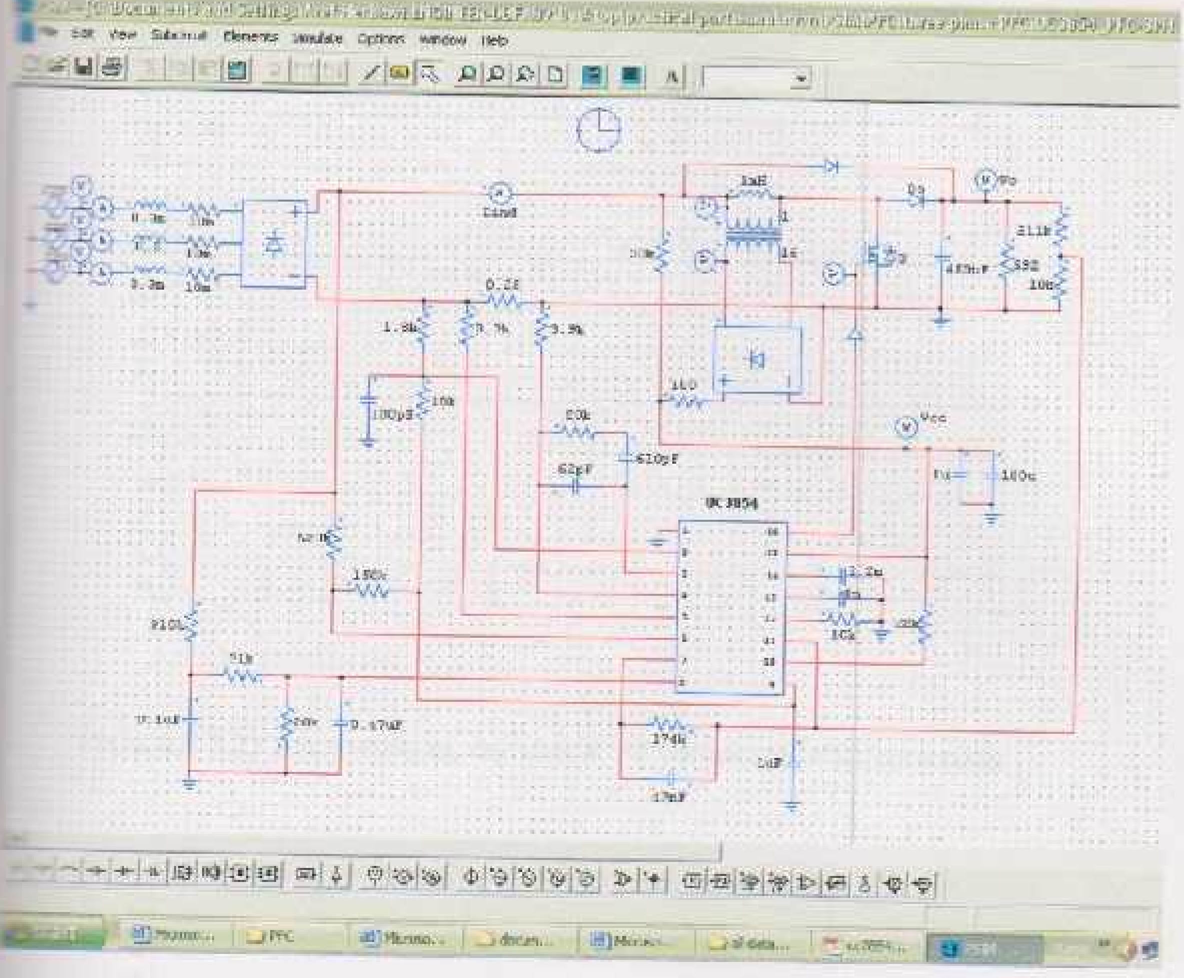


FIGURE 5.22 Three phase complete circuit with PFC

The following figures show the input phase voltages, currents, PF, DPF and harmonic content of the input phase currents waveforms of the three phase boost PFC.

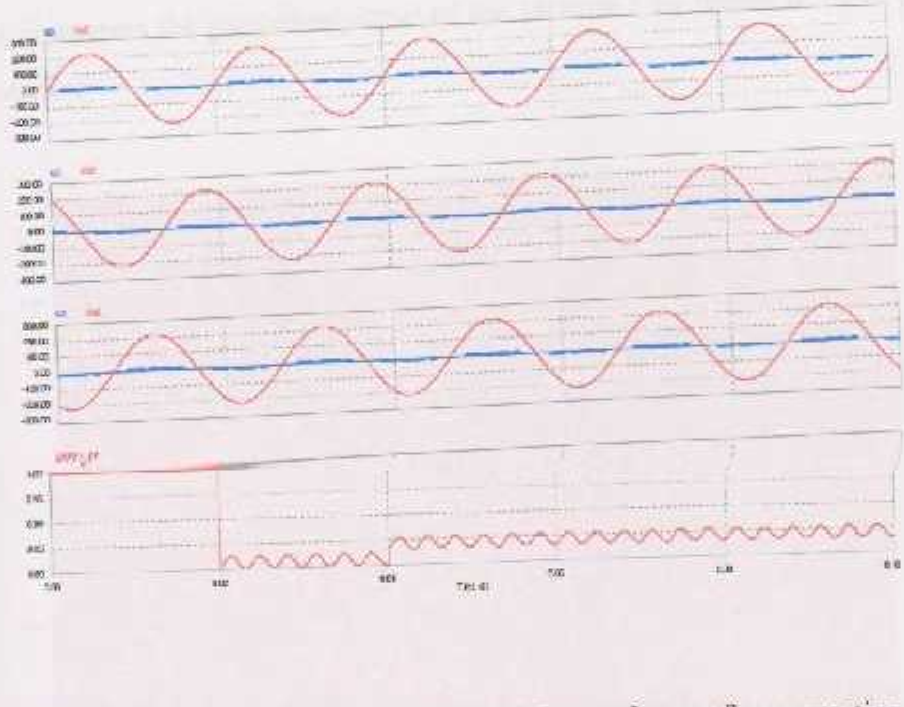


FIGURE 5.23 Input voltages, currents & PF waveforms after correction

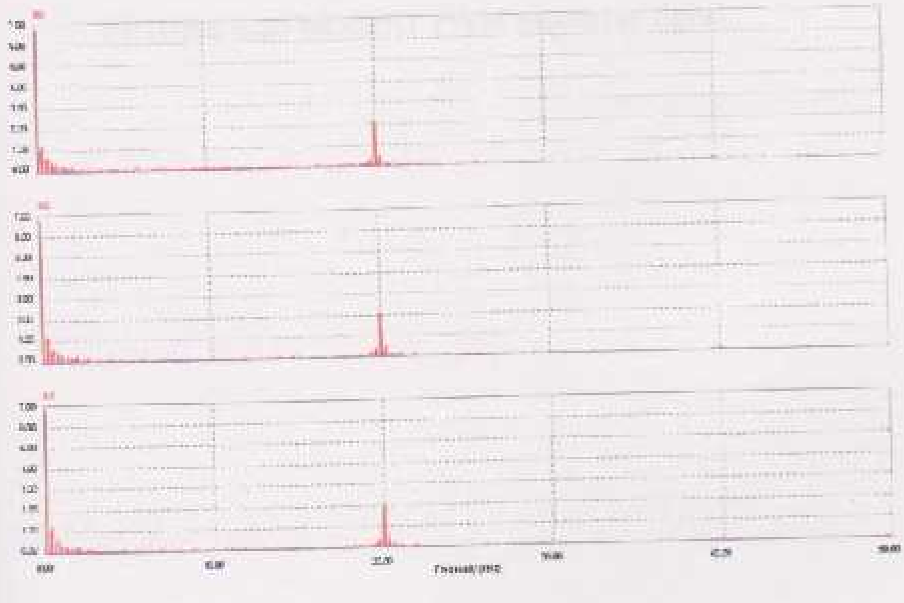


FIGURE 5.24 Input current harmonic content of the three phases after correction

Following represents the gate drive signal of the MOSFET by means of three phase PWM controller.

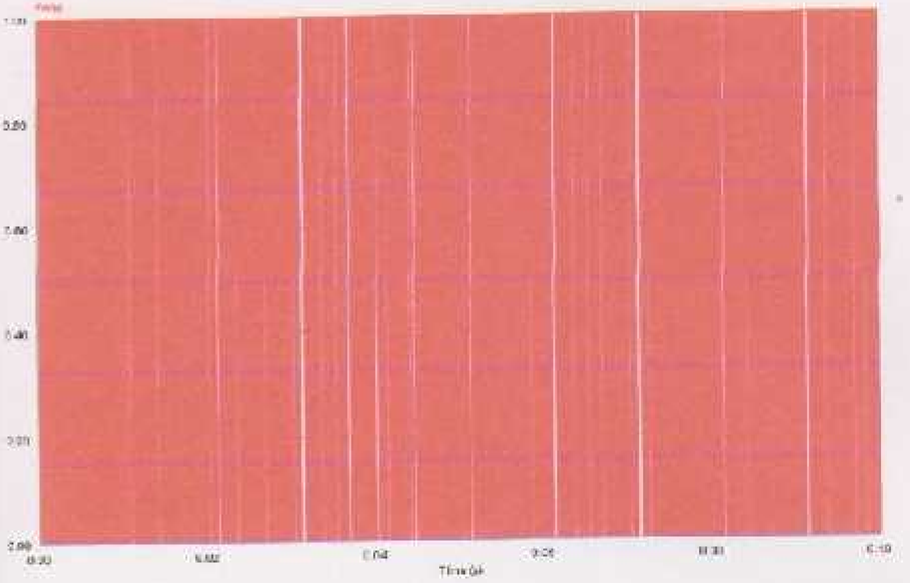


FIGURE 5.25 MOSFET PWM gate drive signal

CHAPTER SIX

TESTS AND RECOMMENDATIONS

6.1 Introduction

The implementation and test of any project is the final and the most important step of project's success. The realization of aims and targets of the project is completely dependent on how much the theoretical part is compatible with the practical one.

The success of the practical design results in local society beneficiaries, requiring adoption from any governmental or formal sides to achieve it's real utilization and to prove it's role as a new design for various activities.

6.2 Tests and results (part one)

The testing procedure has passed through three different stages but dependent on each other. Those stages can be summed as follows.

6.2.1 Planning, imagination and temporary connection

This stage started with determination of required objectives and principle of operation, with a basic representation on the shape of the practical circuit.

Then, the check of availability of required equipments and devices, weather they are found or not first before going ahead into the practical configuration.

After that, comes the role of a powerful tool for circuit analysis with recourse to the computer software, which is simulation. In the project design, various simulating and implementing softwares were used, such as PSIM, PsPisc, SIMPLORER & ORCAD.

analytical calculations are also important that is they can be used to determine the comparative or exact parameters of the proposed work. Even that there may be some deviation between the simulated results and the calculated terms due to the difference between a PC and a board for attaining a certain circuit.

Depending on the previous summary, the step of a initial implementation of the practical circuit has taken place on bread board.

FIGURE 6.1 Temporary full circuit implementation on Bread Board

6.2.2 Step by step basic test and implementation

This stage was built on partitioning the whole circuit into four main parts. The partitioning of the circuit depended on cascade power and control and their arrangement in the circuit. The four parts were as follows:

- SMPS part: the part of the circuit that consists of AC source, input capacitor, bridge rectifier and filtering capacitor.

FIGURE 6.2 SMPS part

- DC – DC step up converter (step up DC chopper): consists of boost inductor, power MOSFET, inrush diode, bulk capacitor and the load.

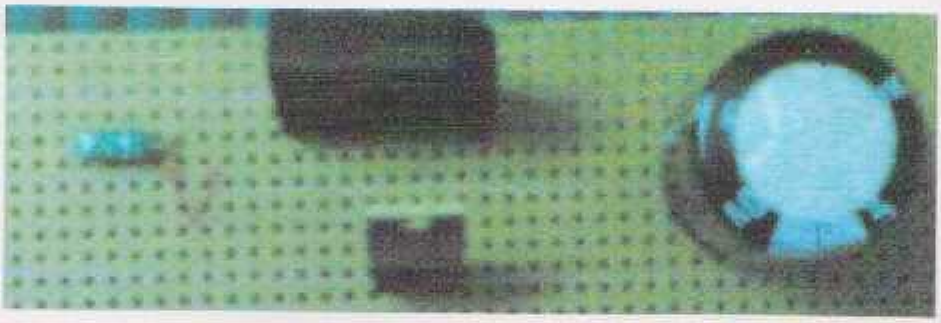


FIGURE 6.3 DC – DC step up converter part

- PWM controller: UC2854 with all pin configurations as mentioned in chapter 5 in addition to various resistors and capacitors for voltage and current division.

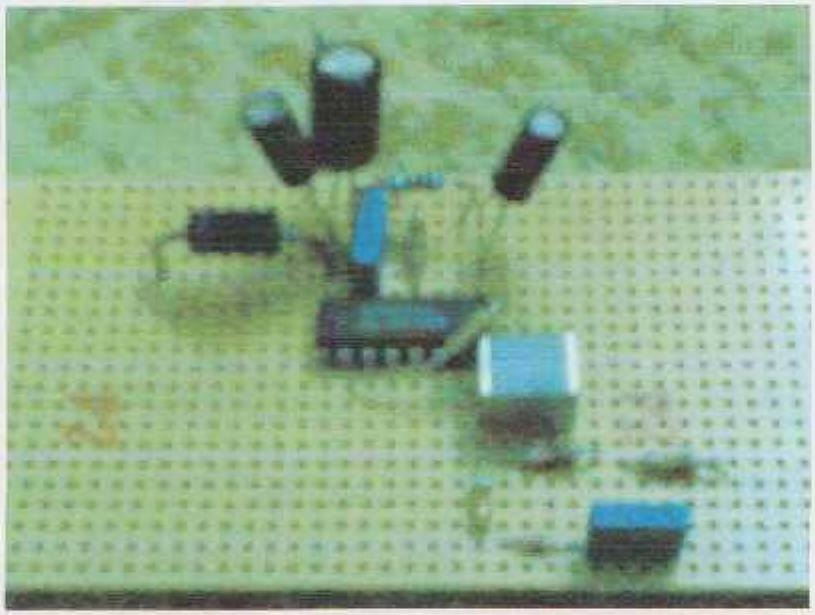


FIGURE 6.4 PWM controller part

- Voltage and current sensing: DC output voltage sense, V_{rms} sense, AC current sense and maximum current sense.

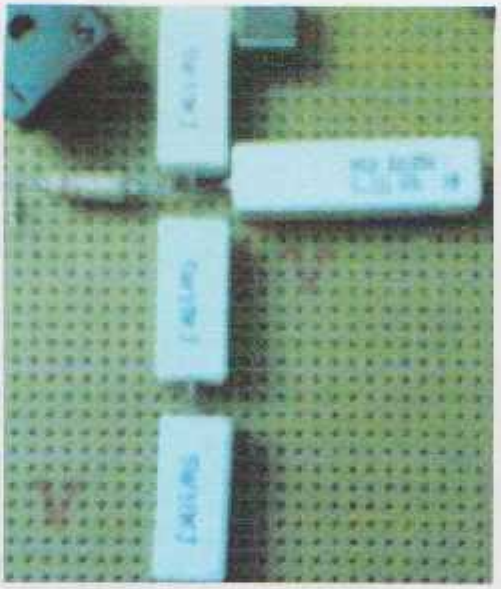


FIGURE 6.5 Voltage and current sensing part

6.2.3 final assembly and operational process

The complete assembly of the final circuit was dependent of the initial and basic assembly. The final circuit resulted as a complete single phase high boost PFC pre – regulated circuit.

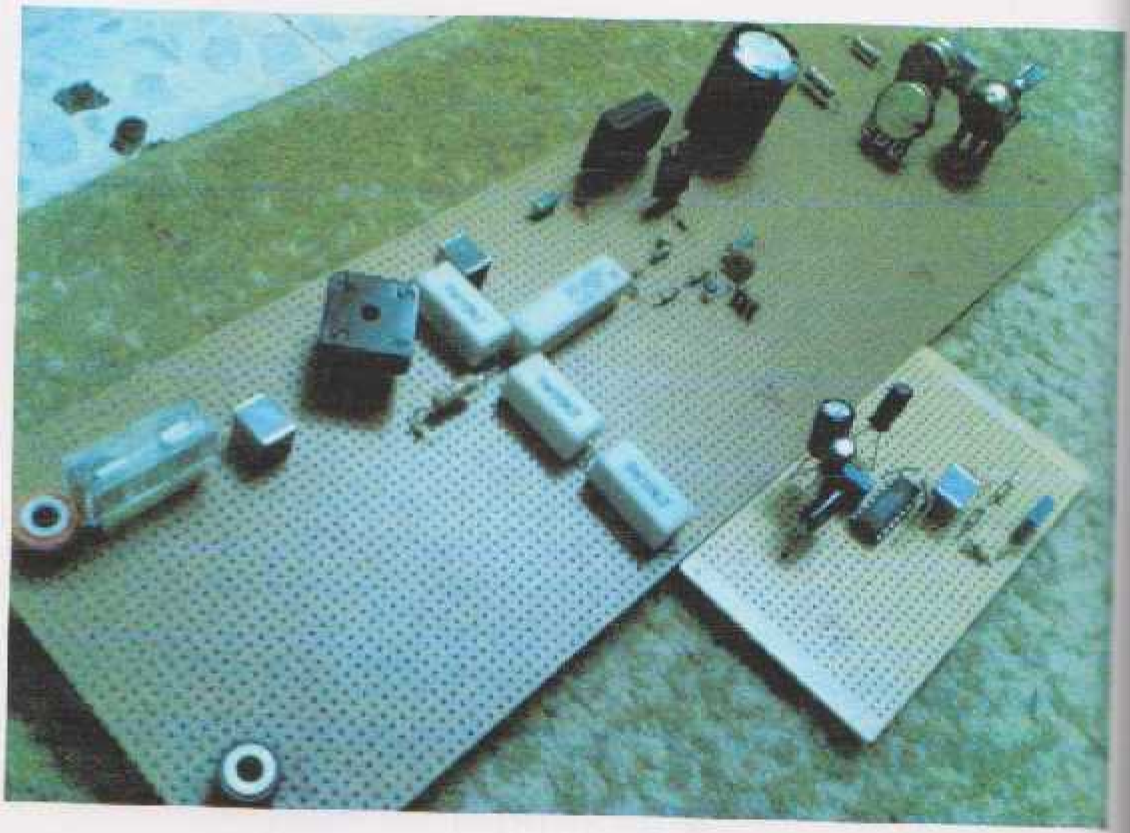


FIGURE 6.6 Practical circuit of single phase high boost PFC pre – regulated circuit

6.3 Test and results (part two)

Since the first practical circuit chosen was operationally failed, another circuit is suggested and implemented to achieve the desired target. This circuit was basically dependent of an optocoupler instead of the PWM IC; in order to pass the problems faced when using the IC – dependent circuit.

6.3.1 Circuit and simulation

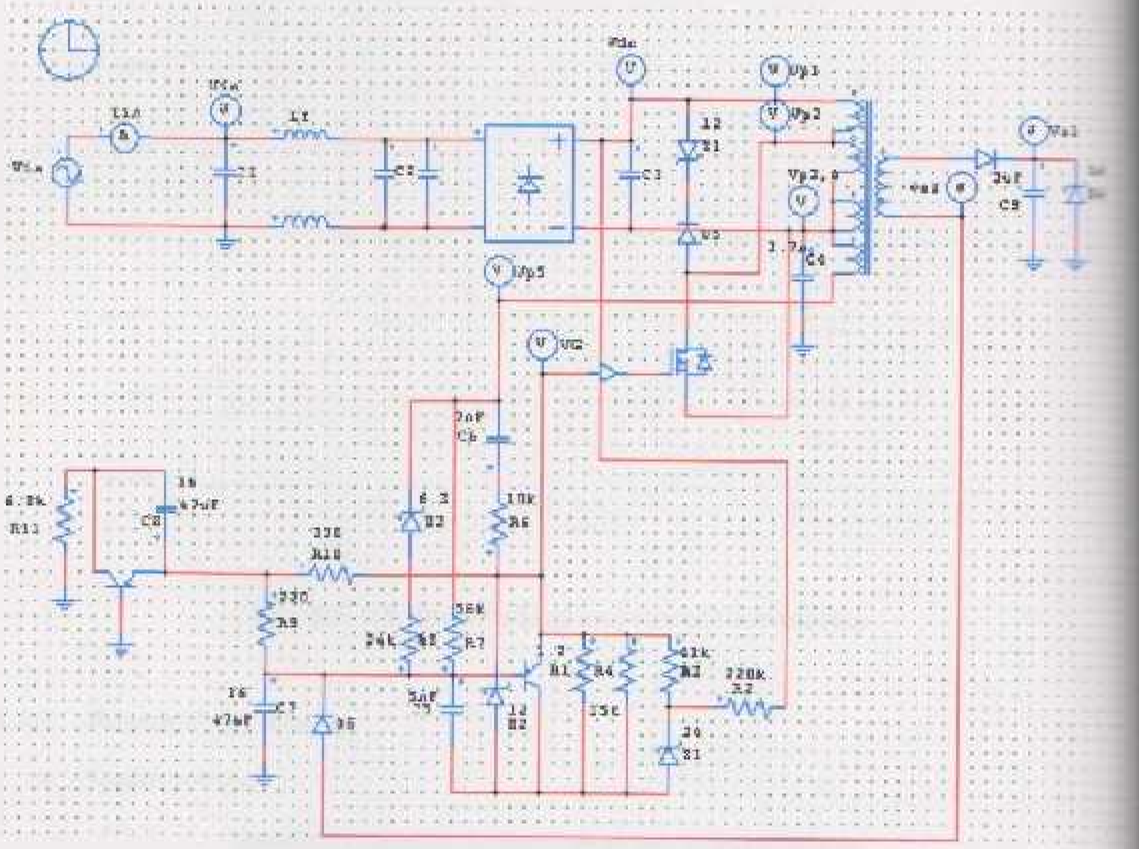


FIGURE 6.7 Schematic of practical circuit design

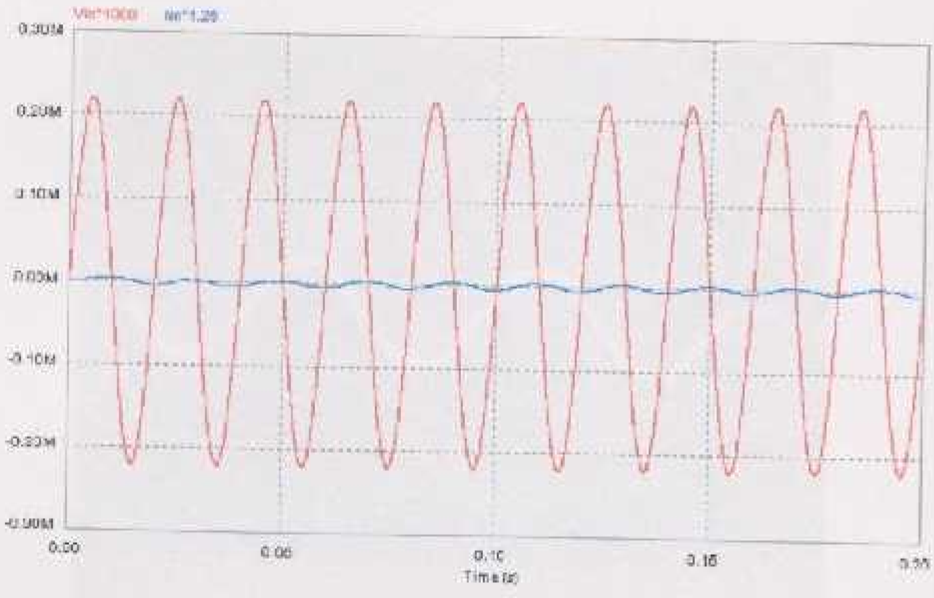


FIGURE 6.8 Input voltage and current waveforms

6.3.2 Practical waveforms

- **Input voltage**

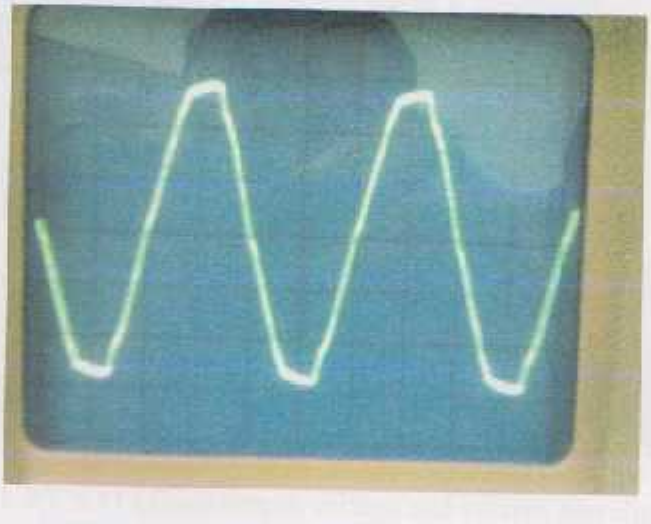


FIGURE 6.9 circuit input voltage waveform

- **Input current**

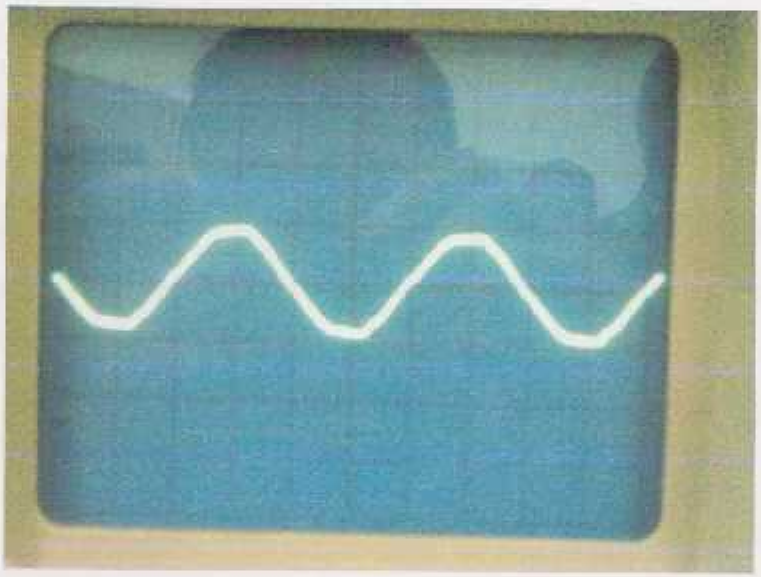


FIGURE 6.10 circuit input current waveform

- **Input voltage and current**

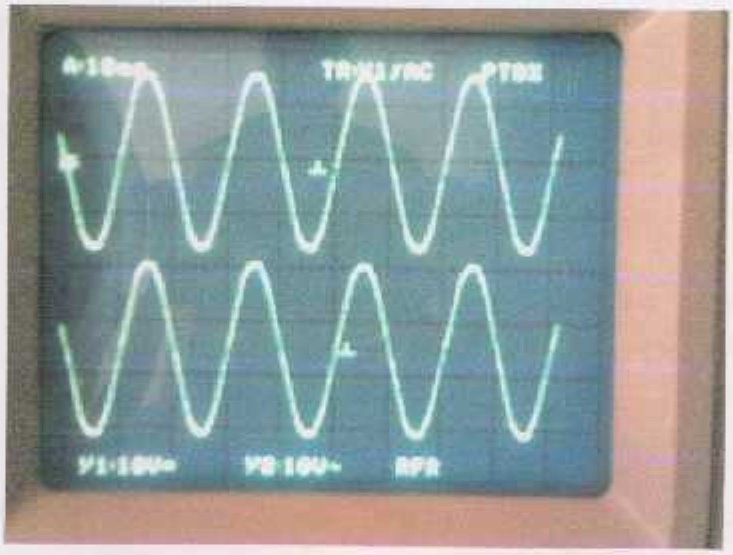


FIGURE 6.11 circuit output voltage and current waveforms

6.3.3 Final results

- Improvement of PF: the PF was corrected from 42% to a very good value, around 98%, and this was noticed on the power factor measurement device.

- Voltage regulation: the voltage from 160 V to 220 V was finely regulated; that is, any input voltage applied between these two values, the inverter output will have the regulated value of 200 VAC.

6.4 Problems encountered during the project

This project faced a lot of problems, those problems can be categorized into three main fields as follows.

6.4.1 Questionnaire and survey problems

This field was the most challenging criteria encountered the work team, which can be summed in:

- Lack of awareness of average people, associations and industrial plants managers, that most of them do not have any concern to national objectives and the common welfare.

- Most of factories distributed through Hebron district, especially the core of the region, don't use PFC techniques, even most of them basically don't know what Power Factor is.

- Many surveyed industrial plants don't have an engineers, even no technical engineers, and so; the working group was forced to attain required information themselves.

- Some wrong information provided by Hebron chamber of commerce and industry about industrial plants names and locations, some factories found to be closed since a so long time.

6.4.2 Problems of available devices

Many electrical and electronic devices in the local market were found to be not exist, even if there were a method to buy them abroad, it will absorb more time and more effort to get them. That was a main reason why the practical circuit of the project has changed many times.

6.4.3 Operational problem

This field was of high degree of complexity; because all the implemented devices and ratings have to be chosen accurately, taking into account parameters rating, maximum power, voltages and currents. Also datasheets of the used instruments have to be revised seriously and firmly; because any error in parameters' determination may cause a serious risk.

The most difficult elements to be evaluated were the power resistors; that is all the existed power resistors in the local market were of a so small value with a small power capability. That step resulted in damaging the circuit hardware more than one time because of the misused protective issues due to high power.

6.5 Recommendations

- For this project to see the light, it should be adopted by any governmental or formal committee to attend enough encourage and support.
- Trying as much as possible to raise up the degree of consciousness of people and force them to apply all tips of energy saving summarized in this project.
- It highly regarded that this project should be continued to attain AC voltage regulation for single phase by means of a single phase PWM inverter.
- Also for future work, it would be an excellent idea to implement a complete three phase power supply which results in PFC of the source with a 220 regulated AC voltage through matching between a three phase active high boost PFC pre – regulator and a three phase PWM inverter connected with a three phase transformer.

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APPENDIX A

QUESTIONAIRE FORM

بسم الله الرحمن الرحيم

جامعة بوليتكنك فلسطين
كلية الهندسة والتكنولوجيا
دائرة الهندسة الكهربائية والحاسوب

تعبئة استبيان خاص بترشيد استهلاك الطاقة

السادة الكرام

السلام عليكم ورحمة الله وبركاته ،،،

نود إعلام حضراتكم أننا الفريق الطلابي من جامعة بوليتكنك فلسطين/مرحلة التخرج، نقوم بدراسة مسحية للمنشآت الصناعية والمراكز الكهربائية في المحافظة؛ وذلك لمساعدة الاقتصاد المحلي في ترشيد استهلاك الطاقة الكهربائية والمحافظة على قيم معيارية لمعامل القدرة في المنشآت والمراكز الصناعية.
لذا نرجو من حضراتكم التكرم بالإجابة على الأسئلة المطروحة في هذا الاستبيان بموضوعية ووضوح تام من أجل التوصل إلى الأهداف المرجوة، علما بأن هذه الدراسة سوف تستخدم فقط لأغراض بحثية تطبيقية.
شاكرين لكم حسن تعاونكم

مع فائق الاحترام ،،،

الطلبة الباحثون
أشرف جبرين
أكرم سباتين
سائد وراسنة
عارف الحرباوي
عدي أبو عرقوب

خاصة بالمهندس/الفني/المشرف التقني المسؤول في المصنع

الجزء الأول: الرجاء وضع إشارة × في مربع الإجابة المناسبة

1. هل تستخدم المؤسسة حاليا تقنية لتحسين معامل القدرة للمحركات والأنظمة الكهربائية؟

☐ نعم ☐ لا ☐ لا حاجة لها

2. إذا كانت الإجابة في الفرع (1) لا، ما سبب ذلك؟

....

....

3. هل سبق واستخدمت هذه التقنية وتم الاستغناء عنها؟

☐ نعم ☐ لا ☐ لا أدري

4. هل استفادت المؤسسة من استخدام التقنية؟

☐ نعم ☐ لا ☐ نسبيا

5. ماهو مقدار هذه الاستفادة مقارنة بتكلفة التقنية؟

☐ منخفض ☐ مرتفع نسبيا ☐ عالٍ

6. في حالة استخدام محرك جديد، هل يعتبر تحسين معامل القدرة للمحرك من الأولويات؟

☐ نعم ☐ هناك أولويات أخرى ☐ لا

7. في حال استجدت تقنية جديدة ومميزة لتحسين معامل القدرة، هل ستستخدمها؟

☐ نعم ☐ لا ☐ ربما

8. هل لدى المؤسسة القابلية لإعادة تأهيل المحركات القديمة وترشيد استهلاكها للطاقة؟

☐ نعم ☐ لا ☐ هناك أولويات أخرى

9. هل تبقى المحركات والأجهزة الكهربائية في حالة التشغيل أثناء فترة الاستراحة؟

☐ نعم ☐ لا ☐ أحيانا حسب الحاجة

10. هل يوجد مولد كهرباء احتياطي **(Standby Generator)**؟

☐ نعم ☐ لا

11. إذا كانت الإجابة في الفرع (10) بنعم، ما هي قدرته الظاهرية؟

....

12. هل يستخدم المصنع محولات كهربائية؟

☐ نعم ☐ لا

13. إذا كانت الإجابة في الفرع (12) بنعم، الرجاء تعبئة الجدول التالي

قدرة المحول	جهد منخفض/ مرتفع	الاستخدام

الجزء الثاني: الرجاء الإجابة على الأسئلة التالية

الرقم	السؤال	الإجابة
1	مقدار معامل القدرة الكلي قبل التحسين	
2	مقدار معامل القدرة الكلي بعد التحسين	
3	معدل الطاقة المستهلكة شهريا	
4	القدرة الظاهرية الكلية للمصنع في وقت الذروة	
5	عدد المحركات المستخدمة التي تطبق عليها التقنية	
6	معدل ساعات التشغيل اليومي لهذه المحركات	
7	نوع نظام الطاقة البديل المستخدم (إن وجد)	
8	نوع التقنية المستخدمة حاليا او سابقا لتحسين معامل القدرة	
9	عدد الورديات اليومية للعمل	

الجزء الثالث: الرجاء تعبئة الجدول التالي والخاص ببعض المعلومات عن المحركات المستخدمة

نوع المحرك	القدرة KW	الاستخدام	معامل القدرة	نسبة التشغيل	معدل التشغيل اليومي (ساعة)

الجزء الرابع: الإنارة: الرجاء وضع إشارة × في مربع الإجابة المناسبة

1. ما هو نوع الإنارة المستخدمة؟
☐ مصابيح فلورسنت ☐ مصابيح وهاجة(تنغيستين) ☐ غير ذلك:............

2. هل يوجد أنظمة تهوية وإنارة جانبية؟
☐ نعم ☐ لا

3. هل الأسطح الجانبية مناسبة لانعكاس الإنارة أو امتصاصها؟
☐ نعم ☐ لا

4. هل يستخدم نظام إطفاء إنارة آلي؟
☐ نعم ☐ لا

5. هل اتبعت معايير محددة في تحديد الأجسام المضيئة؟
☐ نعم ☐ لا

6. هل يتم استخدام أنظمة طاقة بديلة لتغطية حاجة الإنارة لساحات العمل المكشوفة؟
☐ نعم ☐ لا

7. هل ارتفاع أجسام الإنارة عن سطح العمل مناسب؟
☐ نعم ☐ لا

8. هل يتم التحقق من فاعلية الأجسام المضيئة وإصلاحها بشكل مستمر؟
☐ نعم ☐ لا

9. هل لدى المؤسسة مسئول فني يتابع أعطال الإنارة؟
☐ نعم ☐ لا

10. هل يعتبر تحسين الإنارة واستخدام ما استجد عليها من أولويات المؤسسة؟
☐ نعم ☐ لا ☐ ربما

APPENDIX B

DATA SHEETS

PWM / PFC CONTROLLER (UC2854AN)

UC1854
UC2854
UC3854

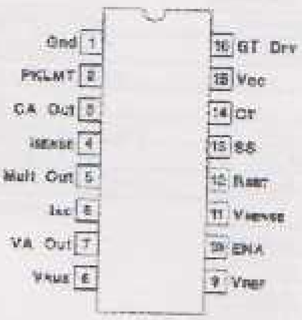
ABSOLUTE MAXIMUM RATINGS

Supply Voltage Vcc	35V
GT Drv Current, Continuous	0.5A
GT Drv Current, 50% Duty Cycle	1.5A
Input Voltage, VSENSE, VRMS	11V
Input Voltage, ISENSE, Mult Out	11V
Input Voltage, PKLMT	5V
Input Current, RSET, IAC, PKLMT, ENA	10mA
Power Dissipation	1W
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 Seconds)	+300°C

Note 1: All voltages with respect to Gnd (Pin 1).
Note 2: All currents are positive into the specified terminal.
Note 3: ENA input is internally clamped to approximately 14V.
Note 4: Consult Unitrode Integrated Circuits databook for information regarding thermal specifications and limits.

CONNECTION DIAGRAMS

DIL-16 & SOIC-16
(Top View)
J, N & DW Packages



PLCC-20 & LCC-20
(Top View)
Q & L Packages

PACKAGE PIN FUNCTION	
FUNCTION	PIN
N/C	1
GND	2
PKLMT	3
CA Out	4
ISENSE	5
N/C	6
Mult Out	7
IAC	8
VA Out	9
VRMS	10
N/C	11
VREF	12
ENA	13
VSENSE	14
RSET	15
N/C	16
SS	17
CT	18
Vcc	19
GT Drv	20

ELECTRICAL CHARACTERISTICS

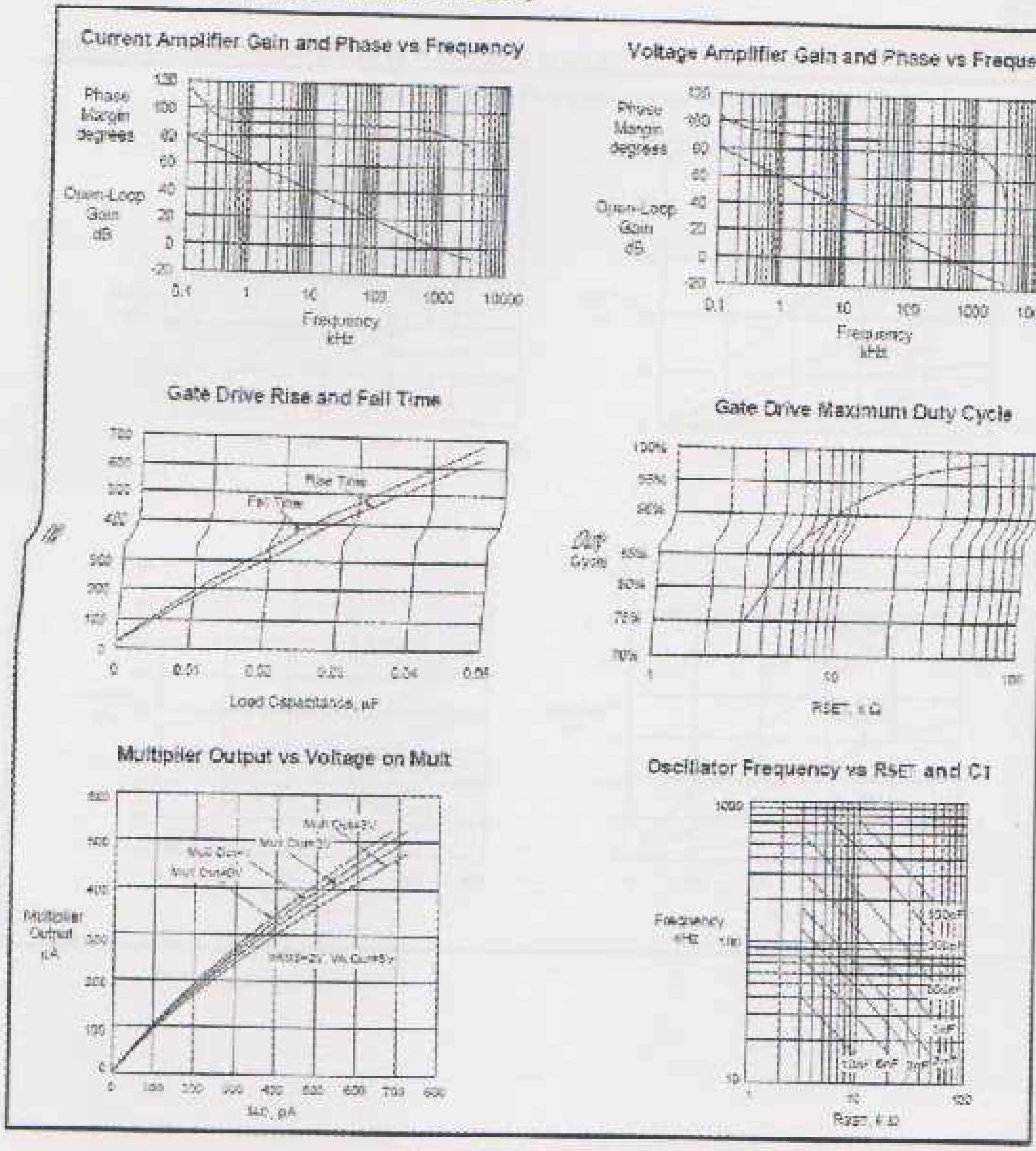
Unless otherwise stated, Vcc=18V, RSET=15k to ground, CT=1.5nF to ground, PKLMT=1V, ENA=7.5V, VRMS=1.5V, IAC=100µA, ISENSE=0V, CA Out=3.5V, VA Out=5V, VSENSE=7.5V, no load on SS, CA Out, VA Out, REF, GT Drv, −55°C<TA<125°C for the UC1854, −40°C<TA<85°C for the UC2854, and 0°C<TA<70°C for the UC3854, and TA=TJ.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
OVERALL					
Supply Current, Off	ENA=0V		1.5	2.0	mA
Supply Current, On			10	16	mA
Vcc Turn-On Threshold		14.5	16	17.5	V
Vcc Turn-Off Threshold		9	10	11	V
ENA Threshold, Rising		2.4	2.55	2.7	V
ENA Threshold Hysteresis		0.2	0.25	0.3	V
ENA Input Current	ENA=0V	−5.0	−0.2	5.0	µA
VRMS Input Current	VRMS=5V	−1.0	−.01	1.0	µA
VOLTAGE AMPLIFIER					
Voltage Amp Offset Voltage	VA Out=5V	−8		8	mV
VSENSE Bias Current		−500	−25	500	nA
Voltage Amp Gain		70	100		dB
Voltage Amp Output Swing			0.5 to 5.8		V
Voltage Amp Short Circuit Current	VA Out=0V	−36	−20	−5	mA
SS Current	SS=2.5V	−20	−14	−6	µA

ELECTRICAL CHARACTERISTICS Unless otherwise stated, V_{CC}=18V, R_{SET}=15k to ground, C_T=1.5nF to ground, PKLMT=1V, ENA=7.5V, V_{RMS}=1.5V, I_{AC}=100μA, I_{SENSE}=0V, CA Out 3.5V, VA Out=5V, V_{SENSE}=7.5V, no load on SS, CA Out, VA Out, REF, GT Drv, −55°C<T_A<125°C for the UC1854, −40°C<T_A<85°C for the UC2854, and 0°C<T_A<70°C for the UC3854, and T_A=T_J

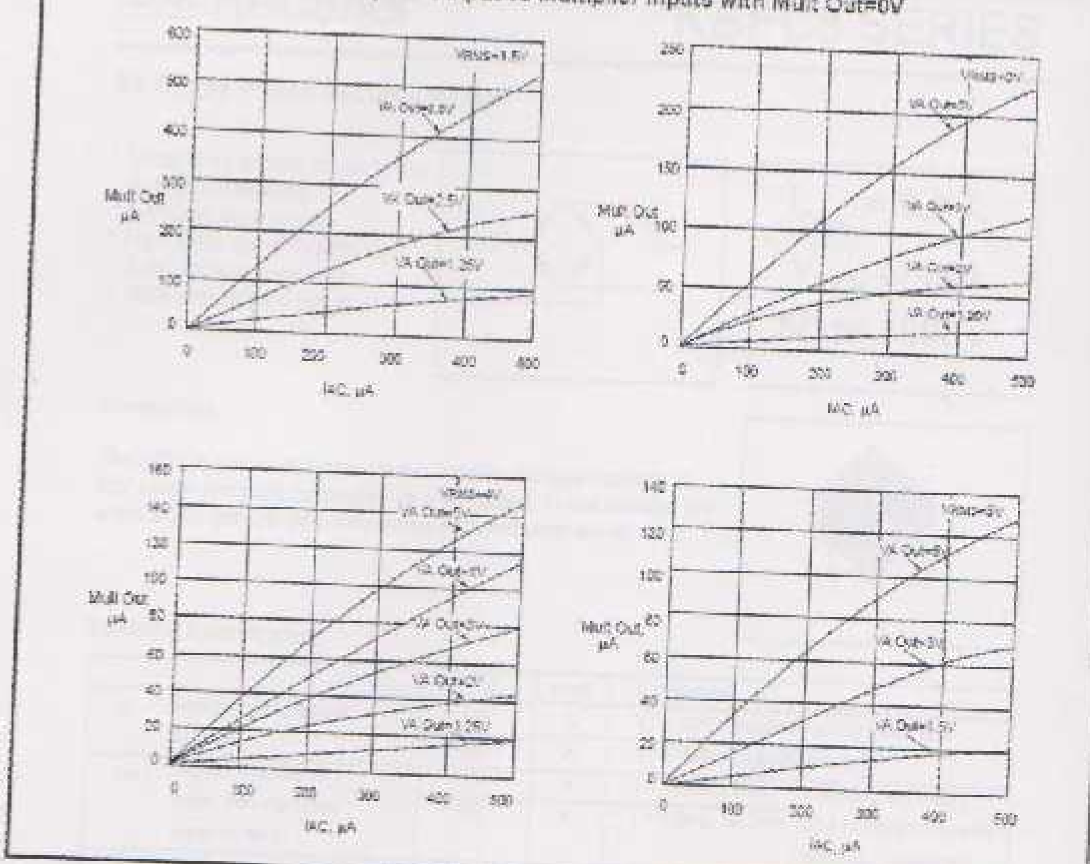
PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
CURRENT AMPLIFIER					
Current Amp Offset Voltage					
I_{SENSE} Bias Current		−4		4	mV
Input Range, I_{SENSE}, Mult Out		−500	−120	500	nA
Current Amp Gain		−0.3 to 2.5			V
Current Amp Output Swing		80	110		dB
Current Amp Short Circuit Current	CA Out=0V		0.5 to 16		V
Current Amp Gain BW Product	T_A=25°C (Note 6)	−36	−20	−5	mA
REFERENCE		400	800		kHz
Reference Output Voltage	I_{REF}=0mA, T_A=25°C	7.4	7.5	7.6	V
	I_{REF}=0mA, Over Temp	7.35	7.5	7.65	V
V_{REF} Load Regulation	−10mA<I_{REF}<0mA	−15	5	15	mV
V_{REF} Line Regulation	15V<V_{CC}<35V	−10	2	10	mV
V_{REF} Short Circuit Current	REF=0V	−50	−28	−12	mA
MULTIPLIER					
Mult Out Current I_{AC} Limited	I_{AC}=100μA, R_{SET}=10k, V_{RMS}=1.25V	−220	−200	−180	μA
Mult Out Current Zero	I_{AC}=0μA, R_{SET}=15k	−2.0	−0.2	2.0	μA
Mult Out Current R_{SET} Limited	I_{AC}=450μA, R_{SET}=15k, V_{RMS}=1V, VA Out = 6V	−280	−255	−220	μA
Mult Out Current	I_{AC}=50μA, V_{RMS}=2V, VA=4V	−50	−42	−33	μA
	I_{AC}=100μA, V_{RMS}=2V, VA=2V	−30	−27	−12	μA
	I_{AC}=200μA, V_{RMS}=2V, VA=4V	−165	−150	−105	μA
	I_{AC}=300μA, V_{RMS}=1V, VA=2V	−250	−225	−150	μA
	I_{AC}=100μA, V_{RMS}=1V, VA=2V	−96	−80	−60	μA
Multiplier Gain Constant	(Note 5)		−1.0		V
OSCILLATOR					
Oscillator Frequency	R_{SET}=15k				
	R_{SET}=8.2k	46	55	62	kHz
CT Ramp Peak-to-Valley Amplitude		86	102	118	kHz
CT Ramp Valley Voltage		4.9	5.4	5.9	V
GATE DRIVER		0.8	1.1	1.3	V
Maximum GT Drv Output Voltage	0mA load on GT Drv, 18V<V_{CC}<35V	13	14.5	16	V
GT Drv Output Voltage High	−200mA load on GT Drv, V_{CC}=15V	12	12.8		V
GT Drv Output Voltage Low, Off	V_{CC}=0V, 50mA load on GT Drv		0.9	1.5	V
GT Drv Output Voltage Low	200mA load on GT Drv		1.0	2.2	V
	10mA load on GT Drv		0.1	0.4	V
Peak GT Drv Current	10nF from GT Drv to Gnd		1.0		A
GT Drv Rise/Fall Time	1nF from GT Drv to Gnd		35		ns
GT Drv Maximum Duty Cycle	$V_{CA\ Out}$=7V		95		%
CURRENT LIMIT					
PKLMT Offset Voltage					
PKLMT Input Current	PKLMT=−0.1V	−10		10	mV
PKLMT to GT Drv Delay	PKLMT falling from 50mV to −50mV	−200	−100		μA
			175		ns

TYPICAL CHARACTERISTICS at $T_A = T_J = 25°C$



TYPICAL CHARACTERISTICS at $T_A = T_J = 25^{\circ}C$ (cont.)

Multiplier Output vs Multiplier Inputs with Mult Out=0V



BRIDGE RECTIFIER-1 (KBPC806)

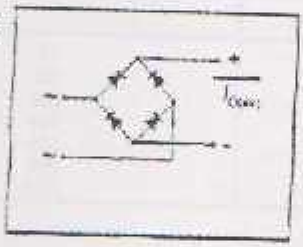
International IOR Rectifier

Provisional Bulletin E2789

KBPC8 SERIES

8A Single Phase Rectifier Bridge

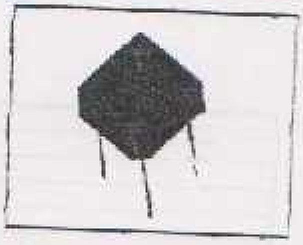
- Suitable for printed circuit board or chasis mounting.
- Compact construction.
- High surge current capability.
- Fully characterised data.
- Wide temperature range.



$I_{O(av)}$ = 8.0 A
V_{RRM} range
50 to 1000V

Description

The KBPC8 Series of Single Phase Rectifier Bridges consists of four silicon junctions connected as a full bridge. These devices are intended for general use in industrial and consumer equipment.



Electrical Specification

		KBPC8...	Units	Conditions	
I_O	Maximum DC output current	8.0	A	T_C = 50°C, Resistive or inductive load	
		5.4	A	T_C = 50°C, Capacitive load	
I_{FSM}	Maximum peak one cycle, non-repetitive surge current	125	A	t = 10ms, 20ms	Following any rated load condition and with rated V_{RRM} reapplied
		137	A	t = 8.3ms, 16.7ms	
I^2t	Maximum I^2t capability for fusing	78	A^2s	t = 10ms	Initial T_J = T_J max 100% V_{RRM} reapplied
		71	A^2s	t = 8.3ms	
		110	A^2s	t = 10ms	Initial T_J = T_J max no voltage reapplied
		100	A^2s	t = 8.3ms	
$I^2\sqrt{t}$	Maximum $I^2\sqrt{t}$ capability for fusing	1105	$A^2\sqrt{s}$	t = 0.1 to 10ms, no voltage reapplied	
V_{FM}	Maximum peak forward voltage per diode	1.0	V	I_{FM} = 3.0A, T_J = 25°C	
I_{RM}	Typical peak reverse leakage per diode	10	mA	T_J = 25°C, 100% V_{RRM}	
		100	mA	T_J = 150°C, 100% V_{RRM}	
f	Operating frequency range	400 to 1000	Hz		
V_{RRM}	Maximum repetitive peak reverse voltage range	50 to 1000	V		

Thermal and Mechanical Specifications

		KBPC8...	Units	Conditions
T_J, T_{stg}	Operating and storage temperature range	-55 to 150	°C	
R_{thJC}	Thermal resistance, junctions to case	8	K/W	
W	Approximate weight	6(0.21)	g (oz)	

KBPC8 SERIES

IOR

Voltage Specifications

Part Number	V_{RRM} Maximum repetitive peak reverse voltage	V_{RSM} Maximum non-repetitive peak reverse voltage
	V	V
KBPC8005	50	80
KBPC801	100	150
KBPC802	200	300
KBPC804	400	500
KBPC806	600	700
KBPC808	800	900
KBPC810	1000	1100

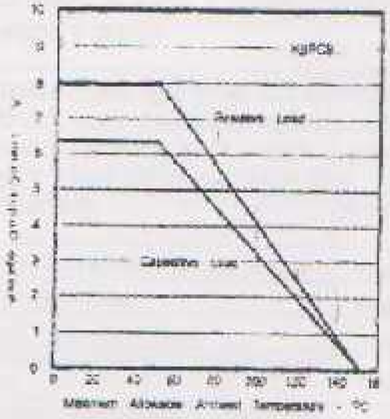


Fig. 1 - Current Ratings

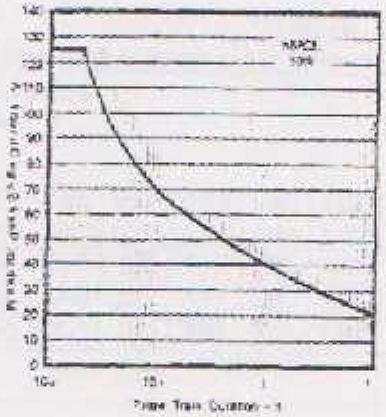
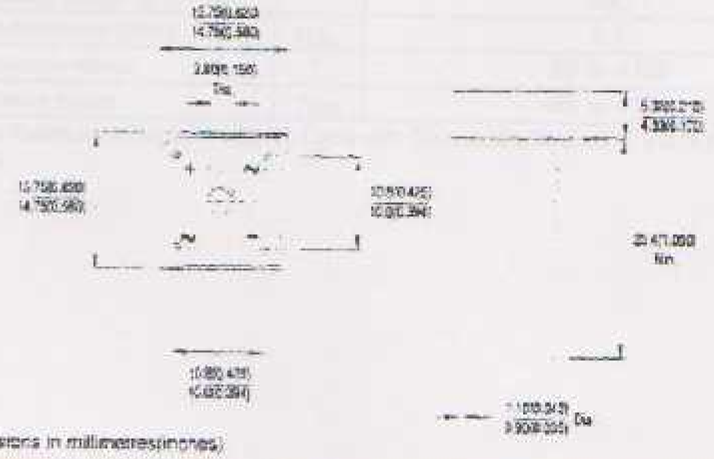


Fig. 2 - Non-Repetitive Surge Ratings

Outline



All dimensions in millimetres(inches)

MJW/05/94

TSC

KBU1001 THRU KBU1007

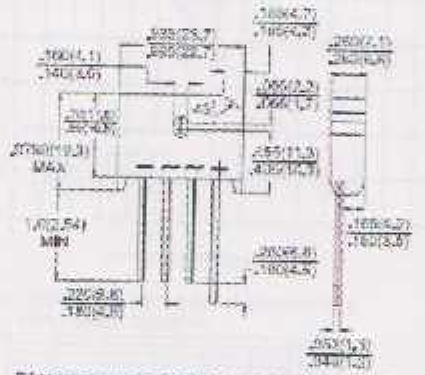
Single Phase 10 AMPS. Silicon Bridge Rectifiers

Voltage Range
50 to 1000 Volts
Current
10.0 Amperes

Features

- UL Recognized File # E-96005
- High surge current capability
- Ideal for printed circuit board
- Reliable low cost construction technique results in inexpensive product
- High temperature soldering guaranteed: 260℃ / 10 seconds / 0.375" (9.5mm) lead length at 5 lbs., (2.3 kg) tension
- Weight: 8 grams

KBU



Dimensions in inches and (millimeters)

Maximum Ratings and Electrical Characteristics

Rating at 25℃ ambient temperature unless otherwise specified.
Single phase, half wave, 60 Hz, resistive or inductive load.
For capacitive load, derate current by 20%

Type Number	Symbol	KBU 1001	KBU 1002	KBU 1003	KBU 1004	KBU 1005	KBU 1006	KBU 1007	Units
Maximum Recurrent Peak Reverse Voltage	V_{RRM}	50	100	200	400	600	800	1000	V
Maximum RMS Voltage	V_{RMS}	35	70	140	280	420	560	700	V
Maximum DC Blocking Voltage	V_{DC}	50	100	200	400	600	800	1000	V
Maximum Average Forward Rectified Current @T_A = 55℃	$I_{(AV)}$	10.0							A
Peak Forward Surge Current, 8.3 ms Single Half Sine-wave Superimposed on Rated Load (JEDEC method)	I_{FSM}	300							A
Maximum Instantaneous Forward Voltage @ 10A	V_F	1.1							V
Maximum DC Reverse Current @ T_A=25℃ at Rated DC Blocking Voltage @ T_A=100℃	I_R	10 500							uA uA
Typical Thermal Resistance (Note)	$R_{\theta JC}$	2.2							℃/W
Operating Temperature Range	T_J	-55 to +125							℃
Storage Temperature Range	T_{STG}	-55 to +150							℃

Note: Thermal Resistance from Junction to Case with Device Mounted on 2" x 3" x 0.25" Al-Plate Heatsink.

TSC

RATINGS AND CHARACTERISTIC CURVES (KBU1001 THRU KBU1007)

FIG.1- MAXIMUM NON-REPETITIVE FORWARD SURGE CURRENT PER BRIDGE ELEMENT

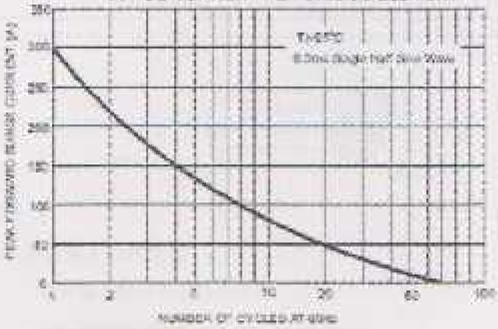


FIG.2- MAXIMUM FORWARD CURRENT DERATING CURVE

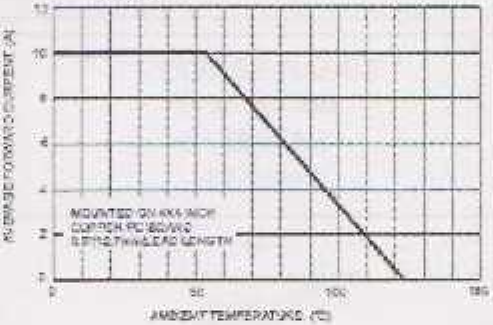


FIG.3- TYPICAL INSTANTANEOUS FORWARD CHARACTERISTICS PER BRIDGE ELEMENT

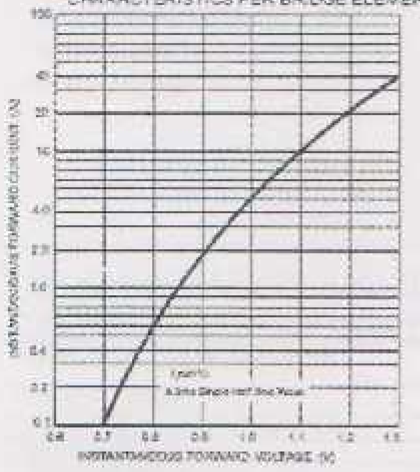
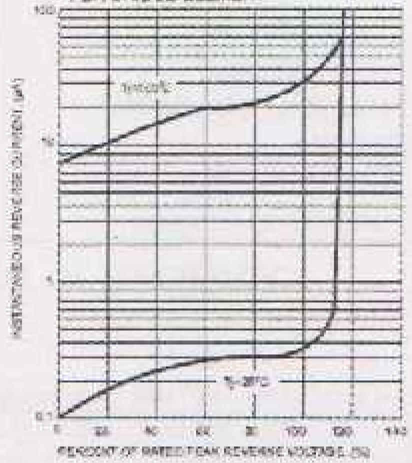
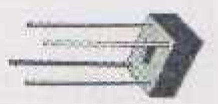


FIG.4- TYPICAL REVERSE CHARACTERISTICS PER BRIDGE ELEMENT



BR305 THRU BR310

SINGLE PHASE 3.0 AMP BRIDGE RECTIFIERS

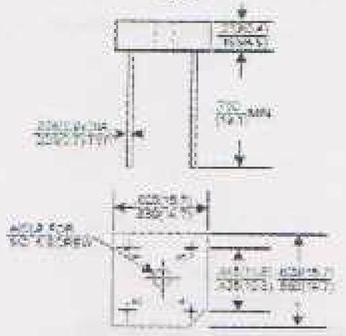


VOLTAGE RANGE
50 to 1000 Volts
CURRENT
3.0 Ampere

FEATURES

* Ideal for printed circuit board
* Low forward voltage
* Low leakage current
* Mounting: Hole thru for #6 screw
* Mounting position: Any
* Weight: 3.38 grams

BR-3



Dimensions in inches and (millimeters)

MAXIMUM RATINGS AND ELECTRICAL CHARACTERISTICS

Rating 25°C ambient temperature unless otherwise specified.
Single phase half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

TYPE NUMBER	BR305	BR31	BR32	BR34	BR36	BR38	BR310	UNITS
Maximum Recurrent Peak Reverse Voltage	50	100	200	400	600	800	1000	V
Maximum RMS Voltage	35	70	140	280	420	560	700	V
Maximum DC Blocking Voltage	50	100	200	400	600	800	1000	V
Maximum Average Forward Rectified Current .375"(9.5mm) Lead Length at Tc=50°C	3.0							A
Peak Forward Surge Current, 8.3 ms single half sine-wave superimposed on rated load (JEDEC method)	60							A
Maximum Forward Voltage Drop per Bridge Element at 1.5A D.C.	1.0							V
Maximum DC Reverse Current Ta=25°C	10							μA
at Rated DC Blocking Voltage Ta=100°C	100							μA
Operating Temperature Range, TJ	-65 — +125							°C
Storage Temperature Range, Tstg	-65 — +150							°C

RATING AND CHARACTERISTIC CURVES (BR305 THRU BR310)

FIG.1-TYPICAL FORWARD CURRENT DERATING CURVE

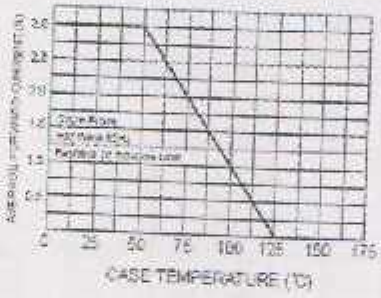


FIG.2-MAXIMUM NON-REPETITIVE FORWARD SURGE CURRENT

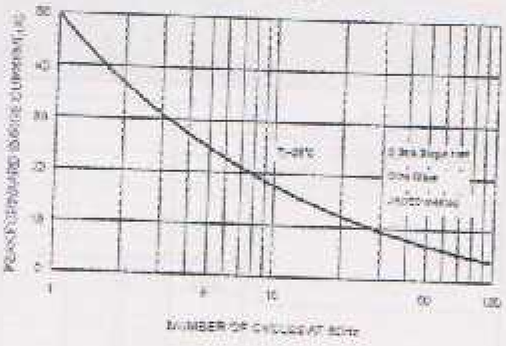


FIG.3-TYPICAL FORWARD CHARACTERISTICS

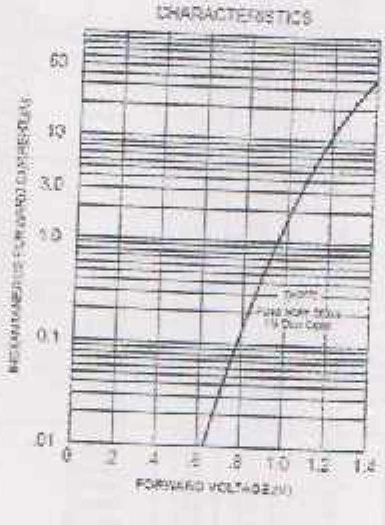
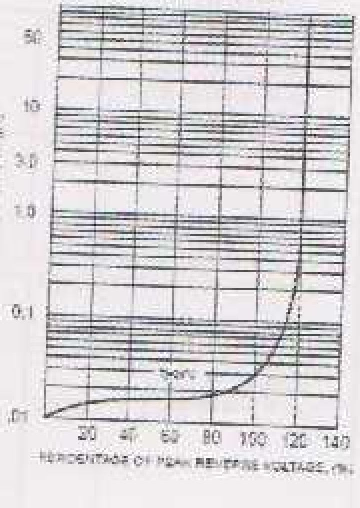


FIG.4-TYPICAL REVERSE CHARACTERISTICS



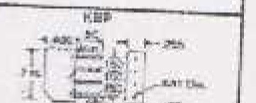
RFE INTERNATIONAL BRIDGE RECTIFIERS 0.5 to 2.0 Amps

SINGLE PHASE PLASTIC BRIDGE RECTIFIERS INCLUDING GLASS PASSIVATED

RF Part Number	Other Reference	Max Avg Rectified Current Io(A)	Peak Inverse Voltage PIV(V)	Peak Fwd Surge Current @ 8.3ms Superimposed Ifsm(A)	Max Forward Voltage @ TA = 25°C @ Rated IO VF(V)	Max Reverse Current @ 25°C @ Rated PIV IR(µA)	Package
Surface Mount General Purpose							
MB2S		0.5A	200	30	1.0	5	
MB4S		0.5A	400	30	1.0	5	
MB6S		0.5A	600	35	1.0	5	
S40	This series is NO Longer Available						
S80							
S125							
S250							
S380							
S500							
DBS101G	DF005S	1.0A	50	50	1.1	10	100 tubes of 50
DBS102G	DF01S	1.0A	100	50	1.1	10	
DBS103G	DF02S	1.0A	200	50	1.1	10	
DBS104G	DF04S	1.0A	400	50	1.1	10	
DBS105G	DF06S	1.0A	600	50	1.1	10	
DBS106G	DF08S	1.0A	800	50	1.1	10	
DBS107G	DF10S	1.0A	1000	50	1.1	10	
DBS151G		1.5A	50	50	1.1	10	100 tubes of 50
DBS152G		1.5A	100	50	1.1	10	
DBS153G		1.5A	200	50	1.1	10	
DBS154G		1.5A	400	50	1.1	10	
DBS155G		1.5A	600	50	1.1	10	
DBS156G		1.5A	800	50	1.1	10	
DBS157G		1.5A	1000	50	1.1	10	
Thru-Hole Schottky DIP Package							
DB1020		1.0A	20	40	0.55	1	50 per tube
DB1030		1.0A	30	40	0.55	1	
DB1040		1.0A	40	40	0.55	1	
DB1050		1.0A	50	40	0.7	1	5000 Bulk
DB1060		1.0A	60	40	0.7	1	
Thru-Hole DIP Package							
DB101G	DF005	1.0A	50	50	1.1	10	100 tubes of 50
DB102G	DF01	1.0A	100	50	1.1	10	
DB103G	DF02	1.0A	200	50	1.1	10	
DB104G	DF04	1.0A	400	50	1.1	10	
DB105G	DF06	1.0A	600	50	1.1	10	
DB106G	DF08	1.0A	800	50	1.1	10	
DB107G	DF10	1.0A	1000	50	1.1	10	
DB151G		1.5A	50	50	1.1	10	100 tubes of 50
DB152G		1.5A	100	50	1.1	10	
DB153G		1.5A	200	50	1.1	10	
DB154G		1.5A	400	50	1.1	10	
DB155G		1.5A	600	50	1.1	10	
DB156G		1.5A	800	50	1.1	10	
DB157G		1.5A	1000	50	1.1	10	
Thru-line							
1W005	PB101M	1.0A	50	30	1.1	10	1000/Box
1W01	PB102M	1.0A	100	30	1.1	10	
1W02	PB103M	1.0A	200	30	1.1	10	
1W04	PB104M	1.0A	400	30	1.1	10	
1W06	PB105M	1.0A	600	30	1.1	10	
1W08	PB106M	1.0A	800	30	1.1	10	
1W10	PB107M	1.0A	1000	30	1.1	10	
W005	PB151M	1.5A	50	50	1.1	10	1000/Box
W01	PB152M	1.5A	100	50	1.1	10	
W02	PB153M	1.5A	200	50	1.1	10	
W04	PB154M	1.5A	400	50	1.1	10	
W06	PB155M	1.5A	600	50	1.1	10	
W08	PB156M	1.5A	800	50	1.1	10	
W10	PB157M	1.5A	1000	50	1.1	10	
KBP201	KBP2005G	2.0A	50	60	1.1	10	1000/Box
KBP202	KBP201G	2.0A	100	60	1.1	10	
KBP203	KBP202G	2.0A	200	60	1.1	10	
KBP204	KBP204G	2.0A	400	60	1.1	10	
KBP205	KBP206G	2.0A	600	60	1.1	10	
KBP206	KBP208G	2.0A	800	60	1.1	10	
KBP207	KBP210G	2.0A	1000	60	1.1	10	

Outline (Typ. unless otherwise noted)

Dimensions (inches)



POWER MOSFET (IRF840)

FAIRCHILD SEMICONDUCTOR

IRF840

Data Sheet **January 2002**

8A, 500V, 0.850 Ohm, N-Channel Power MOSFET

This N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation. All of these power MOSFETs are designed for applications such as switching regulators, switching converters, motor drivers, relay drivers, and drivers for high power bipolar switching transistors requiring high speed and low gate drive power. These types can be operated directly from integrated circuits.

Formerly developmental type TA17425.

Ordering Information

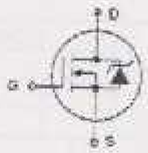
PART NUMBER	PACKAGE	BRAND
IRF840	TO-220AB	IRF840

NOTE: When ordering, include the entire part number.

Features

- 8A, 500V
- $r_{DS(ON)} = 0.850\Omega$
- Single Pulse Avalanche Energy Rated
- SOA is Power Dissipation Limited
- Nanosecond Switching Speeds
- Linear Transfer Characteristics
- High Input Impedance
- Related Literature
  - TB334 "Guidelines for Soldering Surface Mount Components to PC Boards"

Symbol



Packaging

JEDEC TO-220AB
TOP VIEW

Absolute Maximum Ratings $T_C = 25^oC$, Unless Otherwise Specified

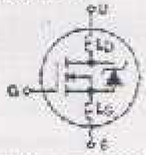
	Symbol	IRF840	UNITS
Drain to Source Voltage (Note 1)	V_{DS}	500	V
Drain to Gate Voltage (R_{GS} = 20kΩ) (Note 1)	V_{DGR}	500	V
Continuous Drain Current	I_D	8.0	A
$T_C = 100^oC$	I_D	5.1	A
Pulsed Drain Current (Note 3)	I_{DM}	32	A
Gate to Source Voltage	V_{GS}	±20	V
Maximum Power Dissipation	P_D	125	W
Linear Derating Factor		1.0	W/^{o}C
Single Pulse Avalanche Energy Rating (Note 4)	E_{AS}	510	mJ
Operating and Storage Temperature	T_J, T_{STG}	-55 to 150	^{o}C
Maximum Temperature for Soldering			
Leads at 0.063in (1.6mm) from Case for 10s	T_L	300	^{o}C
Package Body for 10s, See Techbrief 334	T_{pkg}	260	^{o}C

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

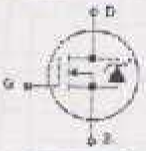
NOTE:

1. $T_J = 25^oC$ to 125^oC.

Electrical Specifications $T_C = 25^oC$, Unless Otherwise Specified

PARAMETER	SYMBOL	TEST CONDITIONS		MIN	TYP	MAX	UNITS
Drain to Source Breakdown Voltage	BV_{DSS}	V_{GS} = 0V, I_D = 250μA (Figure 10)		500	-	-	V
Gate to Threshold Voltage	$V_{GS(TH)}$	$V_{GS} = V_{DS}$, I_D = 250μA		2.0	-	4.0	V
Zero-Gate Voltage Drain Current	I_{DSS}	V_{DS} = Rated BV_{DSS}, V_{GS} = 0V		-	-	25	μA
		V_{DS} = 0.8 x Rated BV_{DSS}, V_{GS} = 0V, $T_J = 125^oC$		-	-	250	μA
On-State Drain Current (Note 2)	$I_{D(ON)}$	$V_{DS} > I_{D(ON)} \times r_{DS(ON)MAX}$, V_{GS} = 10V		8.0	-	-	A
Gate to Source Leakage Current	I_{GSS}	V_{GS} = ±20V		-	-	±100	nA
Drain to Source On Resistance (Note 2)	$r_{DS(ON)}$	V_{GS} = 10V, I_D = 4.4A (Figures 8, 9)		-	0.8	0.85	Ω
Forward Transconductance (Note 2)	g_{fs}	V_{DS} ≥ 50V, I_D = 4.4A (Figure 12)		4.9	7.4	-	S
Turn-On Delay Time	$t_{D(ON)}$	V_{DD} = 250V, I_D ≈ 8A, R_G = 9.1Ω, R_L = 30Ω MOSFET Switching Times are Essentially Independent of Operating Temperature		-	15	21	ns
Rise Time	t_r			-	21	35	ns
Turn-Off Delay Time	$t_{D(OFF)}$			-	50	74	ns
Fall Time	t_f			-	20	30	ns
Total Gate Charge (Gate to Source + Gate to Drain)	$Q_{g(TOT)}$	V_{GS} = 10V, I_D = 8A, V_{DS} = 0.8 x Rated BV_{DSS}, $I_{g(REF)}$ = 1.5mA (Figure 14) Gate Charge is Essentially Independent of Operating Temperature		-	42	63	nC
Gate to Source Charge	Q_{gs}			-	7.0	-	nC
Gate to Drain "Miller" Charge	Q_{gd}			-	22	-	nC
Input Capacitance	C_{ISS}	V_{GS} = 0V, V_{DS} = 25V, f = 1.0MHz (Figure 11)		-	1225	-	pF
Output Capacitance	C_{OSS}			-	200	-	pF
Reverse-Transfer Capacitance	C_{RSS}			-	85	-	pF
Internal Drain Inductance	L_D	Measured from the Contact Screw on Tab to Center of Die	Modified MOSFET Symbol Showing the Internal Devices Inductances	-	3.5	-	nH
		Measured from the Drain Lead, 6mm (0.25in) from Package to Center of Die		-	4.5	-	nH
Internal Source Inductance	L_S	Measured from the Source Lead, 6mm (0.25in) from Header to Source Bonding Pad		-	7.5	-	nH
Thermal Resistance Junction to Case	$R_{\theta JC}$			-	-	1.0	^{o}C/W
Thermal Resistance Junction to Ambient	$R_{\theta JA}$	Free Air Operation		-	-	62.5	^{o}C/W

Source to Drain Diode Specifications

PARAMETER	SYMBOL	TEST CONDITIONS		MIN	TYP	MAX	UNITS
Continuous Source to Drain Current	I_{SD}	Modified MOSFET Symbol Showing the Integral Reverse P-N Junction Diode		-	-	8.0	A
Pulse Source to Drain Current (Note 3)	I_{SDM}			-	-	32	A
Source to Drain Diode Voltage (Note 2)	V_{SD}	$T_J = 25^oC$, $I_{SD} = 8.0A$, V_{GS} = 100A/μs (Figure 13)		-	-	2.0	V
Reverse Recovery Time	t_{rr}	$T_J = 25^oC$, $I_{SD} = 8.0A$, dI_{SD}/dt = 100A/μs		210	475	970	ns
Reverse Recovered Charge	Q_{RR}	$T_J = 25^oC$, $I_{SD} = 8.0A$, dI_{SD}/dt = 100A/μs		2.0	4.6	8.2	μC

NOTES:

2. Pulse Test: Pulse width ≤ 300μs, duty cycle ≤ 2%.
3. Repetitive Rating: Pulse width limited by Max junction temperature. See Transient Thermal Impedance curve (Figure 3).
4. V_{DD} = 50V, starting $T_J = 25^oC$, L = 14mH, $R_G = 25\Omega$, peak I_{AS} = 8A.

Typical Performance Curves Unless Otherwise Specified

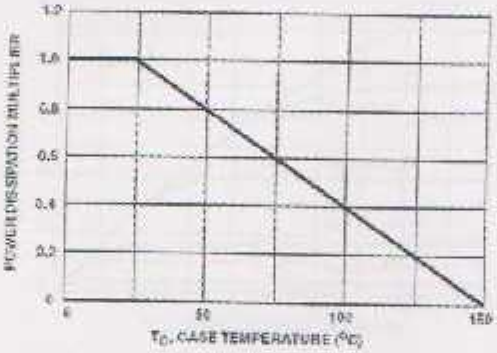


FIGURE 1. NORMALIZED POWER DISSIPATION vs CASE TEMPERATURE

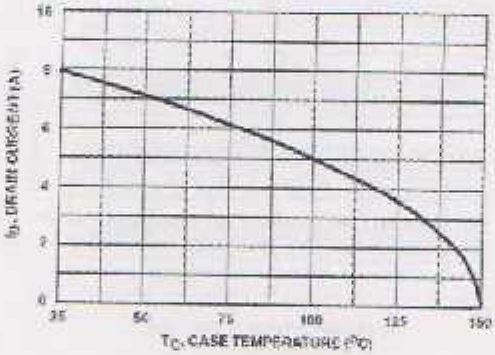


FIGURE 2. MAXIMUM CONTINUOUS DRAIN CURRENT vs CASE TEMPERATURE

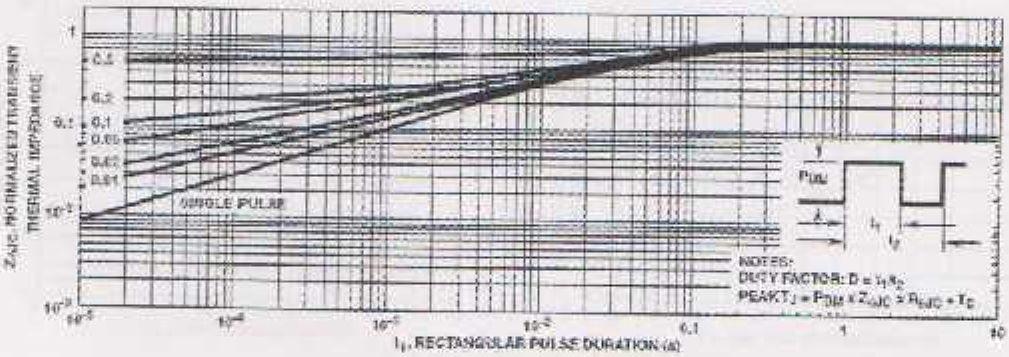


FIGURE 3. NORMALIZED MAXIMUM TRANSIENT THERMAL IMPEDANCE

Typical Performance Curves Unless Otherwise Specified (Continued)

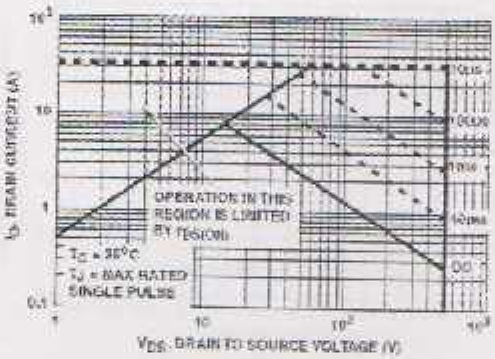


FIGURE 4. FORWARD BIAS SAFE OPERATING AREA

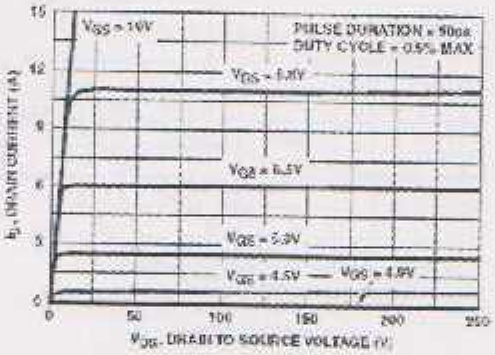


FIGURE 5. OUTPUT CHARACTERISTICS

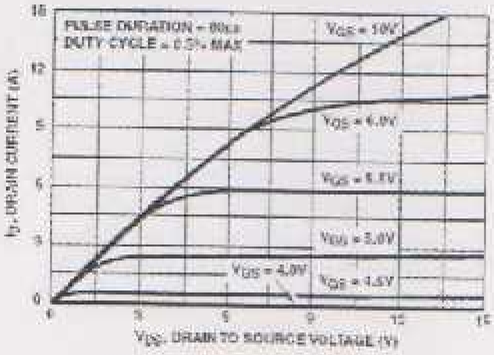


FIGURE 6. SATURATION CHARACTERISTICS

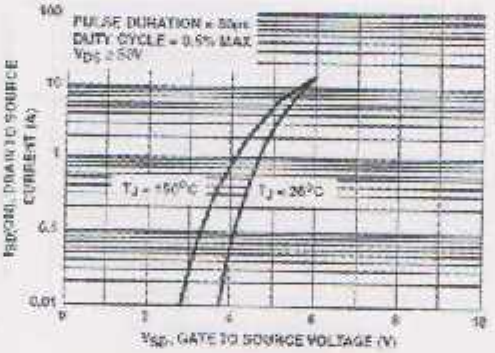


FIGURE 7. TRANSFER CHARACTERISTICS

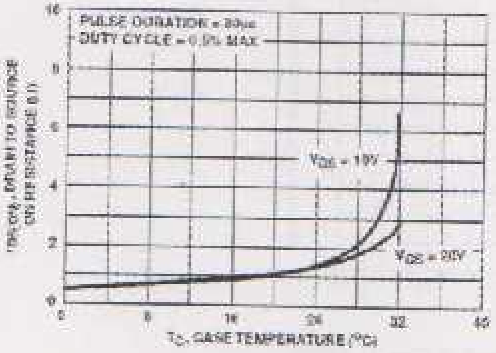


FIGURE 8. DRAIN TO SOURCE ON RESISTANCE vs VOLTAGE AND DRAIN CURRENT

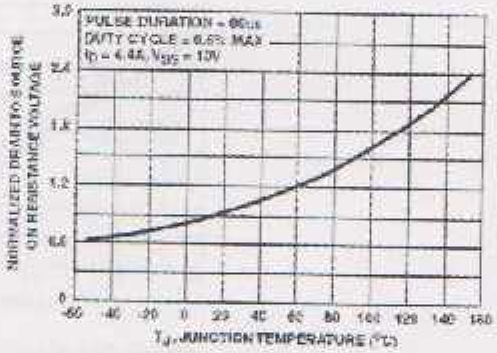


FIGURE 9. NORMALIZED DRAIN TO SOURCE ON RESISTANCE vs JUNCTION TEMPERATURE

Typical Performance Curves Unless Otherwise Specified (Continued)

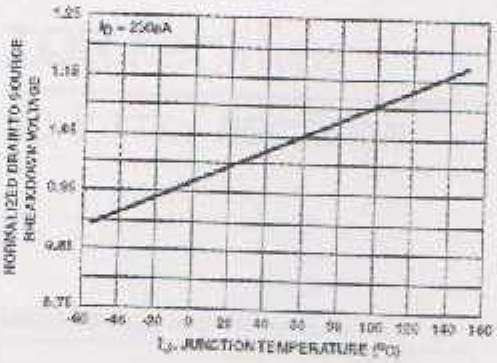


FIGURE 10. NORMALIZED DRAIN TO SOURCE BREAKDOWN VOLTAGE vs JUNCTION TEMPERATURE

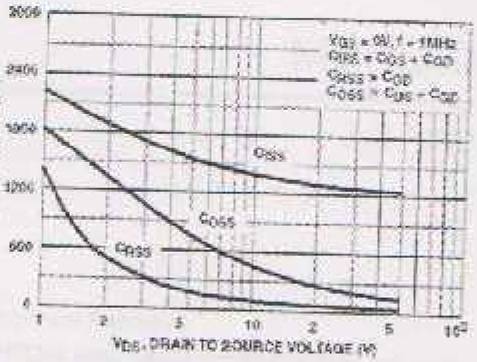


FIGURE 11. CAPACITANCE vs DRAIN TO SOURCE VOLTAGE

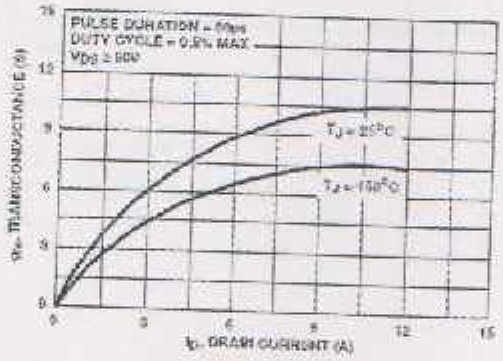


FIGURE 12. TRANSCONDUCTANCE vs DRAIN CURRENT

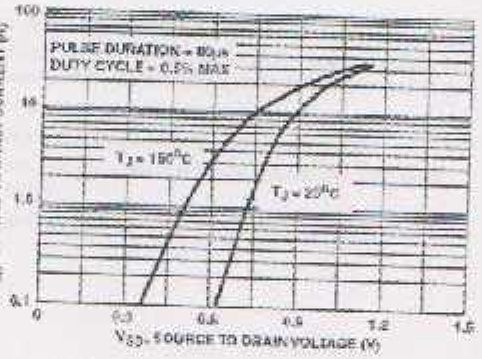


FIGURE 13. SOURCE TO DRAIN DIODE VOLTAGE

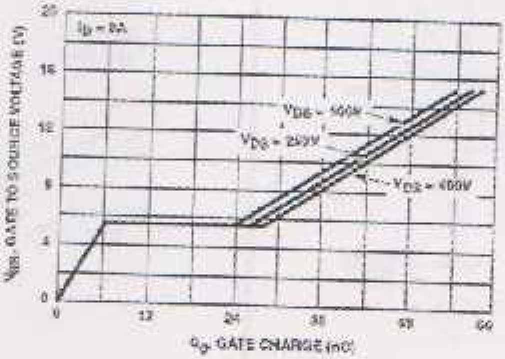


FIGURE 14. GATE TO SOURCE VOLTAGE vs GATE CHARGE

SCHOTTKY DIODE (MBR340)

International
IOR Rectifier

MBR340

SCHOTTKY RECTIFIER

3.0 Amp

Major Ratings and Characteristics

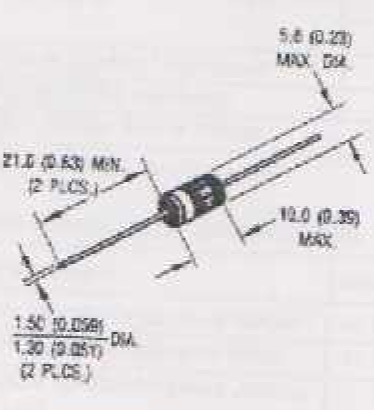
Characteristics	Values	Units
$I_{F(AV)}$ Rectangular waveform	3.0	A
V_{RRM}	30/40	V
I_{FSM} @tp = 5 µs sine	430	A
V_F @3 Apk, T_J = 25°C	0.6	V
T_J	-40 to 150	°C

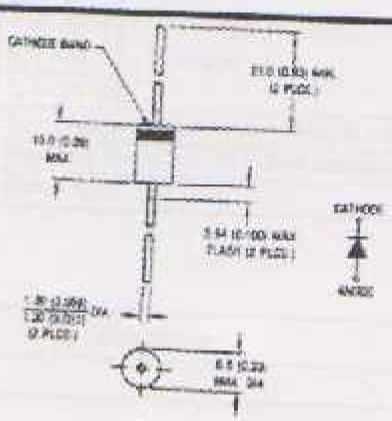
Description/ Features

The MBR340 axial leaded Schottky rectifier has been optimized for very low forward voltage drop, with moderate leakage. Typical applications are in switching power supplies, converters, free-wheeling diodes, and reverse battery protection.

- Low profile, axial leaded outline
- High purity, high temperature epoxy encapsulation for enhanced mechanical strength and moisture resistance
- Very low forward voltage drop
- High frequency operation
- Guard ring for enhanced ruggedness and long term reliability
- Lead-Free plating

CASE STYLE AND DIMENSIONS





Outline C - 16

Dimensions in millimeters and inches

Voltage Ratings

Part number	MBR340
V_R Max. DC Reverse Voltage (V)	40
V_{RWM} Max. Working Peak Reverse Voltage (V)	

Absolute Maximum Ratings

	Parameters	MBR340	Units	Conditions	
$I_{F(AV)}$	Max. Average Forward Current * See Fig. 4	3.0	A	50% duty cycle @ T_C = 92°C, rectangular wave form	
I_{FSM}	Max. Peak One Cycle Non-Repetitive Surge Current * See Fig. 6	430	A	5µs Sine or 3µs Rect. pulse	Following any rated load condition and with rated V_{RRM} applied
		60		10ms Sine or 6ms Rect. pulse	
E_{AS}	Non-Repetitive Avalanche Energy	6.0	mJ	T_J = 25 °C, I_{AS} = 1 Amps, L = 12 mH	
I_{AR}	Repetitive Avalanche Current	1.0	A	Current decaying linearly to zero in 1 µsec Frequency limited by T_J max. V_A = 1.5 x V_R typical	

Electrical Specifications

	Parameters	MBR340	Units	Conditions	
V_{FM}	Max. Forward Voltage Drop * See Fig. 1 (1)	0.5	V	@ 1.0A	T_J = 25 °C
		0.6	V	@ 3.0A	
		0.85	V	@ 9.4A	
		0.37	V	@ 1.0A	T_J = 125 °C
		0.49	V	@ 3.0A	
		0.72	V	@ 9.4A	
I_{RM}	Max. Reverse Leakage Current * See Fig. 2 (1)	0.6	mA	T_J = 25 °C	V_R = rated V_R
		8	mA	T_J = 100 °C	
		20	mA	T_J = 125 °C	
C_T	Typical Junction Capacitance	190	pF	V_R = 5V_{DC} (test signal range 100Khz to 1Mhz) 25°C	
L_S	Typical Series Inductance	9.0	nH	Measured lead to lead 5mm from package body	
dv/dt	Max. Voltage Rate of Change	10000	V/µs	(Rated V_R)	

(1) Pulse Width < 300µs, Duty Cycle <2%

Thermal-Mechanical Specifications

	Parameters	MBR340	Units	Conditions
T_J	Max. Junction Temperature Range(*)	-40 to 150	°C	
T_{stg}	Max. Storage Temperature Range	-40 to 150	°C	
R_{thJL}	Typical Thermal Resistance Junction to Lead (**)	28	°C/W	DC operation (* See Fig. 4)
wt	Approximate Weight	1.2 (0.042)	g (oz.)	
	Case Style	C - 16		

(*) $\frac{dPtot}{dTj} < \frac{1}{Rth(j-a)}$ thermal runaway condition for a diode on its own heatsink

(**) Mounted 1 inch square PCB, thermal probe connected to lead 2mm from package

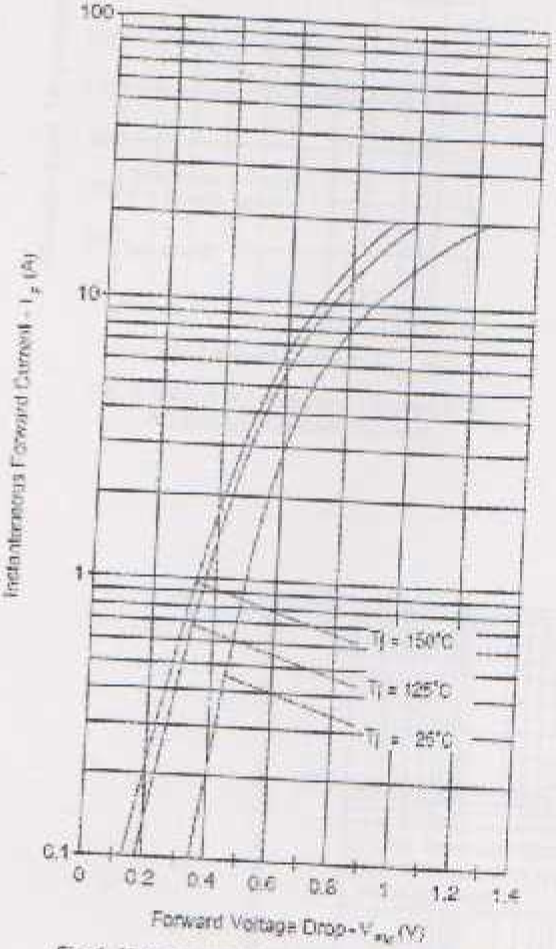


Fig. 1 - Max. Forward Voltage Drop Characteristics

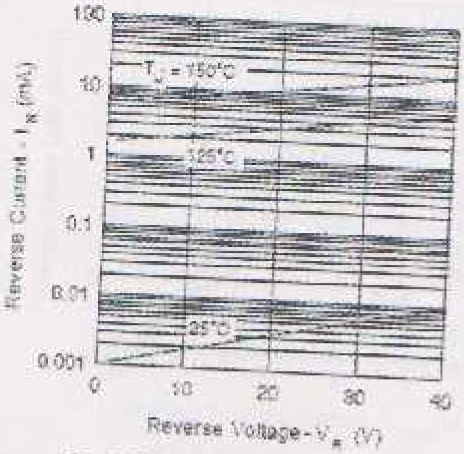


Fig. 2 - Typical Values Of Reverse Current Vs. Reverse Voltage

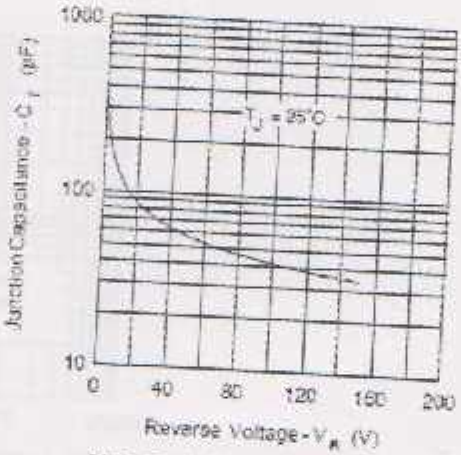


Fig. 3 - Typical Junction Capacitance Vs. Reverse Voltage

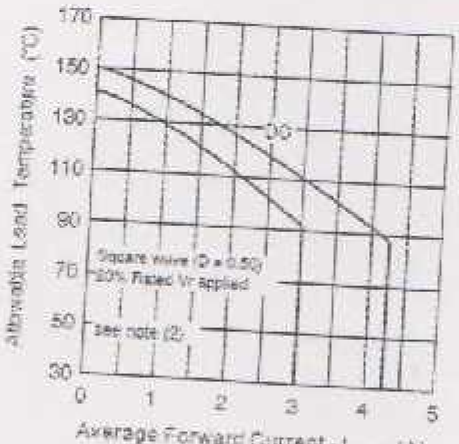


Fig. 4 - Max. Allowable Lead Temperature Vs. Average Forward Current

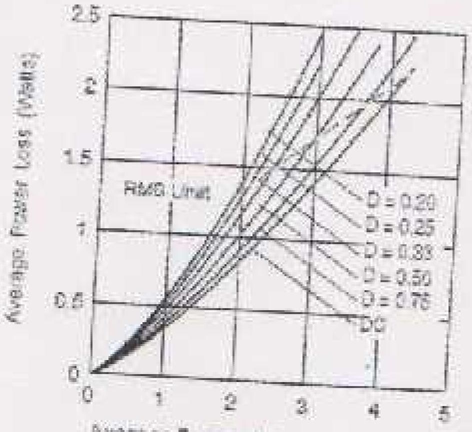


Fig. 5 - Forward Power Loss Characteristics

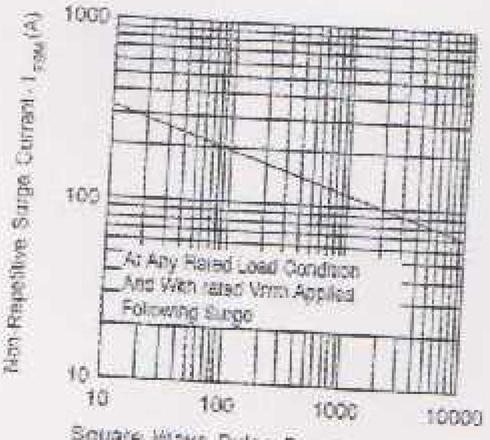


Fig. 6 - Max. Non-Repetitive Surge Current

(2) Formula used: $T_C = T_J - (Pd + Pd_{REV}) \times R_{thJC}$;
Pd = Forward Power Loss = $I_{F(AV)} \times V_{FM}$ @ $(I_{F(AV)}/D)$ (see Fig. 6);
Pd_{REV} = Inverse Power Loss = $V_{R1} \times I_R (1 - D)$; I_R @ V_{R1} = 80% rated V_R

APPENDIX C

LIGHTING

TABLE C.1-(continue) Standard values of lighting intensity in Palestine according to the site, Usage and Brightness

Site	Use	Brighness (Lux)
Commercial	Commercial stores	200-120
	Commercial shops	500-350
	Restaurants	350-250
General	Café	250-150
	Praying places	500-300
	Libraries	400-200
	Museum	1000-500
	Shows	1000-500
	Cinema	200-100
	Stages	200-150

TABLE C.2 Total luminous flux of incandescent lamps

Power of lamps (Watt)	total luminous flux (lm) at 225 V
15	120
25	230
40	430
60	730
75	960
100	1380
150	2220
200	3150
300	5000
500	8400
1000	18800
2000	40000

TABLE C.3 Luminous flux for florescent lamps according to the structure

Lamp structure	Power of lamps (Watt)	total luminous flux (lm) At 225 V
Straight Tubes	4	120
	6	220-240
	8	310-350
	10	460-480
	13	500-650
	15	580-600
	16	750-900
	20	800-1230
	25	1150-1720
	30	1500-1900
	40	1750-2600
	65	2600-4800
U-Tubes	16	720-920
	20	830-1000
	40	1850-2700
	65	3300-4050
Circle Tube	22	980-1100
	32	1500-1900
	40	2150-2700

TABLE C.4 Luminous flux for gas discharge lamps (Halogen, mercury, sodium lamps, Metal halide lamps)

types of lamps	Power of lamps (Watt)	total luminous flux (lm) At 225 V
Metal halide lamps	35	2400
	75	5200
	150	12000
	250	19000
	400	28000
	1000	80000
	2000	170000
	2000	170000
	3500	300000

TABLE C.4(continue) Luminous flux for gas discharge lamps (Halogen, mercury, sodium lamps, Metal halide lamps)

types of lamps	Power of lamps (Watt)	total luminous flux (lm) At 225 V
halogen lamps	200	3500
	300	5500
	400	7500
	500	11000
	750	16500
	1000	24000
	1500	36000
High pressure mercury lamps	50	1800
	80	3800
	125	6300
	250	13000
	400	28000
	700	40000
	1000	130000
High pressure sodium lamps	50	3500
	70	6500
	110	8000
	150	17000
	210	18000
	250	27000
	350	34000
	400	47000
	1000	120000

TABLE C.5 Usage factor

Methods of lighting	Usage factor
Direct lighting	0.45-0.6
Half-direct lighting	0.45-0.55
Homologous lighting	0.35-0.50
Half-indirect lighting	0.35-0.45
Indirect lighting	0.25-0.35

APPENDIX D

POWER FACTOR AND POWER FACTOR CORRECTION

TABLE D.1 Values of Cos (θ) and Tan (θ) for commonly used equipments

Equipment and appliances			cos φ	tan φ
Common induction motor	loaded at	0%	0.17	5.80
		25%	0.55	1.52
		50%	0.73	0.94
		75%	0.80	0.75
		100%	0.85	0.62
Incandescent lamps			1.0	0
Fluorescent lamps (uncompensated)			0.5	1.73
Fluorescent lamps (compensated)			0.93	0.39
Discharge lamps			0.4 to 0.6	2.29 to 1.33
Ovens using resistance elements			1.0	0
Induction heating ovens (compensated)			0.85	0.62
Dielectric type heating ovens			0.85	0.62
Resistance-type soldering machines			0.8 to 0.9	0.75 to 0.48
Fixed 1-phase arc-welding set			0.5	1.73
Arc-welding motor-generating set			0.7 to 0.9	1.02 to 0.48
Arc-welding transformer-rectifier set			0.7 to 0.8	1.02 to 0.75
Arc furnace			0.8	0.75

TABLE D.2 IEC 1000-3-2 Harmonic current limits

Harmonic	Maximum Current (amperes)
2	1.08
3	2.30
4	.43
5	1.14
6	.30
7	.77
even 8<n<40	.23x8/n
9	.40
11	.33
13	.21
odd 15<n<39	.15x15/n

TABLE D.3 Standard data for capacitor ratings

Voltage	μF/kvar Total	Amperes/kvar	
		Single-Phase	Three-Phase
208	61.2	4.81	2.78
240	46.0	4.17	2.41
480	11.5	2.08	1.20
600	7.37	1.67	0.96
2400	0.46	—	0.24
4160	0.153	—	0.139

TABLE D.4 Maximum kVAR of power factor correction applicable to motor terminals without risk of self excitation

3-phase motors 230/400 V					
Nominal power		kvar to be installed			
		Speed of rotation (rpm)			
kW	hp	3000	1500	1000	750
22	30	6	8	9	10
30	40	7.5	10	11	12.5
37	50	9	11	12.5	16
45	60	11	13	14	17
55	75	13	17	18	21
75	100	17	22	25	28
90	125	20	25	27	30
110	150	24	29	33	37
132	180	31	36	38	43
160	218	35	41	44	52
200	274	43	47	53	61
250	340	52	57	63	71
280	380	57	63	70	79
355	482	67	76	86	98
400	544	78	82	97	106
450	610	87	93	107	117

TABLE D.5 Approximate values specified for Individual Motor Compensation

Motor Nominal Rating (kW)	Capacitor Power Rating (kVAR)
1 to 1.9	0.5
2 to 2.9	1.0
3 to 3.9	1.5
4 to 4.9	2.0
5 to 5.9	2.5
6 to 7.9	3.0
8 to 10.9	4.0
11 to 13.9	5.0
14 to 17.9	6.0
18 to 21.9	7.5
22 to 29.9	10
30 to 39.9	approx. 40% of motor power
40 or above	approx. 35% of motor power

TABLE D.6 Approximate values specified for Load Centric compensation

Motor Nominal Rating (kW)	Capacitor Power Rating (kVAR)
70.00 KW	25.00
80.00 KW	30.00
90.00 KW	35.00
100.0 KW	40.00
110.0 KW	45.00
120.0 KW	50.00
150.0 KW	60.00
200.0 KW	70.00
250.0 KW	100.0
300.0 KW	110.0
350.0 KW	125.0
500.0 KW	175.0
800.0 KW -	200.0

TABLE D.7 Multipliers to Determine Capacitor kVAR's Required for Power Factor Correction

Original Power Factor	Corrected Power Factor 0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.0
0.50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
0.52	0.893	0.919	0.945	0.971	0.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
0.53	0.850	0.876	0.902	0.928	0.954	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.685	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.609	0.750
0.81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.079	0.126	0.186	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.058	0.203
0.99																				0.000	0.142
																					0.000