ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

ENERGY AUDITING AND ASSESSMENT OF POWER QUALITY PROBLEM IN INDUSTRIES: (A CASE STUDY OF ALMEDA TEXTILE FACTORY)

A thesis Submitted to Addis Ababa Institute of Technology, School of Graduate Studies, Addis Ababa University

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MASTERS OF SCIENCE IN ELECTRICAL ENGINEERING

(ELECTRICAL POWER ENGINEERING)
By

Ftaw Nugusse

Advisor: Dr. Getachew Bekele

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Addis Ababa, Ethiopia

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DECLARATION

I declare that this thesis is my work and that all sources of materials used in this thesis have been properly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree in Electrical Engineering at Addis Ababa University. I earnestly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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This thesis has been submitted for examination with my approval as a university advisor.

Dr. Getachew Bekele ___________________

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ABSTRACT

Nowadays energy is one of the major areas which need greater attention throughout the world. The textile industry is one of the major energy consuming industries and retains a record of the lowest efficiency in energy utilization. Energy in the textile industry is mostly used in the form of electricity as a common power source for machinery, heating and ventilating air conditioner, lighting system and other equipment etc. In Alameda textile factory about 20.35% energy is consumed in weaving, 42.4% in spinning, 22.39 % in processing, 7.22% new garment and 7.64% in lighting and others. This is a total of 44.31MWh per year. From the information it is difficult to consider the energy loss. Had it been administered an energy audit, the amount of energy mismanaged and lost would be easily estimated. An energy audit is an inspection, survey and analysis of energy flows of energy conservation in a factory, process system to reduce the amount of energy input into the system without negatively affecting the output.

The main objective of this thesis is to identify the energy wastage areas and to asses power quality related problem (harmonics) to take possible measures for improving the energy performance of the manufacturing process of the selected plant. Motor Master +International Software was used to evaluate the performance of the existing motors with the energy efficient motors and Digital Simulation of Electrical Network software (DIgSILENT) was used to assess harmonics. It was found that the specific energy consumption difference between the Almeda Textile and the benchmark is 9.07kWh/Kg. As a result, the company spends an extra 286,703.7$ annually as compared to the benchmark. From the assessment, since the PF for the four transformers in the garment departments was found to be 0.969, most of the energy loss was found in the weaving and spinning departments. After designing multi single tuned passive filters for the two transformers T1 and T2 of the two departments, the THD_I for T1 and T2 was reduced to 0.867% and 0.824% from 25.5% and 21.4% respectively. And the THD_V for T1 and T2 was reduced to 2.91% from 8.8% for both. In addition, the THD_I of substation transformer was reduced to 0.3% from 21.6%.

Key Words: Energy Auditing, Energy Intensity, Power Quality

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List of Abbreviation

AC	Actual Consumption
ALR	Actual Lamp Required
Bs	Birr Saving
CAD	Computer Aided Design
CFL	Compact Fluorescent Lamp
DC	Design Capacity
DIgSILENT	DIgital Simulation of Electrical NeTwork
E.C	Ethiopian Calendars
ED	Energy Difference
EEPCO	Ethiopian Electric Power Cooperation
ELPA	Electric Line Power Authority
En	Efficiency of the Replacement Motor
EnMS	Energy Management System
Eo	Efficiency of Existing Motor
ER	Energy Required
ES	Energy Saving
EU	Energy Utilization
ETB	Ethiopian Birr
FFT	Fast Fourier Transform
FL	Fluorescent Lamp
FMU	Fan Module Unit
FTL	Fluorescent Tube Lamp
HD	Harmonic Distortion
HL	Halogen Lamp
HPS	Horse Power
HV	High Voltage
HVAC	Heating and Ventilating Air Condition
IEEE	Institute of Electrical and Electronics
IL	Illumination Level, Incandescent Lamp
ILR	Illumination Required

IMSSA	International Motor Selection and Saving Software
kVA	Kilo Volt Ampere
Kvar	Kilo Volt Ampere Reactive
Kv	Kilo Volt
kWh	Kilo Watt Hour
LED	Light Emitting Diode
LO	Lumens out Put
LR	Lamp Required
LV	Low Voltage
MC	Measured Capacity
MVAsc	Mega Volt Ampere Short Circuit
NL	Number of Lamps
OPH	Operating Hours
PCC	Point of common Coupling
PDS	Power Demand Saving
PF	Power Factor
PLC	Private Limited Company
RA	Room Area
RMS	Root Mean Square
SCR	Short Circuit Ratio
SPP	Simple Pay Back Period
TDD	Total Demand Distortion
TDDI	Total Demand Distortion of Current
TDDV	Total Demand Distortion of Voltage
TMC	Total Measured Capacity
TRC	Total Rated Capacity
UPS	Interruptible Power Supply
VFD	Variable Frequency Drive

List of Symbols

Cm	Centimeter
Gj	Giga joule
H	Enthalpy of feed water
HZ	Hertz/ Enthalpy of steam
I	Current
Kg	Kilo gram
Km	Kilo meter
m^2	Square meter
Q	Quantity of steam generated per hour
Q	Quantity of fuel used per hour
V	Voltage
W	Watt
Ө	Phase angle
Ω	Ohm
$	Dollar

CHAPTER ONE

INTRODUCTION

1.1 Back Ground of The Study

Industrial sectors consumed consumes more energy about one-half of the world's total delivered energy for a wide range of activities, such as processing, space conditioning and lighting [1]. Both industrial and commercial sectors in the world joint account for approximately 60% of energy use. The total energy consumption of the industrial sectors of developing countries contributes to around 30–40 % of total energy demand [2]. Energy is the basic input in industries its management is of an imminent importance for organizations to reduce energy wastage while maintaining productivity. An energy management system is a collection of procedures and practices to ensure the systematic tracking, analysis and planning of energy use in industries. By implementing Energy Management System (EnMS) in any industry 10-40% of energy can be rescued from wastage [3].

1.2 Energy Audit

An energy auditing is the systematic inspection of existing energy systems to reduce overall energy inputs to the systems without negatively affecting the output and it is a process of checking the way energy is used and identified areas where wastage can minimize if not totally eradicated. The size, function, depth of the energy audit is used to classify the industrial energy audit into two; preliminary (walk through) and detailed (diagnostic) audit [4].

- **Preliminary Audit (Walk-Through Audit):** Readily available data are mostly used for a simple analysis of energy use and performance of the plant. This type of audit does not require a lot of measurement and data collection. That's why it takes a relatively short time [4].

- **Detailed Audit (Diagnostic Audit)**: More detailed data and information are required. Measurements and a data inventory are usually conducted and different energy systems (pump, fan, compressed air, steam, process heating, lightings etc.) are assessed in detail. Hence, the time required for this type of audit is longer than that of preliminary audits. The result of this audit is more comprehensive and useful. Since, they give a more accurate picture of the energy performance of the plant and more specific recommendation for improvements [4].

1.3 Problem Statement

In developing countries industrial sectors approximately consume around 30- 40% of the total energy demand [2]. Energy in the textile industry is mostly used in the forms of electricity, as a common power source for machinery, cooling and temperature control systems, lighting, office equipment, etc.; oil and fuel for steam generation. Conservation of energy is needed to eliminate waste due to current high energy consumption. Saving in energy consumption through energy conservation reduces the atmospheric emissions from fossil fuel electric power plants and industrial facilities. Lack of maintenance and proper replacement for the machines, a shortage of spare parts and accessories, poor design and improper installation and no well-defined audit for energy consumption pattern in industries are some of the problems faced for the in efficient use of energy in textile Industries. Due to this reason the factory lose a lots of money on energy bills, causes problems on the environment, industries will not be competitive, etc. In addition, a growing number of linear and non linear loads such as computers, printers, fluorescent lamps, uninterruptable power supply, adjustable speed drive, heating, ventilating and air conditions and huge arc-furnaces inject current harmonics into power system, this deteriorating the quality of power in electrical networks. Therefore, review on energy use and energy wastage is necessary to reduce energy consumption and assessing the power quality problems is used for designing passive or active filter if harmonics are present in electrical distribution system.

1.4 Objective The Study

1.4.1 General Objective

The main objective of this thesis is to analyze and audit the present use of energy in the manufacturing process of Almeda textile factory. In addition, it assesses power quality problem (harmonics) and improves the energy performance of the factory.

1.4.2 Specific Objectives

- ✓ To clearly identify the energy used and possibly wasted and to analyze alternatives to reduce energy cost.
- ✓ To assess the power quality problem (harmonics) in Almeda textile factory and suggest the appropriate solution.
- ✓ To identify the harmonic distortion levels in voltage and current of an electric supply system in comparison with IEEE guidelines.
- ✓ To understand how to mitigate different power quality problems using either passive or active filter techniques.
- ✓ To design and recommend harmonic filters to reduce the high level of harmonic distortions, if any.
- ✓ Recommend possible energy saving solutions such as:
  - ▪ Opportunities to improve motors performance.
  - ▪ Opportunities to improve lighting systems.
  - ▪ Opportunities to improve the power factor

1.5 Scope and Limitation of The Study

In this thesis, field visit to each manufacturing department of the Almeda textile factory was conducted. And power consumption of motors in each section was measured, interviews has been made with electricians, production data were collected and analyzed, Load ratings of each component in the weaving and spinning departments were studied to calculate the harmonic levels of transformers using single line diagrams, power quality problem (harmonics) was assessed, passive filters were designed to avoid the unnecessary harmonic level of current and voltage in the transformers and possible recommendations was forwarded. The study is limited to simulation outputs from Dig-Silent power factor software.

1.6 Methodology

The methodology in this thesis started with a field visit to each manufacturing department of the Almeda textile factory. And interviews has been made with electricians, production data were collected such as; energy consumptions, fuel consumption, production cost (energy bill) of the last four years, the lighting data, active power, reactive power, power factor, three-phase voltage and current and actual power consumption of equipment in each department. Then analysis of energy consumption breaks down at different departments was conducted and energy conservation mechanisms were recommended. After that, power quality problem (harmonics) was assessed, passive filters were designed to avoid the unnecessary harmonic level of current and voltage in the transformers and finally possible recommendations and conclusion was forwarded.

Software tools such as; International Motor Selection and Savings Analysis (IMSSA) software was used to Support motor and motor systems improvement planning through identifying the most efficient action for a given repair or motor purchase decision and to supports motor management functions at commercial and institutional facilities and DIg SILENT power factor (Digital SImulation of Electrical NeTworks) was used for the analysis of transmission, distribution, and industrial electrical power systems and also used to calculate all harmonic indices for currents and voltages, as defined by relevant IEEE standards, including harmonic current indices and harmonic losses, such as: HD and THD, harmonic losses, active and reactive power at any frequency, power factor, RMS values etc. Finally the analysis of breakdown of energy was done using Microsoft Excel 2013.

1.7 Area Description of The Factory

Almeda Private Limited Company was established in 1994 G.C and located 7 km from Adwa town and 1006 km from Addis Ababa at (latitude 14.1636° N and longitude 38.8937°E). It has 350,000m^2 area. The installation of the machinery and utilities were finalized in 1998 G.C with capital investment \$94 million. In the middle of 1998 G.C, yarn and gray cloth were produced in the factory. After a certain delay in the startup of the processing department and the final optimization, the factory started complete work in October 1999 G.C. Currently, the factory has more than 5600 employees who are involved in operating three shifts of 8 hrs/shift (in the spinning, weaving and finishing departments) as well as two shifts of 8 hrs/shift in the garment Department.

Figure 1-1: Some Part of Almeda Textile factory

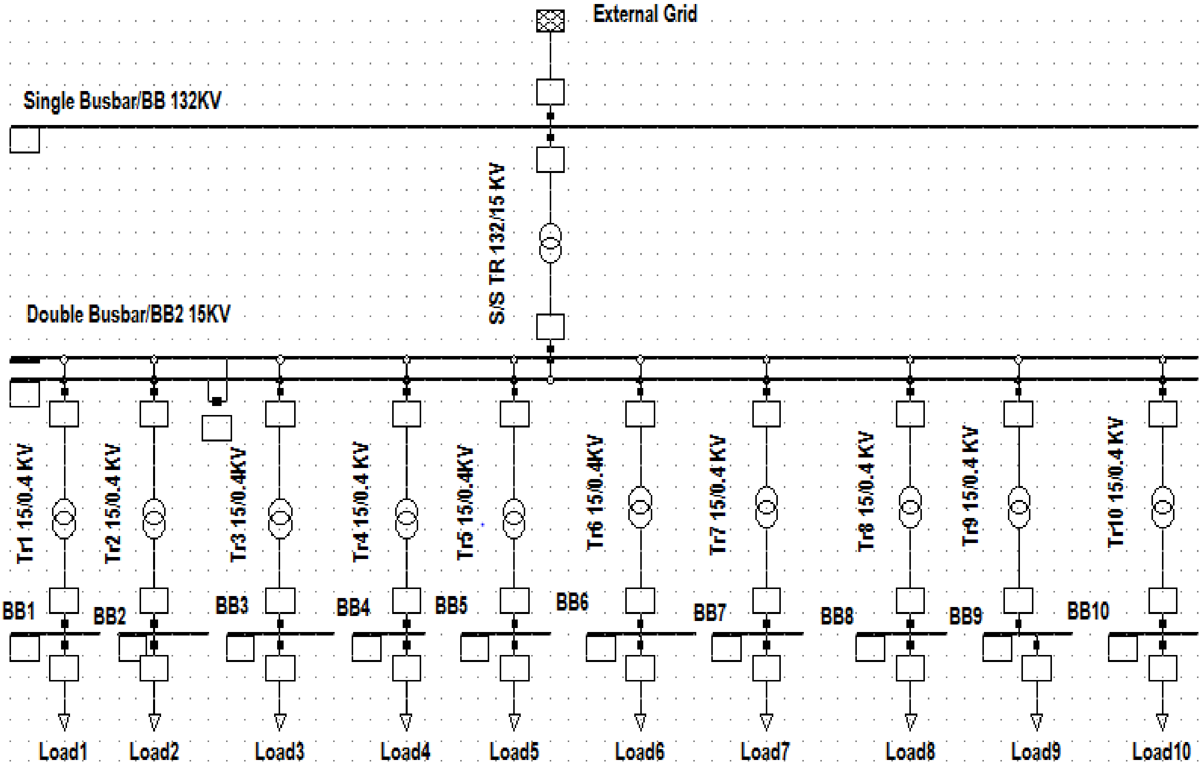


Figure1-2:The Simplified One Line Diagram of Power Distribution System at Almeda Textile

1.8 Outline of the Thesis

The rest of the thesis is organized in five chapters. The second chapter focuses detailing the literatures reviewed for power quality problems (harmonics) and energy auditing on textile industries. The third chapter describes the data collection methodologies and discusses major energy losses and energy saving opportunities through performing a technical evaluation, performing economic evaluation and Calculating payback periods. It also discusses how much energy will be saved using energy auditing. The fourth chapter details about assessing the harmonic levels of voltage and current at the transformers. The fifth chapter discusses about harmonic effects and their mitigation using harmonic filters, design equations of single-tuned harmonic filter results and comparison was made to see whether the THD of voltage and current is within the IEEE limit or not. Final Conclusions and Recommendations for future research are presented in the last chapter.

CHAPTER TWO

Literature Review

2. Literature Reviewed

This chapter explains the detailed literature study on energy auditing and power quality related problems in industries and respective solutions. The information was gathered from several sources such as books, journals and websites. Each reference used is explained in detail as follows.

Jatin Gupta, Man deep Singh [5] This paper provides information on electrical energy audit in the textile plant by identifying the source of energy use, according to the greatest to the least cost effective opportunity for energy saving. Serious of procedures is followed in calculating the energy consumption of lighting, humidification, compressor and large machines. After that, the energy consumptions in each department were analyzed, a range of energy saving was provided and simple payback periods were calculated. Generally, the journal analysis was done only on rewound induction motors for its efficiency improvement.

Y. Dhayaneswaran, L. Ashokkumar [6] This paper discusses the influence of motors and process of optimization in textile industries for energy conservation. The percentage breakdown analysis of energy consumption for each department was analyzed. By means of adopting the techniques such as, installing energy efficient motor in Ring frame machines and Resizing of motors based on the power drawn significant energy saving can be realized in the preparatory process, ring frame, humidification plant and compressor.

Aftab Khan Masood, et al [7] This paper provides information on the collection of necessary data using energy auditing instruments such as; data of electrical loads, air velocity, temperature, relative humidity, average running load of return fan, water pump and supply fan. Then the measured data for each department was analyzed. Implementing the techniques of the flow of air by changing the fan vane angles (only for the variable fans) and discharge the flow rate of water pump through throttling valve, 20% of the energy can be saved in the air conditioner.

E.A. Abdelazizet, et al [8] This journal provides energy saving technologies through high efficiency electric motors, reducing boiler flue gas temperature and implementing variable frequency drive (VFD) to match load requirement. As a result, a cost-effective energy saving mechanism was developed.

R. S. Chanda [9] This paper identifies some areas of energy consumption, such as; cables, distribution systems, motors, lighting system, etc. According to the paper, replacing the standard energy efficient motors with premium high efficient motors (with 4-5% higher efficiency and cost 30% more than the standard ones) valuable energy can be saved with a small period of payback time.

Basel Tahseen et.al [10] This paper conducted energy audit and analyzed the energy consumption in certain textile industry in Palestine. The author identified the most energy intensive areas of the industry and suggested measures which can be implemented to conserve energy loss. Through implementation of energy conservation measures on the most energy consuming equipment such as boilers, compressors and lighting systems, 10-20% of total energy consumed by the facility can be saved.

Oyedepo, et al [11] This paper examines the pattern of energy consumption in food processing industries and distillation and bottling company. And identified the sources of electrical energy loss to be boilers, pumps, compressor, electric motors and HVAC. Then assessed their energy consumption; in which 65% of the total energy is consumed by boiler and 40-47% are total electric energy is consumed by pumps, compressor, electric motors and HVAC. Thus, by replacing old electric motors with new ones, implementing good ventilation to reduce energy loss and installing variable speed drives valuable energy can be saved.

Mohammad Hamid Shwhdi [12] This paper investigates on harmonics in large steel factory with 49 buses, 38 two winding transformers, 3arc furnace, 2 ladle furnace and many inductive loads. Due to the existence of these loads the reading of power factor in different buses was 0.56-0.59. Which would result in penalties to the factory. As a result, the paper presented with a solution that corrects the power factor value from 0.56 to 0.93 through designing passive filters.

Muhammad Rusli, et al [13] This paper presented the single tuned harmonic filter design as a total harmonic distortion compensator in a 20 KV distribution system. The level of harmonic distortion at individual level is increased due to non-linear loads. To avoid this unnecessary level of harmonics a passive filter with 3.465 KVA apparent powers was installed. As a result, the power factor was upgraded from 0.86 to 0.95.

To minimize energy usage and potentially increased profits, through production efficiency gains, while procuring the lowest cost and most reliable supplies of power, the authors take of energy efficiency opportunities such as; more productive state of the art technology that improves a facility’s competitive edge and improved environmental performance and compliance with environmental and pollution abatement regulations. Hence, applying a successful energy management process in different companies they improve production efficiency of the plant, maintaining a high energy load factor and correcting for low power factor. But, in this thesis correctness of the lighting installation was evaluated and corrected; using International Motor Selection and Savings Analysis (IMSSA) software by entering related data from nameplate information it calculates the annual cost saving and calculates the payback periods. As well as, the efficiency of the boiler was calculated; which were not considered in the previous researches read. However, these factors have a great impact on the overall power consumption of the factory. In addition, passive filter was used to reduce harmonic distortion of currents and voltages, which has a low cost as compared to the active filter used in other researches.

CHAPTER THREE

Manufacturing Process and Data Collection in the Textile PLC

3.1 Over View of Textile Industry

Textiles industries in Ethiopia were begun in 1947 G.C. Ethiopia earned over 8,200,000 $ per year from the export of garments and textile products. Nowadays, the number of textile factory accounts for 51% to 65% of the total factories in the country [14]. Textile manufacturing or production is a complex process. The range of textile manufacturing is too long. It starts from fiber to finished products. It is based on the conversion of three types of fiber into yarn, then to fabric, then to textiles. These are then fabricated into clothes. To represent the whole factory a simple diagram is shown below.

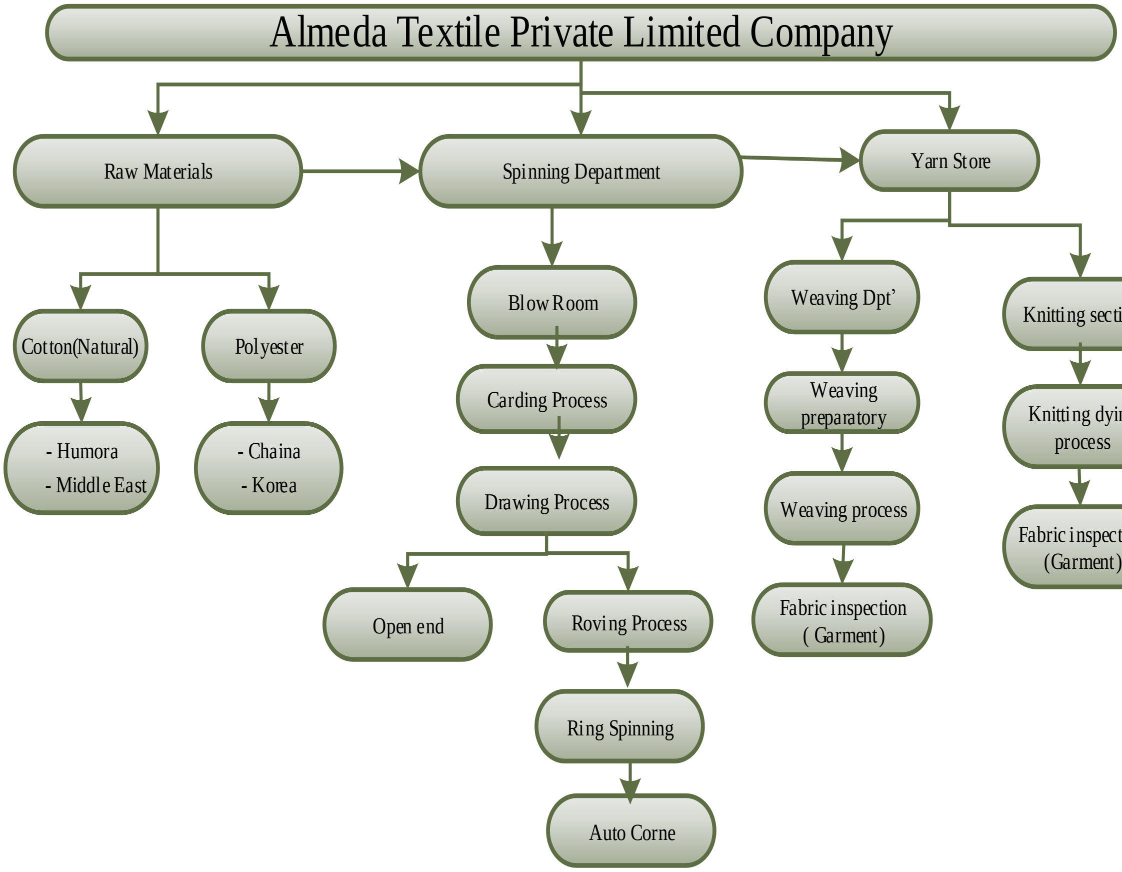


Figure 3-1: The Main Category of Almeda Textile Private Limited Company

3.2 Major Energy Use and Areas

There are four main production processes (activities) in the textile industry. Those are: spinning, weaving and knitting, wet processing and knit, dyeing and garmenting (sewing). The production of fibers to spun yarn takes place through the spinning process and constitutes the first stage. Then the yarn is woven to make fabrics in looms. Most woven fabrics retain the natural color of the fibers from which they are made and are called gray fabrics at this stage. These fabrics, then undergo several different processes, including bleaching, printing, dyeing and finishing.

- **Spinning:** Spinning involves opening/blending, carding, combing, drawing, drafting and spinning.
- **Weaving:** The weaving process uses a loom. The longest way threads are known as the warp, and the cross way threads are known as the weft. The warp, which must be strong, needs to be pre-sented to loom on a warp beam.
- **Wet processing:** This is the third stage. It covers all processes in a textile unit that involve some form of wet or chemical treatment. The wet processing can be divided into three phases: preparation, coloration and finishing.
- **Garment:** This department currently producing different types of wearing apparels for the local and international market. The factory has a total of 1543 sewing machines. The cutting unit with full size cutting table is strengthened by the design & pattern making unit, equipped with computer Aided design (CAD)
- **Knitting:** The knitting department manufactures circular gray fabrics by receiving yarns from spinning department.
- **Knit dyeing**: This department produces dyed and bleached fabrics using sclavos, squeezer, dryers and compactor machines by receiving gray fabrics from knitting department.

3.3 Brief Description of Each Utility and Energy

The plant receives electric power and water from Ethiopian Electric utility and dam respectively.

- **Electricity**: Is a kind of energy produced from renewable and non renewable energy sources like wind, solar, geothermal, nuclear, hydro, etc. This electricity is used as a common energy source for running all Almeda textile machines and lightning.
- **Steam Generation**: Three electrical boilers (steam) and one thermal oil boiler is installed in the plant. The steam is generated at a pressure of 5 bar and utilized at 2-4 bar as per requirement. This steam is used for bleaching, De-sizing, Washing dryer etc.
- **Water**: Is the main sources for producing steam, combining with steam it uses for washing gray fabrics, for preparing solutions of chemicals, drinking and sanitation of the employees.
- **Compressed Air**: Is one form of energy and it uses for converting the potential energy to mechanical energy of all valves and other parts.
- **Thermal Oil**: Is one form of energy produced by the combustion results of air and fuel. This provides high temperature rather than steam. The main advantage of thermal boiler is for drying purposes. The three steam boiler and one thermal boiler are shown below:

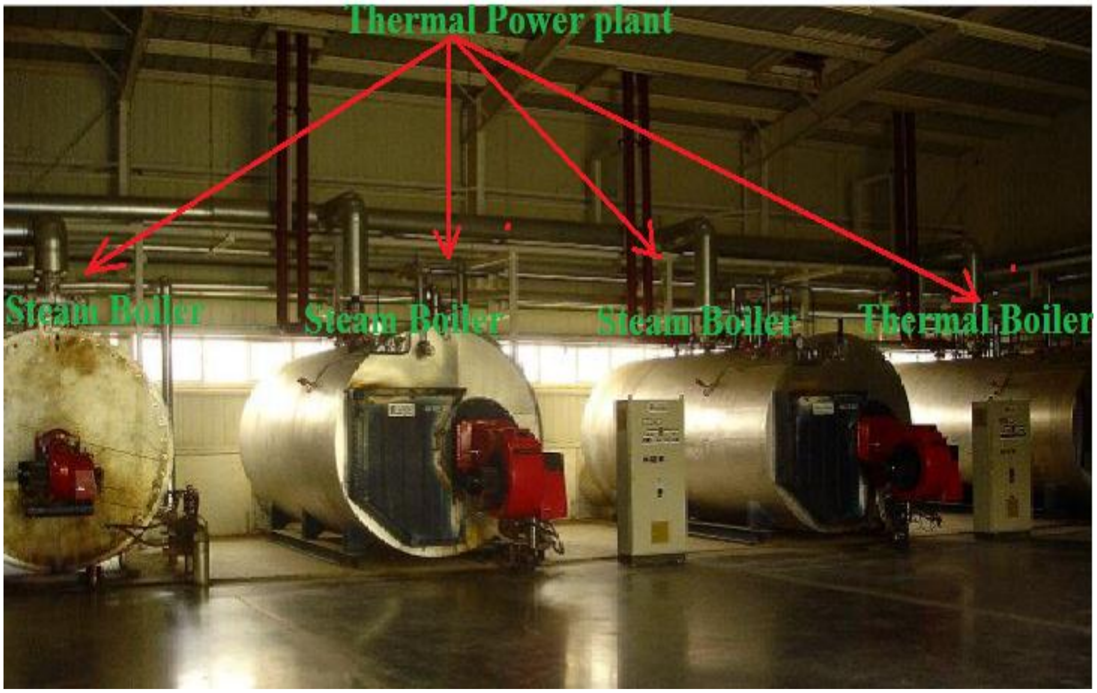


Figure 3-2: Almeda Textile Thermal Power Plants

3.4 Energy Use in The Spinning Process

Electricity is the major type of energy used in spinning plants.

- **Production Machine:** There are different machines in the textile industry. For example carding machine is found in the spinning department having different electric motors like: main drive motor, suction motor, induction motor, fan motor, etc. those motors have their own speed, rated voltage, rated current, rated power, etc. In addition, Blowing, Roving, Combing, Open- end, Ring frame and an Auto-cone machines are found in spinning department. The total electricity consumption of the production machines take a large share about 84.5% as shown in fig 3.4 The energy consumption of spinning department consumes the highest energy about (42.4%) and the weaving department consumes about (20.35%).
- **Lighting:** The lighting consumes 7.15% of the total electricity. Fluorescent lamps are widely used in the factory. Currently, 4217 lamps are installed having different ratings and operation times. Checking the installation, it was found that unnecessary lamps were installed. So it is important to reinstall the lighting for efficient use of energy.
- **HVAC Systems:** Heating, Ventilating, and Air Conditioning (HVAC) is used to move air into the factory to create and maintain a desirable temperature, humidity, ventilation and air purity. This HVAC is mostly found in spinning, weaving and processing departments. The energy consumption of HVAC accounts about 13.23%. The breakdown of energy in the textile is shown as follows:

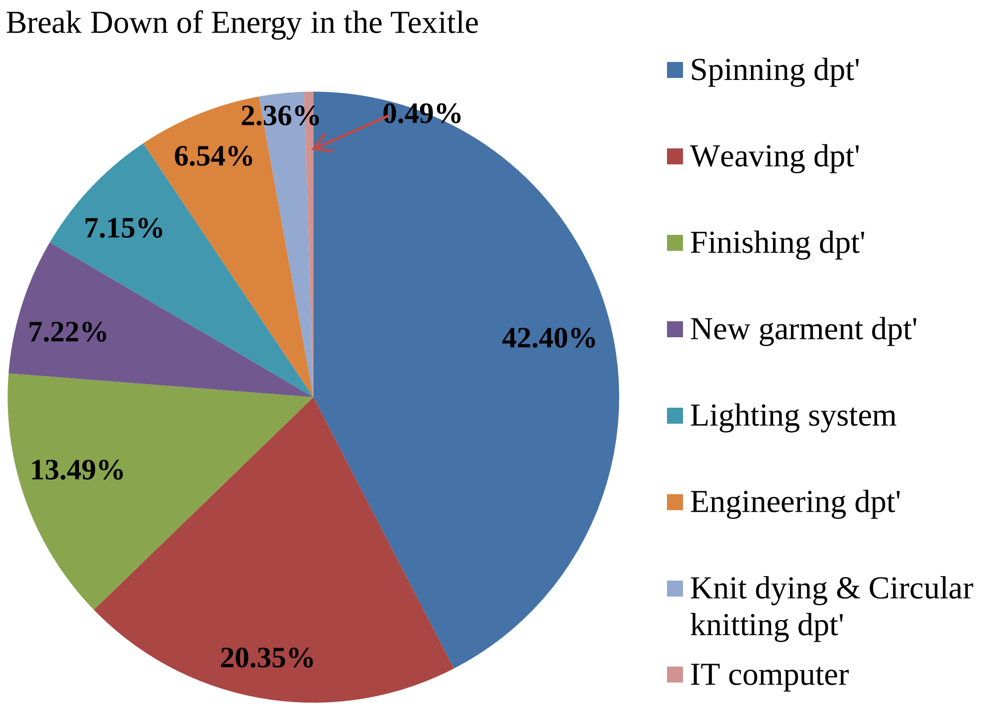
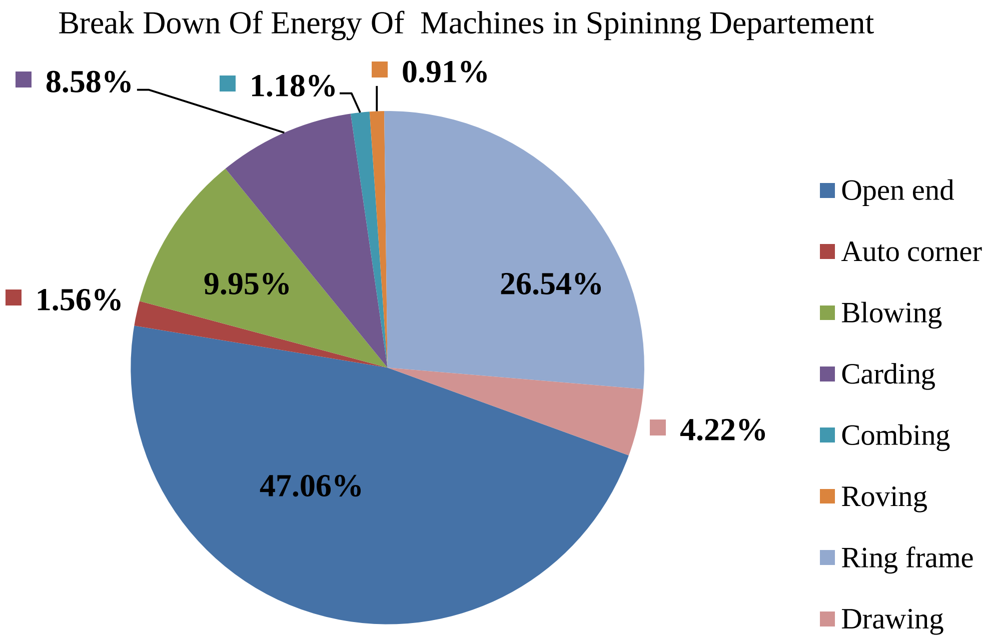


Figure 3-3: Breakdown of Energy Use by Textile Process in Each Department



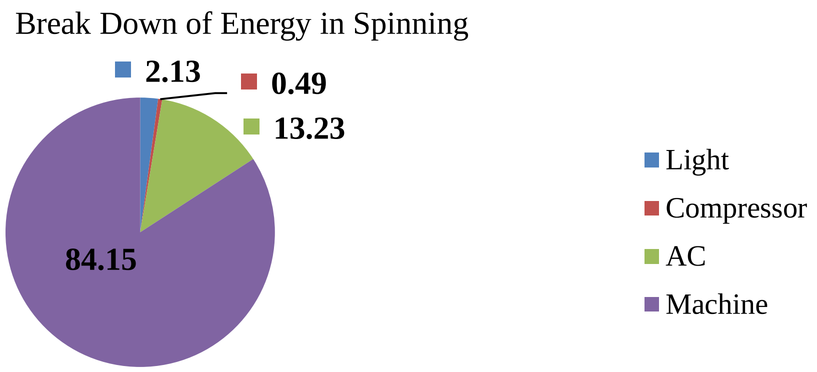


Figure 3-4: Breakdown of Energy in Spinning Plant.

3.5 Energy Consumption Result

The actual power consumptions of the linear and nonlinear loads which exist in the company is measured using the instrument known as clamp meter. So this measured power consumption helps to calculate the hourly, daily, monthly and yearly energy consumption in each section of the whole factory. Therefore, the energy consumption of the equipment's in the whole company is shown below as table form.

Table 3-1: Energy Consumption in Spinning Department

Machine Name	Quantity	RC(kW)	TRC (kW)	MC(kW)	TMC (kW)	OH (hr)	Cost (Birr)
Uniflock	1	10.3	10.3	6.4	6.4	24	65.7
Uniclean	2	11	22	3.5	7	24	68.6
Unimix	3	7.16	21.48	4.6	13.8	24	135.3
Uniflex	3	13	39	8.39	25.17	24	246.83
Condenser	3	5.5	16.5	3.5	10.5	24	102.97
Mixing bale opener	2	6.97	13.94	3.8	7.6	24	74.53
Fine cleaner	1	4.25	4.25	2.8	2.8	24	27.5
Fan motor	11	4	44	1.7	18.7	24	183.4
Fan motor	7	2.2	15.4	1.9	13.3	24	130.4
Fan motor	1	7.5	7.5	3.8	3.8	24	37.3
Manual horizontal bale opener	1	4	4	1.9	1.9	24	18.6

Automatic horizontal bale opener	1	5.5	5.5	1.9	1.9	24	18.6
Mixing opener	1	6.97	6.97	3.4	3.4	24	33.3
AC- A station total	1	119	119	97.06	97.06	24	951.81
Cards	24	13.62	326.4	5.8	139.2	24	1365.1
High speed D/F	9	9.5	85.5	4.1	36.9	24	361.85
High speed D/F	7	11.1	77.7	4.5	31.5	24	308.9
High speed comber	6	5.8	34.8	3.2	19.2	24	188.3
Automatic open end	12	105	1260	64.14	769.68	24	7547.98
AC-2 station total	1	71.2	71.2	54.2	54.2	24	531.51
Winding	4	29.2	119.2	6.4	25.6	24	251.04
Twister	9	22	198	14.2	127.2	24	1247.4
Doubler	2	7.4	14.8	4.3	8.6	24	84.33
Cone to cone	1	25.8	25.8	18.8	18.8	24	184.4
Yarn stripper	2	2.5	5	0.26	0.52	24	5.1
AC-3 station one	1	108.35	108.35	90.3	90.3	24	885.52
Ac-3 station two	1	71.35	71.35	54.26	54.26	24	532.1
Ring frame	15	60.5	907.5	28.7	430.5	24	4221.7
Yarn bending press	1	22	22	7.2	7.2	24	70.6
Rewinding	1	10.3	10.3	6.95	10.3	24	101
Flat wire mounting	1	1.94	1.94	1.28	1.28	24	12.56
Flat wire de mounting	1	2.2	2.2	1.54	1.54	24	15.1
Flat girder	1	3.04	3.04	2.13	2.13	24	20.88
Waste sucker	1	3	3	2.1	2.1	24	20.59
Dust collector	1	55	55	46.3	46.3	24	454.04
Extract fan	6	30	180	21.8	130.8	24	1282.7
Air compressor	1	0.9	0.9	0.53	0.53	24	5.2
Total Cost /Day						21,807.16	
Total Cost Year						7,676,120.32	

Tables 3-2: Energy Consumption in Weaving Departments

Machine Name	Quantity	RC(kW)	TRC (kW)	MC(kW)	TMC (kW)	OH(hr)	Cost (Birr)
Warping	1	21	21	16.55	16.55	24	161.81
Creel	1	48	48	21.6	21.6	24	211.82

Chemical mixer	1	14.5	14.5	4.2	4.2	24	41.2
Sizing	1	14.5	14.5	4.2	4.2	24	41.2
Stirrer	1	9	9	4.5	4.5	24	44.13
Sectional warping	1	34	34	33	33	24	323.61
Loom for drill & twill	64	9.3	595.2	4.9	313.6	24	3075.3
Loom for Populing	48	9.3	446.4	4.9	235.2	24	2306.5
Loom for Tarrat towel	5	8.4	42	4.37	21.8	24	213.8
Loom for Canavas	5	8	40	3.3	16.5	24	161.8
Drolling& plating	1	4	4	4	4	24	39.23
Inspection	4	2.5	10	2.5	10	24	98.1
High pile plating	1	8	8	1.5	1.5	24	14.71
Warp beam storage	1	5.5	5.5	3.6	3.6	24	35.3
Streamer	1	6.6	6.6	6	6	24	58.8
Suplly air unit	1	4	4	1.05	1.05	24	10.3
AC- B	1	47.5	47.5	31.42	31.42	24	308.12
AC-4	1	179.2	179.2	169.6	169.6	24	1663.2
AC-5	1	179.2	179.2	169.6	169.6	24	1663.2
Total Cost /Day						10,472.13	
Total Cost Year						3,686,179.2	

Table 3-3: Energy Consumption in Finishing Departments

Machine Name	Quantity	RC(kW)	TRC (kW)	MC(kW)	TMC(kW)	OH(hr)	Cost (Birr)
Yarn dying	2	19.4	38.8	9.7	19.4	24	190.3
Hydro extractor	1	6	6	2.66	2.66	24	26.1
Seinging/ Desizing	2	30.4	60.8	12.75	25.5	24	250.7
Batcher	2	10	20	8.31	17.18	24	163.3
Bleach	1	68.4	68.4	17.18	13.86	24	168.5
Open width washing range	1	41.8	41.8	13.56	13.56	24	135.9
Cylinder dryer	1	40	40	13.56	13.56	24	132.97
Mercerizing	1	91.2	91.2	46.56	46.56	24	456.59
Constic recovery plant	1	7.5	7.5	3.05	3.05	24	29.91
Jigger	3	10	30	7.8	23.4	24	229.47
Stenter	1	175	175	77.59	77.59	24	760.88

Continuous dyeing range	1	202	202	113.8	113.8	24	1115.96
Dyeing Padder	1	27.75	27.75	12.19	12.19	24	119.54
Rotary screen printing	1	76	76	57	57	24	558.96
Backing/ curing	1	30	30	22	22	24	215.74
Sanforizing	1	44	44	28.5	28.5	24	279.5
Calendaring	1	34.5	34.5	17.9	17.9	24	175.5
Emercing	1	75.38	75.38	46	46	24	451.1
Final inspection	4	4	16	2.5	10	24	98.06
Close rolling	1	2.5	2.5	0.8	0.8	24	7.85
Close rolling	1	4	4	2.56	2.56	24	25.1
Double folding	1	6.5	6.5	3.2	3.2	24	31.38
Baling	1	5.5	5.5	2.3	2.3	24	22.55
Pump house	2	15	30	9.42	18.84	24	184.8
Printing color	1	30.63	30.63	8.31	8.31	24	81.49
Mathis program dryer	1	9	9	6.23	6.23	24	61.1
Mathis lab mat	2	2.3	4.6	2.14	4.23	24	41.97
Micro wave	1	1.23	1.23	0.35	0.35	24	3.43
Padder	1	1	1	0.35	0.35	24	3.43
Laundry/ washing	1	2.1	2.1	1.35	1.35	24	13.24
Lab dryer (binder)	1	1.2	1.2	0.28	0.28	24	2.75
Squeezer	1	0.9	0.9	0.21	0.21	24	2.059
Electrical balance	3	2.7	8.1	0.63	1.89	24	18.53
Strier heater	1	0.05	0.05	0.01	0.01	24	0.098
Tump dryer	1	14.4	14.4	10.5	10.5	24	102.9
Emerizing	1	54.9	54.9	46	46	24	451.1
Polymeerizer	1	14.4	14.4	10.5	10.5	24	102.9
Exposer	1	8.86	8.86	6.37	6.37	24	62.47
Coater	1	3.32	3.32	2.6	2.6	24	25.49
Hank lifter	1	4	4	1.77	1.77	24	17.36
cabinet dryer	1	3.99	3.39	3.1	3.1	24	30.39
Exhaust fan	2	5	10	4.65	9.3	24	91.2
Total Cost /Day						6,941.905	
Total Cost Year						2,443,550.56	

Table 3-4: Energy Consumption in Engineering Department

Machine Name	Quantity	RC(kW)	TRC (kW)	MC(kW)	TMC (kW)	OH(hr)	Cost (Birr)
Duty lathe	2	5.6	11.24	3.53	7.06	8	23.07
Power hack saw	2	2.51	5.02	1.12	2.24	8	7.32
Universal milling	1	6.61	6.61	5.48	5.48	8	17.91
Drill	5	3	15	1.15	5.75	4	9.37
Tool grinder	1	0.37	0.37	0.25	0.25	5	0.51
Floor grinder	1	1.1	1.1	0.92	0.92	4	1.5
Cutting disk	1	2.2	2.2	1.1	1.1	4	1.79
Hydraulic press	1	7.5	7.5	6.6	6.6	4	10.78
Arc welding	3	49	147	12.7	38.1	6	93.4
Migmag	1	5.39	5.39	1.7	1.1	6	4.16
Planner	1	5.54	5.54	3.2	3.2	6	7.84
Oven	1	33	33	23.45	23.45	6	57.49
Auto coil former	1	2	2	0.52	0.52	8	1.69
Compressor	1	1.3	1.3	1.2	1.2	6	2.94
Rolling	1	1.6	1.6	0.276	0.276	6	0.67
Wheel balance	1	0.37	0.37	0.36	0.36	4	0.58
Feed water pump	6	5.5	33	5	30	16	196.12
Screw pump	3	6.92.3	6.9	1.2	3.6	16	23.52
Dozing pump	1	0.2	0.2	0.2	0.2	16	13
Condensate pump	2	1.3	2.6	1.3	2.6	16	16.99
Screw spindle pump	2	1.2	2.4	1.2	2.4	16	15.69
Unloading pump	2	8.4	16.8	8.4	16.8	16	109.83
Circulating pump	1	12.6	12.6	12.6	12.6	16	82.37
Steam boiler	3	69.28	207.84	25.5	76.5	24	750.18
Thermal oil boiler	1	78.7	78.7	38.56	38.5	24	378.13
Thermal oil reservoir	1	1.8	1.8	1.8	1.8	24	17.65
Refrigerant drier	2	3.7	7.4	3	6	24	58.83
Fuel oil depo (tanker)	6	12.7	76.2	7.4	44.4	24	435.4
Condensate tanker	1	1.5	1.5	0.8	0.8	24	7.8
Mixer	10	12.8	128	2.8	28	24	274.57
Diaphragm pump	7	0.18	1.26	0.1	0.7	16	4.57

Rotary Scraper	3	1.2	3.6	1.2	3.6	16	23.53
Submersible pump	3	1.21	3.63	0.12	0.36	16	2.35
Centrifugal pump	8	7.5	60	8	64	16	418.4
HER pump	10	9.2	92	3.9	39	16	254.96
Brine pump	1	0.86	0.86	0.86	0.86	16	5.62
Displacement pump	1	9	9	8	8	16	52.3
Total Cost /Day						3,371.19	
Total Cost Year						1,186,658.88	

Table 3-5: Energy Consumption in Knit Dying and Circular Knitting Department

Machine Name	Quantity	RC(kW)	TRC (kW)	MC(kW)	TMC (kW)	OH(hr)	Cost (Birr)
Sclavos	3	23.9	71.7	8.62	25.86	16	169.1
Squeezer	1	25	25	4.31	4.31	16	28.2
Dryer	2	58	116	26.2	52.4	16	341.9
Compactor	1	27	27	10	10	16	65.4
Sample dryer	1	2.3	2.3	2	2	16	13.1
Sample heater	1	10	10	2.5	2.5	16	16.34
Maier / circular knitting	5	5.5	27.5	5	25	16	163.44
Pailung circular knitting	9	4.56	41.04	4.5	40.5	16	264.77
Flat knitting	6	0.92	5.52	0.76	4.56	16	29.8
Reeling	5	6.1	30.2	3.5	17.5	16	114.41
Inspection	1	1.2	1.2	1.2	1.2	16	7.85
Total Cost /Day						1,214.31	
Total Cost Year						427,437.12	

Table 3-6: Energy Consumption in New Garment Department

Machine Name	Quantity	RC(kW)	TRC (kW)	MC(kW)	TMC (kW)	OH(hr)	Cost (Birr)
Single needle	614	0.3	184.2	0.299	183.6	16	1697.4
Double needle	39	0.425	16.575	0.345	13.5	16	105.3
Button attach	18	0.4	7.2	0.184	3.3	16	30.5
Button hole	23	0.6	13.8	0.345	7.9	16	73
3 thread o lock	79	0.69	54.51	0.69	54.51	16	503.9
5 thread o lock	26	0.69	17.94	0.46	11.96	16	110.5
Kansie	2	2.5	5	0.92	1.84	16	17
Dice motor	6	0.35	2.1	0.32	1.92	16	17.75
Belt loop	8	0.6	4.8	0.345	2.76	16	25.52
Top fusing	6	0.9	19.2	0.414	6.624	16	33.3
East man cutter	16	1.2	4.8	0.414	1.656	16	61.24
Band knife	4	1.2	4.8	0.414	1.656	16	15.31
Caf press	2	2.3	4.6	1.495	2.99	16	27.6
Boiler for two iron	4	8.2	32.8	5.635	22.54	16	208.4
Min press	3	4	12	1.794	5.382	16	49.75
Single needle	46	0.55	25.3	0.291	13.4	16	123.88
Piping	10	1	10	0.6	6	16	55.46
Button hole	21	0.64	13.44	0.258	5.41	16	50.1
Piping kansie	4	0.534	2.136	0.313	1.252	16	11.57
3 thread o lock	29	0.512	14.85	0.276	8	16	73.95
5 thread o lock	74	0.15	11.1	0.03	2.2	16	20.34
Sleaveheam	13	0.913	11.9	0.686	8.92	16	82.46
Rip cutter	1	0.215	0.215	0.11	0.11	16	1.02
Dice cutter	1	0.215	0.215	0.11	0.11	16	1.02
Table suction	6	0.345	2.07	0.23	1.38	16	12.75
Dray iron	9	1	9	0.299	2.7	16	24.99
Steam iron	6	0.55	3.3	0.291	1.78	16	16.2
Steam boiler	2	37.5	75	23.35	46.7	24	647.59
Turbo aspirator	2	30	60	11.9	23.8	24	330.04
Air compressor	2	18	36	16.5	33	24	457.62
Water pump	1	11.5	11.5	7.75	7.75	24	107.47

Soft water plant	1	73.6	73.6	18.69	18.9	24	262.09
Total Cost /Day						5,255.02	
Total Cost Year						1,849,767.04	

Table 3-7: Energy Consumption in IT Computer

Machine Name	Quantity	RC(kW)	TRC (kW)	MC(kW)	TMC (kW)	OH(hr)	Cost (Birr)
Accer laptop	4	0.98	3.92	0.14	0.56	8	1.83
Toshiba laptop	34	1.034	35.156	0.11	3.74	8	12.23
Benq desktop	5	0.96	4.8	0.44	2.2	8	7.2
Dell desktop	133	1.78	236.74	0.44	58.52	8	191.3
HP desktop	3	1.78	5.34	0.51	1.53	8	5
Hanok desktop	2	1.78	3.56	0.48	0.96	8	3.14
Waryt desktop	16	0.6	9.6	0.088	1.408	8	4.6
Total Cost /Day						225.3	
Total Cost Year						79,305.6	

Table 3-8: Energy Consumption in Lighting System

Lamp Type	Quantity	RC(kW)	O H (hr)	Energy(kWh)	Cost (birr)
Fluorescent lamp	1872	0.06	24	2695.68	1101.45
Fluorescent lamp	929	0.036	16	535.104	218.64
Fluorescent lamp	916	0.036	8	297.216	107.79
Incandescent lamp	80	0.1	6	48	19.6128
Halogen lamp	258	0.25	12	774	316.3
Halogen lamp	162	1.5	16	3888	1588.63
Total Energy/ Year				2,889,714	
Total Cost /Year				1,180,737.14	

The total energy per year of all departement and lighting system is **44.31MWh**

Table 3-9: Review of Textile Production and Energy Consumption in Almeda

No	Item	Unit	Year			
			2005	2006	2007	2008
1	Total yarn and fabric production	kg	1,971,105	1,889,899	2,142,846	2,351,244
2	Elec. consumption	kWh	29,566,575	26,143,767	25,252,260	24,253,749
3	Fuel consumption	Lit	160,451	150,320.5	145,631	138,450
4	Spec. Electric cons.	kWh /Kg	15	13.83	11.78	10.32
5	Spec. Fuel cons.	Lit /kg	0.08	0.07	0.06	0.05
6	Energy int (Fuel)	kJ /kg	3,266.48	3,191.74	2,727.2	2,362.9
7	Energy int (Elec.)	kJ /kg	54,000	49,800.31	42,424.02	37,135.02

Table 3-10: Yearly Electric Energy Cost and Furnace Oil Cost of The Textile

Item	Year (E.C)			
	2005	2006	2007	2008
Electric Energy ($)	447,443.6	395,642.4	382,150.86	367,040.1
Furnace oil ($)	103,520.6	96,984.6	93,958.9	89,325.9
Total ($)	550,964.2	492,627	476,109.8	456,366

Table 3-11: Production, Energy use, and Energy intensity for three different spinning and weaving in Iran (A, B, C are in spinning and D, E are in weaving) [15].

Plant	Annual production(tonne)	Annual Electricity consumption (kWh)	Annul Fuel consumption ((GJ)	Spec. Electric Intensity (MWh /ton)	Fuel energy intensity (GJ/ton))	Elect. energy int.(GJ/ton)	Spec. Fuel con.(lit/kg)
A	2003	13,290,450	54,760	6.6	12.4	36.2	0.308
B	8140	38,584,206	57,694	4.7	7.1	24.2	0.177
C	2448	8,860,300	19,808	3.6	8.1	21.1	0.202
D	6027	1,329,045	103,993	2.2	17.3	25.5	0.43
E	6299	7,420,040	67,397	1.2	10.7	14.9	0.267

Table 3-12: Each Rate in ETB

Place	Charge rate ETB	Cost ETB/kWh
Commercial	37.56	Based on Range of kWh
Almeda factory	54.01	0.4086
New garment	53.57	0.5778
Power factor charges at Birr 68.396 (up to 0.9 power factor)		

Price of Diesel / Litter	-	16.2 -19
Price of Furnace Oil/ liter	-	Birr 15.76

3.6 Assessment of Lighting Systems

The luminous intensity of various lamps and the standard illumination required in various working stations are required to evaluate whether the current installation system is appropriate or not. To check whether the current installation of lamps are corrector or not, several calculations is shown below.

Table 3-13: Luminous Intensity and Life time of Various Lamps [16]

No.	Lamp type	Luminous Intensity (Lumens/watt)	Relative Efficiency based on HPS	Lamp Life(hrs)
1	Incandescent	8-18	19	1000-2000
2	Tungsten -Halogen Lamps	18-24	77	2000-4000
3	Fluorescent tube	65-80	65	5000
4	LED Lights	70-120	92	50000-100,000
5	High Pressure Hg Vapor lamps	50-60	46	16,000-24,000
6	High Pressure Na Lamps(HPS)	75-130	100	24,000
7	Compact Fluorescent Light(CFL)	45	46	7000-10,000

Table3-14: Illuminations required in various Working Station [17]

No.	Working Station	Average IL Luminance required(LUX)
1	office , guard rooms, kitchen, library, laboratory, clinic	500
2	Canteens, garage	150
3	Boilers and pump houses	20-100
4	Spinning	150-450
5	Knitting	300-750
6	Weaving ,fabric and general sores	200-700
7	Garment	350-1000
8	Grey close inspection	700-1000
9	Final inspection	700-1000
10	Workshops	200-750
11	Clock rooms, Entrances, Corridors, Stairs,	100

12	maintenance room and winding room, shower	200
13	Toilet	300

Table 3-15: Currently installed types of lamps having different rates

No	Types of Lamps	Quantity	Power rate (Watt)
1	Fluorescent Lamps	1845	36
2	Fluorescent Lamps	1872	60
3	Incandescent Lamps	80	100
4	Halogen Lamps	258	250
5	Halogen Lamps	162	1500
Total		4217	

The fluorescent tubes are T-12 tubes (T-12 lighting tubes are 12/8 inches in diameter and the T- designation refers to a tube diameter in terms of 1/8 inch increments. Therefore, to reexamine the installation different formulas are used to make an appropriate installations.

$TP = LR \times NL$--Eqn (3.1)

where:

LR - Lamp rating (W)

NL - Number of lamps installed in the department.

TP - Total power ratings of the lamps installed in the department given in watt

$TL = NL \times Lo$---Eqn (3.2)

Where:

TL - Total lumens output of lamps installed in the department

Lo - is the luminous output of each fluorescent lamp which is 80lumens/watt obtained in the table for fluorescent lamps.

$IL = TL/RA$---Eqn (3.3)

Where:

RA - Room area of each department measured in (m^2)

IL - The illumination produced by the installed lamps expressed in lux and is obtained by dividing the total lumens to the room area (1 lux is equivalent to 1lumens/m^2)

OH – Operating hours per day.

ALR = (ILR/IL)*NL--Eqn (3.4)

Where:

ALR- The actual lamps required for proper installation

ILR - The illumination required in each place which take from the standard illumination level of various stations appear in the tables above.

EU = NL×LR--Eqn (3.5)

Where:

EU - Energy utilization (kWh)

ER = ALR×LR--Eqn (3.6)

Where: ER - Energy required after a proper illumination(kWh)

ED = EU-ER--Eqn (3.7)

Where: ED - Energy difference (kWh)

Table 3-16: Reexamines of installations in the factory

No	Department	NL	TP(kW)	TL	RA (m^2)	IL(Lux)	ALR	OH(h)	EU (kWh)	ER (kWh)	ED (kWh)	Remark
1	Canteen(2)	32	1.152	92,160	520	177.23	27	24	27.65	23.33	4.32	36W
2	Office(129)	1032	37.152	2,972,160	5418	548.57	941	8	297.216	271	26.23	>>
3	Guard (5)	28	1.008	80,640	150	537.6	26	12	12.096	11.23	0.864	>>
4	Toilet (15)	80	8	80,000	180	444.4	54	6	48	32.4	15.6	100W
5	Shower(40)	40	1.44	115,200	480	240	33	5	7.2	5.94	1.26	36 W
6	Clinic(4)	18	0.648	51,840	100	518.4	17	8	5.184	4.896	0.288	>>
7	Garage	12	0.432	34,560	180.5	191.5	9	8	3.456	2.592	0.864	>>
8	Workshop	12	0.432	34,560	90	384	8	8	3.456	2.304	1.152	>>
9	Winding	18	0.648	51,840	225	230.4	15	8	5.184	4.32	0.864	>>
10	Garment boiler	32	1.152	92,160	435	211	15	24	27.648	12.96	14.688	>>
11	Steam	75	2.7	216,000	765	282.4	27	24	64.8	23.33	41.47	>>

	boiler											
12	Water& waste water treatment	50	1.8	140,000	725.5	192.9	26	24	43.2	22.46	20.8	>>
13	Weaving preparation	496	17.856	1,428,480	1925	742.1	468	24	428.54	404.4	24.14	>>
14	Fabric store	32	1.92	153,600	285.5	538	36	24	46.08	51.84	-5.76	60W
15	General store	40	2.4	192,000	435	441.4	45	24	57.6	64.8	-7.2	>>
16	Garment	272	16.32	1,305,600	1228	1063.2	256	16	261.12	245.8	15.32	>>
17	Spinning	895	53.7	4,296,000	9,415	456.3	883	24	1288.8	1271.5	17.3	>>
18	Weaving	633	37.98	3,038,400	6,145	494.45	576	24	911.52	829.4	82.12	>>
Total		3,797	186.74				3,462		3538.75	3284.5		

Without considering the incandescent and halogen lamps the total installed lamps in the factory is 3,717. Calculated as the total installed capacity of the lighting system is about 178.74 kW and its daily energy consumption is 4,289.76 kWh. The actual FL required in the factory should be around 3,408lamps.Therefore, unnecessary installed lamps are exist in the factory. As a result, there is an energy loss due to lighting systems. After the appropriate illumination has been checked, only 3,408 lamps or 1796lamps of 60W ratings and 1612 lamps of 36W and 54 number of incandescent lamps would be required. This results in total reduction of 309 FL.

3.7 Replacing T-12 Tubes with T-8 Tubes

In many industries including Almeda textile factory T-12 tube florescent lamps are used. T-12 Tubes have poor efficiency, short life, lumen depreciation and its energy consumption and maintenance cost are high. Therefore, Replacing T-12 lamps with T-8 (smaller diameter) lamps approximately doubles the efficiency. Typical energy savings from the replacement of a T-12 lamp with a T-8 lamp are around 30% [18]. As I have been discussed earlier, there are 3,717 T-12 fluorescent tubes, lamps are currently installed in the factory. After re installation 3,408 lamps would be required. Therefore, replacing these 3,408 T-12 lamp tubes with T-8 lamp tubes can save:

Power demand saving (PDS) = $\frac{0.3\times \mathrm{ALR}\times \mathrm{LR}}{1000} = \frac{0.3\times 1612\times 36}{1000} + \frac{0.3\times 1796\times 60}{1000} = 49.7376\mathrm{kW}$

$$\mathrm{ER} = (3284.5 - 32.4)\ \mathrm{kWh} = 3252.1\ \mathrm{kWh}$$

Annual Energy saving (ES)= 0.3 *ER * 365 = 356,104.95kWh/Year

Annual Birr Saving (BS) = ES *R = 356,104.95 kWh * 0.015133 \$ / kWh

Annual Birr Saving (BS) =5,388.94\$

Table 3-17: Annual Saving cost of currently installed lamps and Replaced Lamps

Currently Installed Lamps (W)	Quantity	Replaced Lamp(W)	OH (hr)	Annual Saving Cost (\$)	Initial Cost of Replaced Lamp(birr)	SPP(Month)
IL(100W)	80	CFL(23W)	6	223.99	90	29.8
Halogen(1500W)	162	LED(280W)	16	17,467.2	28,380	7.4
Halogen (250W)	258	LED(50W)	12	6,840.51	16,817.8	4.9

3.8 Assessments of Electric Motors

Motor efficiency: Is the ratio between the amount of mechanical work the motor performs and the electrical power it consumes to do the work represented by a percentage. A higher percentage represents a more efficient motor. The costs of energy efficient motors are higher than those of standard motors. To save energy we should replace the standard efficiency motor with high efficient motors. When new motors are identified for purchase or when older motors require replacement it is wise to consider the purchase of high efficiency motors. Assuming a constant motor speed, the formula to calculate the cost saving is expressed as:

$$\text{Saving} = 0.76 * \text{hp} * \text{hr} * \text{rt} * \left(\frac{1}{\text{Eo}} - \frac{1}{\text{En}} \right)$$

Where: hp = motor size (in horsepower), hr = operating hours per year, rt = utility rate in \$/kilowatt-hour, E_o = Efficiency of the existing motor (decimal fraction) and E_n = Efficiency of the replacement motor (decimal fraction).[19]

$$\text{Efficiency of 3-}\varphi\text{ motor} = \frac{746 \text{ x hp}}{1.732 \text{ x Volts x Current x PF}} \text{ or} \eta = \frac{\text{output power}}{\text{input power}}$$

3.9 Replace Exiting Main Boiler (Electrical) With New Energy Efficient Boiler

$$\text{Boiler efficiency} = \frac{\text{Heat output}}{\text{Heat input}} *100$$

$\eta = Q * \frac{(H - h)}{q * GCV} * 100$---eqn (3.1)

Q = Quantity of steam generated per hour (kg/hr) = 1250 kg/hr

q = Quantity of fuel used per hour (kg/hr)= 2840.4 kg/hr

GCV = Gross calorific value of the fuel (kCal/ kg) = 138.79kCal/ kg

H = Enthalpy of steam (kCal/ kg) = 225kCal/ kg

h = Enthalpy of feed water (kCal/ kg) = 35kCal/ kg using eqn 3.1 The boiler efficiency is

$$\eta = Q * \frac{(H - h)}{q * GCV} * 100 \text{ [20] } = 1250 * \frac{(225 - 35)}{2840.4 * 138.79} * 100 = 60.2\%$$

Due to long age of the factory the boiler efficiency is low. The calculated value of the installed steam boiler efficiency is 60.2%. Therefore, replacing the less efficient boiler by high efficient boilers we can save more money in the factory.

3.10 Pumping System

Two pump systems are installed to supply raw water from well and line water to the overhead tanks. The water circulated from the tanks to water treatment sections and distributes to different sections of the plants. Normally different pumps were in operation to supply cooling water to air compressors and process areas and in the wastewater and water treatment and three boiler feed water pump has been installed to supply soft water to the boiler. Boiler feed water pump is circulating hot water across the hot water tank (receiver). The efficiency of pumps may degrade 10% to 25% in its lifetime due to aging of the pumps, lack of quality of water and poor maintenance as compared to the standard pump efficiency (70%- 75%). Replacing less efficient pump motor with high efficient pump motor reduces an energy use by 2% to 10%.

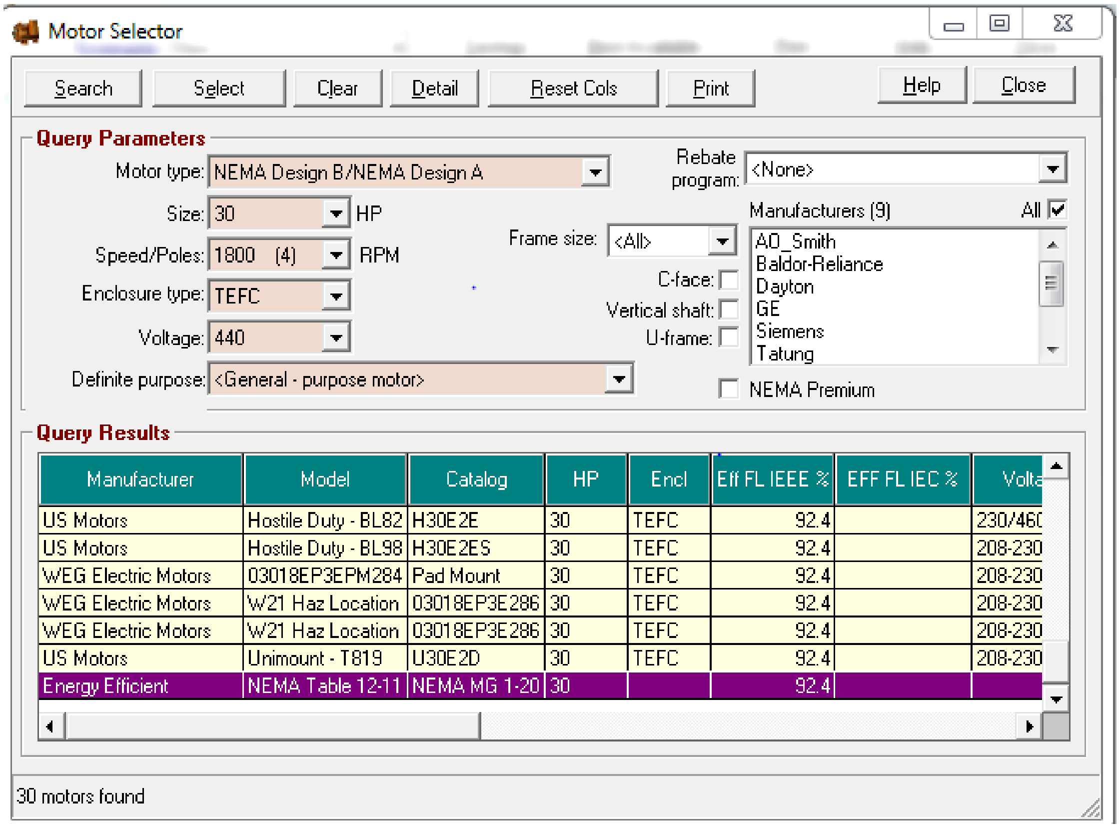
Table 3-18: Install High Efficiency Motors in Place of Lower Efficiency Motors

NO	Motor type	Quantity	DC(hp)	AC (hp)	% Load	V(A)	I(A)	PF	E_o(%)	E_n (%)	S ($)	Unit cost($)	Investment cost ($)	SPP(year)

1	Feed water pump	6	4.103	3.73	90.9	380	8.94	0.85	61.2	89.5	1543.3	387	2434	1.58
2	Submersible pump	3	0.9	0.73	81.1	380	1.75	0.85	68.6	93	113.6	114	442	3.89
3	Centrifugal pump	8	5.6	4.63	82.7	400	10.93	0.82	62.42	80.5	1959.4	615	5032	2.57
4	Exhaust fan(finishing)	2	5	4.65	93	400	11.18	0.80	59.9	92	677.2	598	1296	1.9
5	Exhaust fan(weaving)	3	30	21.8	72.7	400	49.6	0.85	76.59	94.5	2704.3	1285	3949	1.46
6	Fan motor(spinning)	7	2.2	1.9	86.4	380	4.35	0.89	64.41	92.3	878.4	376	2,692	3.06
7	Dust collector fan motor(spinning)	1	41.03	27.38	66.7	400	62.3	0.85	80.4	96.5	1035.7	1765	3,525	3.4

3.11 Analyzing Electric Motors of Almeda Textile PLC with International Motor Selection and Savings Analysis (IMSSA) software

Almeda textile industry uses different electric motors. For example, in the spinning department, the electrical machines consume more than 75% of electrical energy as stated in chapter three figs 3.4. By replacing the less efficient motor with high efficient motors, we can save more electrical energy. The Motor Master+ International Software is used in this work to evaluate the performance of the existing motors with the new energy efficient motors. The loading, efficiency, nameplate speed (RPM), voltage rating (V) and power rating (kW) are the inputs of the software which are taken from the existing motors at Almeda and the specifications for the energy efficient motors are taken from the Motor master + international software catalogue. So the software displays energy, demand savings, money savings and a simple payback period. For example replacement of 30HP cooling water pump motor with 20 HP small head pump motor having the same speed the following outcome should exist using the International Motor Master Software the following outcome will be obtained from the software catalogues.



Query Parameters

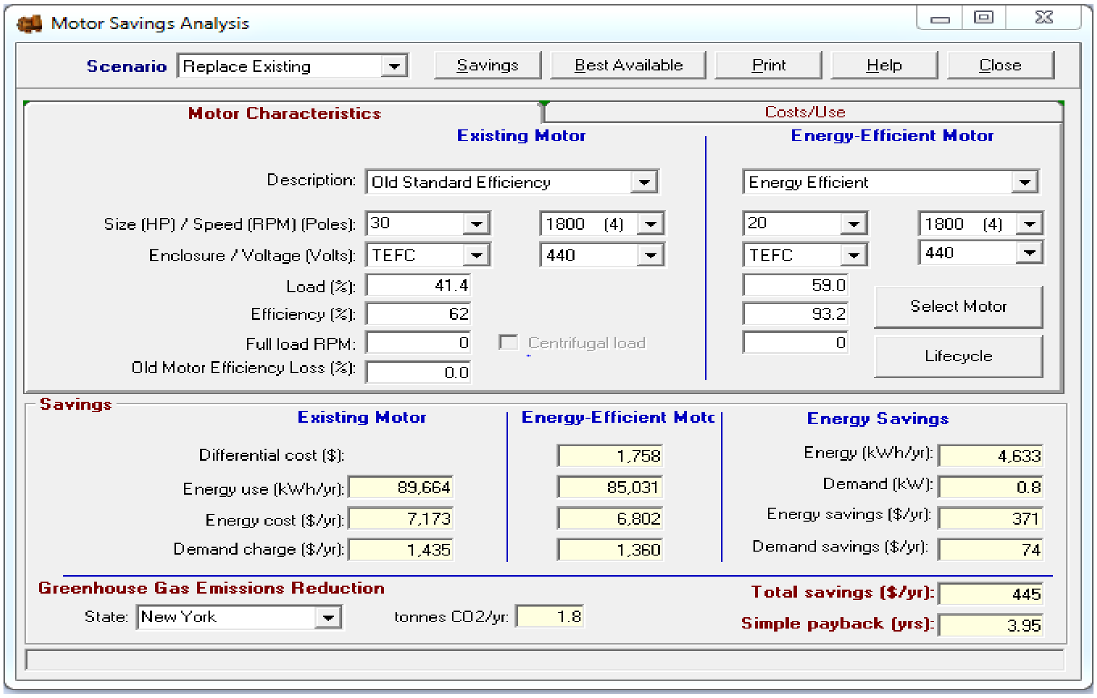
Motor type: NEMA Design B/NEMA Design A
Size: 30 HP
Speed/Poles: 1800 (4) RPM
Enclosure type: TEFC
Voltage: 440
Definite purpose: <General - purpose motor>
Rebate program: <None>
Frame size: <All>
C-face: ☐
Vertical shaft: ☐
U-frame: ☐
Manufacturers (9) All ☑
AO_Smith
Baldor-Reliance
Dayton
GE
Siemens
Tatung
☐ NEMA Premium

Query Results

Manufacturer	Model	Catalog	HP	Encl	Eff FL IEEE %	EFF FL IEC %	Volta
US Motors	Hostile Duty - BL82	H30E2E	30	TEFC	92.4		230/460
US Motors	Hostile Duty - BL98	H30E2ES	30	TEFC	92.4		208-230
WEG Electric Motors	03018EP3EPM284	Pad Mount	30	TEFC	92.4		208-230
WEG Electric Motors	W21 Haz Location	03018EP3E286	30	TEFC	92.4		208-230
WEG Electric Motors	W21 Haz Location	03018EP3E286	30	TEFC	92.4		208-230
US Motors	Unimount - T819	U30E2D	30	TEFC	92.4		208-230
Energy Efficient	NEMA Table 12-11	NEMA MG 1-20	30		92.4		

30 motors found

Figure 3-5: Energy efficient motor selection



Scenario: Replace Existing

Motor Characteristics | Costs/Use

	Existing Motor		Energy-Efficient Motor	
Description:	Old Standard Efficiency		Energy Efficient	
Size (HP) / Speed (RPM) (Poles):	30	1800 (4)	20	1800 (4)
Enclosure / Voltage (Volts):	TEFC	440	TEFC	440
Load (%):	41.4		59.0	
Efficiency (%):	62		93.2	
Full load RPM:	0	☐ Centrifugal load	0	
Old Motor Efficiency Loss (%):	0.0			

Savings

	Existing Motor	Energy-Efficient Motc
Differential cost ($):		1,758
Energy use (kWh/yr):	89,664	85,031
Energy cost ($/yr):	7,173	6,802
Demand charge ($/yr):	1,435	1,360

Energy Savings

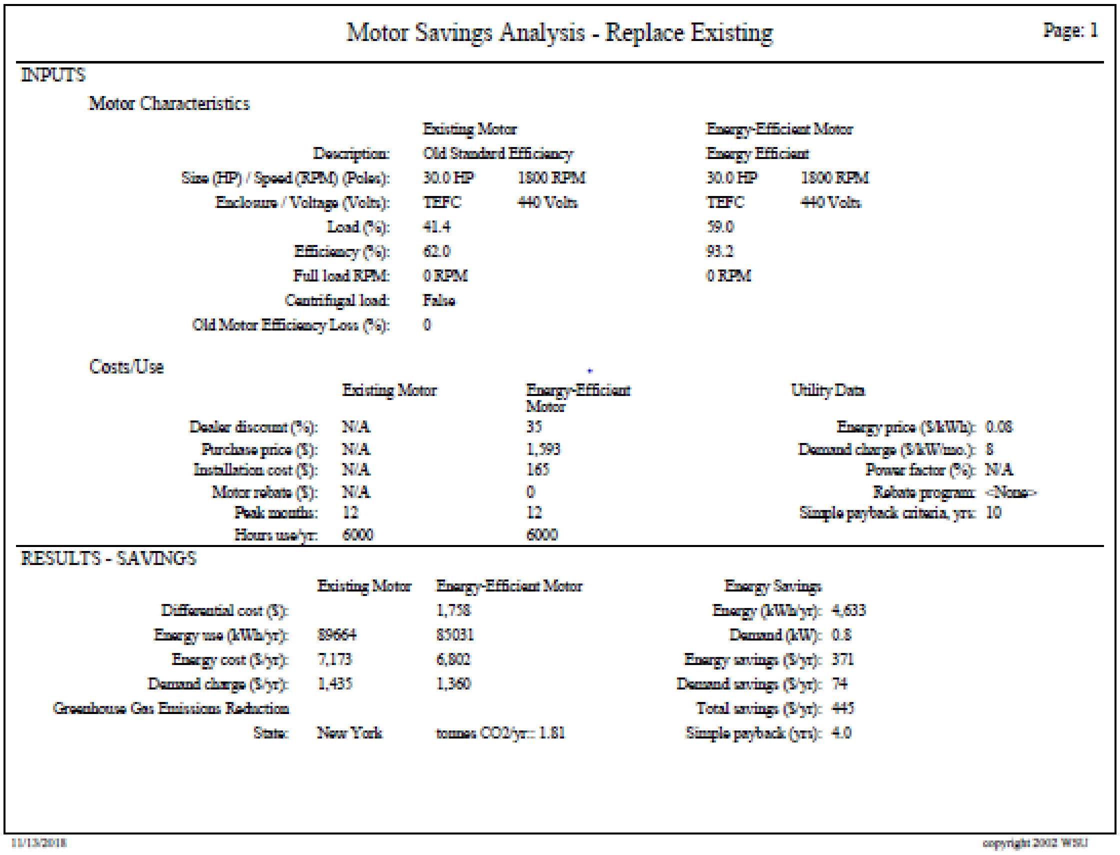
Energy (kWh/yr): 4,633
Demand (kW): 0.8
Energy savings ($/yr): 371
Demand savings ($/yr): 74

Greenhouse Gas Emissions Reduction

State: New York
tonnes CO2/yr: 1.8

Total savings ($/yr): 445
Simple payback (yrs): 3.95

Figure 3-6: Motor saving analysis



Motor Savings Analysis - Replace Existing

Page: 1

INPUTS

Motor Characteristics

	Existing Motor		Energy-Efficient Motor	
Description:	Old Standard Efficiency		Energy Efficient	
Size (HP) / Speed (RPM) (Poles):	30.0 HP	1800 RPM	30.0 HP	1800 RPM
Enclosure / Voltage (Volts):	TEFC	440 Volts	TEFC	440 Volts
Load (%):	41.4		59.0	
Efficiency (%):	62.0		93.2	
Full load RPM:	0 RPM		0 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	Energy-Efficient Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price ($/kWh):	0.08
Purchase price ($):	N/A	1,593	Demand charge ($/kW/mo.):	8
Installation cost ($):	N/A	165	Power factor (%):	N/A
Motor rebate ($):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	10
Hours use/yr:	6000	6000		

RESULTS - SAVINGS

	Existing Motor	Energy-Efficient Motor	Energy Savings	
Differential cost ($):		1,758	Energy (kWh/yr):	4,633
Energy use (kWh/yr):	89664	85031	Demand (kW):	0.8
Energy cost ($/yr):	7,173	6,802	Energy savings ($/yr):	371
Demand charge ($/yr):	1,435	1,360	Demand savings ($/yr):	74
Greenhouse Gas Emissions Reduction			Total savings ($/yr):	445
State:	New York	tonnes CO2/yr:: 1.81	Simple payback (yrs):	4.0

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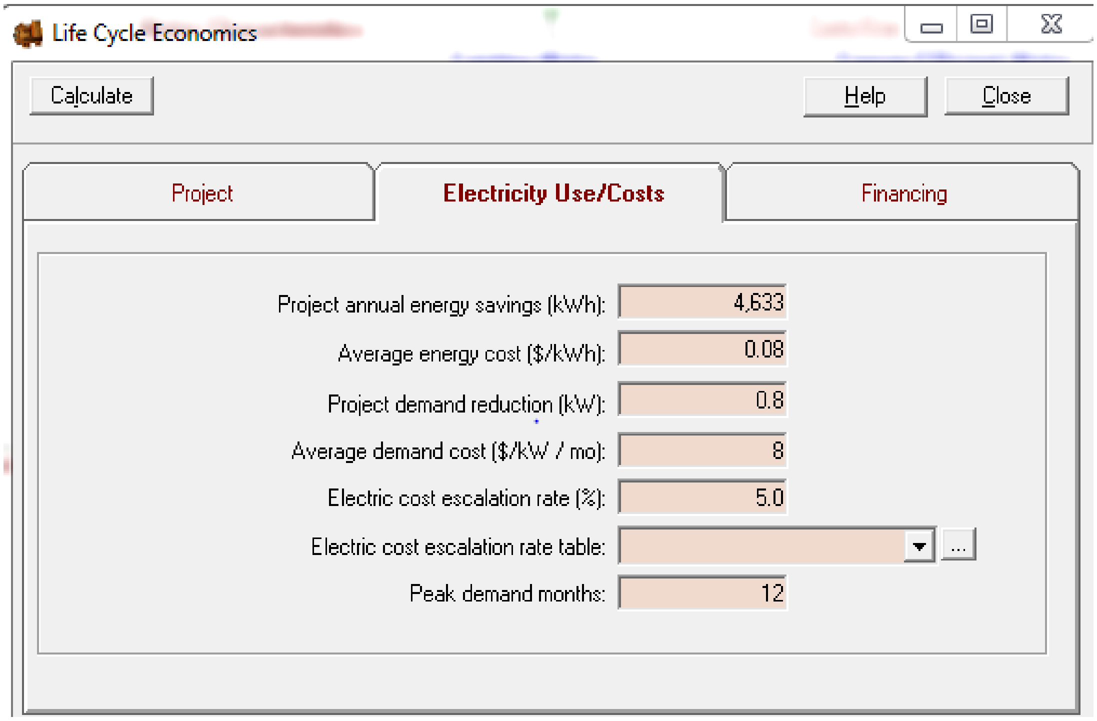
Figure 3-7: Summary of Motor saving analysis



Project annual energy savings (kWh):	4,633
Average energy cost ($/kWh):	0.08
Project demand reduction (kW):	0.8
Average demand cost ($/kW / mo):	8
Electric cost escalation rate (%):	5.0
Electric cost escalation rate table:	
Peak demand months:	12

Figure 3-8: Utility Costs/Use Data

CHAPTER FOUR

HARMONIC MODELING AND SIMULATION IN DISTRIBUTION NETWORKS

4.1 Power Quality and Harmonics Analysis

One of the many aspects of power quality is the harmonic content of voltages and currents. Harmonics are electric voltages and currents on an electric power system that can cause power quality problems.

4.2 Causes of Harmonics

Harmonics are created by electronic equipment with nonlinear loads drawing in current in abrupt short pulses. The short pulses cause distorted current waveforms, which in turn cause harmonic currents to flow back into other parts of the power system. Computers, laser printers, fax machines, copiers, or medical test equipment, fluorescent lighting, uninterruptible power supplies (UPS), and variable speed drives are the most sources of Harmonics in electrical system. Overheating of transformers, equipment and conductors, increased associated losses, fuse blow, machine stop and magnetic contactor failure, over loading neutral conductors, misfiring in variable speed drives and nuisance tripping of circuit breakers are basic problems caused by harmonics in a power system [21].

Voltage and current harmonics are the two types of harmonics. Those harmonics in an electric power system are a result of non-linear electric loads.

- **Current harmonics**: Are caused by non-linear loads. When a non-linear load, such as a rectifier, is connected to the system, it draws a current that is not necessarily sinusoidal.
- **Voltage harmonics**: Are mostly caused by current harmonics. The voltage provided by the voltage source will be distorted by current harmonics due to source impedance. If the source impedance of the voltage source is small, current harmonics will cause only small voltage harmonics.
- **Total Harmonic Distortion (THD):**Is a measure of the effective value of the harmonic components of a distorted waveform. It’s the most common index to measure

waveform distortion and can be applied to current and voltage. It is defined as the summation of the effective value of the harmonic components in the distorted waveform relative to the fundamental component.[22]

$$\mathbf{THD}_v\% = \frac{\sqrt{\sum_{h=2}^{\infty} u_h^2}}{u_1} * 100 \quad \mathbf{THD}_I\% = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} * 100$$

- **The Total Demand Distortion(TDD):** Is defined as the square root of the sum of the squares of the RMS value of the currents from $2^{nd}$to the h^{th} harmonics divided by the peak demand load current and expressed in percentage.

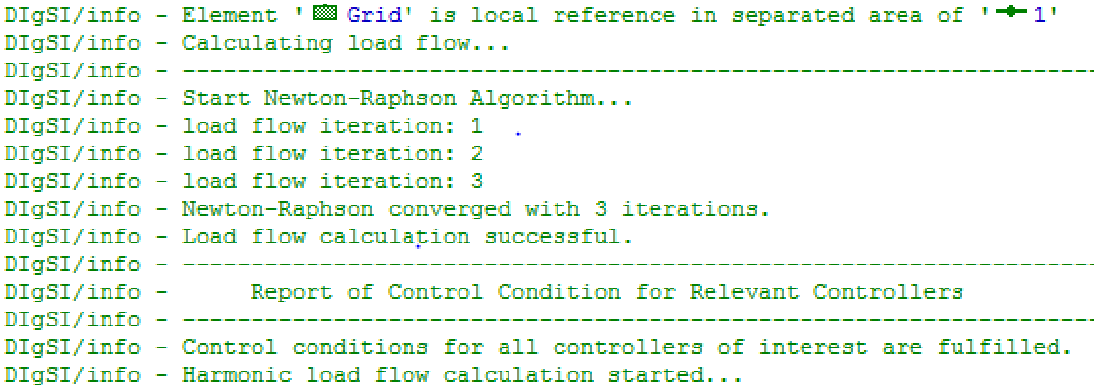
$$\text{TDD} = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_L}$$

Table 4-1:TypicalComponents Data That is Needed for Distribution System Harmonic Modeling Study is Summarized in Table Below.

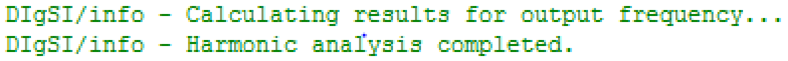
Device	Data Needed
Transformer	Turns ratio, short-circuit impedance, connection configuration (wye, grd wye, or delta)
Capacitor bank	Voltage rating, Var rating, configuration (wye, grd wye, or delta)
Tuned Filter	Tuned frequency, volt, Var rating, configuration
Generator/large motor	Sub-transient impedance, configuration
non-linear Load	Expected level of harmonic current injection, magnitude and phase angle
Linear Load	Watts, Varrating, power factor
Overhead lines, cables	Conductor size, length, or short circuit impedances

4.3 Assessment of Harmonics in Almeda Textile Factory

Three transformers are selected for the purpose of simulation technique to analyze and investigate harmonics, two transformers in the spinning and weaving departments and one in substation transformer. The HV terminal of the transformer is considered as the point of common coupling (PCC) between the customer and Electric utility. Since, there are different large number of single phase non-linear loads and linear loads feed by those two transformer such as computers, copier, fluorescent lamps, HVAC and induction motors.



```
DIgSI/info - Element '▦ Grid' is local reference in separated area of '─┼─1'
DIgSI/info - Calculating load flow...
DIgSI/info - -------------------------------------------------------------------
DIgSI/info - Start Newton-Raphson Algorithm...
DIgSI/info - load flow iteration: 1
DIgSI/info - load flow iteration: 2
DIgSI/info - load flow iteration: 3
DIgSI/info - Newton-Raphson converged with 3 iterations.
DIgSI/info - Load flow calculation successful.
DIgSI/info - -------------------------------------------------------------------
DIgSI/info -      Report of Control Condition for Relevant Controllers
DIgSI/info - -------------------------------------------------------------------
DIgSI/info - Control conditions for all controllers of interest are fulfilled.
DIgSI/info - Harmonic load flow calculation started...
```



```
DIgSI/info - Calculating results for output frequency...
DIgSI/info - Harmonic analysis completed.
```

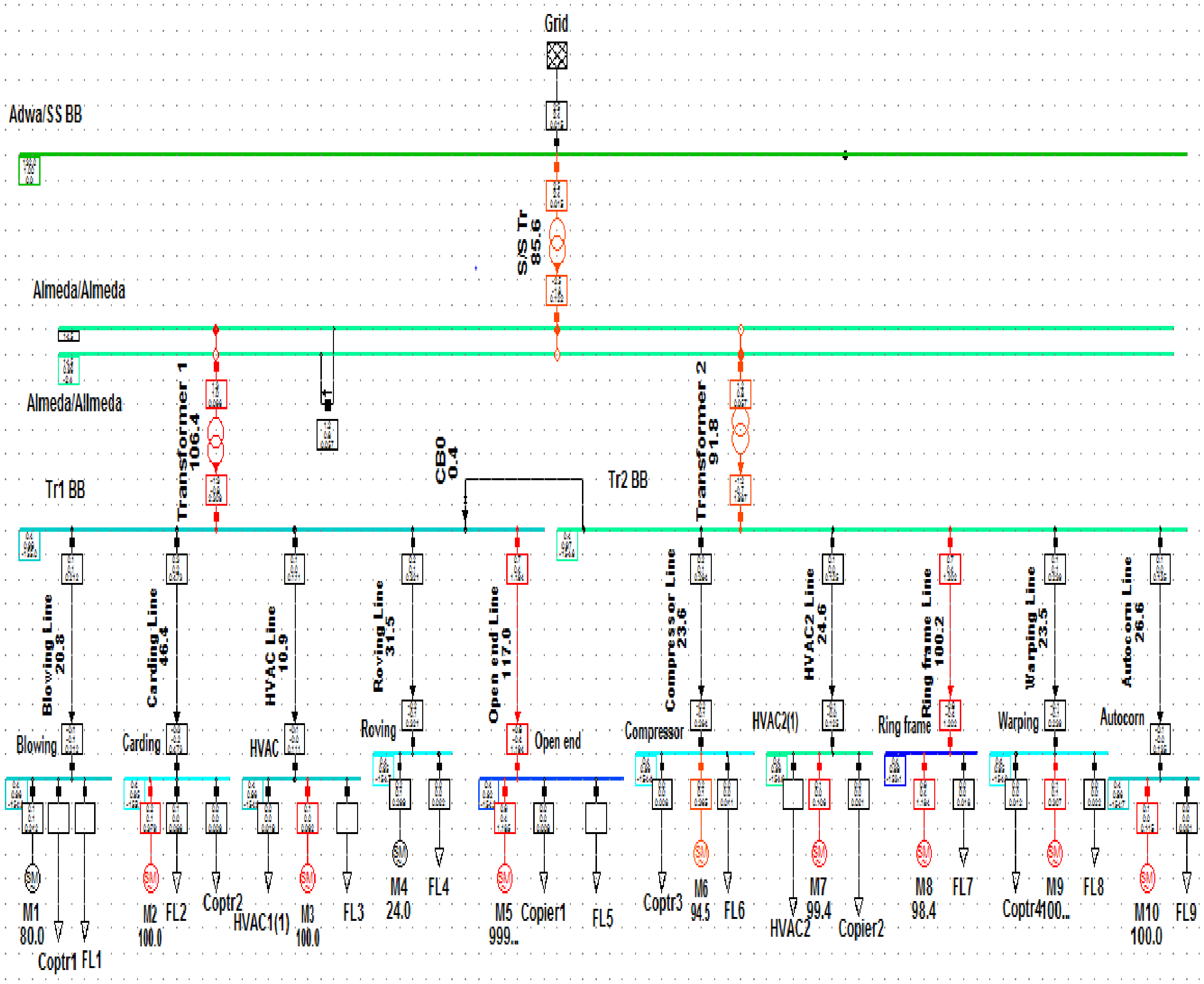


Figure 4-1: One-Line Diagram of Facilities Connected to T1 AndT2

Table 4-2:Network Parameters of Systems Connected to T1 and T2

	Transformer	
	T1	T2
External network lumped impedance	MVAsc = 29.1X/R = 10	MVAsc = 29.1X/R = 10
Specification of Transformers	1^0 Voltage = 15 kV 2^0 Voltage = 0.4 kV Apparent Power = 1600 kVA Short-circuit impedance = 5.5 %	1^0 Voltage = 15 kV 2^0 Voltage = 0.4 KV Apparent Power = 1600 kVA Short-circuit impedance = 5.5 %

The short circuit MVAsc are calculated from the Transformers kVA and short-circuit impedances. To evaluate the harmonic level with the IEEE standards, first the short-circuit ratio, ISC /IL must be evaluated. IL is the maximum demand at the PCC. The maximum short circuit current at the PCC is given [23].

$$I_{SC} = \frac{Irated}{\%\ impedance} = \frac{\frac{kVA}{\sqrt{3}*V}}{\%Z} \text{--} \text{eqn (4.0)}$$

Where: I_{SC} is the Maximum Short circuit current, I_{rated} is the rated current, kVA is the capacity of transformer, V is the rated of secondary voltage and Z is the percent of impedance. The X/R ratio is taken to be 10 which is a typical value for distribution systems. The collected loads prepared for input of the software are shown in table 4.3 below: The system is assumed to be balanced. The power factors are typical values commonly used as suggested in [35] for computer (P.F = 0.65) and [36] for fluorescent lamp (P.F = 0.9) and fan (P.F = 0.7)

Table 4-3: Load Types and Sizes Supplied by T1 andT2

Section	Load Type	Active Power(KW)	Power factor
Blowing	FL1	4.57	0.9
	Induction Motor(M1)	120	0.85
	Cptr1	4.54	0.65
Carding	FL2	5.64	0.9
	Induction Motor(M2)	213	0.85
	Cptr2	4.08	0.65
HVAC1	FL3	8.15	0.9
	HVAC1	12.5	0.7
	Induction Motor (M3)	52	0.85
Roving	FL4	14.48	0.9
	Induction Motor(M4)	168	0.9
Open end	FL5	15.44	0.9
	Copier1	4.4	0.65
	Induction Motor (M5)	640	0.85
Compressor	FL3	7.2	0.9
	Induction Motor(M6)	158	0.85
	Cptr3	3.94	0.65
HVAC2	Induction Motor(M7)	60	0.9
	HVAC2	24.2	0.7
	Copier 2	9.6	0.65
Ring Frame	FL7	12.9	0.9
	Induction Motor(M8)	620	0.9
Warping	FL8	14.08	0.9
	Induction Motor(M9)	116	0.85

	Cptr4	5.6	0.65
Auto corn	FL9	13.4	0.9
	Induction Motor(M10)	65	0.85

4.4 Harmonic Spectrum Data for the Non-linear loads

In this paper the harmonic spectrum data for the non-linear loads is obtained from published data of previous similar researches and typical data obtained from published books. This section presents the values of the harmonic spectrum data for each non-linear load. The recommends values of harmonic spectrum data for a large number of single phase computer loads are shown below which taken from the thesis paper writhe by **A. Mansoor *et al.*** [24].

Table 4-4: Estimates of Net Harmonic Current Injection Levels for Large Numbers of Distributed single phase Computer Load.

Harmonic	% of Fundamental Current
I_3	81
I_5	53
I_7	25
I_9	9
I_{11}	5
I_{13}	4
I_{15}	3

Table 4-5: Typical Harmonic Spectrum Data of Non-Linear Devices [25]

Typical Harmonic Spectrum in percent of fundamental							
h	Fluorescent Lamp	Transformer (saturated)	Computer	Printer/copier	HVAC	Welding machine	Fridge
1	100	100	100	100	100	100	100
3	15.8	50	81	9.39	22.52	71	10
5	8.6	20	53	6.49	15.25	36.8	5.1
7	2.9	5.0	25	3.82	1.86	10.5	0.5
9	2	2.6	9	0	0	2.6	1.0

11	1.4	0	5	1.93	1.9	1.05	0.4
13	0.8	0	4	1.37	0.92	0	0.2
15	0.4	0	3	0	0	0	0.2
17	0.2	0	1	1.52	0.71	0	0.1
19	0.5	0	0	0.75	0.46	0	0
21	0.4	0	0	0	0	0	0
23	0.2	0	0	0.43	0.53	0	0
25	0	0	0	0.35	0.22	0	0

4.5 Components Modeling in Dig SILENT Power Factory

- **Transformers:** The **DIgSILENT Power Factory** requires nameplate values (rated power, primary and secondary voltage, rated no-load and load loss, short circuit impedance and transformer ratio) to be inserted for transformers. So further calculation is not needed as the software internally calculates the parameters.
- **Cables:** The cables are modeled by pi-circuit equivalent representation using lumped parameters. DIgSILENT Power Factory incorporates the automatic calculation of the electrical parameters of any cable/overhead line configuration starting from the layout and geometric characteristics which are typically available in the manufacture’s Datasheets.
- **Linear Loads:** Are modeled as a constant impedance model. The value of active power, reactive power, nominal apparent power, nominal voltage and power factor is inserted to the DIgSILENT software from the nameplate of the linear loads.
- **Non-Linear Loads:** Are modeled as constant harmonic sources in the form of a harmonic current source, specified by its magnitude and phase spectrum. The harmonic spectrum data and power quality parameters of the non-linear load are fed into the model.

4.6 Harmonic Mitigation Techniques Using Harmonic Filters

Passive and active filters are the two types of filters used for filtering the harmonic distortions.

- **Active filters:** This type of filter is an analog electronic filter, distinguished by the use of one or more active components, i.e. voltage amplifiers/ buffers, operational amplifiers and transistors. This requires external power source.

- **Passive Filters:** These filters include RLC elements configured and tuned to serve the purpose of harmonics control and compensating power factor to the desired level. Passive filters are applied either to shunt the harmonic currents off the line or to block their flow between parts of the system by tuning the elements to create a resonance at a selected harmonic frequency. The common passive filter configurations are Single tuned, 1st order high-pass, 2nd order high-pass, and 3rd order high-pass filters [26]. The different topologies for these filters are shown in the figure below:

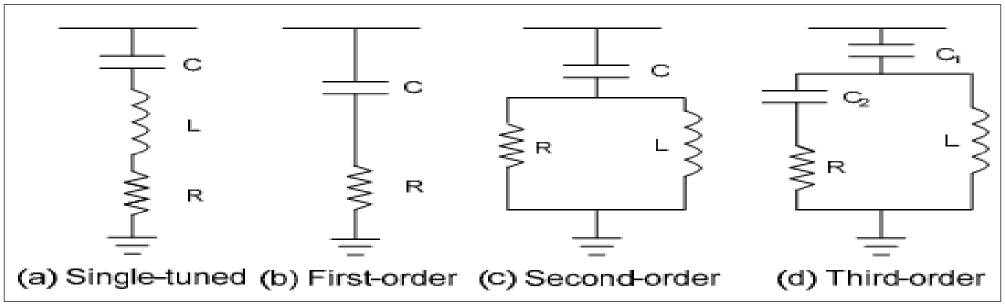


Figure 4-2: Topologies of Shunt Passive Filter [26]

There are many advantages of Passive filter overactive filter. From these, they are easy to design, Guaranteed stability, no power consumption and they are relatively cheaper than other methods of harmonic elimination. But, the disadvantage of passive filter after active filter is bulky in size. Single-tuned passive filters offer reasonable mitigation for harmonic distortion at a specific harmonic frequency with a high filtering percentage. Single tuned filter considered as the most reliable and economical tool for power factor improvement and harmonic suppression.For a wide range of generating harmonics multiple single-tuned filters are designed to eliminate multiple harmonics, as illustrated below in the figure below [27].

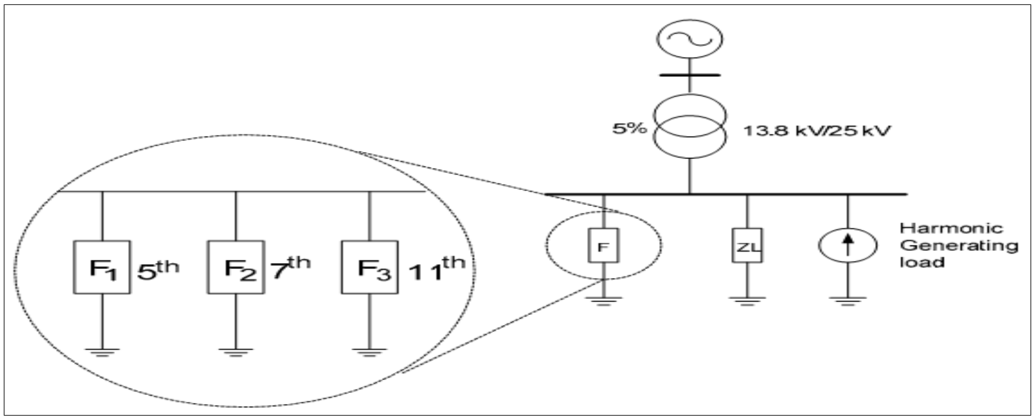


Figure 4-3: Three branch filter [27]

For designing of single –tuned filter different formulas are used as shown below [28].

1. **Select capacitor bank needed to improve the P.F from the present level typically to around 0.92 or higher.** The capacitive reactance needed to compensate the needed VARs to improve the power factor from $P.F_1$ (associated with Θ_1) to $P.F_2$ (associated with Θ_2) is given by:

$Q_{com} = P\,(\tan(\Theta_2) - \tan(\Theta_1))$--- eqn (4.1)

Where, P is the active power and Q_{com} is the reactive power needed for compensation.

The capacitance for a single filter can be sent to:

$Q_f = Q_{com}$---eqn (4.2)

For a multiple parallel single-tuned filter system, the capacitance corresponding to the h^{th} harmonic can be distributed by:

$Q_{fh} = Q_{com} * \frac{Ih}{I2+I3+\cdots.}$,h =2,3---eqn (4.3)

Where, I_h- is the h^{th} harmonic current , Q_{fh} , is the capacity of the h^{th} harmonic filter. Also, the filter capacity Q_{fh} contains the capacity of capacitance (Q_C) and capacity of inductor (Q_L).

$Q_C = Q_{fh} * \frac{h^2}{h^2-1}$---eqn (4.4)

$Q_L = Q_c - Q_{fh}$--eqn (4.5)

$Q_L = \frac{Qc}{h^2}$---eqn (4.6)

2. **Choose reactor that, in series with capacitor, tunes filter to desired harmonic frequency.** The use of an inductor in series with a capacitor results in a voltage rise at the capacitor terminals given by:

$V_C = \frac{h^2}{h^2-1} * V_{sys}$--eqn (4.7)

Where: h = tuned impedance harmonic order of the frequency, V_{sys}= system line-to-line voltage, kV and V_C= capacitor line-to-line voltage, kV.

The Capacitive reactance required is obtained with the following relation

$X_{C1} = \frac{VC^2}{QC}$ --eqn (4.8)

At harmonic frequency h, this reactance is:

$C_h = \frac{XC1}{h}$ ……………………………………………………………...eqn (4.9)

And the inductive reactance its frequency of order h is given by:

$X_{Lh} = h * X_{L1}$--eqn (4.10)

At the resonant frequency the capacitive and reactive impedances are equal. Then the XL and XC are related by the following equation:

$X_L = \frac{XC}{h^2}$---eqn (4.11)

3. Determine whether capacitor-operating parameters fall within IEEE-182 maximum recommended limits. This may require a number of iterations until the desired reduction of harmonic levels is achieved. Capacitor Voltage: The rms and peak voltage of the capacitor must not exceed 110 and 120%, respectively of the rated voltage. They can be determined as follows.

$V_{C\ Peak} = \sqrt{2}\ (V_{c1} + V_{Ch})$---eqn (4.12)

$V_{crms} = \sqrt{2}\ (Vc1^2 + Vch^2)$---eqn (4.13)

Where, voltage through the capacitor at fundamental frequency is given by

$V_{C1} = X_{C1} * I_{C1}$---eqn (4.14)

Vch is found in terms of Ich, which must be determined from measurements or from a typical harmonic spectrum of the corresponding nonlinear load:

$V_{Ch} = X_{Ch} * I_{Ch}$--eqn (4.15)

I_{C1} is the current through the capacitor and it is calculated in terms of the maximum phase-to-neutral voltage, which in turn is specified 5% above the rated value, to account for voltage regulation practices.

$$I_{c1} = 1.05 * \left[\frac{\frac{V_{L-L}}{\sqrt{3}}}{X_{c1} - X_{L1}}\right]$$ ---eqn (4.16))

Current through the capacitor bank: The rms current through the capacitor bank must be within 135% of the rated capacitor current, to comply with IEEE-18. Its value is determined from the fundamental current and from the harmonic currents under consideration:

$$I_{crms} = \sqrt{(Ic1^2 + Ich^2)}$$ --eqn (4.17)

Determine the capacitor bank duty and verify that it is within recommended IEEE-18 limits.

$$K_{var} = \frac{Vcrms * Icrms}{1000}$$ ---eqn (4.18)

Where, Vcrms is the voltage through the capacitor and Icrms is the current through the capacitor. This value must be within 135%. The maximum recommended values are summarized in table given below.

Table 4-6: Maximum Recommended Limits for continuous Operation of shunt Capacitors under Contingency Conditions [28].

VAR	135%
RMS voltage	110%
Rated voltage, including harmonics	120%
RMS current	135%

If IEEE-18 is not met, the process may require more iteration to resizing the size of the capacitor bank for limiting harmonic and improving reactive compensation.

4.7 Simulating Software

DIgSILENT Power Factory Version 15.1[29]: The calculation program **Power Factory**, as written by **DIgSILENT**, is a computer aided engineering tool for the analysis of industrial utility and commercial electrical power system. The **DIgSILENT Power Factory** harmonic load flow features the calculation of harmonic voltage and current distributions based on defined harmonic sources and grid characteristics. It allows the modeling of any user-defined harmonic voltage or current source, both in magnitude and phase angle. DIgSILENT Power Factory calculates all harmonic indices for currents and voltages, as defined by relevant IEEE standards, including harmonic current indices and harmonic losses, such as: HD and THD, harmonic losses, active and reactive power at any frequency, total active and reactive power, power factor, RMS values and unbalance factors.

Results can be represented:

- In the single line diagram (total harmonic indices).
- As histograms (frequency domain).
- As waveform (transformation into the time domain).
- As profile (e.g. THD versus bus bars).

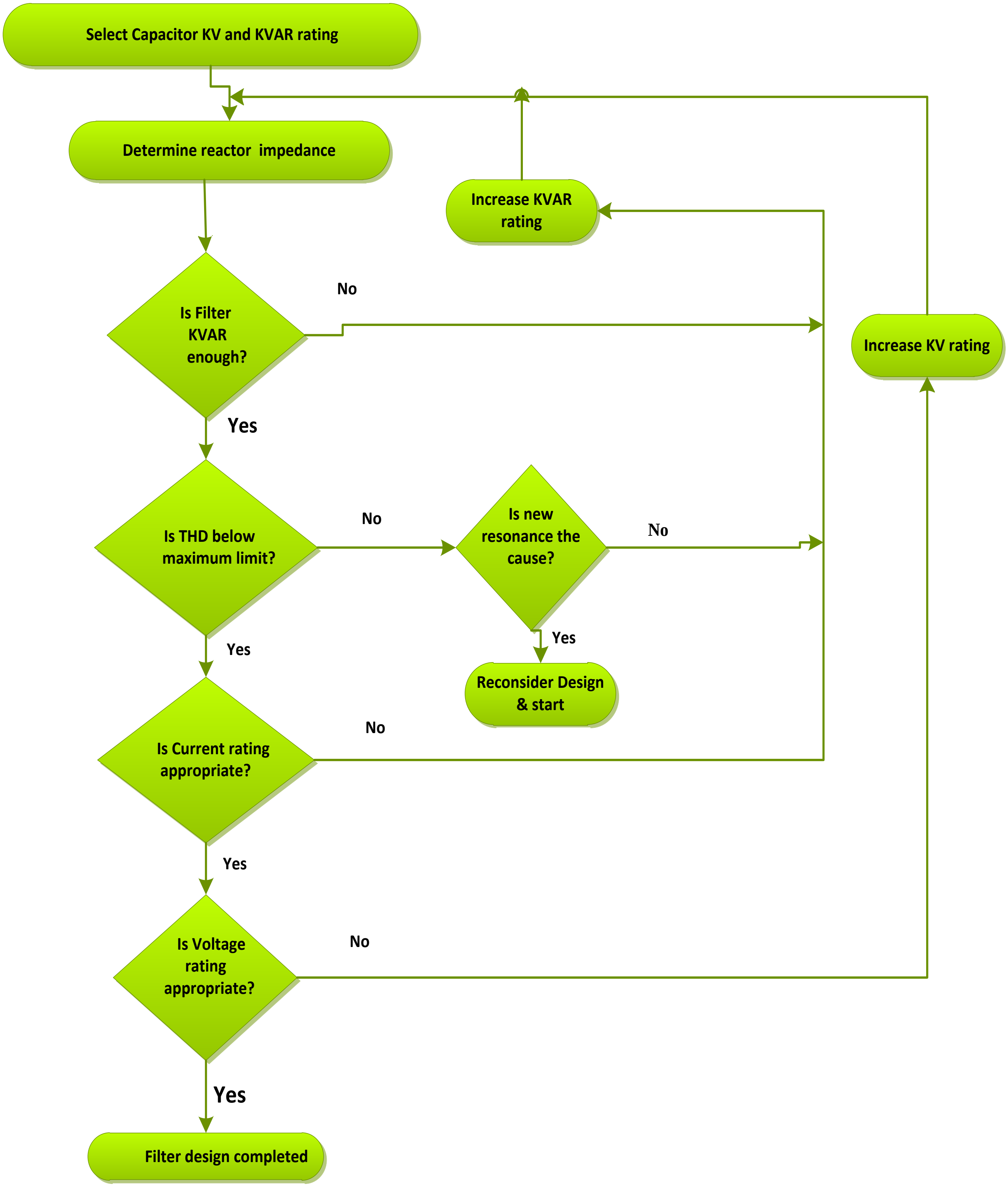


Figure 4-4: Decision flow chart for single-tuned filter [30]

CHAPTER FIVE

RESULTS, ANALYSIS AND DISCUSION

5.1 Computation of Energy Intensity of The Plant

Energy Intensity is measured by the quantity of energy required per unit output and it is a measure of the energy efficiency of the plant. The following graph shows the plot of the energy intensity of the Almeda Textile factory from year 2006 to 2008 E.C and the energy intensity of the selected Textile plants taken as a benchmark. Then, comparison of specific energy between Almeda textile factory and the plant used as a benchmark has been done.

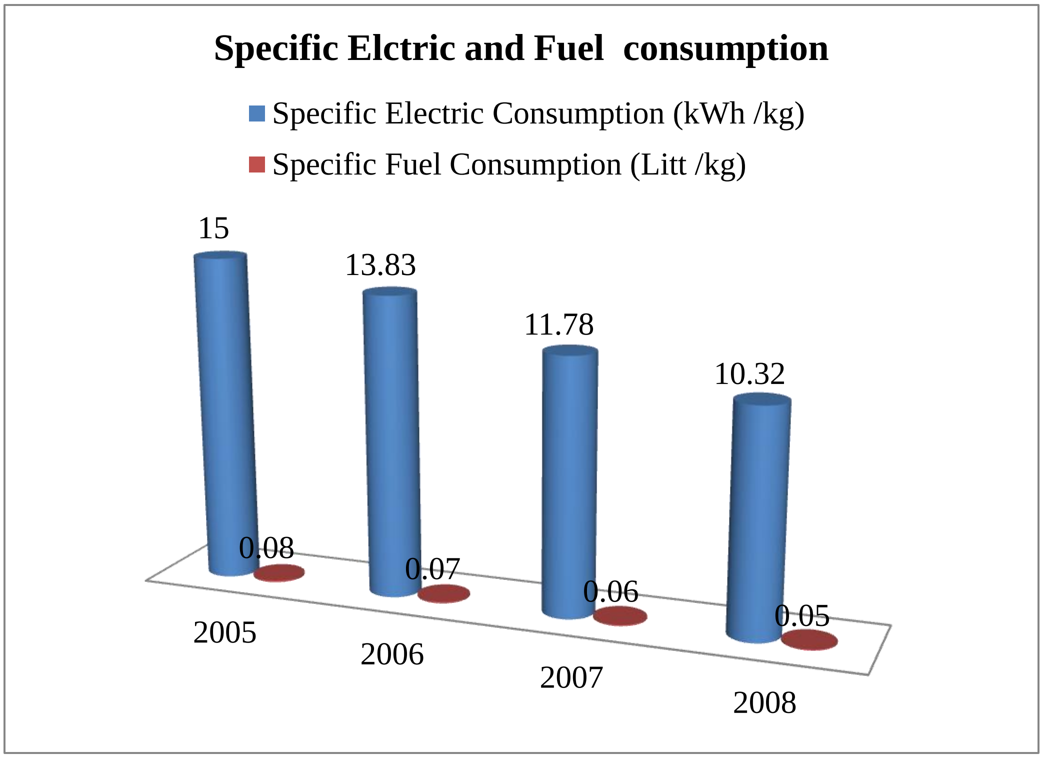


Fig 5-1: The Specified Energy of Almeda Textile Plant (2005- 2008 E.C)

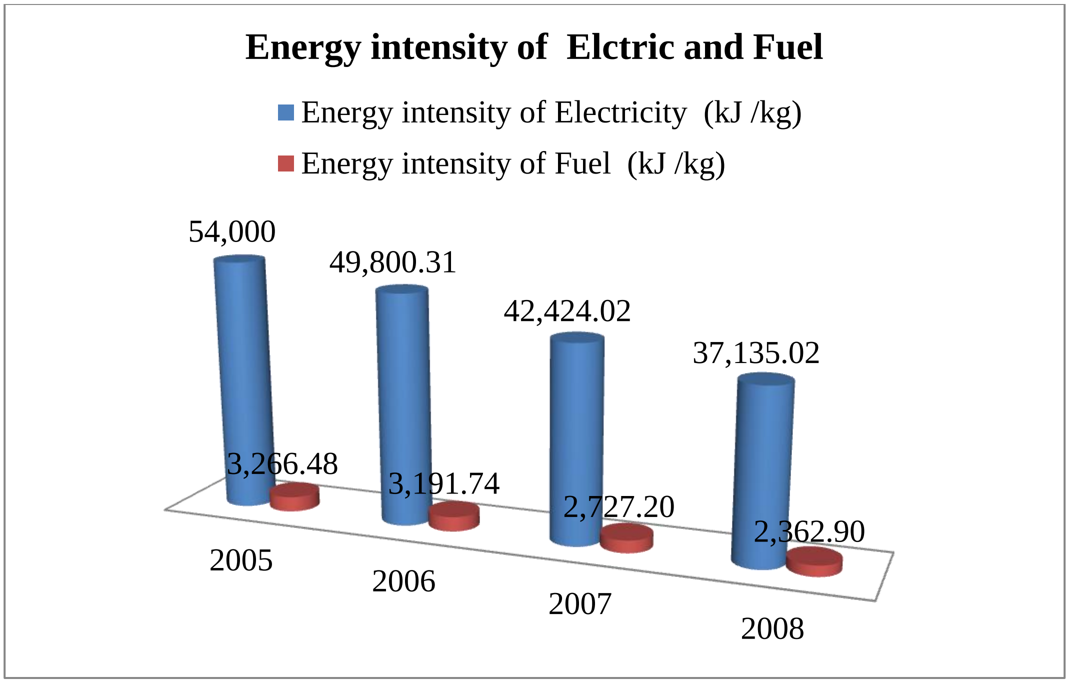


Fig 5-2: The Energy Intensity of Almeda Textile Plant (2005- 2008 E.C)

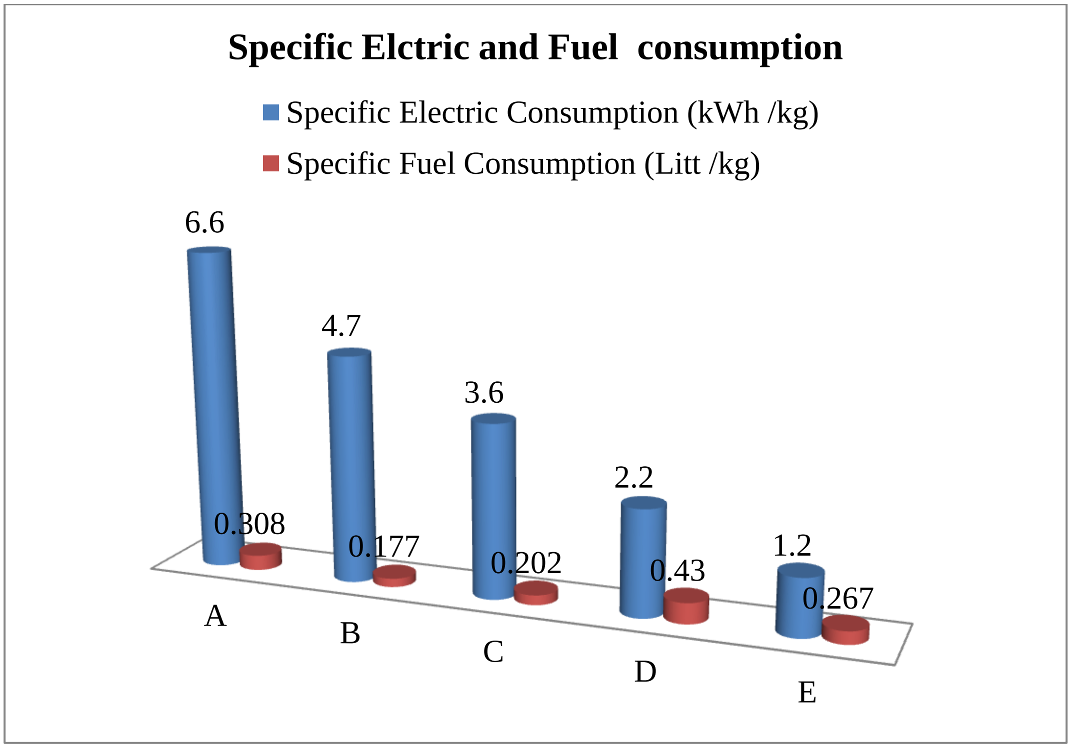


Fig 5-3: The Specific Electric and Fuel Consumption used as a benchmark (A, B, C & D Plant)

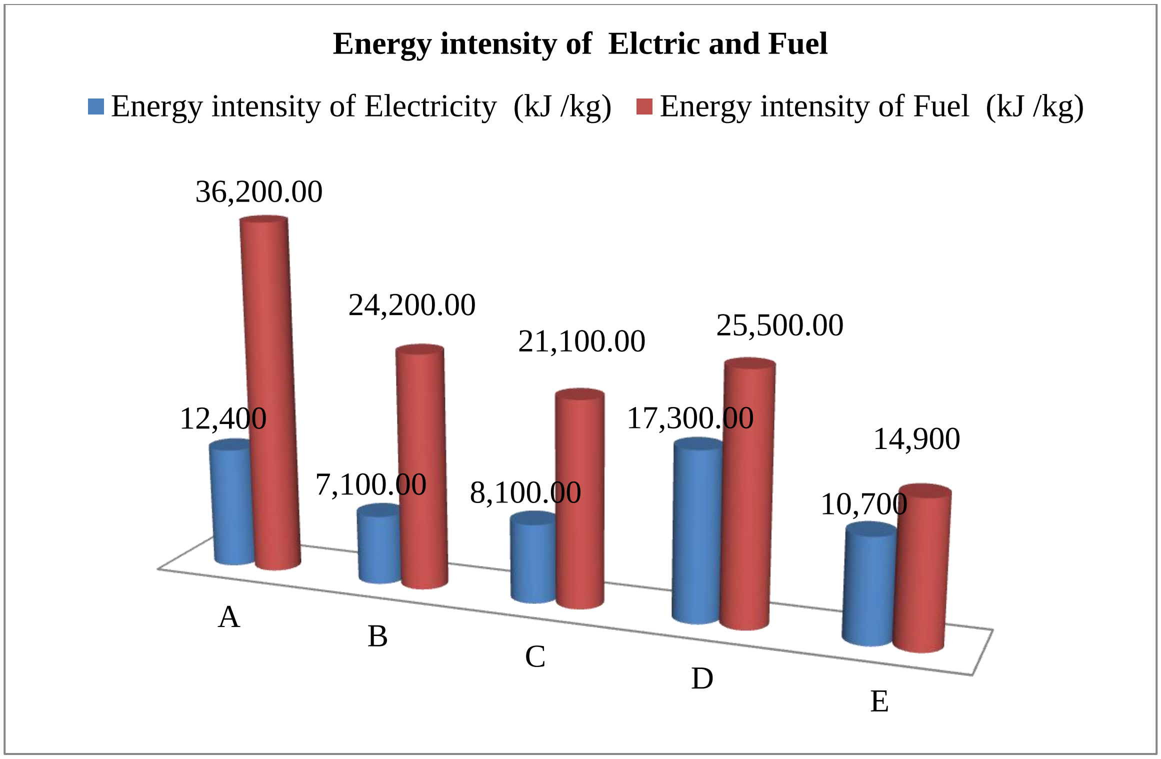


Fig 5-4: The Energy Intensity of Electricity and Fuel used as a benchmark (A, B, C & D Plant)

The Annual Electric energy intensity of Almeda textile PLC from 2005 to 2008E.C ranges from 10.32kW/kg to 15 kWh/kg for yarn and fabric production with an average energy intensity of 12.73kWh/kg. The total electric energy intensity of selected plant as a benchmark shown in Figure 5.2has an average energy intensity of 3.66 kWh/kg. Therefore, the difference in specific energy consumption of Almeda Textile PLC and the selected plant as benchmark is 9.07 kWh/kg. The fuel energy intensity from year 2005 to 2008E.C ranges between 2,362.9kJ/kg to 3,266.48 kJ/kg of yarn and fabric production with average intensity of 2,887.1kJ/kg. The Total fuel energy intensity of plants taken as benchmarks shown in Figure 5.2 gives an average energy intensity of 11,120 kJ/kg.

5.2 Explanation of the Result

From the analysis, there is a difference between the electric energy intensity of Almeda textile PLC and selected plant as a benchmark. Hence, the calculation for the inefficiency of electric energy intensity of Almeda textile factory is calculated below.

- ✓ Annual Average production of Yarn and fabric 2,088,773.5 kg per year.
- ✓ Cost of Electricity = 0.4086 birr per/kWh.
- ✓ Cost of Fuel oil = 16.26- 19 on average 17.63 birr/per lit.
- ✓ Specific Heat of Fuel Oil = 40,128kJ/lit.
- ✓ Difference in Electricity Energy Intensity = 9.07kWh/Kg

Annual cost due to inefficient use of electric energy intensity **=** Electric Consumption in kWh * Cost of Electricity

= Energy Intensity (kWh / kg) * Production (Kg) * Cost of Electricity (Birr / kWh) [31]

= 9.07 kWh/Kg * 2,088,773.5 kg * 0.015133 Birr/ kWh
= 286,703.66$ per year

5.3 Measured Data Analysis of The Transformers in The Textile Factory

Harmonic Current Distortion Limits Recommended in IEEE 519-1992: Institute of Electrical and Electronics Engineers (IEEE) has come out with standards and guidelines regarding harmonics. One of the standards, IEEE Standard 519-1992, provides comprehensive recommended guidelines for investigation, assessment and measurement of harmonics in power systems. The IEEE power quality standards of different power quality problems are given in the following table.

Table 5-1: current distortion limit for distribution systems (120V through 69kV) [32].

Current distortion limit for general distribution systems (120 V - 69000V)						
Max harmonic current distortion % IL						
Individual harmonic order (odd harmonics)						
ISC/IL	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1.0	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1.0	15
>1000	15	7	6	2.5	1.4	20

Where, h= harmonic order, ISC= maximum short circuit at the PCC, IL = maximum demand load current (fundamental frequency current at PCC and TDD is the total demand distortion.

Table 5-2:VoltageDistortionLimits [33]

Bus Voltage at PCC	Individual Voltage Distortion	Total Voltage Distortion
69kV and below	3.0	5.0
69.001kV through 161kV	1.5	2.5
161.001kV and above	1.0	1.5

Table 5-3: The IEEE Power Quality Standards of Different Power Quality Problems [34]

Problem Category	**Standard**
Voltage – Sag	0.1-0.9 pu
Voltage – Swell	1.1-1.8 pu
Under voltage	0.8-0.9 pu
Overvoltage	1.1-1.2 pu
Voltage Unbalance	<3%
Dc Offset	0-0.1%
Harmonics (THD V)	<5%
Harmonics (THD I)	<10%
Power Factor	0.85 -1
Power Frequency Variation	50 ±1%
Current unbalance	<10%

In this thesis first of all analysis of the harmonic levels of current and voltage was conducted. If it’s result is above the IEEE Power Quality Standards a passive filter can designed to reduce the unwanted harmonic level of current and voltages till become the standard values.

5.4 Simulation Results of the factory

This chapter discusses and analyses the simulation results obtained from simulation of the selected Two transformers T1 and T2, which are working in parallel to serve the loads and also for substation transformer. The selected transformers serves a wide range of linear loads and non-linear loads such as, motors, HVAC's, computers, copier machines and Fluorescent lights. The purpose of the simulation is to investigate the extent harmonic distortion levels.

5.5.1 Simulation Results of T1 and T2

The values of harmonic currents and voltages at the primary of the transformer obtained from simulation are given in the tables below. The waveform of Currents and voltages are also given.

Table 5-4: Harmonic Currents at each Harmonic order for T1

Harmonic order	1	5	7	11	13	17	19	23	25	THD%
Harmonic current, %	100	0.281	25.477	0.001	1.306	0.001	0.808	0.001	0.001	25.5
Harmonic Current, A	65.66	0.185	16.73	0.01	0.858	0.01	0.531	0.01	0.01	25.5

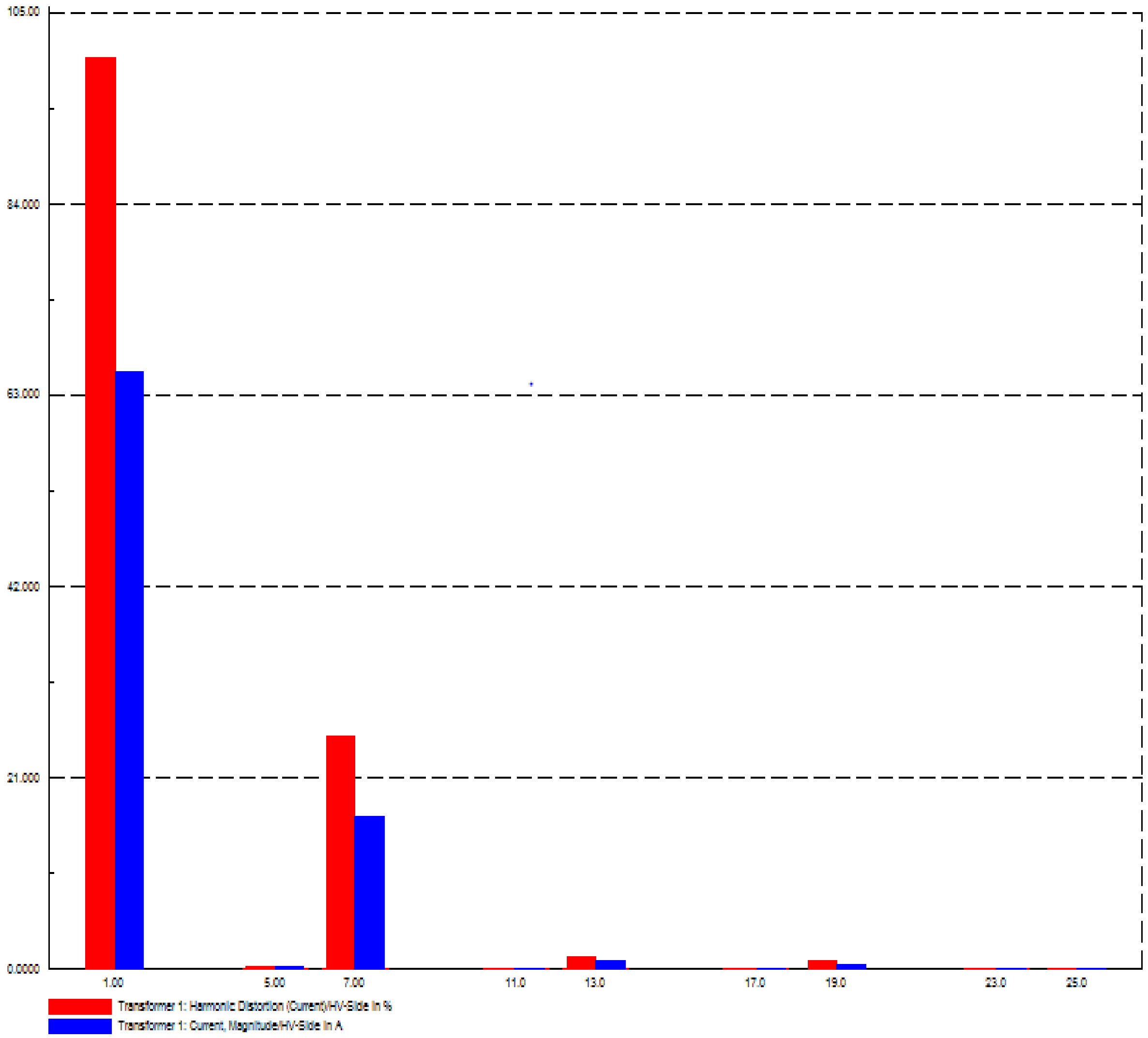


Fig 5-5: Harmonic Current distortion, % (1^{st}) and Harmonic Current Magnitude, A (2^{nd}) of T1 with THD_I 25.5%

Table5-5: Harmonic Currents at each Harmonic order for T2

Harmonic order	1	5	7	11	13	17	19	23	25	THD
Harmonic current, %	100	0.34	21.381	0.001	1.303	0.001	0.919	0.001	0.001	21.4
Harmonic Current, A	56.529	0.192	12.087	0.001	0.737	0.001	0.519	0.001	0.001	21.4

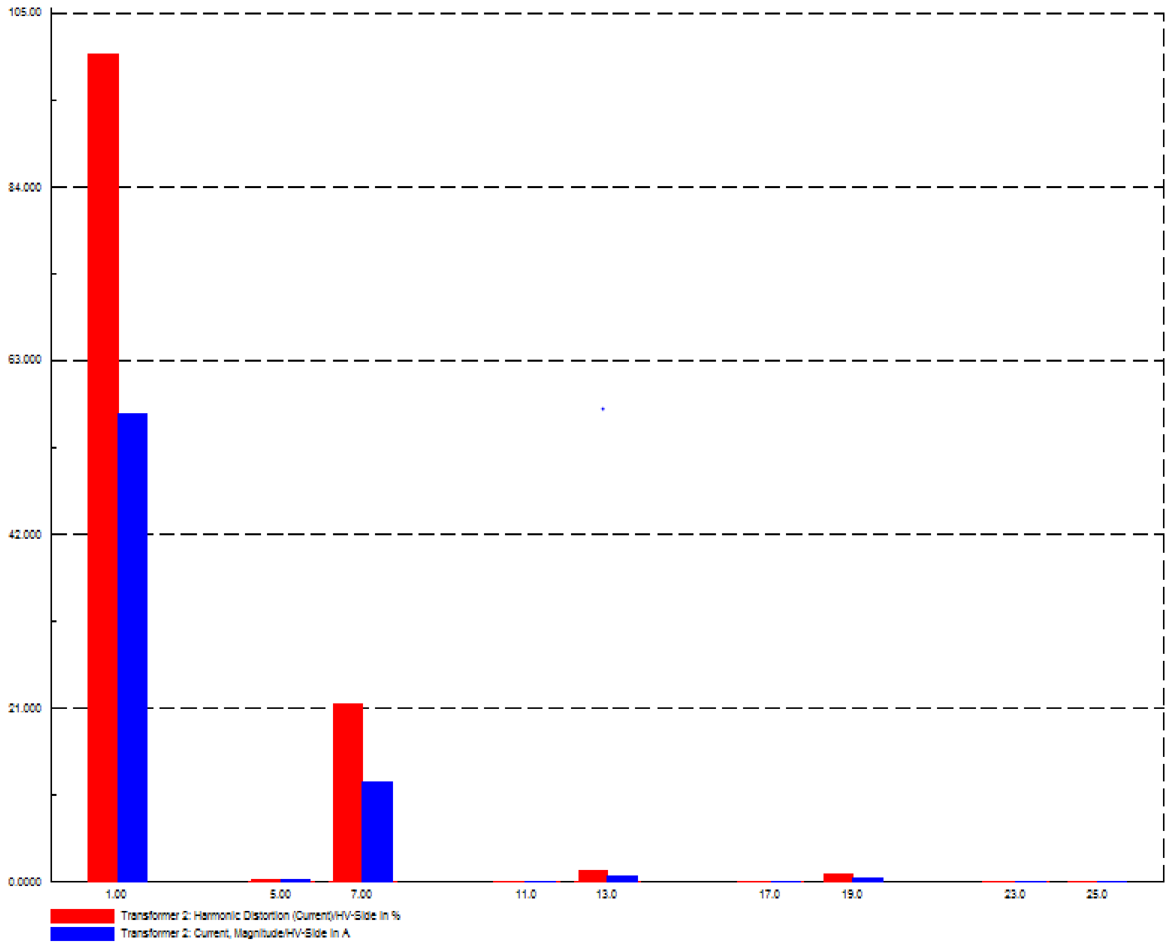


Fig 5-6: Harmonic Current distortion, % (1^{st}) and Harmonic Current Magnitude, A (2^{nd}) of T2 with THD_I21.4%

Table 5-6: Harmonic Voltage distortion of T1 and T2 are equal

Harmonic order	1	5	7	11	13	17	19	23	25	THD
HD of voltage %	100	0.001	8.785	0.001	0.897	0.001	0.860	0.001	0.169	8.8%

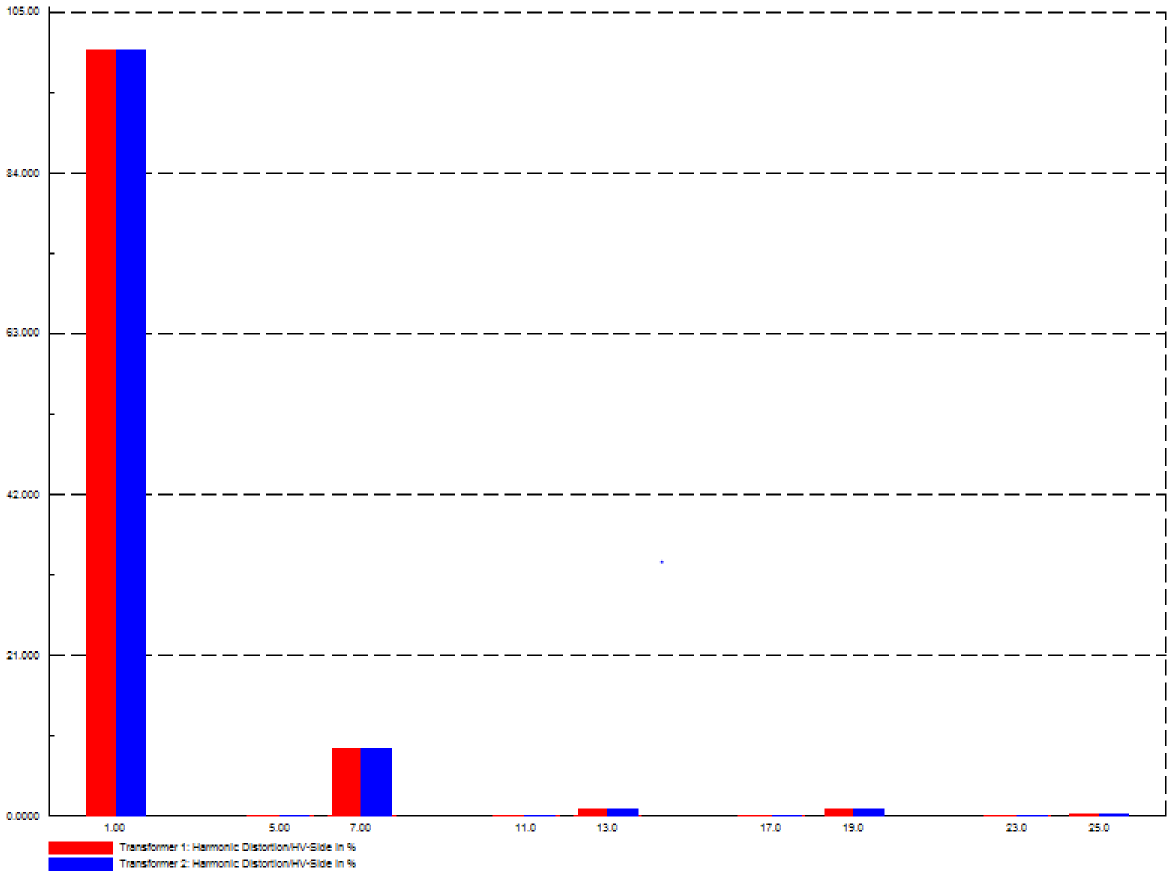


Fig 5-7: Harmonic Current distortion, %of T1 (1st) and T2 (2nd) withTHD$_V$ 8.8%

Table 5-7: Harmonic Currents at each Harmonic order for Substation Transformer

Harmonic order	1	5	7	11	13	17	19	23	25	THD (%)
Harmonic current, %	100	0.267	21.568	0.001	1.185	0.001	0.778	0	0	21.6
Harmonic Current, A	14.989	0.01	3.233	0.01	0.178	0.01	0.01	0	0	21.6

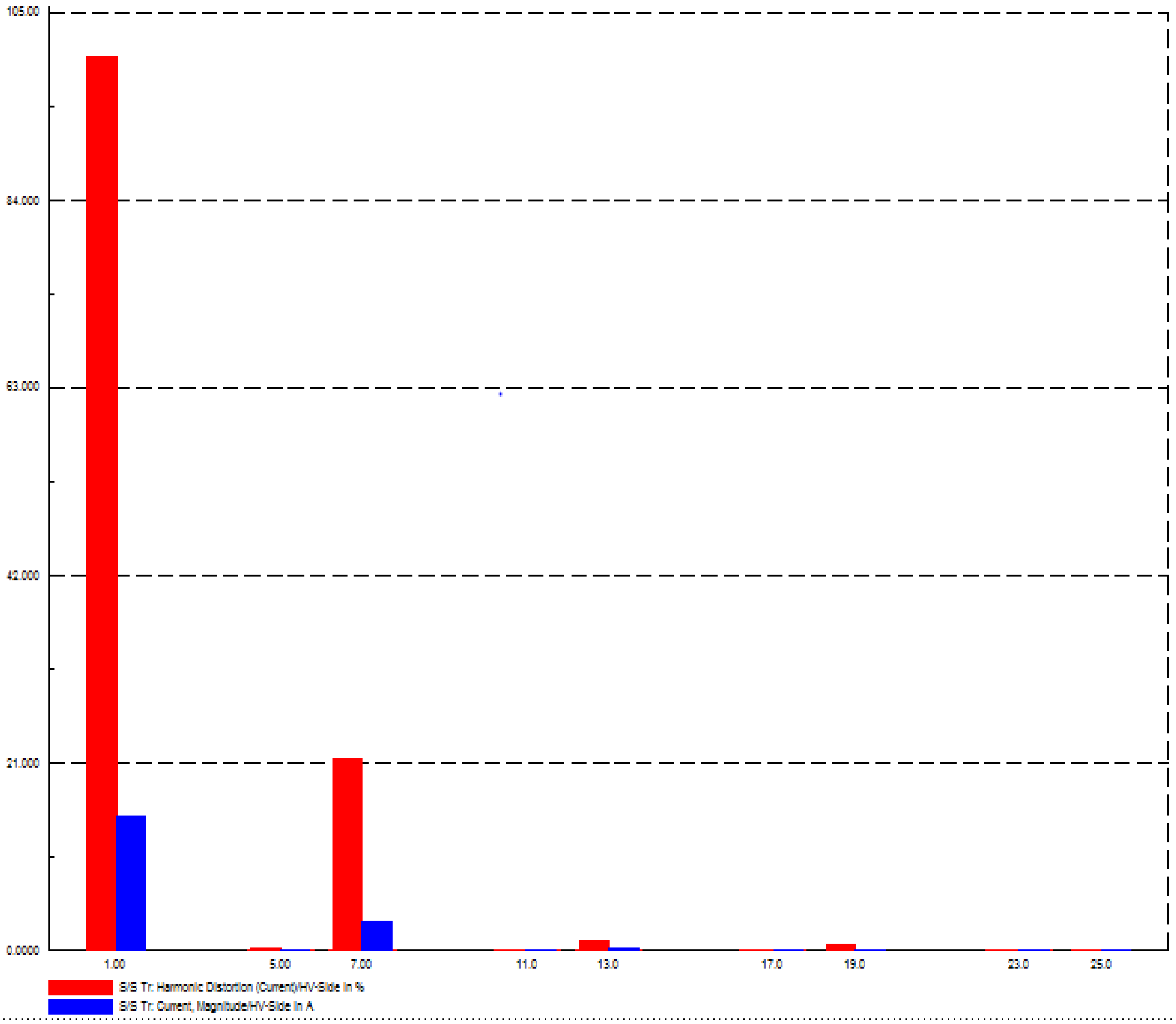


Fig 5-8: Harmonic Current distortion, % (1st) and harmonic current, A (2nd) for Substation Tr with

THD$_I$ 21.6%

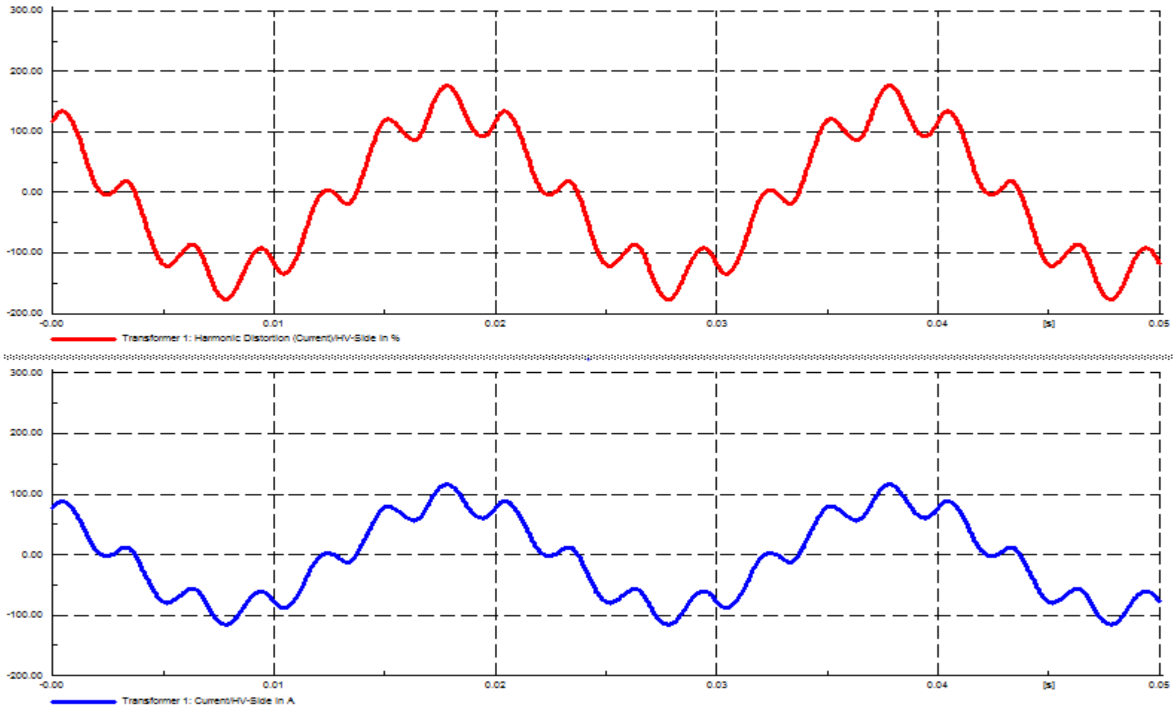


Fig 5-9: Wave ofHarmonic Distortion of Current (%) (upper), Current Magnitude, (A) (lower) for T2 withTHD_I 25.5%

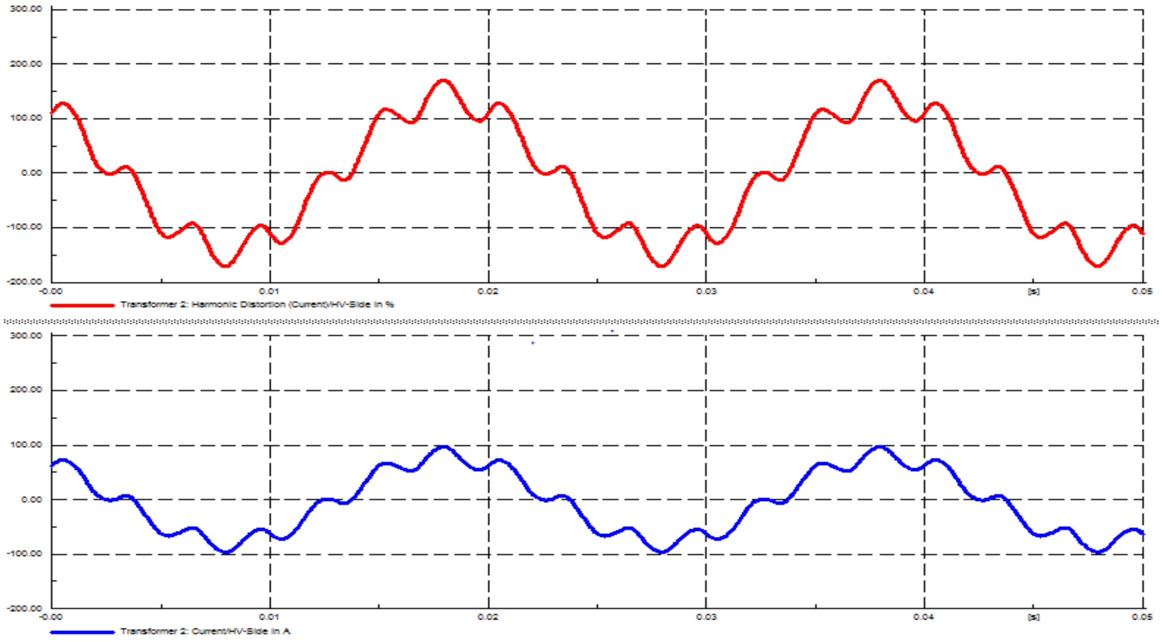


Fig 5-10: Wave Harmonic Distortion of Current, % (upper), Current Magnitude, A (lower) for T2 withTHD_I 21.4%

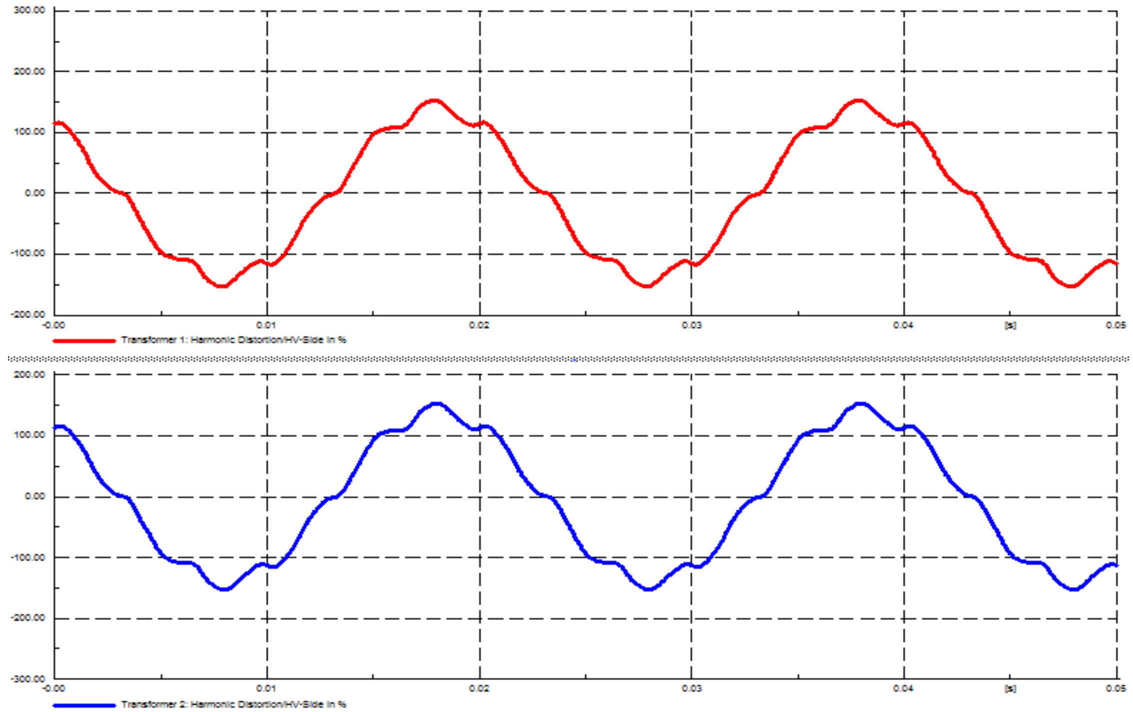


Fig 5-11: Wave of Harmonic Distortion Voltage T1 (upper) and T2 (lower) withTHD$_I$ 8.8%

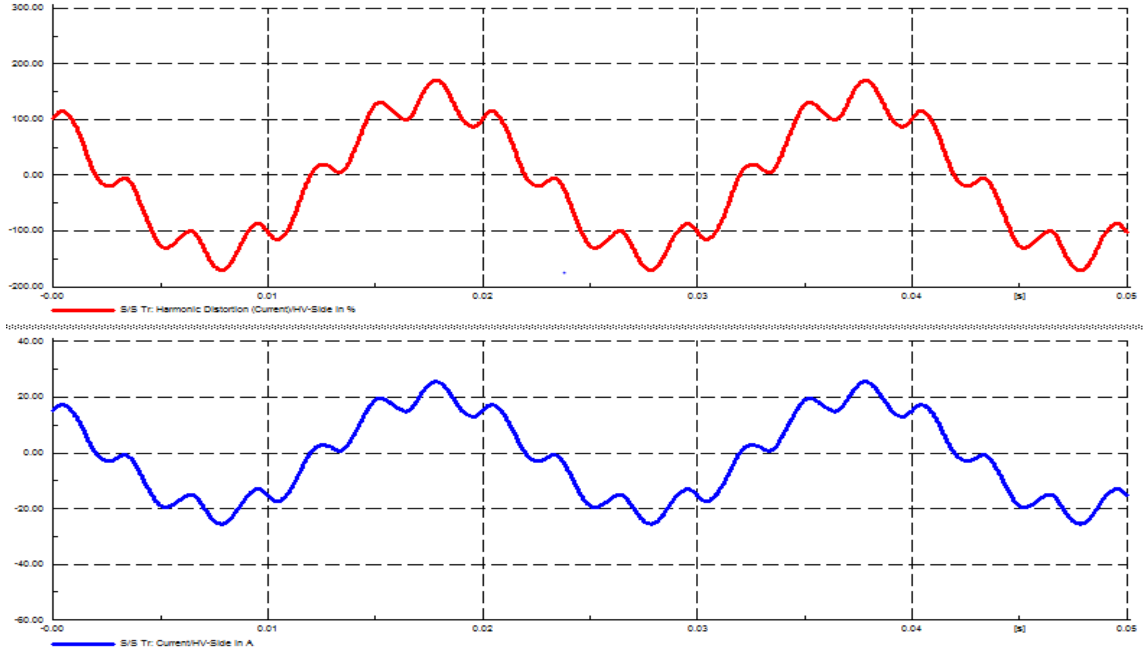


Fig 5-12: Wave of Harmonic Distortion of Current, % (upper), Current Magnitude A,(lower) for Substation Tr with THD$_I$ 21.6%

5.6 Comparing Simulation Results of T1 and T2 with IEEE Standards

After simulating the networks, the next step is to compare the voltage and current distortions with prescribed limits. This comparison will help us to come to conclude if the distortion levels obtained from simulation are of significant concern or not. The primary terminal of each transformer is treated as the point of common coupling (PCC).To evaluate the harmonic level with the IEEE standards, first the short-circuit ratio, ISC/IL must be evaluated. IL is the maximum demand at the PCC. The maximum short circuit current at the PCC can be calculated using eqn (4.0).

5.6.1 Checking Results of T1 and T2 with Standard Limits

The first step to evaluate the distortion levels is to calculate the SCR ratio at the primary of the transformer. This each transformer is rated at 1600 KVA, 15/0.4 KV with a percentage impedance of 5.5%. To obtain the maximum demand current either there should be recorded demand data in 15 or 30 minute period (e.g., billing records) or the fundamental currents taken as the maximum demand. The value is 65.52 A and 56.518 A for T1 and T2 respectively. Using the equation shown below:

$$Isc = \frac{Irated}{\%\, impedance} = \frac{kVA/\sqrt{3}V}{\%Z} = \frac{\frac{1600\ kVA}{\sqrt{3}*0.4\ kV}}{5.5\%} = 41{,}989.11\text{A}.$$

SCR , T1 =ISC/IL $= \frac{41{,}989.11\text{A}}{65.66\text{A}} =$639.5A& SCR T2 = ISC/IL $= \frac{41{,}989.11\text{A}}{56.529\text{A}} =$ 742.8A.

If ISC/IL is 100<1000 then TDD becomes 15%. The individual and total demand distortion levels are tabulated below:

Table 5-8: Harmonic Current as % of IL of T1

Harmonic order	5	7	11	13	17	19	23	25	TDD%
Harmonic current, %	0.281	25.477	0.001	1.306	0.001	0.808	0.001	0.001	25.5

Table 5-9: Harmonic Current as % of IL of T2

Harmonic order	5	7	11	13	17	19	23	25	TDD
Harmonic current, %	0.34	21.381	0.001	1.303	0.001	0.919	0.001	0.001	21.4

The total demand distortion of T1 and T2 at loading condition is 25.5% and 21.4% respectively. Which is unacceptable since it is above the limit. The individual 7th harmonic current is also above the acceptable limit. Therefore, mitigation actions must be carried out to minimize the distortion levels.

5.7 Design of Multi-branch Single-Tuned Filter for T1

The filter is applied at the secondary of the transformer at the load bus bar parallel to the load where the harmonics are the most dominant. The dominant frequencies are 5th, 7th, 11thand 13thharmonics. Therefore, multiple-branch single tuned harmonic filter is going to be designed using load data of T1 and T2.

Tables 5-10: Load Data of T1 and T2

T1		T 2	
Active power (P, kW)	495.8	Active power (P, kW)	393.5
Reactive power (Q, kvar)	384.9	Reactive power (Q, kvar)	295.12
Apparent power (S,kVA)	627.6	Apparent power (S,kVA)	491.86
Power factor (P.F)	0.79	Power factor (P.F)	0.80

Designing Multiple parallel single-tuned filter for T1 to improve the PF value of 0.79 to 0.92 and greater.

Step 1: The first step is to determine the reactive power to be provided by the filter capacitor banks and to calculate the value of the capacitor reactance from it.

Q com = P*(tan (cos-^{1}(Θ$_{1)}$ – tan (cos-^{1}(Θ$_{2}$)) = 495.8*(tan (cos-^{1}(0.79)) – tan (cos^{1}(0.92)) = 173.6 kvar, where $Q_{\mathbf{com}}$ = reactive power to be compensated.

For a multiple parallel single-tuned filter system, the capacitances corresponding to the hth harmonic are obtained using equations in chapter 4. The reactive power is distributed among 5th, 7th, 11th and 13thharmonic filters as follows.

Q_{f5}=Q_{com}* $\left(\frac{I5}{I5+I7+I11+I13}\right)$ = 173.6*($\frac{0.185}{0.185+16.73+0.01+0.858}$) = 1.81Kvar

Q_{f7} = Q_{com}*$\left(\frac{I7}{I5+I7+I11+I13}\right)$ =173.6 *($\frac{16.73}{0.185+16.73+0.01+0.858}$) = 163.3Kvar

Q_{f11}= Q_{com}* $\left(\frac{I11}{I5+I7+I11+I135}\right)$= 173.6* ($\frac{0.01}{0.185+16.73+0.01+0.858}$) = 0.097Kvar

$Q_{f13} = Q_{com} *(\frac{I13}{I5+I7+I11+I13}) = 173.6 * (\frac{0.858}{0.185+16.73+0.01+0.858})$ =8.37Kvar

Where Qf5, Qf7, Qf11 and Qf13 are reactive power share of 5th, 7th, 11th and 13th harmonic filters respectively.

For 5th harmonic filter

The voltage across the capacitor is determined by

$$\mathbf{V_C} = V_S * \frac{h2}{h2-1} = 0.4 * (\frac{25}{24}) = 0.417\text{kv}$$

The standard voltage available near this value is 480 V, referring to appendix F The reactive power to be supplied by the capacitor is calculated using

$\mathbf{Q_C} = \frac{h2}{h2-1} * Qf5 = \frac{25}{24} * 1.81\text{kvar} = 1.88\text{kvar}$. Let this value be 35kvar, looking at the table given in appendix F. Then XC is determined using

$\mathbf{X_C} = \frac{(VC)2}{Qc} = *1000 = \frac{(0.48)2}{35} * 1000 = 6.58\Omega$, $\mathbf{X}L = \frac{XC}{h^2} = \frac{6.58\ \Omega}{25} = 0.2632\Omega$

Using similar procedure the design parameters are summarized in table below:

Table 5-11: Design Parameters of Multi-branch Harmonic filter for T1

Branch	Qc	Vc	Xc, Ω	XL, Ω
5th	35	480	6.58	0.2632
7th	100	480	2.304	0.047
11th	20	480	11.52	0.095
13th	50	480	4.608	0.0273

Step 2: The second step is to determine whether capacitor-operating parameters fall within IEEE-18 recommended limits. RMS current through the filter, RMS & peak voltage values are calculated using formulas shown below. First the designed values for the 5th harmonic filtering are compared with the standard in the table below.

Table5-12: Comparison Table for Evaluating Filter Duty Limit of 5th Harmonic Filter

Duty	Defintion	Limit%	Actual values%	Actual values %
RMS current	$\frac{\text{Irms, total}}{\text{Icap, rated}}$	135	46.14/65.3	70.66
RMS voltage	$\frac{\text{VL} - \text{G, Cap(rms, total)}}{\text{KVrated}}$	110	303.34/429.38	70.6

Peak voltage	$\frac{\text{VL} - \text{G, Cap(max, peak)}}{\text{KV rated}}$	120	430.93/429.38	100.36
Kvar	$\frac{\text{Kvar cap(wye), total}}{\text{Kvar rated}}$	135	13.99/35	39.96

All the values meet the limits requiring so no further iterations to be carried out. Using the same procedure as 5thharmonic filter comparison is made for the rest harmonics as shown below.

Table 5-13: Comparison Table for Evaluating Filter Duty Limit of 7th, 11th and 13th Harmonic Filter.

Duty	Limit%	Actual values %		
		7th	11th	13th
RMS current	135	70.712	70.712	70.712
RMS voltage	110	70.73	70.72	70.71
Peak voltage	120	100.063	100.101	100.038
Kvar	135	38.29	36.74	37.2

Designing Multiple parallel single-tuned filter for T2 to improve the PF value of 0.80 to 0.92 and greater.

Step 1: The first step is to determine the reactive power to be provided by the filer capacitor banks and to calculate the value of the capacitor reactance from it.

$Q\ com = P*(\tan(\cos^{-1}(\Theta_1) - \tan(\cos^{-1}(\Theta_2)) = 393.5*(\tan(\cos^{-1}(0.8)) - \tan(\cos^{-1}(0.92))$

$= 137.75$kvar, where Qcom = reactive power to be compensated.

For a multiple parallel single-tuned filter system, the capacitances corresponding to the hth harmonic are obtained using equations in chapter 4. The reactive power is distributed among 5th, 7th, 11th and 13th harmonic filters as follows.

$$Q_{f5} = Q_{com} * \left(\frac{I5}{I5+I7+I11+I13}\right) = 137.75 * \left(\frac{0.192}{0.192+12.087+0.01+0.737}\right) = 2.03\text{kvar}$$

$$Q_{f7} = Q_{com*} \left(\frac{I7}{I5+I7+I11+I13}\right) = 137.75 * \left(\frac{12.087}{0.192+12.087+0.01+0.737}\right) = 127.8\text{kvar}$$

$$\mathbf{Q_{f11} = Q_{com}} \left(\frac{\boldsymbol{I11}}{\boldsymbol{I5+I7+I11+I13}}\right) = 137.75* \left(\frac{0.01}{0.192+12.087+0.01+0.737}\right) = 0.106\text{kvar}$$

$$\mathbf{Q_{f13} = Q_{com} * } \left(\frac{\boldsymbol{I13}}{\boldsymbol{I5+I7+I11+I13}}\right) = 137.75* \left(\frac{0.737}{0.192+12.087+0.01+0.737}\right) = 7.79\text{kvar}$$

Where Qf5, Qf7, Qf11 and Qf13are reactive power share of 5th, 7th, 11th and 13thharmonic filters respectively.

For 5th harmonic filter

The voltage across the capacitor is determined by

$$V_C = V_S \frac{h2}{h2-1} *= 0.4\ (\frac{25}{24}) = 0.417\text{kv}$$

The standard voltage available near this value is 480 V, referring to appendix G. The reactive power to be supplied by the capacitor is calculated using

$Q_C = \frac{h2}{h2-1} * Qf_5 = \frac{25}{24}$ *2.03kvar= 2.115Kvar. Let this value be 35kvar, looking at the table given in appendix F. Then X_C is determined using

$X_C = \frac{(VC)2}{Qc} *1000 = \frac{(0.48)2}{35} *1000 = 6.58\Omega$, $X_L = \frac{xc}{h2} == \frac{6.58}{25} = 0.2633\Omega$ Using similar procedure the design parameters are summarized in table below:

Table 5-14: Design Parameters of Multi-branch Harmonic filter for T2

Branch	Qc	Vc	Xc, Ω	XL, Ω
5th	35	480	6.58	0.2633
7th	100	480	2.304	0.04702
11th	20	480	11.52	0.0952
13th	50	480	4.608	0.0273

Step 2: The second step is to determine whether capacitor-operating parameters fall within IEEE-18 recommended limits. RMS current through the filter, RMS & peak voltage values are calculated using formulas shown below. First the designed values for the 5th harmonic filter are compared with the standard in the table below.

Table 5-15: Comparison Table for Evaluating Filter Duty Limit of 5th, 7th, 11th and 13th Harmonic Filter.

Duty	Limit%	Actual values %			
		5th	7th	11th	13th
RMS current	135	70.712	70.712	70.712	70.712
RMS voltage	110	70.6	70.73	70.72	70.71
Peak voltage	120	100.36	100.063	100.101	100.038
Kvar	135	39.96	38.29	36.74	37.2

5.8 Simulation Results of the Designed Filters for T1 and T2

After designing the filter, the simulation results of Harmonic distortion of voltage and current as well as the wave forms of current and voltages are presented below.

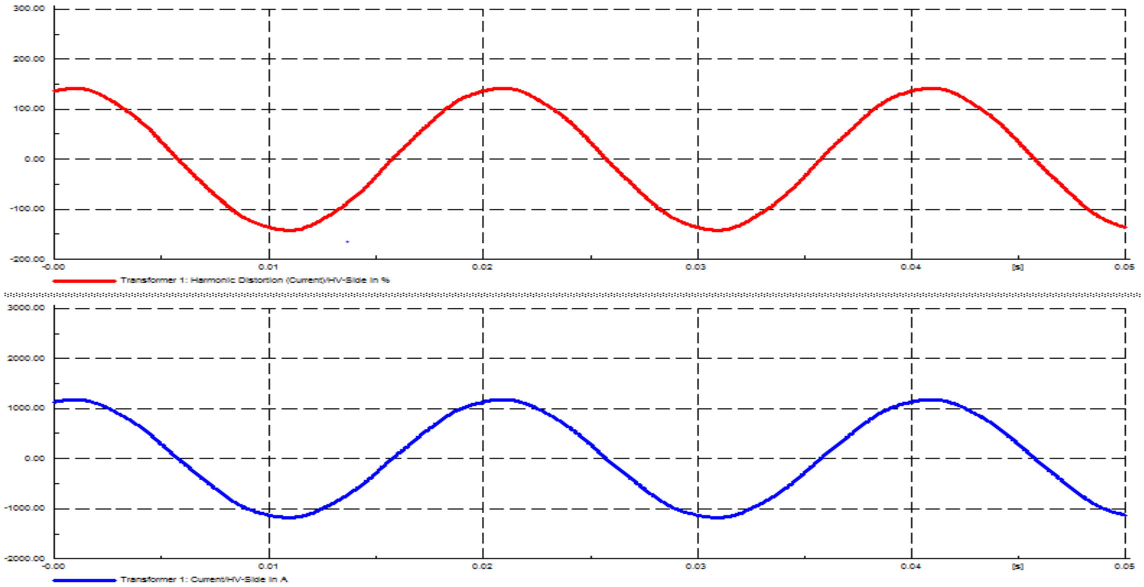


Fig 5-13: Wave of Harmonic Distortion of Current, % (upper), Current Magnitude, A (lower) for T1 with THD_I 0.867%

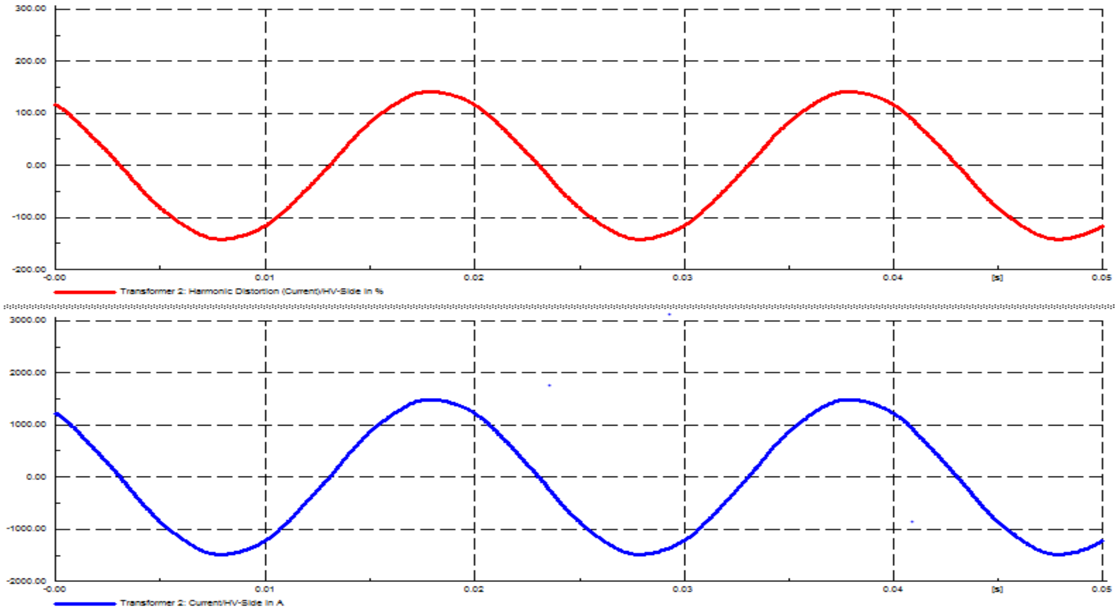


Fig 1-14: Wave of Harmonic Distortion of Current, % (upper), Current Magnitude, A (lower) for T2 with THD_I 0.824%

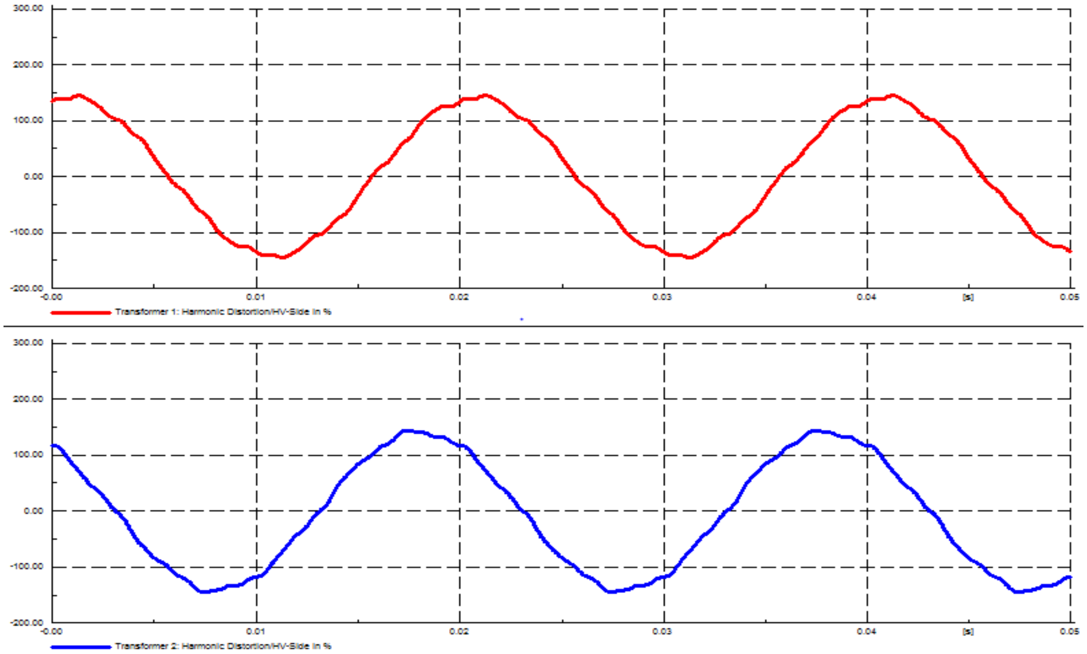


Fig1-15: Harmonic Distortion Voltgage of T1 (upper), T2 (lower) with THD_V 2.91%

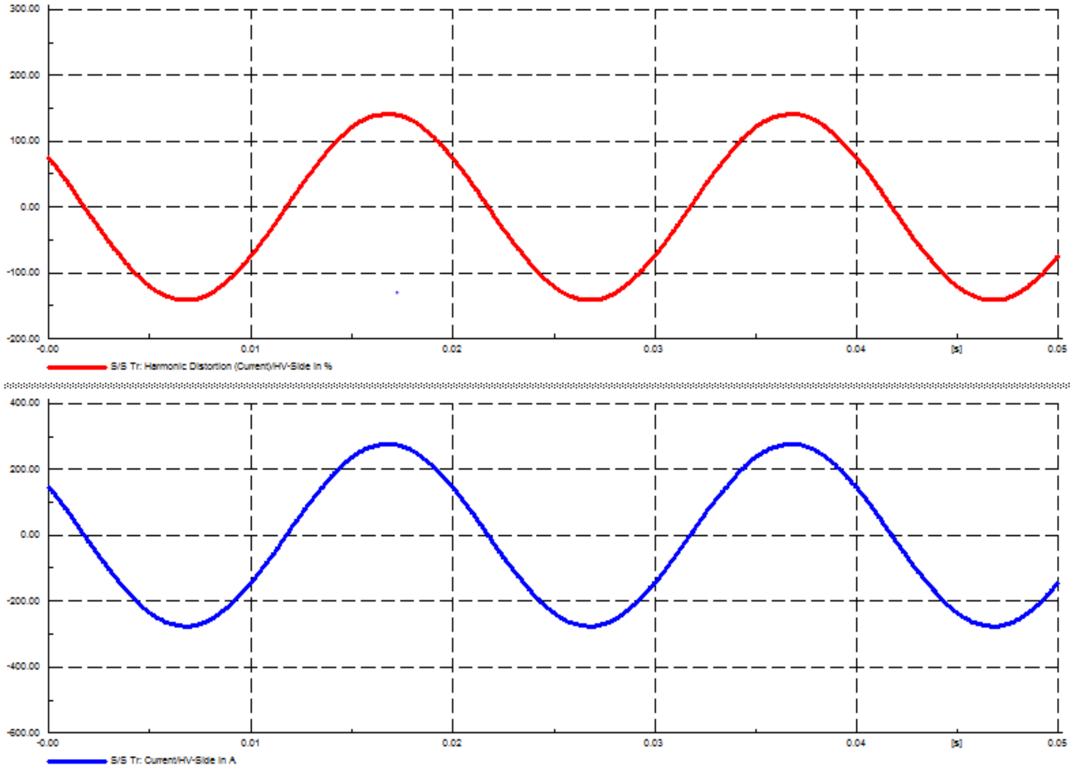
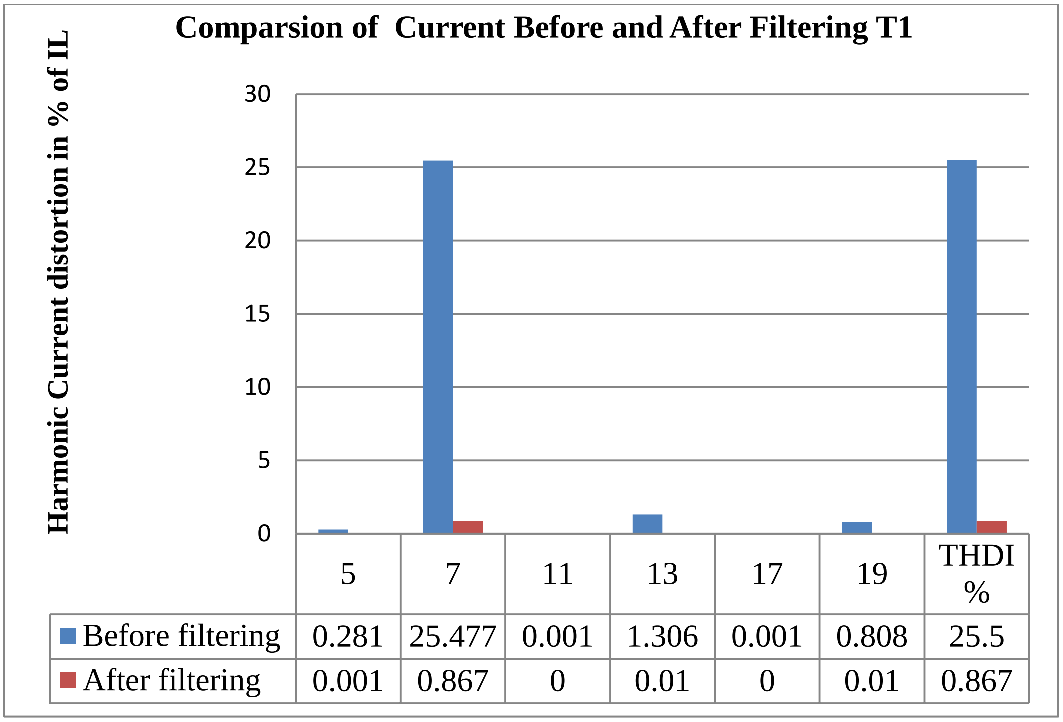
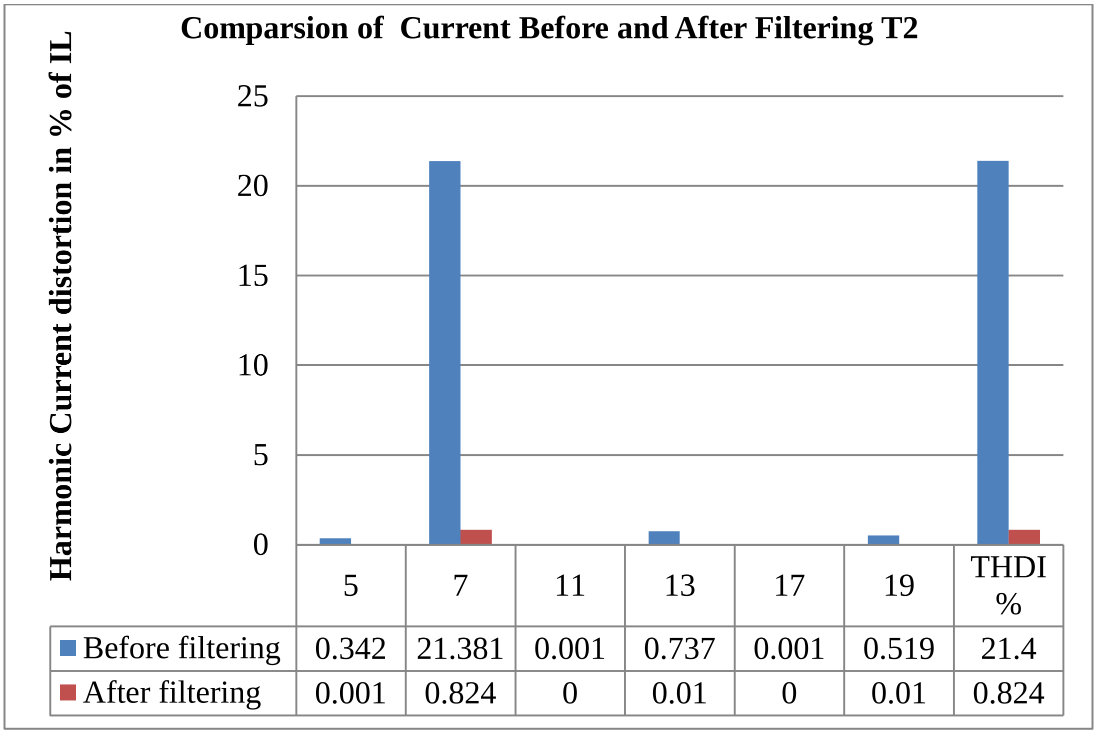


Fig 1-16: Wave of Harmonic Distortion of Current, % (upper), Current Magnitude, A (lower) for Substation Tr with THD_I 0.3%



	5	7	11	13	17	19	THDI %
🟦 Before filtering	0.281	25.477	0.001	1.306	0.001	0.808	25.5
🟥 After filtering	0.001	0.867	0	0.01	0	0.01	0.867

Fig 1-17: Comparisons of Harmonic Current Values Before and After Filtering for T1



	5	7	11	13	17	19	THDI %
🟦 Before filtering	0.342	21.381	0.001	0.737	0.001	0.519	21.4
🟥 After filtering	0.001	0.824	0	0.01	0	0.01	0.824

Fig 1-18: Comparisons of Harmonic Current Values Before and After Filtering for T2

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The objective of this thesis study is to present a general overview of the energy auditing and assessment of power quality problems (harmonics) in an Almeda textile factory, then to provide a range of energy saving opportunities. As shown in table 3-18 the currently installed pump motors have an average efficiency of 57.4%. whereas , the replaced pump motors have an average efficiency of 91.2%. from this replacements of pump motor can save 11,412.18$ per year. As well as, as shown in table 3-16 the total installed lamps are 3717 T-12 fluorescent lamps, after reexamine the installation the number of lamps are 3408 T-12 lamps. Hence, replacement of the 3408 T-12 by T-8 can save 30,376.71$ per year. The efficiency of boiler is about 60.2%. replacing this less boiler efficiency by higher one can save more money dollar per year. The annual cost difference due to inefficient use of electric energy intensity between Almeda Textile PLC and textile industries in Iran in different departments such as, spinning and weaving were 286,703.65$. Using Motor Master + International Software, in the waste water treatment, replacing 30HP standard efficiency cooling water pump motor with 20HP energy efficient motor having the same speed can save 4,633kWh /year and 371$/year with SPP of 3.95 years. Assessment of the harmonic problems for two transformers in spinning and weaving departments with ratings1600 KVA, 15/0.4kV was done. Hence, the simulation result of THD_V for both transformers (T1and T2) is 8.8% and the THD_I are 25.5% and 21.4% for T1 and T2 respectively. In addition, the THD_I of the substation transformer is 21.6%. After designing a passive filter the THD_I of T1 and T2 reduced to 0.867% and 0.824% respectively. Where\as the THD_V for both T1 and T2 is reduced to 2.91 %. As well as, the THDI of substation transformer is reduced to 0.3%. As a result, a considerable amount of electrical energy can be saved per year in textiles in general by incorporating and implementing the above techniques.

6.2 Recommendations and Future Work

It should be understood that the simulation results obtained in the factory are not measured values, rather they are estimates due to lack of advanced measuring device to take real measurements of device parameters. So, it is recommended that the simulation results to be verified by measurement in the future. If there is HIOKI 3196 Power Quality Analyzer and Tri vector instruments in the factory it is simple and easy to know any power quality disturbance which displayed in those instruments. Those devices will provide great help for studying problems associated to power quality issues smoothly and easily. And through automating the light switching mechanism by using occupancy sensors10-20% of facility lighting energy use can be saved for the future. In addition, when the light is interrupted, to continue the process in some departments the factory uses four generators as a backup power. Hence, the factory spent 6444.5$ per year 92,593$ per month to buy fuel and furnace oil (to boil the water in boiler room) respectively. Therefore, to avoid this payment, the factory should design a Solar PV system.

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Appendix A: The Most Commonly Used Passive Filter is Single-Tuned Filter

This filter is simple and least expensive as compared with other means for mitigating the harmonic problems. This filter is connected in shunt with the main distribution system and is tuned to present low impedance to a particular harmonic frequency. Therefore, harmonic currents are diverted from the least impedance path through the filter. In design of the filter, the proper selection of the capacitor size is very essential from power factor point of view. The relation between capacitor reactance and reactive power is expressed as:

$$\mathbf{Q}_{\text{Filter}} = \frac{Vcap^2}{Xc}$$

Where:V^2_{cap} is the line voltage of the capacitor in volts, Q is the reactive power in kVAR and Xcis the capacitive reactance of capacitor in ohms. The capacitive reactance is given by:

$$\mathbf{C} = \frac{1}{2\pi fxc} \text{ (Farads)}$$

The resonance condition will occur when capacitive reactance is equal to inductive reactance as:

$X_L = X_{C,}$ from this Resonance Condition, $\mathbf{2\pi f\ L} = \frac{1}{2\pi fC}$ then the inductive value of the filter is

$$\mathbf{L} = \frac{1}{C(2\pi f)^2} \text{ (Henry).}$$

The resistance of filter depends on the quality factor (Q) by which sharpness of the tuning is measured. Mathematically quality factor is defined as:

$$\mathbf{Q} = \frac{\sqrt{\frac{L}{C}}}{\mathbf{R}}.$$

The resistive value of the filter can be obtained by selecting the quality factor in the range of **20<Q<100**. The larger value of the quality factor gives the best reduction in harmonic reduction [26]. The other methods to find the required capacity of Capacitance in micro farads is:

$$\mathbf{C} = \frac{\text{kVAR}}{2\pi fV^2}\mu\text{F}$$

Tables of Capacitor, Inductor and Resistor values using the above formula are shown below:

Transformers	**Harmonic level**	**Capacitor(μF)**	**Inductor (mH)**	**Resistor(Ω)**
Tr1	5th	483.75	20.94	0.00188
	7th	1381.5	7.33	0.000023
	11th	276.3	36.67	0.000576
	13th	690.7	14.66	0.000922
Tr2	5th	483.75	20.94	0.00188
	7th	1381.5	7.33	0.000023
	11th	276.3	36.6	0.000576
	13th	690.7	14.6	0.000922

Appendix B: Formulas used to Calculate the Annual Saving Cost of Replaced Lamp

Energy (KWh) = Quantity of Lamp*Power (KW) *Operating Time (h)
Annual Cost =Quantity Of Lamp*Energy (KWh) X (Cost Of Energy)

*A*nnual Savings Cost=Cost of Currently Installed Lamps in The Year-Cost of Replaced Lamps in The Year

Simple Payback Period = Initial Cost /Annual Savings Cost

Appendix C: Recorded Data's of Real Power, Reactive Power and Apparent Power

Date	***Shift***	***ALTEX***				*Shift*	***Garment***	
		Almeda Meter		***Epeco meter***			***Epeco meter***	
		P (KW)	Q(Kvar)	P (KW)	Q(Kvar)		P (KW)	Q(Kvar)
19/12/16	*A*	951.098	725.819	3804.42	2660.93	*A*	2573.8	652.6
	B	951.322	726.04	3804.64	2661.15	*B*	2574.3	651.6
	C	951.572	726.28	3804.88	2661.39	*A*	2575	652.6
20/12/16	*A*	951.845	726.533	3805.36	2661.87	*B*	2575.1	652.7
	B	952.058	726.766	3805.36	2661.87	*A*	2576	652.8
	C	952.284	727	3805.58	2662.1	*B*	2576.8	652.8
21/12/16	*A*	952.538	727.233	3805.83	2662.39	*A*	2577.2	652.8
	B	952.764	727.47	3806.05	2662.79	*B*	2577.6	652.8
	C	952.991	727.698	3806.27	2662.79	*A*	2578	652.8
22/12/16	*A*	953.204	727.964	3806.54	2663.06	*B*	2578.6	652.9
	B	953.452	728.148	3806.72	2663.24	*A*	2579.1	653
	C	953.696	728.35	3806.95	2663.48	*B*	2579.6	653.1
23/12/16	*A*	953.973	728.609	3807.26	2663.76	*A*	2580	653.1
	B	954.13	728.823	3807.38	2665.91	*B*	2580.4	653.1
	C	954.363	729.06	3807.6	2664.15	*A*	2580.8	653.2
24/12/16	*A*	954.643	729.223	3807.88	2664.41	*B*	2581.4	653.2
	B	954.848	729.526	3808.07	2664.61	*A*	2581.8	653.2
	C	955.03	729.749	3808.29	2664.83	*B*	2582	653.3
25/12/16	*A*	955.325	729.99	3808.54	2665.08	*A*	2582.1	653.3
	B	955.514	730.193	3808.72	2665.77	*B*	2582.2	653.3

	C	955.515	730.397	3808.93	2665.48	*A*	2597.7	654.6
Date	***Shift***	***ALTEX***				***Shift***	***Garment***	
		Almeda meter		***Epeco meter***			***Epeco meter***	
		P (KW)	Q(Kvar)	P (KW)	Q(Kvar)		P (KW)	Q(Kvar)
02/01/17	*A*	960.46	735.149	3813.55	2670.21	*A*	2590.5	654.0
	B	960.629	735.319	3813.71	2670.38	*B*	2591.2	654.1
	C	960.838	735.531	3813.92	2670.59	*A*	2591.8	654.1
03/01/17	*A*	961.078	735.786	3814.15	2670.83	*B*	2591.9	654.1
	B	961.289	735.977	3814.36	2671.03	*A*	2592.5	654.2
	C	961.499	735.190	3814.56	2671.24	*B*	2593.2	654.2
04/01/17	*A*	961.733	736.416	3814.79	2671.47	*A*	2593.3	654.3
	B	961.945	736.623	3815.00	2671.68	*B*	2594.0	654.3
	C	961.178	736.855	3815.22	2671.91	*A*	2594.4	654.3
05/01/17	*A*	962.734	737.107	3815.48	2672.16	*B*	2594.7	654.4
	B	962.613	737.283	3815.64	2672.33	*A*	2595.5	654.4
	C	962.820	737.493	3815.84	267254	*B*	2596.0	654.4
06/01/17	*A*	963.074	737.740	3816.09	2672.79	*A*	2596.2	654.5.
	B	963.277	737.935	3816.29	2672.90	*B*	2596.8	654.5
	C	963.541	738.187	3817.55	2673.23	*A*	2597.1	654.5
07/01/17	*A*	963.710	738.364	3816.71	2673.41	*B*	2597.1	654.5
	B	963.723	738.392	3816.72	2673.44	*A*	2597.5	654.5
	C	963.730	738.415	3816.73	2673.46	*B*	2597.5	654.5
08/01/17	*A*	963.738	738.427	3816.74	2673.49	*A*	2597.5	654.6
	B	963.890	738.594	3816.88	2673.65	*B*	2597.7	654.6
	C	963.052	738.764	3817.04	2673.82	*A*	2597.7	654.6

Appendix D: Data of Electric Power Generator Consumption Report

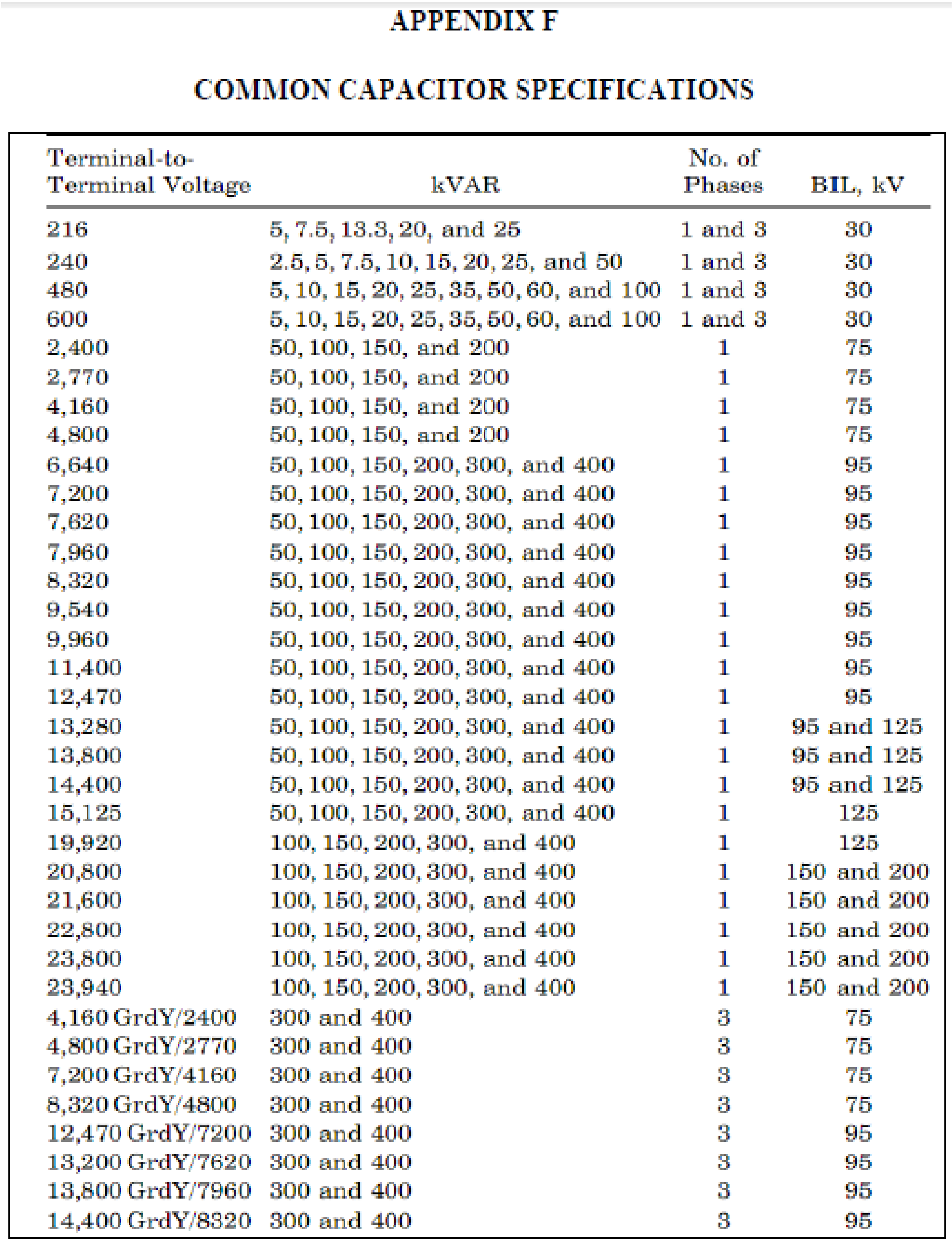
Month	Capacity(KW)	Running hr	Fuel/hr	Total fuel	p.fuel/litter	Total price	description
September	120	3:30	20	364	17	6,188	Residence
	480		70				Knit dyeing
	480	7:30	70	350	17	5,950	Weaving
	592		110				Processing
Number of power fluctuation							54 times
Total power interruption hours							5:10
Number of power interruption							3 times
October	120	13:40	20	274	16.2	4,438.8	Residence
	480		70		16.2		Knit dyeing
	480	11:30	70	805	16.2	13,041	Weaving
	592		110		16.2		Processing
Number of power fluctuation							66 times
Total power interruption hours							4:35
Number of power interruption							12 times
November	120	5:00	20	100	16.16	1,666	Residence
	480						Knit dyeing
	480	13:30	70	945	16.16	15,271.2	Weaving
	582						Processing
Number of power fluctuation							67 times

Total power interruption hours							15hr
Number of power interruption							8 times
December	120	8hr	20	160	16.26	2,592	Residence
	480						Knit dyeing
	480	23hr	70	1610	16.26	26,082	Weaving
	592						Processing
Number of power fluctuation							38 times
Total power interruption hours							24hr
Number of power interruption							7times
January	120	17hr	20	304	16.2	5,508	Residence
	480	1:30	70	105	16.2	1701	Knit dyeing
	480	44hr	70	3,080	16.2	49,896	Weaving
	592						Processing
Number of power fluctuation							35 times
Total power interruption hours							40hr
Number of power interruption							8times
February	120	3:30	20	70	16.6	1,162	Residence
	480						Knit dyeing
	480	7:30	70	525	16.6	8,715	Weaving
	592						Processing
Number of power fluctuation							50times
Total power interruption hours							22hr
Number of power interruption							14times

Appendix E: Cable Data for T1 and T2

Line	*Area* mm^2	*Current rating, A*		*Electrical characteristics*		Length(km)
		In air	*In ground*	*R(Ω/km)*	*X(Ω/km)*	
Transformer 1						
L1	400	1.02	1.034	0.154	0.015	0.01
L2	400	1.02	1.034	0.154	0.015	0.02
L3	400	1.02	1.034	0.17	0.012	0.03
L4	400	1.02	1.034	0.154	0.015	0.04
L5	350	1.02	1.034	0.17	0.058	0.05
Transformer 2						
L6	400	1.2	1.25	0.1504	0.013	0.06
L7	300	0.51	0.517	0.0752	0.011	0.07
L8	400	1.2	1.25	0.19	0.045	0.08
L9	300	1.02	1.304	0.17	0.01	0.09
L10	300	0.51	0.517	0.0752	0.075	0.1

Appendix F: Tables for Common Capacitor Specification [37]



APPENDIX F

COMMON CAPACITOR SPECIFICATIONS

Terminal-to-Terminal Voltage	kVAR	No. of Phases	BIL, kV
216	5, 7.5, 13.3, 20, and 25	1 and 3	30
240	2.5, 5, 7.5, 10, 15, 20, 25, and 50	1 and 3	30
480	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30
600	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30
2,400	50, 100, 150, and 200	1	75
2,770	50, 100, 150, and 200	1	75
4,160	50, 100, 150, and 200	1	75
4,800	50, 100, 150, and 200	1	75
6,640	50, 100, 150, 200, 300, and 400	1	95
7,200	50, 100, 150, 200, 300, and 400	1	95
7,620	50, 100, 150, 200, 300, and 400	1	95
7,960	50, 100, 150, 200, 300, and 400	1	95
8,320	50, 100, 150, 200, 300, and 400	1	95
9,540	50, 100, 150, 200, 300, and 400	1	95
9,960	50, 100, 150, 200, 300, and 400	1	95
11,400	50, 100, 150, 200, 300, and 400	1	95
12,470	50, 100, 150, 200, 300, and 400	1	95
13,280	50, 100, 150, 200, 300, and 400	1	95 and 125
13,800	50, 100, 150, 200, 300, and 400	1	95 and 125
14,400	50, 100, 150, 200, 300, and 400	1	95 and 125
15,125	50, 100, 150, 200, 300, and 400	1	125
19,920	100, 150, 200, 300, and 400	1	125
20,800	100, 150, 200, 300, and 400	1	150 and 200
21,600	100, 150, 200, 300, and 400	1	150 and 200
22,800	100, 150, 200, 300, and 400	1	150 and 200
23,800	100, 150, 200, 300, and 400	1	150 and 200
23,940	100, 150, 200, 300, and 400	1	150 and 200
4,160 GrdY/2400	300 and 400	3	75
4,800 GrdY/2770	300 and 400	3	75
7,200 GrdY/4160	300 and 400	3	75
8,320 GrdY/4800	300 and 400	3	75
12,470 GrdY/7200	300 and 400	3	95
13,200 GrdY/7620	300 and 400	3	95
13,800 GrdY/7960	300 and 400	3	95
14,400 GrdY/8320	300 and 400	3	95