ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Electrical and Computer Engineering

ENERGY EFFICIENCY AND POWER QUALITY IMPROVEMENT IN TEXTILE INDUSTRIES: (CASE STUDY: ARBAMINCH TEXTILE FACTORY)

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MASTERS OF SCIENCE IN ELECTRICAL ENGINEERING
(ELECTRICAL POWER ENGINEERING)

By

Marishet Kebede

Advisor: Getachew Bekele (PhD)

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BY

MARISHET KEBEDE

GSR/0489/05

APPROVAL BY BORD OF EXAMINERS

CHAIRMAN DEPARTMENT OF GRADUATE COMMITTEE **SIGNATURE**

Dr.Getachew Bekele
ADVISOR **SIGNATURE**

INTERNAL EXAMINER **SIGNATURE**

EXTERNAL EXAMINER **SIGNATURE**

DECLARATION

I, the undersigned, declare that this thesis is my original work, has not been presented for a degree in this or other universities, all sources of materials used for this thesis work have been fully acknowledged.

Name: Marishet Kebede

Signature: ______________________

Place: Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa

Date of submission: ___________________

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

Dr.Getachew Bekele	___________________
Advisor's Name	**Signature**

DEDICATION

… To my beloved Mather

Mulunesh Abebe

&

To My Brother

Engida Kebede

… For their incomparable support in my entire academic carrier!

ACKNOWLEDGMENT

First and foremost, I take this opportunity to give glory to the almighty God, without whom the completion of this work would have been impossible.

Next, I would like to express my sincere gratitude to my advisor, Dr.Getachew Bekele, for his expert guidance, constructive comments, suggestions and supports for the successful completion of this paper. He has also played an indispensable role as the primary source of inspiration on every step of the activities or proceedings of my study.

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ABSTRACT

Energy is one of the main cost factors in the textile industry. Especially in times of high energy price volatility, improving energy efficiency should be a primary concern for textile plants. Focusing on energy utilization assessment and consumption reduction efforts through efficient energy usage, better production management and also through introduction of new Technologies significant results can be achieved; saving money on energy bills, improving energy efficiency and maintaining sustainable environment.

The main objective of this thesis is to analyse the current use and management of electrical energy as well as to identify the power quality problems in the textile manufacturing processes of the selected plant, a detailed assessment of energy consumption and loss has been taken. Based on the losses, energy efficiency performance assessments on the major energy intensive equipments like electric motors and drives, lightings have been done. In addition, measurements and simulations have been made to assess power quality related problems of the factory. Based on the results obtained from measurement (voltage unbalance, current unbalance, power factor) and simulation results (total harmonic distortion of voltage, total harmonic distortion of current) a comparison has been made with the standard values. With this comparison a mitigation technique to the harmonic problem has been done by design of passive filters and power factor correction using **ETAP** software tool.

It has been found from Energy Audit results that there exists a difference of 1.23KWh/Kg between the benchmarks and what exists at Arbaminch Textile factory; the factory spends 1,282,988 Birr per year on this account. In the breakdown of energy use in the different section of the textile factory, the Ring frame and the Open end machineries are observed to have large consumptions of energy 43.7% and 30.3% respectively. Thus some measures are proposed to reduce the energy lose.

Using motor master+ international software, it has been seen that in the ring frame section replacing 22KW of the existing motor with a 15KW energy efficient motor can bring energy savings of 13,189KWh per year and money savings of 325 dollars per year with four years payback periods. And also through improving the lighting installation systems resulted in energy saving of 209,802KWh/y and in money savings of 85,725 Birr annually.

The voltage and the current unbalance for the factory distribution system are all within the standard (< 3% for voltage and <10% for the current). The total harmonic distortion of the current (26%), and the individual (5th) harmonic distortion of the current (25.8%) and The individual (5th) voltage distortion (3.57%) levels are found to exceed the standard limits(8% for THDI, 7% for 5th harmonic distortion of current and 3% for 5th harmonic distortion of voltage) for transformers T1 and T2. Therefore, a single-tuned multi-branch filter is designed which reduces the total current harmonic distortion levels to 6%, the individual current to 6.57% and the individual voltage distortion to1.24%.

Keywords: Energy Audit, Energy Efficiency, Energy intensity, power Quality, point of common coupling (PCC)

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NOMENCLATURE

AAC	All Aluminium Conductor
ALR	Actual lamp required
AM S/S	Arbaminch substation
AMTF	Arbaminch Textile Factory
AS	Actual saving
BS	Birr saving
C	Cable
CAP	Capacitor bank
CB	Circuit Breaker
CFL	Compact florescent lamp
CSA	Central Statistical Agency
ED	Energy difference
EEU	Ethiopian Electric Utility
EMDS	Electric motor-driven systems
ER	Energy required
ES	Energy Utilized
ETAP	Electrical Transient Analysis program
EU	Energy Utilized
FL	Florescent lamp
HPS	High Pressure Sodium Lamps
HV	High voltage
HVAC	Heating, Ventilating, and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
IL	Lamp illumination
IMSSA	International Motor Selection and Analysis
IUF	Current Unbalance Factor
KJ	Kilo joule
KVA	Kilo Volt Ampere

KVAR	Kilo Volt Ampere Reactive
KWh	Kilo Watt hour
LB/B	Load Bus Bar
Lo	Luminous output of each lamp
LV	Low Voltage
Mtr	Motor
MVA	Mega Volt Ampere
MVAsc	Short Circuit Mega Volt Ampere
NEC	National Electricity Code
NEMA	National Electricity Manufacturer's Association
NL	Number of lamps
OH	Operating hour
PCC	Point of Common Coupling
PDS	Power demand saving
PF	Power factor
PQ	Power Quality
RA	Room Area
RMS	Root Mean Square
SCC	Short Circuit Current
SCR	Short Circuit Ratio
Syn Mtr	Synchronize motor
TDD	Total Demand Distortion
THD	Total Harmonic Distortion
THDI	Current Total Harmonic Distortion
THDV	Voltage Total Harmonic Distortion
TL	Total lumens output of lamps
TP	Total power rating
T	Transformer
VFD	Variable frequency drive
VUF	Volt Unbalance Factor

1. INTRODUCTION

1.1 Background

Textile Industry is one of the most important industries in the world. The industry suffers from inadequate development planning, which is atypical problem with most of the textile industries. Atypical textile industry structure contains subsections which are occupied by a number of different units working independently. There might be some hidden defects left in the structure that leads to unnecessary energy use.

Few studies have been conducted in the past, which shows that there are many opportunities in textile industries to save energy. In 1988, it was estimated that reduction rates of 16 % in process heat and 8% in power consumption could be achieved in the finish textile industry just like other manufacturing industries by using available technology [1].

The industrial sector in general accounts around 40% of the commercial energy. The electrical and thermal energies are widely used in various equipment's like in water pumps, boilers compressors etc. But there are many problems in the industry sectors to efficiently use their energy. They are not well informed on the concept of energy conservation. Due to this they lose lots of money on energy bills, causes problems on the environment, industries will not be competitive, etc. [2].

The energy distribution and utilization assessment that has done on several industries mostly occur on the thermal energy efficiencies but the electrical energy has also major impact on the industries [3].

Today manufacturers face an increasingly competitive global business environment; they seek opportunities to reduce production costs without negatively affecting product yield or quality. For public and private companies alike, rising energy prices are driving up costs and decreasing value added at the plant. Successful, cost-effective investment into energy-efficiency technologies and practices meets the challenge of maintaining the output of a high quality product despite reduced production costs. This is especially important in the current age, as energy-efficient technologies often include “additional” benefits, such as increasing the productivity of the company or reducing the water and/or materials consumption [4].

Energy efficiency does not mean rationing or having to do without energy rather, energy efficiency means identifying wasteful energy use and taking actions to reduce or illuminate that waste. Production levels should not be affected, only the amount of energy and the expense incurred in generating that production. The objective is to reduce energy costs and consequently increase profitability [5].

1.2. Energy Audit

An energy audit is an inspection, survey and analysis of energy flow for energy conservation in buildings, processor systems to reduce the amount of energy input(s) into the system without affecting negatively to the output(s). It is an important commercial tool to save energy and to improve financial state of an organization. Almost all the large scaled and many small scaled organizations i.e. industries as well as non-industrial sectors are conducting energy audit to save energy and to minimize the electricity cost. Energy audits assist industrial companies or facilities in understanding how they use energy and help to identify the areas where waste occurs and where opportunities for improvement exist [1].

The objectives of an energy audit can vary from one plant to another. However, an energy audit is usually conducted to understand how energy is used within the plant and to find opportunities for improvement and energy saving. Sometimes, energy audits are conducted to evaluate the effectiveness of an energy efficiency project or program.

The type of industrial energy audit conducted depends on the function, size, and type of the industry, the depth to which the audit is needed, and the potential and magnitude of energy savings and cost reduction desired. Based on these criteria, an industrial energy audit can be classified into two types: a preliminary audit (walk-through audit) and a detailed audit (diagnostic audit) [6].

1.3. Problem Statement

Energy efficiency is the goal to reduce the amount of energy required to provide products and services. Improvements in energy efficiency are generally achieved by adopting a more efficient technology or production process or by application of commonly accepted methods to reduce energy losses. There are many motivations to improve energy efficiency. Reducing energy use reduces energy costs and may result in cost savings, reducing energy use is also seen as a solution to the problem of reducing greenhouse gas emissions

Energy in the textile industry (Arbaminch textile factory) is used in the forms of electricity, as a common power source for machinery, cooling and temperature control systems, steam generators, lighting, office equipment, etc. Most often the inefficient use of the energy in the factories causes wastage and losses. The reasons for the inefficient use of energies are:

- Lack of awareness how to conserve the resource
- Lack of responsibility to manage and monitor the resource
- Poor design and improper installation
- Lack of proper replacement, regular maintenance and control of industrial equipments
- The obsolete machines and equipments
- Shortage of spare parts and accessories
- Due to the nonlinear devices in the factory such as ASD(adjustable speed derives) harmonic currents injected into power system and deteriorating the quality of power and hence increase the loss

This thesis thus makes a detailed analysis of the above cited problems, identify their causes and effects and try to recommend possible solutions.

1.4. Objectives

1.4.1. General Objective

The general objective of this thesis is to analyse the present use and management of electrical energy as well as to identify the power quality problems in textile industries and suggest appropriate measures to improve the energy usage and power quality.

1.4.2. Specific objectives

The specific objectives are:

- ✓ To Survey the working conditions and collect relevant data from Arbaminch Textile factory
- ✓ To analyse the data and determine energy conservation opportunities for the major energy consuming equipments.
- ✓ Determine the potential of energy savings in different energy consuming equipments through energy auditing.
- ✓ Analyse the major causes of energy losses at AMTF.
- ✓ Recommend possible energy saving solutions,
    - ➢ To improve motors performance.
    - ➢ To improve lighting systems.
    - ➢ To improve the power factor.
- ✓ Assess the power quality related problems in textile industries and suggest the appropriate solution.

1.5. Scope and Limitation of the Study

The energy consumption of Arbaminch textile factory had no investigation since its establishment. This thesis is confined only to the Study of electrical energy use and power Quality in the textile manufacturing processes. The study encompasses reading relevant literature, collecting and analysing data from the company for energy consumption, monitoring, accounting and management in the company.

The study is focussed on identification of the major energy using equipments, processes and the amount of energy that is lost when generating textile.

1.6. Methodology

Data collection

The necessary data for the thesis are collected from different sources. The necessary dates are:

- ✓ The energy consumptions of the factory for the last four years.

- ✓ The current energy requirement to produce a unit product (specific electrical and fuel Consumptions).
- ✓ Specification, working conditions and maintenance procedures of the equipment's in Utility plants.
- ✓ The current production cost of the factory, energy bill, lighting data.
- ✓ Measurements like 3-phase voltage, 3-phase current, power factor, active power, reactive power, etc.

And also the performances of the major energy intensive equipment's like motors, Air conditioners, Lightings are assessed. Then the data are analysed quantitatively and qualitatively. Depending on the assessed data opportunities to reduce energy loses are done. From the analysed data, conclusion and recommendation have been forwarded.

Software tools

Software's like Motor master+ International and Electrical transient analyser programs (ETAP) are incorporated to assist this work. The motor master + international program supports motor and motor systems improvement planning through identifying the most efficient action for a given repair or motor purchase decision. It can also be used to identify inefficient or oversized inventory motors and compute the energy and demand savings associated with selection of a replacement energy-efficient model. ETAP power station, developed by Operation Technology Inc (OTI), is also a comprehensive analysis platform for design, analysis and operation of generation, distribution and industrial power systems and so it is used in this work to design, model and analysis of the factory substation in order to assess the power quality issues of the factory.

1.7. Description of the Study Area

Arbaminch Textile Factory was established, in 1991(G.C), in Arbaminch Town, located 505km south of the capital Addis Ababa ($06^0$00'N, $37^0$30'E) to supply textiles to Hawassa Textile Factory. The factory was designed primarily to produce polyester and cotton blended woven fabrics and yarns.

Equipped with spinning technology, open end spinning, the pre-spinning stages of 2nd passage drawing and roving, the post-spinning stage of winding can all be accomplished as just one point. The factory is also equipped with high speed shuttle less rap air loom; each of which fitted with a microprocessor facility to enable the operatives to adjust and configure the required production and machine parameters. Air conditioning system, well-equipped physical testing laboratory, water treatment plant, a complete fire-fighting and protection system as well as organized mechanical, electrical and automotive workshops are its additional features.

The factory power distribution system consists of six (6) distribution transformers of capacity 1250KVA each. A bank of capacitors having total capacity of 450KVA each is installed at each transformer secondary terminal. The Factory has one Diesel generator of capacity 450KVA in the factory, which is used as emergency power supply for some critical loads. This generator only supplies loads connected to the transformer named T6. The factory has a total connected load of about 5.7MVA as obtained from the factory's one-line diagram

The total investment cost of the factory was 192,374,000 Birr. The fenced area of the factory is 180,000 square-meters of land at a suitable plot four kilometres far from the town. The construction work is carried out on a total area of 32,400 square-meters occupied by factory building, utility building, multipurpose and changing room, office building, Gate House and power-substation.

Figure 1-1: Some Part of Arbaminch Textile factory

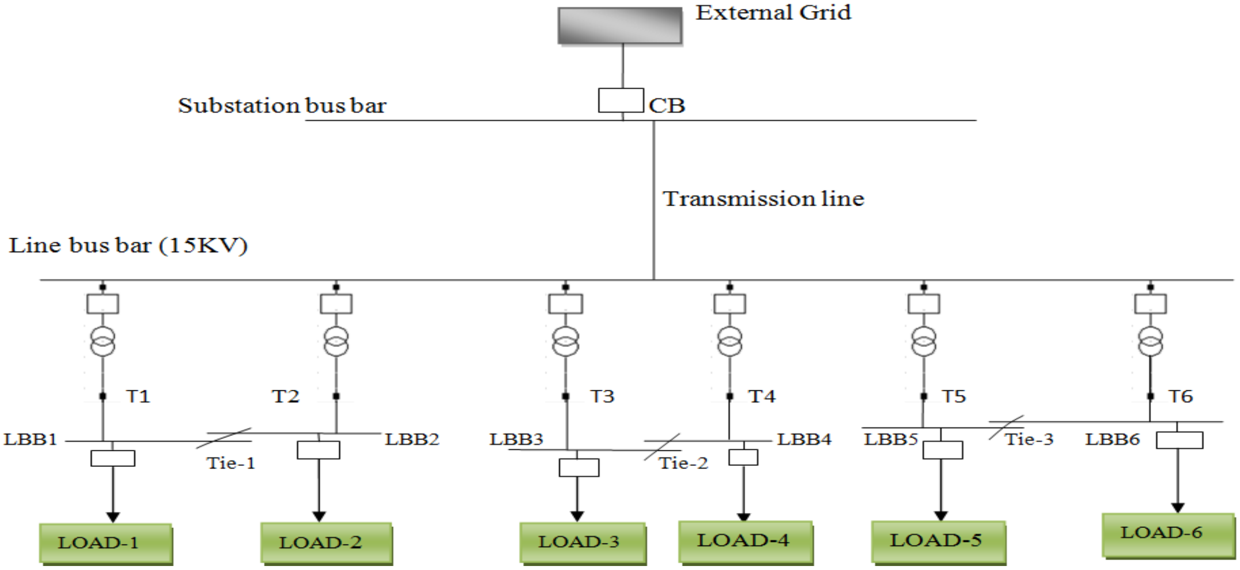


Figure 1-2: The Simplified one line diagram of power distribution System at Arbaminch Textile factory

1.8. Literature Review

The study required broad knowledge of the issues regarding Energy Auditing and efficiency improvement in industries: power qualities in the industrial systems, and harmonic modelling and simulation techniques, standard limits and requirements, sizing of compensators, and results from previous studies by other researchers. All these information are necessary to address, understand and complete the research. The following sections include brief knowledge of energy audit, power quality and reviews on papers and previous works relevant to this research.

Jatin Gupta [1] provides information on energy-efficient technologies and production measures applicable to the textile industry. The work also includes analysis of an audit conducted on motors of different horsepower in a textile plant and includes energy saving and cost information available. For some measures this report also provides range of savings and payback periods found in under varying conditions. The thesis report analysis is done only on rewound induction motors for its efficiency improvement.

Ali Hasanbeigi et.al [7] the thesis aims to contribute to the understanding of energy use in the textile industry by presenting the energy use of textile plants in five major sub-sectors in Iran, i.e.

spinning, weaving, wet-processing, worsted fabric manufacturing, and carpet manufacturing. The energy intensity of each plant was calculated and compared against other plants within the same sub-sector. The results showed the range of energy intensities for plants in each subsector. It also showed that energy saving/management efforts should be focused on motor driven systems in spinning plants, whereas in other textile sub-sectors thermal energy is the dominant type of energy used and should be focused on.

For conducting a fair and proper comparison or benchmarking studies, factors that significantly influence the energy intensity across plants within each textile sub-sector (explanatory variables) are explained. Finally, lists of energy efficiency improvement measures observed during the study are presented.

The thesis mainly focused on the energy intensities on the plant level; it didn't consider analysis on energy loss and money saving on equipment level and doesn't consider the barriers on process of manufacturing, energy management and power quality issues.

Amare Matebu [8] on top of providing some background information on the features of textile, this work identified the major components of quality management system (QMS) for textile industries and proposed the appropriate implementation model of quality management system and also provided guidance to the management of textile industries on the application and use of quality management system to improve its overall performance.

Currently, almost all textile industries in Ethiopia are suffering from quality related problems. These problems include: poor performance of products in the export market, low quality and insufficient raw material supply, incompetence in the world market, customer dissatisfaction, low productivity, and poor utilization of the resources. Because of these problems, most of the textile companies in the country are not profitable and most are in a huge loss.

This research work mainly focused on how this loss and low market share in textile companies could be mi with the help of quality management system (QMS).

Eng. Basel Tahseen et.al [9] this work tried to establish a start or a beginning step toward the efficient use of energy and energy conservation opportunities in different industry through conducting energy audit and analysis of industrial consumption in Palestine.

The work identifies the most energy intensive areas of the industries and suggests measures which can be implemented to conserve energy or reduce energy consumption. It was showed that there is a decent potential for energy savings in the audited industrial facilities. On the national level 10 to 20% savings from the total energy consumption in the industrial sector could be achieved by implementing some energy conservation measures on the most energy consumption equipment in the facility such as boilers, compressors, lighting system and low power factor. In addition decreasing the demand on energy that enhancing the national economy, there is a huge reduction in the environmental emissions such as CO_2 (175 tons) reduction.

S.Khalid et.al [10] this thesis presented an innovative technology management by critically analysing about power quality problems, issues, related to international standards, and their effect in life and the corrective measures using different means. The corrective measures are also discussed which can be remedy for power quality problems generated in different equipment's. Coordination with existing industry practices and international harmonic standards is also considered in this paper.

M.K.Pradhan et.al [11] the thesis presents a case study of application of solid-state harmonic filter to improve electric power quality and reduce energy consumption in textile industries. Detailed studies were carried out in various textile firms in India and the effects of poor power quality especially harmonics were analysed on the productivity and energy consumption. Harmonic current generated by nonlinear loads like motors driven by Variable Frequency Drives (VFD) cause power system heating and add to user power bills. The harmonic related losses are present in the power cables, bus bars linking the loads with source, the power transformer itself. A more serious effect of harmonic loads served by transformer is due to an increase in winding eddy current losses. The heat generated due to harmonics must be removed in order to save electrical energy, thus leading to savings in the utility bill. The paper is a case study where a 1.5 MVA transformer used for powering the spinning section of a textile mill. The current

Harmonics is recorded with & without using the Active harmonic filter (AHF). The power parameters are recorded on both the primary & secondary side of transformer to demonstrate how the active harmonic filter can reduce the effects of harmonics and save energy.

Sharmistha Bhattacharyya et.al [12] presented the effect and interaction of mixed LV linear and non-linear loads on the level of harmonic distortion. The paper used software called Dig SILENT Power Factory to simulate the LV customer installation. Various household devices were measured and the harmonic spectrums of the connected devices obtained from measurement were fed into the software to perform harmonic simulations. Furthermore, a case study was carried out to evaluate the total current harmonic distortion level at a customer’s installation when the grid voltage is polluted with a specific order of harmonics. The analysis of this paper shows that the use of non-linear loads in the household activities has significant influence on the networks harmonic current pollution level. The combined effects of various non-linear LV devices (home appliances, etc.) attenuate the total harmonic current distortion in the network mainly because of phase cancellation and diversity effects. In this study, it was found that the total current harmonic distortion level at the customer’s installation is around 14% when the customer has mixed loads.

2. Textile Manufacturing Process and Data collection

2.1. Over View of Textile Industry

Textile industry has played an important role in the development of human civilization over several decades. The textile industries fulfil one of the three basic needs of human being (housing, food and clothing) by providing clothes. The technological developments from the second part of the eighteenth century onwards led to an exponential growth of cotton and synthetic fibres outputs, first starting in the UK and later spreading to other European countries and others [1].

According to CSA medium and large-scale industries survey, the current number of establishments engaged in the textile and garment manufacturing sector is 56. The most numerous establishments are involved in spinning, weaving and finishing of textiles. The knitting mills and the wearing apparel manufacturers are much smaller in size [8].

The main products manufactured by the state enterprises are cotton fabrics, nylon fabrics, acrylic yarn, cotton yarn, woollen and waste yarn cotton blankets, and sewing threads. Most of the integrated textile mills are engaged in the production and finishing of fabrics. Market yarn for the handloom weavers (local weavers) and cottage industries is commonly produced in most of the textile mills. The privately owned factories are predominantly engaged in garment making, but the types of product manufactured by this sub-sector are diverse. Table below shows the major textile and garment products manufactured in the country and the public factories engaged in the production of these items [8].

Table 2-1: Major produced items [8]

S.N	Major item produced	Enterprise engaged in the production
1	Cotton yarn	Akaki textile share company, Adey Ababa yarn share company, Arbaminch textile share company, Awassa textile factory, Diredawa textile factory, Ediget yarn and sewing factory
2	Acrylic yarn	Diredawa textile factory, KK textile industry
3	Fabrics	Akaki Textile share company, Ethio-japan synthetic factory, Arbaminch textile share company, Awassa textile factory, Diredawa textile factory, bahirdar Textile share company, combolcha Textile factory and Almeda Textile factory.
4	Blanket	Adey Ababa yarn share company, KK Textile industry
5	Woven Garment	Addis garment, Akaki garment, Nazareth garment factory
6	Knitted Garment	Adey Ababa yarn share company, Almeda Textile factory
7	Sewing threads	Ediget yarn factory, Nefase silk yarn factory

2.2. Textile Manufacturing Process

Textile is any kind of woven, knitted, knotted or tufted cloth, or a non-woven fabric. Non-woven fabric is a fabric which is made of fibers / yarn that have been bonded into a sheet like structure by means of mechanical actions or chemical bonding. The production of textiles is an ancient art, whose speed and scale of production has been increased almost beyond recognition by mass-production with the introduction of modern manufacturing techniques [8].

Textile mills take natural and synthetic fibers, such as cotton and polyester and transform them into yarn, thread, or webbing. Yarns are strands of fibers in a form ready for weaving, knitting, or otherwise intertwining to form a textile fabric. They form the basis for most textile production and commonly are made of cotton, wool, or a synthetic fiber such as polyester. Yarns also can be made of thin strips of plastic, paper, or metal. To produce spun yarn, natural fibers such as cotton and wool must first be processed to remove impurities and give products the desired texture and durability, as well as other characteristics. After this initial cleaning stage, the fibers are spun into yarn [8].

Fabrics are mostly produced by means of weaving, knitting, or tufting. Workers in weaving mills use complex, automated looms to transform yarns into cloth, a process that has been known for centuries. Looms weave or interlace two yarns, so they cross each other at right angles to form fabric. Knitting uses automated knitting machines to interlock a series of loops of one or more yarns to form goods, such as sweaters, socks, and underwear. Tufting, used by carpeting and rug mills, is a process by which a cluster of soft yarns is drawn through a backing fabric [8].

At any time during the production process, a number of processes, called finishing, may be performed on the fabric. These processes, which include dyeing, bleaching, and stonewashing, among others, may be performed by the textile mill or at a separate finishing mill. Finishing encompasses chemical or mechanical treatments performed on fiber, yarn, or fabric to improve appearance, texture, or performance. Most of the textile industries in Ethiopia produce yarns and fabrics from 100 % cotton fiber for domestic consumption. Some of them such as, Arbaminch textile share company; Almeda textile Share Company; Awassa textile Share Company produces yarns and fabrics by blending the cotton fiber with polyester fiber for different end use [8].

Most textile industries in Ethiopia contain three main plants: spinning plant, weaving plant, and textile finishing plant. These companies produce yarns from textile fibers (such as cotton fibers, polyester fiber, nylon fiber, and acrylic fibers), fabrics (such as cotton fabrics, nylon fabrics, blankets) and others. There is a possibility to find each plant independently.

For example Ediget yarn factory produces only yarn and has a spinning plant only. The same is true for weaving and finishing plant. Most of the textile industries in Ethiopia produce a woven fabric. Interlacing the warp and weft yarns makes fabric and the process is called weaving. The final output of weaving plant is grey fabric. The textile finishing plant makes dyeing, coating, bleaching, or printing of the fabrics. A simple diagram, the figure below, could represent the general outlook of the textile industry [8].

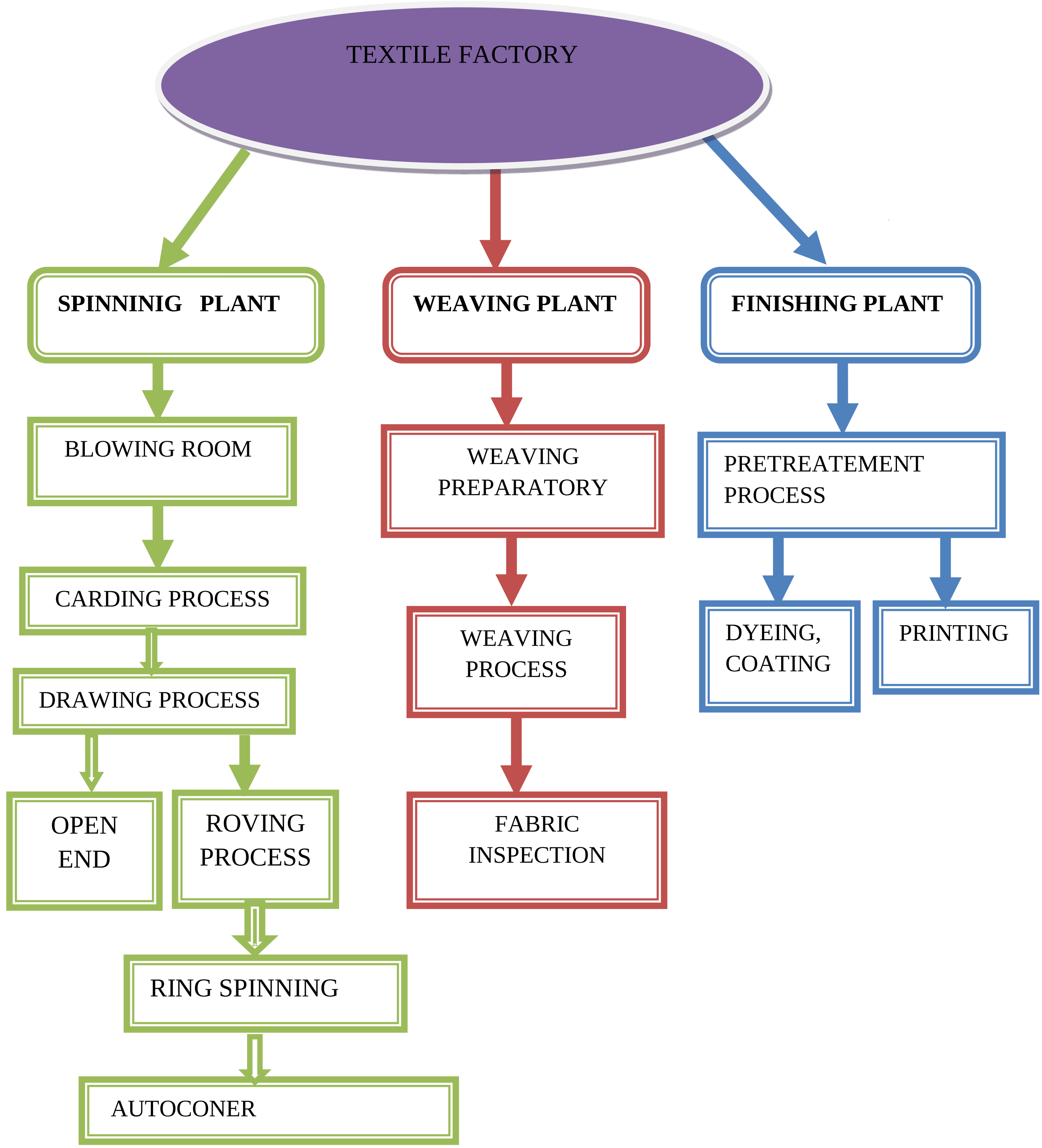


Figure 2-1: Three main categories of Textile factory

2.3. Breakdown of Energy Use by Textile Process

Breakdown of electrical energy is done on the bases of the part of energy consumed by different section of the plant. In these different sections of the textile industry, the electricity is used for production, lightening, HVAC, etc.

2.3.1. Energy use in the spinning process

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

- **Production Machine**

The textile industry uses a vast number of electric motors, and most of them are relatively small. While some of conventional machines are driven by a single motor, many modern machines utilize multiple motors with a control board for controlling the movement of each motor. The types of spinning machines involved in the production are the Blowing, Carding, Roving, Combing, Open- end, Ring frame and An Auto-cone. The pie chart below shows the distribution of energy by the machines and thus the total electricity consumption by the production machines take a large share (average 61.4 %).

- **Lighting**

The share of lighting in total electricity use is relatively high (average about 12.10%). fluorescent lamps are widely used in the spinning section. In order to use electricity efficiently for lighting, it is important to re-examine whether the light source is utilized in the most efficient way. Natural lightening at the factories could be used in order to minimize electricity consumption.

- **HVAC Systems**

Heating, Ventilating, and Air Conditioning (HVAC) related to systems that perform processes designed to regulate the air conditions within the factories for the comfort purpose and for some processes. HVAC systems condition and move air into the factories to create and maintain desirable temperature, humidity, ventilation and air purity. For the textile industry, during weaving process, temperature range should be about 30^0C, while the relative humidity is approximately 80% [8]. HVAC process consumes high-energy rate, especially in cotton spinning systems, if the spinning plant just produces raw yarn in cotton spinning system, and does not dye or fix the produced yarn, the electrical energy may just be consumed in the cold seasons for preheating the fibers before spinning them together. As can be seen from the pie chart, about 20.7% of total electricity is consumed by HVAC systems for AMTF. For the energy saving and use the energy efficiently, recommended guidelines should be followed closely so that too much fresh air is not introduced unnecessarily. Also some conditioned air after filtered can be used with the fresh air to reduce the electricity consumption.

Figure 2-2, shows the Breakdown of final energy use in a spinning plant. The graph on the right shows the breakdown of the energy use by the category “Machines” that is shown in the graph on the left. The pie-charts are plotted based on the energy distribution table (appendix-D)

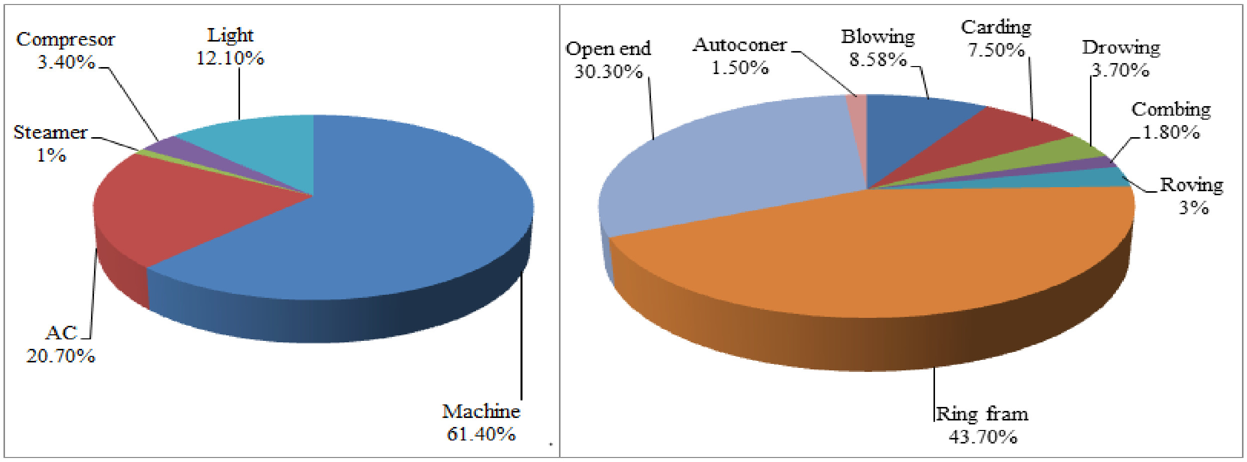


Figure 2-2: Breakdown of the final energy use in a spinning plant

2.3.2. Breakdown of Energy in composite process (spinning-weaving)

The Figure below shows the breakdown of the typical electric energy use by different sections of the plant. As can be seen, spinning consumes the greatest share of electricity (44.7%) followed by weaving (weaving preparation and weaving) (29.7%).

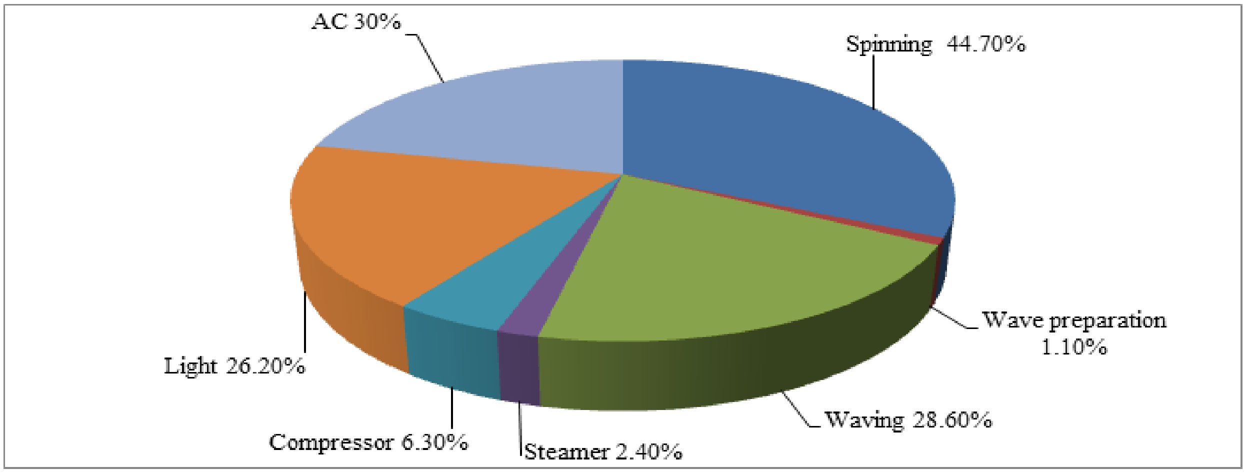


Figure 2-3: Breakdown of typical electricity use in composite plan

2.4. Data Collections

In the research work on industrial energy Auditing and efficiency improvement at Arbaminch Textile factory, the data collection has been done through different methods: personal interviews, direct observation of the companies, telephone, and the available documents of the company.

Tables 2-2, provides the factory four years of Textile production and energy consumption data and also shows the specific energy consumption. Energy costs of AMTF as well as the standard plants taken as a benchmark, the electric motors and lighting data's and the transformers measurement date are located in the following tables.

Table 2-2: Review of textile production and energy consumption at AMTF

No	Items	Unit	years (G.C.)			
			2011/12	2012/13	2013/14	2014/15
1	Yarn Production	Kg	1,009,400	1,349,677	1,615,776	2,056,345
2	Gray Fabric Prod.	Kg	338,838.76	612,697.8	1,328,025	1,900,500
3	Total production	Kg	1,348,238.76	1,962,374.8	2,943,801	3,956,845
4	Elec. consumption	KWh	10,339,000	10,077,000	10,346,500	12,690,000
5	Fuel consumption	Lit	150,766.7	102,572	208,961.5	…………
6	Specific elec. Cons	KWh/Kg	7.67	5.14	3.51	3.21

7	Specific fuel. Cons	Lit/Kg	0.112	0.1	0.1	…………
8	Energy int(elec.)	KJ/Kg	27,606.68	18,486.38	12,652.63	11,545.56
9	Energy int(fuel)	KJ/Kg	4,487.31	2,097.46	2,848.43	…………

Table 2-3: Energy costs at AMTF for both electric and furnace oil

Items	Unit	Year(G.C)			
		2011/12	2012/13	2013/14	2014/15
Furnace oil	Birr	2,400,495.31	1,621,140.35	3,179,850.26	…………..
Electric energy	Birr	4,224,515.4	4,117,462.2	4,227,579.9	5,185,134
Total	Birr	6,625,010.71	5,738,602.6	7,407,430.16	5,185,134

Table 2-4: Production, Energy use, and Energy intensities of three different Spinning and Weaving plants in Iran (A, B, and C are Spinning and D, E are Weaving) [7]

plant	**Annual production (tonne)**	**Annual Elec. Consumption (KWh)**	**Annual fuel Consumption (GJ)**	**Spec. elect Consumption (KWh/kg**	**Spec. fuel Consumption (lit/Kg)**	**Elec. Energy intensity (KJ/Kg)**	**Fuel Energy intensity (KJ/Kg)**	**Total Energy intensity (KJ/Kg)**
A	2003	13,290,450	24,760	6.6	0.308	23,760	12,400	36,160
B	8140	38,584,206	57,694	4.7	0.177	16,920	7,100	24,020
C	2448	8,860,300	19,808	3.6	0.202	12,960	8,100	21,060
D	6027	13,290,450	103,993	2.21	0.43	7,920	17,300	25,220
E	6299	7,420,040	67,397	1.12	0.267	4,320	10,700	15,020

Table 2-5: Lighting Data

No.	Department	LN	TP	TL	RA	IL	OH
1	Guard	6	240	20,400	32	637.5	24
2	Time Keeper	4	160	13,600	36	377.8	24
3	Fire alarm control room	2	80	6,800	34	200	24
4	Raw materials stores	20	800	68,000	140	485.7	24

No.	Department	LN	TP	TL	RA	IL	OH
5	clinic	6	240	20,400	164	124.4	8
6	Spinning	1,036	80,808	6,868,680	13,134	523	24
7	Weaving	1173	91,494	7,776990	10,806	719.7	24
8	Wave preparation	564	43,992	3,739,320	4,558	820.4	24
9	Utilities	167	13000	1,105,000	820	1348	24
9	Canteen	12	480	40,800	245	166.53	8
10	Administration building	89	3,560	302,600	510	593.33	8
11	Garage	10	400	34,000	513	66.28	8
12	Get house	4	160	13,600	40	340	24
13	Substation	20	800	68,000	464	147	16
14	Water pump & Air compressor	16	640	54,400	820	66.34	24
15	Fabric store	20	800	68,000	104	653.84	24
16	General store	25	1,000	85,000	201	422.89	8
	Total	3188	239,214				

Table 2-6: Selected Electric Motors data (for more and detail see Appendix B)

No.	**Motor Description**	**Name plate power(KW)**	**Nameplate Speed(Rpm)**	**Department**
1	Main motor drive	2.2	1460	Blowing (blending feeder)
2	Motor fun	3.0	1420	Blowing(Gage condenser)
3	Beater drive motor	3.0	592	Blowing(Horizontal opening)
4	Main drive motor	3.0	1460	comber
5	Bush drive motor	1,5	1420	comber
6	B150 Motor fan	4.0	1425	Carded line
7	Main drive motor	7.3	2910	Silver Drawing winder
8	Suction drive motor	4.0	1420	Roving
9	Main drive motor	22.0	2910	Ring spinning
10	Suction drive motor	7.5	2910	Ring spinning
11	Main drive motor	5.5	1425	Card
12	Undercard suction drive	1.5	1425	Card
13	Fan motor	11.0	1350	Winding
14	Spinning rotor motor drive	30	2950	Open end
15	Drive box cooling fun	115	1420	Open end
16	Technological air fun drive motor	20.0	2935	Open end
17	GA55C Main drive motor	55	2975	Compressor

No.	Motor Description	Name plate power(KW)	Nameplate Speed(Rpm)	Department
18	GA22 Main drive motor	22.0	3000	Compressor
19	Soft water booster pumps A	5.5	2910	Utility
20	Soft water booster pumps B	5.5	2910	Utility
21	Pump for sprinklers	115	1780	Utility
22	Pump for hydrants	115	1780	Utility
23	Soft water feeder pump A	3.0	1430	Utility
24	Mobile compressor drive motor	5.5	2930	Utility
25	Submersible water pump	24.5	960	Utility
26	Main motor	15.0	1460	Steamer/Humidification
27	Main motor	37.3	2800	Preparatory(sizing)
28	Motor turbine	7.5	960	Preparatory(sizing cooker)
29	Main motor	5.0	2850	Loom shade
30	Suction motor	3.0	2830	Loom shade
31	Main motor	15.0	2800	Warping
32	Hydraulic motor	5.5	1420	Warping

Table 2-7: Transformer Measurement Data

Transformer code	Line code	Vp[V]	V[L]	I[A]	P[KW]	S[KVA]	Q[KVAR]	Cosϕ	fr[Hz]
T-1	**L-a**	227.5	391.3	707.9	149.6	168.2	77.0	0.88	49.7
	L-b	228.1	390.7	708.3	145.5	163.9	75.7		
	L-c	225.3	390.0	709.6	144.2	161.2	72.1		
T-2	**L-a**	227.4	393.3	700.4	85.4	97.6	46.5	0.86	49.6
	L-b	225.7	392.2	699.0	84.0	94.7	43.6		
	L-c	227.5	392.7	702.0	84.2	95.1	44.6		
T-3	**L-a**	227.3	393.3	461.6	94.1	106.9	50.4	0.87	49.8
	L-b	227.8	394.2	460.2	94.8	108.6	52.5		
	L-c	228.9	396.5	459.8	94.2	107.8	50.9		
T-4	**L-a**	228.0	394.4	355.2	70.8	81.6	40.5	0.87	49.8
	L-b	226.1	391.7	355.4	70.3	81.3	40.9		
	L-c	225.9	392.4	355.8	70.3	81.3	40.9		

Transformer code	Line code	Vp[V]	V[L]	I[A]	P[KW]	S[KVA]	Q[KVAR]	Cosϕ	fr[Hz]
T-5	**L**	Left open, currently not connected							
T-6	**L-a**	225.8	392.9	548.2	55.6	63.9	31.4	0.86	49.1
	L-b	224.4	391.3	544.8	56.1	65.2	33.3		
	L-c	224.5	388.8	544.2	54.8	63.6	32.2		

3. Causes of Major Energy Losses and Their Energy Saving Opportunities in Textile Plant

Based on the walk-through audit conducted in the plant as well as information from the collected data, the major power consuming areas in the textile plant which have high energy saving opportunities are lightings, ring frame parameters, rewound motors, electrical networks, air conditioners and air compressors. Energy efficiency improvements for the textile industry refers to a reduction in the energy usage for a given energy service (production, heating, lighting, etc.). This reduction in the energy consumption is not necessarily associated to technical changes, since it can also result from a better organization and management or improved economic efficiency in the sector (e.g. overall gains of productivity). Energy efficiency is first of all a matter of individual behaviour and rationale of energy consumers. Avoiding unnecessary consumption of energy or choosing the most appropriate equipment to reduce the cost of the energy contribute to decrease individual energy consumption without decreasing individual welfare and production. It is obvious that it also contributes to increase the overall energy efficiency of the national economy [13].

There are different opportunities to improve energy efficiency at AMTF while maintaining or enhancing productivity. Improving energy efficiency at textile plant should be approached from several directions. First, the plant uses energy for different equipment's which require regular maintenance, good operation, and replacement, when necessary. Thus, a critical element of plant energy management involves the efficient control of cross-cutting equipment that powers the production processes of a plant. A second and equally important area is the proper and efficient operation of the processes. Process optimization and ensuring that the most productive technologies are in place are keys to realize energy saving in a plant's Operation [4].

3.1. 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 and are given in table 3.1 and 3.2 below consequently.

Various terms and definitions are used to quantify light, light source, etc. They are luminous flux, luminous intensity, illumination, luminance, etc. These definitions are explained in Appendix -A.

Table 3-1: Luminous Intensity and Life time of Various Lamps [14]

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 vapour lamps	50-60	46%	16,000-24,000
6	High Pressure Na Lamps(HPS)	75-130	100%	24,000
7	Low Pressure Na	100-200	------	16,000
8	Compact Fluorescent Light(CFL)	45	46%	7000-10,000

Table 3-2: Illuminations Required in various Working Station [15]

No.	Working Station	Average ILLuminance required(LUX)	Remark
1	office	500	
2	canteens	150	
3	Boilers and pump houses	20-100	
4	Spinning	150-450	
5	Knitting	300-750	
6	Weaving	200-700	
7	Grey close inspection	700-1000	
8	Final inspection	700-1000	
9	Work shops	200-750	
10	Clock rooms, Entrances, Corridors, Stairs	100	

The lighting point's data in each section of the factory has been collected and analysed as in table 3.3 below. Currently 3188 fluorescent lamps are installed with 40 W and 78W (including ballast) power ratings and 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's diameter in terms of 1/8 inch increments). It can be observed from the table that the total installed capacity of the lighting system is about 239.24KW with a daily energy consumption of 5,741.76KWh.

The key descriptions and discussions of the results of the lighting data of table 3.3 are given below.

All the lamps found at Arbaminch Textile factory are florescent lamps with ratings 40 W and 78W. The symbols used in the table are explained as;

NL – number of lamps installed in the department

TP – Total power ratings of the lamps installed in the department given in watts and Obtained as follows:

$$\mathbf{TP = LR \times NL} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

Where LR is lamp rating

TL – Total lumens output of lamps installed in the department

$$\mathbf{TL = NL \times Lo} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

Lo – is the luminous output of each fluorescent lamp which is 85lumens/watt obtained in the table for fluorescent lamps.

RA – Room area of each department measured in square meter.

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/m2).

$$\mathbf{IL = TL/RA} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3)}$$

OH – Operating hours per day and explains the time each department is devoted to the factory works.

ALR – The actual lamps required for proper illumination which is used to analyse energy wastes due to improper illumination. Let us calculate the actual number of lamps with the same ratings at the factory.

$$\mathbf{ALR = (ILR/IL)*NL} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.4)$$

Where,

ILR is the illumination required in each office (department) which is 500 Lux from table 3.2 above and this figure is compared with the actual lux produced in each office. The actual florescent lamp required (ALR) are calculated for each department and compared with number of lamps (NL) currently installed. Energy utilization (EU) for the lighting systems can be calculated using equation and compared with the energy required (ER) after a proper illumination as shown in table the energy difference(ED) explains the energy utilization and the energy required after proper illumination.

$$\mathbf{EU = NL\times LR} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.5)$$

$$\mathbf{ER = ALR\times LR} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.6)$$

$$\mathbf{ED = EU\text{-}ER} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.7)$$

Table 3-3: Lighting Data Summary

No	Department	NL	TP	TL	RA	IL	ALR	OH	EU (kwh)	ER (kwh)	ED
1	Guard	6	240	20,400	32	637.5	5	24	5.76	4.8	0.96
2	Time Keeper	4	160	13,600	36	378	5	24	3.84	4.8	-0.96
3	Fire alarm control room	2	80	6,800	34	200	5	24	1.92	4.8	-2.88
4	Raw material store	20	800	68,000	140	485.7	21	24	19.2	20.2	-1
5	clinic	6	240	20,400	164	124.4	24	8	1.92	7.7	-5.78
6	Spinning	1,036	80,808	6,868,680	13,134	523	891	24	1939.4	1668	271.4
7	Weaving	1,173	91,494	7,776,990	10,80 6	720	1140	24	2196	2134.1	62.0
8	Wave preparation	564	43,992	3,739,320	4,558	820.4	481	24	1055.8	900.4	155.4

9	Utilities	167	13,000	1,105,000	820	1348	61	24	312.0	114.2	197.8
10	Canteen	12	480	40,800	245	166.53	36	8	3.84	11.52	-7.68
11	Administration building	89	3,560	302,600	510	593.3	75	8	28.5	24	4.5
12	Garage	20	800	68,000	513	133	75	8	6.4	24	-17.6
13	Get house	4	160	13,600	40	340	6	24	3.84	5.76	-1.92
14	Substation	20	800	68,000	464	147	68	16	12.8	43.5	-30.7
15	Water and air compressor	20	800	68,000	720	94.4	21	24	19.2	20.16	-0.96
16	Fabric store	20	800	68,000	104	653.84	15	24	19.2	14.4	4.8
17	General store	25	1,000	85,000	201	422.9	9	8	8.0	2.9	5.1
	Total	3188	239,214				2938			5005.2	

The lighting data of each department of the factory is collected and analysed in the table 3.3. Totally there are around 3188 florescent lamps of which 248 are 40W and 2940 are 78W ratings and are currently installed in the factory. The total installed capacity of the lighting system is about 239.24kw and a daily energy consumption of 5,741.76kWh. The actual florescent lamps required in the factory should be around 2938 lamps. Therefore there are unnecessary lamps installed. There are a significant energy differences (ED) between the energy utilization (EU) due to currently install florescent lamps and the actual energy required (ER). This shows that there are energy losses due to lighting systems in the factory.

3.2. Energy Efficiency opportunities in Lighting System

As shown above, there exists an opportunity to conserve energy within this lighting system. Therefore, it is important to examine whether the light source is utilized in the most efficient way and take energy saving measures. In the next sub-sections energy saving opportunities of the lighting system that should be implemented in the factory will be discussed.

3.2.1. Task Lighting

Task lighting implies providing the required good illuminance only in the actual small area where the task is being performed, while the general illuminance of the shop floor or office is kept at a lower level; e.g. Machine mounted lamps or table lamps. Energy saving takes place because good task lighting can be achieved with low wattage lamps. The concept of task lighting if sensibly implemented, can reduce the number of general lighting fixtures, reduce the wattage of lamps, save considerable energy and provide better illuminance and also provide aesthetically pleasing ambience. In some textile mills, lowering of tube light fixtures has resulted in improved illuminance and also elimination of almost 40% of the fixtures. The dual benefit of lower energy consumption and lower replacement cost has been realized. In some engineering industries, task lighting on machines is provided with CFLs. Even in offices, localised table lighting with CFLs may be preferred instead of providing a large number of fluorescent tube lights of uniform general lighting [16].

3.2.2. Lighting Controls

Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors that turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10-20% of facility lighting energy use. System Manual controls can be used in conjunction with automatic controls to save additional energy in smaller areas. One of the easiest measures is to install switches to allow occupants to control lights. It is also important to make employees aware of the importance of turning off lights in other lighting controls include daylight controls for indoor and outdoor lights, which adjust the intensity of electrical lighting based on the availability of daylight [17].

3.2.3. Improvement of the Installation System

There must be sufficient and appropriate illumination for varieties of operation in the factory. The illumination required for various operations and the luminous intensity of various lamps are given in table 3.1 and 3.2. As explained in section 3.1, currently, there are 3188 lighting points installed in the factory all fitted with 40W and 78w fluorescent lamps. In certain office segments the illumination is not significant and additional lamps need to be installed to bring the appropriate brightness. On the other hand, there is more than sufficient illumination in the other offices indicating possibility of reducing the number of lamps installed in these offices. After the appropriate illumination has been checked, only 2938 lamps or 365 lamps of 40W ratings and 2573 lamps of 78W ratings would be required. This results in total reduction of 250 lamps which is equivalent to 23.95KW of power. It also results in energy saving of 209,802KWh/y and in money savings of 85,725 Birr annually.

3.2.4. Lighting Maintenance

Maintenance is vital to lighting efficiency. Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. Together, these factors can reduce total illumination by 50 percent or more, while lights continue drawing full power. The following basic maintenance suggestions can help prevent this.

- Make fixtures, lamps and lenses clean every 6 to 24 months by wiping off the dust.
- Replace lenses if they appear yellow.
- Clean or repaint small rooms every year and larger rooms every 2 to 3 years. Dirt collects on surfaces, which reduces the amount of light they reflect [16].

3.2.5. Replacing T-12 Tubes with T-8 Tubes

In many industries including Arbaminch textile factory T-12 tube florescent lamps have been found. A T-12 tube refers to the diameter in 1/8 inch increment (T-12 means 12/8 inch or 3.8 cm diameter tubes). The initial output and energy consumption of these lights is high. These also have extremely poor efficiency, lamp life, lumen depreciation, and colour rendering index. Because of these maintenance and energy costs of T-12 tubes are high. Replacing T-12 lamps with T-8 (smaller diameter) lamps approximately doubles the efficiency of the former. Also, T-8 tubes generally last 60% longer than T-12 tubes, which lead to savings in maintenance costs. Typical energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30% [17].

As it has been discussed earlier, there are 3188 lamps currently installed in the factory indicating that there are 3188 T-12 fluorescent tubes. After the corrected installation, however, only 2938 lighting points would be required. Replacing these 2938 T-12 lamp tubes with T-8 lamps tubes, therefore, it is obtained:

Power demand saving (PDS):

PDS = $(0.3\times ALR\times LR)/1000 = (0.3\times 365\times 40)/1000 + (0.3\times 2573\times 78)/1000$

$= 64.6KW$

Energy Saving (ES):

ES = $(0.3\times ER\times 365) = 548{,}073.78KWh$

Birr Saving (BS):

BS = ES×R**=** 548,073.78kwh/year × 0.4086 birr/KWh

= 223,942.95 Birr/year

3.2.6. Replacement with CFL

The existing florescent lamps which have 40W power rating can be replaced by energy efficient compact florescent lamps (CFL) with 11W power ratings. It should be noted, however, that energy saving is not realized in replacement of the existing fluorescent lamps with CFL lamps because the luminous intensity of fluorescent lamps is better than that of the CFL as we can see in the table. Therefore it is recommended that the existing fluorescent lamps should be replaced by the CFL of small rating in the rooms with sufficient day lighting and in the offices that are unused and locked at night as the day lighting and the small rating CFL supplements each other. In this regard much higher saving could be realized in the Lighting system [17].

3.2.7. Use of Natural Day Lighting

Day lighting is the efficient use of natural light in order to minimize the need for artificial light in buildings. Increasing levels of daylight within rooms can reduce electrical lighting loads. Efficient day lighting system may provide evenly dispersed light without creating heat gains. Day lighting differs from other energy efficiency measures because its features are integral to the architecture of a building, and so it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can be cost-effectively refitted with day lighting systems. Various day lighting systems are available on the market; some of which can be supplied as kits to retrofit an existing building. Day lighting can be combined with lighting controls to maximize its benefits. Because of its variability, day lighting is usually combined with artificial lighting to provide the necessary illumination on cloudy days or after dark. Day lighting technologies include properly placed and shaded windows, atria, angular or traditional (flat) roof lights, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts utilize angles of the sun and redirect light with walls or reflectors.

Not all parts of a facility may be suitable for the application of day lighting. Day lighting is most appropriate for those areas that are used in daytime hours by people. In office spaces, day lighting may save between 30 and 70%. The savings will vary widely depending the facility and buildings. Some problems associated with day lighting in industrial buildings have been identified due to the structure of the building. Various companies offer day lighting technologies. Day lighting systems will have a payback period of around 4 years, although shorter paybacks have been achieved [16].

3.3. Assessments of Electric Motors

3.3.1. Motor Loading

The ‘loading’ (or load factor) of a motor is the amount of work it does compared with its Maximum rated power output or it is the motor’s torque output and corresponding speed required. For example, a motor rated at 90kW driving an 81kW load is said to be 90% loaded. Modern motors operate most efficiently above 50% loading with a peak between 75% and 90% load. Note that the rating plate on a motor declares its output power at the shaft, so the actual electrical input energy drawn will be the output power at the shaft plus the power lost due to the motor inefficiency [18].

Loads can generally be categorized into three groups:

- **Constant torque loads** are those for which the output power requirement may vary with the speed of operation but the torque does not vary. Conveyors, rotary kilns, and constant-displacement pumps are typical examples of constant torque loads.
- **Variable torque loads** are those for which the torque required varies with the speed of operation. Centrifugal pumps and fans are typical examples of variable torque loads (torque varies as the square of the speed).

- **Constant power loads** are those for which the torque requirements typically change inversely with speed. Machine tools are a typical example of a constant power load [16].

Because the efficiency of a motor is difficult to assess under normal operating conditions, the motor load can be measured as an indicator of the motor's efficiency. As loading increases, the power factor and the motor efficiency increase to an optimum value at around full load. Most electric motors are designed to run at 50% to 100% of rated load. Maximum efficiency is usually near 75% of rated load [19]. Thus, a 10-horsepower (hp) motor has an acceptable load range of 5 to 10 hp; peak efficiency is at 7.5 hp. A motor's efficiency tends to decrease dramatically below about 50% load. However, the range of good efficiency varies with individual motors and tends to extend over a broader range for larger motors, as shown in Figure 3.1.

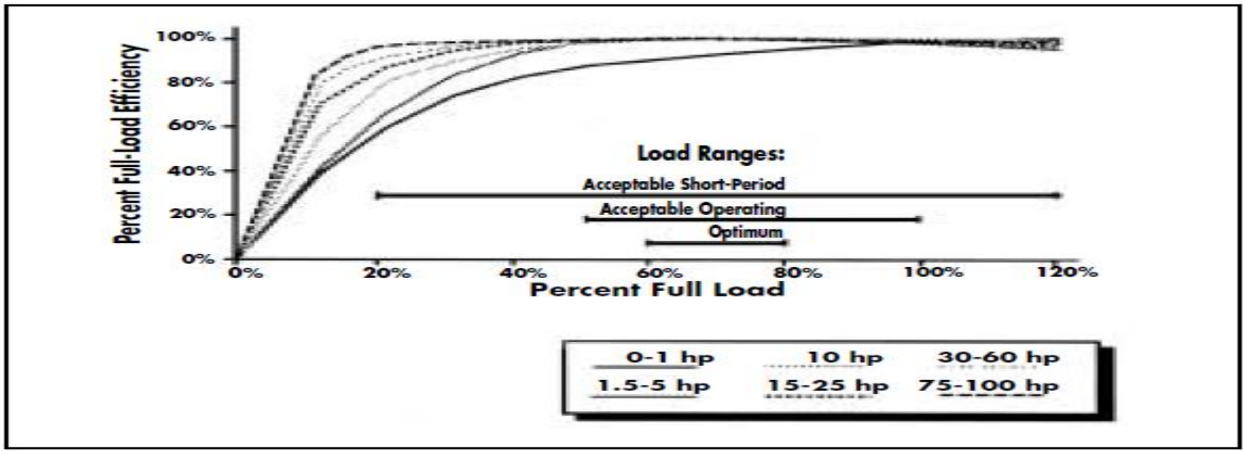


Figure 3-1: Motor part-load Efficiency [18]

A motor is considered under loaded when it is in the range where efficiency drops significantly with decreasing load. Overloaded motors can overheat and lose efficiency. Many motors are designed with a service factor that allows occasional overloading. Service factor is a multiplier that indicates how much a motor can be overloaded under ideal ambient conditions. For example, a 10-hp motor with a 1.15 service factor can handle an 11.5-hp load for short periods of time without incurring significant damage. Although many motors have service factors of 1.15, running the motor continuously above rated load reduces efficiency and motor life [19].

To compare the operating costs of an existing standard motor with an appropriately-sized energy efficient replacement, you need to determine operating hours, efficiency improvement values, and load. Part-load is a term used to describe the actual load served by the motor as compared to the rated full-load capability of the motor. Motor part-loads may be estimated through using input power, amperage, or speed measurements.

- **Input Power Measurements:**

This method calculates the load as the ratio between the input power (measured with a power analyser) and the rated power at 100% loading**.** In this case, the motor's measured kW (or V, I and PF) is required.

$$P_i = \frac{V \times I \times PF \times \sqrt{3}}{1000} \quad \text{.......................................} \ (3.8)$$

Where:

Pi = Three-phase power in KW

V = RMS voltage, mean line-to-line of 3 phases

I = RMS current, mean of 3 phases

PF = Power factor as a decimal

And

$$P_{ir} = \frac{hp \times 0.7457}{\eta fl} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.9)$$

Where:

P_{ir}= Input power at full-rated load in kW

Hp = Nameplate rated horsepower

ηfl = Efficiency at full-rated load

$$\text{Thus,} \quad \text{Loading} = \frac{P_i}{P_{ir}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.10)$$

- **Voltage Compensated Current Ratio**:

The motor load varies almost linearly with motor current draw, down to approximately 50 - 60% load. (Below that, magnetizing current requirements and other inefficiencies cause increasing non-linearity). Therefore, if the nameplate full-load current is known and the actual current is measured, one can estimate the motor load. As with rated speed in the slip calculations, the rated full load current is based on operation at the rated voltage. If the actual operating voltage is different from the rated voltage, the full-load current must be corrected, thus

$$\text{Loading} = \frac{I}{I_r} \times \frac{V}{V_r}\ 100 \quad \text{……………………………… (3.11)}$$

Where:

Load = Output power as a % of rated power

I = RMS current, mean of 3 phases

Ir = Nameplate rated current

V = RMS voltage, mean line-to-line of 3 phases

Vr = Nameplate rated voltage

- **Slip Method**

The load is determined by comparing the slip measured when the motor is operating with the slip for the motor at full load. The accuracy of this method is limited but it can be used with the use of a tachometer only (no power analyser is needed).

$$\text{Load} = \frac{\text{Slip}}{S_s - S_r} \times 100 \quad \text{……………………………….. (3.12)}$$

Where:

Load = Output power as a % of rated power

Slip = Synchronous speed - Measured speed in rpm

Ss = Synchronous speed in rpm

Sr = Nameplate full-load speed

3.3.2. Efficiency of Electric Motors

The efficiency of a motor is the ratio of mechanical power output to electrical power input and is usually expressed as

$$\eta = \frac{0.7457 \times hp \times Load}{P_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.13)$$

Where:

η = Efficiency as operated in %

Hp = Nameplate rated horsepower

Load = Output power as a % of rated power

Pi = Three-phase power in KW

Motors convert electrical energy to mechanical energy to serve a certain load. In this process, Energy is lost as shown in Figure 3.2.

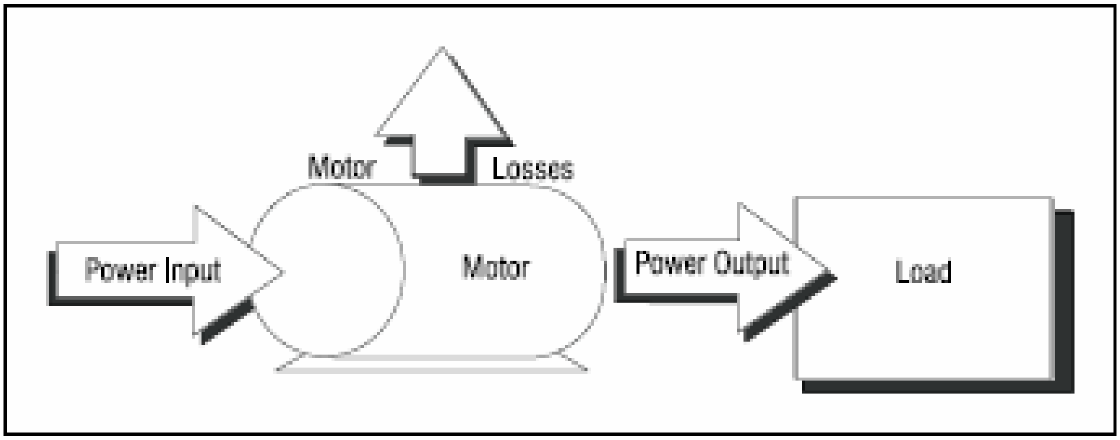


Figure 3-2: Motor Losses [16]

Motors can experience losses, whereby they consume electrical energy, but do not contribute useful mechanical energy output [20].

They occur in five areas:

- Core losses (25%)
- Stator losses (I^2 R loss about 35%)
- Rotor losses (I^2 R loss about 25%)
- Friction and windage (5%)
- Stray load losses (10%)

Factors that influence motor efficiency include:

- Age. New motors are more efficient
- Capacity. As with most equipment, motor efficiency increases with the rated capacity
- Speed. Higher speed motors are usually more efficient
- Type. For example, squirrel cage motors are normally more efficient than slip-ring motors
- Temperature. Totally-enclosed fan-cooled (TEFC) motors are more efficient than screen protected drip-proof (SPDP) motors
- Rewinding of motors can result in reduced efficiency
- Load, as described Above

Using Input Power Measurements and line current estimation technique to estimate motor loading and equation 3.13 to estimate motor efficiency, the most energy intensive AMTF motors are summarized in table 3.4 and the rest are found in Appendix B.

Table 3-4: Electric Motor Data Summary

No.	**Motor Description**	**Input power (kW)**	**Nameplate power(KW)**	**Nameplate speed(RPM)**	**Output power(KW)**	**Loading (%)**	**Efficiency (%)**	**Current draw (A)**	**Voltage measured(V)**	**power factor (Pf)**	**Department**
1	AC3(Return fun-1)	11.1	30	1420	9.59	32	86.3	19.7	370	0.88	Spinning
2	AC3(Return fun-2)	10.8	30	1420	9.17	30.6	85.3	19.1	365	0.89	Spinning
3	Spinning rotor motor drive	13.98	30	2950	12.6	41.9	90.1	21.8	394	0.94	Open end
4	Technological air fun motor drive	12.1	20	2935	10.78	53.9	88.9	22.4	355	0.88	Open end
5	Main motor drive	15.5	22	2910	11.55	52.5	74.5	25.0	380	0.94	Ring Spinning
6	Machine drive	4.46	5.5	1425	3.14	57.1	70.4	7.1	390	0.93	Carding
7	Machine drive motor	5.38	5.8	2910	3.96	68.3	73.6	10.4	360	0.83	Drawing
8	fun motor	8.53	11	1420	7.06	64.2	82.8	15.3	370	0.87	Winding
9	Main mtr drive	10.1	15	2800	8.68	57.9	85.9	17.2	390	0.87	Warping

10	Hydro lick motor	4.66	5.5	1450	3.44	62.5	73.8	8.3	360	0.90	Warping
11	Main motor	3.57	5	2850	3.46	69.2	96.9	6.0	390	0.88	Loom shed
12	Suction drive motor	3.64	4	1420	2.39	59.6	65.5	7.2	365	0.80	Roving
13	Main motor drive	7.94	37.3	2800	7.15	19.2	89.9	12.9	395	0.90	Sizing
14	Main motor	10.8	15	1760	9.32	62.1	86.3	17.4	394	0.91	Steamer
15	Motor turbine	5.13	7.5	960	3.98	53.0	77.5	8.33	391	0.91	Sizing cooker
16	Pump for sprinkler	53.3	100	1480	49.8	49.8	93.4	99.7	355	0.87	Utility
17	Pump for hydrant	37	100	1480	30.1	30.1	81.4	56.7	377	0.87	Utility
18	Submersible water pump	10.5	24.5	960	8.75	35.7	83.6	18.6	365	0.89	Utility
19	Compressor GA55C(Main drive motor)	41.5	55	2975	33.0	60.0	79.5	69	390	0.89	Utility
20	Compressor GA22(Main drive motor)	8.56	22	3000	7.23	32.8	84.4	14.4	390	0.88	Utility

3.4. Energy Efficiency Opportunities in Electric Motors

When planning to improve the efficiency of the motor system in an industry, a system' approach incorporating pumps, compressors, and funs must be used in order to attain optimal savings and performance. Consideration with respect to energy use and energy saving opportunities for a motor system are discussed below.

3.4.1. Install High Efficiency Motors In Place of Lower Efficiency Motors

High efficiency motors have been designed specifically to increase operating efficiency compared to standard motors. Design improvements focus on reducing intrinsic motor losses and include the use of lower-loss silicon steel, a longer core (to increase active material), thicker wires (to reduce resistance), thinner laminations, smaller air gap between stator and rotor, copper instead of aluminium bars in the rotor, superior bearings and a smaller fan, etc. Energy efficient motors cover a wide range of ratings and the full load. Efficiencies are 3% to 7% higher compared with standard motors as shown in Figure 3.3.

As a result of the modifications to improve performance, the costs of energy efficient motors are higher than those of standard motors. The higher cost will often be paid back rapidly through reduced operating costs, particularly in new applications or end-of-life motor replacements. But replacing existing motors that have not reached the end of their useful life with energy efficient motors may not always be financially feasible, and therefore it is recommended to only replace these with energy efficiency motors when they fail [16].

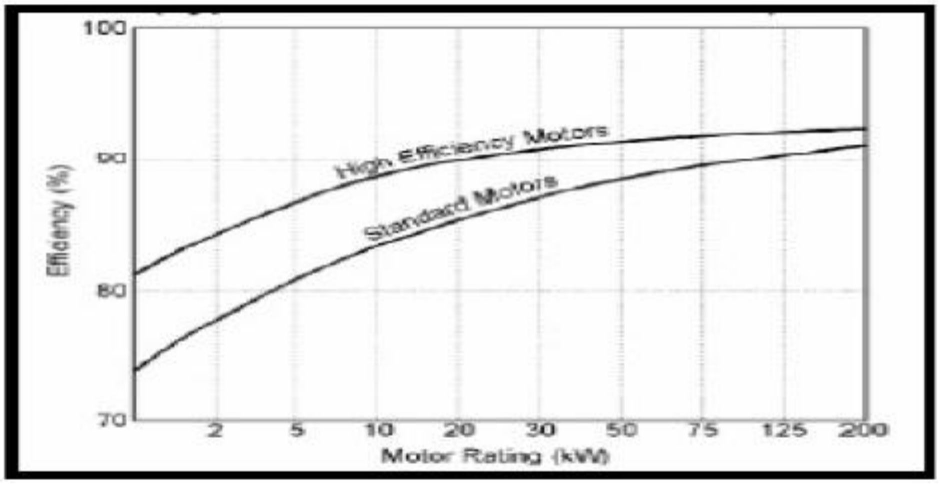


Figure 3-3: Typical efficiencies of standard and energy efficient motors [16]

- **Analyzing Electric Motors of AMTF with software**

The Arbaminch textile industry uses a vast number of relatively small electric motors. These are used to drive many different machines. The motors consume more than 70% of electrical energy in the factory. By improving the efficiencies of these motors or by replacing with energy efficient motors, we can save 5% to 15% of electrical energy.

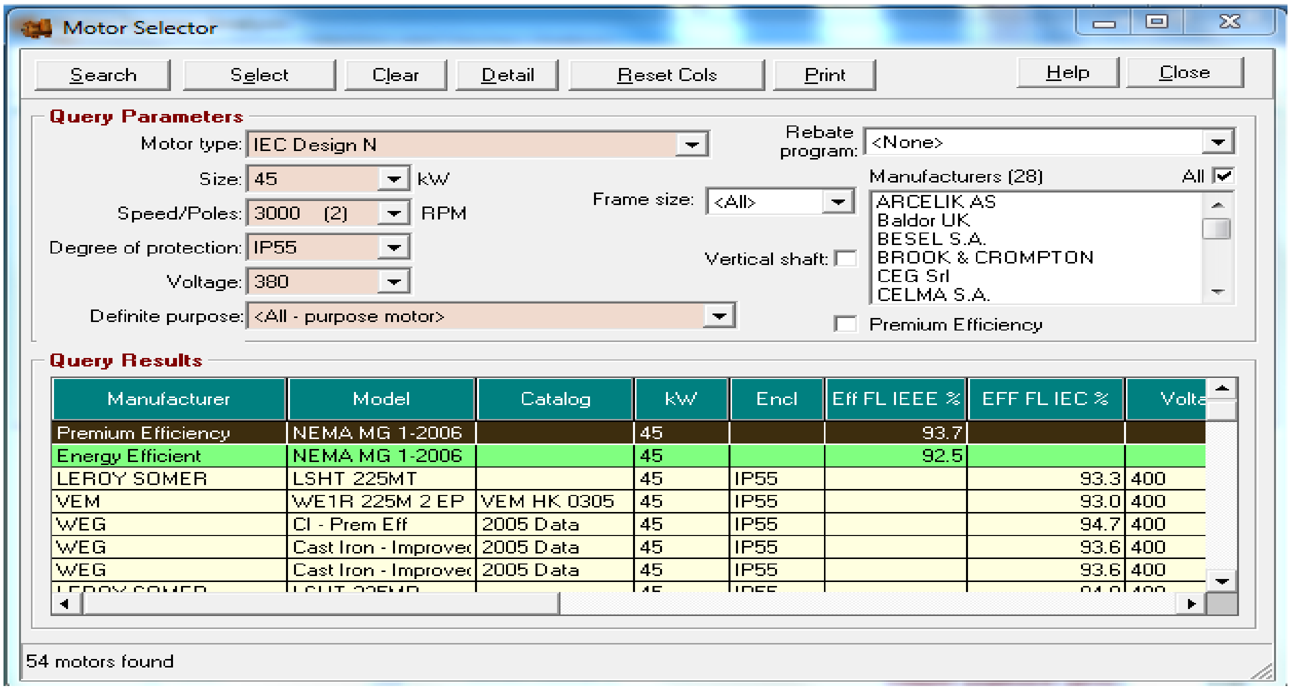
Many motors of different power ratings are currently in operation in the factory. Most of these motors are old, rewound and not regularly maintained. Currently the motor technology is improved. Energy efficient motors are being designed to transfer the input energy to the shaft very efficiently. Efficient motors also tend to have a better relative performance at part load, which is of increased benefit for applications with variable load requirements. In this regard there is a high opportunity to save energy in the factory.

- **Motor master+ international (IMSSA) software**

The International Motor Selection and Analysis (IMSSA), supports motor management functions at commercial and institutional facilities, water supply and wastewater treatment systems, irrigation districts, and medium-sized and large industrial facilities. Designed for utility auditors, energy managers, and plant or consulting engineers, IMSSA supports motor and motor systems improvement planning through identifying the most efficient action for a given repair or motor purchase decision. IMSSA can be used to compute the energy and demand savings associated with purchase of a new EFF1 instead of a standard EFF3 or Improved Efficiency EFF2 motor model or evaluate the cost-effectiveness of replacing a failed or operable EFF3 motor with an EFF1 motor[21].

Motor master+ international software is used in this work to evaluate the performance of the existing motors with the 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 AMTF and the specifications for the energy efficient motors are taken from the **Motor master + international** software catalogue. These values are selected in such a way to improve the loadings of the existing operation. The output parameters of the software are: Energy and demand savings, money savings and a simple back period.

For example if we evaluate the compressor main drive motor (GA22) of 55KW which exist in AMTF to the energy efficient motor model from the software catalogue, the following outcome will be obtained.



Query Parameters

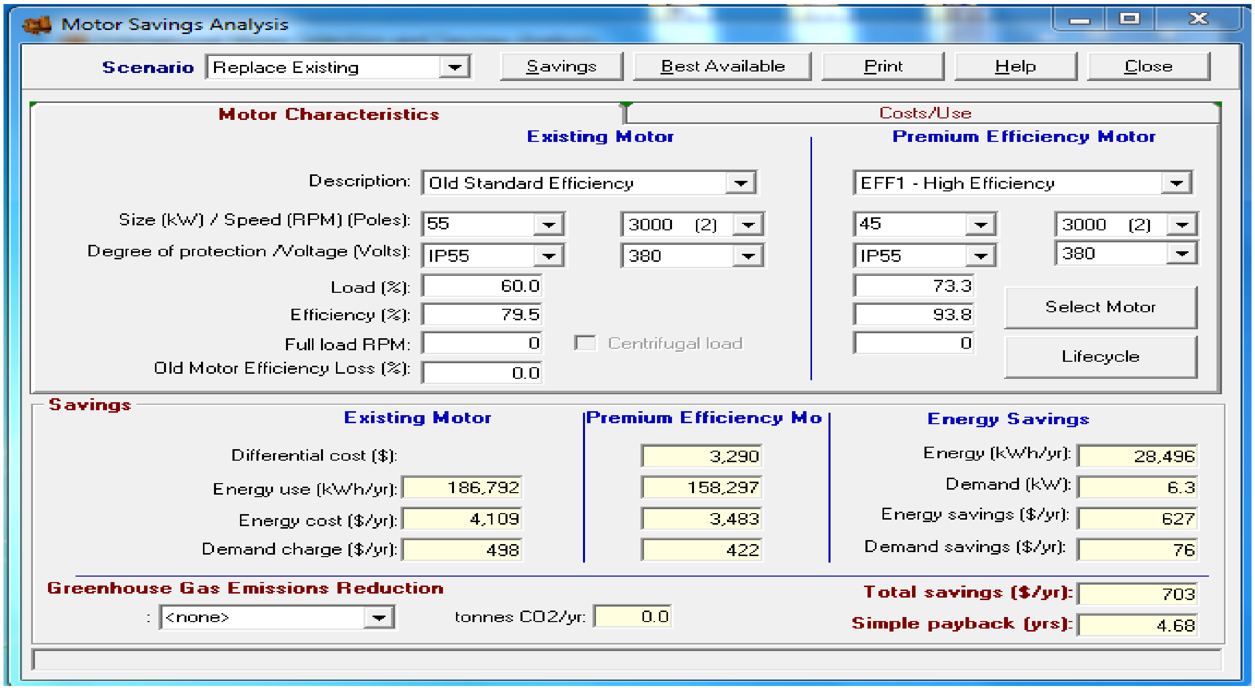
Motor type: IEC Design N
Size: 45 kW
Speed/Poles: 3000 (2) RPM
Degree of protection: IP55
Voltage: 380
Definite purpose: <All - purpose motor>
Rebate program: <None>
Frame size: <All>
Vertical shaft: ☐
Manufacturers (28) All ☑
ARCELIK AS
Baldor UK
BESEL S.A.
BROOK & CROMPTON
CEG Srl
CELMA S.A.
☐ Premium Efficiency

Query Results

Manufacturer	Model	Catalog	kW	Encl	Eff FL IEEE %	EFF FL IEC %	Volta
Premium Efficiency	NEMA MG 1-2006		45		93.7		
Energy Efficient	NEMA MG 1-2006		45		92.5		
LEROY SOMER	LSHT 225MT		45	IP55		93.3	400
VEM	WE1R 225M 2 EP	VEM HK 0305	45	IP55		93.0	400
WEG	CI - Prem Eff	2005 Data	45	IP55		94.7	400
WEG	Cast Iron - Improve	2005 Data	45	IP55		93.6	400
WEG	Cast Iron - Improve	2005 Data	45	IP55		93.6	400

54 motors found

Figure 3-4: Energy efficient motor selection



Scenario Replace Existing

Motor Characteristics Costs/Use

	Existing Motor		Premium Efficiency Motor	
Description:	Old Standard Efficiency		EFF1 - High Efficiency	
Size (kW) / Speed (RPM) (Poles):	55	3000 (2)	45	3000 (2)
Degree of protection /Voltage (Volts):	IP55	380	IP55	380
Load (%):	60.0		73.3	
Efficiency (%):	79.5		93.8	
Full load RPM:	0	☐ Centrifugal load	0	
Old Motor Efficiency Loss (%):	0.0			

Savings

	Existing Motor	Premium Efficiency Mo
Differential cost ($):		3,290
Energy use (kWh/yr):	186,792	158,297
Energy cost ($/yr):	4,109	3,483
Demand charge ($/yr):	498	422

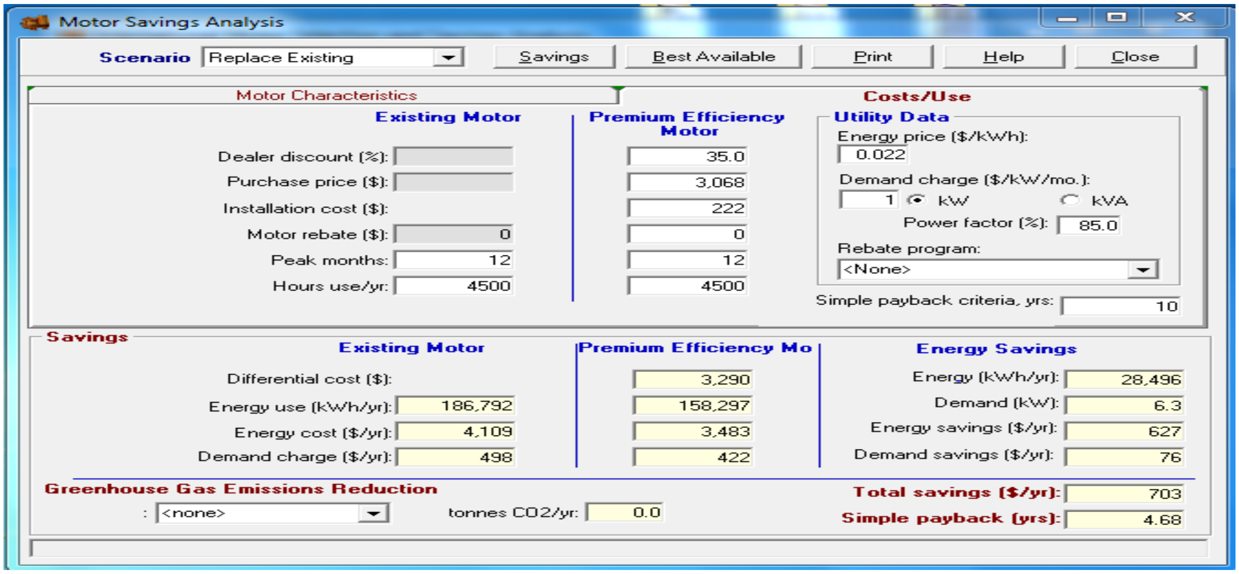
Energy Savings

Energy (kWh/yr):	28,496
Demand (kW):	6.3
Energy savings ($/yr):	627
Demand savings ($/yr):	76
Total savings ($/yr):	703
Simple payback (yrs):	4.68

Greenhouse Gas Emissions Reduction

: <none> tonnes CO2/yr: 0.0

Figure 3-5: Motor saving analysis



Scenario: Replace Existing

Motor Characteristics

	Existing Motor	Premium Efficiency Motor
Dealer discount (%):		35.0
Purchase price ($):		3,068
Installation cost ($):		222
Motor rebate ($):	0	0
Peak months:	12	12
Hours use/yr:	4500	4500

Costs/Use

Utility Data

Energy price ($/kWh): 0.022

Demand charge ($/kW/mo.): 1 ● kW ○ kVA

Power factor (%): 85.0

Rebate program: <None>

Simple payback criteria, yrs: 10

Savings

	Existing Motor	Premium Efficiency Mo
Differential cost ($):		3,290
Energy use (kWh/yr):	186,792	158,297
Energy cost ($/yr):	4,109	3,483
Demand charge ($/yr):	498	422

Energy Savings

Energy (kWh/yr): 28,496

Demand (kW): 6.3

Energy savings ($/yr): 627

Demand savings ($/yr): 76

Greenhouse Gas Emissions Reduction

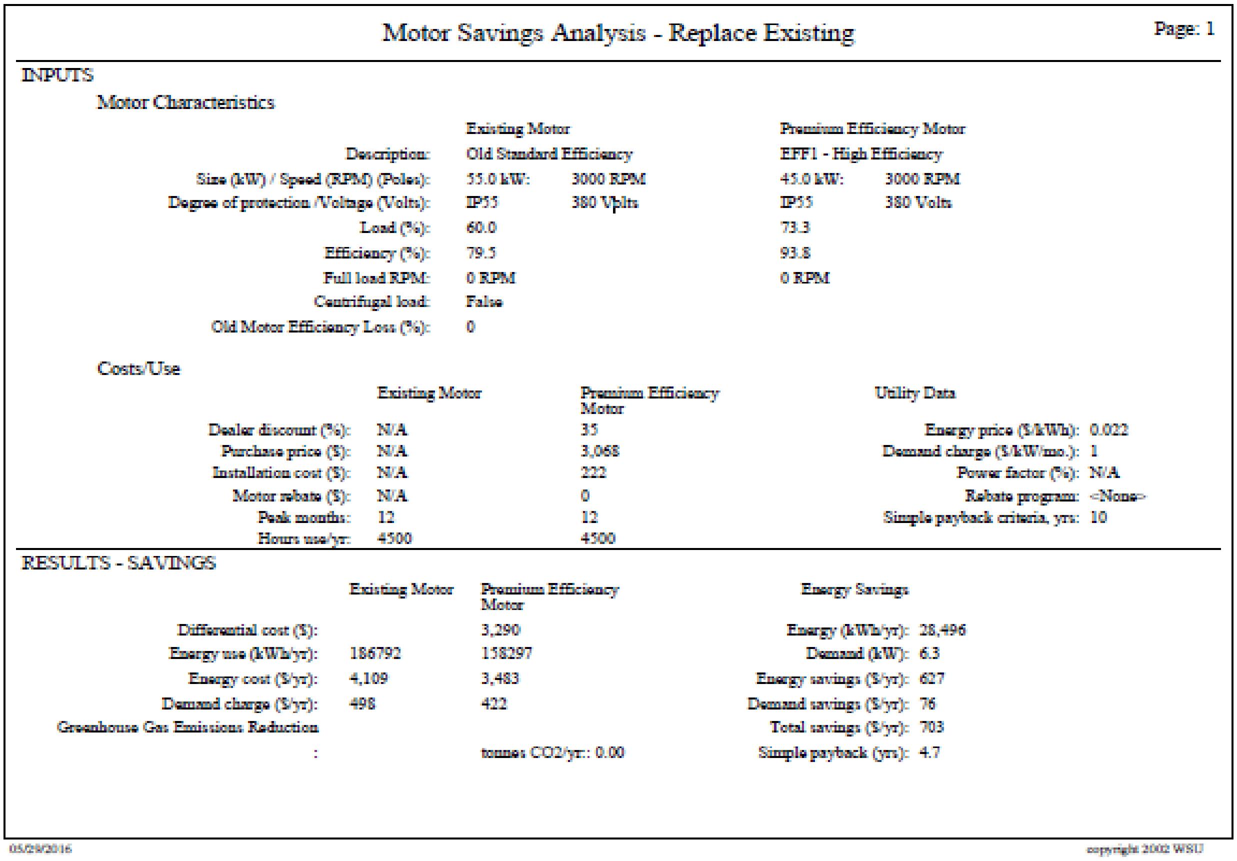
: <none> tonnes CO2/yr: 0.0

Total savings ($/yr): 703

Simple payback (yrs): 4.68

Figure 3-6: Utility Costs/Use Data

Table 3-5: Summary of Motor saving analysis



Motor Savings Analysis - Replace Existing

Page: 1

INPUTS

Motor Characteristics

	Existing Motor		Premium Efficiency Motor	
Description:	Old Standard Efficiency		EFF1 - High Efficiency	
Size (kW) / Speed (RPM) (Poles):	55.0 kW:	3000 RPM	45.0 kW:	3000 RPM
Degree of protection /Voltage (Volts):	IP55	380 Volts	IP55	380 Volts
Load (%):	60.0		73.3	
Efficiency (%):	79.5		93.8	
Full load RPM:	0 RPM		0 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	Premium Efficiency Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price ($/kWh):	0.022
Purchase price ($):	N/A	3,068	Demand charge ($/kW/mo.):	1
Installation cost ($):	N/A	222	Power factor (%):	N/A
Motor rebate ($):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	10
Hours use/yr:	4500	4500		

RESULTS - SAVINGS

	Existing Motor	Premium Efficiency Motor	Energy Savings	
Differential cost ($):		3,290	Energy (kWh/yr):	28,496
Energy use (kWh/yr):	186792	158297	Demand (kW):	6.3
Energy cost ($/yr):	4,109	3,483	Energy savings ($/yr):	627
Demand charge ($/yr):	498	422	Demand savings ($/yr):	76
Greenhouse Gas Emissions Reduction			Total savings ($/yr):	703
:		tonnes CO2/yr:: 0.00	Simple payback (yrs):	4.7

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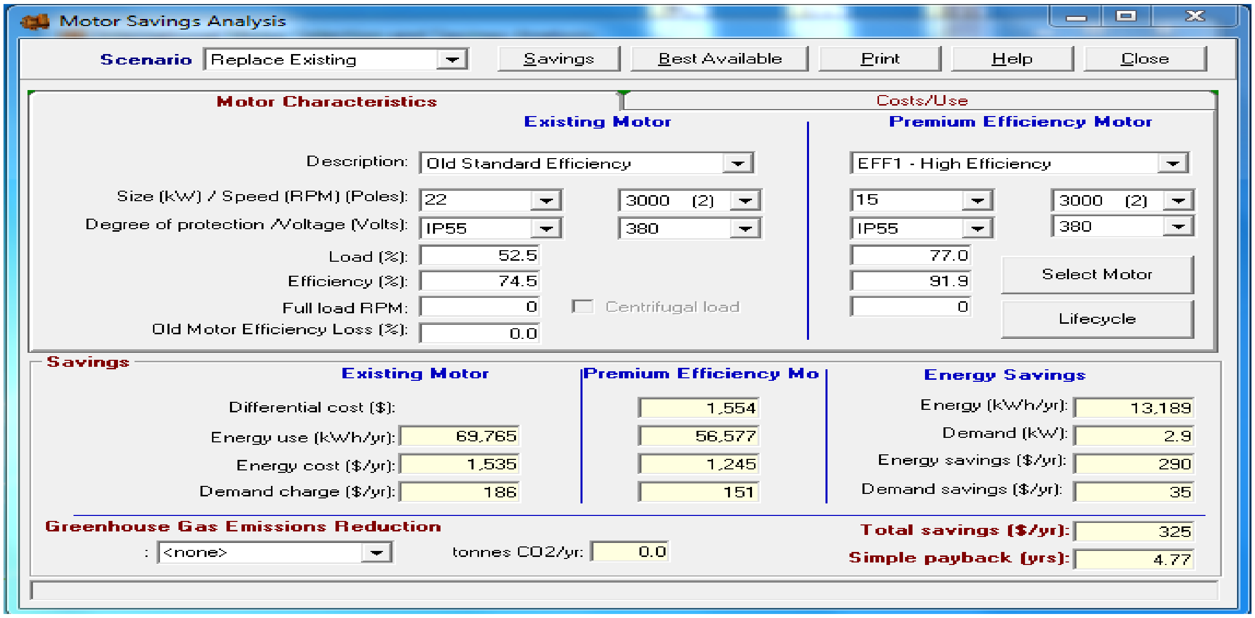
- ➢ Table 3.5 summarises the motor saving analysis and the figures 3.4 to 3.6 are sample outputs of the software

- ➢ The energy saving and back pay period columns explain the kilowatt hour energy savings per year and the number of years required to recover the investment in energy efficient motors respectively

To buy an energy efficient motor for air Compressor with 55KW found in the utility, the company should have 3086 dollars to purchase the motor, 222 dollar for the installation [38]. But these costs will be back after 4 years of operation with energy savings of 28,496KWh per year and money savings of 703 dollars per year.

Another example, to buy an energy efficient motor for main motor drive found in Ring frame, it needs 1431 dollars to purchase the motor, 123 dollar for the installation [38]. But these costs will be back after 4.8 years of operation with energy savings of 13,189KWh per year and money savings of 325 dollars per year. Therefore, this method should be implemented in the factory to use electric energy more efficiently.



Scenario: Replace Existing

	Existing Motor		Premium Efficiency Motor	
Description:	Old Standard Efficiency		EFF1 - High Efficiency	
Size (kW) / Speed (RPM) (Poles):	22	3000 (2)	15	3000 (2)
Degree of protection /Voltage (Volts):	IP55	380	IP55	380
Load (%):	52.5		77.0	
Efficiency (%):	74.5		91.9	
Full load RPM:	0		0	
Old Motor Efficiency Loss (%):	0.0			

Savings

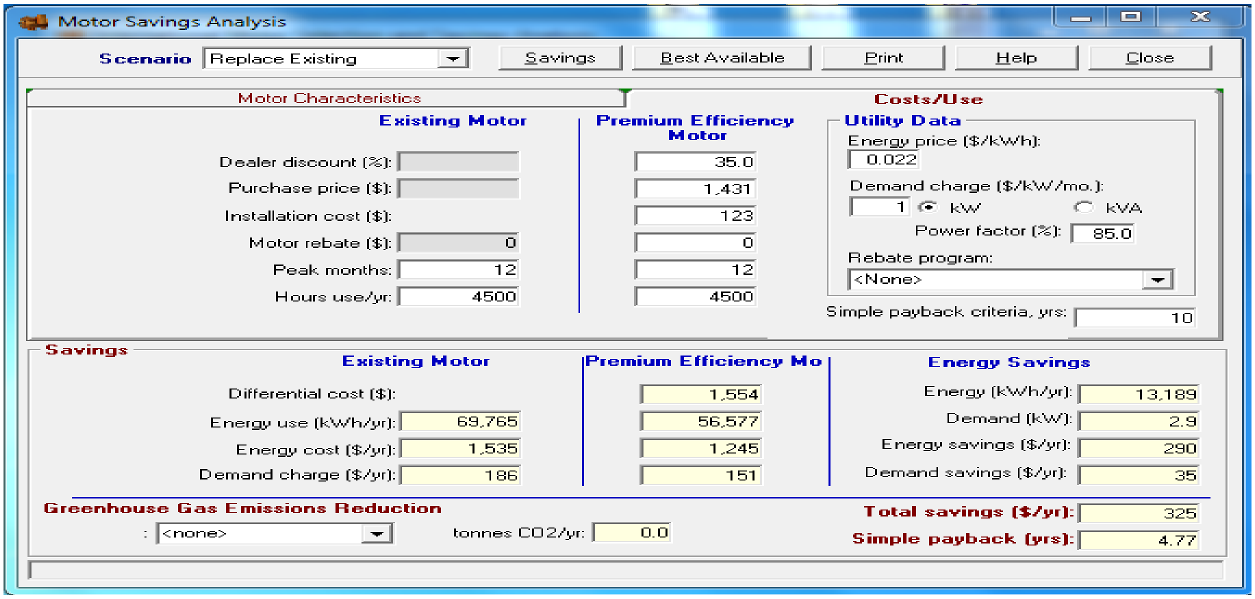
	Existing Motor	Premium Efficiency Mo
Differential cost ($):		1,554
Energy use (kWh/yr):	69,765	56,577
Energy cost ($/yr):	1,535	1,245
Demand charge ($/yr):	186	151

Energy Savings	
Energy (kWh/yr):	13,189
Demand (kW):	2.9
Energy savings ($/yr):	290
Demand savings ($/yr):	35
Total savings ($/yr):	325
Simple payback (yrs):	4.77

Greenhouse Gas Emissions Reduction

: <none> tonnes CO2/yr: 0.0

Figure 3-7: Motor saving analysis



Scenario: Replace Existing

Motor Characteristics

Costs/Use

	Existing Motor	Premium Efficiency Motor
Dealer discount (%):		35.0
Purchase price ($):		1,431
Installation cost ($):		123
Motor rebate ($):	0	0
Peak months:	12	12
Hours use/yr:	4500	4500

Utility Data

Energy price ($/kWh): 0.022

Demand charge ($/kW/mo.): 1 ● kW ○ kVA

Power factor (%): 85.0

Rebate program: <None>

Simple payback criteria, yrs: 10

Savings

	Existing Motor	Premium Efficiency Mo
Differential cost ($):		1,554
Energy use (kWh/yr):	69,765	56,577
Energy cost ($/yr):	1,535	1,245
Demand charge ($/yr):	186	151

Energy Savings

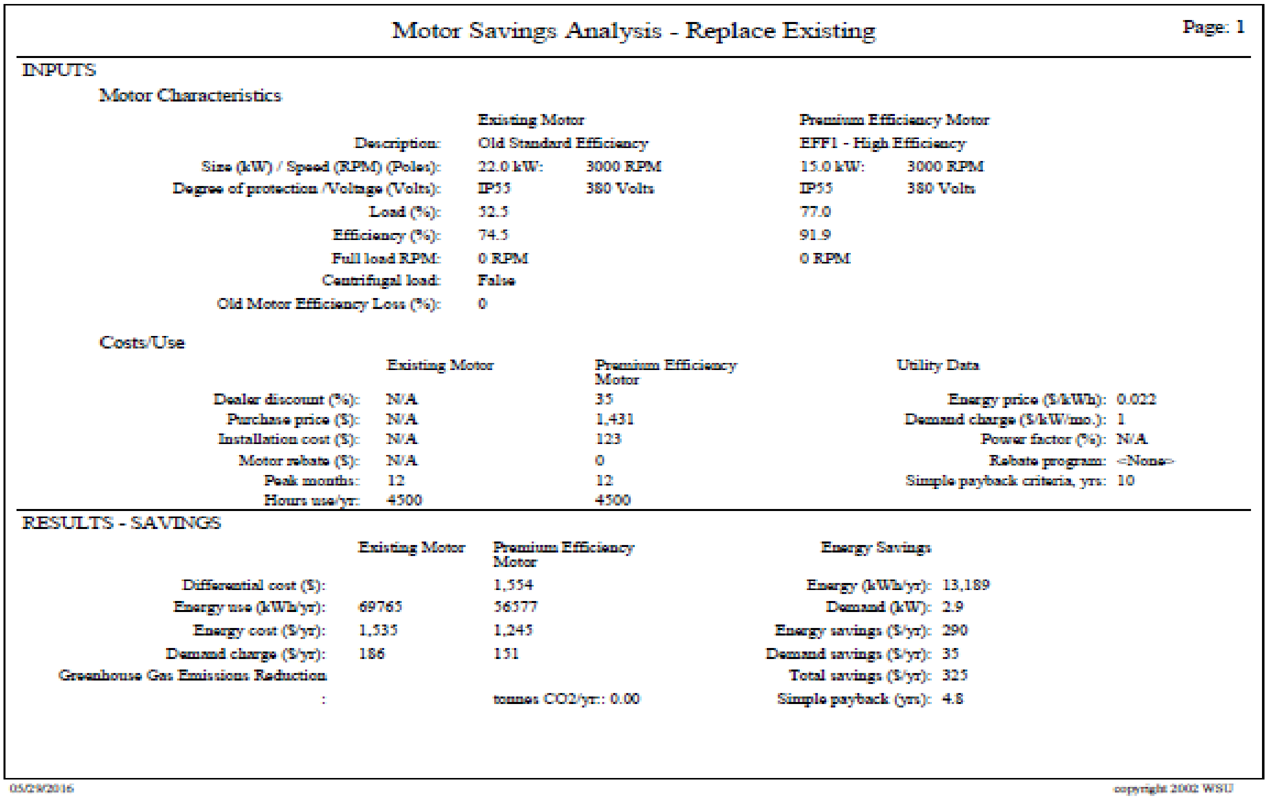
Energy (kWh/yr):	13,189
Demand (kW):	2.9
Energy savings ($/yr):	290
Demand savings ($/yr):	35
Total savings ($/yr):	325
Simple payback (yrs):	4.77

Greenhouse Gas Emissions Reduction

: <none> tonnes CO2/yr: 0.0

Figure 3-8: Utility Costs/Use Data

Table 3-6: Summary of motor saving analysis



Motor Savings Analysis - Replace Existing

Page: 1

INPUTS

Motor Characteristics

	Existing Motor		Premium Efficiency Motor	
Description:	Old Standard Efficiency		EFF1 - High Efficiency	
Size (kW) / Speed (RPM) (Poles):	22.0 kW:	3000 RPM	15.0 kW:	3000 RPM
Degree of protection /Voltage (Volts):	IP55	380 Volts	IP55	380 Volts
Load (%):	52.5		77.0	
Efficiency (%):	74.5		91.9	
Full load RPM:	0 RPM		0 RPM	
Centrifugal load:	False			
Old Motor Efficiency Loss (%):	0			

Costs/Use

	Existing Motor	Premium Efficiency Motor	Utility Data	
Dealer discount (%):	N/A	35	Energy price ($/kWh):	0.022
Purchase price ($):	N/A	1,431	Demand charge ($/kW/mo.):	1
Installation cost ($):	N/A	123	Power factor (%):	N/A
Motor rebate ($):	N/A	0	Rebate program:	<None>
Peak months:	12	12	Simple payback criteria, yrs:	10
Hours use/yr:	4500	4500		

RESULTS - SAVINGS

	Existing Motor	Premium Efficiency Motor	Energy Savings	
Differential cost ($):		1,554	Energy (kWh/yr):	13,189
Energy use (kWh/yr):	69765	56577	Demand (kW):	2.9
Energy cost ($/yr):	1,535	1,245	Energy savings ($/yr):	290
Demand charge ($/yr):	186	151	Demand savings ($/yr):	35
Greenhouse Gas Emissions Reduction			Total savings ($/yr):	325
:		tonnes CO2/yr:: 0.00	Simple payback (yrs):	4.8

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3.4.2. Improving maintenance

The purposes of motor maintenance are to prolong motor life and to foresee a motor failure. Motor maintenance measures can be categorized as either preventive or predictive. Preventative measures, the purpose of which is to prevent unexpected downtime of motors, include electrical consideration, voltage imbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The purpose of predictive motor maintenance is to observe on going motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs. The savings associated with an on-going motor maintenance program are significant, and could range from 2% to 30% of total motor system energy use [22].

The maintenance condition of the motors in AMTF is poor because, there is no a regular schedule for measuring the line voltages and currents to check the line imbalance and loading conditions of the motors. They do not inspect motors regularly for wear in bearings and housings (to reduce frictional losses) and for dirt/dust in motor ventilating ducts (to ensure proper heat dissipation). Although more motors do have their own ventilating fun for cooling, there are some motors which do not have fun for ventilation. The installed AC conditioning systems do not work is some section of the factory. Also Appropriately Lubrication is not done according to the manufacturer’s recommendations. Thus a proper on going motor maintenance program should be applied to save energy from 2% to 30% of the motor use.

3.4.3. Rewinding

It is common practice in industry to rewind burnt-out motors. The number of rewound motors in some industries exceeds 50% of the total number of motors. Careful rewinding can sometimes maintain motor efficiency at previous levels, but in most cases results in efficiency losses. Rewinding can affect a number of factors that contribute to deteriorated motor efficiency: winding and slot design, winding material, insulation performance, and operating temperature. For example, when heat is applied to strip old windings the insulation between laminations can be damaged, thereby increasing eddy current losses. A change in the air gap may affect power factor and output torque [16].

Rewinding is a common practice in AMTF; however there are some problems in the process, removing the old winding, selecting wires of appropriate size, slot size design and rewinding the motors more than one times. All these have an impact on the efficiency of the rewound motor. However, if proper measures are taken, the motor efficiency can be maintained after rewinding.

3.4.4. Power factor correction

Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs.

Capacitors connected in parallel (shunted) with the motor are often used to improve the power factor. The capacitor will not improve the power factor of the motor itself but of the starter terminals where power is generated or distributed. The benefits of power factor correction include reduced KVA demand (and hence reduced utility demand charges), reduced I^2R losses in cables upstream of the capacitor (and hence reduced energy charges), reduced voltage drop in the cables (leading to improved voltage regulation), and an increase in the overall efficiency of the plant electrical system [16].

At Arbaminch Textile Share Company, a bank of capacitors having total capacity of 450KVA each is installed at each transformer secondary terminal. The bank of capacitor contains twelve cans of capacity 37.5 KVA each, connected in parallel. The twelve cans are operated in a switchable manner with a control signal coming from the power factor meters installed at the transformer secondary terminals. As result the power factor of the factory is within the acceptable range that is above 0.85 which is Ethiopian electric utility (EEU's) acceptable range as it has been seen in table 2.7.

3.4.5. Improving Power Quality

Motor performance is affected considerably by the quality of input power, which is determined by the actual volts and frequency compared to rated values. Fluctuation in voltage and frequency much larger than the accepted values has detrimental impacts on motor performance.

Voltage unbalance can be even more detrimental to motor performance and occurs when the voltages in the three phases of a three-phase motor are not equal. This is usually caused by the supply different voltages to each of the three phases. It can also result from the use of different cable sizes in the distribution system.

The voltage of each phase in a three-phase system should be of equal magnitude, symmetrical, and separated by 120°. Phase balance should be within 1% to avoid derating of the motor and voiding of manufacturers' warranties. Several factors can affect voltage balance: single-phase loads on any one phase, different cable sizing, or faulty circuits. An unbalanced system increases distribution system losses and reduces motor efficiency.

In general resolve power-quality problems such as under or over voltage or phase voltage unbalance prior to taking field measurements or conducting a motor replacement assessment.

More information on power quality issues of Arbaminch Textile factory will be discussed in the next chapter.

4. Harmonics Modelling and Mitigation Techniques

4.1. Harmonic Modelling

Ideally, an electricity supply should invariably show a perfectly sinusoidal voltage signal at every customer location. However, it is hard to preserve such desirable conditions. The deviation of the voltage and current waveforms from sinusoidal is described in terms of the waveform distortion, often expressed as harmonic distortion [23].

The goal of harmonic studies is to quantify the distortion in voltage and current waveforms at various points in a power system. Similar to other power systems, the harmonic study consists of the following steps [24]:

- ✓ Definition of harmonic-producing equipment and determination of models for their presentation.
- ✓ Determination of the models to represent other components in the system including external networks.
- ✓ Simulation of the system

The most common model for harmonic sources is in the form of harmonic current source, specified by its magnitude and phase. The data can be obtained from an idealized theoretical model or from actual measurements. In many cases, the measured waveforms provide a more realistic representation of the harmonic sources to be modeled [24].

In order to simulate the propagation of harmonics throughout a network, adequate models for harmonic generating loads as well as system components must be developed. A number of different models have been proposed to represent harmonic sources. The current injection model is the most commonly used model in commercial power system harmonic analysis programs. This model simply treats power electronic device as harmonic current source. The magnitude and phase angle for each harmonic of the source can be calculated, e.g., from typical harmonic current spectrum of the device [24]. A more accurate procedure to establish the current source model is as follows

- The Power electronic load devices are treated as PQ loads at the fundamental frequency

- The current injected from the load into the system is then calculated and denoted as $I_1<\theta$.

- The magnitude of the harmonic current source representing the load is determined as the percentage of the fundamental current. The spectrum can be obtained from measurement, or from manufactures data.

Harmonic modeling for power systems involves the incorporation of harmonic sources in to a power system model. The development of accurate system models for harmonic studies involves the selection of the network components to include in the model as well as the selection of harmonic source models that achieve a balance between complexity and accuracy for the study. Typical components data that is needed for distribution system harmonic modeling study is summarized in table below [24].

Table 4-1: Summary of Typical data needed for a distribution system harmonic study

Device	Data needed
Transformer	Turns ratio, short-circuit impedance, connection configuration (wye, grd wye, or delta)
Overhead lines, cables	Conductor size, length, or short circuit impedances, capacitance (when needed)
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
Linear Load	Watts, Var, power factor, composition, balance
non-linear Load	Expected level of harmonic current injection, magnitude and phase angle

4.1.1. Investigation of Harmonic Pollution in Arbaminch Textile Factory

For this study, simulation technique is used to analyze and investigate harmonic pollution in the factory distribution system of selected facilities. Two transformers (T1 & T2) were selected for harmonic pollution study. Harmonic studies begin with the development of a system model, which must include all the major components that affect harmonic generation and propagation. One-line diagrams of the facilities distribution system, which are the objects of this harmonic study, are presented below. The HV terminal of the transformer is considered as the point of common coupling (PCC) between the customer and EEU. The facilities selected are occupied by a large number of three phase non-linear loads, such as Transformers, adjustable speed drives, heating and ventilating air conditioners, fluorescent lumps(single phase) and other significant number of linear loads, such as induction motors, electric boilers.

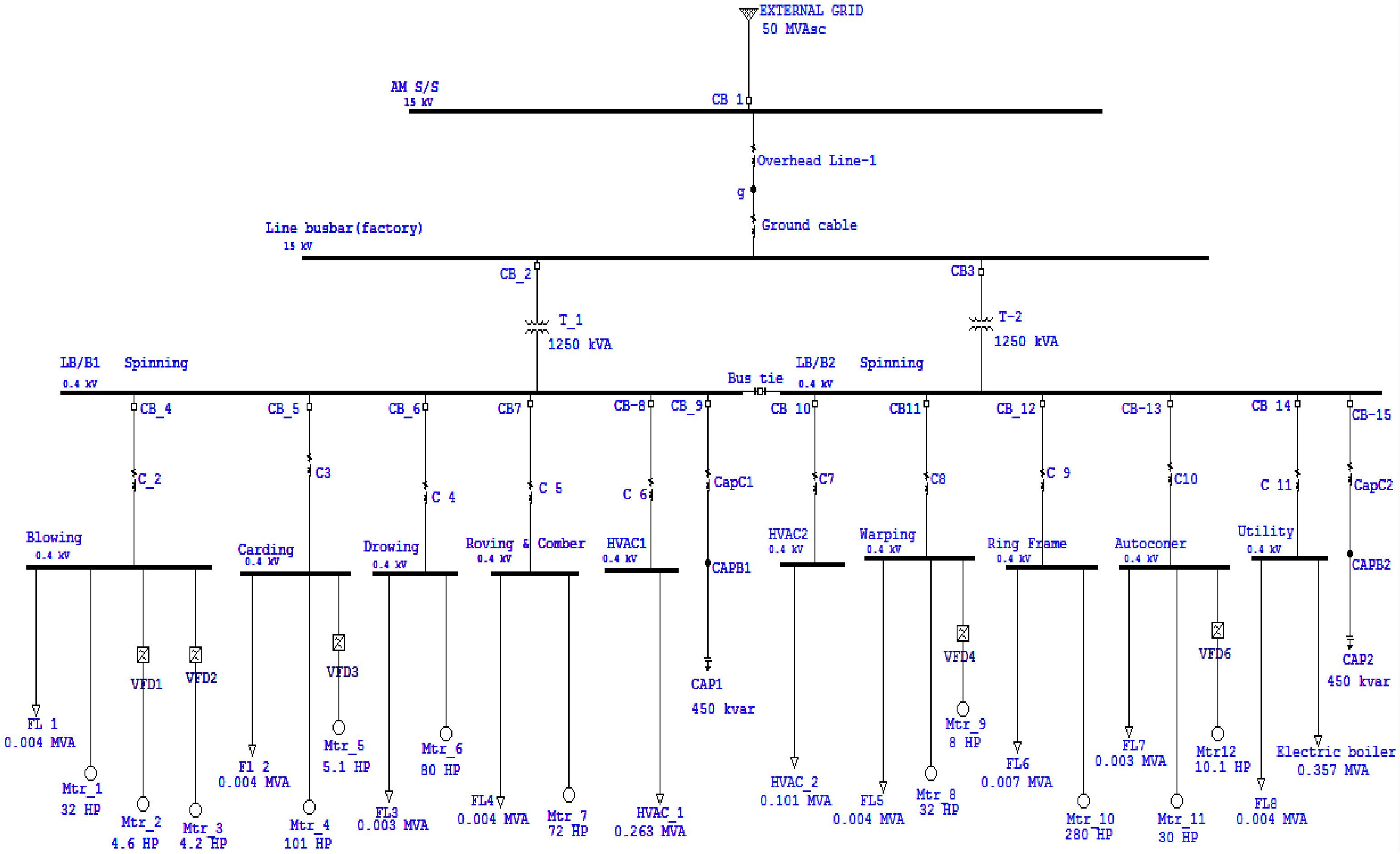


Figure 4-1: One-line diagram of facilities connected to T1 and T2

The purpose of modeling and simulation of these distribution systems are to investigate if the levels of the voltage and current THD at the PCC will be within IEEE standard 519-1992 or not.

4.1.2. Harmonic Modelling of the Facilities Considered

Non-linear loads at the 0.4 KV buses introduce harmonic current in to the distribution system. In the modeling and simulation of these facilities, the harmonic source data are obtained from typical values and from recommended values in previously published papers. The models of the distribution systems are developed to include external network as seen from 15 KV bus, transformers and facility loads.

As mentioned above, the first part of the process was to gather information on the system. This involved finding circuit diagrams, information on transformers, cables etc., and finally the nature of the load – the size (KVA) and type (linear or non-linear). The model built was that of the transformers serving the Blowing section, the Carding, the drawing, the ring frame and the electric boiler. The approach taken was to start at the load and work backwards. Information was gathered from the electricians; the nameplate of the equipment's and from published papers. The tables below summarize the system information.

Table 4-2: Network parameters of systems connected to T1 and T2

	Transformer	
	T1	**T2**
External network lumped impedance	MVAsc = 25, X/R = 10	MVAsc = 25, X/R = 10
Specification of Transformers	15/0.4 KV, KVA = 1250 KVA, Δ/Y11,short-circuit impedance = 5 %	15/0.4 KV, KVA = 1250 KVA, Δ/Y11,short-circuit impedance = 5 %

Note: The short circuit MVAs are calculated from the transformers KVA and short-circuit impedances. The X/R ratio is taken to be 10 which is a typical value for distribution systems as recommended in [25].

The power consumption of the collected loads is obtained from their name-plate ratings and is prepared for input of the software as shown in the table below. The system is assumed to be balanced. The power factors are typical values commonly used as suggested in [26].

Table 4-3: Load types and sizes supplied by T1 and T2

Section	**Load Type**	**Active power(KW)**	**Power factor**
Blowing	Lightings(FL1)	7.0	0.9
	Induction motors(Mtrs1)	17.2	0.81
	Induction motors(Mtrs2)	7.5	0.81
	Induction motors(Mtrs3)	8.8	0.81
Carding	Lightings(FL2)	7.0	0.9
	Induction motors(Mtrs4)	93.3	0.86
	Induction motors(Mtrs5)	23.1	0.86
Drawing	Lightings(FL3)	7.0	0.9
	Induction motors(Mtrs6)	138.8	0.81
Roving & Comber	Lightings(FL4)	6.0	0.9
	Induction motors(Mtrs7)	93.3	0.8
Air Conditioner	HVAC1	260	0.99
	HVAC2	100	0.99
Warping	Lightings(FL5)	6.0	0.9
	Induction motors(Mtrs8)	17.0	0.9
	Induction motors(Mtrs9)	20.0	0.87
Ring frame	Lightings(FL6)	8.0	0.9
	Induction motors(Mtrs10)	358.1	0.89
Automatic winder	Lightings(FL7)	6.0	0.9
	Induction motors(Mtrs11)	2.71	0.87
	Induction motors(Mtrs12)	22.0	0.87
Utility	Lightings(FL8)	7.0	0.9
	Electric Boiler	700	0.98

Table 4-4: Line (Cable) Data at Textile Factory [30]

Line(Cable) Code	**Formation**	**Z (Ω/km)**	**Length(km)**	**Z1 (Ω)**	**Z0(Ω)=3*Z1**
L1	3*25	1.35+j0.086	2	2.7+j0.18	8.1+j0.52
C1	3*50	0.641+j0.08	0.6	0.385+j0.05	1.15+j0.15
C2	3*95+70	0.3 + j0.078	0.115	0.03 + j0.01	0.09 + j0.03
C3	3*240+12	0.125+j0.075	0.125	0.02+j0.01	0.06+j0.03
C4	3*185+95	0.164+j0.078	0.6	0.01+j0.005	0.03+j0.015
C5	3*150+70	0.2+j0.078	0.115	0.02+j0.01	0.06+j0.03
C6	3*240+120	0.125+j0.075	0.125	0.02+j0.01	0.06+j0.03
C7	3*240+120	0.125+j0.075	0.125	0.02+j0.01	0.06+j0.03
C8	3*150+70	0.21+j0.076	0.11	0.04+j0.01	0.12+j0.03
C9	3*240+120	0.125+j0.075	0.1	0.013+j0.01	0.018+0.06
C10	3*120+70	0.21+j0.076	0.11	0.04+j0.01	0.12+j0.03
C10	3*120+70	0.21+j0.076	0.11	0.04+j0.01	0.12+j0.03
Cap1	3*240+120	0.125+j0.075	0.015	0.02+j0.01	0.06+j0.03
Cap2	3*240+120	0.125+j0.075	0.015	0.002+j0.001	0.006+j0.003

4.1.3. Harmonic Spectrum Data for the Non-linear loads

As mentioned in the literature review, the most common method of representing non-linear loads in system modeling is to represent them as constant harmonic current sources. The harmonic spectrum is obtained from measurement or from approximate typical theoretical values. 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

For other non-linear loads the following spectrum data were used. These data were obtained from appendix of reference [27].

Table 4-5: Typical Harmonic Spectrum data of non-linear devices

Typical Harmonic Spectrum in percent of fundamental							
h	Fluorescent Lamp	Transformer (saturated)	Computer	Printer/copier	PWM ASD	Welding machine	Fridge
1	100	100	100	100	100	100	100
3	15.8	50	81	9.39	2.5	71	10
5	8.6	20	53	6.49	75	36.8	5.1
7	2.9	5.0	25	3.82	60	10.5	0.5
9	2	2.6	9	0	0	2.6	1.0
11	1.4	0	5	1.93	25	1.05	0.4
13	0.8	0	4	1.37	10	0	0.2
15	0.4	0	3	0	0	0	0.2
17	0.2	0	1	1.52	2.5	0	0.1
19	0.5	0	0	0.75	3	0	0
21	0.4	0	0	0	0	0	0
23	0.2	0	0	0.43	4	0	0
25	0	0	0	0.35	4	0	0

4.1.4. Consideration of Diversity Effects

The net harmonic currents injected by large numbers of single phase electronic loads are significantly affected by diversity. When a system contains a single dominant source of harmonics, phase spectrum is not important. However, phase angles should be taken into consideration when multiple harmonic current sources are present. The distortion of an aggregate waveform might be limited because of the ''diversity effect". This effect is due to the possible harmonic cancellations among the non-linear loads because of the dispersion in harmonic current sources [27]. In order to quantify the effect of the phase angle dispersion, this research borrows commonly applied diversity factors from previous researches. According to [27], research and field measurement verifications have shown that the diversity factors in table below are appropriate in both three-phase and single-phase studies.

Table 4-6: Current Diversity factor Multipliers for Large Numbers of Non-linear Loads

Current Harmonic	3	5	7	9	11	13	15	Higher Odds	All Evens
Diversity Factor	1	0.9	0.9	0.6	0.6	0.6	0.5	0.2	0

When the numbers of same loads are greater than 10, the arithmetic sum of their harmonic current magnitudes is multiplied by typical diversity factors to account the phase cancellation of the loads. This enables us to model multiple loads as a single load point.

4.1.5. Simulating Software

In this paper, the network analysis tool "ETAP power station'' is used for Harmonic modeling and simulation purposes. When starting the harmonic simulation, it carries out a three phase load flow to determine the steady state conditions of the voltage, current magnitudes and phase angles at each network terminal and each network branch. The in-built programming language has been used to add the analysis for harmonic fingerprint models. The following section briefly discusses about the software.

- **ETAP power station [28]**

ELECTRICAL TRANSIENT ANALYSIS PROGRAM, ETAP power station, developed by Operation Technology Inc. (OTI), is also a comprehensive analysis platform for design, analysis and operation of generation, distribution and industrial power systems and used in more than 5000 electrical firms worldwide. Its full version contains all calculation modules such as:

- ✓ Load flow analysis
- ✓ Short circuit analysis
- ✓ Transient analysis
- ✓ Harmonic analysis
- ✓ Protective device coordination

- ✓ Optimal capacitor placement
- ✓ Reliability analysis

Its' another feature is that it allows the power system analyst to select standards such as American National Standard Institute (ANSI) or Institute of Electrical Electronics Engineering (IEEE) for new project.

The ETAP POWER STATION 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.

The Power station "Harmonics" functions allow analyzing harmonics in the frequency domain. Two different functions are supported by Power Factory: Harmonic Load-Flow and Frequency Scan. The so-called "Harmonic Load-Flow" calculates actual harmonic indices related to voltage or current distortion. When starting the "Harmonic load flow", Power station carries out a steady state network analysis at each frequency at which harmonic sources are defined. In contrast to the "Harmonic Load-Flow", the "Frequency Scan" allows a continuous frequency domain analysis. Every switched device produces harmonics and must be modeled as a harmonic source. In ETAP Power station harmonic sources can be both current and voltage sources. In this research the non-linear loads are modeled as harmonic source general loads.

ETAP Power station 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, displacement and 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)

The frequency dependent representation of network elements such as lines, cables, two- and three-winding transformers, machines, loads, filter banks etc. for considering skin effects is fully-supported.

- **Component Modeling in ETAP Power station**

For Harmonic analysis, frequency characteristics and the non-linearity of power system components must be recognized and modelled appropriately. Depending on their nature and behaviour, these components are modelled in very different way.

This section describes the techniques used to model the various system components of the facilities (loads, transformers, cables) used for simulation.

Transformers: For proper analysis of distribution system, three phase transformers have to be modeled correctly showing the various connection types and grounding systems. The most commonly used distribution transformer grounding connections are delta-grounded wye and ungrounded wye-delta. Two winding transformers and three winding transformers have to be modeled in a way that represents:

- ✓ Voltage transformation ratios between primary to secondary winding and primary to tertiary winding
- ✓ Winding resistance and reactance referred to either high voltage side or low voltage side
- ✓ Shunt element for core loss and magnetization
- ✓ Tap changing information(on-load tap changing or off-load tap changing)

The following figure is an equivalent circuit of two winding transformer when all secondary quantities are referred to primary side,

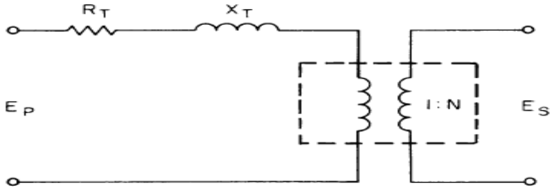


Figure 4-2: Equivalent circuit of two winding transformer

In the above circuit model, R_T and X_T are expressed as follows

$$\mathbf{R_T = R_P + Rs/N^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.1)}$$

$$\mathbf{X_T = X_p + Xs/N^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... \text{(4.2)}$$

Where, R_T and X_T are total resistance and reactance, R_P and R_S are resistances at primary and secondary sides, X_P and X_S are reactance's at primary and secondary sides and N is transformation ratio.

In the modeling of three winding transformers, the three windings have to be shown separately as indicated below.

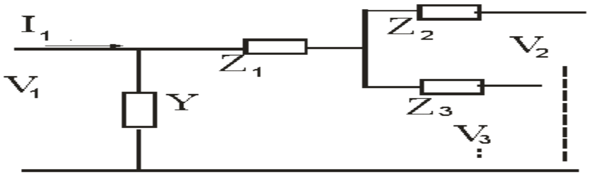


Figure 4-3: Equivalent circuit of three winding Transformer

In most cases, name plate winding data are expressed in short circuit impedance (%ZSC) and reactance to resistance ratio(X/R), from which the three parameters (Z, X and R) can be easily obtained by using the relation,

$$\mathbf{Z} = \sqrt{\mathbf{R^2 + X^2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots........ \text{(4.3)}$$

The ETAP power station requires nameplate values (Rated power, Transformer ratio, vector group, short-circuit impedance, connection configuration) to be inserted for transformers. So further calculation is not needed as the software internally calculates the parameters used in the equivalent circuit.

Cables: The cables are modeled by pi-circuit equivalent representation using lumped parameters. ETAP POWER STATION incorporates the automatic calculation of the electrical parameters of any cable/overhead line configuration starting from layout and geometric characteristics which are typically available in manufacture's datasheets. The calculation is applicable over a wide range of frequencies and supports the step-up process of highly accurate line and cable models for harmonic analysis.

The following information are obtained from the electricians, documentations and site visit and used in the calculation of overhead line parameters

- ✓ Overhead line arrangement: flat Vertical
- ✓ Spacing between conductors: ab=1m, bc = 1m, ac = 2m
- ✓ Type of conductor: AAC
- ✓ Size : 25sq. mm

Resistances per unit length are obtained from the manufacturer's standard table, having known the type of material and its size (cross sectional area) and reactance per unit length of overhead lines at 50Hz is calculated as follows [29].

$$\mathbf{X_o = 0.0628 \times ln\frac{Deq}{r} + 0.0157\Omega/km} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.4)}$$

Where,

- ✓ r — radius of conductor
- ✓ D_{eq} — geometric mean distance between phase lines : Deq = $\sqrt[3]{(\mathrm{Dab} \times \mathrm{Dbc} \times \mathrm{Dca})}$
- ✓ d_{ab},d_{bc}, d_{ca} are distance between phase lines.

For overhead lines, capacitive susceptance is usually neglected. The positive sequence impedance (Z_1) of the overhead distribution lines is calculated as follows:

$$\mathbf{Z_1 = (r_o + jx_o) * Length} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.5)}$$

The zero sequence impedance is usually three times higher than positive sequence impedance. Although it is possible to calculate the cable resistance and reactance, the "hard to find" data such as conductor spacing among the phase lines has constrained the process. Therefore, electrical characteristics of cables are obtained from the standard cable data provided in factory documentation manuals [30]. The documentation provides the type and size of cables used and electrical characteristic values are then selected from the catalogue attached in Appendix E.

Loads:

Linear loads: are not modeled as Harmonic sources. They can be modeled as constant impedance model, from the active and reactive power of the load, the impedance values are calculated.

Non-linear loads: are modeled as constant harmonic sources in the form of a harmonic current source, specified by its magnitude and phase spectrum. This research uses this modeling type of non-linear loads, i.e. constant harmonic source.

The data are obtained from published papers. The harmonic spectrum data and PQ parameters of the non-linear load are fed into the model.

4.2. Harmonic Mitigation Techniques using Harmonic Filters

Harmonic distortions can have significant adverse effects on both power system components and customer devices. These effects may result into permanent damage of the devices. Various harmonic-mitigation techniques have been proposed and applied in recent years. There are two types of filters used for filtering the harmonic distortions: passive filters and active filters [23].

4.2.1. Passive Filters

The main components of a passive filter are inductance, capacitance and resistance. They are relatively cheaper than other methods of harmonic elimination. 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 [31]: Single tuned, 1st order high-pass, 2nd order high-pass, and 3rd order high-pass.

The different topologies for these filters are shown in the figure below.

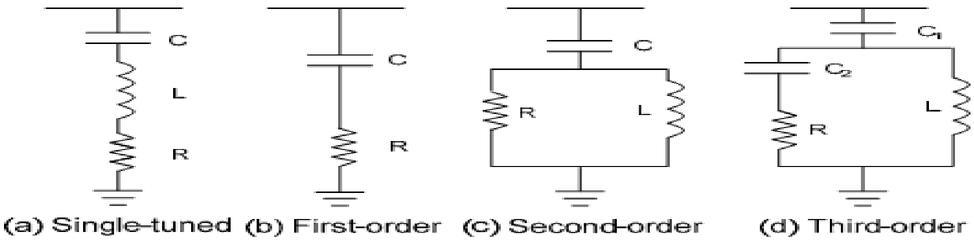


Figure 4-4: Topologies of shunt passive filters [31].

The most common type of passive filter is single-tuned notch filter, shown in fig (a), which is the most economical and frequently sufficient for the application. In the single-tuned filter circuit, a capacitor, an inductor and a resistor are connected in series. This filter is also known as low pass filter. The filter is single-tuned to present low impedance to a particular harmonic current. It is connected in shunt with the power system there by diverting the harmonic currents from their normal flow path on the line into the filter. Notch filter can provide power factor correction in addition to harmonic suppression [31]. The first order high-pass filter, in fig (b), is not normally used, as it requires a large capacitor and has excessive loss at fundamental frequency. The second order high-pass filter provides the best filtering performance, but has higher fundamental frequency losses as compared with the third order. The third order high-pass filter's main advantage over second order is a substantial reduction in fundamental frequency loss, owing to increased impedance at that frequency caused by the presence of the capacitor C2. Moreover, the rating of C2 is very small compared with C1 [32].

4.2.2. Active Filters

Active filters are relatively new types of devices for eliminating harmonics. They are based on sophisticated power electronics and much more expensive than passive filters. In this way, they are designed to inject harmonic currents to counterbalance existing harmonic components as they show up in the distribution system [23].

However, they have distinct advantage that they do not resonate with the system. They can be used in very difficult circumstances where passive filters cannot operate successfully because of where the parallel resonance lies. They can also address more than one harmonic at a time and combat other power quality problems such as flicker. They are particularly useful for large, distorting loads from relatively weak points on the power system [33].

Passive filters have been the most effective solution for power system harmonic mitigation [34]. Active filtering is so extensive and specialized that it is not possible to cover it within the scope of this thesis. This section, therefore, will describe how passive filters are designed for the purpose of this research.

4.2.3. Single-tuned Harmonic Filters & their Design

The single tuned filter is probably the most common shunt filter in use. Because passive filters always provide reactive compensation to a degree dictated by the volt-ampere size and voltage of the capacitor bank used, they can in fact be designed for the double purpose of providing the filtering action and compensating power factor to the desired level. This passive filter presents very low impedance, with respect to line impedance, at the tuning frequency, through which all current of that particular frequency will be diverted. Harmonic suppression is achieved provided that the line impedance magnitude is considerably higher than the shunt filter impedance at the harmonic frequency [32]. Despite its reactive power compensation advantage, a single tuned shunt filter can only eliminate a single current harmonic component. This may not be adequate to filter all the problematic current harmonics effectively. Therefore, for a wide range generated harmonics a single tuned filter is to be designed for each current harmonic to be suppressed, individually. This means multiple single-tuned filters are designed to eliminate multiple harmonics, as illustrated below in the figure below [32].

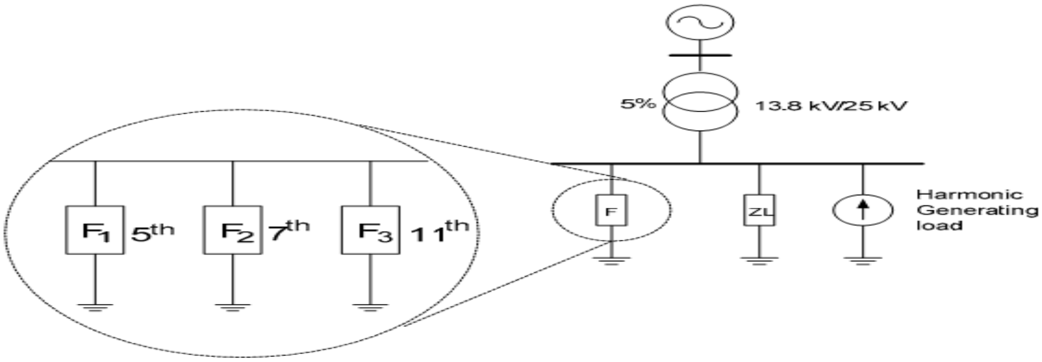


Figure 4-5: Three-branch filters [32].

As explained in the literature review, the most common type of passive filter is single-tuned filter which is the most economical and frequently sufficient for low voltage application, because of its dual purpose as power factor correction and harmonic control. This section presents design procedures and equations of single-tuned filters. The main components of a harmonic filter are the capacitors, reactor, and a damping resistance if necessary, as illustrated in the figure 4.4 (a). The series-connected resistance decides the sharpness of the filtering action. But it is usually ignored because the value of R usually results in a significant increase in losses within the filter. Therefore, practically the value of R consists only of the internal resistance of the inductor.

The process of designing a filter is a compromise among several factors: low maintenance, economy and reliability. The design of the simplest filter that does the desired job is what will be sought in the majority of cases [23]. The recommended procedure for the design and validation of single-tuned harmonic filters is summarized as the following [23].

1. Calculate capacitor bank needed to improve the power factor from the present level typically to around 0.96 or higher

The capacitive reactance needed to compensate the needed VARs to improve the power factor from PF1 (associated with θ1) to PF2 (associated with θ2) is given by

$$\mathbf{Q_{com} = P\,(\tan\theta_2 - \tan\theta_1)} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(4.6)$$

Where, P is the active power and Q_{com} is the reactive power needed for compensation. The capacitance for a single filter can be set to [24].

$$\mathbf{Q_f = Q_{com}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(4.7)$$

For a multiple parallel single-tuned filter system, the capacitance corresponding to the h^th^ harmonic can be distributed by [24].

$$\mathbf{Q_{fh} = Q_{com} \times \frac{I_h}{I_2 + I_3 + \cdots}}\ \mathbf{,\ h =}\ 2, 3\ \ldots\ldots\ldots \;(4.8)$$

Where I_h , is the h^{th} harmonic current and 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),

$$\mathbf{Q_c = \frac{h^2}{h^2-1} \times Q_{fh}} \quad \text{……..…………… (4.9)}$$

$$\mathbf{Q_L = Q_C - Q_{fh}} \quad \text{……………….……… (4.10)}$$

$$\mathbf{Q_L = \frac{1}{h^2} \times Q_c} \quad \text{……………………….... (4.11)}$$

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:

$$\mathbf{V_C = \frac{h^2}{h^2-1} \times V_{sys}} \quad \text{.....................…............ (4.12)}$$

Where h = tuned impedance harmonic order of the frequency
V_{sys}= system line-to-line voltage, KV
V_C = capacitor line-to-line voltage, KV
The Capacitive reactance required is obtained with the following relation

$$\mathbf{X_{C1} = \frac{{V_C}^2}{Q_C}} \quad \text{…………………….…... (4.13)}$$

At harmonic frequency h, this reactance is,

$$\mathbf{X_{Ch} = \frac{X_{C1}}{h}} \quad \text{……..………….…… (4.14)}$$

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

$$\mathbf{X_{Lh} = hx_{L1}} \quad \text{................................ (4.15)}$$

At the resonant frequency the capacitive and reactive impedances are equal. Then the X_L and X_C are related by the following equation,

$$\mathbf{X_L = \frac{X_C}{h^2}} \quad \text{................................... (4.16)}$$

3. Determine whether capacitor-operating parameters fall within IEEE-182 maximum recommended limits. This may require a number of iterations until 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

$$\mathbf{V_{Cpeak}} = \sqrt{2}(\mathbf{Vc1} + \mathbf{Vch}) \quad \text{………….…..... (4.17)}$$

$$\mathbf{V_{Crms}} = \sqrt{\boldsymbol{V_{C1}}^2 + \boldsymbol{V_{Ch}}^2} \quad \text{..……….…..... (4.18)}$$

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

$$\mathbf{V_{C1}} = \mathbf{X_{C1}} \times \mathbf{I_{C1}} \quad \text{……….......................... (4.19)}$$

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

$$\mathbf{V_{Ch}} = \mathbf{X_{ch}} \times \mathbf{I_{ch}} \quad \text{….….………...……… (4.20)}$$

IC_1 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.

$$\mathbf{I_{C1}} = \mathbf{1.05} \times \left[\frac{\frac{\mathbf{V_{L-L}}}{\sqrt{3}}}{\mathbf{X_{C1}} - \mathbf{x_{L1}}}\right] \quad \text{…………………… (4.21)}$$

- ✓ 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:

$$\mathbf{I_{Crms}} = \sqrt{\mathbf{I_{C1}}^2 + \mathbf{I_{Ch}}^2} \quad \text{……………..…..... (4.22)}$$

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

$$\mathbf{K_{VAR}} = \frac{\mathbf{Vcms * Icrms}}{\mathbf{1000}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.23)$$

Where, V_{crms} is the voltage through the capacitor, I_{crms} is the current through the capacitor. This value must be within 135%. The maximum recommended values are summarized in table given below.

Table 4-7: Maximum Recommended Limits for continuous Operation of shunt Capacitors under Contingency conditions [23]

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 designing appropriate tuned filter, the IEEE filter design practice for limiting harmonic and improving reactive compensation, depicted in Fig 4.6, is going to be used for this research.

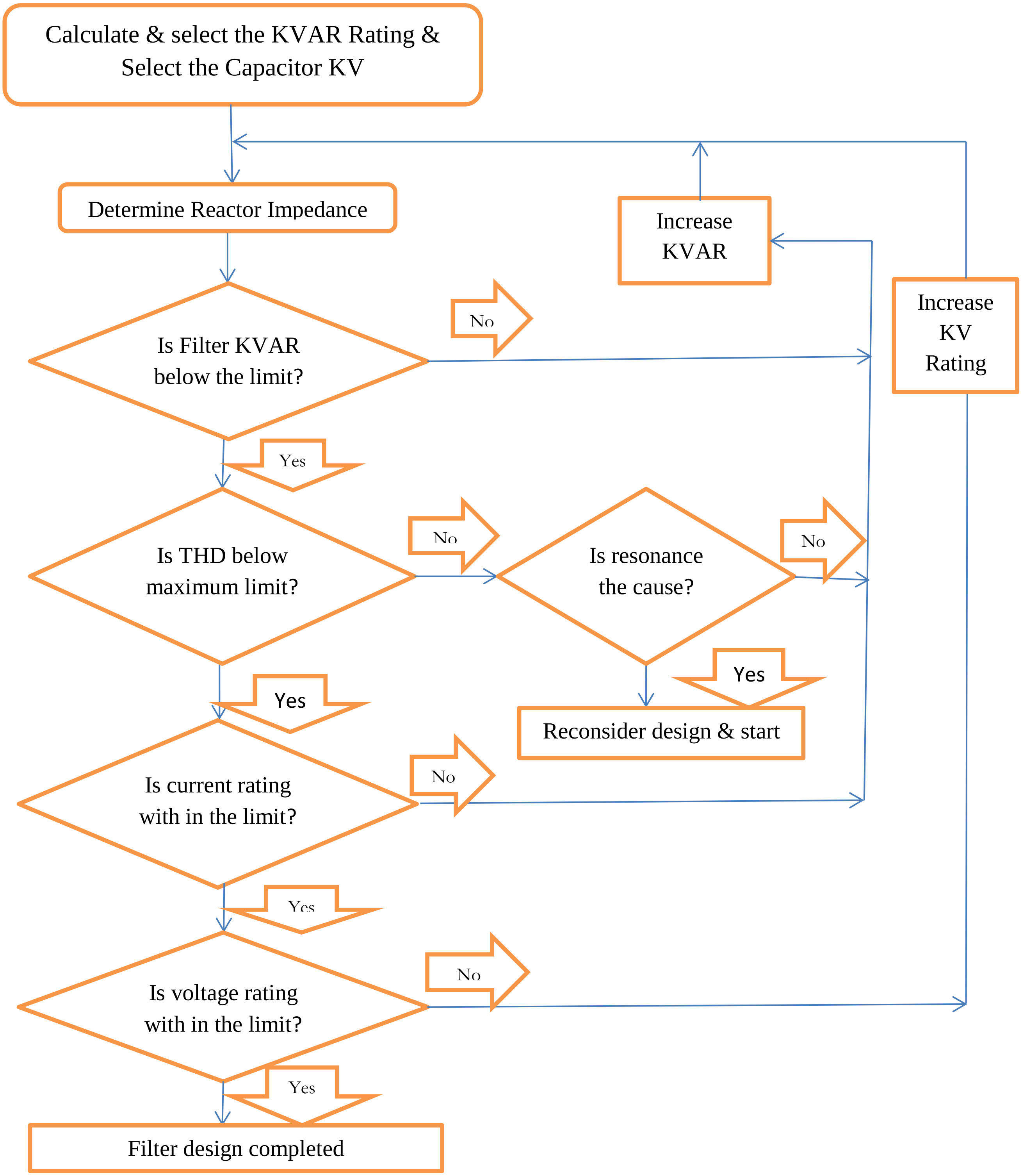


Figure 4-6: Decision flow chart for single-tuned filter [35]

5. RESULTS, ANALYSIS AND DISCUSION

5.1. Energy Lose Assessment

5.1.1. Computation of Energy Intensity of the Plant

Energy intensity is the amount of energy consumed to produce a unit amount of product and is a measure of the energy efficiency of the plant. The following graphs show the plot of the energy intensity of the Arbaminch Textile factory from year 2011/12-2014/15 G.C and the energy intensity of the selected Textile plants taken as a benchmark. The graph also compares the specific energy of the AMTF and the selected benchmark textile plants.

The selected benchmarks have higher energy efficiency performance as compared to other Textile factories and also they have the same yarn and fabric production technology as AMTF.

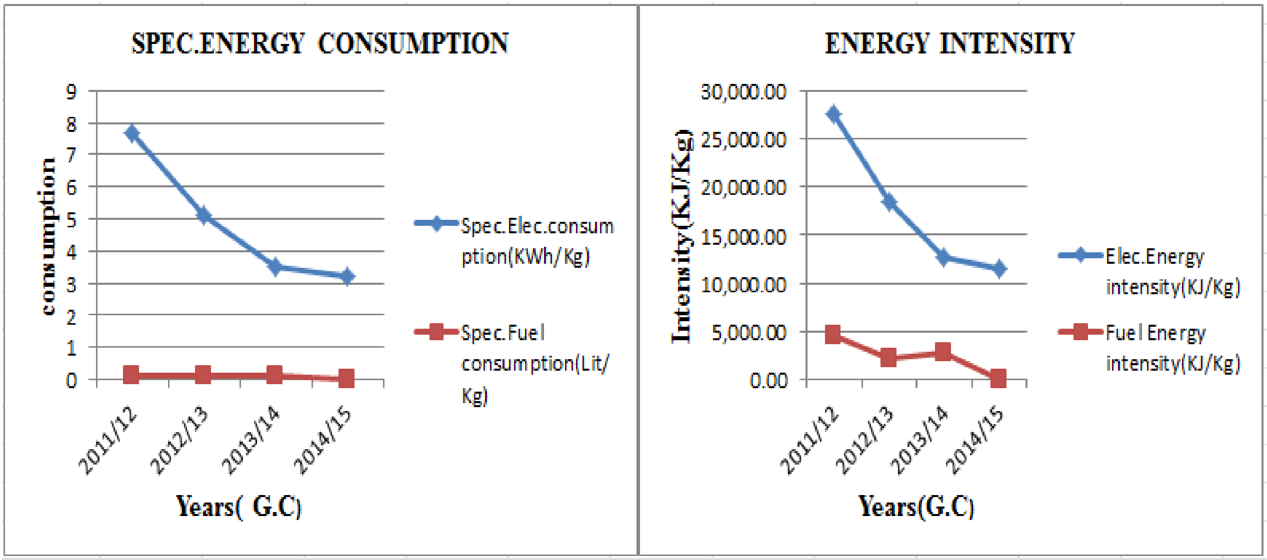


Figure 5-1: The specific energy and the energy intensity of AMTF

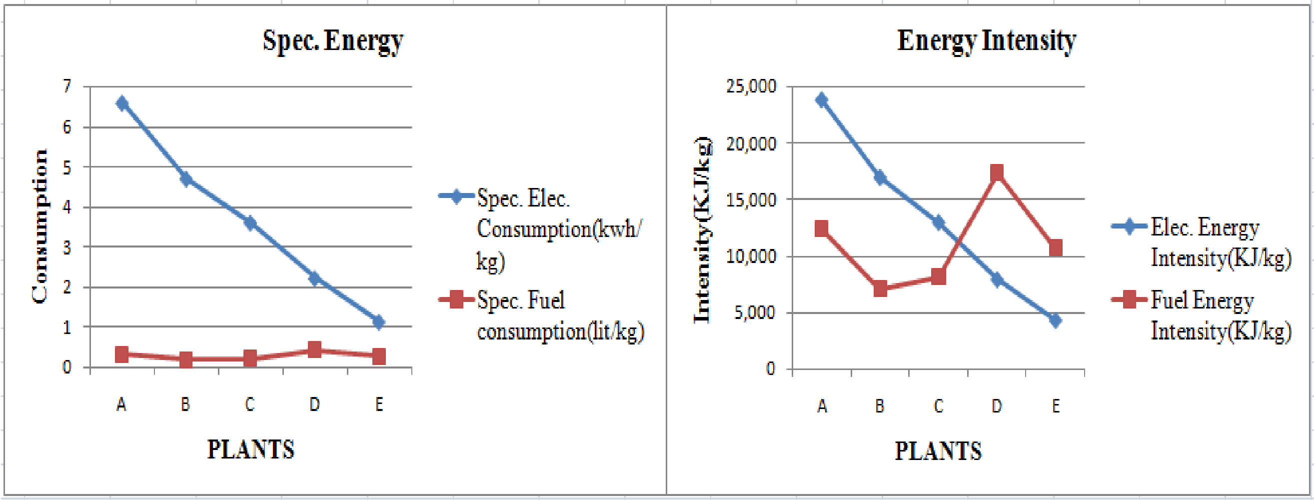


Figure 5-2: The specific energy and the energy intensity of selected plants

The Annual Electric energy intensity at AMTF in the year's 2011/12 to 2014/15 (G.C) ranges from 3.21KWh/kg to 7.67KWh/kg for Yarn and Fabric production with an average energy intensity of 4.88KWh/Kg. The Total Electric energy intensity of various plants taken as bench mark shown in Fig 5-2, gives an average energy intensity of 3.65KWh/Kg. Hence a difference of 1.23KWh/Kg exists between the average practice and what exists at AMTF.

With regards to fuel energy intensity of AMTF in the year's 2011/12 to 2013/14 (G.C) ranges between 2,097.46KJ/Kg to 4,487.31KJ/Kg of Yarn and Fabric production with average intensity of 2,358.3KJ/Kg. The Total fuel energy intensity of various plants taken as bench marks shown in Fig 5-2, give average energy intensity of 11,120 KJ/Kg.

5.1.2. Explanation of the results

It can be seen that from the analysis of the energy intensity of AMTF, there is a difference between the Electric energy intensity of AMTF as compared to the selected benchmarks plant experience. This shows that there is an actually a room for improving the energy efficiency of the plant. The following calculation shows clearly how much the company is actually spending for energy which was not necessary.

- Annual Average production of Yarn and fabric 2,552,814.9Kg per year.

- Cost of electricity = 0.4086 Birr per/KWh.
- Cost of fuel oil = 16.0 Birr/per lit. (2013/14 G.C.)
- Specific heat of fuel oil = 40,128KJ/lit.
- Difference in electricity energy intensity

  = 1.23KWh/Kg

- Annual cost due to inefficient use of electric energy intensity

  = electric consumption in KWh * cost of electricity.

  = energy int (KWh / Kg) * production (Kg) * cost of electricity (Birr / KWh)
  = 1,282,988 Birr per year.

The fuel energy consumption is very good relative to the bench mark plants selected; however it is good the company totally left the fuel furnace and use Electric boiler machine for better cost minimization. Doing this the company saves about 1,800,371.5 Birr every year.

From the breakdown of energy use in the different section of the textile industry the ring frame and the open end machineries are observed to have large proportions of energy consumptions 43.7% and 30.3% respectively. Thus the facility should do the following measures to reduce the energy consumption

- Use of energy-efficient spindle oil
- Optimum oil level in the spindle bolsters
- Replacement of lighter spindles in place of conventional spindles in ring frames
- Installation of energy-efficient excel fans in place of conventional aluminum fans in the suction system of ring frames
- Installation of electronic roving end break stop-motion detectors instead of pneumatic systems
- Installation of VFD on humidification system pumps

5.2. Measured data analysis of all transformers in Arbaminch Textile Factory

5.2.1. 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 on investigation, assessment and measurement of harmonics in power system. The standard includes steady state limits on current harmonic and harmonic voltages at all system voltage levels. The limit was set for a steady state operation and for worst case scenario [36].

The IEEE power quality standards of different power quality problems are given in the following table.

Table 5-1: Current distortion limit for general distribution systems (120V through 69000V) [36]

Maximum Harmonic Current Distortion in Percent of IL						
ISC/IL	<11	11≤h≤ 17	17≤ $h < 23$	23≤ $h < 35$	35≤ h	TDD (%)
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

h = odd harmonic order

ISC = maximum short-circuit at the common point of coupling (PCC)

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

TDD = Total Demand Distortion

Even harmonic are limited to 25% of the odd harmonic limits above.

Table 5-2: Voltage Distortion Limits

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

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%

5.2.2. Assessment of Voltage and current Unbalance Factor

The voltage and current unbalance factors of the Textile Factory Distribution Systems are determined based on the line-to-line measurement data provided in the table 2.7 above.

Table 5.4 below gives the average line -to- line voltage values, and voltage unbalance factor at the bus bars found in main distribution board (MDB). And table 5.5 gives the line to line current values, and current unbalance factor.

Table 5-4: Voltage Unbalance Factor for AMTF Distribution System

Transformer code	Line voltage code	Measured value(volt)	Mean of (Vab,Vbc,Vca)	Maximum deviation from the mean	VUF (%)
T-1	Vab	391.3	390.67	0.63	0.16
	Vbc	390.7			
	Vca	390.0			
T-2	Vab	393.3	392.73	0.57	0.15
	Vbc	392.2			
	Vca	392.7			
T-3	Vab	393.3	394.67	1.83	0.46
	Vbc	394.2			
	Vca	396.5			
T-4	Vab	394.4	392.83	1.57	0.4
	Vbc	391.7			
	Vca	392.4			
T-5	No data				
T-6	Vab	392.9	391	2.2	0.56
	Vbc	391.3			
	Vca	388.8			

Table 5-5: Current Unbalance Factor for Textile Factory Distribution System

Transformer code	Line current code	Measured value(A)	Mean of (Iab,Ibc,Ica)	Maximum deviation from the mean	IUF (%)
T-1	Iab	707.9	708.6	1.0	0.14
	Ibc	708.3			
	Ica	709.6			

T-2	Iab	700.4	700.47	1.53	0.22
	Ibc	699.0			
	Ica	702.0			
T-3	Iab	461.6	460.53	1.07	0.23
	Ibc	460.2			
	Ica	459.8			
T-4	Iab	355.2	355.47	0.33	0.093
	Ibc	355.4			
	Ica	355.8			
T-5	No data				
T-6	Iab	548.2	545.73	2.47	0.45
	Ibc	544.8			
	Ica	544.2			

As seen from the Tables 5.4 and 5.5, the voltage and the current unbalance factors for the factory distribution system are within the standard values given in table 5.3(< 3% for voltage and <10% for the current). Although the values are within the acceptable standard, the transformer number six (T6) unbalance factor values are relatively larger than that of the others.

5.2.3. Power Factor Assessment

The power factor values of loads at the Textile Factory are obtained from already installed power factor meters. The readings are taken for five days and their average values are all greater than the minimum acceptable value of 0.85 as shown in Table 2.7 above.

5.3. Simulation Results of the factory

This section 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. The selected transformers serve buildings which have a wide range of industrial loads such as Boilers, Motors, HVAC's, Compressors and fluorescent lights. The purpose of the simulation is to investigate the extent of harmonic distortion levels at different loading conditions and to study the effect of linear loads over harmonic distortion levels.

5.3.1. 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 tables below. The waveform of Currents and voltages are also given.

Table 5-6: Harmonic Currents at each harmonic order for T1 and T2

Harmonic order	1	5	7	11	13	THD
harmonic current, A	47.0	25.8	3.2	0.0	0.0	26%

Table 5-7: Harmonic Voltages at each harmonic order for T1 and T2

	Harmonic Voltage as percent of fundamental Voltage							
Harmonic order	1	5	7	11	13	19	23	THD
Harmonic Voltage, %	100	3.57	0.61	0.03	0.03	0.01	0.01	3.62%

The waveform outputs from simulation are given below

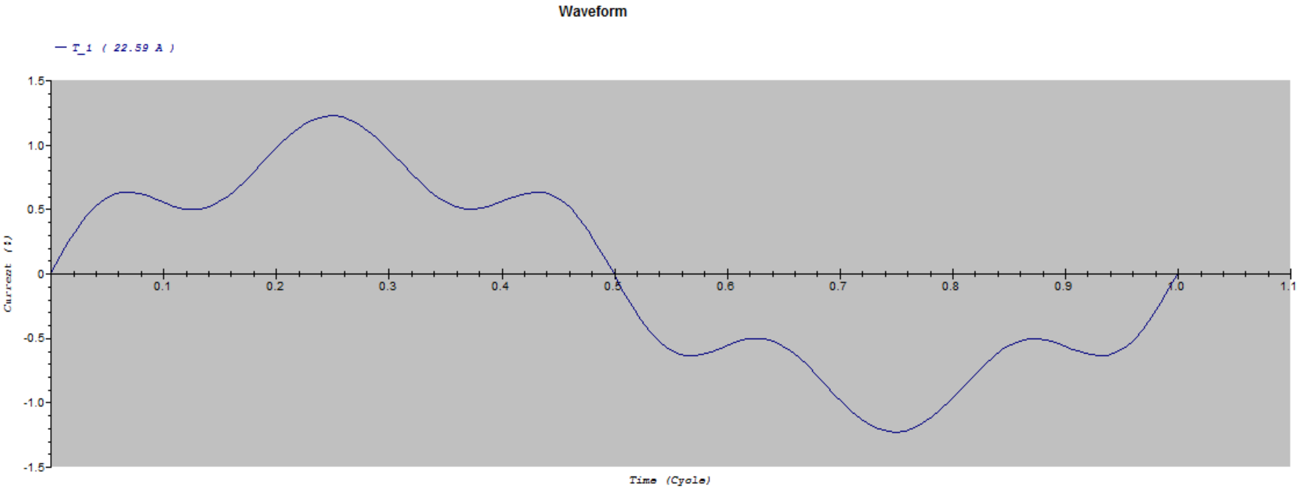


Figure 5-3: Waveform of current for T1 with THDI 26%

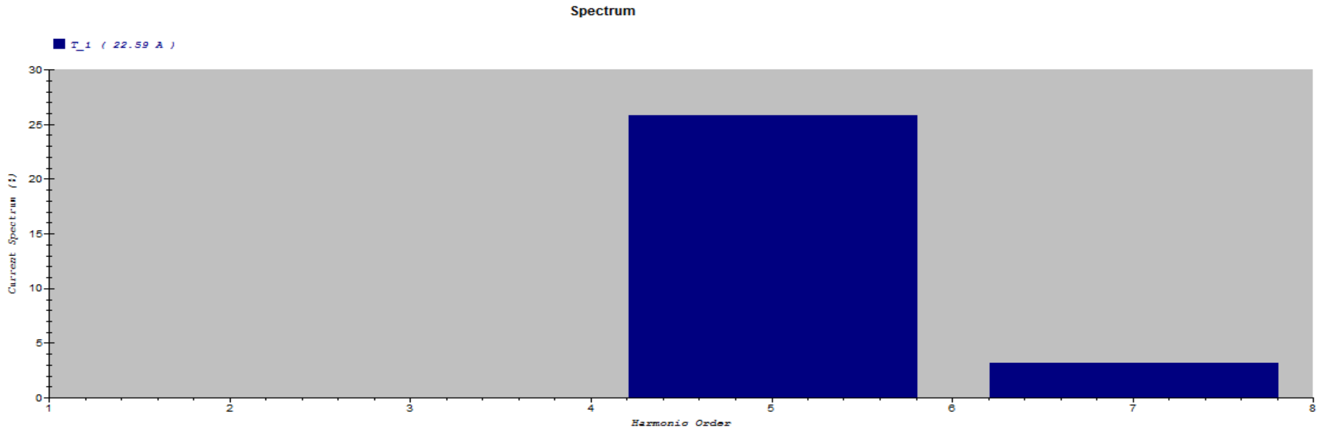


Figure 5-4: Graph form of currents for T1 with THDI 26%

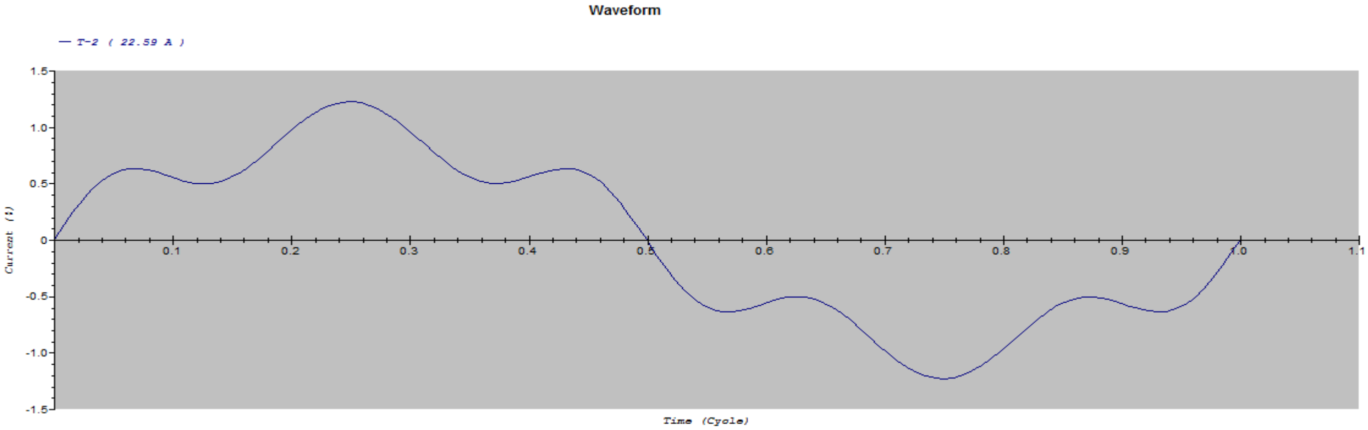


Figure 5-5: Waveform of currents for T2 with THDI 26%

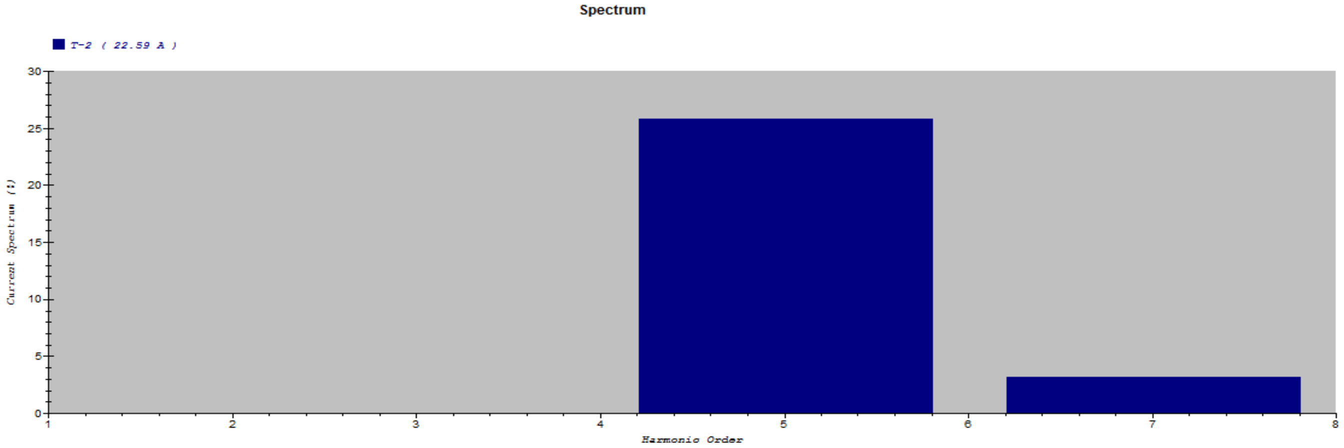


Figure 5-6: Graph form of currents for T2 with THDI 26%

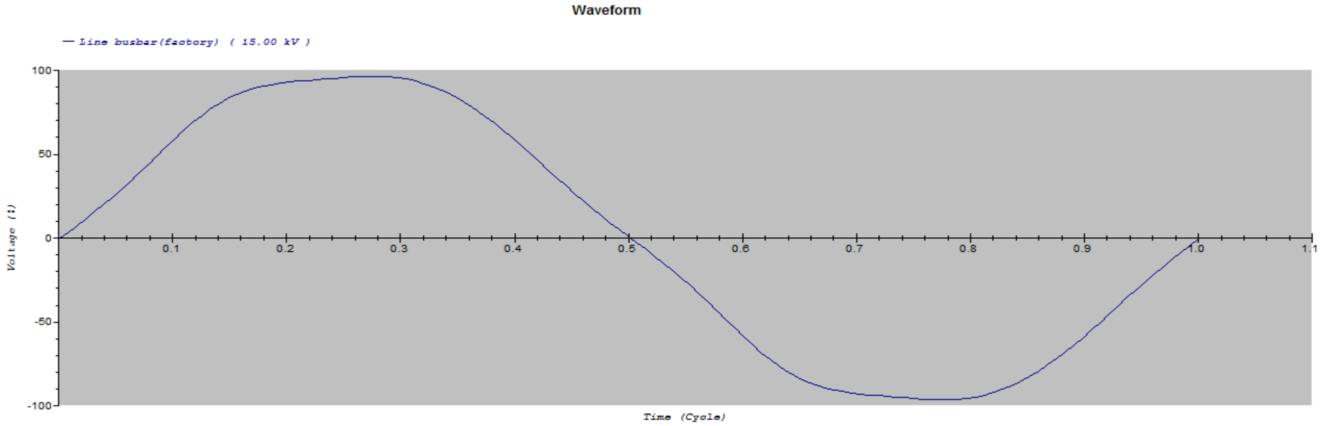


Figure 5-7: Waveform of voltage for the factory line bus bar with THDV 3.62%

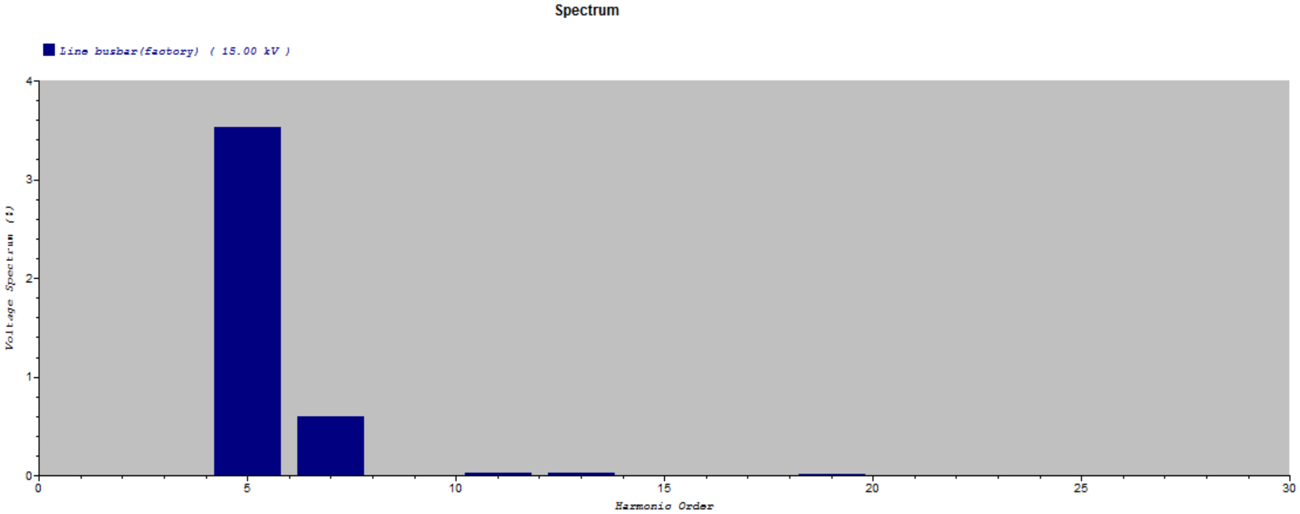


Figure 5-8: Graph form of voltage for the factory line bus bar with THD 3.62%

5.3.2. 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 conclusion if the distortion levels obtained from simulation are of significant concern or not. EEU takes billing measurements from the primary terminal of the transformers. So the primary terminal of each transformer is treated as 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 is given by [37].

$$\mathrm{I_{SC}} = \frac{\mathrm{I_{rated}}}{\%\,\mathrm{impedance}} = \frac{\frac{KVA}{\sqrt{3}V}}{\%Z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (5.1)$$

Where $\mathrm{I_{SC}}$ = maximum Short circuit current, I rated = rated current, KVA = capacity of transformer, V = rated secondary voltage and Z = percent impedance.

5.3.2.1. 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 1250KVA, 15/0.4 KV with a percentage impedance of 5%. Then the total short circuit current is 1924.5 A. To obtain the maximum demand current either there should be recorded demand data in 15 or 30 minutes period (e.g. billing records) or the fundamental currents should be taken as the maximum demand. This value is 47A. The SCR is then obtained to be 1924.5/47= 41.0, which requires the limit TDD = 8% to be applied. The individual and total demand distortion levels are tabulated below.

Table 5-8: Harmonic Current as % of IL

	Harmonic currents as percentage of IL					
Harmonic Order	5	7	11	13	15	TDD%
value	25.8	3.2	0.0	0.0	0.0	26

Note: All highlighted values are out of the standard limit

The total demand distortion at this loading condition is 26% which is unacceptable since it is above the limit. The individual 5th harmonic current is also above the acceptable limit. The total Voltage distortion level is in the acceptable range but the individual 5th harmonic voltage is unacceptable.

The effect of harmonics is significant in the selected transformers (T1 and T2) since the current distortion levels in that transformers are very high. It is convincing that their effects must be evaluated and mitigation actions must be carried out to minimize the distortion levels. Reducing harmonics will save energy and release additional capacity to serve other loads.

5.4. Harmonic Mitigation Using Single-tuned Multi-branch Filter

This subtopic presents a method of designing single-tuned filters to reduce harmonic distortion and correct the power factor. The filters for both transformers will be designed using design equations in chapter 4. The designed filters will be simulated and results will be presented if the harmonic distortion is reduced to acceptable range after filter application.

5.4.1. 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 is the most dominant. The dominant frequencies are 5th, 7th, 11th and 13th harmonics. Therefore, multiple-branch single tuned harmonic filter is going to be designed. The harmonic filter design will be done according to the equations and flow chart given in fig 4.6 of chapter 4. The effectiveness of the filters will be analyzed by comparing the harmonic currents obtained from simulations before and after applying the filters.

In order to design a multiple parallel single-tuned filter for T1 the following dates are arranged in a tabular form.

Table 5-9: Simulation Results of the most dominant harmonic loads at T1 (Blowing)

Harmonic order, h	1	5	7	11	13	17	19	23	THD%
Harmonic current, A	120	36	20.88	4.44	3.96	0.20	0.73	0.19	35%

Table 5-10: Transformer T1 Load data

Active power (P, KW)	497.98
Reactive power (Q, KVAR)	295.5
Apparent power (S,KVA)	579.04
Power factor (P.F)	0.86

As can be seen from the above table, the current Power factor obtained is 0.86 and it is desired to improve this value to 0.95 and greater. The total active power for this condition is 497.98 KW.

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 (arccospf0) – tan (arccospf1)) = 497.98*(tan ($\cos^{-1}$0.86) – tan ($\cos^{-1}$0.95)) = 131.81KVAR, 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 6, i.e. equations (6.2) to (6.9). The reactive power is distributed among 5th, 7th, 11th and 13th harmonic filters as follows.

$$Qf_5 = Qcom \times \frac{I5}{I5 + I7 + I11 + I13} = 131.81 * \frac{36}{36+20.88+4.44+3.96} = 72.7KVAR$$

$$Qf_7 = Q_{Com} \times \frac{I7}{I5 + I7 + I11 + I13} = 131.81 * \frac{20.88}{36+20.88+4.44+3.96} = 42.2KVAR$$

$$Qf11 = Q_{Com} \times \frac{I11}{I5+I7+I11+I13} = 131.81 * \frac{4.44}{36+20.88+4.44+3.96} = 8.97KVAR$$

$$Qf13 = Q_{Com} \times \frac{I13}{I5+I7+I11+I13} = 131.81 * \frac{3.96}{36+20.88+4.44+3,96} = 8.0KVAR$$

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

<u>For 5th harmonic filter</u>

The voltage across the capacitor is determined by equation (4.12)

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

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 equation (4.9).

$$\mathbf{Q_C} = \left(\frac{\mathbf{h2}}{\mathbf{h2-1}}\right) * \mathbf{Qf5} \; = \; \frac{25}{24} * 72.7\text{Kvar} \; = 75.73\text{KVAR}$$

Let this value be 100KVAr, looking at the table given in appendix F. Then X_C is determined using equation (4.13).

$$\mathbf{X_C} = \frac{(\mathbf{Vc})^2}{\mathbf{Qc}} \times \mathbf{1000} = \frac{(0.48)2}{100} \times 1000 = 2.3\Omega$$

$$\mathbf{X_L} = \frac{\mathbf{XC}}{\mathbf{h2}} = \frac{\mathbf{2.3}}{\mathbf{25}} = 0.092\ \Omega$$

Using similar procedure the design parameters are summarized in table below

Table 5-11: Design parameters of multi-branch harmonic filter

Branch	Qc	V_C	X_C, Ω	XL,Ω
5th	100	480	2.3	0.092
7th	100	480	2.3	0.047
11th	50	480	4.61	0.038
13th	50	480	4.61	0.027

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 in chapter 6. First the designed values for 5th harmonic filter are compared with the standard in the table below.

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

DUTY	Definition	Limit, %	Actual Values	Actual Values, %
RMS CURRENT	$\frac{\text{Irms, total}}{\text{Icap, rated}}$	135	136.63/120.5	113
RMS VOLTAGE	$\frac{\text{VL}-\text{G, Cap(rms, total)}}{\text{KVrated}}$	110	303.6/277.1	109.5
PEAK VOLTAGE	$\frac{\text{VL}-\text{G, Cap(max, peak)}}{\text{KV rated}}$	120	452.1/391.92	115

DUTY	Definition	Limit, %	Actual Values	Actual Values, %
KVAR	$\frac{\text{KVAR cap(wye), total}}{\text{KVAR rated}}$	135	41.5/100	41.5

- ✓ All the values meet the limits requiring so no further iterations to be carried out.

Using the same procedure as 5^{th} harmonic filter comparison is made for the rest harmonics as shown below.

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

Duty	Limit, %	Actual Values, %		
		7th	11th	13th
RMS current	135	109	106	106
RMS Voltage	110	107	106	106
Peak Voltage	120	109.6	107	106
KVAR	135	38.9	37.4	37.2

5.4.2. Design of Multi-branch Single-tuned Filter for T2

Here also multi-branch single-tuned filter will be designed. Exactly the same procedure as for T1 is used. Table below gives the simulation results of T2.

Table 5-14: Simulation Results of the most dominant harmonic Loads at T2 (Warping)

Harmonic order, h	1	5	7	11	13	17	19	23	THD%
Harmonic currents ,A	77	38.5	20.02	4.0	3.31	0.17	0.49	0.18	57%

Table 5-15: Transformer T2 load data

Active power(P,KW)	735.63
Reactive power(Q,KVAR)	356.28
Apparent power(S,KVA)	817.37
Power factor	0.9

The current Power factor obtained is 0.9 and it is desired to improve this value to 0.96 and greater. The total active power for this condition is 735.63 KW.

Q com = P*(tan (arccospf0) – tan (arccospf1)) = 735.63*(tan ($\cos^{-1}$0.9) – tan ($\cos^{-1}$0.96)) = 141.72kvar, where Qcom = reactive power to be compensated.

The reactive power is distributed among 5th, 7th, 11th and 13th harmonic filters as follows.

$$Qf5 = Q_{Com} \times \frac{I5}{I5+I7+I11+I13} = 141.72 * \frac{38.5}{38.5+20.02+4.0+3.31} = 82.88KVAR$$

$$Qf7 = Q_{Com} \times \frac{I7}{I5+I7+I11+I13} = 141.72 * \frac{20.02}{38.5+20.02+4.0+3.31} = 43.1KVAR$$

$$Qf11 = Q_{Com} \times \frac{I11}{I5+I7+I11+I13} = 141.72 * \frac{4.0}{38.5+20.02+4.0+3.31} = 8.61KVAR$$

$$Qf13 = Q_{Com} \times \frac{I13}{I5+I7+I11+I13} = 141.72* \frac{3.31}{38.5+20.02+4.0+3.31} = 7.13KVAR$$

<u>For 5th harmonic filter</u>

The voltage across the capacitor is determined by equation (4.12)

$$\mathbf{V_C = V_S * (\frac{h^2}{h^2-1})} = = 0.4\ (25/24) = 0.417KV$$

The standard voltage available near this value is 480 V, referring to appendix. The reactive power to be supplied by the capacitor is calculated using equation (4.9).

$$\mathbf{Q_C = (\frac{h^2}{h^2-1}) * Q_{f5}} = (25/24)*82.88Kvar = 86.33KVAR$$

Let this value be 100KVAR, looking at the table given in appendix. Using similar procedure the design parameters are summarized in table below.

Table 5-16: Design Parameters of multi-branch harmonic filter

Branch	Qc	V_C	X_C, Ω	X_L,Ω
5^{th}	100	480	2.3	0.092
7th	100	480	2.3	0.049

11th	50	480	4.61	0.038
13th	50	480	4.61	0.027

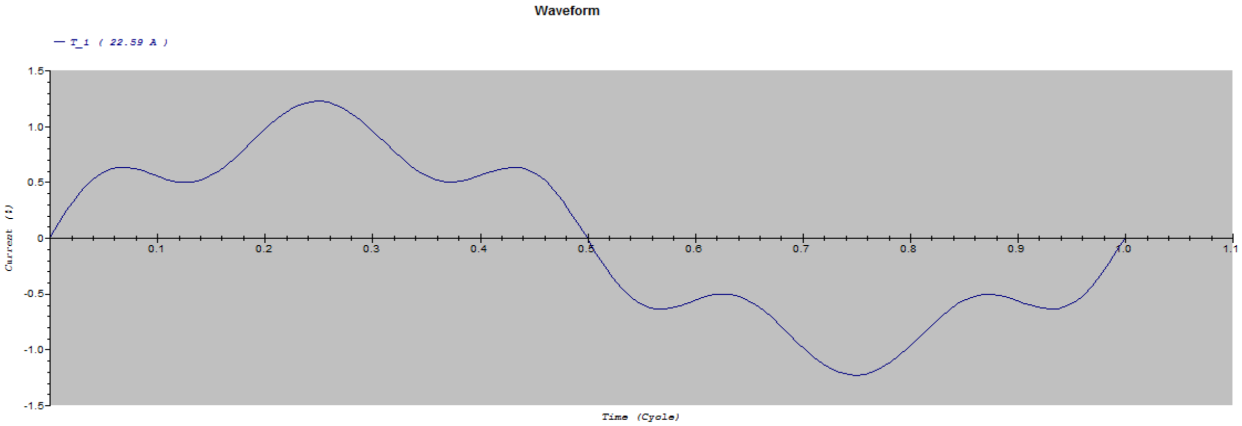
Table 5-17: Comparison Table for Evaluating Filter Duty Limit of Harmonic filter

Duty	Limit, %	Actual Values, %			
		5th	7th	11th	13th
RMS current	135	114	108.5	106.1	106
RMS Voltage	110	109.6	107	105.9	106
Peak Voltage	120	116	109.7	106.5	106
KVAR	135	41.7	38.83	37.4	37.22

- ✓ All the values are within the requiring limits so no further iterations to be carried out.

5.4.3. Simulation Results of the Designed Filters for T1 and T2

The designed filters are simulated to see if they can effectively reduce the distortion levels in both transformers to acceptable values. The current and voltage waveforms before and after filtering are presented below for comparison.



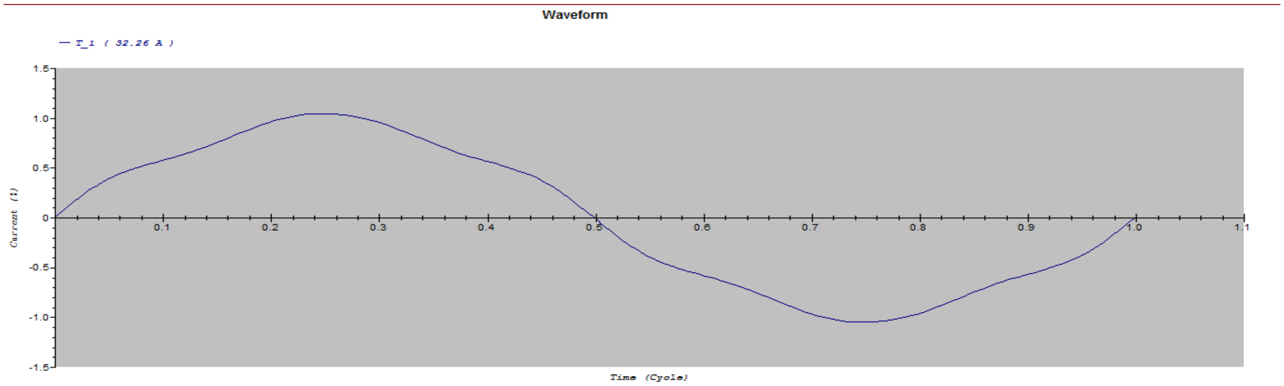


Figure 5-9: Current of T1 before (upper) and after (lower) filtering

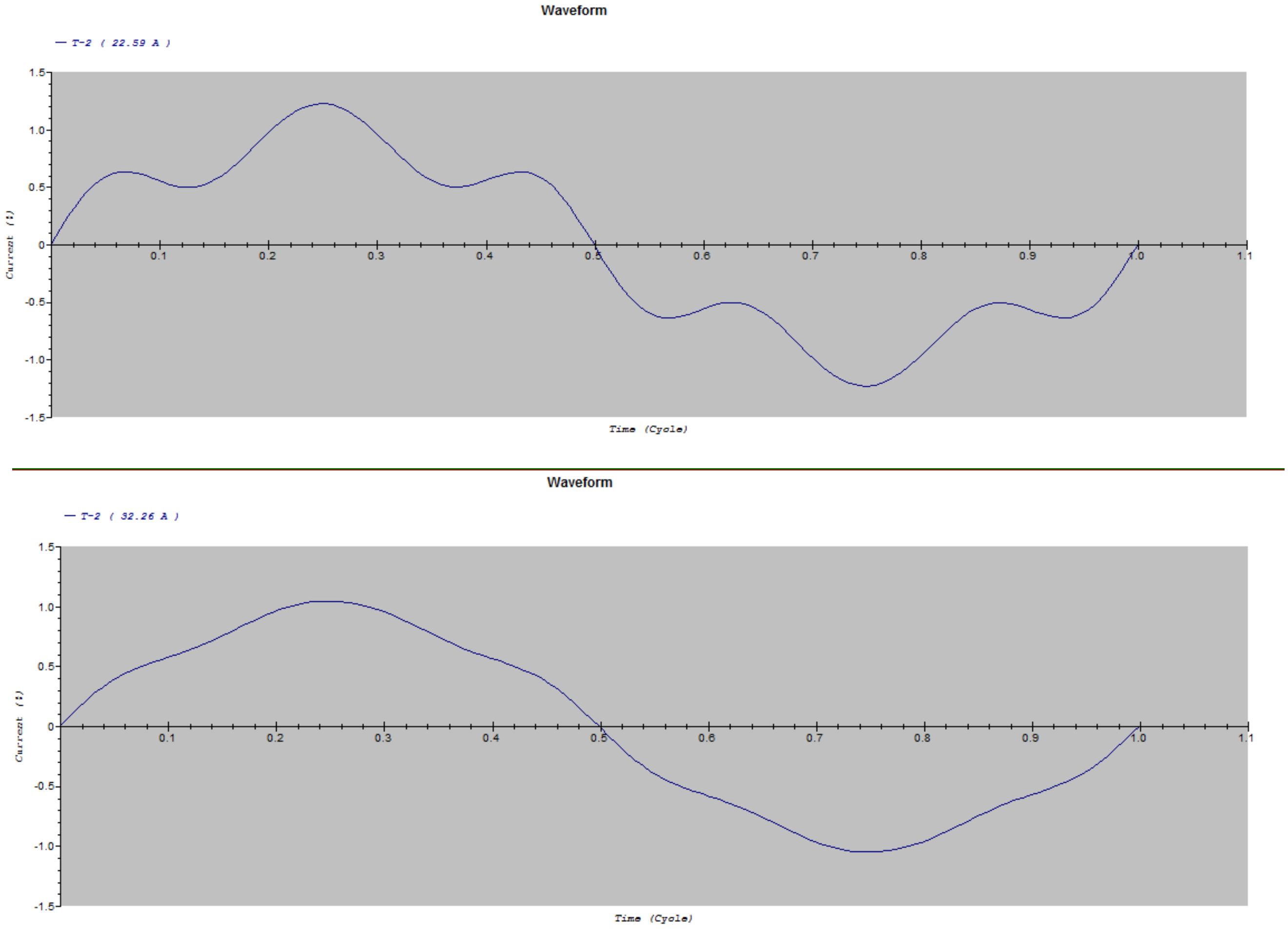


Figure 5-10: Current of T2 before (upper) and after (lower) filter.

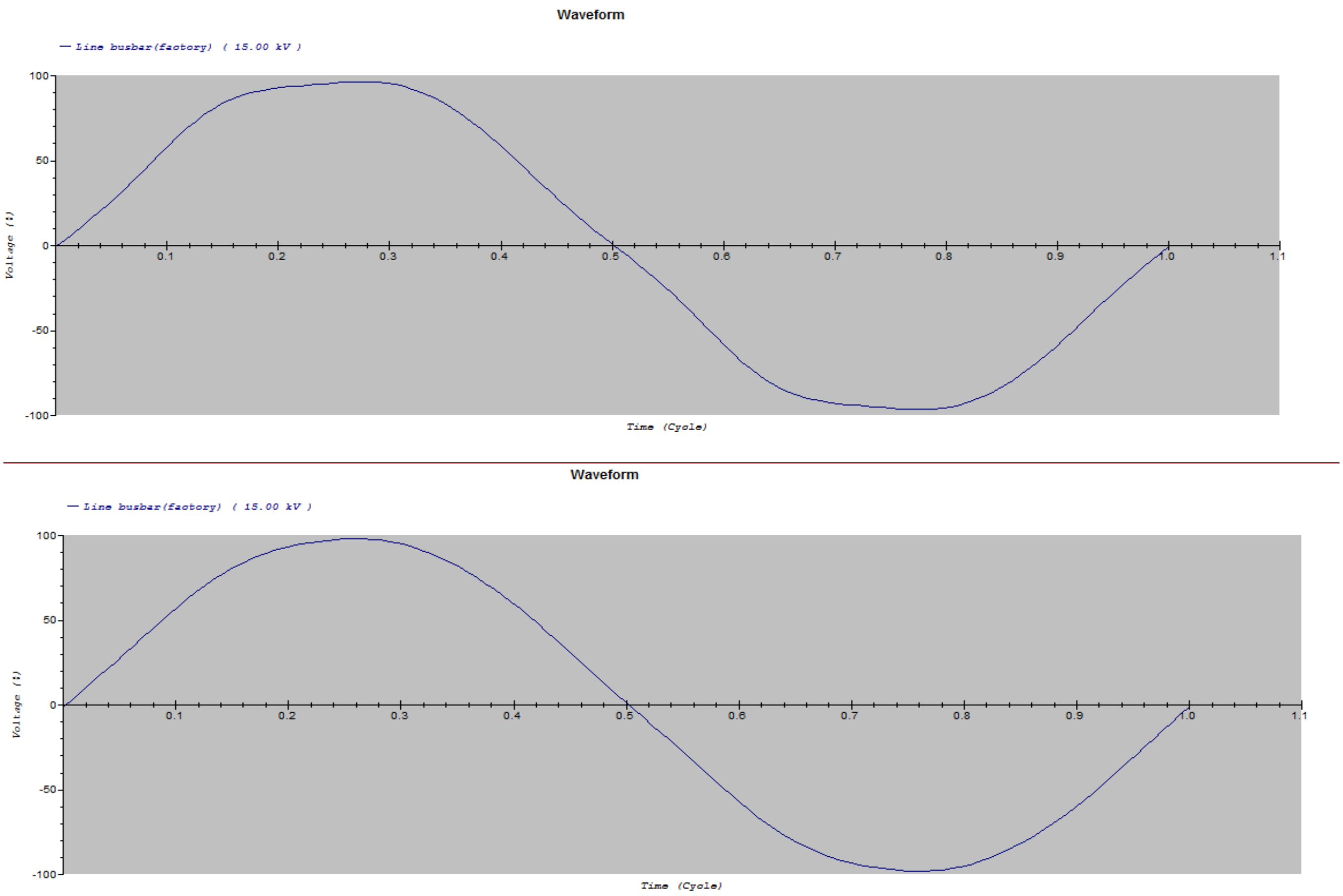


Figure 5-11: Voltage of T1 and T2 at the factory line bus bar(PCC) before (upper) and after(lower) filtering

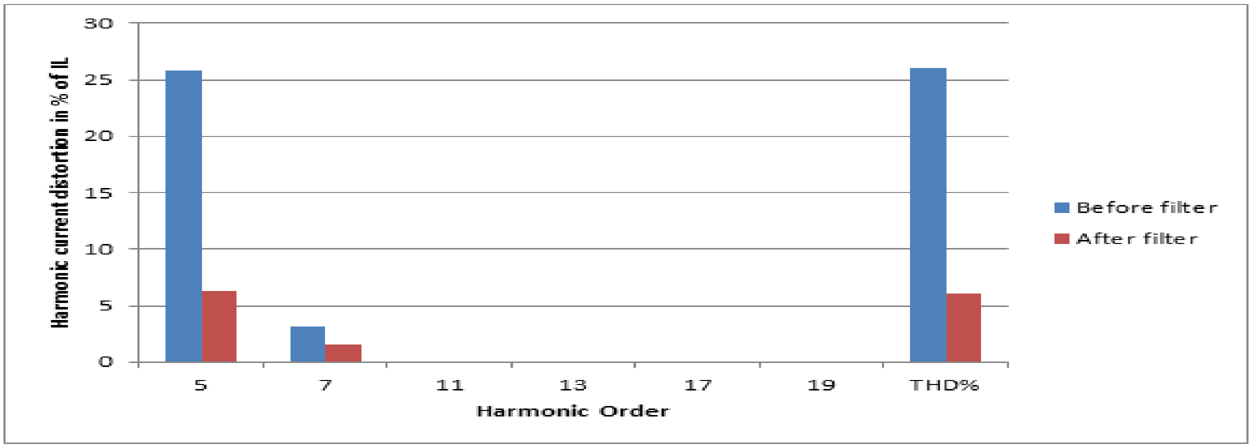


Figure 5-12: Comparisons of harmonic current values before and after filtering at PCC

5.4.4. Summary of Simulation Results using Filter

The results obtained above show the multi-branch single tuned filter has significantly reduced the harmonics of that appear at the primary terminals (PCC) of the transformers. The total current distortion level of T1 and T2 is reduced from 26% to 6% and the individual harmonic (5^{th}) distortion of the current is damped from 25.8% to 6.57%. The total harmonic distortion of the voltage is within the standard limit and is reduced from 3.63% to 1.31% and the individual (5^{th} harmonic) voltage which is above the standard is reduced from 3.57% to 1.24%

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusions

In general, energy in Arbaminch the textile industry is mostly used in the forms of: electricity, as a common power source for machinery, cooling and temperature control systems, lighting systems, steam generation, office equipment, etc.

The Figure 2.2 in chapter two shows the distribution of energy consumption in different section of the spinning department in AMTF. These sections include the blowing, carding, drawing and ring frame. The ring frame (43.7%) and the open end (30.3%) have the highest energy consumptions. And also in the composite process spinning consumes the greatest share of electricity (44.7%) followed by weaving (weaving preparation and weaving) (29.7%). Based on the analysis on the result section where some analysis have been done on energy intensity of the plant and comparisons made with benchmark factories, showed still there are many possible energy saving areas in the textile Plants.

Using motor master+ international software, it has been seen that in the ring frame section replacing 22kw of the existing motor with a 15kw energy efficient motor can bring energy savings of 13,189KWh per year and money savings of 325 dollars per year with four years payback periods. And also through improving the lighting installation systems resulted in energy saving of 209,802kWh/y and in money savings of 85,725 Birr annually were obtained.

Assessment of power quality problems such as voltage unbalance factor, current unbalance factor, and Harmonic distortions have been studied and comparisons were made with standards and filters were designed.

It has been found that voltage and current unbalance factors are within the acceptable limits of the IEEE standards. But the simulation results, total current and the individual current (5^{th}) distortion levels were violating the prescribed limit by 18% and 18.5% respectively. And the individual voltage (5^{th}) distortion levels were violating the prescribed limit by 0.57%. This was due to the fact that the transformer supplies non-linear loads like fluorescent lamps, ASDs.

The designed filters were observed to reduce the total harmonic distortion of the current from 26% to 6%, the individual harmonic (5th) distortion of the current from 25.8% to 6.57% and the individual harmonic distortion of the voltage (5th) from 3.57% to 1.24%. This reduction in distortion level shows how important a filter is to get rid of the ill effects, additional heating, false tripping and equipment malfunction associated with harmonics.

By implementing the energy efficiency and power quality improvement opportunities in this thesis work, the factories can get the following benefits:

- It has been seen on the energy loss assessment part; around 1,300,000 million birr per year is due to inefficient use of energy. So, by reducing these losses the factories will reduce their energy costs.
- By reducing their energy intensity, the factories will be competent with the world market. Which means the factory will produce products with minimum cost
- Avoids power quality problems generated in different equipments like in cables, motors, transformers etc.
- Will ensure reliable power supply and hence continues production throughout the year

6.2. Recommendations

Efficient utilization of electrical energy by reducing the quantity of energy consumed and modifying the process of manufacturing provides sustainable development. For a country like Ethiopia, accelerating towards industrialization, efficient utilization of energy should be highly emphasized as it helps the economy grow smoothly. This study has assessed energy efficiency and power quality improvement in Arbaminch Textile Factory. The results of the thesis have showed that unnecessarily energy is lost in AMTF due to the existence of low energy efficient motors, Accessories, lightings etc. thus replacement with energy efficient equipments and proper lighting installation is necessary. The ring frame with large energy consumption is recommended to use lighter spindles, energy-efficient spindle oil, and electronic roving end break stop-motion detectors. The results obtained have also showed that effective filters parallel to the loads are necessary.

6.3. Suggestions for future work

The results obtained in this thesis point to several issues where future research may be carried out. Some of these issues are:

- This thesis reflects study done on a typical textile plant (Arbaminch textile plant) with regard to conservation of electrical energy only. Scope for further study exists in doing a detailed energy audit covering not only the electrical energy but thermal and other sources of energy as well.

- Some of the energy savings opportunities in this work are quick and low cost measures that can be implemented in the existing systems. The high cost or capital intensive measures may need further detailed audit and analysis.

- The electronic loads, such as entertaining digital equipments are increasing in residential facilities. So future work must incorporate these loads in to study of harmonic analysis and investigate the distortion levels produced.

- It should be understood that the simulation results obtained in the industry are only approximate estimates since several assumptions have been made 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. Real measurements are always preferred since they try to accurately reflect the true characteristics of the system. For this purpose it is recommended that the industry to purchase different electrical instruments such as oscilloscopes, HIOKI 3196 Power Quality Analyzer (for all power quality problems) or AEMC F25 Clamp-ON Harmonic Power Meter (for harmonics only) for future researches. These devices will provide great help for studying problems associated to power quality issues smoothly and easily.

- The impact of harmonics on age of a transformer must be studied in the future

- Tuned filters can cause undesirable system resonance that leads to catastrophic failure. Filters effectiveness will also change when loads changes. Other options like active filters, phase-shifting transformers and series reactors must be considered in future research.

- In this thesis, meter recordings were taken on daily basis because of time constraints. But it would be better to take the readings on 15 min or hourly basis as this will give valuable and accurate information

- Finally, it is recommended that the factory to replace the analogue meters with digital one because it is difficult to get accurate readings from the analogue measuring devices.

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Appendix A: Terms and Definitions used to Quantify Light source

Various Terms and Definitions Used to Quantify Light or Light Source.

Luminaire: A luminaire is a complete lighting unit, consisting of a lamp or lamps together with the parts designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply

Lumen: Unit of luminous flux; the flux emitted within a unit solid angle by a point source with a uniform luminous intensity of one candela. One lux is one lumen per square meter. The lumen (lm) is the photometric equivalent of the watt, weighted to match the eye response of the "standard observer". 1 watt = 683 lumens at 555 nm wavelength

Lux: This is the metric unit of measure for illuminance of a surface. Average maintained illuminance is the average of lux levels measured at various points in a defined area. One lux is equal to one lumen per square meter. The difference between the lux and the lumen is that the lux takes into account the area over which the luminous flux is spread. 1000 lumens, concentrated into an area of one square meter, lights up that square meter with an illuminance of 1000 lux. The same 1000 lumens, spread out over ten square meters, produce a dimmer illuminance of only 100 lux

Luminous Intensity and Flux:

The unit of luminous intensity I is the candela (cd) also known as the international candle. One lumen is equal to the luminous flux, which falls on each square meter (m2) of a sphere one meter (1m) in radius when a 1-candela isotropic light source (one that radiates equally in all directions) is at the center of the sphere. Since the area of a sphere of radius r is 4πr2, a sphere whose radius is 1m has 4πm2 of area, and the total luminous flux emitted by a 1- cd source is therefore 4π1m. Thus the luminous flux emitted by an isotropic light source of intensity I is given by:

Luminous flux (lm) = 4π × luminous intensity (cd)

Installed Load Efficacy: This is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior expressed in lux/W/m².

Installed Load efficacy ratio: This is the ratio of target load efficacy and installed load.

Rated luminous efficacy: The ratio of rated lumen output of the lamp and the rated power consumption expressed in lumens per watt

Room Index: This is a ratio, which relates the plan dimensions of the whole room to the height between the working plane and the plane of the fittings

Target Load Efficacy: The value of Installed load efficacy considered being achievable under best efficiency, expressed in lux/W/m².

Utilization factor (UF): This is the proportion of the luminous flux emitted by the lamps, reaching the working plane. It is a measure of the effectiveness of the lighting scheme

The Inverse Square Law

The inverse square law defines the relationship between the luminance from a point source and distance. It states that the intensity of light per unit area is inversely proportional to the square of the distance from the source (essentially the radius).

$$\mathbf{E} = \frac{\mathbf{I}}{\mathbf{d^2}}$$

Where, E = illuminance, I = luminous intensity and d = distance

Color Temperature

Color temperature, expressed on the Kelvin scale (K), is the color appearance of the lamp itself and the light it produces. Imagine a block of steel that is steadily heated until it glows first orange, then yellow and so on until it becomes “white hot.” At any time during the heating, we could measure the temperature of the metal in Kelvin (Celsius + 273) and assign that value to the color being produced. This is the theoretical foundation behind color temperature. For incandescent lamps, the color temperature is a "true" value; for fluorescent and high intensity discharge (HID) lamps, the value is approximate and is therefore called correlated color temperature. In the industry, “color temperature” and “correlated color temperature” are often used interchangeably. The color temperature of lamps makes them visually "warm," "neutral" or "cool" light sources. Generally speaking, the lower the temperature is, the warmer the source, and vice versa.

Color Rendering Index

The ability of a light source to render colors of surfaces accurately can be conveniently quantified by the color-rendering index. This index is based on the accuracy with which a set of test colors is reproduced by the lamp of interest relative to a test lamp, perfect agreement being given a score of 100. The CIE index has some limitations, but is the most widely accepted measure of the colour rendering properties of light sources

Appendix B: Electric Motor Description in AMTF

NO	Motor Description	Input power (kW)	Nameplate power (kW)	Nameplate speed (RPM)	Output power (kW)	Loading (%)	Efficiency (%)	Current draw (A)	Voltage measured (V)	power factor (pf)	Department
1	AC3(Return fun-1)	11.1	30	1420	9.59	32	86.3	19.7	370	0.88	Sinning
2	AC3(Return fun-2)	10.8	30	1420	9.17	30.6	85.3	19.1	365	0.89	Sinning
3	AC3(Supply fun-1)	14.3	22	1460	12.04	54.7	84.4	24.0	390	0.88	Spinning
4	Machine drive mtr	1.92	2.2	1420	0.98	44.4	50.9	3.8	361	0.81	Blowing
5	Beater drive motor	1.88	2.2	955	0.97	44	51.6	3.7	367	0.8	Blowing
6	Spinning rotor motor drive	14.0	30	2950	11.96	39.9	85.3	21.8	395	0.94	Open end
7	Spinning rotor mtr drive cooling fun	0.13	0.27	2690	0.11	41.2	85.6	0.23	375	0.88	Open end
8	Left hand opening rollers motor drive	4.3	5.5	1455	3.57	65.0	83.1	7.9	372	0.84	Open end
9	Right hand opening rollers motor drive	4.47	5.5	1455	3.73	67.9	83.5	8.1	379	0.84	Open end
10	Draw-off mtr drive	5.5	7.5	1460	3.7	49.3	67.2	9.1	381	0.91	Open end
11	Technological air fun motor drive	12.1	20	2935	10.78	53.9	88.9	22.4	355	0.88	Open end
12	Third hand fun motor drive	2.66	4	2905	2.11	52.7	79.3	4.8	360	0.89	Open end
13	Main motor drive	15.5	22	2910	11.55	52.5	74.5	25.0	380	0.94	Ring frame
14	Suction drive motor	4.64	7.5	2910	3.53	47	76	7.5	397	0.9	Ring frame
15	Machine drive	4.46	5.5	1425	3.14	57.1	70.4	7.1	390	0.93	Carding

16	Machine drive mtr	5.38	5.8	2910	3.96	68.3	73.6	10.4	360	0.83	Drawing
17	Suction motor	2.2	1.5	1440	0.89	59.6	40.2	4.5	355	0.8	Drawing
18	Upper suction drive motor	2.17	2.2	1350	1.07	48.7	49.4	4.0	365	0.86	Carding
19	Conveyor motor	0.21	0.25	14	0.2	81.3	93	0.4	360	0.86	Winding
20	fun motor	8.53	11	1420	7.06	64.2	82.8	15.3	370	0.87	Winding
21	Main motor drive	10.1	15	2800	8.68	57.9	85.9	17.2	390	0.87	Warping
22	Hydro lick motor	4.66	5.5	1450	3.44	62.5	73.8	8.3	360	0.90	Warping
23	Main motor	3.57	5	2850	3.46	69.2	96.9	6.0	390	0.88	Loom shed
24	Unrolling motor	2.66	3	1500	1.5	50	56.4	4.7	380	0.86	Brushing
25	Suction motor	4.54	5.5	1420	2.7	50	59.5	6.9	380	0.86	Brushing
26	Lowering M	2.24	2.24	1420	1.1	49.6	49.1	3.95	380	0.86	Folding
27	Freno M	2.24	2.24	1420	1.1	50	49.1	3.98	378	0.86	Folding
28	Suction drive motor	3.64	4	1420	2.39	59.6	65.5	7.2	365	0.80	Roving
29	Main motor drive	7.94	37.3	2800	7.15	19.2	89.9	12.9	395	0.90	Sizing
30	Utility motor pump	1.43	1.5	1420	0.58	38.4	40.3	2.7	365	0.84	Sizing
31	Motor I pump transfer size	1.42	1.5	1400	0.57	38.1	40.2	2.75	355	0.84	Sizing
32	Motor II pump transfer size	1.43	1.5	1420	0.58	38.5	40.3	2.7	360	0.85	Sizing
33	Main motor	10.8	15	1760	9.32	62.1	86.3	17.4	394	0.91	Steamer
34	Distillation motor	0.53	0.55	1420	0.28	51	52.9	0.9	377	0.9	Steamer
35	Conveyor drive motor	0.46	0.75	1450	0.31	41.5	67.7	0.92	360	0.81	Steamer
36	Motor turbine	5.13	7.5	960	3.98	53.0	77.5	8.33	391	0.91	Size coker

37	Soft water boster- C	7.52	11	2920	6.59	59.9	87.6	13.8	370	0.85	Utility
38	Pump for sprinkler	53.3	100	1480	49.8	49.8	93.4	99.7	355	0.87	Utility
39	Pump for hydrant	37	100	1480	30.1	30.1	81.4	56.7	377	0.87	Utility
40	Submersible water pump	10.5	24.5	960	8.75	35.7	83.6	18.6	365	0.89	Utility
41	Soft water booster - A	3.29	5.5	2910	2.81	51.1	85.4	5.8	372	0.88	Utility
42	Soft water booster- B	3.47	5.5	2910	2.97	53.9	85.4	6.1	373	0.88	Utility
43	Soft water feeder - A	1.86	3.0	1430	1.51	50.2	80.9	3.5	365	0.84	Utility
44	Drinking water feeder-B	1.2	1.5	1400	0.94	62.7	78.4	2.2	379	0.83	Utility
45	Drinking water booster-A	1.2	2.2	2805	0.95	43.3	79.4	2.1	368	0.88	Utility
46	Mobile compressor drive motor	2.59	5.5	2930	2.3	41.8	88.7	4.5	374	0.89	Utility
47	Compressor GA55C(Main drive motor)	41.5	55	2975	33	60	79.5	69	390	0.89	Utility
48	Compressor GA22(Main drive mtr)	8.56	22	3000	7.23	32.8	84.4	14.4	390	0.88	Utility

Appendix C: Transformer Measurement Data for AMTF

Table C-1: Line to Line Voltage

Transformer Code	Line Voltage	Measured values(Volts)					
		Day-1	Day-2	Day-3	Day-4	Day-5	Average
T-1	Vab	392.4	391.2	388.1	394.7	390	391.3
	Vbc	389.9	390	391	393.6	389	390.7
	Vca	392.6	390.4	387	392.1	388	390.0
T-2	Vab	396	394.0	394.6	391.3	390.8	393.34
	Vbc	394.5	392.9	390.3	388.4	394.7	392.2
	Vca	394.5	390.6	389.5	395.7	393.4	392.7
T-3	Vab	394.9	396.2	390.8	393.8	391.0	393.3
	Vbc	394.9	395.6	393.2	397.2	390.0	394.2
	Vca	398.2	395.9	396.5	395.7	396.0	396.5
T-4	Vab	396.8	390.6	395.3	393.3	396.1	394.4
	Vbc	395.4	392.0	390.8	389.6	390.8	391.7
	Vca	395.4	389.7	392.5	394.0	390.3	392.4
T-5							
T-6	Vab	394.4	390.0	396.0	390.0	394.2	392.9
	Vbc	394.3	393.4	391.0	387.0	390.8	391.3
	Vca	392.5	388.0	389.3	385.0	389.0	388.8

Table C-2: Line current

Transformer Code	Line Current(A)	Measured values(Current)					
		Day-1	Day-2	Day-3	Day-4	Day-5	Average
T-1	Ia	696	700	720	698	724.4	707.9
	Ib	700.3	714	711	697	719	708.3
	Ic	696	709	716	705	722	709.6
T-2	Ia	620	715	722	725	720	700.4
	Ib	622	710	718	730	715	699.0
	Ic	620	721	717	736	716	702.0
T-3	Ia	468	450	462	462	466	461.6
	Ib	460	455	468	458	460	460.2
	Ic	458	460	455	467	459	459.8
T-4	Ia	366	356	340	366	348	355.2
	Ib	355	350	356	349	367	355.4
	Ic	358	345	366	350	360	355.8
T-5							
	Ia	494	580	590	587	490	548.2

T-6	Ib	470	585	590	593	486	544.8
	Ic	485	580	587	591	478	544.2

Table C-3: Phase voltage (V)

Transformer Code	Phase voltage(V)	Measured values(volt)					
		Day-1	Day-2	Day-3	Day-4	Day-5	Average
T-1	Va	230.5	225.9	224.1	228.0	229.1	227.5
	Vb	235.1	224.1	228.7	228.0	224.6	228.1
	Vc	228.6	224.3	223.4	226.4	224.0	225.3
T-2	Va	229.1	228.0	228.0	226.0	226.0	227.4
	Vb	227.8	224.8	223.0	224.0	229.0	225.7
	Vc	230.3	226.0	225.0	228.0	228.0	227.5
T-3	Va	229.0	228.0	226.0	227.3	226.0	227.3
	Vb	229.0	228.3	227.0	229.3	225.2	227.8
	Vc	230.0	226.5	231.0	228.5	228.6	228.9
T-4	Va	229.0	225.5	228.2	227.1	230.0	228.0
	Vb	228.3	226.3	225.6	225.0	225.1	226.1
	Vc	225.1	224.9	226.6	227.5	225.3	225.9
T-5	V						
T-6	Va	227.7	220.1	228.6	225.2	227.6	225.8
	Vb	220.4	227.1	225.7	223.4	225.6	224.4
	Vc	226.6	224.0	224.8	222.3	224.6	224.5

Table C-4: Active power (kW)

Transformer Code	Power(kw)	Measured values					
		Day-1	Day-2	Day-3	Day-4	Day-5	Average
T-1	Pa	154.4	153.6	150.4	143.6	145.8	149.6
	Pb	148.5	143.5	145.7	146.7	143.0	145.5
	Pc	150.1	140.2	148.6	140.7	141.2	144.2
T-2	Pa	86.2	84.6	86.3	86.1	83.8	85.4
	Pb	84.3	80.1	83.0	87.4	85.0	84.0
	Pc	86.7	82.2	82.2	85.3	84.8	84.2
T-3	Pa	93.1	92.6	94.4	95.0	95.3	94.1
	Pb	95.3	93.8	96.2	95.1	93.6	94.8
	Pc	95.4	90.1	95.1	96.7	93.7	94.2
T-4	Pa	73.1	70.2	67.5	73.1	70.0	70.8
	Pb	70.9	69.2	70.3	68.5	72.6	70.3
	Pc	70.5	67.6	72.9	69.6	71.0	70.3
T-5	P						
T-6	Pa	56.9	52.4	56.3	54.9	57.4	55.6

	Pb	56.2	56.3	55.6	56.3	56.1	56.1
	Pc	54.9	54.6	54.8	55.6	54.3	54.8

Table C-5: Reactive Power (kvar)

Transformer Code	Q(KVAr)	Measured values					
		Day-1	Day-2	Day-3	Day-4	Day-5	Average
T-1	Qa	70.2	80.9	73.1	80.3	80.4	77.0
	Qb	77.7	75.86	72.6	74.4	77.8	75.7
	Qc	74.6	70.6	73.2	70.1	72.2	72.1
T-2	Qa	42.7	40.9	51.5	48.9	48.4	46.5
	Qb	40.6	43.8	45.9	40.1	47.8	43.6
	Qc	41.3	38.1	46.7	48.6	48.4	44.6
T-3	Qa	50.4	50.5	55.0	44.0	51.9	50.4
	Qb	53.7	51.1	56.0	50.4	51.3	52.5
	Qc	53.7	51.4	55.4	45.0	48.9	50.9
T-4	Qa	43.6	35.1	39.4	45.1	39.5	40.5
	Qb	42.4	37.7	41.0	42.6	40.7	40.9
	Qc	41.9	36.9	42.3	43.2	40.0	40.9
T-5	Q						
T-6	Qa	30.3	30.4	34.9	30.9	30.5	31.4
	Qb	34.8	31.9	34.5	33.4	31.8	33.3
	Qc	34.0	30.9	34.0	33.2	28.9	32.2

Table C-6: Apparent Power (KVA)

Transformer Code	S(KVA)	Measured values					
		Day-1	Day-2	Day-3	Day-4	Day-5	Average
T-1	Sa	169.6	173.2	167.2	164.5	166.5	168.2
	Sb	167.3	162.3	162.8	164.5	162.8	163.9
	Sc	167.6	157.0	165.7	157.2	158.6	161.2
T-2	Sa	96.2	95.3	100.5	99.0	96.8	97.6
	Sb	93.6	91.3	94.8	96.2	97.5	94.7
	Sc	93.9	90.6	95.2	98.2	97.6	95.1
T-3	Sa	105.9	105.5	109.8	104.7	108.5	106.9
	Sb	109.4	108.2	111.0	107.6	106.7	108.6
	Sc	109.5	106.8	110.1	106.7	105.7	107.8
T-4	Sa	85.1	78.5	78.2	85.9	80.4	81.6
	Sb	82.6	78.8	81.4	80.7	83.2	81.3
	Sc	82.0	77.0	84.3	81.9	81.5	81.3
T-5	S						

T-6	Sa	64.5	60.6	66.2	63.0	65.0	63.9
	Sb	66.1	64.7	65.4	65.5	64.5	65.2
	Sc	64.6	62.7	64.5	64.8	61.5	63.6

Table C-7: power factor measurement (cosϕ)

Transformer Code	Measured power factor (Cosϕ)					
	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6
T-1	0.89	0.88	0.88	0.86	0.87	0.88
T-2	0.88	0.86	0.85	0.86	0.86	0.86
T-3	0.84	0.85	0.87	0.88	0.89	0.87
T-4	0.87	0.87	0.84	0.87	0.88	0.87
T-5						
T-6	0.89	0.87	0.86	0.85	0.84	0.86

Table C-8: frequency measurement (Hz)

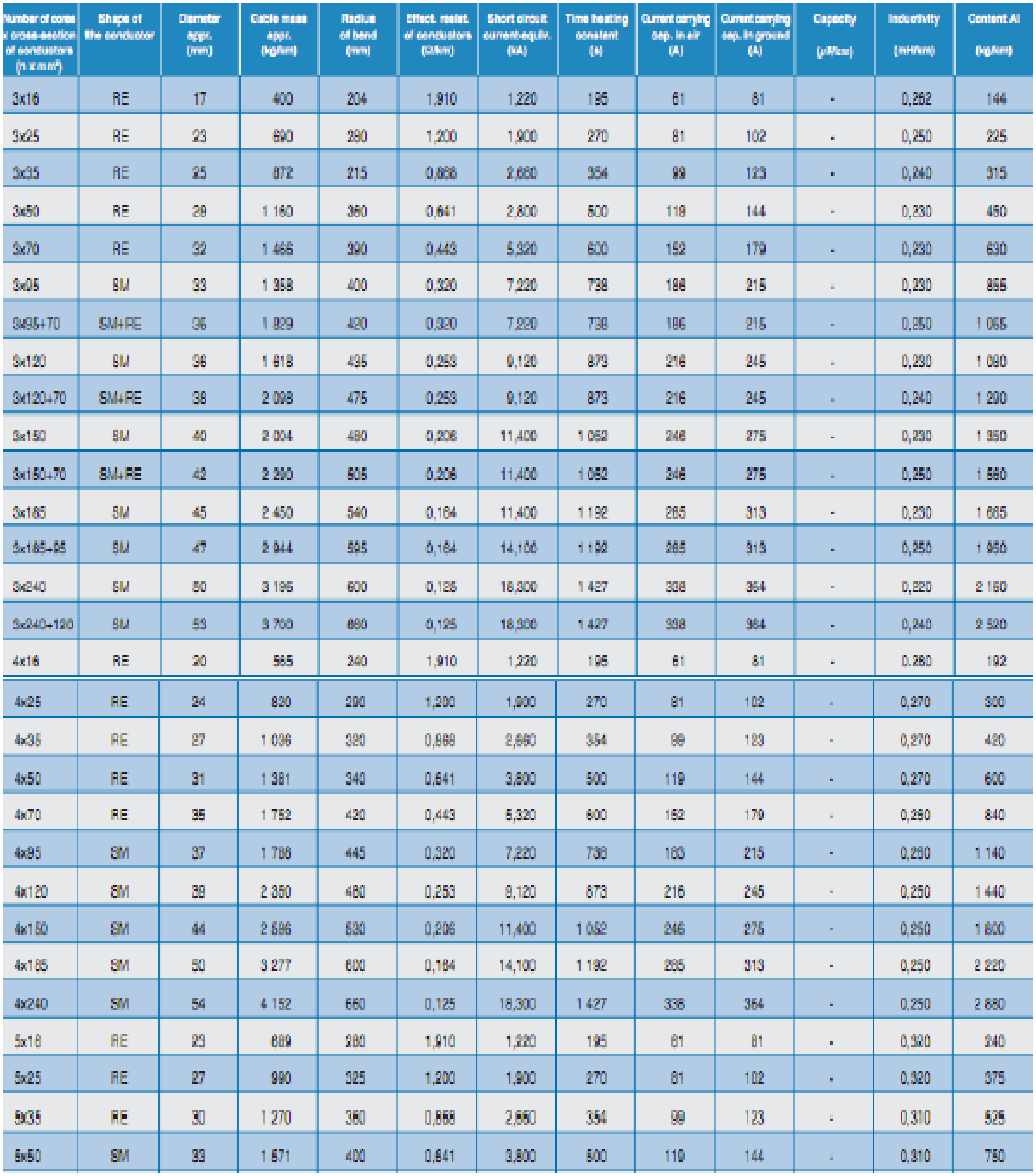
Transformer Code	Measured Frequency (Hz)					
	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6
T-1	49.5	50	50	49.5	49.5	49.7
T-2	49.5	49.5	50	49.5	49.5	49.6
T-3	49.5	49.9	50	50	49.5	49.8
T-4	49.5	50	50	49.9	50	49.8
T-5						
T-6	50	50	49.9	49.9	49.5	49.1

Appendix D: The types of the machines and distribution of electrical energy in spinning and weaving process in AMTF

Machines (spinning)		Quantity	Each rated power (Kw)	Operating hours per year	Energy consumption(Mwh/year)
1	Flat Carding Machine	20	5.64	4164	469.7
2	Drawing frame	5	11.1	4164	231.1
3	Roving Frame	3	15.8	4164	197.4
4	comber	4	6.6	4164	109.9
5	Ring Frame	25	26.4	4164	2,748.24
6	Open end	4	114	4164	1,898.78
7	Automatic Winder (Autoconer)	2	11.4	4164	94.94
8	Blowing	3	42.4	4164	529.7
	Auxiliary equipments				
9	AC	5	508,total	4164	2116.8
10	steamer	3	16.3, total	4164	67.9
11	compressor	3	82.5,total	4164	343.5
12	light	1036	78	4164	336.5
	Machines (Weaving)				
13	Wave preparation	20	44.8	288	258.1
	Waving	200	5	4164	4164
	Steamer	1	700	288	201.6
	Compressor	3	82.5	4164	343.5
	Light	1173	78	4168	380.1

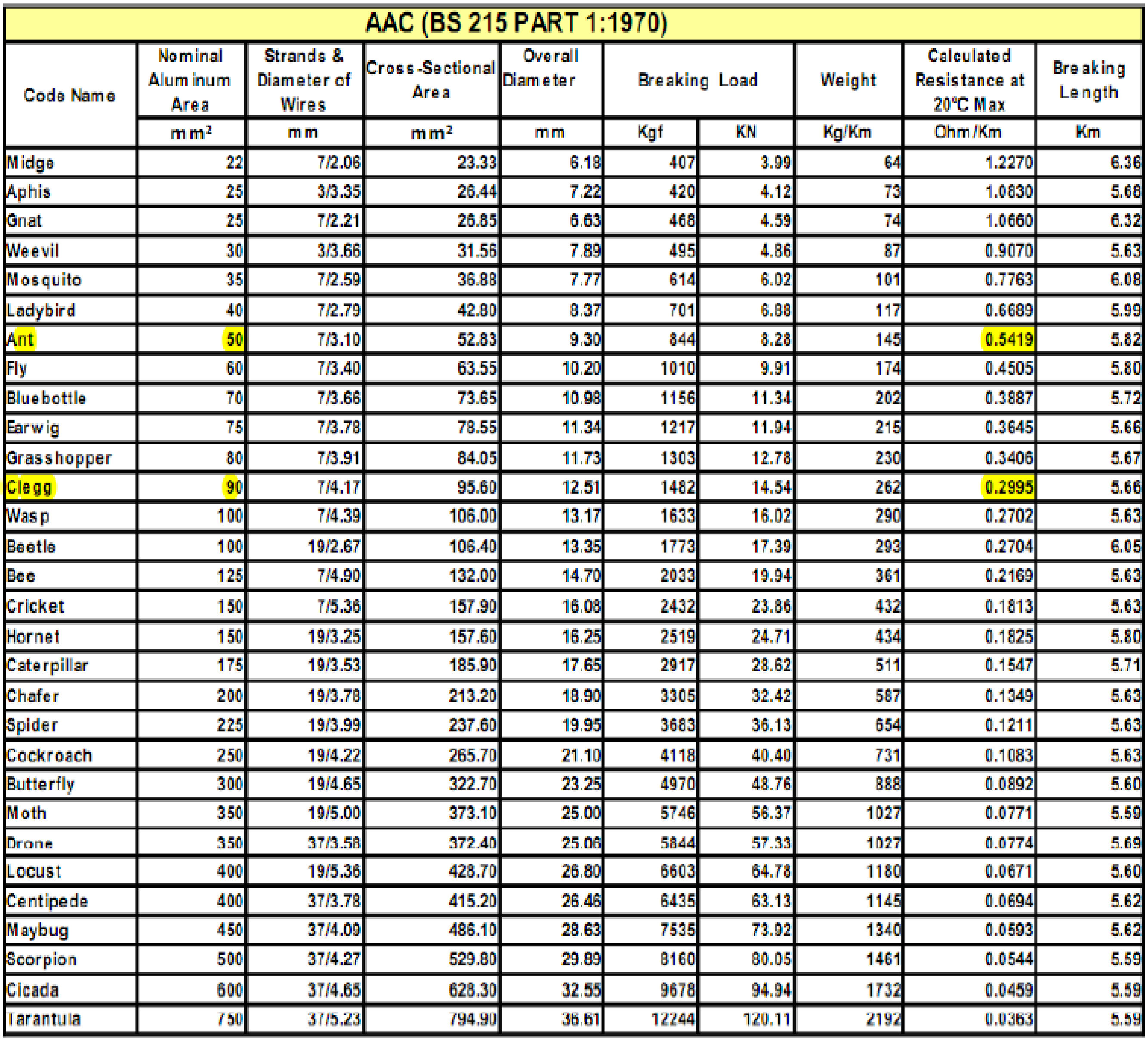
Appendix E: Conductor (Cable) Data

Table E-1: AYKY Cable Data



Number of cores x cross-section of conductors (n x mm²)	Shape of the conductor	Diameter appr. (mm)	Cable mass appr. (kg/km)	Radius of bend (mm)	Effect. resist. of conductors (Ω/km)	Short circuit current-equiv. (kA)	Time heating constant (s)	Current carrying cap. in air (A)	Current carrying cap. in ground (A)	Capacity (μF/km)	Inductivity (mH/km)	Content Al (kg/km)
3x16	RE	17	400	204	1,910	1,220	195	61	81	-	0,262	144
3x25	RE	23	690	290	1,200	1,900	270	81	102	-	0,250	225
3x35	RE	25	872	215	0,868	2,660	354	99	123	-	0,240	315
3x50	RE	29	1 160	360	0,641	2,800	500	119	144	-	0,230	450
3x70	RE	32	1 466	390	0,443	5,320	600	152	179	-	0,230	630
3x95	SM	33	1 358	400	0,320	7,220	738	186	215	-	0,230	855
3x95+70	SM+RE	36	1 829	420	0,320	7,220	738	186	215	-	0,250	1 065
3x120	SM	38	1 818	435	0,253	9,120	873	216	245	-	0,230	1 080
3x120+70	SM+RE	38	2 098	475	0,253	9,120	873	216	245	-	0,240	1 290
3x150	SM	40	2 004	480	0,206	11,400	1 052	246	275	-	0,230	1 350
3x150+70	SM+RE	42	2 290	505	0,206	11,400	1 052	246	275	-	0,250	1 560
3x185	SM	45	2 450	540	0,164	11,400	1 192	265	313	-	0,230	1 665
3x185+95	SM	47	2 944	595	0,164	14,100	1 192	265	313	-	0,250	1 950
3x240	SM	50	3 196	600	0,125	18,300	1 427	338	364	-	0,220	2 160
3x240+120	SM	53	3 700	680	0,125	18,300	1 427	338	364	-	0,240	2 520
4x16	RE	20	565	240	1,910	1,220	195	61	81	-	0.280	192
4x25	RE	24	820	290	1,200	1,900	270	81	102	-	0,270	300
4x35	RE	27	1 036	320	0,868	2,660	354	99	123	-	0,270	420
4x50	RE	31	1 381	340	0,641	3,800	500	119	144	-	0,270	600
4x70	RE	35	1 752	420	0,443	5,320	600	152	179	-	0,260	840
4x95	SM	37	1 786	445	0,320	7,220	738	183	215	-	0,260	1 140
4x120	SM	39	2 350	480	0,253	9,120	873	216	245	-	0,250	1 440
4x150	SM	44	2 696	530	0,206	11,400	1 052	246	275	-	0,250	1 800
4x185	SM	50	3 277	600	0,164	14,100	1 192	265	313	-	0,250	2 220
4x240	SM	54	4 152	650	0,125	18,300	1 427	336	364	-	0,250	2 880
5x16	RE	23	689	280	1,910	1,220	195	61	81	-	0,320	240
5x25	RE	27	990	325	1,200	1,900	270	81	102	-	0,320	375
5x35	RE	30	1 270	360	0,868	2,660	354	99	123	-	0,310	525
5x50	SM	33	1 571	400	0,641	3,800	500	119	144	-	0,310	750

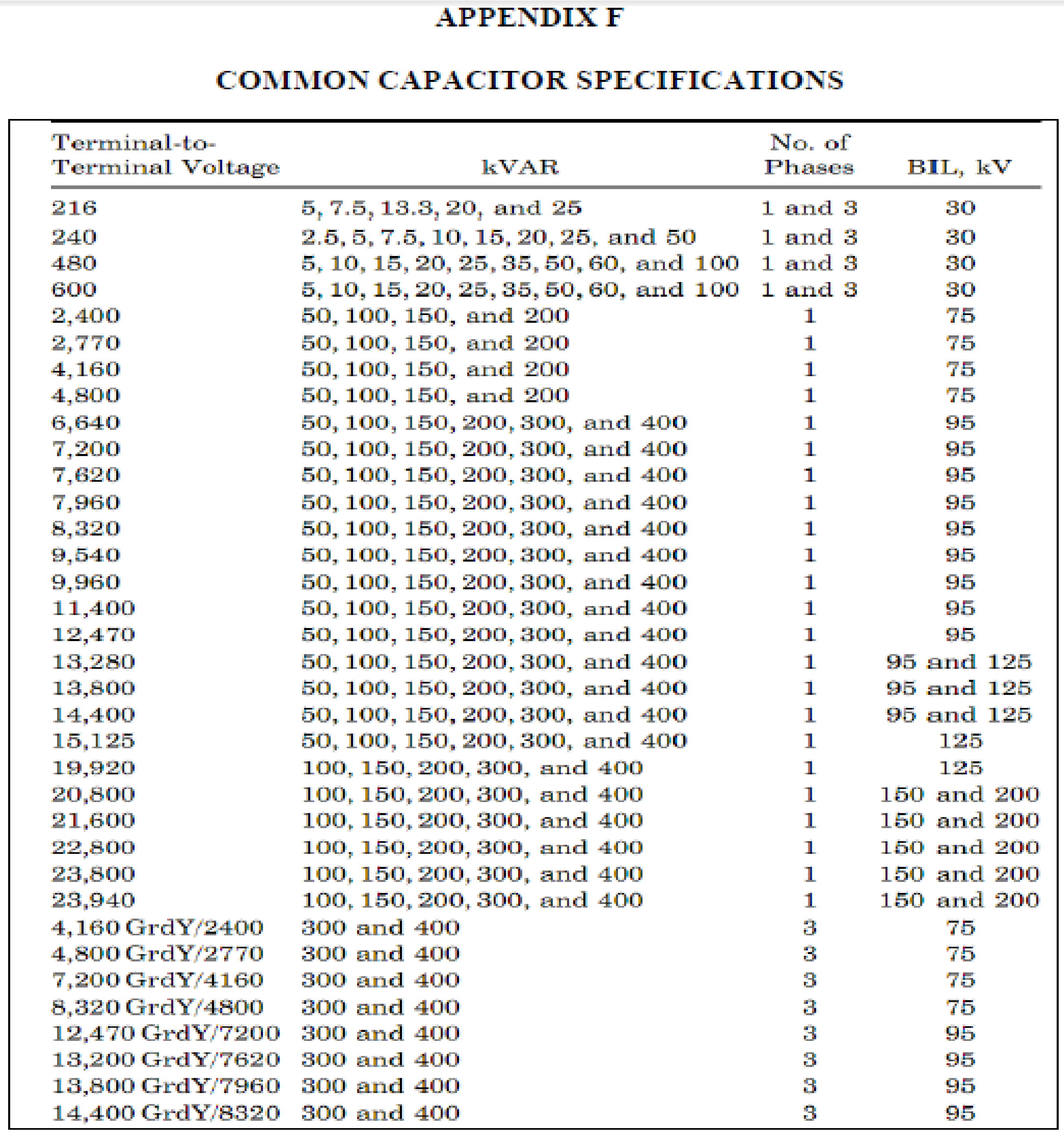
Table E-2: All Aluminum Conductor (AAC) Data



AAC (BS 215 PART 1:1970)

Code Name	Nominal Aluminum Area	Strands & Diameter of Wires	Cross-Sectional Area	Overall Diameter	Breaking Load		Weight	Calculated Resistance at 20°C Max	Breaking Length
	mm²	mm	mm²	mm	Kgf	KN	Kg/Km	Ohm/Km	Km
Midge	22	7/2.06	23.33	6.18	407	3.99	64	1.2270	6.36
Aphis	25	3/3.35	26.44	7.22	420	4.12	73	1.0830	5.68
Gnat	25	7/2.21	26.85	6.63	468	4.59	74	1.0660	6.32
Weevil	30	3/3.66	31.56	7.89	495	4.86	87	0.9070	5.63
Mosquito	35	7/2.59	36.88	7.77	614	6.02	101	0.7763	6.08
Ladybird	40	7/2.79	42.80	8.37	701	6.88	117	0.6689	5.99
Ant	50	7/3.10	52.83	9.30	844	8.28	145	0.5419	5.82
Fly	60	7/3.40	63.55	10.20	1010	9.91	174	0.4505	5.80
Bluebottle	70	7/3.66	73.65	10.98	1156	11.34	202	0.3887	5.72
Earwig	75	7/3.78	78.55	11.34	1217	11.94	215	0.3645	5.66
Grasshopper	80	7/3.91	84.05	11.73	1303	12.78	230	0.3406	5.67
Clegg	90	7/4.17	95.60	12.51	1482	14.54	262	0.2995	5.66
Wasp	100	7/4.39	106.00	13.17	1633	16.02	290	0.2702	5.63
Beetle	100	19/2.67	106.40	13.35	1773	17.39	293	0.2704	6.05
Bee	125	7/4.90	132.00	14.70	2033	19.94	361	0.2169	5.63
Cricket	150	7/5.36	157.90	16.08	2432	23.86	432	0.1813	5.63
Hornet	150	19/3.25	157.60	16.25	2519	24.71	434	0.1825	5.80
Caterpillar	175	19/3.53	185.90	17.65	2917	28.62	511	0.1547	5.71
Chafer	200	19/3.78	213.20	18.90	3305	32.42	587	0.1349	5.63
Spider	225	19/3.99	237.60	19.95	3683	36.13	654	0.1211	5.63
Cockroach	250	19/4.22	265.70	21.10	4118	40.40	731	0.1083	5.63
Butterfly	300	19/4.65	322.70	23.25	4970	48.76	888	0.0892	5.60
Moth	350	19/5.00	373.10	25.00	5746	56.37	1027	0.0771	5.59
Drone	350	37/3.58	372.40	25.06	5844	57.33	1027	0.0774	5.69
Locust	400	19/5.36	428.70	26.80	6603	64.78	1180	0.0671	5.60
Centipede	400	37/3.78	415.20	26.46	6435	63.13	1145	0.0694	5.62
Maybug	450	37/4.09	486.10	28.63	7535	73.92	1340	0.0593	5.62
Scorpion	500	37/4.27	529.80	29.89	8160	80.05	1461	0.0544	5.59
Cicada	600	37/4.65	628.30	32.55	9678	94.94	1732	0.0459	5.59
Tarantula	750	37/5.23	794.90	36.61	12244	120.11	2192	0.0363	5.59

Appendix F: Common capacitor specification

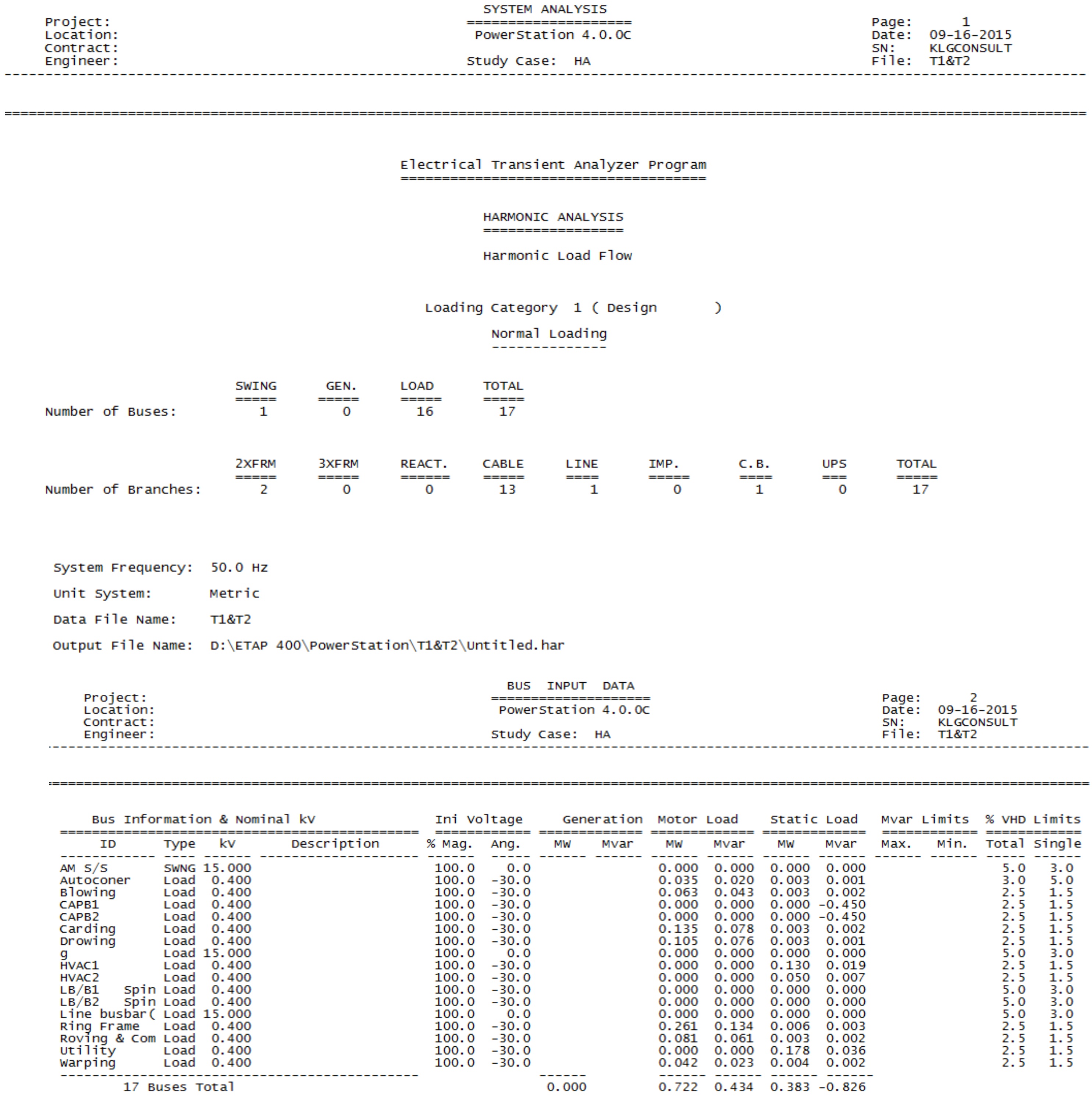


APPENDIX F

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

Appendix G: Overall System Analysis Text Report



```
                                                       SYSTEM  ANALYSIS
  Project:                                           ====================                                   Page:      1
  Location:                                           PowerStation 4.0.0C                                   Date:   09-16-2015
  Contract:                                                                                                 SN:     KLGCONSULT
  Engineer:                                          Study Case:  HA                                        File:   T1&T2
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                                                Electrical Transient Analyzer Program
                                                =====================================

                                                          HARMONIC ANALYSIS
                                                          =================

                                                          Harmonic Load Flow


                                                   Loading Category  1 ( Design       )

                                                           Normal Loading
                                                           --------------


                                SWING     GEN.      LOAD      TOTAL
                                =====     =====     =====     =====
  Number of Buses:                1         0        16        17


                                2XFRM     3XFRM     REACT.    CABLE     LINE      IMP.      C.B.      UPS       TOTAL
                                =====     =====     ======    =====     ====      =====     ====      ===       =====
  Number of Branches:             2         0         0        13         1         0         1         0        17



   System Frequency:   50.0 Hz

   Unit System:        Metric

   Data File Name:     T1&T2

   Output File Name:   D:\ETAP 400\PowerStation\T1&T2\Untitled.har


                                                          BUS  INPUT  DATA
       Project:                                         ====================                                  Page:      2
       Location:                                         PowerStation 4.0.0C                                  Date:   09-16-2015
       Contract:                                                                                              SN:     KLGCONSULT
       Engineer:                                        Study Case:  HA                                       File:   T1&T2
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    Bus Information & Nominal kV                  Ini Voltage    Generation   Motor Load    Static Load   Mvar Limits  % VHD Limits
 ============================================  ============ ============= ============= ============= ============= ===========
      ID        Type   kV        Description     % Mag.  Ang.    MW    Mvar     MW    Mvar    MW    Mvar    Max.   Min.  Total Single
 ------------ ---- ------ -------------------- ------  -----  ------ ------ ------ ------ ------ ------ ------ ------ ----- ------
 AM S/S       SWNG 15.000                      100.0    0.0                 0.000  0.000  0.000  0.000                    5.0   3.0
 Autoconer    Load  0.400                      100.0  -30.0                 0.035  0.020  0.003  0.001                    3.0   5.0
 Blowing      Load  0.400                      100.0  -30.0                 0.063  0.043  0.003  0.002                    2.5   1.5
 CAPB1        Load  0.400                      100.0  -30.0                 0.000  0.000  0.000 -0.450                    2.5   1.5
 CAPB2        Load  0.400                      100.0  -30.0                 0.000  0.000  0.000 -0.450                    2.5   1.5
 Carding      Load  0.400                      100.0  -30.0                 0.135  0.078  0.003  0.002                    2.5   1.5
 Drowing      Load  0.400                      100.0  -30.0                 0.105  0.076  0.003  0.001                    2.5   1.5
 g            Load 15.000                      100.0    0.0                 0.000  0.000  0.000  0.000                    5.0   3.0
 HVAC1        Load  0.400                      100.0  -30.0                 0.000  0.000  0.130  0.019                    2.5   1.5
 HVAC2        Load  0.400                      100.0  -30.0                 0.000  0.000  0.050  0.007                    2.5   1.5
 LB/B1   Spin Load  0.400                      100.0  -30.0                 0.000  0.000  0.000  0.000                    5.0   3.0
 LB/B2   Spin Load  0.400                      100.0  -30.0                 0.000  0.000  0.000  0.000                    5.0   3.0
 Line busbar( Load 15.000                      100.0    0.0                 0.000  0.000  0.000  0.000                    5.0   3.0
 Ring Frame   Load  0.400                      100.0  -30.0                 0.261  0.134  0.006  0.003                    2.5   1.5
 Roving & Com Load  0.400                      100.0  -30.0                 0.081  0.061  0.003  0.002                    2.5   1.5
 Utility      Load  0.400                      100.0  -30.0                 0.000  0.000  0.178  0.036                    2.5   1.5
 Warping      Load  0.400                      100.0  -30.0                 0.042  0.023  0.004  0.002                    2.5   1.5
 --------------------------------------------                 ------        ------ ------ ------ ------
        17 Buses Total                                         0.000         0.722  0.434  0.383 -0.826
```

```
                                   CABLE DATA
Project:                      ====================                      Page:      3
Location:                      PowerStation 4.0.0C                      Date:   09-16-2015
Contract:                                                               SN:     KLGCONSULT
Engineer:                     Study Case:   HA                          File:   T1&T2
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CKT / Branch       Ohms/1000 m  per Conductor (Cable) or per Phase (Line)                    Impedance
============    ==========================================================    ===================================
     ID         Library  Size  L(m ) #/ø T °C    R1      X1      Y1      Ro      Xo      MVAb   % R1    % X1      % Y1
------------    -------- ----  ------ --- ----  ------- ------- ------- ------- -------   -----  ------- -------  ------------
C3                             125.   3   20   0.1600  0.0800 0.00000  0.4800  0.2400   100.0  416.67  208.33   0.0000000
C 4                             60.   3   20   0.1667  0.0833 0.00000  0.5000  0.2500   100.0  208.33  104.17   0.0000000
C 5                            115.   3   20   0.1739  0.0870 0.00000  0.5217  0.2609   100.0  416.67  208.33   0.0000000
C 6                            125.   3   20   0.1600  0.0800 0.00000  0.4800  0.2400   100.0  416.67  208.33   0.0000000
C7                             125.   3   20   0.1600  0.0800 0.00000  0.4800  0.2400   100.0  416.67  208.33   0.0000000
C8                             110.   3   20   0.3636  0.0909 0.00000  1.0909  0.2727   100.0  833.33  208.33   0.0000000
C 9                            100.   3   20   0.1300  0.1000 0.00000  0.3900  0.3000   100.0  270.83  208.33   0.0000000
C10                            115.   3   20   0.2609  0.0870 0.00000  0.7826  0.2609   100.0  625.00  208.33   0.0000000
C 11                           115.   3   20   0.3478  0.0870 0.00000  0.1130  0.2609   100.0  833.33  208.33   0.0000000
C_2                            115.   1   20   0.2609  0.0870 0.00000  0.7826  0.2609   100.0  1875.0   625.0   0.0000000
CapC1                           15.   3   20   1.3333  0.6667 0.00000  4.0000  2.0000   100.0  416.67  208.33   0.0000000
CapC2                           15.   3   20   1.3333  0.6667 0.00000  4.0000  2.0000   100.0  416.67  208.33   0.0000000
Ground cable      0MALN3  8    600.   3   20   0.6417  0.0833 0.00000  1.9167  0.2500   100.0    5.70    0.74   0.0000000

Line resistances are listed at the specified temperatures.
```

```
                                   2W XFMR DATA
Project:                      ====================                   Page:      5
Location:                      PowerStation 4.0.0C                   Date:   09-16-2015
Contract:                                                            SN:     KLGCONSULT
Engineer:                     Study Case:   HA                       File:   T1&T2
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=====================================================================================================================

CKT / Branch              Transformer                   %Tap Setting     XFRM Grounding      Imped.
============   ======================================  ============   ===================   ======
     ID           MVA      kV      kV      % Z    X/R    From    To    Conn.    Type   Amp   % Tol.
------------   -------  ------  ------  -------  -----  ------ ------  -----  ------- ------  ------
T-2             1.250  15.000   0.400    6.750    7.1   1.500  0.000   D-Y   Solid           0.00
T_1             1.250  15.000   0.400    6.750    7.1   1.500  0.000   D-Y   Solid           0.00
```

```
                                   BRANCH CONNECTIONS
Project:                      ====================                   Page:      6
Location:                      PowerStation 4.0.0C                   Date:   09-16-2015
Contract:                                                            SN:     KLGCONSULT
Engineer:                     Study Case:   HA                       File:   T1&T2
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     CKT / Branch              Connected Bus ID          %Impedance (100 MVA Base)
========================   =========================   =========================
    ID             Type          From          To          R        X        Z
------------   ----------   ------------ ------------   -------  -------  -------
C3             Cable        LB/B1   Spin Carding          416.7    208.3    465.8
C 4            Cable        LB/B1   Spin Drowing          208.3    104.2    232.9
C 5            Cable        LB/B1   Spin Roving & Com     416.7    208.3    465.8
C 6            Cable        LB/B1   Spin HVAC1            416.7    208.3    465.8
C7             Cable        LB/B2   Spin HVAC2            416.7    208.3    465.8
C8             Cable        LB/B2   Spin Warping          833.3    208.3    859.0
C 9            Cable        LB/B2   Spin Ring Frame       270.8    208.3    341.7
C10            Cable        LB/B2   Spin Autoconer        625.0    208.3    658.8
C 11           Cable        LB/B2   Spin Utility          833.3    208.3    859.0
C_2            Cable        LB/B1   Spin Blowing         1875.0    625.0   1976.4
CapC1          Cable        LB/B1   Spin CAPB1            416.7    208.3    465.8
CapC2          Cable        LB/B2   Spin CAPB2            416.7    208.3    465.8
Ground cable   Cable        g            Line busbar(       5.7      0.7      5.8
Overhead Lin   Line         AM S/S       g                 94.8     34.1    100.7
T-2            2W XFMR      Line busbar( LB/B2   Spin      76.4    542.7    548.1
T_1            2W XFMR      Line busbar( LB/B1   Spin      76.4    542.7    548.1
Bus tie        Tie PD       LB/B2   Spin LB/B1   Spin       0.0      0.0      0.0
```

```
                                                                 MACHINE DATA
Project:                                                      ====================                                 Page:      7
Location:                                                      PowerStation 4.0.0C                                 Date:   09-16-2015
Contract:                                                                                                          SN:     KLGCONSULT
Engineer:                                                     Study Case:  HA                                      File:   T1&T2
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==============================================================================================================================


 Conned Bus     Machine Info.          Rating (Base)        Negative Seq. Imp.          Grounding              Zero Seq. Imp.
============  =================    ===================    ====================     ==================      ======================
   Bus ID     Machine ID  Type      MVA     kV    RPM      X/R   % R     % X2      Conn. Type   Amp        X/R   % Ro     % Xo
------------  ----------  ----    ------- ------ -----    ----- ------- -------    ----- ----- ------      ----- ------- -------
AM S/S        EXTERNAL GRI Uty.   50.000  15.00     0.   10.00  9.950   99.50     Wye  Solid              10.00  19.901  199.01
Autoconer     Mtr12        IndM    0.010   0.40 1500.    3.49  7.972   27.83     Wye  Open
Blowing       Mtr_1        IndM    0.058   0.40 1500.    3.74  7.436   27.83     Wye  Open
Blowing       Mtr_2        IndM    0.008   0.40 1500.    1.72 16.145   27.83     Wye  Open
Blowing       Mtr_3        IndM    0.008   0.40 1500.    2.26 12.294   27.83     Wye  Open
Carding       Mtr_4        IndM    0.146   0.40 1500.   14.55  1.375   20.00     Wye  Open
Carding       Mtr_5        IndM    0.007   0.40 1500.    2.39 11.657   27.83     Wye  Open
Drowing       Mtr_6        IndM    0.129   0.40 1500.   10.27  1.947   20.00     Wye  Open
Roving & Com  Mtr_7        IndM    0.102   0.40 1500.    4.42  4.526   27.83     Wye  Open
Warping       Mtr_8        IndM    0.037   0.40 1500.    4.41  6.318   27.83     Wye  Open
Warping       Mtr_9        IndM    0.009   0.40 1500.    2.46 11.302   27.83     Wye  Open
Ring Frame    Mtr_10       IndM    0.293   0.40 1500.    4.93  4.060   27.83     Wye  Open
Autoconer     Mtr_11       IndM    0.029   0.40 1500.    6.13  4.539   20.00     Wye  Open
```

```
                                                      HARM CURRENT LIBRARY
Project:                                              ====================                                 Page:      8
Location:                                              PowerStation 4.0.0C                                 Date:   09-16-2015
Contract:                                                                                                  SN:     KLGCONSULT
Engineer:                                             Study Case:  HA                                      File:   T1&T2
----------------------------------------------------------------------------------------------------------------------------


============================================================================================================================


        Device                                           % Harmonic Source Current
========================== ==============================================================================================
                               2     3     4     5     6     7     8     9    10    11    12    13    14    15    17    19    23
Manufacturer     Model        25    29    31    35    37    41    43    47    49    53    55    59    61    65    67    71    73
------------ ------------  ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
PWMWARP&AUTO ASD            0.00  0.70  0.00109.48  0.00 60.16  0.00  0.60  0.00  4.61  0.00  9.29  0.00  0.41  0.48  0.62  0.43
                            0.06  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
PWM          ASD            0.00  0.35  0.00 60.82  0.00 33.42  0.00  0.50  0.00  3.84  0.00  7.74  0.00  0.41  1.27  1.54  1.08
                            0.16  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
PWMCARD      ASD            0.00  2.45  0.00200.00  0.00200.00  0.00  2.10  0.00 16.13  0.00 32.51  0.00  1.44  1.78  2.26  1.50
                            0.22  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
Typical      FL50           0.00200.00  0.00200.00  0.00130.50  0.00 60.00  0.00 42.00  0.00 24.00  0.00 10.00  2.00  5.00  2.00
                            0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
Typical      FL40           0.00200.00  0.00200.00  0.00104.40  0.00 48.00  0.00 33.60  0.00 19.20  0.00  8.00  1.60  4.00  1.60
                            0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
Typical      FLC            0.00200.00  0.00200.00  0.00182.70  0.00 84.00  0.00 58.80  0.00 33.60  0.00 14.00  2.80  7.00  2.80
                            0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
```

```
                                                                 HARM CURRENT SOURCE
Project:                                                      ====================                                 Page:      9
Location:                                                      PowerStation 4.0.0C                                 Date:   09-16-2015
Contract:                                                                                                          SN:     KLGCONSULT
Engineer:                                                     Study Case:  HA                                      File:   T1&T2
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=============================================================================================================================


Connected Bus            Harmonic Library Info
=============    ===================================
     ID            Type     Manufacturer     Model
------------     --------- ------------  -----------
Autoconer        Current   PWMWARP&AUTO  ASD
Blowing          Current   PWM           ASD
Blowing          Current   PWM           ASD
Carding          Current   PWMCARD       ASD
Warping          Current   PWMWARP&AUTO  ASD
Blowing          Current   Typical       FL50
Carding          Current   Typical       FL50
Drowing          Current   Typical       FL40
Roving & Com     Current   Typical       FL40
Warping          Current   Typical       FL40
Ring Frame       Current   Typical       FLC
Autoconer        Current   Typical       FL40
Utility          Current   Typical       FL50
```
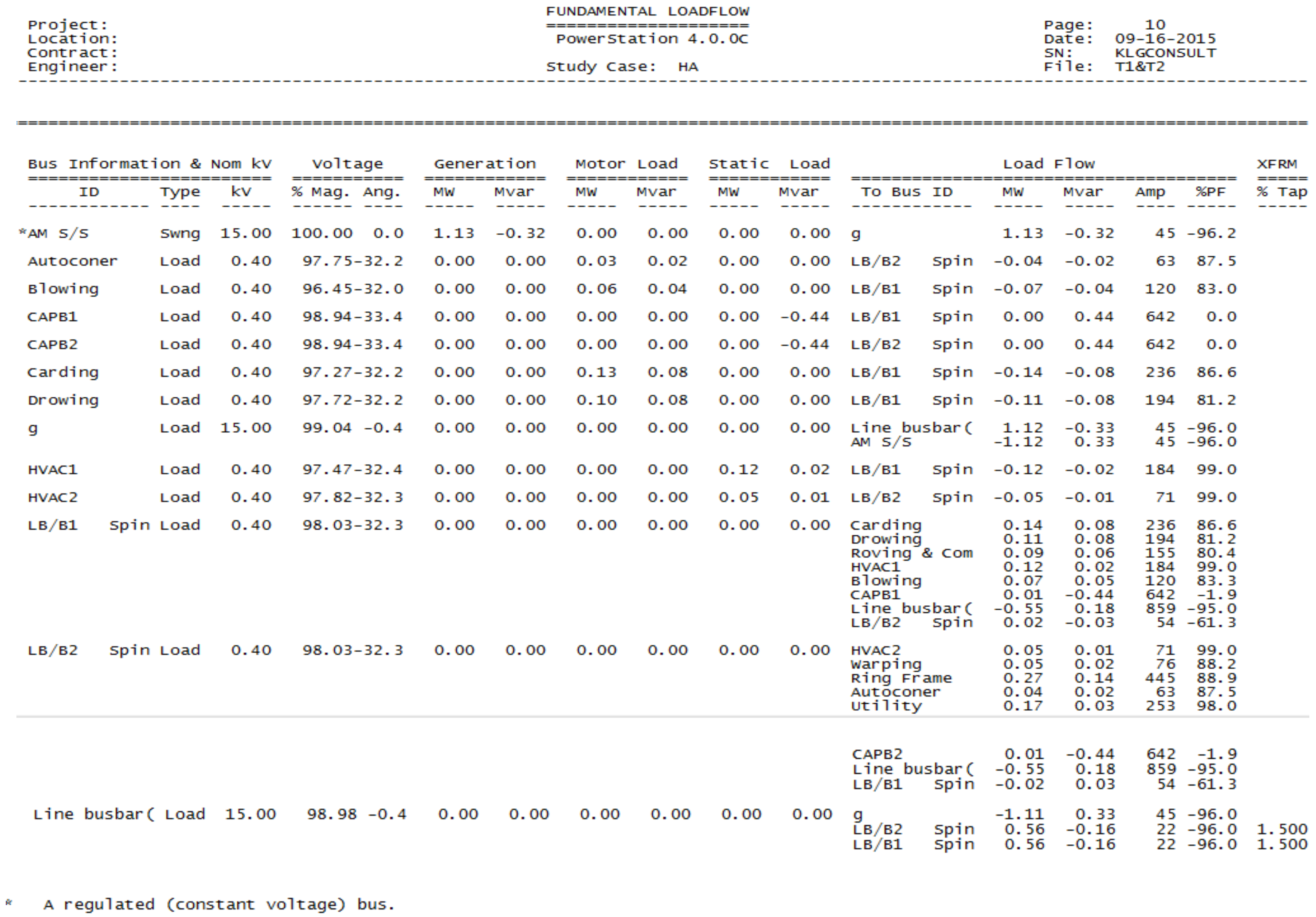
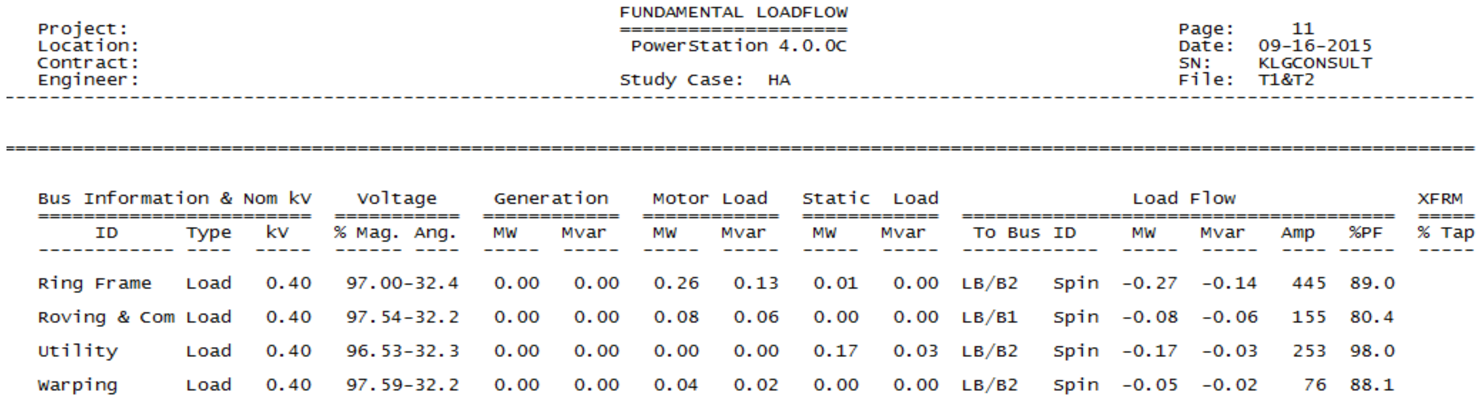



```
                                          FUNDAMENTAL LOADFLOW
 Project:                                 ====================                                   Page:     10
 Location:                                 PowerStation 4.0.0C                                   Date:   09-16-2015
 Contract:                                                                                       SN:     KLGCONSULT
 Engineer:                                Study Case:  HA                                        File:   T1&T2
-----------------------------------------------------------------------------------------------------------------------

=======================================================================================================================

 Bus Information & Nom kV    Voltage      Generation    Motor Load    Static  Load              Load Flow                XFRM
 ========================  ===========  ============  ============  ============  =====================================  =====
      ID        Type  kV   % Mag. Ang.    MW    Mvar    MW    Mvar    MW    Mvar    To Bus ID      MW    Mvar   Amp   %PF  % Tap
 ------------   ----  -----  ------ ----  -----  -----  -----  -----  -----  -----  ------------  -----  -----  ----  -----  -----

*AM S/S         Swng  15.00  100.00  0.0   1.13  -0.32   0.00   0.00   0.00   0.00  g               1.13  -0.32    45  -96.2
 Autoconer      Load   0.40   97.75-32.2   0.00   0.00   0.03   0.02   0.00   0.00  LB/B2   Spin   -0.04  -0.02    63  87.5
 Blowing        Load   0.40   96.45-32.0   0.00   0.00   0.06   0.04   0.00   0.00  LB/B1   Spin   -0.07  -0.04   120  83.0
 CAPB1          Load   0.40   98.94-33.4   0.00   0.00   0.00   0.00   0.00  -0.44  LB/B1   Spin    0.00   0.44   642   0.0
 CAPB2          Load   0.40   98.94-33.4   0.00   0.00   0.00   0.00   0.00  -0.44  LB/B2   Spin    0.00   0.44   642   0.0
 Carding        Load   0.40   97.27-32.2   0.00   0.00   0.13   0.08   0.00   0.00  LB/B1   Spin   -0.14  -0.08   236  86.6
 Drowing        Load   0.40   97.72-32.2   0.00   0.00   0.10   0.08   0.00   0.00  LB/B1   Spin   -0.11  -0.08   194  81.2
 g              Load  15.00   99.04 -0.4   0.00   0.00   0.00   0.00   0.00   0.00  Line busbar(   1.12  -0.33    45 -96.0
                                                                                    AM S/S        -1.12   0.33    45 -96.0
 HVAC1          Load   0.40   97.47-32.4   0.00   0.00   0.00   0.00   0.12   0.02  LB/B1   Spin   -0.12  -0.02   184  99.0
 HVAC2          Load   0.40   97.82-32.3   0.00   0.00   0.00   0.00   0.05   0.01  LB/B2   Spin   -0.05  -0.01    71  99.0
 LB/B1    Spin  Load   0.40   98.03-32.3   0.00   0.00   0.00   0.00   0.00   0.00  Carding        0.14   0.08   236  86.6
                                                                                    Drowing        0.11   0.08   194  81.2
                                                                                    Roving & Com   0.09   0.06   155  80.4
                                                                                    HVAC1          0.12   0.02   184  99.0
                                                                                    Blowing        0.07   0.05   120  83.3
                                                                                    CAPB1          0.01  -0.44   642  -1.9
                                                                                    Line busbar(  -0.55   0.18   859 -95.0
                                                                                    LB/B2   Spin   0.02  -0.03    54 -61.3
 LB/B2    Spin  Load   0.40   98.03-32.3   0.00   0.00   0.00   0.00   0.00   0.00  HVAC2          0.05   0.01    71  99.0
                                                                                    Warping        0.05   0.02    76  88.2
                                                                                    Ring Frame     0.27   0.14   445  88.9
                                                                                    Autoconer      0.04   0.02    63  87.5
                                                                                    Utility        0.17   0.03   253  98.0

                                                                                    CAPB2          0.01  -0.44   642  -1.9
                                                                                    Line busbar(  -0.55   0.18   859 -95.0
                                                                                    LB/B1   Spin  -0.02   0.03    54 -61.3
 Line busbar( Load  15.00   98.98 -0.4   0.00   0.00   0.00   0.00   0.00   0.00  g             -1.11   0.33    45 -96.0
                                                                                    LB/B2   Spin   0.56  -0.16    22 -96.0  1.500
                                                                                    LB/B1   Spin   0.56  -0.16    22 -96.0  1.500

*   A regulated (constant voltage) bus.
```



```
                                          FUNDAMENTAL LOADFLOW
 Project:                                 ====================                                   Page:     11
 Location:                                 PowerStation 4.0.0C                                   Date:   09-16-2015
 Contract:                                                                                       SN:     KLGCONSULT
 Engineer:                                Study Case:  HA                                        File:   T1&T2
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=======================================================================================================================

 Bus Information & Nom kV    Voltage      Generation    Motor Load    Static  Load              Load Flow                XFRM
 ========================  ===========  ============  ============  ============  =====================================  =====
      ID        Type  kV   % Mag. Ang.    MW    Mvar    MW    Mvar    MW    Mvar    To Bus ID      MW    Mvar   Amp   %PF  % Tap
 ------------   ----  -----  ------ ----  -----  -----  -----  -----  -----  -----  ------------  -----  -----  ----  -----  -----

 Ring Frame     Load   0.40   97.00-32.4   0.00   0.00   0.26   0.13   0.01   0.00  LB/B2   Spin   -0.27  -0.14   445  89.0
 Roving & Com   Load   0.40   97.54-32.2   0.00   0.00   0.08   0.06   0.00   0.00  LB/B1   Spin   -0.08  -0.06   155  80.4
 Utility        Load   0.40   96.53-32.3   0.00   0.00   0.00   0.00   0.17   0.03  LB/B2   Spin   -0.17  -0.03   253  98.0
 Warping        Load   0.40   97.59-32.2   0.00   0.00   0.04   0.02   0.00   0.00  LB/B2   Spin   -0.05  -0.02    76  88.1
```

```
 *   A regulated (constant voltage) bus.


     Project:                                     SYS. HARMONICS INFO.                                 Page:     12
     Location:                                    ====================                                 Date:   09-16-2015
     Contract:                                     PowerStation 4.0.0C                                 SN:     KLGCONSULT
     Engineer:                                    Study Case:  HA                                      File:   T1&T2
----------------------------------------------------------------------------------------------------------------------------


============================================================================================================================

       Bus Info. & Rated kV              Voltage Distortion                                  Current Distortion
       ===================     =====================================  ===========================================================
           ID           kV     Fund(%) RMS(%) ASUM(%) THD(%)   TIF      To Bus ID     Fund.(A)  RMS(A)   ASUM(A)  THD(%)  TIF      IT
       -----------    ------   ------- ------ ------- ------ -------  ------------    -------- -------- --------- ------ -------- --------
   #   AM S/S          15.00   100.00 100.05  103.60   3.06    7.69   g                  45.19    46.69     58.35  25.99   59.70  0.28E+04

 * #   Autoconer        0.40    97.75  98.06  107.00   8.00   20.26   LB/B2    Spin      63.05    72.50    117.02  56.79  234.62  0.17E+05

 * #   Blowing          0.40    96.45  96.77  106.05   8.17   23.29   LB/B1    Spin     120.03   127.21    186.54  35.08  183.79  0.23E+05

 * #   CAPB1            0.40    98.94  99.45  111.31  10.11   27.34   LB/B1    Spin     642.63   723.79   1091.29  51.82  154.03  0.11E+06

 * #   CAPB2            0.40    98.94  99.45  111.31  10.11   27.34   LB/B2    Spin     642.63   723.79   1091.29  51.82  154.03  0.11E+06

 * #   Carding          0.40    97.27  97.56  106.08   7.76   19.62   LB/B1    Spin     236.62   247.17    348.63  30.19  156.45  0.39E+05

 * #   Drowing          0.40    97.72  98.03  106.85   7.92   19.88   LB/B1    Spin     194.73   196.38    230.97  13.07   51.98  0.10E+05

   #   g               15.00    99.04  99.11  103.24   3.60    9.04   Line busbar(       45.17    46.67     58.33  25.98   59.67  0.28E+04
                                                                      AM S/S             45.17    46.67     58.33  25.98   59.67  0.28E+04

 * #   HVAC1            0.40    97.47  97.77  106.59   7.95   19.91   LB/B1    Spin     185.00   185.57    202.14   7.87   19.72  0.37E+04

 * #   HVAC2            0.40    97.82  98.12  106.98   7.96   19.92   LB/B2    Spin      71.30    71.52     77.90   7.88   19.71  0.14E+04

 * #   LB/B1    Spin    0.40    98.03  98.34  107.22   7.96   19.93   Carding           236.62   247.17    348.63  30.19  156.45  0.39E+05
                                                                      Drowing           194.73   196.38    230.97  13.07   51.98  0.10E+05
                                                                      Roving & Com      155.59   157.61    193.70  16.15   77.95  0.12E+05
                                                                      HVAC1             185.00   185.57    202.14   7.87   19.72  0.37E+04
                                                                      Blowing           120.03   127.21    186.54  35.08  183.79  0.23E+05
                                                                      CAPB1             642.63   723.79   1091.29  51.82  154.03  0.11E+06
                                                                      Line busbar(      859.68   887.39   1106.70  25.59   58.87  0.52E+05
                                                                      LB/B2    Spin      54.33   180.68    234.89 317.16  220.69  0.40E+05


 * #   LB/B2    Spin    0.40    98.03  98.34  107.22   7.96   19.93   HVAC2              71.30    71.52     77.90   7.88   19.71  0.14E+04
                                                                      Warping            76.61    88.07    142.89  56.70  242.26  0.21E+05
                                                                      Ring Frame        445.45   448.98    537.88  12.62   78.55  0.35E+05
                                                                      Autoconer          63.05    72.50    117.02  56.79  234.62  0.17E+05
                                                                      Utility           253.69   254.14    280.78   6.01   50.84  0.13E+05
                                                                      CAPB2             642.63   723.79   1091.29  51.82  154.03  0.11E+06
                                                                      Line busbar(      859.68   887.39   1106.70  25.59   58.87  0.52E+05
                                                                      LB/B1    Spin      54.33   180.68    234.89 317.16  220.69  0.40E+05




 * - THD ( Total Harmonic Distortion exceeds the limit)
 # - IHD (Individual Harmonic Distortion exceeds the limit)
```

```
     Project:                                     SYS. HARMONICS INFO.                                 Page:     13
     Location:                                    ====================                                 Date:   09-16-2015
     Contract:                                     PowerStation 4.0.0C                                 SN:     KLGCONSULT
     Engineer:                                    Study Case:  HA                                      File:   T1&T2
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============================================================================================================================

       Bus Info. & Rated kV              Voltage Distortion                                  Current Distortion
       ===================     =====================================  ===========================================================
           ID           kV     Fund(%) RMS(%) ASUM(%) THD(%)   TIF      To Bus ID     Fund.(A)  RMS(A)   ASUM(A)  THD(%)  TIF      IT
       -----------    ------   ------- ------ ------- ------ -------  ------------    -------- -------- --------- ------ -------- --------
   #   Line busbar(    15.00    98.98  99.05  103.19   3.62    9.08   g                  45.17    46.67     58.33  25.98   59.67  0.28E+04
                                                                      LB/B2    Spin      22.59    23.34     29.12  25.98   59.57  0.14E+04
                                                                      LB/B1    Spin      22.59    23.34     29.12  25.98   59.57  0.14E+04

 * #   Ring Frame       0.40    97.00  97.29  106.02   7.81   20.30   LB/B2    Spin     445.45   448.98    537.88  12.62   78.55  0.35E+05

 * #   Roving & Com     0.40    97.54  97.84  106.67   7.92   19.96   LB/B1    Spin     155.59   157.61    193.70  16.15   77.95  0.12E+05

 * #   Utility          0.40    96.53  96.83  105.65   7.98   20.23   LB/B2    Spin     253.69   254.14    280.78   6.01   50.84  0.13E+05

 * #   Warping          0.40    97.59  97.91  106.86   8.03   20.40   LB/B2    Spin      76.61    88.07    142.89  56.70  242.26  0.21E+05
```

```
                                                BUS TABULATION
Project:                                     ====================                                    Page:     14
Location:                                     PowerStation 4.0.0C                                    Date:   09-16-2015
Contract:                                                                                            SN:     KLGCONSULT
Engineer:                                    Study Case:  HA                                         File:   T1&T2
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=====================================================================================================================


         Bus                                         Harmonic Voltages (% of fundamental voltage)
 ====================  ===============================================================================================
      ID      Fund. kV     2     3     4     5     6     7     8     9    10    11    12    13    14    15    17    19    23
                          25    29    31    35    37    41    43    47    49    53    55    59    61    65    67    71    73
 ------------ --------  ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
 AM S/S        15.00    0.00  0.00  0.00  3.01  0.00  0.52  0.00  0.00  0.00  0.02  0.00  0.03  0.00  0.00  0.00  0.01  0.00
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 g             14.86    0.00  0.00  0.00  3.55  0.00  0.61  0.00  0.00  0.00  0.03  0.00  0.03  0.00  0.00  0.00  0.01  0.01
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 LB/B1   Spin   0.39    0.00  0.00  0.00  7.84  0.00  1.35  0.00  0.00  0.00  0.06  0.00  0.07  0.00  0.00  0.01  0.03  0.01
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 LB/B2   Spin   0.39    0.00  0.00  0.00  7.84  0.00  1.35  0.00  0.00  0.00  0.06  0.00  0.07  0.00  0.00  0.01  0.03  0.01
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 Line busbar(  14.85    0.00  0.00  0.00  3.57  0.00  0.61  0.00  0.00  0.00  0.03  0.00  0.03  0.00  0.00  0.00  0.01  0.01
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
```

```
                                                BRANCH TABULATION
Project:                                     ====================                                    Page:     17
Location:                                     PowerStation 4.0.0C                                    Date:   09-16-2015
Contract:                                                                                            SN:     KLGCONSULT
Engineer:                                    Study Case:  HA                                         File:   T1&T2
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=====================================================================================================================


         Branch                                      % Harmonic Currents (% of fundamental current)
 ====================  ===============================================================================================
      ID      Fund(A)      2     3     4     5     6     7     8     9    10    11    12    13    14    15    17    19    23
                          25    29    31    35    37    41    43    47    49    53    55    59    61    65    67    71    73
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 C3             237.    0.00  0.00  0.00 24.41  0.00 17.41  0.00  0.00  0.00  2.37  0.00  2.61  0.00  0.00  0.15  0.25  0.11
                        0.01  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C 4            195.    0.00  0.00  0.00 12.25  0.00  4.35  0.00  0.00  0.00  1.14  0.00  0.63  0.00  0.00  0.05  0.13  0.05
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C 5            156.    0.00  0.00  0.00 14.63  0.00  6.48  0.00  0.00  0.00  1.91  0.00  1.08  0.00  0.00  0.09  0.22  0.09
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C 6            185.    0.00  0.00  0.00  7.76  0.00  1.33  0.00  0.00  0.00  0.06  0.00  0.07  0.00  0.00  0.00  0.03  0.01
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C7              71.    0.00  0.00  0.00  7.76  0.00  1.33  0.00  0.00  0.00  0.06  0.00  0.07  0.00  0.00  0.00  0.03  0.00
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C8              77.    0.00  0.00  0.00 49.95  0.00 25.95  0.00  0.00  0.00  5.24  0.00  4.30  0.00  0.00  0.22  0.63  0.24
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C 9            445.    0.00  0.00  0.00 10.37  0.00  6.81  0.00  0.00  0.00  2.01  0.00  1.14  0.00  0.00  0.09  0.24  0.09
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C10             63.    0.00  0.00  0.00 50.05  0.00 26.09  0.00  0.00  0.00  4.60  0.00  4.16  0.00  0.00  0.08  0.54  0.08
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C 11           254.    0.00  0.00  0.00  4.17  0.00  4.02  0.00  0.00  0.00  1.39  0.00  0.80  0.00  0.00  0.07  0.17  0.07
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 C_2            120.    0.00  0.00  0.00 30.06  0.00 17.39  0.00  0.00  0.00  3.70  0.00  3.30  0.00  0.00  0.17  0.61  0.16
                        0.04  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 Ground cable    45.    0.00  0.00  0.00 25.78  0.00  3.16  0.00  0.00  0.00  0.09  0.00  0.09  0.00  0.00  0.00  0.00  0.00
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 Overhead Lin    45.    0.00  0.00  0.00 25.79  0.00  3.16  0.00  0.00  0.00  0.09  0.00  0.09  0.00  0.00  0.00  0.00  0.00
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00


 T-2             23.    0.00  0.00  0.00 25.78  0.00  3.16  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00

 T_1             23.    0.00  0.00  0.00 25.78  0.00  3.16  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
                        0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
```