Power Factor Improvement of Electrical Load Using Voltage Source Converter (VSC) Based D-STATCOM (A Case Study: Adama Spinning Factory)

Efa Tona Warji

A Thesis Submitted to the department of Electrical Power and

Control Engineering,

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (power Engineering)

Office of Graduate Studies

Adama Science and Technology University

June 2023

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Declaration

I hereby declare that this Master Thesis entitled "Power Factor Improvement of Electrical Load Using Voltage Source Converter (VSC) Based D-STATCOM (Case Study: Adama Spinning Factory)" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Efa Tona Warji ________________ 14/07/2023

Name of the student Signature Date

Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Power Factor Improvement of Electrical Load Using

Voltage Source Converter (VSC) Based D-STATCOM

(Case Study: Adama Spinning Factory)” prepared under my guidance by Efa Tona Warji submitted in partial fulfillment of the requirements for the degree of Mater’s of Science in Electrical Power and Control Engineering (Power Engineering). Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

Dr.Tefera T.Y	____________________	14/07/2023
Major Advisor	Signature	Date

Approval Page of M.Sc. Thesis

I, the advisor of the thesis entitled "Power Factor Improvement of Electrical Load Using

Voltage Source Converter (VSC) Based D-STATCOM

(Case Study: Adama Spinning Factory)" and developed by Efa Tona Warji, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr.Tefera T.Y	________________	14/07/2023
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Efa Tona Warji have read and evaluated the thesis entitled "Power Factor Improvement of Electrical Load Using Voltage Source Converter (VSC) Based D-STATCOM

(Case Study: Adama Spinning Factory)" and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electrical Power and Control Engineering (Power Engineering).

Dr. Shubhashish Bhakta	Shubhashish Bhakta	13-07-2023
Chairperson	Signature	Date
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Internal Examiner	Signature	Date
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Final approval and acceptance of the thesis is contingent upon submission of its final copy to the office of postgraduate studies (OPGS) through the department graduate council (DGC) and school graduate committee (SGC).

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Office of Postgraduate Studies, Dean	Signature	Date

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LIST OF ACRONYMS AND ABBREVIATION

AC	Alternative Current
APFC	Automatic Power Factor Correction
ASD	Adjustable Speed Drive
ASF	Adama Spinning Factory
CMDB	Central Main Distribution Board
CPD	Custom Power Device
CSC	Current Source Converter
CSI	Current Source Inverter
CT	Current Transformer
DC	Direct Current
DSTATCOM	Distribution Static Synchronous Compensator
DVR	Dynamic Voltage Restorer
EEU	Ethiopian Electric Utility
FACTS	Flexible Alternative Current Transmission System
FFM	Fundamental Frequency Modulation
HF	Harmonic Frequency
GTO	Gate Turn Off Thyristor
HV	High Voltage
IEEE	Institute of Electrical and Electronics Engineers
IGCT	Insulated Gate Commutated Thyristor

IGBT	Insulated Gate Bipolar Transistor
KVA	Kilo Volt Ampere
KWH	Kilo Watt Hour
KVAR	Reactive Power
LCL	Inductor, Capacitor & Inductor Passive Filter
LC	(Inductor & Capacitor) Filter
Lf	Interfacing Inductor
LPF	Low Passive Filter
MATLAB	Matrix Laboratory
Ma	modulation Index
MVA	Mega Volt Ampere
PCC	Point of Common Coupling
PFC	Power Factor Correction
PLC	Programmable Logic Circuit
PQ	Power Quality
PWM	Pulse Width Modulation
RMS	Root Mean Square
RLC	Resistive Inductive Capacitive
STATCOM	Static Synchronous Condenser
SRF	Synchronous Rotating Frame
SVC	Static VAR Compensator

ABSTRACT

One of Ethiopia's most significant sectors is textiles. These sectors experience power factor issues. Like other textile companies, the Adama Spinning textile mill has a low-power problem that needs to be fixed. Power factor correction was investigated for this reason by utilizing a fact-controller three-leg voltage source converter (VSC) D-STATCOM. Accordingly, numerous study-related data have been gathered through surveys, interviews, and measurements. As a result of the increased current caused by the poor power factor, all power system components experience additional active power losses. The power factor should be as close to unity as possible to guarantee the most favorable conditions for the supply system. By directly measuring the power factor of the load with a power stability recorder, using recorded data, and examining examples of the Adama Spinning Factory's power factor-charged electricity bills from Ethiopia, it is possible to determine the factory's low power factor. According to the findings, the factory's distribution system had a significant level of power loss and a power factor of 0.75 lagging. Therefore, I fall below the electricity provider's specified minimum acceptable value (0.85). This thesis uses a fact-controller three-leg voltage source converter (VSC) D-STATCOM (distribution Static Synchronous Compensator) that is connected at the three-phase power entrance of the factory in parallel to the load to solve the low power factor of the factory. Reactive power compensation for power factor correction, voltage control, elimination of unbalanced load current, and elimination of harmonic currents at the point of common coupling are accomplished using a VSC-based D-STATCOM. According to the study, when the power factor is changed from the current (0.75) to the desired value (0.98), the factory load can be reduced by 25%.This lowers electrical energy waste and lowers the factory's electricity costs. The goal of this thesis for this system is to increase the factory's power factor from its current operational level of 0.75 lagging to 0.98 lagging. The Synchronous Rotating Reference Frame (SRF) theory, which is modeled and emulated by MATLAB Simulink software, was used by the system to mimic a D-STATCOM. This design, which was entirely carried out in MATLAB simulation software, allowed the factory's power factor to be maintained at 0.98 at all times while keeping the load bus voltage at one per unit. The active and reactive power components behave independently when the system changes.

***Key words**: Distribution Static Synchronous Compensator, Power factor Improvement, MATLAB, and Synchronous Rotating Reference Frame (SRF) theory.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Alternating current is virtually always used to generate, transmit, and distribute electrical energy. Since the majority of loads (such as arc lamps and induction motors) are inductive in nature, their lagging power factors are generally low. As a result of the increased current caused by the poor power factor, all components of the power system from the power station generator down to the utilization devices experience additional active power losses. From an engineering and financial perspective, it is crucial to have a power factor that is as close to unity as possible for a supply system (Thomas E G. S., May 3/2017) .

The majority of industrial and commercial alternating current loads are inductive. Due to the nature and the many kinds of electrically connected gadgets Steel/foundries, chemicals, textiles, pulp and paper, automotive, rubber, and plastics are a few examples of certain industries where power factor may be crucial. Transformers, motors, lighting, arc welders, and induction furnaces are a few examples of commonly used equipment where power factor is a concern. All of these devices require reactive power to generate an electromagnetic field in order to function. Such machinery may produce power factors that are subpar or low (Nimmaya Mathew, 06 June 2020) .

This thesis work designed a D-STATCOM to improve the low power factory of Adama Spinning Factory**.** Due to the rise in a range of loads that contaminate the power system, maintaining power quality in the power system is crucial in the current situation. Reactive power is necessary for the magnetization of inductive loads such as induction generators, induction motors, power transformers, and arc furnaces; if this power is drawn from the grid, a poor power quality results. In an electrical power system, the balance of active and reactive power between the transmitting end and the receiving end should be maintained. If this isn't the case, voltage and frequency imbalances may happen, making the power system unstable. Active and reactive power control is required for the stable operation of the power system. One of the most cutting-edge power electronics devices, static synchronous compensator (STATCOM) technology delivers quick and continuous capacitive inductive reactor power correction. The vast majority of loads in an electrical power system are inductive, drawing currents with a trailing power factor. This high demand for reactive power raises feeder losses and decreases the flow of active power (Osama A. Al-Naseem and Ahmad Kh. Adi, 6, January 2017) .

For large users and utilities, power factor correction at the distribution level is a crucial element to take into account. Power factor is the ratio of actual to apparent power flowing through the load. While apparent power is the result of the voltage and current drawn into the circuit, real power refers to the circuit's ability to accomplish work in a specific amount of time. The ideal power factor is 1, meaning that the real and perceived powers are equal. Because current and voltage are in phase, there is no effective power, also known as reactive power, drawn into the circuit in this situation. The amount of current drawn into the circuit increases as the power factor decreases albeit not all of the current drawn contributes to the actual power.

The number of harmonics and inter harmonics has increased overall. These loads result in low power factor, which forces utilities to increase the VA rating of their switchgear and distribution transformers in order to offer more reactive power. Low power factor leads to indecencies in the electrical supply network. Capacitor banks were once employed by utilities to rectify the power factor, but they were cumbersome and rigid. Reactive power compensation has become more effective and flexible thanks to the development of Flexible Alternating Current Transmission System (FACTS) controllers like the D-STATCOM (distribution Static Synchronous Compensator) The problem of power quality in industrial plants is growing due to the increasing number of rectifier-controlled motors and industrial plants and a poor power factor indicates ineffective utilization of electricity there by affects the total energy of plant as well as cost of bills. This low power factor operating of the of the factory is due to the imbalance of machine size and driving loads, which results a numerous amount of reactive power consumptions, is takes place . This improper utilization of reactive power led to lower the power factor of the factory which affects the total electric consumption of country and these problems are aggravated by the proper selection, sizing and installation of selective corrective equipment. To improve the low power factor of the factory this thesis work have designed and simulated a three-leg voltage source-converter(VSC) based D-STATCOM is used for compensation of reactive power for power factor correction, voltage regulation or for along with load balancing and elimination of harmonic current at the point of common coupling (Matthew Borody, 2019) .

1.2. Statement of the problem

Adama Spinning Factory, began operation in 2008 with innovative, sensitive manufacturing machinery and equipment, is situated in Adama City. The plant, like every other electric consumer in Ethiopia, is having a lot of issues as a result of the poor power factor and dependability of the supplied electricity. Adjustable speed drives (ASD), which are frequently used in factories, introduce current harmonic distortions into the system, which then distort the supplied voltage. Additionally, the distribution system's characteristics are occasionally altering as a result of the addition of new electric consumers. The cumulative effect of these facts increases the factory's susceptibility to power factor and reliability issues.

Reactive power is absorbed by loads. In addition, a factory with shifting loads conditions. Due to the huge inductive loads and poor power factor of induction, modern industries have a very low overall power factor. A three-leg voltage source converter (VSC) based D-STATCOM was most advantageous for industries.

According to the factory's weekly and monthly performance reports , the power quality disturbances are another cause of numerous issues at the factory, including repeated burnout of electric motors, failure of expensive electronic printed circuit boards and ASD (inverters), software corruption, and fire accidents in the power factor correcting unit. Power quality assessment must be done at the factory in order to accurately identify and define the current power quality disturbances, as well as to choose and implement a suitable solution to reduce the disturbances that exceed the standard limits specified by standard organizations.

The biggest obstacle to lowering the energy needed to produce goods and services is poor power quality. A more efficient production process, technology, or application of generally known techniques to lower power losses are usually required to improve power quality. Adama Spinning Factory uses electricity, as a common power source for machinery, cooling and temperature control systems, diesel generators, lighting, office equipment, steamer (Boiler), Canteen, compressor, water pump station, etc. The main problem of the factory is, operating power factor is out of the prescribed limit of EEU and unbalanced current of transformers is the big problem of the factory. The factory receives 15KV from EEU at 50-Hertz frequency and operates at a power factor of 0.75 lagging. Due to this the factory as well as EEU loses a high amount of energy every seconds. As this thesis work compare's the power factor of Adama Spinning Factory with EEU standard of minimum 0.98 lagging, and

IEEE minimum standard power factor of 0.85 lagging, thus Adama Spinning Factory power factory is below 0.8 lagging, due to this the Ethiopian electric utility (EEU) charges the factory around 9,500birr per month. Now, this thesis work has done to solve the energy loss due to operating of low power factor and to eliminate the unbalanced current from the load system. Some of the reasons for the low power factor operating of the factory are:

- Absence of power factor corrective equipment to compensate the consumed reactive Power.
- Absence of harmonic filters to filter harmonic currents.
- Due to the operating of large Induction motors with varying load which is with lightly and loaded conditions.
- Due to the unbalanced current of the load.

1.3. Objectives of the Research

1.3.1 General Objective

The aim of this thesis is to give a best solution to high energy consumption by Adama Spinning Textile Factory, through D-STATCOM power factor correction by using VSC.

1.3.2 Specific objectives

To achieve the main objective, the following specific objectives will be done.

- Improve the power factor by recording relevant data.
- To determine the value of D-STATCOM needed for power factor correction.
- The performance of the system with and without a mitigating device will be compared.
- Develop a D-STATCOM power factor corrector with VSC as the brain of the control system.
- To design the appropriate values of D-STATCOM that correct the power factor of the system.
- Using D-STATCOM, the existing low power factor will be improved from 0.75 within the range of between 0.85 and 0.98 lagging.

- Compensating of the reactive power of the load.
- Solving unbalanced current and loss of energy in the factory.

1.4. Motivation of the thesis

Adama Spinning Factory is one of the biggest factories in the city of Adama, with modern technological and electro-mechanical technology.

I am one of the employees, since November 2022, and I have been working in the Nazmed medical textile as Senior Electrical Maintenance Engineer in which I got the best opportunity to closely examine the general electrical phenomenon of the plant. During those times, I encountered and saw numerous electrical issues that are causes for poor power factor.

A tuned shunt passive filter is suggested and developed to correct for the existing harmonic distortion present on the system that was conducted in the factory. In 2011, there was a factory expansion project to boost its manufacturing capacity by 35%.

As a result, the factory's current distribution network may not be compatible with the mitigation strategies suggested by the researcher.

So, one additional 800KVA distribution transformer is installed in the factory to enable the installation of machineries with a total additional installed capacity of about 1107.04 KVA. In order to meet the growing demand for energy in the city, the utility substation that supplies the factory improved its capacity by adding one 50MVA step down transformer. Additionally, the factory's load is moved to a new feeder line in 2016.

In order to produce a value added products by utilizing partially the spinning mill yarn products as an input, the company has started implementing a Nazmed Medical textile expansion project in the 2020/21, with a total additional installed capacity of about 1835.275KVA.

1.5. Significance of the thesis work

- The purpose of this study, in particular, is to assist Adama Spinning factory in reducing the costs paid in its process owing to power factor problems. In recent years, industries have tried to optimize their processes to remain competitive in the manufacturing of their particular product.

- Power factor correction at distribution level is an important consideration for large consumers and utilities. A low power factor causes inefficiencies in the electrical supply network by forcing utilities to increase the VA rating of their switchgear and distribution transformers in order to supply more reactive power.
- The main benefit of this study's findings is that the factory can better understand the quality of the electricity used by its production machinery and equipment; moreover, by putting the study's suggested solution into practice, the factory can minimize the effects of power factor issues, minimizing production loss and downtime as well as the production of off-standard goods.
- The study also urges businesses and/or researchers to investigate the power factor in various distribution networks and take appropriate corrective action. As a result, industries will become profitable and competitive on the world market, which greatly aids the economic expansion of the nation.

1.6. Scope and Limitation of the thesis

The study is primarily concerned to improve the power factor of Adama Spinning Textile Factory distribution network. It is obvious that, the most practical and economical power factor improvement device is D-STATCOM. Because there are considerable low losses and little maintenance as there are no rotating parts. Thus, the scope of the study was limited to reduce the power loss in the distribution network using D-STATCOM.

Provide utility customers and industrial end users a guidebook of procedures, methods and analysis tools which can be used to analyze how to improve the power factor in industrial plants. The study involves reading relevant literature, collecting and analyzing data from the factory to improve the low power factor of the factory. Within the scope of this thesis, three leg voltage source converters (VSC) based D-STATCOM employing reactive power compensation, power factor correction. Synchronously rotating reference frame theory used as the reactive power control technique and PWM technique are investigated to approximate the input voltage and current waveforms to pure sine waves.

Thus, this thesis work has made the following contribution to the factory:

- ✓ The lower power factor, reactive power compensation and unbalanced current problems of the factory has been solved by VSC based D-STATCOM.
- ✓ Investigation of the effect of input filter size on the action of VSC based D-STATCOM for reactive power compensation and power factor correction.

Based on current effort, there is finding that the capacitance value is standard in market. The challenging for circuit designer is to modify the capacitance value of capacitor using the standard unit to gain the required capacitance value then fit them onto the electrical circuit.

1.7. Background of Adama Spinning Factory and its power system

Adama Spinning Factory, a subsidiary of Adama Development P.L.C, is one of pioneers and the largest yarn manufacturing factory, in East Africa, both in open end and ring spun. It is constructed by Norinco-Lalibela Engineering & Construction Share Company on 53,495Sqm plot of land to process 10 ton of cotton a day.

Adama Spinning Textile Factory is located in Oromia Regional State, Adama city, Dembela sub city, Degaga Kebele(05), about 100km away from the capital- Addis Ababa, Ethiopia. The company was established in August, 2008 with an initial capital (a total project investment) of Birr 160 million from which, 70% was covered by bank loan and 30% by owners' Equity having yarn spinning mill under it. Expansion project was implemented in 2011/2012 budget year with an additional investment of Birr 115 million. Currently, the total capital of the spinning mill has reached Birr 405 million.

The spinning mill is a modern textile mill in Ethiopia equipped with latest technology of spinning machineries from Switzerland companies known as Reiter and Luwa and the winding machines equipped with yarn cleaner are imported from Murata of Japan. The laboratory is equipped by the Italian Company, MESDAN and tries to ensure quality twisting fully processed cotton yarn as per customer's specific need. Using Most of these existing installed facilities, it can wind 2 Kg- 2.5 Kg cotton yarn on cones for final delivery and is intending an immediate expansion program to produce COMBED YARN, Thus by enhancing the current capacity by 40%. It produces high quality 100 % cotton carded and combed yarn of different counts.

The Factory has two operating lines, Open-End (OE) spinning and Ring Frame (RF) spinning line. It has a total capacity of 11 ton per day at an average count of Ne 24 and Ne 18 of Ring spun and Open End respectively. Out of the total capacity 5 ton (45%) are ring spun yarn and the remaining 6 ton (54%) are open end spun yarn per day. The yarn for Open end line ranges from Ne 6 to Ne24 whereas Ring spun comprises, Ne16 to Ne40 carded yarn and Ne 20 to Ne 60 combed yarn.

In the 2011/12 budget year the Factory has expanded the Ring spinning line capacity by 65 % and Open End preparatory capacity by 33%.

Towards this, the company with an advisory board and team of executives including the General and the six department Managers, is planning to install an appropriate operating/network systems and international bench mark standards. It has also planned to implement a quality management system, automated management information system and the world wide responsible accredited production (WRAP) certification.

100% cotton yarn suitable for weaving, knitting and hosiery manufacturing processes. In order to produce a value-added product by utilizing partially the spinning mill yarn products as an input, the company has started implementing a Nazmed Medical textile expansion project in the 2020/21 budget year based on a feasibility study conducted earlier. The expansion project was realized with investment capital of birr 158.6 million from which, 60% was covered by bank loan and 40% by owners' Equity.

Currently, the total capital of the company is reached birr 580 million including Nazmed medical textile factory.

Accordingly, the company has offered an employment opportunity for about 465 employee's so far. In addition to this, the Nazmed medical textile factory is expected to provide additional employment opportunity for about 325 employees when it starts full operation.

The Factory by virtue of its location has the advantage of getting enough electric power supply; proximity to cotton growing areas, port of Djibouti and Modjo dry port; availability of relatively inexpensive labor; basic infrastructure of water supply, schools, hospitals; and other infrastructural facilities such as potential train transport.

System for Providing Electric Power to Adama Spinning Factory

The Adama substation, which is approximately 4Km away from the factory supplies power to the electrical system of the Adama Spinning Factory. The substation is linked to Ethiopia's national grid system. Two 132KV inbound lines, one from the Koka power plant and the other from the Adama Wind power plant, are available at the Adama substation. Two $132 \pm 10 \times 1.25\%/15$KV, 25000kVA, %Z=18 Wye-Delta permanent step-down transformers and one $132 \pm 10 \times 1.25\%/15$KV, 50000kVA, %Z=10.75 Wye-Delta portable step-down transformer are now present in the substation. Through two different common bus bars, a total of thirteen feeder lines, seven feeders from stationary and six feeders from portable step-down transformers, provide electricity to various commercial, industrial, and industrial customers, primarily in Adama city.

Additionally, a large number of customers in nearby cities like Wolenchiti, Wonji, Koka, High court, Peacock and Koka metal factory etc. as well as those inside of them are supplied by this substation. One feeder is solely assigned to the Adama spinning factory (which includes the factory's Nezmed Medical facility) and ELSE Addis Textile Factory out of the seven 15KV primary distribution feeder lines on the stationary step-down transformers. A micro-industry and a warehouse beside the plant are powered by an additional two tiny distribution transformer that is connected to this feeder line.

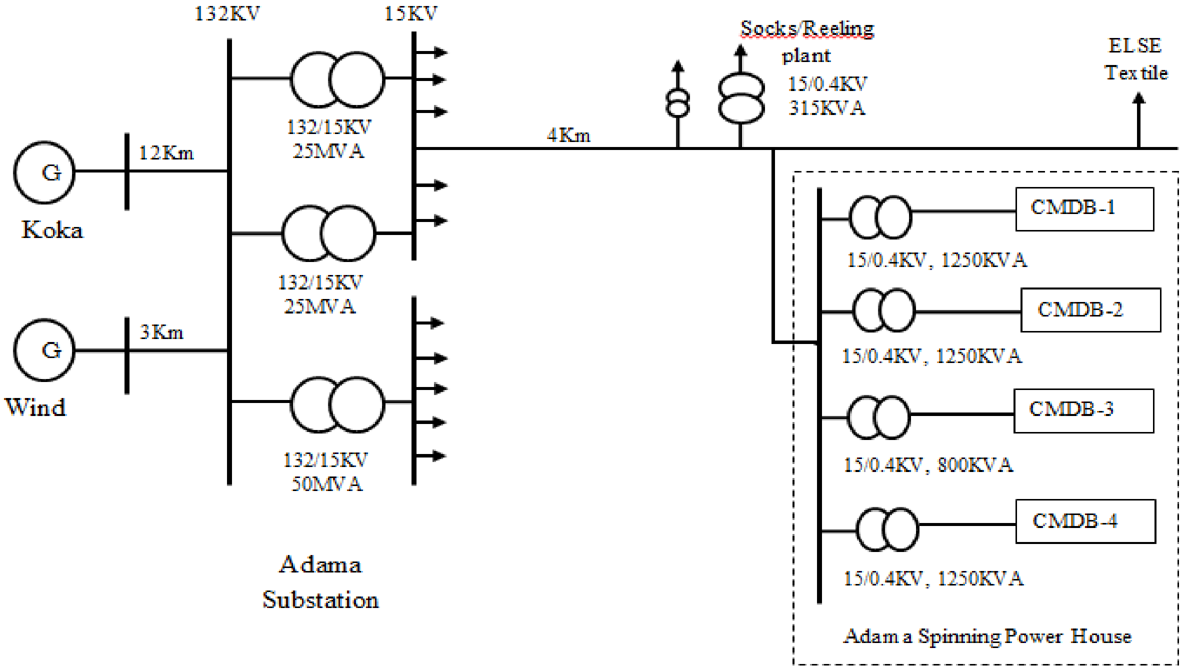


Figure.1. 1.Single diagram from Adama Substation to Adama Spinning Factory Power Network

Adama Spinning Factory's Electrical Power Distribution Network

The overhead distribution system is the 15KV primary distribution feeder line that runs from Adama substation to Adama Spinning Factory. A power house built inside the plant supplies power to the spinning plant and supplies for Nazmed Medical, 30 weaving machines, the two main compressor of weaving plant, two warping machines, one compressor for warping machines, one re-winding machine, and one leno machine. Figure 1.6 shows the power house in partial view. The distribution feeder line is inserted underground into the power house. Figure 1.5 Illustrates how a common bus bar connects a 15kV feeder line to three 15/0.4Kv, 1250kVA, %Z=5.05 Delta-Wye and one 15/0.4Kv, 800kVA, %Z=5.03 Delta-Wye step down net distribution transformers to provide a maximum load of 4.55MVA. In addition to the powerhouse supplying the spinning plant, there are two pole-mounted distribution transformers with 15/0.4KV, 315KVA that supply the 70 weaving machines and one by 15/0.4, 200KVA, that supply warehouse.

Generally the factory's power distribution system consists of six (6) distribution transformers. Thus, the factory has one by 15/0.4Kv, 800KVA, %Z=5.03, 15/0.4, 315KVA, %Z =3.81 15/0.4Kv, 200KVA, %Z=2.5 and three by 15/0.4Kv, 1250KVA, %Z=5.05, delta-wye, step-down distribution transformers

Table.1. 1.transformer rating of Adama Spinning Factory

No.	**Transformer Rating**
1	1250KVA
2	1250KVA
3	1250KVA
4	800KVA
5	315KVA
6	200KVA
Total	4965KVA

The factory power distribution system consists of six (6) distribution transformers, with different capacity as indicated in the table. The factory possess total designed connected load of about, **3.781MVA** as obtained from the designed energy consumption of the factory.

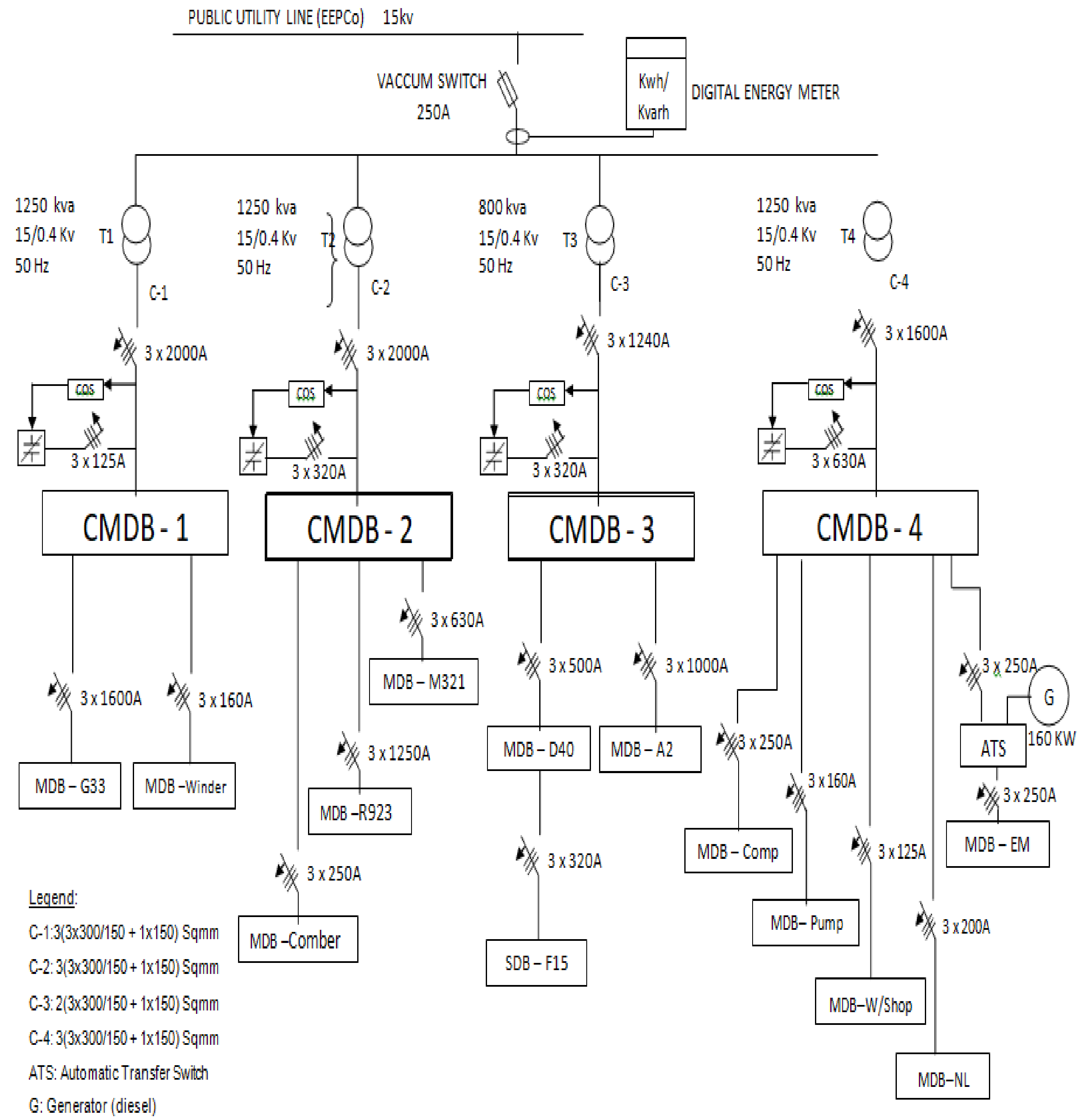
Figure.1. 2.Powerhouse of the Adama Spinning Factory seen in part

And all transformers are Delta-Wye step down net distribution transformers, through a common bus bar, to supply maximum load level of 3.972MW, 4.965MVA. So, 15Kv, 50Hz power from Adama substation is then transformed to 400V by each transformer.

For the case of utility power failure, the factory has one 200KVA, 1500RPM diesel generator with Automatic Transfer.

Switch (ATS) which, is used to supply lightening loads for the factory, offices, stores and other simple loads but not for the factory machinery.

As shown in figure 1.7, the spinning plant's electrical power is supplied by four Central Main Distribution Boards (CMDBs). Through Main Distribution Boards (MDBs) and Sub Distribution Boards (SDBs) positioned in various locations around the plant close to the loads they fed, these four CMDBs supply a variety of various and dispersed loads. Figure 1.8 has a portion of the CMDB boards in view. For 30 weaving machines, two main compressor of weaving plant, two warping machines, one compressor for warping machines, one re-winding machine, and one leno machine supplied by T_2 , and all bleaching and finishing machinery supplied by T_1, which is not indicated in this figure(Henock Habte, 2018**)** Power


PUBLIC UTILITY LINE (EEPCo) 15kv
VACCUM SWITCH
250A
Kwh/
Kvarh
DIGITAL ENERGY METER
1250 kva
15/0.4 Kv
50 Hz
T1
C-1
1250 kva
15/0.4 Kv
50 Hz
T2
C-2
800 kva
15/0.4 Kv
50 Hz
T3
C-3
1250 kva
15/0.4 Kv
50 Hz
T4
C-4
3 x 2000A
3 x 2000A
3 x 1240A
3 x 1600A
COS
3 x 125A
3 x 320A
3 x 320A
3 x 630A
CMDB - 1
CMDB - 2
CMDB - 3
CMDB - 4
3 x 630A
MDB – M321
3 x 1600A
3 x 160A
MDB – G33
MDB –Winder
3 x 1250A
MDB –R923
3 x 250A
MDB –Comber
3 x 500A
3 x 1000A
MDB – D40
MDB – A2
3 x 320A
SDB – F15
3 x 250A
MDB – Comp
3 x 160A
MDB– Pump
3 x 125A
MDB–W/Shop
3 x 200A
MDB–NL
3 x 250A
G
160 KW
ATS
3 x 250A
MDB – EM
Legend:
C-1:3(3x300/150 + 1x150) Sqmm
C-2: 3(3x300/150 + 1x150) Sqmm
C-3: 2(3x300/150 + 1x150) Sqmm
C-4: 3(3x300/150 + 1x150) Sqmm
ATS: Automatic Transfer Switch
G: Generator (diesel)

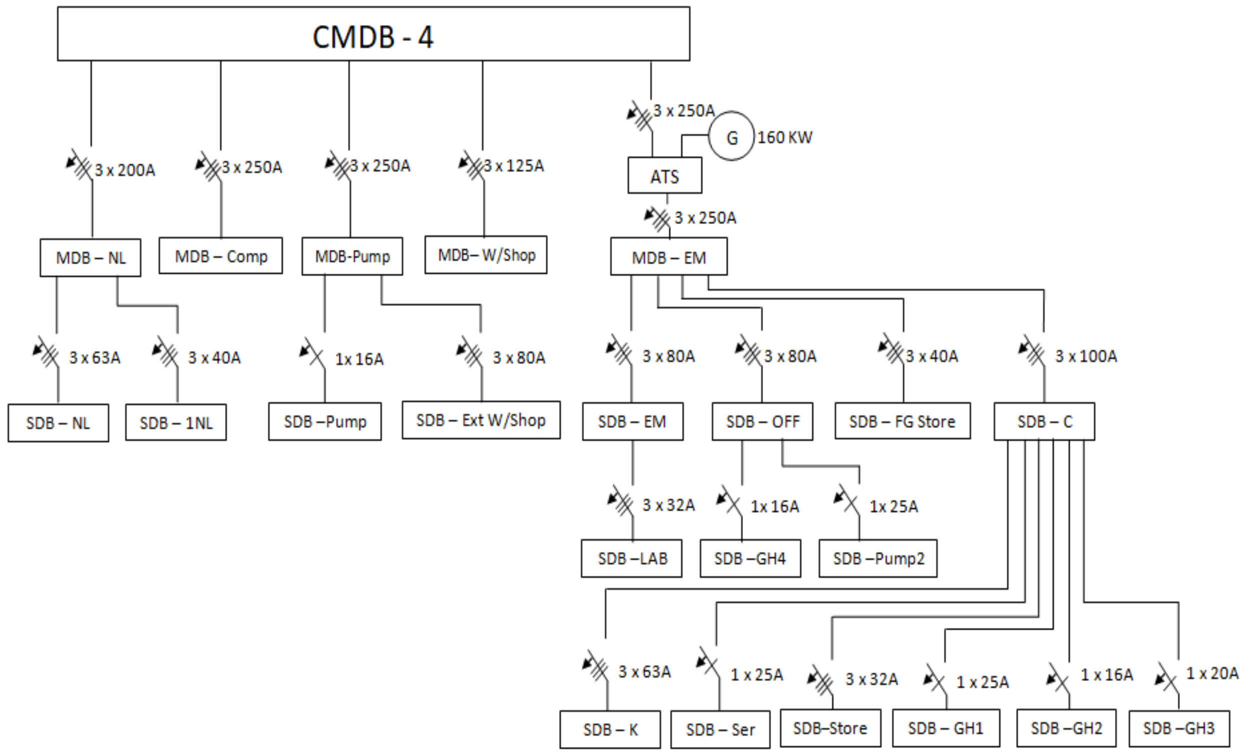


Figure.1.3. Part of an actual single line diagram of Adama Spinning Textile Factory.

The majority of the production equipment at the plant receives power from CMDB-1, -2, and -3. The linked loads to CMDB-4, on the other hand, are primarily utility loads, including sizable Air Conditioning (AC) units, lighting loads, office and kitchen equipment, and welding machines. As illustrated in Figure 3.5, the factory has a single 200KVA standby diesel generator that is linked to the emergency main distribution board (MDB-EM) by an ATS (Automatic Transfer Switch).The administrative office, canteen, stores, physical laboratory, compound lighting, and factory emergency lighting are all powered by this generator in the event of a power outage. In this document's figure 1.7 shows, the complete electrical installation architecture for the Adama Spinning Factory.

Figure.1.4.Distribution system CMDB boards for Adama Spinning Factory

The plant, which is a modern production facility, employs highly sophisticated and energy-saving machinery, which is sensitive to even tiny variations in the quality of the power supplied and, at the same time, has a propensity to contaminate the pure sine wave given. The loads in the factory fall into the following categories:

• Fluorescent lamps; Gas discharge lamps; ASD (Inverters); Resistive heaters; Single and three- phase Power Supplies; Microprocessor-based Controllers; Welding machines

• Business supplies (computers, printers, etc.)

There are several AC induction motors installed in the factory that are controlled by Direct on Line (DOL) and Star-Delta starting techniques, in addition to the induction motors controlled by these ASD.

Each CMDB board has an Automatic Power Factor Controller (PFC) unit that continuously checks the instantaneous power factor (cos) and corrects it when it drops below 0.75 by gradually adding various-sized capacitors to the network. Based on the types and patterns of the loads connected to each CMDB, the capacitor stages are pre-designed. Anti-resonance harmonic filters (reactors) are connected in series to each power factor adjusting capacitor in order to detune the system and prevent resonance phenomena.

Instruments for Measuring

DELAB NV8s PFC measuring equipment is primarily intended for automatic power factor controlling using3-phase capacitor banks, and also have a capability to measure %THD and individualharmonic distortion up to 11^{th} order for voltage and current.

A PFC that uses a microprocessor that complies with IEC 6100-4-2/4-4/4-5/255-5:1 requirements is the DELAB NV8s.

Figure.1.5.DELAB NV8s automatic power factor controller front view

In addition to regulating and adjusting power factor, the controller has the capacity to measure other electrical parameters, including:

- Voltage, frequency, totals harmonic distortion voltage and current (%THDV and %THDI), secondary current, and voltage and frequency.
- Odd harmonic spectrum level of voltage and current up to 11th order.

For the purpose of controlling and adjusting the power factor on the corresponding transformers,

DELAB NV8s PFC devices installed on each CMDB board of the factory. Only the device placed on CMDB-1 is not capable of detecting both voltage and current harmonic levels due to a fire accident had happened in CMDB-1 PFC board and all fuse boxes and connecting cables of capacitors have been damaged.

Only the device placed on CMDB-4 is capable of detecting both voltage and current harmonic levels due to the different software versions on these devices.

The only thing the other two devices on CMDB-2, and CMDB-3, can measure is the level of present harmonic distortion. In order to monitor the voltage and current harmonic distortion levels across all four CMDB boards, the DELAB NV8s PFC device installed on CMDB-4 is used in this investigation. With the aid of these devices, secondary current values (I sec) and individual nth odd harmonic current amplitude values (I h) were measured.

1.8. Organization of the Thesis

In this study, power factor problems in Adama Spinning Factory, particularly unbalanced current and voltage dip on distribution network, have been investigated and their proper mitigation technique is proposed. The thesis is organized into five chapters. The study's background, a statement of the problem, objectives, motivation, significance, and the electrical distribution network of the factory is presented and how the electrical power is distributed, are all included in the first chapter.

The second chapter examines various power factor issues, including methods of power factor correction, description of the monitoring equipment used for this study, advantages of power factor correction, effects of harmonics, and source of reactive power is presented in this chapter. In addition, this chapter discusses a number of related papers on power factor issues.

The third chapter discusses data collection methods, data analysis, mathematical Design of mitigation device, designing the Size of D-STATCOM Parameters for ADSF, and modeling of D-STATCOM. This chapter also describes the design of mitigating devices with theirrespective controlling methods.

In chapter four, the MATLAB/SIMULINK model has been simulated with and without the proposed mitigating device to identify the existing power factor problem. The distribution networks performance before and after the integration of this device was then discussed.

Chapter 5 outlines the conclusion developed based on the investigation results, as well as the recommendations provided to the industry and the electric utility; and the further future work to be done.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Theoretical Background

This thesis describes of the low power factor and reactive power compensation using Distribution Static Compensation (D-STATCOM) in Adama Spinning textile factory. The model is based on the voltage source converter (VSC) D-STATCOM principle. The D-STATCOM injects a current into the system to improve harmonic distortion and low power factor. Different related literatures review about methods for power factor correction are discussed and from the different power factor correction methods for this thesis work, it is selected three leg voltage source converter D-STATCOM to improve the low power factor of Adama Spinning textile factory .

Provide information on power factor correction with Synchronous Condenser for power quality improvement in Industrial Load. The researcher compare's power factor correcting methods such as capacitor banks, reactors synchronous condenser in their role of load power factor correction. The researcher uses MATlab program for overall plant power factor calculations and from this, the researcher concludes that, the use of synchronous condenser to improve the load power factor is somewhat better than the capacitor banks (Moe Kay Thikhaing r. f., 2018).

Present Implementation of Static VAR Compensator (SVC) for power factor improvement on industrial loads. Those researchers describes that since most of the industrial loads are inductive in nature and hence have low lagging power factors which is highly undesirable as it causes an increase in current, resulting in additional losses of active power in all the elements of power system. They used a static VAR compensator consisting of capacitor bank in four binary sequential steps with a thyristor (SCR) controlled reactor of smallest step size is employed in the investigative work. From this the researchers conclude that, power factor of inductive loads without compensation is less than 0.9 lagging and with the help of static VAR compensator power factor can improves near to unity for inductive load (Amol P.Patil, May, 2017).

Deal with automatic Power Factor Correction Using Capacitor Bank.

The researcher describes as power factor of electrical load is a common problem to all industrial companies. They Proposed that, automated power factor corrector (APFC) using capacitive load bank is helpful in providing the power factor correction. From this point, the researchers conclude that, by installing suitably sized power capacitors into the circuit the Power Factor is improved and the value becomes nearer to unity, thus minimizing line losses and improving the efficiency of the plant (Mr.Anant Kumar M. D., 2018).

Presents Enhancement of Power Quality in Distribution System Using D-STATCOM, their objective is the enhancement of voltage sags, harmonic distortion and low power factor using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter in distribution system. Its model is based on the Voltage Source Converter (VSC) principle.

The researcher describes D-STATCOM is a custom power devices which locate shunt in network and applied to mitigate voltage sag and voltage swell. From this the researcher concluded that D-STATCOM is emerged as a promising device to provide not only for voltage sag mitigation but also for a host of other power quality solutions such as voltage stabilization flicker suppression, power factor correction, and harmonic control (M. T. Ehsan, "Pic microcontroller based power factor correction for both leading and lagging loads using compensation method,", 2019 16th)

Fuzzy logic based control of STATCOM for Mitigation of SSR IEEE STATCOM a FACTS device is a second generation Static VAR Compensator (SVC) based on voltage sourced inverter and has better reactive power support even at low voltages. From this, the researcher concludes that the Fuzzy logic controller does not depend on the system model. This eliminates the need to linearize the power system model to tune the parameters of controller. The researcher also conclude that, STATCOM is shunt device and is widely used FACTS device for reactive power generation, voltage support and improving steady state stability of power system (Anand & Singh, Vol 65, Issue 2, 2018.)

Has introduced new control approach for capacitor supported D-STATCOM in three phase four wire distribution systems under non-ideal supply voltage conditions based on SRF theory From this research, the researcher has been concluded that SRF theory employed in D-STATCOM improve the performance of the system and it fulfills the objective of load balancing, harmonic current compensation, indirect current control and neutral current compensation (Mohamadi, Rashidi, Nejad, & Ebrahimi, 2018)

Presents a review paper on custom power device for the improvement of power quality. This paper presents a comprehensive survey of device in distribution system.

The researcher concludes that, to eliminate various power quality disturbances like voltage sag/swell, dip, flicker, low power etc. According to this paper shunt connected D-STATCOM provides better power quality in both transmission and distribution system, UPQC can compensate both voltage and current related problems at the same time (Wang, Shi, & Meng, " Study Bidirectional AC-DC Converter Circuit of the Wireless Charging for Portable Devices", Vol.8 October 2020.) .

Studies linear and nonlinear methods of current regulation referring to D-STATCOM performance using synchronous reference frame through this paper. In this paper merits and demerits of each regulation methods are stated. The researcher concluded that when the PWM with carrier technique in reference frame is implemented, fixing switching of VSC results in overshoot of about 2.5 times more as compared to hysteresis current controller. In case of nonlinear load the THD in fixed switching frame is far higher than that in variable switching frame. He also concluded that hysteresis based D-STATCOM in SRF frame is feasible for load compensation at distribution level (Liu, Xie, & Yang, Vol.8 April 2020.)

This paper presents the compensation provided by D-STATCOM for power factor improvement and different control schemes are available for the D-STATCOM .The researcher concluded that, control method used for it must provide complete reactive power compensation, correction of power factor and voltage regulation and the harmonics are also checked for achieving improved power quality levels at distribution end. In addition to this the researcher concludes that power factor correction using D-STATCOM is the most efficient than the other power factor correction methods.

Deals distribution level static synchronous compensator (D-STATCOM) for dynamic load compensation of unbalanced loads in distribution system. For dynamic response a new feed forward compensation method was derived and engaged. Compensation scheme of the D-STATCOM is derived with the symmetrical component method (Tashakor & Khooban, " An Interleaved Bi- Directional AC–DC Converter With Reduced Switches and Reactive Power Control", Issue 1 2020.) .

MAT lab simulation software is used to confirm the effectiveness of the proposed D-STATCOM.

This paper concludes that, D-STATCOM was a shunt device that generates a balance three-phase voltage or current with ability to control the magnitude and the phase angle. The VSC converter the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system of network through the reactance of the coupling transformer (Thomas E G. S., 2019)

Offers Design and Implementation of a D-STATCOM for Power Factor Correction with in ECE4600 Group Design Project. This system uses IGBT –based power electronics in a 6-pulse inverter configuration, controlled through the use of a decoupled instantaneous current controller. From this the researcher concluded that, a solid-state device enabling full power factor correction with a completely independent control of both active and reactive power (Schneider electric, 2016)

Presents Reactive Power Compensation using D-STATCOM for improving the power factor, power quality and to control power flow control in the distribution line. From this the researcher conclude that , by injecting suitable reactive power in the power distribution line, the load power factor and the overall electrical system performance improves. It was also conclude that, the system provides continuous support of the source voltage and current in phase with each other after compensation. From this the power factor of the utility supply is always reaming at unity (Adeesh Sharmal H. S., Reactive Power Compensation Using D-STATCOM, 2020).

2.2. Power Factor

Power Factor is the cosine of the phase angle between the applied voltage and the current drawn from the circuit. It varies from zero to unity. The power factor can be explained by the victoria and sinusoidal relations of power triangle as shown in figure 2.1. The term cosϕ is known as power factor of the circuit. If the circuit is inductive, the current is lags behind the voltage and the power factor is called lagging power factor and if the circuit is capacitive then current leads the voltage and power factor is said to be leading power factor (Mr.Anant Kumar M. D., 2019).

The low power factor's problem can be solved by connecting power factor improvement capacitors in delta or star to the plant distribution system. Power factor correction capacitors reduce the total current drawn from the distribution system and subsequently increase the system's capacity by raising the power factor level (M. T. Ehsan, "Pic microcontroller based power factor correction for both leading and lagging loads using compensation method," , 2019 16th)

The current required by motors, lights, and computers is made up of real and reactive components. This concept of a two component current is helpful in understanding the capacitor current. Loads such as a heater require the supply of only the real component of current. Some loads, such as an induction motor, require both real and reactive currents. The real current is that component that is converted by the equipment into useful work such as production of heat through a heater element. The unit of measurement of this current is ampere (A) and of power (voltage real current) is watts (W). The reactive current is that component that is required to produce the flux necessary for the functioning of induction devices. The current is measured in ampere (A) and the reactive power in VARs.

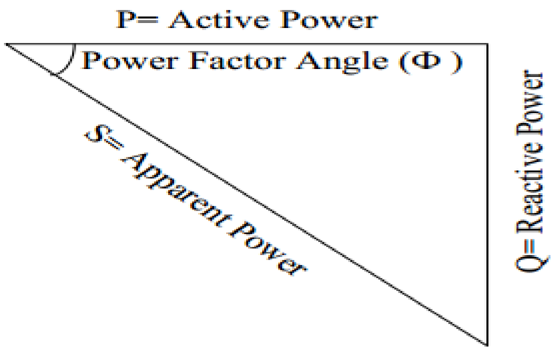


Figure.2. 1.Power triangle

Power factor is the ratio of working power to apparent power or kW/kVAR. Power factor values can carry from zero to one. Typically, values range from 0.80 to 0.98. A power factor below 0.80 is considered low (Mr.Anant Kumar M. D., 2018).

2.3. Methods of Power Factor Correction

Power factor correction can be accomplished using a variety of techniques. Capacitor banks and synchronous condensers are the 2 most popular. Systems called capacitor banks use a number of capacitors to store energy and provide reactive power. A star (wye) connection or a delta connection can be used to connect capacitor banks.

The electrical system can be improved by using the following tools and equipment.

• Capacitor Banks: Installing a bank of capacitors can lower the load's reactive power requirement and boost power factor. Depending on the needs of the load, the capacitors can either be fixed or swapped.

• Synchronous Condensers: To increase the system's power factor, a synchronous motor that is overexcited and operating at no load can be employed as a synchronous condenser.

• Phase Advancers: To increase the power factor of induction motors, phase advancers are AC exciters coupled to the rotor circuit.

• Static Var Compensators (SVCs): These solid-state devices provide continuous reactive power compensation through the use of a thyristor-controlled reactor (TCR) and a thyristor-switched capacitor (TSC).

• Active Power Filters: By generating current, these filters can fix power factor problems.

• Switched Capacitor Banks: A switched capacitor bank improves the power factor by adjusting the reactive power demand based on the load requirements using automatic switching mechanisms.

• Static Synchronous Compensator (STATCOM): A STATCOM is a voltage source converter with the ability to regulate voltage, filter harmonics, and compensate for reactive power.

• Hybrid Power Filters: Hybrid power filters combine active and passive filtering methods to offer a complete remedy for power factor enhancement and harmonic distortion reduction (Tashakor & Khooban, “ An Interleaved Bi- Directional AC–DC Converter With Reduced Switches and Reactive Power Control”, . Issue 1 2020.)

2.4. The common methods used for power factor correction as follows:

2.4.1. Static Capacitor

We know that most industries and power system loads are inductive, which causes a decrease in the system power factor due to lagging current (see disadvantages of low power factor). To improve the power factor, static capacitors are connected in parallel with these devices operated on low power factor.

These static capacitors supply leading current, which balances out the lagging inductive component of the load current. This effectively eliminates or neutralizes the lagging component of the load current and corrects the power factor of the load circuit to enhance the overall efficiency.

To enhance system or device efficiency, these capacitors are installed near large inductive loads, like induction motors and transformers, to improve the load circuit power factor.

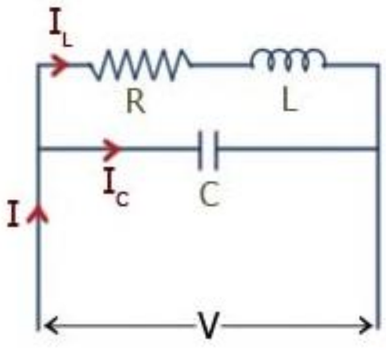


Figure 1

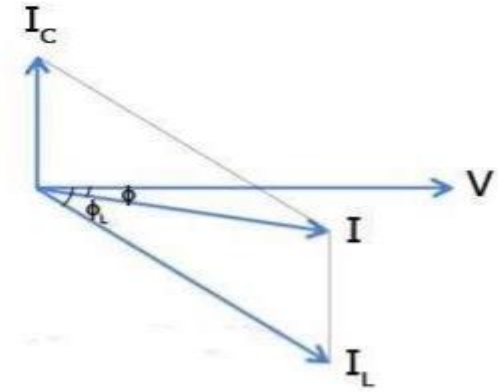


Figure 2

Figure.2. 2.RLC Circuit and its Voltage and Current Phaser Diagram

Figure 1 show the load with a capacitor (C) connected in parallel. As a result, a current (I_C) flows through the capacitor and leads 90° from the supply voltage. In other words, the capacitor provides leading current, and in a purely capacitive circuit, the current leads the supply voltage by 90°, which means the voltage lags 90° behind the current. The load current remains (I), and the vector sum of (I) and (I_C) is (I_L) which lags behind the voltage at Φ, as shown in Figure 2.

Figure 2 demonstrates that the angle of $\Phi < \Phi_L$, implying that Cos Φ_2 is less than Cos Φ_1 (Cos Φ_2 > Cos Φ_1). Therefore, the capacitor improves the load power factor.

It is significant to note that the circuit current is lower than the low power factor circuit current following power factor enhancement. Furthermore, because the capacitor only reduces the reactive component of current, the active component of current is unaffected by power factor enhancement. Last but not least, active power (measured in Watts) is unaffected by power factor correction.

A capacitor bank offers several advantages over other methods of power factor improvement, including:

- Low losses in static capacitors
- No moving parts, therefore requiring low maintenance
- Ability to work in normal conditions (i.e., ordinary atmospheric conditions)
- No requirement for a foundation for installation
- Lightweight, making them easy to install (M. B. Khan and M. Owais, , 2016)

2.4.2. Synchronous Condenser

When a synchronous motor operates at no-load and is over-excited, it is called a synchronous condenser. When a synchronous motor is over-excited, it provides leading current and works like a capacitor.

In a synchronous motor, a separate DC source is used to excite the field winding. Therefore, the input supply only provides current to energize the stator, i.e., the current provided is in-phase with the supply voltage. So the power factor remains unity.

The power factor can be adjusted by varying the DC excitation. By increasing the DC excitation, the power factor varies from lagging to unity and leading power factor. When the DC excitation increases, the field windings are over-magnetized. The input supply provides a current component to the stator to compensate for this over-magnetization. This current leads to the supply voltage, causing a leading power factor or generating reactive power.

An inductive load consumes reactive power, causing a lagging power factor, while a capacitive load generates reactive power, causing a leading power factor. A synchronous motor can be used to improve the overall power factor of an electrical system by adjusting the

DC excitation. The synchronous motor used specifically for power factor improvement without any mechanical load is called a synchronous condenser. The synchronous condenser is used in parallel with the load to improve the power factor. Improving the power factor reduces the extra current drawn from the source that is wasted in the power lines. Consequently, it helps in the reduction of electricity bills and saves energy.

When a synchronous condenser is connected across the supply voltage (in parallel), it draws leading current and partially eliminates the reactive component. This way, the power factor is improved. Generally, synchronous condensers are used to improve the power factor in large industries:

- Long lifespan (up to 25 years)
- High reliability
- Allows for steeples adjustment of power factor
- Does not generate harmonics or require maintenance for them
- Faults can be easily removed
- Is not affected by harmonics
- Requires low maintenance (only periodic bearing greasing is necessary) (Kumar, ”Operation of D-STATCOM in Voltage Control Mode”, 2018)

2.4.3. Phase Advancer

The Phase Advancer is a simple AC exciter that connects to the main shaft of a motor and operates with the motor’s rotor circuit to improve power factor. It is commonly used in industries to improve the power factor of induction motors.

Since the stator windings of an induction motor take lagging current 90° out of phase with voltage, the power factor of the motor is low. By supplying exciting ampere-turns from an external AC source, the current does not affect the stator windings, and the power factor of the induction motor improves. This process is done by the Phase Advancer:

- Sufficiently reduces the lagging kVAR (reactive component of power or reactive power) drawn by the motor because the exciting ampere turns are supplied at slip frequency (fs).
- The Phase Advancer can be easily used where the use of synchronous motors is unacceptable (J.Patel, "Simulation And Analysis of DSTATCOM", 2014)

2.4.4. Capacitor Banks

The capacitor bank (published as separate & descriptive article) is connected in parallel to the load, and when the inductive load draws current from the system, the capacitor bank supplies capacitive reactive power to offset the inductive reactive power. The amount of capacitive reactive power needed to improve the power factor depends on the characteristics of the load, such as the magnitude of the inductance and the phase angle between the voltage and current (P. Venkata Kishore, Jan. 2014).

2.4.5. Static VAR Compensator (SVC)

We have covered this topic in a separate article describing Static VAR Compensator (SVC) including a circuit diagram, construction, working principles, and applications. You can read the article to learn how SVCs are used for power factor improvement (Thomas E G. S., 3, May/June 2017.)

2.5. Power Factor Correction Using Distribution STATCOM

Recently, the major area of research in power systems is to develop systems that can compensate reactive current dynamically under varying load conditions. Generally load centers are located far away from power generation units, so power transmission and distribution network is built to meet the load demand. The overloaded transmission lines lead to deterioration of voltage profile and decreases the system stability. The degree of utilization of the power depends on the power factor of the loads connected to the network. Most of the loads in the distribution line, being inductive in nature, consume much of the reactive power. As a result, the power factor of the load deteriorates, leading to the limitation of the active power flow in the line. This necessitates reactive power control for load compensation to improve the power factor. D-STATCOM acts as one of the most suitable equipment to mitigate this problem at minimum cost in distribution systems. A VSC-based DSTATCOM can be made to inject reactive power into the ac supply system to improve the power factor and for reactive power compensation by making the amplitude of its output voltage exceed the ac supply system voltage., a three-phase voltage source converter with a dc bus capacitor is employed as a D-STATCOM for balancing of source currents, power factor correction and harmonic mitigation in three-phase, three-wire distribution system supplying delta connected load under various source voltage conditions. This will track the reference currents in a hysteresis band scheme. The performance of the proposed scheme has been evaluated under balanced sinusoidal, unbalanced sinusoidal and unbalanced no sinusoidal source voltage conditions' (G. Gupta, , 2017,)

One of the major reasons to select D-STATCOM as load compensator is its capability to generate reference compensator currents. The compensator injects three-phase currents in the ac system by tracking the reference currents to cancel out disturbances caused by the load.

Under the circumstances, this paper presents the modeling of a D-STATCOM based on three-phase VSC to improve the power factor at the load end. There usage of PV solar farm as STATCOM during night time is explained in:

- A D-STATCOM, based on voltage-source converter (VSC), has been proposed to improve the power factor of the load locally by injecting suitable reactive power in the power distribution line. The amplitude of the output voltage of the D-STATCOM is made greater than the system voltage for the purpose of controlling the VAR generation. Thus it can internally generate capacitive reactive power to be used for shunt compensation.
- The D-STATCOM is controlled using a Hysteresis controller. The STATCOM is controlled such that it tracks the power factor reference and maintains the same in the line.
- The implementation of the D-STATCOM and its controller is carried out in MATLAB/ Simulink.

Basic Model of D-STATCOM STATCOM is the static counter-part of rotating synchronous condenser, which generates or absorbs reactive power at a faster rate by suitable control of the inverted voltage with respect to the ac supply line voltage.

When it is used in distribution systems it is termed as D-STATCOM. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. D-STATCOM mainly consists of a dc energy storage device (dc capacitor), three phase inverter (VSC), coupling transformer and controller circuits.

Fig 2.3 shows the basic configuration of D-STATCOM. The VSC converts the dc voltage across the storage device into ac output voltages. These ac voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Inverter is the main component of the D-STATCOM. The three basic operation modes of the DSTATCOM output current I_{Out} which varies depending upon V_i. If V_i is equal to V_S than the reactive power is zero and the D-STATCOM does not generate or absorb reactive power. When V_i is greater than V_S, the D-STATCOM shows an inductive reactance connected at its terminal. The current flows through the transformer reactance from the D-STATCOM to ac system and the device generates capacitive reactive power. If V_S is greater than V_i, the D-STATCOM shows the system as a capacitive reactance. This time the current flows from the ac system to the D-STATCOM which results absorbing inductive reactive power. Where V_S is system voltage and V_i is inverter voltage (Badoni, 2016).

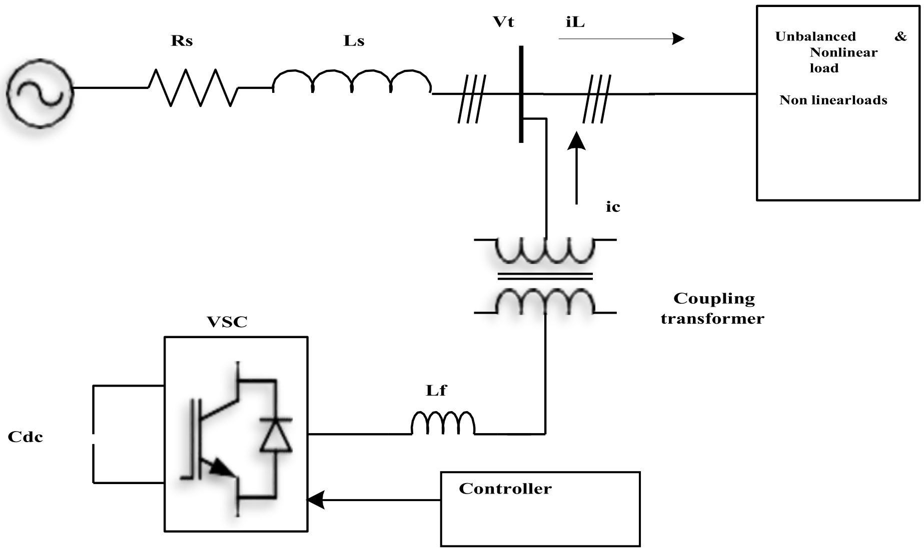


Figure.2. 3.D-STATCOM Model (J.Patel, Simulation And Analysis of DSTATCOM, 2014)

Some Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and ac system. The VSC connected in shunt to ac system provides a multifunctional topology which can be used for three quite distinct purposes:

- ✓ Voltage regulation and compensation of reactive power
- ✓ Correction of power factor
- ✓ Elimination of current harmonics.

The control system design determines the priorities and functions developed in each case. The D-STATCOM regulates voltage at the point of connection. The control of DSTATCOM is based on sinusoidal PWM which requires voltage measurements and no reactive power measurement.

2.5.1 VSC (VOLTAGE SOURCE CONVERTER)

A VSC as a power electronic device is most important in DSTATCOM which can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. Voltage source converters are widely used in ASD (Adjustable-Speed Drives), but can also be used to mitigate voltage dips. The VSC is used completely to replace the voltage or to inject the „missing voltage‟. The missing voltage is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. DC source as battery is connected parallel to the DC capacitor. It carries the input ripple current of the converter and it is the main reactive energy storage element. This DC capacitor could be charged by a battery source or could be recharged by the converter itself. The switching strategy based on a sinusoidal PWM method which offers simplicity and good response (Agraekar, 2020).

2.5.2 CONTROLLER

The main aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. In this control scheme it measures the RMS voltage at the load point and no requirements of reactive power measurements. Here the sinusoidal PWM technique is used for the switching of VSC offers simplicity and good response. The input of the controller is an error signal which is obtained from the reference voltage and the value RMS of the terminal voltage measured at load point. The PWM generator generates the sinusoidal PWM waveform or signal (Anand & Singh, " Power Factor Correction in Cuk–SEPIC- Based Dual-Output-, , 2018).

Advantages of power factor correction using D-STATCOM over the other methods of power factor correction:

- It operates with a very fast transient response, thus appearing to be almost without any inertia, unlike the synchronous condenser.
- It provides virtually step-less compensation for reactive VARs and maintains the desired power factor set as control reference automatically, even in the event of load fluctuations. It can be controlled to provide leading or lagging VARs and adjusts itself automatically as per the load VAR requirement.
- In event of increase in plant load, putting additional units in parallel can increase compensation capacity.

- ❖ Better dynamics, no inertia, lower investment cost and maintenance cost than synchronous condenser.
- ❖ Continuous and dynamic voltage control.
- ❖ Allows full grid control.
- ❖ High dynamic and fast step response of 8 ms to 30 ms
- ❖ Helps in system stability control, as active power control is possible with a D-STATCOM
- ❖ High efficiency. Single-phase control for unbalanced loads.
- ❖ No potential for making a resonance point. This is because no capacitor banks or reactors are essential to produce the reactive power for a D-STATCOM.

From the different power factor correction methods of discussed the D-STATCOM method of power factor correction is the better for power factor correction at distribution level and large consumers.

That is why the D-STATCOM is, selected for power factor correction in my thesis work in Adama Spinning Textile Factory.

2.6 D-STATCOM's operating principles

Reactive power compensation is accomplished with a Distribution STATCOM (D-STATCOM), a shunt compensation device. It can be utilized in voltage regulation mode or power factor correction mode. A three-phase shunt connected power electronics-based device called D-STATCOM is attached close to the load. The inverter is operated by the D-STATCOM controller in such a way as to a technique for dynamically adjusting the phase angle between the line voltage and the inverter voltage such that the D-STATCOM can produce or absorb the desired reactive power at the Point of Common Coupling (PCC).

Reactive power is zero and the D-STATCOM does not produce or absorb reactive power if the inverter's output voltage is equal to the system voltage Vs. When the inverter voltage is higher than the system voltage the collector current from the D-STATCOM flows via the coupling inductor and into the ac system, meaning that the device produces capacitive reactive power. When the D-STATCOM receives current from the ac system because the inverter voltage is less than the system voltage, the device absorbs inductive reactive power.

Six IGBT switches with anti-parallel diodes are used to construct a three-phase voltage source converter (VSC).A three phase load could have a trailing power factor, be unbalanced, or be nonlinear. In order to lessen switching ripples at the point of common coupling (PCC) voltage injected by switching of D-STATCOM, a filter is connected to the system in parallel with the load and the compensator.

A three phase AC mains feeding three phase loads, such as lagging power factor loads, unbalanced loads, non-linear loads, and mixed of these loads of Adama Spinning textile loads at PCC is coupled to a D-STATCOM schematic diagram as shown in Figure 2.4 To lessen ripple in compensating currents, interface inductors (L_f) are utilized on the AC side of the voltage source converter (VSC). To eliminate the harmonic/reactive power component of the load currents, the D-STATCOM injects harmonic/reactive currents. Since the load reactive power is also compensated, the source currents are harmonic free.

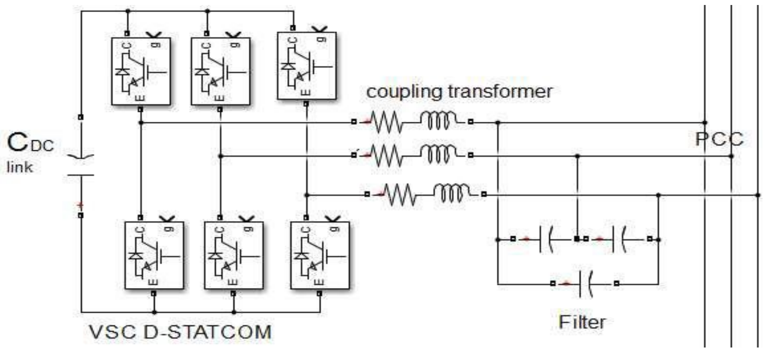


Figure.2. 4. 2 levels, 3leg voltage Source with Filter

The rating of the switches is determined by the needed compensation's voltage and current rating.

Active power flows from the leading source to the lagging source and reactive power from the higher voltage magnitude AC source to the lower voltage magnitude AC source when the two AC sources of the same frequency are connected through a series inductance. The difference in phase angle between the sources determines active power flow, whereas the difference in voltage amplitude between the sources determines reactive power flow.

The choice of the voltage source converter's power stage is influenced by the design's preferred control strategy, harmonic reduction methodology, reactive power compensation, and load characteristics. The D-STATCOM's power semiconductors are only turned on and off once during a Fundamental period in the techniques of Fundamental Frequency Modulation (FFM). Typical FFM schemes include the following:

• Multiple six-pulse converters connected in parallel on the dc side and to phase-shifting transformers on the ac side make up multi-pulse converters. Transformer connections can be used to reduce specific harmonics, although complex transformer connections are needed for lower harmonic spectra.

• The dc link capacitor is divided into the converters in a multi-level converter. By using a switching control, the AC side is linked to the chosen converter, and staircase waveforms with lowered harmonics are produced. Because of this topology, capacitor voltage equalization can be maintained without complex control systems by using simpler transformer connections.

• To provide lowest harmonic spectra, each power semiconductor is switched at higher frequencies (250Hz–5 kHz). The system voltage and required power ratings determine the power stage to use D-STATCOM. The Voltage Source Converter scheme illustrated in Figure 2.4 which has two levels and three legs, provides the foundation for this thesis.

The switching harmonics of the converter are filtered out using an input filter, as seen in Figure ... Depending on the system's reactive power generation constraints and the IEEE 519-1992 standard; it can be constructed as either an inductance-only filter or a low pass LC filter (Sabha Raj Arya, " PowerFactor Correction and Zero Voltage Regulation in Distribution System Using DSTATCOM",, December16-19, 2019)

2.6.1 Basic D-STATCOM Components

The following components make up the basic configuration of D-STATCOM:

- ✓ Voltage Source Converter,
- ✓ L-C Passive Filter,
- ✓ Coupling Transformer,
- ✓ Reactive Power Control Block, and
- ✓ De Link Capacitor are only a few of the components.

The different components of D-STATCOM are as shown in Figure…

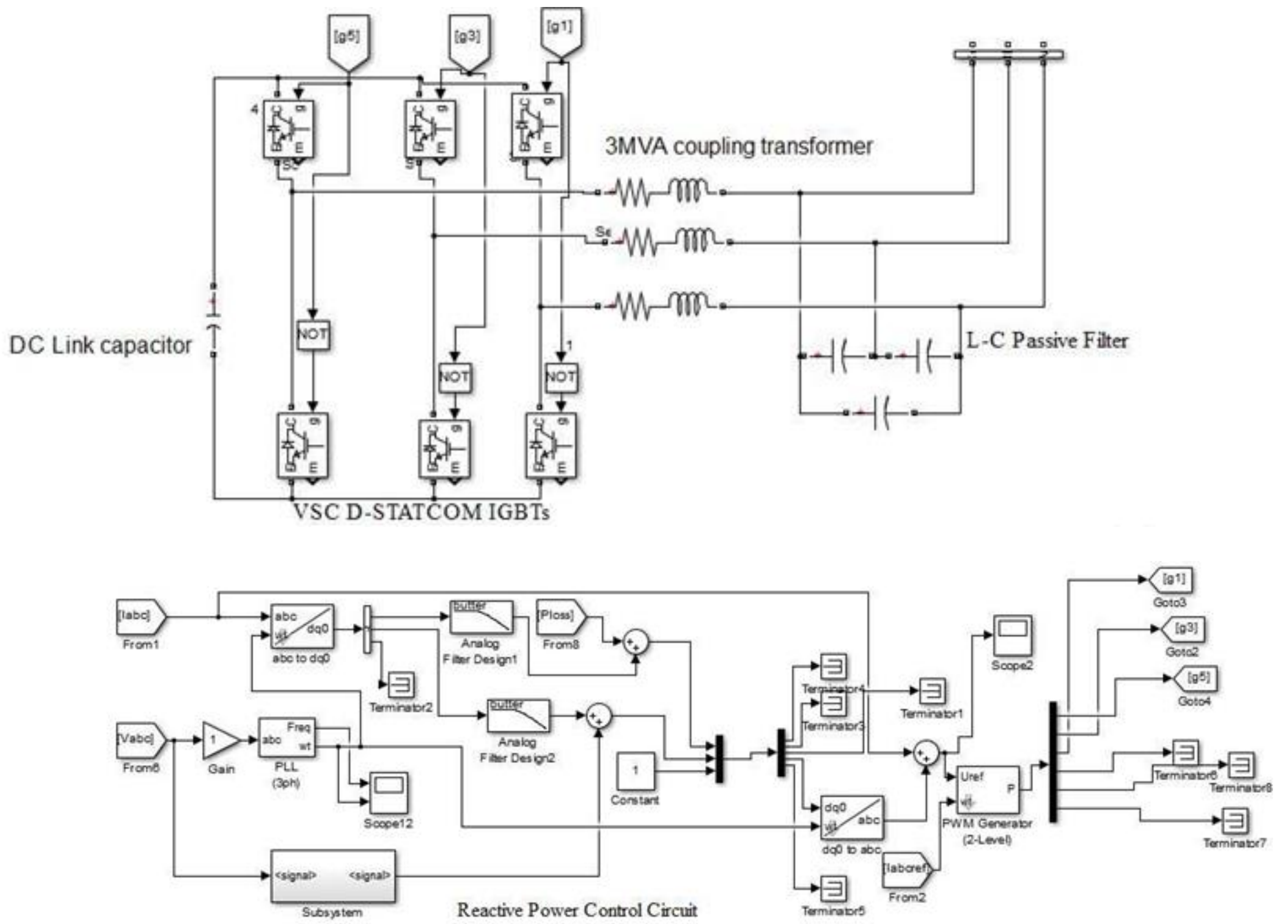


Figure.2. 5.Components of D-STATCOM Device

1) Voltage Source Converter

A voltage source converter (VSC) gives the controlled output voltage in terms of magnitude and phase angle to produce either leading or lagging reactive current, depending on the necessary compensation. It carries out its functions using semiconductor medium voltage IGBT technology operation. It assists in turning the DC voltage present in the storage de-link capacitor into three-phase AC output.

Advantages of VSC-based transmission

- Operation in extremely weak systems.
- No commutation failures.
- No need for polarity reversal to reverse power.
- Independent control of reactive and active power.
- Reactive control independent of other terminals.
- Simpler interface with ac system.

- Continuous ac voltage regulation (Sabha Raj Arya, " PowerFactor Correction and Zero Voltage Regulation in Distribution System Using DSTATCOM", , December16-19, 2012).

Self-commutated VAR compensator based on IGBT Operating principle

The Self-commutated VAR compensator is used in shunt with the Load because it is designed. For step less (smooth) and dynamic reactive compensation of a specific load reactive power demand. Self-commutated VAR compensators have the ability to produce or consume reactive power without the usage of vast banks of capacitors or reactors; instead, they employ a capacitor with a controlled dc voltage. Self-commutated compensators are employed to enhance power factor correction and voltage management. IGBTs based on voltage source converters (VSCs) with pulse width modulation (PWM) serve as the self-commutated power supply for the compensator (K. A.-H. Ambrish Chandra, 2015).

With an output DC voltage larger than the peak supply voltage, the VSC is a boost converter.

The desired capacitive or inductive current is produced when the basic PWM voltage reacts with the input supply voltage. The VSC receives feedback on the load current from the load and computes the reactive current component. To provide precise compensation for the predicted reactive current component of the load current, the fundamental component of the PWM voltage is dynamically modified. As a result, the source is freed from providing any reactive current or VAR. By altering the amplitude of the fundamental component of the voltage, the reactive power is controlled while ignoring the internal power losses of the entire converter. Its operating principle is comparable to the synchronous (Moe Kay Thikhaing, Volume 3,2018.)

2) L-C Passive Filter

Combinations of capacitors and inductors adjusted to resonate at a single frequency or across a range of frequencies make up a passive filter component. Passive filters are used in power systems to reduce voltage distortion and harmonic currents that appear in sensitive areas of the system. By displaying various impedance values at the resonance frequency, passive filters function. The harmonic frequency that needs to be blocked should have high impedance when a filter is coupled in series. Although connecting filters in a series configuration is an option, parallel connections are more typical.

Such a shunt configuration diverts harmonic currents to ground, and simultaneously provides reactive power, which may be used to correct the power factor. As such, passive shunt filters are designed to be capacitive at the fundamental frequency. The LC filter helps in suppressing harmonics and couples inverter output impedance to that of inverter in order to partake current. The choice of LC filter is established on the grounds of the character of the system and the anticipated harmonics (system (Sharma et. al, 2018))

3) Coupling Transformer

The medium used to relate the generated voltage of VSC to the AC system is a coupling transformer. The coupling transformer reactance fulfills this need. The three-phase transformer used for coupling has a star delta connector. By using a delta-connected transformer, this connection of the transformer eliminates harmonics and spreads current imbalance.

4) DC-Link Capacitor

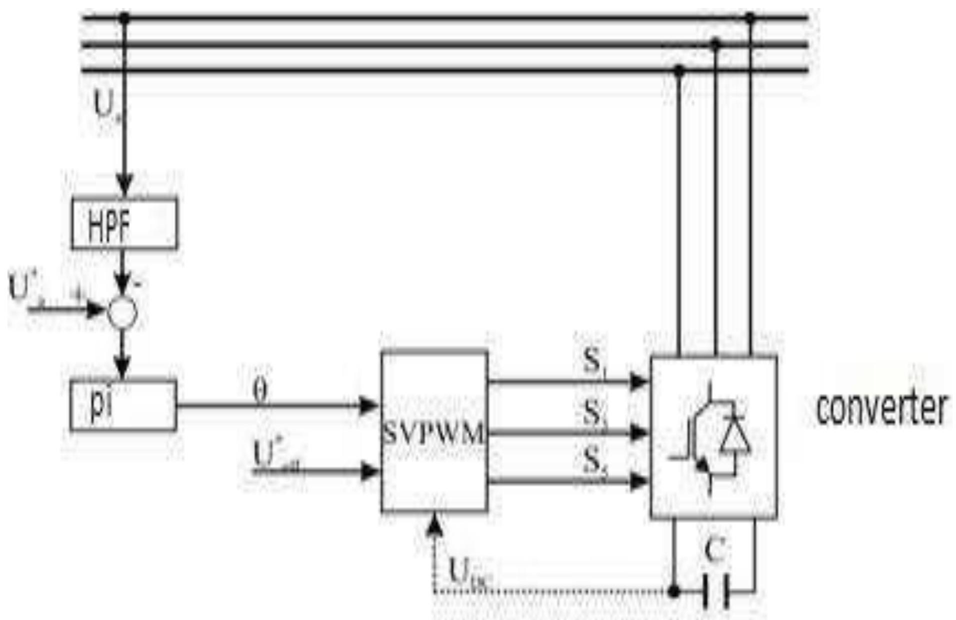
A load-balancing energy storage component between the dc (battery) and ac (load) sides of a VSC is the dc-link capacitor. In order to maintain a stiff dc-link voltage across the VSC, this component is connected in parallel to the battery. In other words, the suppression of electro-magnetic interference (EMI) created by pulsed inverter current and stray inductance and resistance of the dc-bus requires a certain level of dc-line current ripple

2.7. Application of space vector pulse width modulation to control D-STATCOM voltage

A symmetrical voltage system is created by the SVPWM modulator, which is based on the reference voltage in the -coordinate system, which provides control impulses that lead to the base of the transistor in the Control Bridge. A sine wave with the desired amplitude, frequency, and beginning phase can be used as the reference voltage. Then, a reference to the domain is obtained from such references by simply placing voltage in the Klarkine transformation. Therefore, the reference amplitude value (effective value) and the initial phase of the required system are all that are required to generate the output voltage. This bus, which connects to DSTATCOM, is essentially rated voltage. Utilizing the PI controller, reference phase signal can be discovered. The reference voltage, measured voltage phase A, and other normalized rms values are introduced by the PI controller. The phase value needed to produce the sine reference signal is the output of the PI controller.

Three phase quantities are reduced to their equivalent two phase quantities in the stationary reference frame when using the space vector modulation technique. It is possible to compute the magnitude of the reference vector, which is used to modulate the inverter output, from these two-phase components. The definition of collapse voltage takes into account the length of work D-STATCOMs, which should not exceed 30 periods of 50 [Hz] signal in the case that improvement is unsuccessful. The main purpose of the D-STATCOM is to reduce voltage dips. According to IEEE 1159-1995, a ruin voltage (also known as a voltage sag) is a voltage that typically has an amplitude between 10% and 90% of the nominal voltage and a duration between 0.5 and 30 periods of the signal frequency of 50 [Hz].

The system performance that is observed is basic in order to reduce stress on the MATLAB simulation. This suggests that a coupling transformer is not employed and that just one portion of the distribution system is visible at a voltage of 0.4 [kV]. This technique has the unique ability to account for harmonics, imbalance, reactive power from the load, and active



power from the load. Although the load currents are unbalanced and distorted, the system simulation results demonstrate the effectiveness of the SVPWM based DSTATCOM in producing balanced sinusoidal source currents. It is expected that the secondary distribution transformers supply power to this area of the network. A sensitive customer and a consumer group with a rough start are connected to the same bus. The switch that connects these consumers to the network at time t = 0.1 [s] closes. This only simulates attracting customers, who have a high initial current value. As a result, the voltage drops to 0.7(s).

Figure. 2.6. Block schematic of the SVPWM control system (Sharma et. al, 2018)

2.7. Advantages of Power Factor Improvement

- Reduce electricity consumption in a plant
- Reduce electricity costs only
- Reduce both electricity cost and electricity consumption
- Voltage Profile Improvement
- Line and Transformer Loss Reduction
- Release of Power System Capacity
- Release of Generator Capacity

The synchronous generator has kW limit as well as kVA limit. The kVA limit of the generator may correspond to unity power factor operation. If the load is a low power factor apparatus, then the generator has to deliver a kW at a lower power factor. But the generator output cannot exceed the nominal kVA rating. The power factor correction at the generator terminals can release the kVA capability (Adeesh Sharmal H. S., Reactive Power Compensation Using D-STATCOM, 2020).

2.9. Effects of Harmonics

There are effect of harmonics in electrical installation and capacitors. The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms. Harmonic currents are currents circulating in the networks and which frequency is an integer multiple of the supply frequency. Harmonic currents are caused by non-linear loads connected to the distribution system. A load is said to be nonlinear when the current it draws does not have the same waveform as the supply voltage. The flow of harmonic currents through system impedances in turn creates voltage harmonics, which distort the supply voltage. The most common non-linear loads generating harmonic currents are using power electronics, such as variable speed drives, rectifiers, inverters, etc…. Loads such as storable reactors, welding equipment, arc furnaces, also generate harmonics. Other loads such as inductors, resistors and capacitors are linear loads and do not generate harmonics.

2.9.1. Influence of Harmonics in Capacitors

Capacitors are particularly sensitive to harmonic currents since their impedance decreases proportionally to the order of the harmonics present.

This can result in a capacitor overload, shortening steadily its operating life. In some extreme situations, resonance can occur, resulting in an amplification of harmonic currents and a very high voltage distortion.

Amplification of Harmonic currents is very high when the natural resonance frequency of the capacitor and the network combined happens to be close to any of the harmonic frequencies present. This situation could result in severe over voltages and overloads which will lead to premature failure of capacitors

To ensure a good and proper operation of the electrical installation, the harmonic level must be taken into account in the selection of the power factor correction equipment. A significant parameter is the cumulated power of the non-linear loads generating harmonic currents (Leonard L. Grigsby, 2017).

2.10. Reactive Power

Reactive power is a concept used by engineers to describe background energy movement in alternating current system arising from the production of electric and magnetic fields.

These fields store energy which store energy by virtue of a magnetic field by flow of current are said to absorb reactive power, those which store energy by virtue of electric fields are said to generate reactive power

2.10.1. Sources of Reactive Power

Synchronous Generators

Can generate or absorb reactive power depending on the excitation. When over excited they supply reactive power, and When under excited they absorb reactive power. The capability To continuously supply or absorb reactive power is, however, Limited by the field current, armature current and region of Heating limits. Synchronous generators are normally equipped with automatic voltage regulators which continually adjust the excitation so as to control the armature voltage.

Synchronous Compensators

Certain generators once run up to speed and synchronized to the system, can be declutched from their turbine and provide reactive power without producing real power, this mode of operation is called synchronous compensation.

Capacitive and Inductive Compensators

These are devices that can be connected to the system to adjust voltage level. A capacitive compensator produces an electric field there by generating reactive power whilst an inductive compensator produces a magnetic field to absorb reactive power. Compensation device are available as either capacitive or inductive alone or as hybrid to provide both generation and absorption of reactive power (Moe Kay Thikhaing ". , 2018).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Methodology for Data Collections

The relevant information for this thesis was gathered from several sources of the Adama Spinning Textile Factory.

The relevant data includes:

- The factory's average annual energy use over the last one year.
- The factory's existing production costs and energy costs.
- Measurements including power factor, three-phase current, and voltage.

Opportunities to increase the factory's power factor and lower losses are taken depending on the assessed data.

Conclusions and suggestions have been made based on the data that has been analyzed.

Table.3. 1.power factor charges of Adama Spinning Textile Factory

No.	Sample from energy consumption and payment year	Amount of power factor charges	Operating Power Factor
1	21/8/2021	3,683.74birr	0.75 lagging
2	19/11/2022	9,500birr	
3	28/12/2022	3,850.29birr	
4	28/1/2023	3,358.73birr	

The total designed energy consumed by the factory as the tables in appendixes B and C, W_T =

(555724+430329+231134+640736+498120+700295+655211+7369+427108+801296 +652202+21677.28+13560+2781.72+2801.688+128.736) KWh=12249998.144KWh.

$$\text{Energy} = \text{Power} \times \text{Time} \tag{3.1}$$

$$\text{Power} = \frac{Energy}{Time} \quad (3.2)$$

This energy is consumed by the factory within one hour period.

$$\text{So,} \quad P_T = \frac{WT}{t} \quad (3.3)$$

$$P_T = \frac{12249998.144KWh}{3600S} = 3402.777\text{kw} \approx 3403\text{KW} = 3.403\text{MW}$$

Utilizing the total active power, the total apparent power can be calculated. The apparent power of the Adama textile factory is calculated as active power divided by the internationally acceptable industrial power factor, which is approximately 0.9 lagging (IJETT) - Volume 4 July 2013 from this point of view. Most industrial applications are designed to operate near 0.9 and above.

$$\text{So,} \quad S = \frac{PT}{PF} = \frac{3403}{0.9} = 3781\text{KVA}$$

From the designed apparent power the designed primary load current can be calculated as

$$S = \sqrt{3} \text{ x } V_L \text{ x } I_{PL}$$

$$I_{PL} = \frac{S}{\sqrt{3}\ x\ VL} = \frac{3781KVA}{\sqrt{3}\ x 15KV} = 145.5\text{A.}$$

This is the maximum primary load current of the total designed energy consumption of the factory.

3.2. Mathematical Design of D-STATCOM Based on voltage Source Converter

On this chapter, depend on the factory data, mathematical designs the reactive power is needed to improve the low power factor of the factory.

Depend on the reactive power requirements the component rating of the D-STATCOM has been designed.

3.2.1. Design of Voltage Source Converter D-STATCOM parameters

Depending on the factory data mathematical design have been performed. From the required reactive power for the power factor improvement the load reactive power rating, the component rating of the D-STATCOM such as the compensation current, medium voltage IGBT collector current, coupling transformer rating, DC link capacitor rating, filter ratings, energy transfer of the dc link capacitor are obtained (K. Somsai and T. Kulworawanichpong, April 3,2014). Depending on the designed parameters of D-STATCOM, the output power factor is designed mathematically as well as simulated using MATlab soft wares for both before and after correction of the factory power factor.

Table.3. 2.given data from Adama Spinning Factory

Types of Data	**Amount**
Input Primary Voltage (V_{LP})	15KV
Input Primary Load Current (I_{LP}, I_{L-L})	145.5A
Currently Operating Power Factor	0.75 or θ= 46°
Total energy consumption of the Factory (W_T)	12249998.144KWh

3.2.2. Mathematical Analysis of Electrical Parameters of Adama Spinning Textile Factory

The Designed consumed total energy of the factory as indicated from the appendixes C and E Total energy consumed (W_T) =12249998.144KWh

$$\text{Designed total power} = \frac{Energy}{Time} \quad (3.4)$$

$$\text{Time} = 1\text{hour} \quad (3.5)$$

As the total power calculated, $P_T = 3403$KW

Even if the IEEE standard acceptable power factor of an industrial application is above 0.85 lagging but in most of the world countries the acceptable load power factor is 0.9 and above .From this point of view the designed reactive and apparent power of the Adama Spinning textile factory is calculated as

Apparent power(S) = $\frac{PT}{PF}$ by setting power factor to 0.9 lagging

Apparent power (S_T) = $\frac{PT}{PF} = \frac{3403KW}{0.9}$ = 3781KVA and the reactive power is $Q^2 = S^2 - P^2$,

Q=$\sqrt{S^2 - P^2}$=$\sqrt{3781^2 - 3403^2}$ = 1647.89KVAR

$S = \sqrt{3} \text{ x } I_L \text{ x } V_L$, $I_{PL} = \frac{S}{\sqrt{3} x VL} = \frac{3781KVA}{\sqrt{3} x 15KV} = 145.5A$

A11 distribution transformers of Adama Spinning textile factory are connected in delta-star (Δ -Y) with voltage ratings of 15kv/400v. Using transformation ratio of three phase transformer (Δ -Y) the secondary load current can be calculated as

Primary line to line voltage (V1) =15kv,

Secondary line to line voltage (V2) =400V, $V2 = \sqrt{3} V_{phase}$ (3.6)

Primary line to line current (I_P) = $\sqrt{3} I_{phase}$ (3.7)

Secondary line to line current (I_S) = I_{phase}, from this the secondary line to line current is calculated as

$$\frac{V1}{V2} = \frac{I2}{I1} , \frac{15000V}{400V} = \frac{I2}{145.5} , I_2 = \frac{15000V x 145.5A}{400V} = 5456A$$

Therefore, the designed Power parameters of Adama Spinning textile factory are:-

S= 3781KVA, P=3403KW, Q=1647.89KVAR, I_L = 145.5A

The factory currently operating active and reactive is calculated as:

$P_{1=} S \times \cos\theta$ where θ=46°

So, P_1= 3781KVA × cos 46°= 2626.5KW

$Q_1 = S\ x \sin\theta$ =3781KVA x sin 46 =j2719.8KAVR

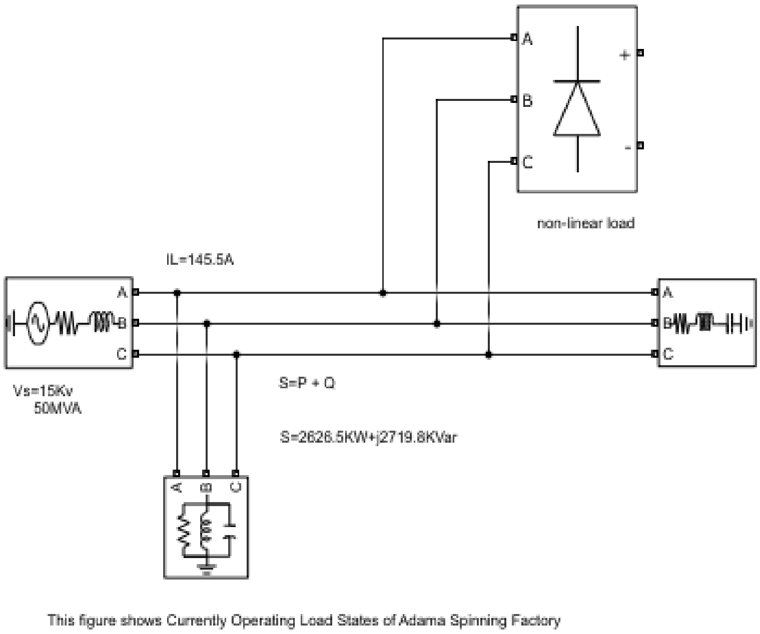


Figure.3. 1.Adama Spinning operating load state

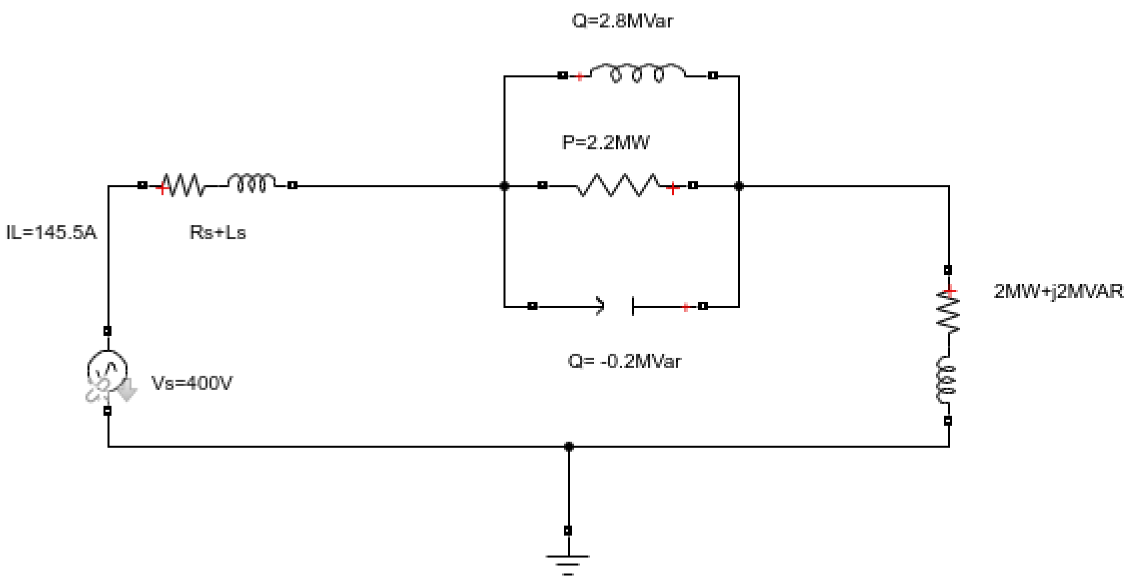


Figure.3. 2.Adama Spinning textile factory Currently Operating Load States with circuit diagram

3.2.3. Designing the Size of D-STATCOM Parameters for ADSF

This thesis work designed to improve the power factor of the factory from presently operating 0.75 lagging to between 0.85 & 0.98 lagging. Depend on IEEE standard **in** most of the world countries power factor correction is considered from 0.92 lagging and above (IJETT)- Volume 4 July 2013. From this concept designed power factor after correction is to get 0.92 *or* θ_1 = 23, from this the power parameters, when the power factor improved from 0.75 to 0.92 lagging are

$P_2 = S x \cos\theta 1 =$ 3781 x cos 23 = 3480.43KW

$Q_2 = S x \sin\theta 1 =$ 3781 x sin 23 = 1477.4Kvar

From this the reactive power to be compensated is

$Q_{new} = Q_2 - Q_1$ = 1477.4Kvar- 2719.8Kvar =-1242.4Kvar

As in (IJETT) - Volume-40 October 2016 giving 10% tolerance

$Q_3 = Q_{new}$x10%=1366.24Kvar

So, the D-STATCOM size to compensate the reactive power of 1242.4Kvar is 1366.24Kvar

Converters having a power level in the neighborhood of one mega volt ampere use mostly high voltage **(HV)** power semiconductors. The voltage ratings of available HV power semiconductor for these power levels are 2500V, 3300V. Switching frequency of 3.3Kv HV IGBT module should be kept around 1 KHz in order to have 1% converter active power loss. The rating of the D-STATCOM is almost fully reactive power with on the D-STATCOM IGBT switches 1% active power dissipation

From this concept the active power of the D-STATCOM is calculated as

P= Qx1%=13.6624Kw

Apparent power of the designed D-STATCOM is

$S^2 = Q^2 + P^2$, $S = \sqrt{Q^2 + P^2} = \sqrt{1366.24^2 + 13.6624^2}$=1366.2KVA

So, 1366.2Kva rating of D-STATCOM is used to compensate the reactive power or the power factor to be corrected from 0.75 to between 0.85 to 0.98 laggings.

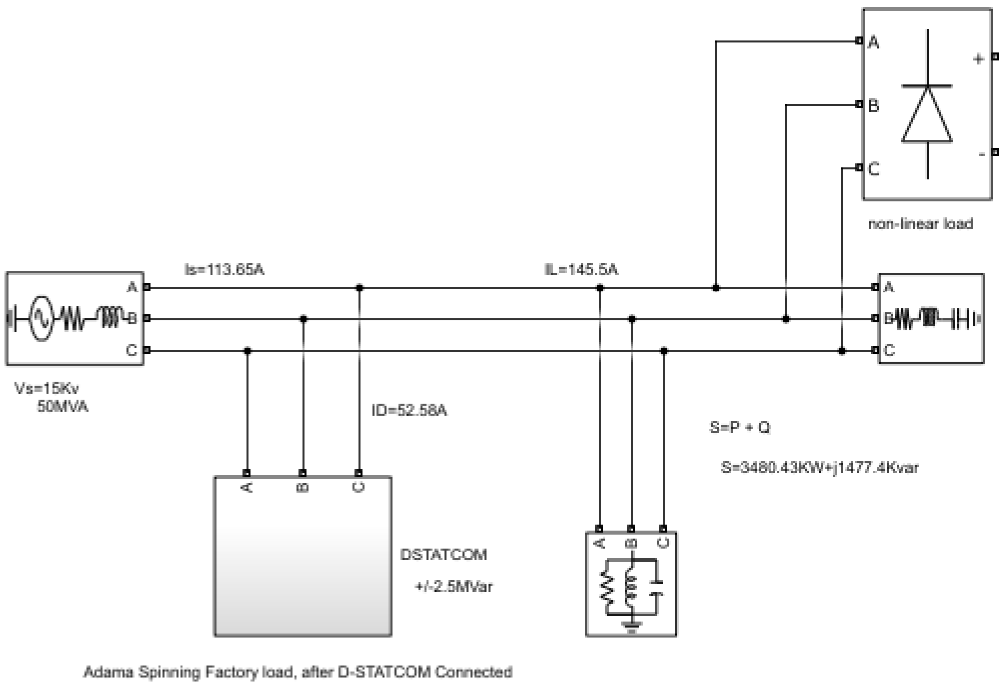


Figure.3. 3. Adama Spinning Factory load with D-STATCOM

Depending on the manufactured rating of VSC D-STATCOM, the rating of the IGBT can be calculated as follows:

The D-STACOM primary coupling Transformer voltage is 15KV and depend on the operating voltage rating of collector to emitter voltage of the IGBT switches, the secondary transformer voltage is slated to 3.3kv (M. M. Uddin, 2019 1st International Conference).

To calculate the coupling transformer primary current

S=1366.2Kva, Q=1366.24Kvar, P=13.6624KW,

$V_{Primary}$ =15Kv, $I_{Primary=?}$

So, $S=\sqrt{3}$ x Ip x V_L

$I_{Primary}=\frac{S}{\sqrt{3xVL}}$ $=\frac{1366.2KVA}{\sqrt{3x15KV}}$ =52.58A=Current Primary of D-STATCOM Coupling transformer

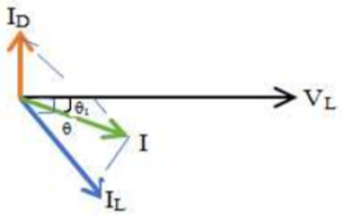


Figure.3. 4.Phasor Diagram Resultant Current after power factor correction

From the Phasor Diagram above I_L is lagging load current, which is a current operating at an angle of ADSF load which is: $I_L<46°$ =145.5<46°A

I_D is D-STATCOM current, which is at angle of 90 degree, leading current

That is $I_D<90°=52.58<90°=j52.58$

I is the phasorically calculated resultant current or the current which gets after power factor correction or after the rated D-STATCOM is connected in shunt to the load. So the resultant current I is calculated as:

$I=I_L<46°-I_D< 90°=(145.5\cos 46+j145.5\sin 46)$ -$(52.58x\cos 90+j52.58x\sin 90)$

$$= (101.1+j104.5)\ A-(0+j52.58)\ A=101.1+j51.92$$

So, I=101.1+j51.92=113.65<27.2

The new power factor of the Adama Spinning textile load is cos (27.2), which is 0.91 lagging, based on this θ_1 =27.2 result. From this perspective, the load power factor has increased from its former level of 0.75 to its present level of 0.91 lagging.

The resultant load current on the primary 15KV transformer is decreased from 145.5<46° to 113.65<27.2° after the power factor improves.

This study indicates that when the power factor increases:

- Power loss decreases (I^2R)
- Life time of the equipment increases
- The size of power cables decrease
- Reducing energy bill of charges

The new secondary load current of the factory is calculated as

$\frac{Vp}{Vs}=\frac{Is}{Ip}$, $\frac{15Kv}{400v}=\frac{Is}{113.65}$, I_s=4261.875A, which is reduced from 5456A<46° to 4261.875A<27.2, this is due to the improvement of the load power factor from 0.75 lagging to 0.91 lagging

Depending on the transformer transformation ratio formula the secondary current of the D-STATCOM coupling transformer can be calculated as:

$\frac{Vp}{Vs}=\frac{Is}{Ip}$, $\frac{15Kv}{3.3Kv}=\frac{Is}{52.58}$, I_S=239A .The line current of the medium voltage IGBT is 239A, as is the secondary current of the coupling transformer. Since the calculated current on the IGBT manufacturer's data sheet is not available, either the next rating of medium voltage IGBT current of 800A is chosen for the VSC based DSTATCOM or the 5SNA0800N330100 3300V 800A Single IGBT is chosen for the designed VSC DSTATCOM.

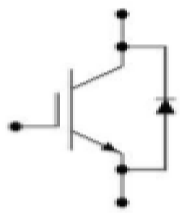


Figure.3. 5.Selected IGBT Symbol Configuration

Table.3. 3.Mathematical Analysis Result of Adama Spinning Textile Factory and D-STATCOM Size Designs

Name		Amount in number
Energy[KWH]		12249998.144
ADSF designed electrical Parameters	Apparent Power S [KVA]	3781
	Active Power P [KW]	3403
	Reactive Power Q [KVAR]	1647.89
	Power Factor cos θ []	≥0.9
Currently Operating Electrical Parameters of the factory	Apparent Power S [KVA]	3781
	Active Power P [KW]	2626.5
	Reactive Power Q [KVAR]	2719.8
	Power Factor cos θ[-]	0.75
	Primary Current [A]	145.5
	Secondary Current [A]	5456
D-STATCOM Electrical Parameters	Apparent Power S [KVA]	1366.2
	Active Power P [KW]	13.6624
	Reactive Power Q [KVAR]	1366.24
	Primary Current [A]	52.58
	Secondary Current [A]	239
	IGBT Collector current	239
After the D-STATCOM connected to the load, the electrical parameters of ADSF becomes	Apparent Power S [KVA]	3781
	Active Power P [KW]	3480.43
	Reactive Power Q [KVAR]	1477.4
	Power Factor cos θ [-]	0.91
	Primary Current [A]	113.65

	Secondary Current [A]	4261.875

3.3. Design of DC link Capacitor Voltage

In various applications, such as three-phase Pulse Width Modulation (PWM) inverters, solar and wind power inverters, industrial motor drives, and onboard chargers and inverters for automobiles, DC-Link capacitors play a crucial role in the power conversion process.

DC-Link capacitors can increase system energy density and eliminate the ripples that are physically difficult to deal with when switching occurs quickly.

As a result, the DC-link capacitor's function is to provide a more stable DC voltage while reducing fluctuations due to the inverter's irregularly high current demands. Different DC-Link capacitor technologies, such as aluminum electrolytic, film, and ceramic kinds, can be used in a design.

The maximum amount of capacitor ripple that the DC bus voltage will tolerate

3.4. Selection of the DC Bus Voltage

The distribution system's distribution system's minimum DC bus voltage should be larger than twice the distribution system's peak phase voltage. The DC bus voltage is determined as follows:

$V_{dc}=2\frac{\sqrt{2}}{\sqrt{3}}\frac{VLL}{m}$, where VLL is the AC line output voltage of the D-STATCOM and m is the modulation index, which is taken to be 1. VLL = 3300V, hence V_{dc} = 5388.9V ≈ 5389V and it is chosen to be 5400V.

So the DC link capacitor is selected with a 5400v rating to compensate the designed reactive power needed by the load.

3.5. Design of the Input Filter

The input filter is used to improve the voltage THD and current TDD at PCC as well as to remove converter switching harmonics. A single inductor or inductance capacitance LC filter combines to form the input filter.

When compared to an LC filter combination, using a single L filter requires higher inductance values in order to meet the same voltage THD and current TDD specifications.

Higher inductance values result in slower step responses to reactive power changes and higher voltage regulation on the DC link capacitor from full inductive mode to full capacitive mode.

The switching harmonics produced by power electronic capacitors are filtered out by the input filter, which is built with a reactive power rating of 10–20% of the converter. Other ways in which the filter capacitor is designed by power capacitors are as a tuned filter to remove the harmonics of the load or as a detuned filter to reduce the risk of sinking of load harmonic currents. Greater filter inductance is also used, which results in greater DC link voltages for a given amount of reactive power, affecting the rating of power semiconductors and DC link capacitor.

Therefore, the input filter capacitor was calculated as follows using 10–20% of the IGBT's reactive power.

$$Q_{IGBT}=2500KVAR$$

$$X_c = \frac{V^2}{0.15xQ} = \frac{3300x3300}{0.15x1366240} = 53 \text{ ohm}$$

$$C = \frac{1}{2\pi x f X_c} = \frac{1}{2x3.14x50x53} = \frac{1}{16650} = 60.1\mu F$$

Therefore, three 60.1μF single phase input filter capacitors are needed to filter out the harmonics, which is generated by the IGBT switches.

The reactive power capacity of the input filter is calculated as

$$Q_{filter} = \frac{V^2}{X_c} = \frac{(15KV)^2}{53} = 4245.3Kvar$$

So, 4245.3Kvar capacitive reactive value is used to filter out harmonics distortion produced from the D-STATCOM IGBTs at PCC.

3.6. Selecting a DC Bus Capacitor

When selecting the DC link capacitor, there are two key factors to take into account. In order to prevent high harmonics in the D-STATCOM AC voltage output, it must be large enough to supply the VSC with a suitably stable DC voltage. It must also be able to provide the system with the necessary reactive power for power factor compensation. A small capacitor will produce high harmonics in the D-STATCOM AC voltage output, but a larger capacitor will cut down the DC link controller's response time (Kebedew, “Design and Simulation of Power Factor Correction Using D-STATCOM”., . 2018)

The amount of instantaneous energy that the D-STATCOM has access to during transients determines the value of the DC capacitor (CDC) of the VSC of the D-STATCOM (Kumar, , September-2018)

When a system is operating temporarily, the D-STATCOM instantly supplies energy to it. D-STATCOM's response time is between 200 and 350 s (Calderon-Lopez, Scoltock, Wang, Laird, Yuan, & Forsyth, . 2019.). As the value of the capacitor (CDC) of VSC D-STATCOM depends on the instantaneous energy available to the D-STATCOM during transients, energy transfer from the capacitor to the system to provide reactive power is calculated if the DC voltage is reduced during load voltage regulation during transients. The following equation illustrates how the principle of energy conservation is used:

Energy transmission = $(Vdc2 - Vdc12) = 6$ (3.8)

Where 'a' is the overloading factor, V is the phase voltage, I is the phase current, and t is the time by which the DC bus voltage is to be recovered, VDC is the nominal DC voltage that is equal to the reference DC voltage and VDC1 is the minimum voltage level of the DC bus. By considering the minimum voltage level of the DC link bus (VDC1) =5380V, VDC = 5400 V, V= 3300V, I= 145.5A, a=1.2

The calculation of the recovery time for the dc voltage is calculated as:

Time= input resistance x input filter capacitor = 3.125 x 60.1 micro farad = 187.8 micro seconds.

As explained on the above:

V is ac Phase voltage.

I stand for phase current, and t for the amount of time required for dc voltage recovery. Taking into account the dc link's minimum voltage levels (V_{dcl}= 5380 V) and reference dc voltage (V_{dc}= 5400 V), the reference voltage Since the coupling transformer is in star-delta connection (V_{LL} =V_{ph}=3300v) and that the IGBT D-STATCOM collector current (I_D=239A) is the current in the delta connection,

V_{ph}=3300V.

Equation (3.8) becomes

$$\frac{1}{2}C_{DC} [(V_{dc}^2) - (V_{dc1}^2)] = 3xV (Ixa) xt \quad (3.9)$$

$$C_{dc}=\frac{6Vph(Iphxa)xt}{[(Vdc^2)-((Vdc1^2)]}=\frac{6x3300(145.5x1.2)x187.8}{5400^2-5380^2}=3011\mu F$$

The determined value of CDC is 3011 micro Farad, with a 15% tolerance chosen as 4000 micro Farad.

To compensate for the load's necessary 2.5MVAR reactive power, a D-STATCOM DC link capacitor is required, which requires four 1000 μF capacitors or eight 500 μF capacitors must be connected in parallel.

The formula used to determine the inductor value required to absorb a 2.5 MVAR reactive power of the D-STATCOM is: $X_L=\frac{V^2}{Q}=\frac{15000^2V}{2500000VAR}=90\Omega$ from which the inductor value is determined to be as:

X_L=2rrfL, inductor (L) $=\frac{X_L}{2\pi f}=\frac{90\Omega}{314.159}=286.5$ mil henry (mH),

Consequently, the value of series inductor connected to the coupling transformers is 286.5 milli henry

3.7. Design of AC inductors

The choice of the AC inductance (L_{Ac}) of VSC depends on the bus voltage (V_{dc}), switching frequency (f_s), and ripple currents (i_{cr} p-p). These variables play a major role in the calculation of AC inductance. The following is the formula for calculating AC inductance:

$$L_{AC}=\frac{\sqrt{3}\ mV_{dc}}{12xaxf_sxi_{ripple}}= \qquad (3.10)$$

Where a is the overloading factor and m is the modulation index.

Peak current (I_{DP}) = $\sqrt{2}$ x I_D = $\sqrt{2}$ x52.58A = 74.36A= I_{DP}

I_{ripple} = I_{DP} x 20% = 74.36A x 0.2=14.87A

Considering ripple current as, $I_{cr,\ pp}$=15%,

15% of I_{ripple}=14.87Ax0.15=2.23A

Switching frequency (fs) =10Hz,

Modulation index, m=1,

V_{dc}=5400V,

Overloading factor (a) =1.2

The value of L_{AC} is calculated as:

$$L_{AC}=\frac{\sqrt{3}\ \ mV_{dc}}{12xaxf_sxi_{ripple}}=\frac{\sqrt{3}\ \ x1x5400}{12x1.2x10x1000x2.23}=29.13mH$$

From this, $L_{fAC} = 2\pi fL = 2\pi x50x0.02913 = 9.2\Omega$

So, the resistance of the Coupling transformer is calculated as:

$$R_{coupling}=\frac{transformer\ rating\ x\ 2\ x\ pi\ x\ f}{40}=\frac{50x10^{-6}x2x\pi x50}{40}=0.392m\Omega$$

Table.3. 4.Compensation of Reactive Power to limits D-STATCOM for Adama Spinning Textile Factory

<table>
<tr><td rowspan="2">D-STATCOM Exchange of reactive Power[KVAR]</td><td rowspan="2">Input filter[KVAR]</td><td colspan="3">Coupling Transformer</td></tr>
<tr><td>Rated Power[MVA]</td><td>Primary Voltage[KV]</td><td>Secondary Voltage[KV]</td></tr>
<tr><td>±1366.24</td><td>4245.3</td><td rowspan="2">3</td><td rowspan="2">15</td><td rowspan="2">3.3</td></tr>
<tr><td>0</td><td>4245.3</td></tr>
<tr><td colspan="4">D-STATCOM Voltage rating[KV]</td><td>≥3.3</td></tr>
<tr><td colspan="4">D-STATCOM Current rating[A]</td><td>≥800</td></tr>
<tr><td colspan="4">D-STATCOM Switching frequency[KHz]</td><td>≥10</td></tr>
<tr><td colspan="5">D-STATCOM Components and their ratings</td></tr>
<tr><td>1</td><td colspan="3">Series inductor and Coupling transformer total AC Inductor[mH]</td><td>315.63</td></tr>
<tr><td>2</td><td colspan="3">DC link Capacitor[mF]</td><td>60.1</td></tr>
<tr><td>3</td><td colspan="3">DC link Capacitor Voltage[V_{dc}]</td><td>5400</td></tr>
<tr><td>4</td><td colspan="3">Input Filter reactive power[KVAR]</td><td>4245.3</td></tr>
<tr><td>5</td><td colspan="3">Input filter[μF]</td><td>60.1</td></tr>
<tr><td>6</td><td colspan="3">Coupling transformer resistance[mΩ]</td><td>0.392</td></tr>
</table>

3.8. Modeling of D-STATCOM

The fundamental circuit diagram and control of the D-STATCOM system are shown in Figure 3.6. It consists of a three phase voltage source converter (VSC), interfacing inductors, DC link capacitor, and control systems. In this Figure each VSC D-STATCOM IGBT switches represents a power semiconductor device and anti-parallel diode combination. The VSC D-STATCOM is connected to the network through the coupling transformer and interfacing inductors which are used to filter high-frequency components of compensating currents. The transformers and the interfacing inductors' Leakage inductance are represented by the inductance Lr in this figure.

A resistance Rr stands in for the copper loss of the connecting transformer and the loss of the interface inductor. In this thesis, the D-STATCOM is used for power factor correction by injecting the reactive power to the Adama Spinning Textile Factory load. As a result, the D-STATCOM's control systems are divided into three categories: current control, DC voltage control, and AC voltage control.

The main goal of the control is to quickly adjust the D-STATCOM currents to the reference values produced by the voltage controllers. A secondary control goal is to maintain the DC voltage at or near a target level, which is around 5400 volts in order to maintain a consistent value for the textile load bus voltage.

The D-STATCOM output AC voltage is shown in Figure 3.6 as VT, abc. The converter produces this voltage, which has a waveform that is thought to be quasi-sinusoidal.

Therefore, the voltage equation for an AC system can be expressed as

$$L_f = \frac{di_{f,abc}}{dt} = -R_f I_{f,abc} - V_{t,abc} + V_{st,abc} \tag{3.11}$$

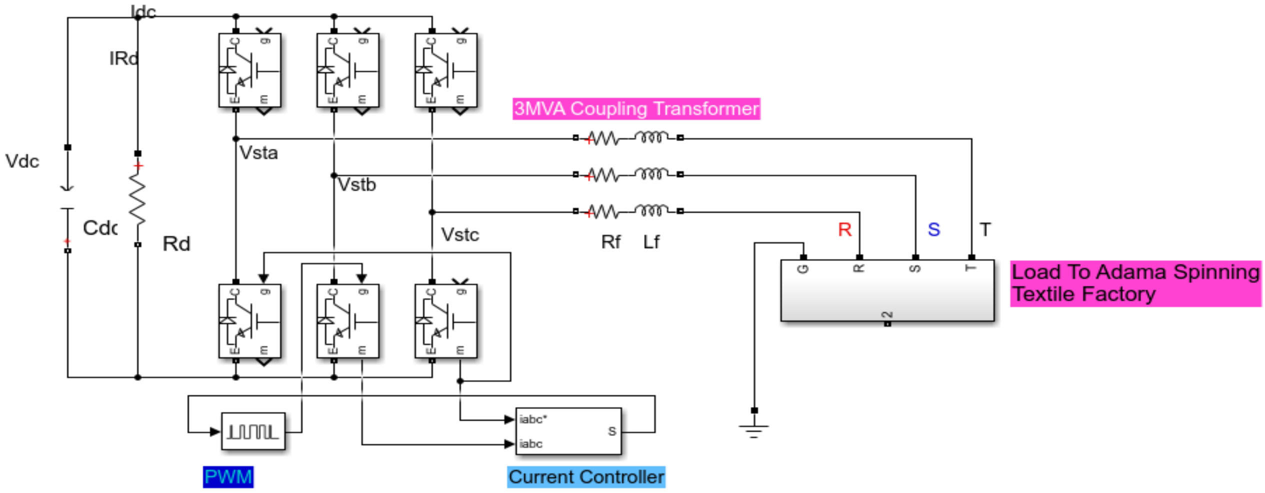


Figure.3.6:Schematic Diagram of D-STATCOM with 3-phase

Consider the DC system in Fig. The DC current i_{dc} consists of capacitor current i_c and resistor current i_{Rd} . The resistor R_d represents losses in the converter. The power flow into the converters equals to the instantaneous power of the DC capacitor which can be described as

$$P_{dc} = V_{dc} i_{dc} = V_{dc}(i_c + i_{Rd}) = P_{ac} = V_{st,abc}^{T} i_{f,abc} \quad (3.12)$$

Here, V_{dc} is the D-STATCOM DC voltage, i_f is the DSTATCOM output current, Vt is the load voltage, while the subscript "abc" implies vectors consisting of individual phase quantities. From Fig, the DC current can be expressed as

$$i_{dc} = C_{dc}\frac{dv_{dc}}{dt} + \frac{v_{dc}}{R_{dc}} \quad (3.13)$$

Where C_{dc} is the DC link capacitance. From the fig the relation between DC power and AC power can be expressed as

$$V_{dc}\left(C_{dc}\frac{dv_{dc}}{dt} + \frac{v_{dc}}{R_{dc}}\right) = -\left(V_{st,abc}^{T} i_{f,abc}\right) \quad (3.14)$$

After applying the three-phase to two-phase transformation and followed by the rotational transformation with the chosen dq reference frame.

The D-STATCOM dynamics in (1) and (4) can be written as:

$$\frac{di_{fd}}{dt} = -\frac{1}{T_f} i_{fd} + \omega i_{fq} - \frac{1}{L_f} V_{dt} + \frac{1}{L_f} K_p u_d v_{dc} \quad (3.15)$$

$$\frac{di_{fq}}{dt} = -\frac{1}{T_f} i_{fq} - \omega i_{fd} + \frac{1}{L_f} K_p u_q v_{dc} \quad (3.16)$$

$$\frac{dv_{dc}}{dt} = -\frac{V_{dc}}{T_{dc}} - \frac{3}{2C_{dc}} K_p u_d i_{fd} - \frac{3}{2C_{dc}} K_p u_q i_{fq} \quad (3.17)$$

Where T_f is the time constant of the transformer and interfacing inductor, $T_f = L_f / R_f$ while T_{dc} is the time constant of the DC system, $T_{dc} = C_{dc} R_{dc}$ .Here, $K_p u_d v_{dc}$ and $K_p u_q v_{dc}$ represent the D-STATCOM output AC voltage on d-axis and q-axis ($v_{st,d\ and}\ v_{st,q}$), respectively. ω is the synchronous angular speed of the system, $v_{dc,}$ i_{fd} and i_{fq} represent the state variables of the D-STATCOM, k_p is the constant value depending on the type of converter and transformer ratio (Wang, Shi, & Meng, " Study on Novel Bidirectional AC-DC Converter Circuit of the Wireless Charging for Portable Devices" , , Vol.8 October 2020.)

3.9. D-STATCOM's cost analysis

The EEU bills an average of 9,500 birr per month and 114,000 birr annually due to the operating low power factor of the Adama textile factory. The power factor of the Adama textile factory improved from 0.75 lagging to 0.92 lagging when the D-STATCOM was connected to the load bus, saving not only the monthly fee of 9500 Birr but also EEU saved 1242.4KVAR of reactive power.

As a result, using a VSC D-STATCOM to improve the power factor and reactive power compensation system is better for the dependability of the power system operation and minimization of loss and operating costs. The total cost of the D-STATCOM to improve the power factor from 0.75 to 0.92 is approximately eight hundred fifty six thousand eight hundred (856,800) birr. This birr is recovered by the factory within less than 7.6 years of previously charged power factor bills.

Therefore the proposed CPD's cost effectiveness is assessed by the cost analysis utilizing common financial metrics like the payback period. According to (El-Gammal et al., 2010), the payback period is the amount of time it takes a specialized power equipment to recoup its initial investment. Utilizing mitigating tools with a quick payback period is essential.

$$\text{Payback Period} = \frac{Net\ Investment}{Net\ Annual\ Return}$$

The initial cost, which includes both the installation fee and the cost of the mitigating device, is referred to as the net investment. To get the net yearly return, the annual benefit is reduced from the annual expenses (operating + maintenance).

Table.3. 5.cost analysis of D-STATCOM Component

D-STATCOM component specification and their price				
Name	Specification	Price per piece	No. of piece needed	Total cost
Coupling transformer (for 2.5MVAR D-STATCOM)	15kv/3.3kv, 3MVA, oil immersed outdoor installation	600,000 birr	1	1* 600,000 =600,000 birr
IGBT switches	800A/3300V indoor installation	1350-2700 birr	4	4*2700=10,800birr
Filter Capacitor	4.2453 MVAR Indoor installation	3000 birr	2	2*3000=6000 birr
DC-link capacitor	2.5MVAR Indoor installation	180,000 birr	1	1*180,000=180,000 birr
D-STATCOM controller	Indoor installation	50,000 birr	1	1*50,000=50,000 birr
D-STATCOM cabinet	1.5m by 1m	10,000 birr	1	1*10,000=10,000 birr
Subtotal cost of D-STATCOM				856,800 birr

As a result, the overall price of mitigating device is 856,800birr.

Therefore, PBP = $\frac{856800}{114,000}$ =7.5year

CHAPTER FOUR

4. Result and Discussion

4.1. Distribution Network Model for Adama Spinning Factory

The Adama spinning factory is supplied by the Adama substation, and the 15KV line enters a powerhouse, as was mentioned in Chapter 1. The four step-down distribution transformers in this powerhouse step down the electricity to 400V. Power is distributed to diverse loads by the distribution board. The system's parameters and loads are calculated analytically, and MATLAB/SIMULINK is used to show the factor's whole distribution network. The electrical distribution network for the factory is shown in Figure 4.1 without the compensating device.

According to Adama Spinning textile factory's load reactive power requirements, a $\pm$2.5 MVAr VSC D-STATCOM is designed and tested. This VSC D-STATCOM power factor correction system works by injecting a maximum of -2.5 MVAR (capacitive reactive power) into the load when the load power factor falls below 0.85 lagging. The result is an increase in the load power factor of up to 0.98 while maintaining a constant bus voltage at the PCC per unit system. The load voltage rises above one per unit as the load power factor rises above 0.98, trailing results. The manufacturing load system becomes harmonic as a result.

In this instance, the load's inductive reactive power can be absorbed by the VSC D-STATCOM absorbers up to a maximum of +2.5Mvar. There is no need to absorb and inject reactive power into the load if the load bus voltage is constant at one per unit. This indicates that the D-STATCOM bus voltage and the load bus voltage at PCC are same. In this scenario, the D-STATCOM provides or absorbs no reactive power to the load. According to this theory, the load voltage and load power factor are directly related to reactive power. To provide power factor adjustment and compensate for reactive power, the designed system is simulated for use in the Adama Spinning.

Figure 4.1 in the MATLAB simulation and in the D-STATCOM with Adama Spinning load system's entire load flow circuit diagram.

4.2. MATLAB Simulation Diagram and Result without VSC DSTATCOM connected to the load

Due to the various inductive loads present in the factory, the factory suffers from power factor problems. For simulation purposes, these loads are modeled as three-phase rectifiers connected in parallel with linear loads. On the other side, due to numerous short circuits in the distribution, there is voltage sag on the networks. Different fault types, such as symmetrical and unsymmetrical faults, are simulated. The study claims that because this distribution has a number of Adjustable Speed Derives (ASDs) for regulating motor speed, current harmonics exist under it. Figure 4.2 shows the present simulation result without the application of any compensating methods.

As seen in figure 4.2, nonlinear loads demand current in brief, sharp pulses. These pulses cause harmonics, which can lead to power issues for both the distribution system's equipment and the loads linked to it. The loads require greater reactive power when there are harmonics in the network. The power factor is lowered as a result. The return of the distorted current to the source from the load has likewise interrupted the source current, as can be seen from the outcome.

In this Simulink, model of uncompensated System contains linear and nonlinear loads. The linear loads consist of series loads of resistance, Inductance and capacitance joined in parallel by delta connections. The model for the Adama Spinning load is shown in figure 4.1 below. On this simulation, the three-phase waveform of the operational load power factor, current, and load bus voltage at PCC are shown and briefly reviewed.

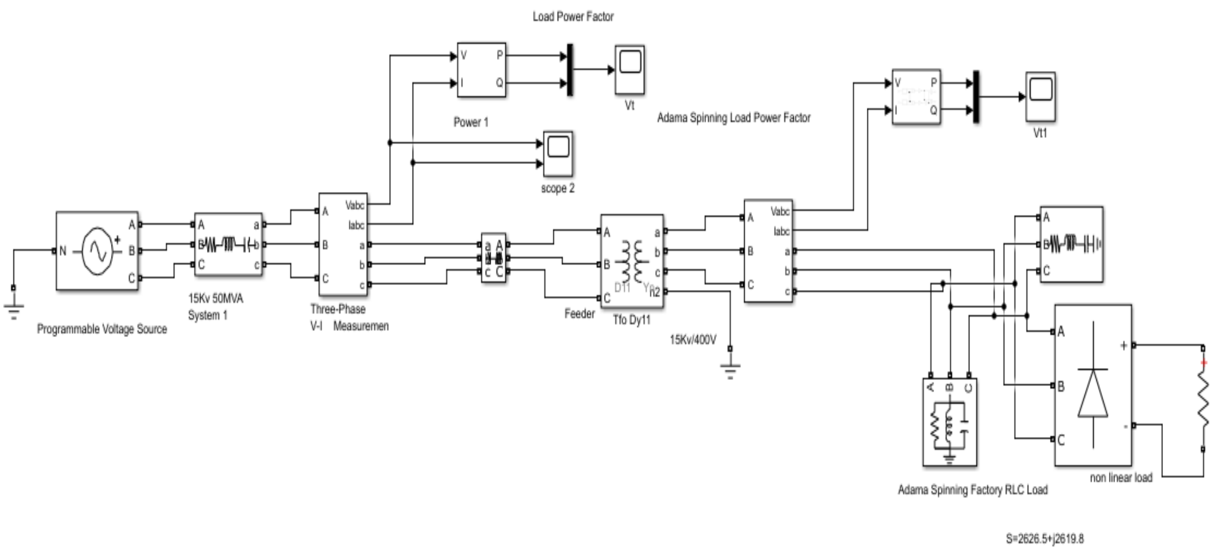


Figure.4.1.Matlab Simulation Diagram of Adama Spinning load without D-STATCOM connection

Three phase MATLAB simulation result of uncompensated voltage, current waveform

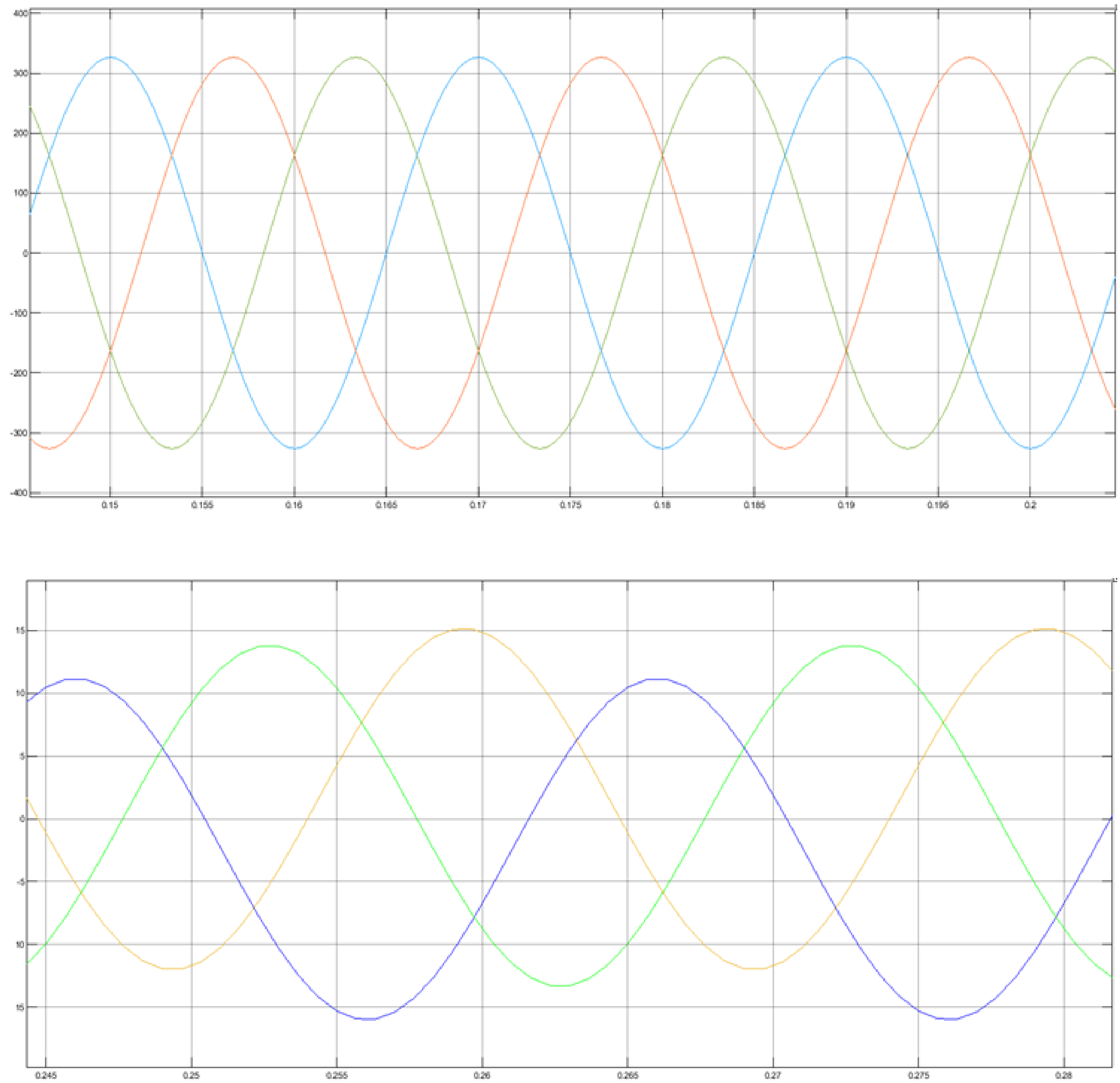


Figure.4. 2.MATLAB Simulation Results for Voltage and Current Versus Time Waveform without D-STATCOM Connected to Adama Spinning Load

The voltage and current waveforms from the MATlab simulation are shown in Figure 4.2. The three phase current waveform is out of balance, which shows that the factory has unbalanced three phase load connections. By connecting VSC D-STATCOM in parallel to the Adama Spinning load, this unbalanced three phase current is adjusted.

As seen in figure 4.2, nonlinear loads demand current in short, sharp pulses. These pulses cause harmonics, which can lead to power issues for both the distribution system's equipment and the loads linked to it. The loads require greater reactive power when there are harmonics in the network. The power factor is lowered as a result. The return of the distorted current to the source from the load has likewise interrupted the source current, as can be seen from the outcome.

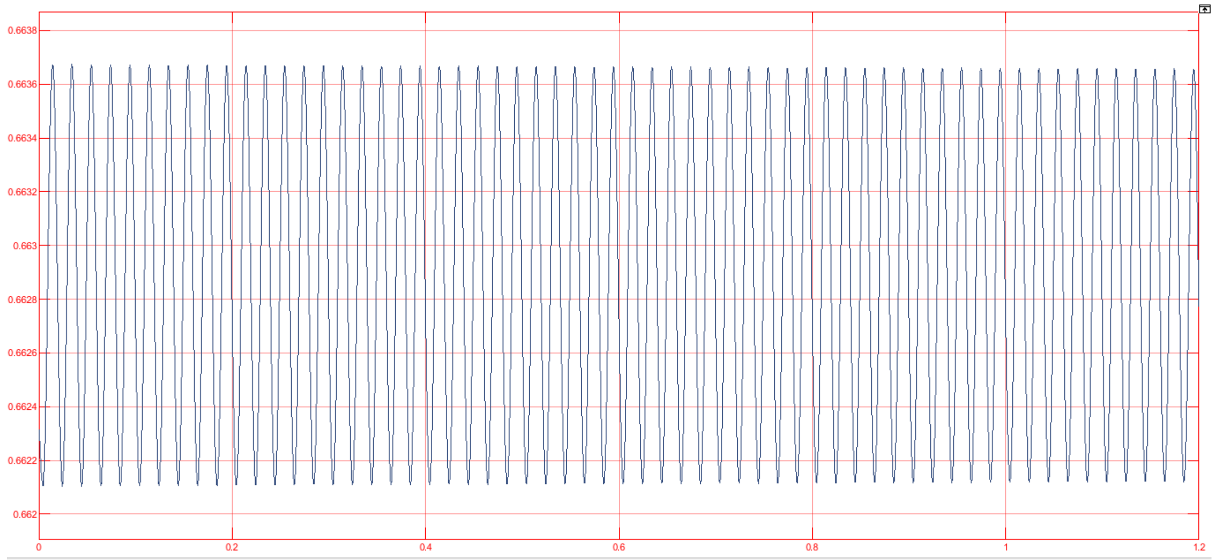


Figure.4. 3 The Results of a MATLAB simulation of the load power factor verses time before the D-STATCOM is connected to the load

According to the MATLAB simulation results shown in Figure 4.4, the output load power factor fluctuates from 0.66 to 0.67 to some extent when the ADSF load varies from 0.7 pu to 1 per unit or when the load varies from 70% load to peak load. The majority of textile machinery is induction-type; when these machines run under weakly loaded conditions, their magnetizing current rises, consuming more reactive power from the system and lowering average load power factor. These machines use less reactive power while they are operating close to capacity, which raises the factory's average load power factor

Unsymmetrical Faults

Faults that have unbalanced magnitude and unequal phase shifts are said to be asymmetrical. These faults come in three different varieties: double line-to-ground, double line-to-line, and line-to-ground. To evaluate the system's performance when these unsymmetrical errors are present, the factory is simulated, as seen from figure 4.4

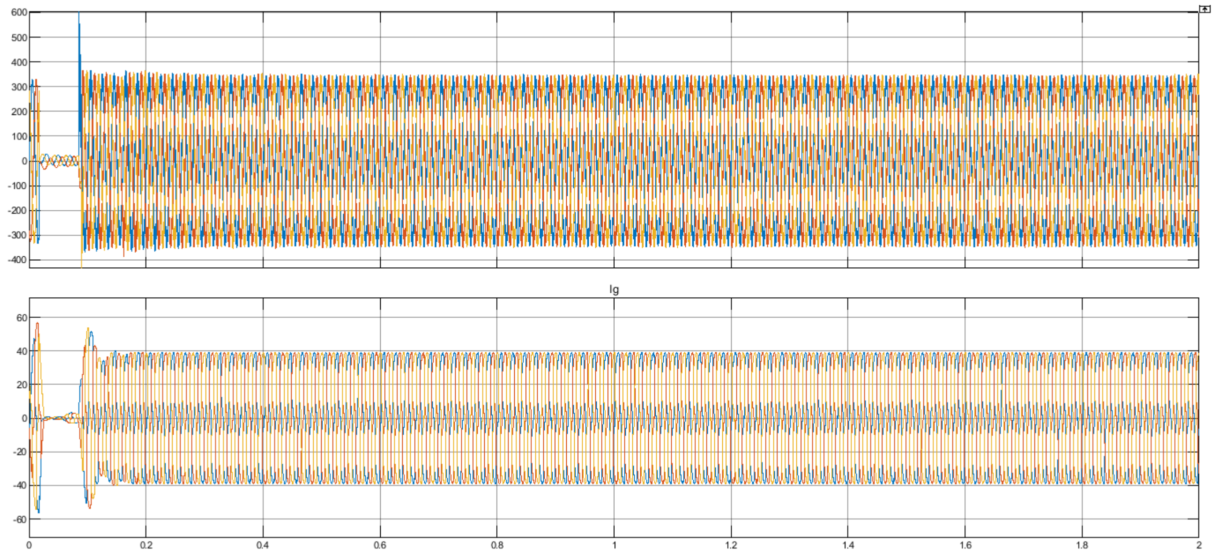


Figure.4. 4 Waveform of unsymmetrical voltage and current verses time without mitigating device

4.3. MATLAB Simulation Diagram and Results after VSC DSTATCOM connected to Adama Spinning load

Without compensating devices, current harmonics and voltage sag exist in the Adama spinning factory, which causes low power factor.

The load of the Adama Spinning is represented in this Simulink adjusted system model as seen in Figure 4.6. In this simulation, the three-phase waveforms of the running load power factor, bus voltage, and current are displayed on each scope and analyzed.

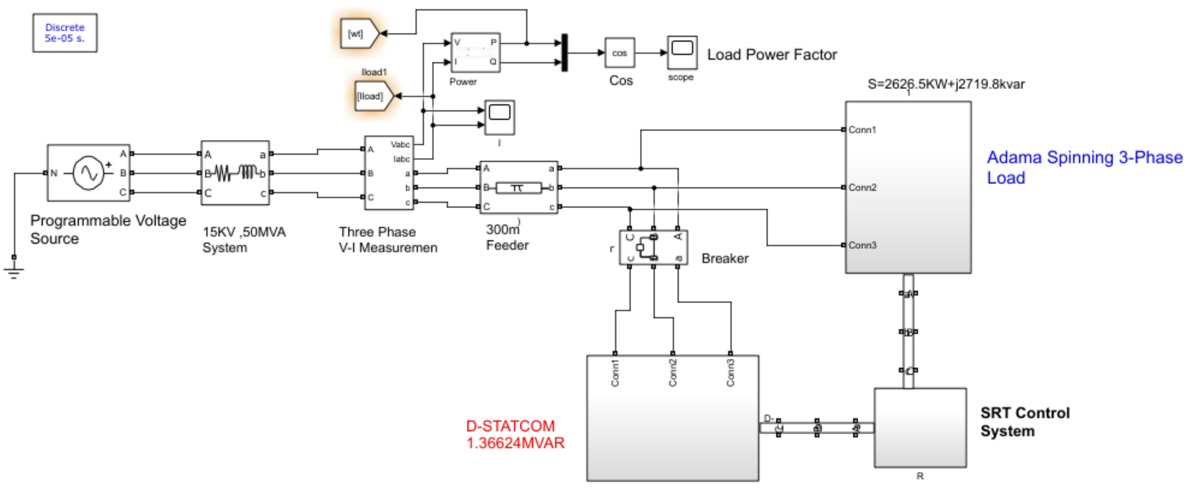


Figure.4. 5 shows the control circuit with Adama Spinning load in MATLAB Simulink and with D-STATCOM.

For this mitigation, synchronous reference frame theory is the control mechanism applied to generate gate pulses.

For DSTATCOM, the modeled control theory is displayed as in figure 4.7 bellow.

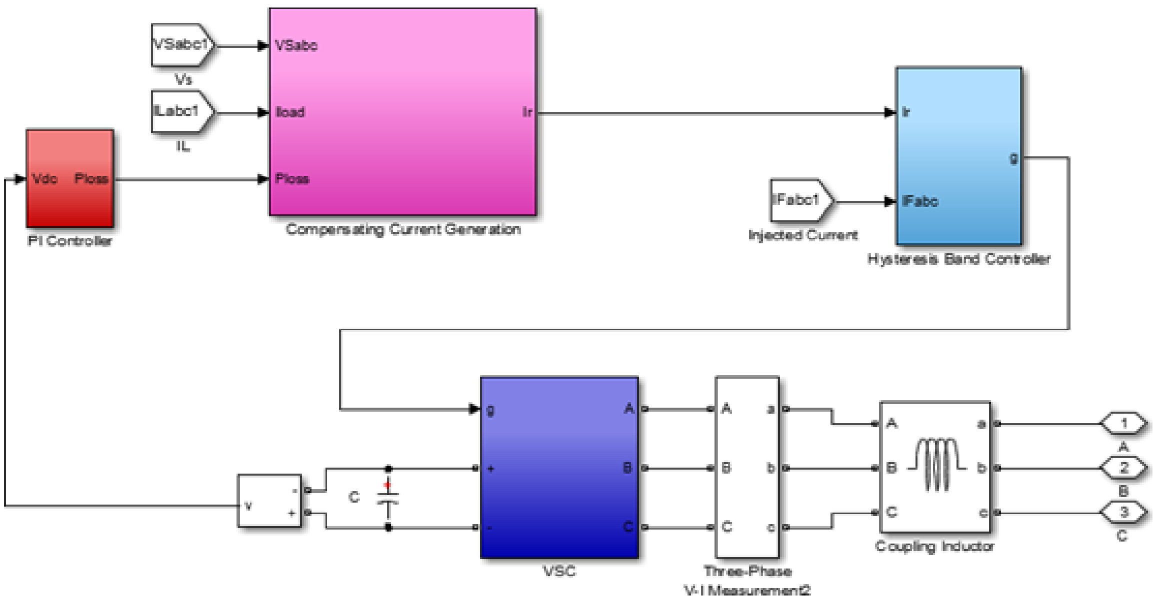


Figure.4. 6 Simulink Model of D-STATCOM

DSTATCOM is utilized on this distribution reduces unbalanced current waveform on by nonlinear loads. Figure 4.8 shows the current waveform after compensating.

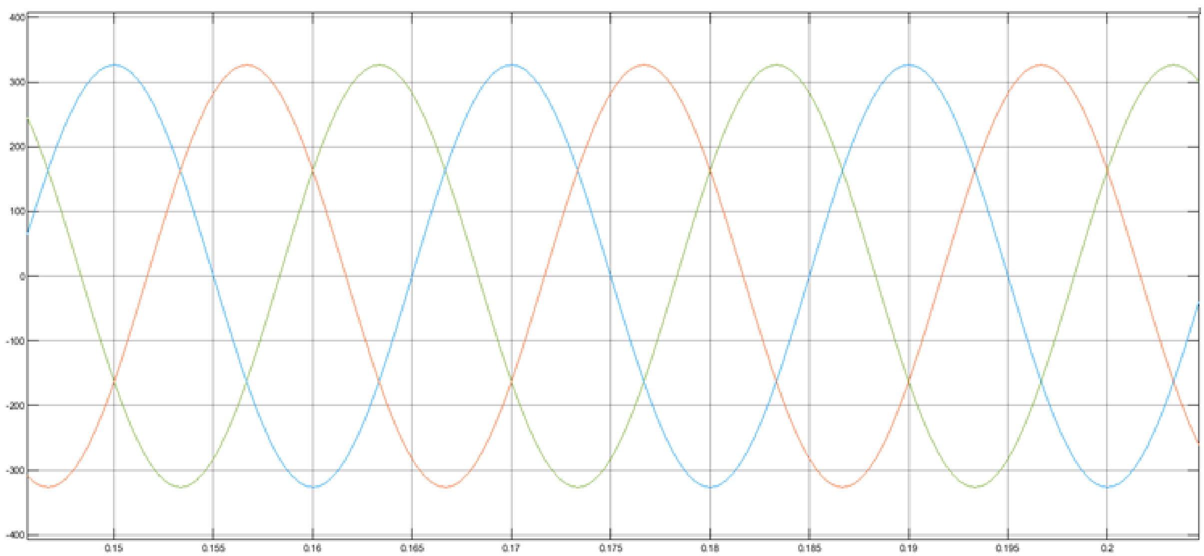
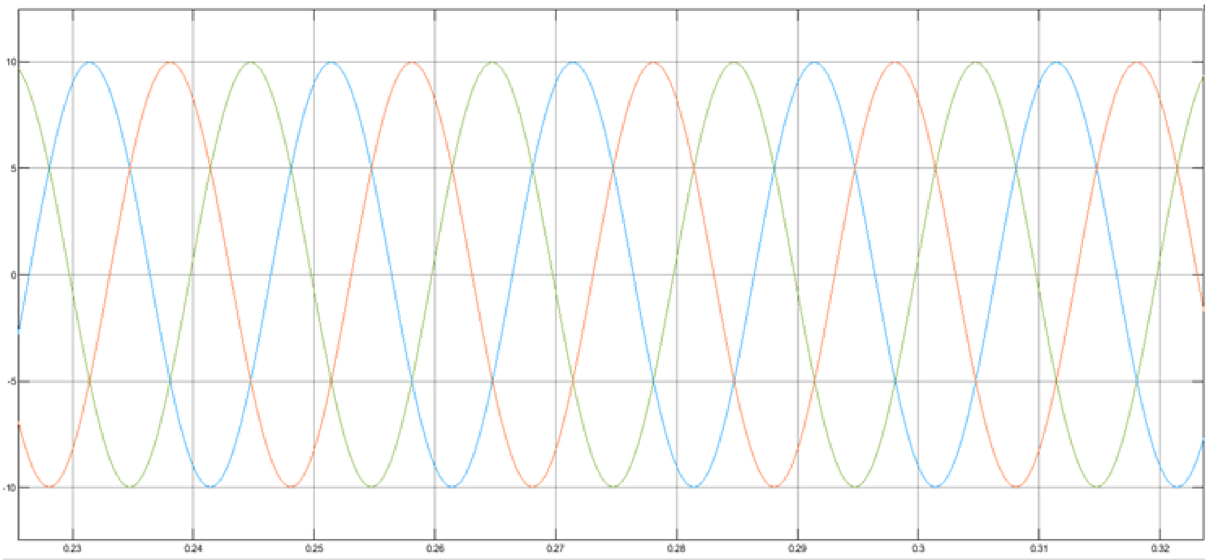


Figure.4. 7 shows the voltage waveform verses time after compensating



.Figure.4. 8 MATLAB Simulation Result of Current versus Time Waveform After Connecting the D-STATCOM to Adama Spinning Load

The unbalanced three-phase load current in Figure 4.2 is balanced by connecting the D-STATCOM in shunt to the Adama Spinning loads, and the load voltage is controlled and increased to one per unit value. This is seen in the three-phase voltage and current waveform Figure 4.3. A quick corrective action to manage the unbalanced current, compensating reactive power and power factor correcting system in big customer loads is provided by the D-STATCOM as a result. The voltage and current waveforms are based on a system per unit with a base power of 50MVA and a base phase-to-phase voltage of 15kv.

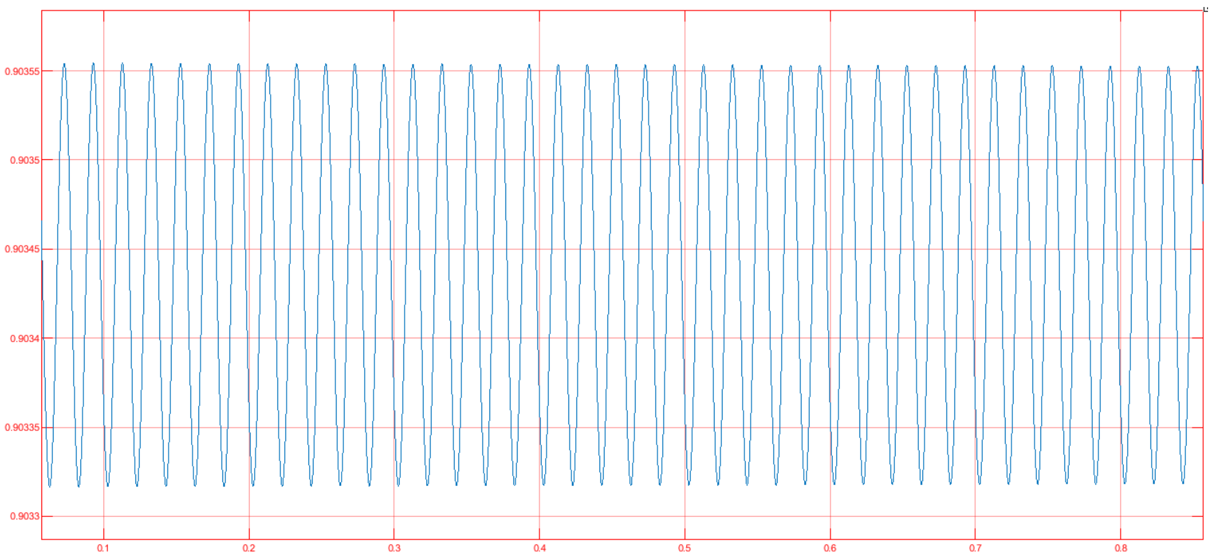


Figure 4.9 shows that power factor verses time after D-STATCOM Connected to the load of ADSF

as a result, the current operating load power factor of Adama Spinning textile is around 0.75 lagging. The manufacturing power factor is increased from 0.75 lagging to 0.92 lagging using fact controller VSC D-STATCOM. The factory's power losses and energy billing costs are eliminated by this improvement in the factory.

4.4. Results of D-STATCOM (IGBT) simulation in MATLAB with output voltage

IGBT switches' inherent ability to produce harmonics in their switching structure. This harmonic voltage is eliminated by the delta-connected low pass filter at the D-STATCOM's input, which then feeds a pure sine wave that is in phase with the source voltage to the load bus at PCC. The voltage at the PCC is fully sine wave form or harmonic free and in phase with the load voltage since this D-STATCOM IGBT output single phase voltage is about 1900v and with a three phase voltage of 3300 voltage ac.

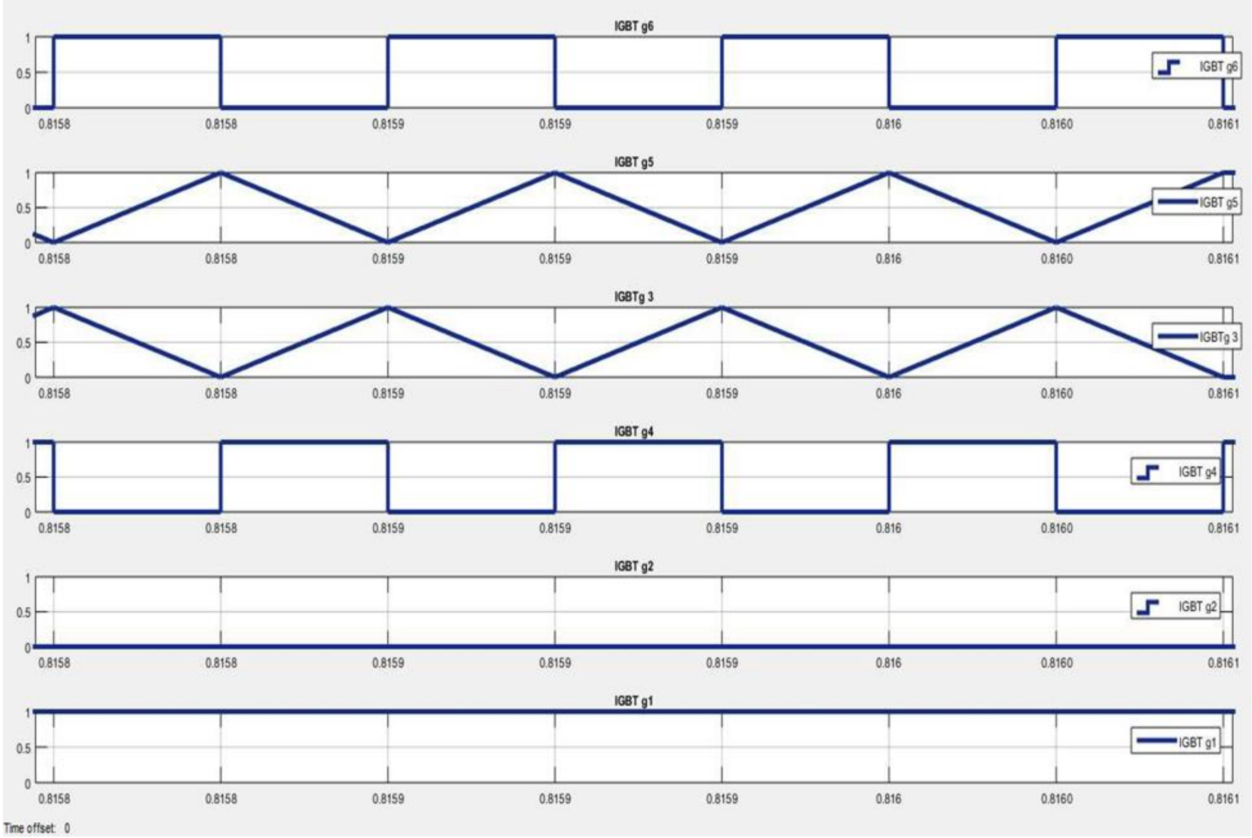


Figure.4.10. PWM Based SRF Switching D-STATCOM IGBT Pair of Converters Simulation Results in MATLAB

Results from simulations are used to address the application and operation of the control circuits on this PWM-based switching sequence of the D-STATCOM IGBT utilizing the synchronous reference theory. Figure 4.10 shows that when the IGBTs Switch ON - OFF state take place action are take place. This switching mechanism is used to manage the load's reactive current, which in turn manages the load power factor of the Adama Spinning textile load.

4.5. Unsymmetrical Faults

The distribution network is simulated for factory unsymmetrical faults such line to ground, line to line, and double line to ground when the D-STATCOM is attached to the network. The voltage waveforms obtained after compensation is shown below.

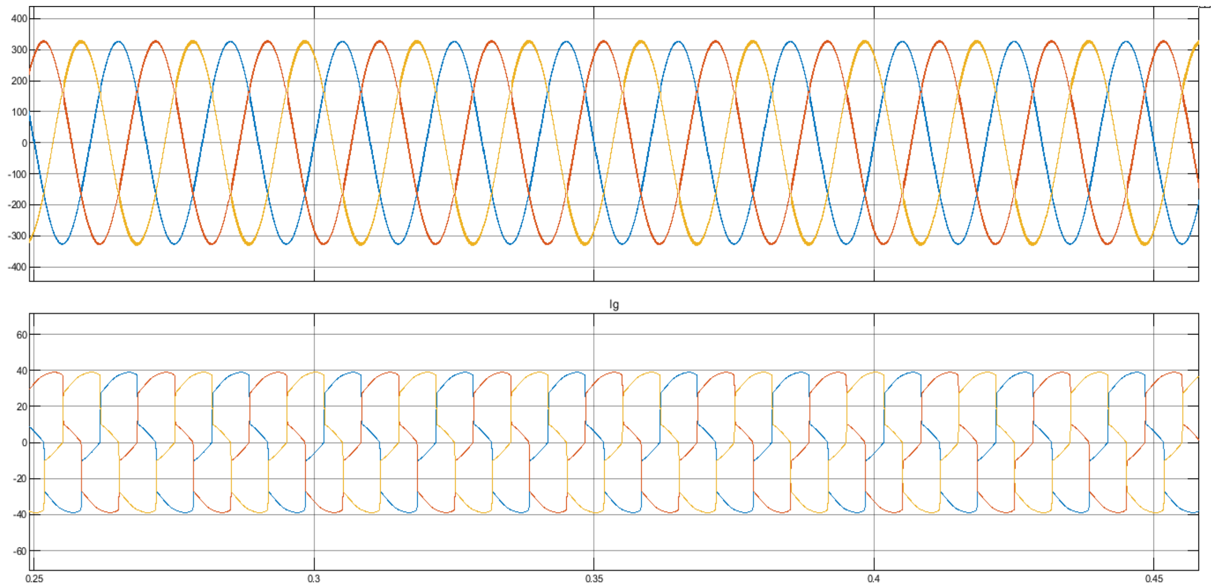


Figure.4. 11: Waveform unsymmetrical voltage *and current* verses time *fault with-DSTATCOM*

Figure 4.6 illustrates the relationship between the Adama Spinning load, D-STATCOM, and its synchronously rotating frame theory (SRF). By rapidly switching VSC D-STATCOM IGBT switches, the SRF circuit maintains constant load bus voltage at PCC, load current, load reactive power and load power factor. By turning on and off the VSC D -STATCOM IGBT switches, the SRF control circuit is intended to regulate the Adama Spinning load's reactive current and load power factor. Using PWM approaches, the SRF control system manages the VSC D-STATCOM IGBT switching system. This indicates that the load bus voltage and load current are coupled to the SRF control system's control circuits, and that when the load current increases, the angle (-1) between the load current and the load increases. The D-STATCOM injects capacitive reactive power to the load to increase load power factor up to 0.98 lagging when the load current decreases and the angle (θ) between load current and load voltage decreases below 18°. When the load current decreases and the angle (θ) between load current and load voltage decreases below 18°, the load power factor increases above 0.98 lagging, in which case the SRF control circuit switches ON the D-STATCOM IGBT. The VSC D-STATCOM SRF control circuit typically maintains load power factor.

4.6. Discussions

D-STATCOM, which operates at low voltage and injects reactive power into the line to make up for it, does the same. D-STATCOM functions as a VSC that can be employed on the system's load side to enhance the voltage profile and lower power losses. By injecting the necessary quantity of reactive power from D-STATCOM, the amount of reactive power delivered from the source can be made equal to the desired value in the reactive power control mode.

The simulation's outcome demonstrates the D-STATCOM's function in supplying balanced sinusoidal source currents even when the load is carrying unbalanced and distorted currents. The source does not need to supply any reactive power, and all reactive power is supplied by D-STATCOM when STATCOM is utilized as full reactive power compensation. After correction, this system also continues to sustain the source voltage and current's phase alignment. As a result, the utility supply's power factor always closes to unit. As a result, D-STATCOM offers compensation in the distribution line, which improves the distribution network's overall performance.

Using MATLAB/SIMULINK, the distribution network of the Adama Spinning Factory is studied and simulated. A balanced three-phase pure sinusoidal voltage supply with linear and non-linear loads is used to simulate the factory's distribution system. When the real power factor of the loads is taken into consideration, the linear loads are defined by the active and reactive power of a series RL load. To model nonlinear loads, a three-phase rectifier with RL loads is employed. Finally, a simulation of the modeled distribution network is performed with and without the integration of DSTATCOM.

When the DSTATCOM is integrated into the system, the waveform of the source current transforms into a pure sinusoidal wave. The suggested DSTATCOM can therefore correct the power factor that bellows 0.75 already exists in the system.

The current harmonics present in the system cause a reduction in power factor. However, the power factor is enhanced if DSTATCOM is incorporated into system. This is shown in Table below

CMDB	Pf without DSTATCOM	Pf with DSTATCOM
CMDB-1	No record	No record
CMDB-2	0.79	0.95
CMDB-3	0.83	0.95
CMDB-4	0.84	0.96
Power Factor Charge	9,500birr	---

4.7. Improved load power factor

Adama Spinning load power factor was 0.75 lagging prior to the D-STATCOM connection; however, once the planned VSC D-STATCOM was connected in shunt to the load, the load power factor improved to within the range of between 0.85 and 0.98 lagging. This increase in power factor shows that the plant uses less reactive power and experiences fewer energy losses. The factory benefits from this acceptable load power factor in the following ways:

• Reduce the cost of electricity bills.

• Minimize equipment heating, which is accomplished by lowering line current.

• The factory's equipment lasts a long time because reactive power usage is being reduced.

• EEU reduces electrical consumption

• At any moment, the factory obtains a supply of power that is suitable and sustainable for its use.

5. CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1. Conclusion

On this thesis work, a D-STATCOM employed for compensation of reactive power and power factor improvement at Adama Spinning Textile Factory using synchronous reference frame theory based control algorithm on three phase load system. Various types of power factor correction methods have been studied and investigated from those methods D-STATCOM power factor correction method , is selected and thereby the factory low power factor has been improved significantly from 0.75 lagging within the range of between 0.85 and 0.98 lagging. The various function of D-SATCOM in linear and nonlinear distribution system such as harmonic elimination, source current compensation and load balancing have been demonstrated in power fact or correction observed as per expected. The dc bus voltage of the D-SATCOM has been regulated to the reference dc bus voltage under all varying loads. The specification of the D-STATCOM components that used for this thesis work is designed depend on the reactive power requirement of the factory. Depend on the designs and MATLAB simulation results of D-STATCOM the Adama Spinning Textile low power factor is improved from the 0.75 lagging to 0.98 lagging.

Due to this, the factor solves its power penalty bill of charges of 60,000 per month. In addition to this Ethiopian Electrical Utility (EEU) saves 1242.4kvar reactive power which was consumed by Adama Spinning Textile Factory every second.

Based on MATLAB Simulation test result, it’s conclude that the developed D-STATCOM and its control algorithm has been found suitable for power factor correction in a dynamic loads

5.1.2. Recommendation

Sustainable development is achieved through the efficient use of electrical power, which is achieved through lowering power consumption and altering the production process. The effective use of electrical power should be strongly stressed for any nation that is moving quickly toward industrialization since it supports steady economic progress. For the Adama Spinning textile industry, the D-STATCOM method of power factor correction was designed and simulated in this thesis. According to the results of the power factor correction simulation, the factory's low power factor has improved, which results in more electrical energy savings. The factory with the following points is advised from the standpoint of this thesis work:

The majority of the factory's machines are merely loaded, and since lightly loaded machines especially induction type machines consume more reactive power from the system, those machines should run at 0.72 to 0.9% of their load to reduce reactive power consumption. To fix each induction machine's unloaded operation, the load should be redesigned. To reduce the loss, the induction machines should operate at approximately full load.

5.1.3 Suggestions for Future Work

The findings of this thesis point to a number of topics for further investigation. Some of these problems include: This thesis summarizes research done on the Adama Spinning textile facility specifically for power factor adjustment. There is room for more research if a thorough power quality issue is undertaken. Transformer sample samples with imbalanced current show that the system's load is unbalanced. This may require more research.

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APPENDIXES

Appendixes A: power factor of Adama Spinning Textile Factory recorded on different days

Table A: power factor of Adama Spinning Textile Factory recorded on different days.

Date	CMDB-1	CMDB-2	CMDB-3	CMDB-4
4-10-2022	No record	0.74	0.73	0.74
5-10-2022	No record	0.73	0.72	0.75
8-10-2022	No record	0.71	0.73	0.74
9-10-2022	No record	0.74	0.74	0.75
10-10-2022	No record	0.73	0.75	0.75
12-10-2022	No record	0.75	0.75	0.74
14-10-2022	No record	0.75	0.74	0.73
20-10-2022	No record	0.75	0.73	0.72
25-10-2022	No record	0.74	0.73	0.75
27-10-2022	No record	0.74	0.75	0.75
29-10-2022	No record	0.72	0.7	0.75
30-10-2022	No record	0.75	0.75	0.73
Average	No record	0.74	0.74	0.8

Appendixes B: Energy Consumption recorded of Weaving Part of Machineries

Table B-1 Energy Consumption recorded of Weaving Part of Machineries

No	Machine name	Quantity	Power Consumption (KWh)	
			Designed capacity	Total
1	Loom shade	100	1.8	180
2	Main Compressor For loom Shade	2	220	440
3	Fan Motors of Main Compressor	4	3	12
4	Dryer	2	16.6	33.2
5	Exhaust Fan of dryers	16	0.2	3.2
6	Exhaust Fan Of loom Shade	18	3	27
7	Warping Machine (main motor)	2	15	30
8	Warping Compressor	1	11	11
9	Submersible pump for AC	2	1.5	3

10	Rewinding machine	1	1.5	1.5
11	LED lamp	101	0.016	1.616
12	Fluorescent lamp	164	0.036	5.904
13	Take-up of motor	100	0.75	75
14	Servo motor	100	0.75	75
15	Pump motor of AC	1	1.5	1.5
16	Pump motor of AC	1	1.1	1.1
17	Gear motor of warping	2	1.1	2.2
Total				21677.28KWh

Table B-2 Energy Consumption recorded Finishing Part of Machineries

No	Machine Name	Quantity	Load (kw)
1	Drier	2	32
2	Bleaching	1	110
3	Dehydration	1	55
4	Winding	2	15.75
5	Boiler	2	60
6	Fuel depo(furnaces) tanker	1	9.7
7	Bandage Rolling	1	3.5
8	Gauge Swap pre folding	1	1.5
9	Gauze Sponge folding with unfolding	2	2.2
10	Gauze Rolling & folding	3	4.5

11	Turning	1	5.5
12	Carne	1	11.5
13	Mixer	1	0.55
14	Compressor	2	33
15	Bandage Cutter	1	2.6
16	Water Softening Unit	1	189.05
17	Fabric Roll Slitting	1	20.3
18	Salvage Sucker	1	7.5
19	Gauze Swabs Packing	1	1.1
Total			13560KWh

Appendixes C: Adama Spinning Factory monthly energy consumption report

Table C -1 Energy Consumption recorded of spinning machinery on 9/7/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	3883186.0	43301.0	5487884.0	64789.0	0.66834	66,293.8
2	Draw Frame	515471.0	5709.0	598404.0	6762.0	0.84428	8,740.5
3	Combing	767559.0	11971.0	2885369.0	44961.0	0.26625	18,327.6
4	Open End	8332503.0	116901.0	10657296.0	148261.0	0.78848	178,975.4
5	Roving Frame	812616.0	7557.0	822511.0	7652.0	0.98758	11,569.8
6	Ring Frame	10118335.0	111489.0	10743755.0	120183.0	0.92766	170,689.7
7	Winding	1611288.0	20874.0	1771598.0	23254.0	0.89765	31,958.1
8	Twisting	365557.0	8382.0	543000.0	15154.0	0.55312	12,832.8
9	Steaming	421322.0	3173.0	437459.0	3236.0	0.98053	4,857.9
10	AC Station 1+2	9321010.0	116952.0	11279738.0	144970.0	0.80673	179,053.5

11	AC Station 3+4	4437869.0	55913.0	5482036.0	70435.0	0.79382	85,602.8
12	Compressor	3200781.0	-1193.0	4268611.0	21173.0	-0.05635	(1,826.5)
13	Pump Station	187827.0	1041.0	201779.0	1089.0	0.95592	1,593.8
14	Normal Lighting	1447205.0	15121.0	1449717.0	15121.0	1.00000	23,150.3
15	Emergency Lighting	2573455.0	20518.0	2649297.0	21195.0	0.96806	31,413.1
16	Dalol Hotel	1559581.0	18015.0	1574259.0	18324.0	0.98314	27,581.0
Total:			**555724.0**	**726559.0**	**850,813.4**		

Table C -2 Energy Consumption recorded of spinning machinery on 9/8/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	3934056.0	50870.0	5563149.0	75265.0	0.67588	77,882.0
2	Draw Frame	521895.0	6424.0	606096.0	7692.0	0.83515	9,835.1
3	Combing	781157.0	13598.0	2936026.0	50657.0	0.26843	20,818.5
4	Open End	8467606.0	135103.0	10829096.0	171800.0	0.78640	206,842.7
5	Roving Frame	822945.0	10329.0	833054.0	10543.0	0.97970	15,813.7
6	Ring Frame	10268905.0	150570.0	10905021.0	161266.0	0.93367	230,522.7
7	Winding	1635718.0	24430.0	1798526.0	26928.0	0.90723	37,402.3
8	Twisting	371306.0	5749.0	553305.0	10305.0	0.55788	8,801.7
9	Steaming	427140.0	5818.0	443375.0	5916.0	0.98343	8,907.4
10	AC Station 1+2	9448750.0	127740.0	11438485.0	158747.0	0.80468	195,569.9
11	AC Station 3+4	4499362.0	61493.0	5559098.0	77062.0	0.79797	94,145.8
12	Compressor	3199835.0	-946.0	4296442.0	27831.0	-0.03399	(1,448.3)
13	Pump Station	189436.0	1609.0	203427.0	1648.0	0.97633	2,463.4
14	Normal Lighting	1463502.0	16297.0	1466013.0	16296.0	1.00006	24,950.7
15	Emergency Lighting	2596226.0	22771.0	2672617.0	23320.0	0.97646	34,862.4
16	Dalol Hotel	1579928.0	20347.0	1594923.0	20664.0	0.98466	31,151.3
Total:			652202.0	845940.0	998,521.3	0	

Table C -3 Energy Consumption recorded of spinning machinery on 14/9/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	3987918.0	53862.0	5642437.0	79288.0	0.67932	82,462.7
2	Draw Frame	528945.0	7050.0	614703.0	8607.0	0.81910	10,793.6
3	Combing	925258.0	144101.0	2978464.0	42438.0	3.39557	220,618.6
4	Open End	8612268.0	144662.0	11011189.0	182093.0	0.79444	221,477.5
5	Roving Frame	832949.0	10004.0	843297.0	10243.0	0.97667	15,316.1
6	Ring Frame	10426567.0	157662.0	11073170.0	168149.0	0.93763	241,380.5
7	Winding	1658311.0	22593.0	1823338.0	24812.0	0.91057	34,589.9
8	Twisting	372653.0	1347.0	5555699.0	5002394.0	0.00027	2,062.3
9	Steaming	433924.0	6784.0	450266.0	6891.0	0.98447	10,386.3
10	AC Station 1+2	9580453.0	131703.0	11599603.0	161118.0	0.81743	201,637.3
11	AC Station 3+4	4559970.0	60608.0	5634571.0	75473.0	0.80304	92,790.8
12	Compressor	3198889.0	-946.0	4336933.0	40491.0	-0.02336	(1,448.3)
13	Pump Station	191169.0	1733.0	205201.0	1774.0	0.97689	2,653.2
14	Normal Lighting	1477571.0	14069.0	1480088.0	14075.0	0.99957	21,539.6
15	Emergency Lighting	2621286.0	25060.0	2698434.0	25817.0	0.97068	38,366.9
16	Dalol Hotel	1600932.0	21004.0	1616195.0	21272.0	0.98740	32,157.1
Total:			801296.0	5864935.0	1,226,784.2		

Table C -4 Energy Consumption recorded of spinning machinery on 1/10/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	4027157.0	39239.0	5700858.0	58421.0	0.67166	60,074.9
2	Draw Frame	532881.0	3936.0	619363.0	4660.0	0.84464	6,026.0
3	Combing	802602.0	-122656.0	2654550.0	-323914.0	0.37867	(187,786.3)
4	Open End	8718749.0	106481.0	11146302.0	135113.0	0.78809	163,022.4
5	Roving Frame	841408.0	8459.0	851951.0	8654.0	0.97747	12,950.7
6	Ring Frame	10566823.0	140256.0	11222178.0	149008.0	0.94126	214,731.9
7	Winding	1678770.0	20459.0	1845895.0	22557.0	0.90699	31,322.7
8	Twisting	372890.0	237.0	556072.0	-4999627.0	-0.00005	362.8
9	Steaming	438692.0	4768.0	455117.0	4851.0	0.98289	7,299.8
10	AC Station 1+2	9700001.0	119548.0	11745812.0	146209.0	0.81765	183,028.0
11	AC Station 3+4	4615331.0	55361.0	5703363.0	68792.0	0.80476	84,757.7
12	Compressor	3197778.0	-1111.0	4374459.0	37526.0	-0.02961	(1,700.9)
13	Pump Station	192690.0	1521.0	206764.0	1563.0	0.97313	2,328.7
14	Normal Lighting	1489991.0	12420.0	1492510.0	12422.0	0.99984	19,015.0
15	Emergency Lighting	2642718.0	21432.0	2720539.0	22105.0	0.96955	32,812.4
16	Dalol Hotel	1617690.0	16758.0	1633164.0	16969.0	0.98757	25,656.5
Total:			427108.0	-4634691.0	653,902.3		

Table C -5 Energy Consumption recorded of spinning machinery on 5/11/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	4063279.0	36122.0	5754861.0	54003.0	0.66889	55,302.8
2	Draw Frame	536431.0	3550.0	623593.0	4230.0	0.83924	5,435.1
3	Combing	811760.0	9158.0	3051136.0	396586.0	0.02309	14,020.9
4	Open End	8834412.0	115663.0	11292343.0	146041.0	0.79199	177,080.1
5	Roving Frame	849599.0	8191.0	860326.0	8375.0	0.97803	12,540.4
6	Ring Frame	10694350.0	127527.0	11357362.0	135184.0	0.94336	195,243.8
7	Winding	1694995.0	16225.0	1863879.0	17984.0	0.90219	24,840.5
8	Twisting	373155.0	265.0	556487.0	415.0	0.63855	405.7
9	Steaming	442633.0	3941.0	459133.0	4016.0	0.98132	6,033.7
10	AC Station 1+2	9804773.0	104772.0	11873113.0	127301.0	0.82303	160,405.9
11	AC Station 3+4	4664273.0	48942.0	5764023.0	60660.0	0.80682	74,930.2
12	Compressor	3196725.0	-1053.0	4409097.0	34638.0	-0.03040	(1,612.1)
13	Pump Station	193885.0	1195.0	207979.0	1215.0	0.98354	1,829.5
14	Normal Lighting	1500185.0	10194.0	1502704.0	10194.0	1.00000	15,607.0
15	Emergency Lighting	2661072.0	18354.0	2739501.0	18962.0	0.96794	28,100.0
16	Dalol Hotel	1632013.0	14323.0	1647710.0	14546.0	0.98467	21,928.5
Total:			517369.0	1034350.0	792,091.9		

Table C -6 Energy Consumption recorded of spinning machinery on 8/12/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	4112375.0	49096.0	5826774.0	71913.0	0.68271	75,166.0
2	Draw Frame	542490.0	6059.0	630829.0	7236.0	0.83734	9,276.3
3	Combing	822574.0	10814.0	3091770.0	40634.0	0.26613	16,556.2
4	Open End	8973962.0	139550.0	11467594.0	175251.0	0.79629	213,651.1
5	Roving Frame	859755.0	10156.0	870648.0	10322.0	0.98392	15,548.8
6	Ring Frame	10857808.0	163458.0	11530237.0	172875.0	0.94553	250,254.2
7	Winding	1713869.0	18874.0	1884657.0	20778.0	0.90836	28,896.1
8	Twisting	375117.0	1962.0	559615.0	3128.0	0.62724	3,003.8
9	Steaming	448350.0	5717.0	464958.0	5825.0	0.98146	8,752.7
10	AC Station 1+2	9930804.0	126031.0	12026168.0	153055.0	0.82344	192,953.5
11	AC Station 3+4	4724049.0	59776.0	5837745.0	73722.0	0.81083	91,517.1
12	Compressor	3195555.0	-1170.0	4450939.0	41842.0	-0.02796	(1,791.3)
13	Pump Station	195782.0	1897.0	209930.0	1951.0	0.97232	2,904.3
14	Normal Lighting	1513550.0	13365.0	1516069.0	13365.0	1.00000	20,461.8
15	Emergency Lighting	2683285.0	22213.0	2762405.0	22904.0	0.96983	34,008.1
16	Dalol Hotel	1649426.0	17413.0	1665398.0	17688.0	0.98445	26,659.3
Total:			645211.0	832489.0	987,818.0		

Table C -7 Energy Consumption recorded of spinning machinery on 11/01/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	4166081.0	53706.0	5904636.0	77862.0	0.68976	82,223.9
2	Draw Frame	549527.0	7037.0	639423.0	8594.0	0.81883	10,773.6
3	Combing	835241.0	12667.0	3138854.0	47084.0	0.26903	19,393.2
4	Open End	9126228.0	152266.0	11657916.0	190322.0	0.80004	233,119.2
5	Roving Frame	870837.0	11082.0	882027.0	11379.0	0.97390	16,966.5
6	Ring Frame	11031448.0	173640.0	11714023.0	183786.0	0.94479	265,842.8
7	Winding	1735017.0	21148.0	1907916.0	23259.0	0.90924	32,377.6
8	Twisting	379273.0	4156.0	565632.0	6017.0	0.69071	6,362.8
9	Steaming	455384.0	7034.0	472230.0	7272.0	0.96727	10,769.1
10	AC Station 1+2	10069138.0	138334.0	12194384.0	168216.0	0.82236	211,789.4
11	AC Station 3+4	4787235.0	63186.0	5915998.0	78253.0	0.80746	96,737.8
12	Compressor	3194260.0	-1295.0	4495597.0	44658.0	-0.02900	(1,982.6)
13	Pump Station	197556.0	1774.0	211748.0	1818.0	0.97580	2,716.0
14	Normal Lighting	1527510.0	13960.0	1530031.0	13962.0	0.99986	21,372.8
15	Emergency Lighting	2706607.0	23322.0	2786490.0	24085.0	0.96832	35,706.0
16	Dalol Hotel	1667704.0	18278.0	1683942.0	18544.0	0.98566	27,983.6
Total:			700295.0	905111.0	1,072,151.6		

Table C -8 Energy Consumption recorded of spinning machinery on 8/02/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	3682707.0	-483374.0	5188883.0	-715753.0	0.67534	(740,045.6)
2	Draw Frame	490598.0	-58929.0	569079.0	-70344.0	0.83773	(90,220.3)
3	Combing	724731.0	-110510.0	2725778.0	-413076.0	0.26753	(169,190.8)
4	Open End	7869478.0	-1256750.0	10076323.0	-1581593.0	0.79461	(1,924,084.3)
5	Roving Frame	778511.0	-92326.0	787993.0	-94034.0	0.98184	(141,351.1)
6	Ring Frame	9701535.0	-1329913.0	10297959.0	-1416064.0	0.93916	(2,036,096.8)
7	Winding	1524852.0	-210165.0	1675439.0	-232477.0	0.90402	(321,762.6)
8	Twisting	346900.0	-32373.0	511070.0	-54562.0	0.59333	(49,563.1)
9	Steaming	407177.0	-48207.0	423032.0	-49198.0	0.97986	(73,804.9)
10	AC Station 1+2	8758528.0	-1310610.0	10589031.0	-1605353.0	0.81640	(2,006,543.9)
11	AC Station 3+4	4195518.0	-591717.0	5178652.0	-737346.0	0.80250	(905,918.7)
12	Compressor	3209474.0	15214.0	41273052.0	36777455.0	0.00041	23,292.6
13	Pump Station	182289.0	-15267.0	395942.0	184194.0	-0.08289	(23,373.8)
14	Normal Lighting	1380873.0	-146637.0	1383371.0	-146660.0	0.99984	(224,501.2)
15	Emergency Lighting	2470262.0	-236345.0	2542721.0	-243769.0	0.96954	(361,844.2)
16	Dalol Hotel	1476089.0	-191615.0	1489421.0	-194521.0	0.98506	(293,362.6)
Total:			6099524.0	29406899.0	(9,338,371.2)		

Table C -9 Energy Consumption recorded of spinning machinery on 12/3/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	3727800.0	45093.0	5255687.0	66804.0	0.67500	69,037.4
2	Draw Frame	496323.0	5725.0	575757.0	6678.0	0.85729	8,765.0
3	Combing	731849.0	7118.0	2752751.0	26973.0	0.26389	10,897.7
4	Open End	7957431.0	87953.0	10186068.0	109745.0	0.80143	134,656.0
5	Roving Frame	787134.0	8623.0	796706.0	8713.0	0.98967	13,201.8
6	Ring Frame	9788324.0	86789.0	10390236.0	92277.0	0.94053	132,874.0
7	Winding	1544874.0	20022.0	1697639.0	22200.0	0.90189	30,653.7
8	Twisting	347280.0	380.0	511817.0	747.0	0.50870	581.8
9	Steaming	413071.0	5894.0	429024.0	5992.0	0.98364	9,023.7
10	AC Station 1+2	8879950.0	121422.0	10737869.0	148838.0	0.81580	185,897.1
11	AC Station 3+4	4250630.0	55112.0	5247707.0	69055.0	0.79809	84,376.5
12	Compressor	3205981.0	-3493.0	4162536.0	-37110516.0	0.00009	(5,347.8)
13	Pump Station	183775.0	1486.0	197508.0	-198434.0	-0.00749	2,275.1
14	Normal Lighting	1394266.0	13393.0	1396765.0	13394.0	0.99993	20,504.7
15	Emergency Lighting	2494186.0	23924.0	2567305.0	24584.0	0.97315	36,627.6
16	Dalol Hotel	1494768.0	18679.0	1508388.0	18967.0	0.98482	28,597.5
Total:			498120.0	##########	762,621.7		

Table C -10 Energy Consumption recorded of spinning machinery on 19/4/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	3779648.0	51848.0	5333440.0	77753.0	0.66683	79,379.3
2	Draw Frame	502299.0	5976.0	582601.0	6844.0	0.87317	9,149.3
3	Combing	744229.0	12380.0	2797576.0	44825.0	0.27619	18,953.8
4	Open End	8081191.0	123760.0	10339658.0	153590.0	0.80578	189,476.6
5	Roving Frame	797150.0	10016.0	806808.0	10102.0	0.99149	15,334.5
6	Ring Frame	9912370.0	124046.0	10522561.0	132325.0	0.93743	189,914.4
7	Winding	1568439.0	23565.0	1723774.0	26135.0	0.90166	36,078.0
8	Twisting	349362.0	2082.0	514859.0	3042.0	0.68442	3,187.5
9	Steaming	415968.0	2897.0	431985.0	2961.0	0.97839	4,435.3
10	AC Station 1+2	9032503.0	152553.0	10923686.0	185817.0	0.82099	233,558.6
11	AC Station 3+4	4318498.0	67868.0	5332161.0	84454.0	0.80361	103,905.9
12	Compressor	3204314.0	-1667.0	4199686.0	37150.0	-0.04487	(2,552.2)
13	Pump Station	184997.0	1222.0	198779.0	1271.0	0.96145	1,870.9
14	Normal Lighting	1410621.0	16355.0	1413119.0	16354.0	1.00006	25,039.5
15	Emergency Lighting	2521147.0	26961.0	2595169.0	27864.0	0.96759	41,277.3
16	Dalol Hotel	1515642.0	20874.0	1529533.0	21145.0	0.98718	31,958.1
Total:			640736.0	831632.0	980,966.8		

Table C -11 Energy Consumption recorded of spinning machinery on 2/05/2022

S/N	Cost Center	Active Energy		Total Energy		Power Factor	Active Energy Cost (Birr)
		Reading	KWh	Reading	KVAh		
1	Blow & Card	3801464.0	21816.0	5366188.0	32748.0	0.66618	33,400.3
2	Draw Frame	505279.0	2980.0	586348.0	3747.0	0.79530	4,562.4
3	Combing	747830.0	3601.0	2810927.0	13351.0	0.26972	5,513.1
4	Open End	8135119.0	53928.0	10407702.0	68044.0	0.79255	82,563.8
5	Roving Frame	798533.0	1383.0	808234.0	1426.0	0.96985	2,117.4
6	Ring Frame	9930244.0	17874.0	10541650.0	19089.0	0.93635	27,365.1
7	Winding	1573895.0	5456.0	1729974.0	6200.0	0.88000	8,353.1
8	Twisting	354204.0	4842.0	522733.0	7874.0	0.61494	7,413.1
9	Steaming	416293.0	325.0	432322.0	337.0	0.96439	497.6
10	AC Station 1+2	9103330.0	70827.0	11011104.0	87418.0	0.81021	108,436.1
11	AC Station 3+4	4334502.0	16004.0	5352180.0	20019.0	0.79944	24,502.1
12	Compressor	3203327.0	-987.0	4219713.0	20027.0	-0.04928	(1,511.1)
13	Pump Station	185567.0	570.0	199383.0	604.0	0.94371	872.7
14	Normal Lighting	1419121.0	8500.0	1421624.0	8505.0	0.99941	13,013.5
15	Emergency Lighting	2534534.0	13387.0	2609037.0	13868.0	0.96532	20,495.5
16	Dalol Hotel	1526270.0	10628.0	1540349.0	10816.0	0.98262	16,271.5
Total:			231134.0	314073.0	353,866.2		

Table C -12 Energy Consumption recorded of spinning machinery on 1/06/2022

S/N	Cost Center	Active Energy Reading	Active Energy KWh	Total Energy Reading	Total Energy KVAh	Power Factor	Active Energy Cost (Birr)
1	Blow & Card	3839885.0	38421.0	5423095.0	56907.0	0.67515	58,822.6
2	Draw Frame	509762.0	4483.0	591642.0	5294.0	0.84681	6,863.5
3	Combing	755588.0	7758.0	2840408.0	29481.0	0.26315	11,877.5
4	Open End	8215602.0	80483.0	10509035.0	101333.0	0.79424	123,219.5
5	Roving Frame	805059.0	6526.0	814859.0	6625.0	0.98506	9,991.3
6	Ring Frame	10006846.0	76602.0	10623572.0	81922.0	0.93506	117,277.7
7	Winding	1590414.0	16519.0	1748344.0	18370.0	0.89924	25,290.6
8	Twisting	357175.0	2971.0	527846.0	5113.0	0.58107	4,548.6
9	Steaming	418149.0	1856.0	434223.0	1901.0	0.97633	2,841.5
10	AC Station 1+2	9204058.0	100728.0	11134768.0	123664.0	0.81453	154,214.6
11	AC Station 3+4	4381956.0	47454.0	5411601.0	59421.0	0.79861	72,652.1
12	Compressor	3201974.0	-1353.0	4247438.0	27725.0	-0.04880	(2,071.4)
13	Pump Station	186786.0	1219.0	200690.0	1307.0	0.93267	1,866.3
14	Normal Lighting	1432084.0	12963.0	1434596.0	12972.0	0.99931	19,846.4
15	Emergency Lighting	2552937.0	18403.0	2628102.0	19065.0	0.96528	28,175.0
16	Dalol Hotel	1541566.0	15296.0	1555935.0	15586.0	0.98139	23,418.2
Total:			430329.0	566686.0	658,833.7		

Appendixes D: Adama Spinning Textile Factory Power Factor Charge Bill

[illegible]

Registered Office:
Piassa,Deguale square,
P.O. box 1233, AddisAbaba, Ethiopia

[illegible]
Ethiopian Electric Utility
Tin No. 0041082177

ETHIOPIAN ELECTRIC UTI

Print Date: 18.11.2022

BILLING ADDRESS		SUPPLY DETAILS		CURRENT DUE DETAILS	
Business Partner ID	2001997127	Consumer CA No.	100001562242	Meter Reading Type	ACTUAL
Full Name	ATO ADAMA	Contract No	7001814226	Bill Type	PERIODIC
Billing Address		Legacy ACC No.	2764644	Bill No.	10008266164
Region	OROMIA	Supply (Premise) Add.		Invoice Date	12-NOV-22
Zone	SERVICE NO-2	Kebele	SERVICE NO-2	Bill Month	TIKIMIT-2015
City/town	ORO_ADAMA	Block/Floor No	013027/0/0/	Portion	PBAG2001
Sub City	SERVICE NO-2	House No		Bill Period	02-OCT-22 to 01-NOV
Wereda		Landmark		Bill Days	31
Kebele	SERVICE NO-2	Premise Tel No.			
Block/Floor No.	013027/0/0/	Region	08		
House Number		District Office	BA		
Near to (Landmark)		CSC	BA02		
Tel. / Mobile Number		Call Centre / CSC Phone	905		
Fax No		Tariff Category	ICS-LV_IND		
E-mail		Route / MRU No.	/BA02B034		
		Walking Sequence			

Last Invoice Value	Last Payment Made	Current Invoice Value	Net Due Amount	Due Date
3,801,056.34	0.00	1802036.03	1,802,036.03	19-NOV-22

METER DETAILS		DETAILS OF CONSUMPTIONS Items	Unit	Current Reading	Previous Reading	Multiplication factor	Curr Consum
Sanction Load	24.00						
Power Factor	0.8748837						
Pole No		Active	KWH	402.15000	242.16000	6000.00	95994
Cycle No	11	Re-active	KVARH	217.36000	128.79000	6000.00	53142
Energization Date	30.07.2004						
Meter Type	Three Phase	Max Demand	KW	0.26920		6000	1615
Supply Type	Low Voltage						
Meter Number	7A30000000018?						
Meter Constant	0.0000						

DETAILS OF PAYMENT

Titles	Units Consumed	Rate	Amount
Charges (A)			
Consumption Charge	959,940.0000		1,469,668.14
	959,940.0000	1.5310	1,469,668.14
Service Charge		54.0000	54.00
Demand Charge	1,615.2000	200.0000	323,040.00
PF Charge			9,273.89
Subsidy / Discount (B)			
Other Dues (C)			
Current Month Dues Payable (A) + (-B) + (C)			1,802,036.03
Net Amount Payable for this Month			1,802,036.03

Ola
18/11/22

Details of Security Deposit			
Date	Deposit Type	Purpose of Deposit	Amount
15.11.2012	New Connection Security Deposit	115900954	145,920.41
Total			145,920.41

PAID
CPV NO 5311
Date 22/11/22
Doc NO