Investigation and Design of Power Factor Correction Using Static VAR Generator (Case Study Wonji /Shoa Sugar Factory)

Ketema Dejene Negesa

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

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Declaration

I, hereby declare that this Master Thesis entitled "**Investigation and Design of Power Factor Correction Using Static VAR Generator (Case Study Wonji /Shoa Sugar Factory)"** is my own work and has not been submitted to any university for similar purpose.

All sources of materials that I used for this thesis were acknowledged through citation.

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Name of student	Signature	Date

Recommendation of Advisors

I, the major advisor of this thesis, hereby certify that I have closely advised version of the thesis entitled "**Investigation and Design of Power Factor Correction Using Static VAR Generator (Case Study Wonji /Shoa Sugar Factory)"** prepared under my guidance by Ketema Dejene Negesa 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. Tafesse Asrat	_______________	_______________
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Approval Page of M.Sc. Thesis

I, the advisor of the thesis entitled "Investigation and Design of Power Factor Correction Using Static VAR Generator (Case Study Wonji /Shoa Sugar Factory)" and developed by Ketema Dejene Negesa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Tafesse Asrat		
Major Advisor/Supervisor	Signature	Date

Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the thesis by KetemaDejene Negesa have read and evaluated the thesis entitled "Investigation and Design of Power Factor Correction Using Static VAR Generator (Case Study Wonji /Shoa Sugar 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).

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CONTENTS

LIST OF ABBRIVATIONS AND ACRONYMS

AC	Alternating current
ACC	Auxiliary Cane carrier
APFC	Automatic Power Factor Correction
ATP	Alternative Transient Program
BFP	Boiler Feed pump
CT	Current Transformer
DOL	Direct on line
ESP	Electrostatic precipitator
ETB	Ethiopian Birr
DG	Diesel generator
FD	Force Derived
ICC	Inter mi diet Cane Carrier
ID	Induced derived
IGBT	Insulated-gate bipolar Transistor
KVA	Kilovolt-Ampere
KVAR	Kilovolt-Ampere Reactive
MCC	Motors, Main Cane Crier
NTNU	Norwegian University of Science and Technology
PCC	Power Control Center
PFC	Power factor correction

PID	Proportional integrated derivative
PCC,	Power control center
PLL	Phase - Locked Loop
PT	Potential transformer
PRDS	Plant reduce distribution system
PWM	Pulse-width modulated
RO	Reverse Osmosis
SA	Secondary Air
SVG	Static VAR Generator
THD	Total Harmonic Distortion
VFD	Variable Frequency Derived
VAR	Volt-Ampere Reactive
VSI	Voltage Source Inverter
VFD	Variable Frequency Drive
VT	Voltage Transformer

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ABSTRACT

Most of the loads in Sugar industries are inductive in nature and causes low power factor. A low value of power factor leads to increase in losses of active power, and also draws penalty by the utility. Today Electrical Engineers compensate this loss by the Correcting of power factor. There are some methods of power factor correction have been proposed but with the technological revolution growth automation of every system is desired. The main goal of this project is to increasing the current power factor of Wonji/Shoa Sugar Factory from 0.722 to 0.99. In this paper, the power Factor correction in the system is done by using Static VAR Generator (SVG) in Load Transient condition. The system power factor is become constant by using SVG in the power control center (PCC), where it is changed in different conditions. To obtain the best power factor in system, Proportional Integral Derivative (PID) Algorithm controller is used to check the important reactive power created by the loads and connected to PCC. The simulation results will display with MATLAB/Simulink to verify the effectiveness of the proposed system.

Key words: *Low Power factor, Active Power, Penalty, power Factor correction, Static VAR Generator, and MATLAB/Simulink.*

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In a present world of technology, one of the most problems which affect the economy of sugar industry is its operational cost is very high relative to other industries. Because it uses so many machines which consumes in megawatts power at operation times. In these cases, its major problem is the low power factor which results in high electric power consumption.

Hence the use of more inductive load in industries causes, the systems power factor get lagging in nature, that means the system power factor gets poor due to excess of reactive power consumed by the inductive load which increases the reactive losses(Technology & Routray, 2015). Therefore, it is necessary to reduce such losses by power factor correction technique and keep the safety for machines. Most of the Machines used in Sugar industry are Fibrizer, mills, elevator, motors, conveyor, pumps, continuous batches, Pans, dryers, boring machines, shaper machines, lath machines, horizontal slot machines, drilling machines, rolling machines, compressors, heaters, Vessels machines, burner machines, mud separator etc. runs on electricity(Wonji/Shoa Sugar Factory, 2023). Thus, all of the machines described above are Couse inductive loads and low power factor in nature. This low value of power factor leads to increase in electric losses and also draws penalty by the utility. And when consumers connect inductive loads to the power system, the power factor lags, creating high current demand and high active power losses are incurred in the system. In our country (Ethiopia), when the power factor goes to lagging, the electric supply company do not care about it, their work is only charging penalty to the consumers. Similar to this the Ethiopia Electric utility was installed dual Energy meter at Wonji/Shoa sugar factory and Exaction in thousands of birr from company per months. The existing power factor correction at the company is Capacitor bank type, which was failed before six years. To overcome this problem the existing system must be revised and Corrected by Using Static VAR Generator. Because it has the advantage of being able to correct power factor of both leading and lagging and can correct unbalance network. The Power Factor gives an idea about the efficiency of the system to do useful work out of the supplied electric power. A low value of power factor leads to increase is electric losses and also draws penalty by the utility. Significant savings in utility power costs can be realized by keeping up an average monthly power factor close to unity(Chen et al., 2015). To correct the power factor to desire level, reactive power compensator (SVG) is connected to High Tension (HT) for Wonji/Shoa sugar factory case. Power factor correction techniques can be applied to industrial units, power systems and also households to make them stable. As a result, the system becomes stable and efficiency of the system as well as of the apparatus increases. Therefore, the use of Static VAR Generator with Proportional Integrated Derivative (PID) Feedback control, based power factor correction results in reduced overall costs for both the consumers and the suppliers of electrical energy. Power factor correction using Static VAR Generator reduces reactive power consumption which will lead to minimization of losses and at the same time increases the electrical system's efficiency.

This paper discusses Investigation and Design of Power Factor Correction Using Static VAR Generator.

1.1.1 Background of Wonji/Shoa Sugar Factory and its Power Supplying system

Wonji sugar factory is the most established and groundbreaking factory in Ethiopia's sugar business history. It was built by Holland Company known as United N.V Handles Vereeniging Amsterdam (HVA) on 5000 hectares of land for both cane plantation and building sugar factory in 1954. It is located in Oromia region state, East Shoa Zone, Dembela Woreda Gefersa Wonji kilil at 110 km from Addis Ababa.

Similar to this Shoa sugar Factory is also built by the same company which built Wonji sugar factory called United N.V Handles Vereeniging Amsterdam (HVA) on 2000 hectares of land for both cane plantation and building sugar factory in 1962. It is similarly located in Oromia region state, Arsi zone, Dera woreda, Alem Tena Shoa kilil at 118 km from Addis Ababa. Starting from June 2013, the new merged both factory project has been conducted in the factory and attempt to replace the wonji and shoa sugar factories with a new and contemporary one. The built factory began production before 2024. Then the Ethiopia sugar corporation management with wonji /shoa sugar factory makes agreement with Indian company which is constructed by Indian company, At Oromia Regional state, near Dera city, at Dodota kebele 128 km from Addis Ababa. Its design capacity of crushing is 6,250,000 Kg sugar cane in one day and produces 174,946 000 kilograms sugar in one year. Latest factory, had ethanol production facility on its plan and starting built it, but till today it is not finished. As I saw their plan the ethanol plant has the capacity to produce 10,000 cubes of ethanol each year and with additional growth, it will annually produce 12,800-meter cubes.

Similar to this the factory was designed for producing 30 MW electric powers to contribution 15 MW for national grid and around 15 MW for its own consumption. But the turbine was failed before 10 years and they got supply from the Ethiopia power corporation. Because of they didn't generate their own power they pay millions of birrs for Ethiopia power utility per month.

With regard to social responsibility, over 13.48 million birr were spent to the construction of social institutions such as schools, health station, potable water centers, etc. and more than 6491 members of community had benefitted from the job opportunities created by the factory as a permanent, contract, seasonal employees.

It is a factory which was become autonomous by the council of minister's regulation number 496/2022.

1.1.2 Electric Power Supplying System for case study Factory

The Factory substation, is approximately 6Km away from Awash Melkasa Power Generation /Substation. The Substation is linked to Ethiopian's National Grid system. One 132 KV line is feeding from Awash Substation and connected to Shoa /Wonji Substation for step down 11 KV. The transformer used for step down in substation is Wye-Delta type with132KV/11KV, 30MVA, %Z=12 data. After stepped to 11KV it was fed to High Tension for distribution different plants like, Boiler plant, mill plant, fibrazer plant, process house plant, Awash Pump station plants, boiling and Evaporation plants, etc.

1.1.3. Wonji/Shoa Sugar Factory Substation

Wonji/Shoa Substation is a kind of substation which used for Step-down 132kv to 11kv voltage, feed power to the high tension of the plant and accepts power from the plant while the factory is produce its own power and send to the grid. Substations provide several other vital functions in addition to switching from high to low voltage or low to high. There could a power flow between the generation station and end of customer through several voltage statuses. Similar to this Wonji/ shoa sugar factory was step down 132KV Voltages to 11KV voltages by using Wye-Delta type with132KV/11KV, 30MVA, %Z=12 transformer. In this substation there are some electrical equipment's which are used for different purposes in the substation. These are 132KV,2500A,40KA 3SEC BAR, lightning Arrester (LA),3 Isolators 2500A, breaker with 2000A, 40KA, current transformers (CT-Core 1-5), potential transformer, metering and relay panel etc. in this substation the function of those equipment's are as follows.

Bus Bar: is a substantial piece of conducting type metal that conducts power inside the substation. In order to calculate the maximum quantity of the electricity that may be transported safely, the bus-bar's size is crucial. The anticipated peak current load ought to be supported by the bus-bar with no going above a certain temperature restriction. Additionally, the bus's highest temperature during short circuit conditions needs to be verified.

Lightning Arrester (LA) or Surge Arrestors is protects equipment by discharging or avoiding surge current, thereby limiting peak voltages. "Surges" or "transients" are the terms used to describe massive excess voltages that occur suddenly on a power delivery and distribution network. Those are brought through switching circuit activities or strikes of lightning. Surge arrestors are placed to safeguard 132 kV switching equipment, transformers that operate related equipment, 11 kV and 132 kV lines from excessive voltages without a second thought.

Isolators are switches with mechanical mechanisms that have the ability to open or close a circuit, in the subsequent role.

- if a small amount of current is created or broken
- The electrical charge is only going to be disrupted somewhat.
- When there isn't a noticeable voltage differential between each pole's endpoints.

Under normal circumstances, isolators may convey current and, for a limited period of time, can short circuits currents. When the isolation device is in the open status, it should create an isolating space between the endpoints.

Standard values for the authorized duration of short-term current capacity withstands for earthing switches and isolators are typically one second.

Circuit Breaker: is a switch that is constructed with durability in mind, allowing it to interrupt or generate both the required load current and the much larger fault current that may arise on a circuit. There are movements and permanent contacts on electrical circuit breakers. Circuit breakers are found at the arrivals and departures of all line's incident on a Circuit. It used to cut off short circuits that develop on a line. The contacts are held together when the circuit breaker is closed. Every circuit breaker operates by severing the issue with current by means of the moveable contacts being separated from the permanent ones.

As soon as the contact points separate, an arc is formed. After the arc at these contacts extinguishes and the current falls to zero, the current is interrupted.

Earthing Switches: are offered in a number of places to make maintenance easier. Both manual and electrical methods are used to interlock the primary and earth gears. The earthing switches must be able to sustain a short circuit current for a brief period of time when used with an isolator.

Current transformers: are employed in electrical installations to provide the signaling meters' current circuits and safeguard relays. When the specified current passes via the primary, those transformers are intended to generate an appropriate secondary current result of either 1 or 5 A. The conversion proportion, or the proportion of the estimated main to estimated auxiliary current, is one of CT's key characteristics. There are two intrinsic flaws in electric current transformers. Phase displacement and the current ratio. So CT's are categorized for accuracy based on these two flaws.

Potential transformers: are employed to provide the voltage circuit to tripping coils, safeguarding relays, integrated meters, and other devices for measurement. These can be either dry or oil-immersed, with a single phase or 3 phase system. A voltage transformer, often known as a PT, is rated according to the greatest load (VA output) it can produce within predetermined error bounds. An Electrical power transformer, on the contrary hand, is rated according to the secondary outputs it can provide without going above a particular temperature rise. Every voltage transformer is made to operate at 110 volts or $110\sqrt{}/3$ Volts as the typical secondary voltage.

Power Transformers: Is static electrical equipment which is used for transmitting electrical transferring power between circuits without altering frequency.

Metering and Panels of control are erected in a switchyard's monitoring building to offer installation for relays that operate, meters, monitoring switches, check switches, signaling lights, signaling equipment, and additional control components. The panel has sections with room for sectionalizing, relays, measurement equipment, and other components, as well as chambers for both inbound and outbound lines including bus bar.

In general, Wonji/Shoa Sugar factory Substation is step down 132KV to 11KV because the plant (factory) turbine was generated 11KV, for that reason they used it for synchronization and used for receive and send power to the grid system. Fig below shows wonji/shoa sugar factory single line diagram.

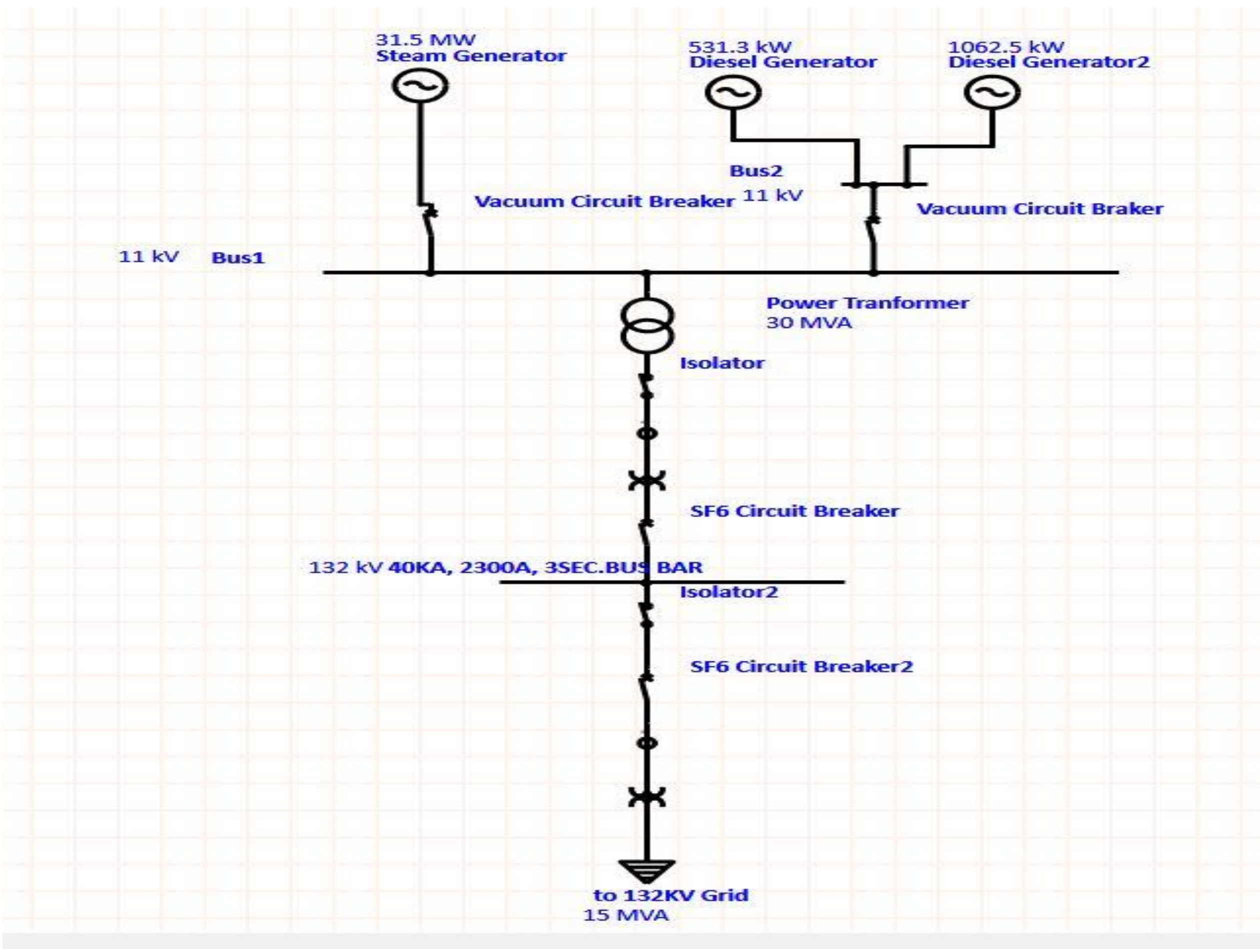

Figure1. 1 Wonji/Shoa sugar factory single line diagram

Similar to the supply feeds from substation to the plant, the plant is also supplied power to the substation reversely as shown in in fig above. The reverse or the sender line has the following equipment's, 11KV Vacuum circuit breaker, current transformers, 11KV/132KV step up power transformer etc.

The Overhead transmission system 132KV primary Feeder line runs from Awash Melkasa Power Generation /Substation to Wonji/Shoa Sugar Factory. The High Tension (HT) was built in power generation plant and it was designed to distributed power for the following Transformers and Sub high Tensions.

1, Transformer for Steam and power Generation (11KV/0.4KV): which feeds supply for Ash Handling motors systems, Bagasse feeder motors, Screw feeder motors, Bagasse Handling Conveyor motors, ESP plant motors, Soot blowers motors, Plant reduce distribution system (PRDS), Makeup pump motors, Cooling Fans motors, Secondary Air (SA) fan motors, Transfer Motors and Compressors motors etc.

2, **Transformer for ID and FD feeder (11KV/0.69KV)**: which feeds supply to Induced derived (ID) Fans motors and Force Derived (FD) Fans motors.

3, Transformer for mill house (11KV/0.69KV): these transformers are five in numbers, which are step down 11kv to 0.69kv and feeds supply for five mill motors for operation purposes.

4, Transformer for Evaporation, Boiling and Reverse Osmosis plant: is a kind of transformer which step down 11kv to 0.4kv and feeds supply power to Imbibition motors, Circulation pump motors, Mud pump motors, Nash pump motors, Auxiliary Cane carrier (ACC) motors, Main Cane Crier (MCC) motor, Inter mi diet Cane Carrier (ICC) motors, rotary screen motors, Cane un loader motors, Injection motors, Fire hydrant motors, Reverse Osmosis (RO) motors injection motors etc.

5, Sub High Tension 11KV Panels: This feeds supply for Boiler Feed pump (BFP) motors and Fiberizer motors.

6, Transformer for PAN house (11KV/0.4KV): which feeds supply for Batch motors, Pan motors, molasses motors, A heavy motors, A light motors, B heavy molasses motors, sugar dryer motors, Elevator motors, sugar bagging motors, compressor motors etc. figure 1.2 Shows the A solitary line illustration of wonji/shoa distribution power framework from High tension too different plant transformers.

Generally, the factory power distribution system has three 11KV/0.4KV,3150KVA, Wye-Delta type step down transformers, seven 11KV/0.69KV, Delta-Wye-Delta step down power transformer, one Wye-Delta type with132KV/11KV, 30MVA, %Z=12 step down power transformer, and one Earthing with 1100V,2500A, as shown blow.

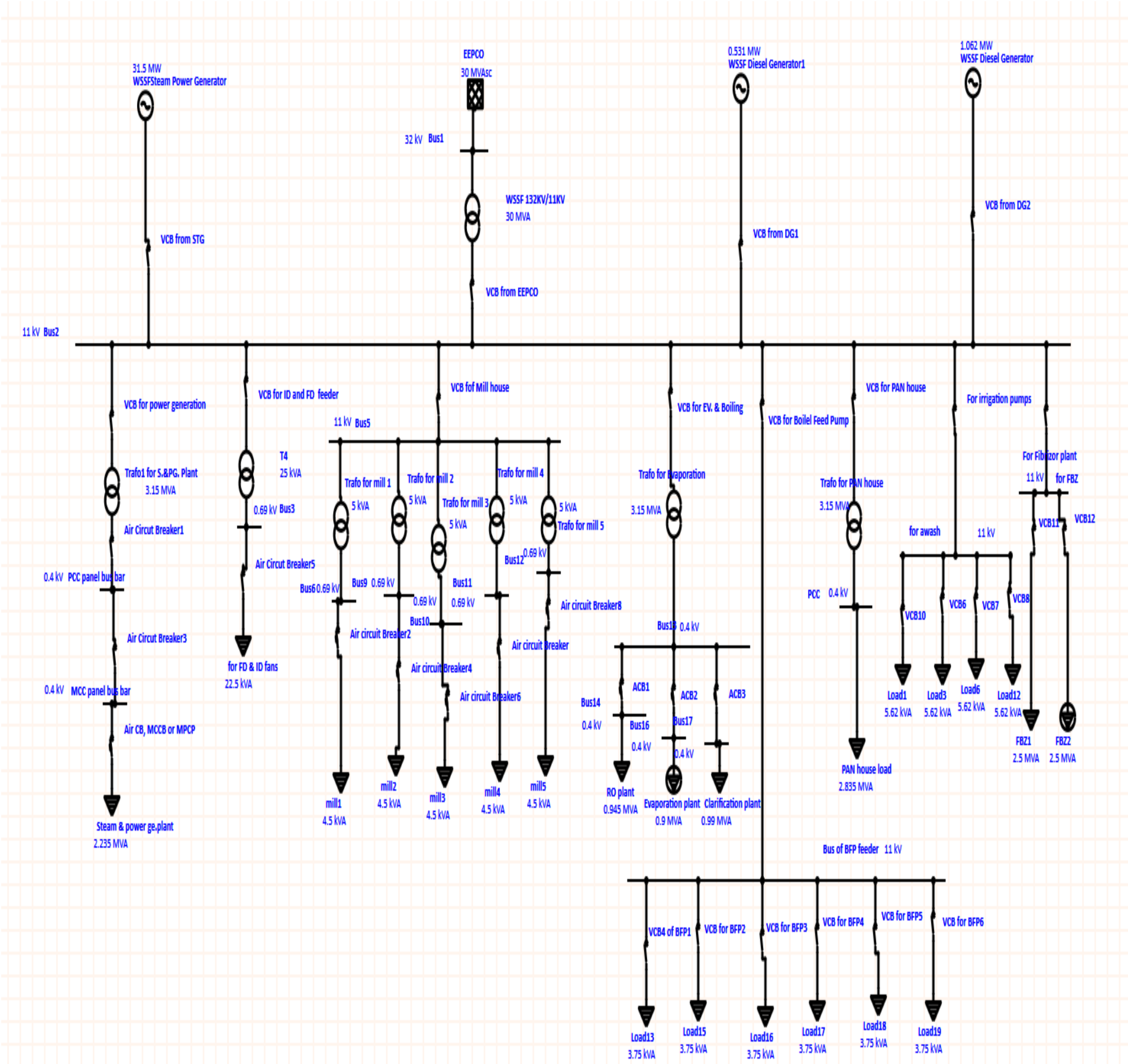

Figure1. 2Wonji/ Shoa Sugar Factory's Electrical Power Distribution Network

As I show above the total power design in wonji/shoa sugar factory is generalized in table 1.1

Table 1. 1 Transformer rating of Wonji/Shoa sugar factory

No.	Transformer rating
For Transformer 1	3.15 MVA
For Transformer 2	3.15 MVA
For Transformer 3	3.15 MVA
For ID and FD fans	25 KVA
Plant Water supply (RO)	25 KVA
For two fibrizors	5 MVA
For Awash Pump station	20 KVA
For mill (1-5)	25 KVA
For boiler feed water pumps (1-6)	25 KVA
Total	17.725 MVA

As it was shown on above table the factory total designed load is about 30MWA and it ready for use up to 17.725 MVA when the ethanol plant will be starting work but for sugar production purpose, they are only using 10 MVA as I gathered data from their background history and their designed documents. The connection types of transformers are Wye-Delta step down distribution type transformers, Delt-Wye-Delta step down distribution transformers and the rest one is earthing type transformer which is used for deliver a ground for transformer poles and links at the generating voltage while the electrical breaker is enabled. Using a shared bus bar, to provide the highest possible level 24 MW, and 30MVA. Therefore 132KV, 50HZ power supplied for Wonji/ Shoa sugar Factory is transformed to 11KV, 690V, 400V by those transformers. For the case of power interruption/failure the factory has two standby diesel generators with 1.5 MVA and 1 MVA ratings.

In general the wonji/ shoa sugar factory electrical power were supplied by 15 Motor Control Centers (MCCs) by three 11KV/0.4KV step down power transformers, seven 11KV/0.69KV steps down transformers three 11KV rating Vacuum circuit breakers and with three power control center. Therefore, the Power control centers (PCCs) and Motor Control Centers are positioned nearer to the loads they fed.

The plant had some recent technologies like, sophisticated software’s, energy saving machines, highly protective systems, modern control systems, modern operation system etc.

In general, the factory had the following loads.

- Mercury type incandescent lamps, fluorescent lamps, Light emit diode lamps, Welding machines, boring machines, shaper machines, lath machines, horizontal slot machines, drilling machines, rolling machines.
- Electronic equipment’s like, Computers, Printers, copy machines etc.
- AC induction motors which are managed through Direct Online, Star delta, Resistor monitoring system, Variable Frequency Derived (VFD).

All of the system above must have an automatic Power Factor Controller (PFC) on their Power control center or Motor control center to maintain the system's power factor consistently. Similarly Wonji/Shoa sugar factory was installed Power factor controller by using Capacitor bank as General on High Tension, but the system on High Tension was failed during test and commission because of that the factory was paid penalty for Ethiopia electric utility.

1.2 Statement of the Problem new

In an electrical system with equal useable power delivered, a load with a low power factor requires greater current than one with a high power factor. Moreover, large inductive loads with a very low power factor are characteristics of an industrial facility with changeable load conditions.

The system in which, with a very poor power factor will follows different kinds of technical and economic problems such as reduce of machines life , increase open and short circuits in the machines, increase power losses , increase voltage drops and penalization in the electric bills respectively. The all problems mentioned above were the cases that I observed in Wonji/Shoa Sugar factory throughout my work time. Hence, it is necessary to solve those problems by improving the utilities performance and keep the customers satisfaction.

1.3 Objectives of the Project

1.3.1 General objectives

The Overall, this thesis's goal is Investigation and design of Power Factor Correction Using Static VAR Generator.

1.3.2 Specific objectives

- Data collection from company and analysis of it.
- To reduce demand charges by the utility.
- To develop new model or the apparatus.
- Make use of MATLAB program to simulate the obtained model.
- Determining the economic analysis of the new model.
- Reduce energy loss in electrical system.

1.4 Significance of the Study

This project used to achieve goal of Wonji/Shoa sugar factory's economic development through proper management of electric power. Since without electric power it is not possible to accelerate any satisfied work, it is mandatory to look at possible approaches which will help to minimize voltage drops in the specified site.

Generally, this work will provide good and suitable electric accesses, improve productivity of not only for Wonji/Shoa sugar factory's but also for all private and governmental owned companies by creating low utility fees; eliminating power factor penalty; increasing system capacity and decreasing system losses.

1.5 Limitation of Study

This thesis will focus on Investigation and Design Power factor correction by using Static VAR Generator. The system model will be created using software materials instead of hardware, due to the challenges of high costs and limited availability of components for hardware implementation. So, the system model and simulation studies will be conducted using MATLAB/Simulink software.

1.6 Organization of the Thesis

In this study, a Power factor problem in Wonji/Shoa Sugar Factory particularly Investigation and Design of Power Factor Correction Using Static VAR Generator is proposed. There are five sections in the thesis .A study's background, a statement of the problem; objectives, significance, and the plant's electric distribution system are offered in the first chapter.

Second chapter Contains various power factor issues, including Theoretical Background of study, Importance of PF, Correction for power factor , Methods for Correction for power factor , Common Correction for power factor Methods of Electrical System, Correction for power factor Using Static VAR Generator, Controller of Static VAR Generator, Advantage PFC using Static VAR Generator over other methods of PFC, Static VAR Generator Operating Principles and Basic Components of Static VAR Generator.

The third chapter discusses Methodology for Data Collections, Mathematical Modeling of Static VAR Generator, Analysis of Electrical Parameters Mathematically of Wonji/Shoa Sugar Factory, Designing Static VAR Generator Size and Parameter for Wonji/Shoa Sugar Factory, Design of Voltage source Inverter, Design of Controller system block, Design of Capacitor Filter, Selection of AC inductor for SVG design purpose, Modeling of Static VAR Generator and Static VAR Generator Cost analysis.

In chapter four, the MATLAB/SIMULINK model has been simulated with and without the suggested method to pinpoint the current power factor issue.

Distribution networks performance before and after the integration of this device was then discussed.

Chapter 5 the conclusion developed based on the investigation results, as well as the recommendations needed for the industry and the suggestion future works were discussed.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Background

This thesis explains Investigation and Design of Power Factor Correction Using Static VAR Generator for Wonji/Shoa Sugar Factory. The design is based on Voltage Source Inverter Static VAR Generator. In order to offset the inductive as well as capacitive power of the installation process, which the Static VAR Generator injects a current in the reverse direction, guaranteeing that the goal cosϕ is reached. In addition, it instantly compensates and changes its course in milliseconds in response to demand. Similarly, it makes up for phase-to-phase imbalances in systems. For locations where reactive energy use is strictly penalized, the SVG is the ideal device. There was discussion of several relevant literature reviews about investigation and design power factor adjustment. Standing on these discussions Static VAR Generator is selected for design and correcting Power factor system of Wonji/Shoa sugar Factory. Several reviewed articles were analyzed on power factor correction by using different methods and on different systems. Though improving as well as power factor correction is a relatively ancient technique; in my thesis, I take new work into consideration. While several of the authors listed below have offered recommendations and methods for power factor improvement as well as correction, the focus of this thesis is on automatic power factor improvement through the use of capacitor banks. The followings authors are studies on this area.

(Rossetto et al., 2000).Proposed Conducted EMI issues in a boost PFC design. They used to present the results with the development of a 600W Boost Power Factor Corrector (PFC) complying with the EMC standards for conducted EMI in the 150 kHz-30MHz range.

(Allah, 2014) proposed the use of the Alienation approach to implement an automatic power factor correction. To determine the number of capacitor banks needed to achieve the target power factor, as well as the basic power factor online, active, and compensatory reactive powers, an alienation technique was created. Phase voltage and current signals of the power supply were compared to calculate their respective alienation coefficients. The suggested method was put into practice using MATLAB programs and the Alternative Transient Program (ATP).

(Uddin & Mahmud, 2019) designed and implemented a microcontroller-based automatic power factor correction system for various types of loads. A PIC microcontroller is used in this system and a relay driver and relay module with a capacitor bank can compensate for the other load.

(Papechen & Sebastian, 2016) suggested Capacitor Bank-Based Automatic Power Factor Correction. They improve and modernize the way single-phase capacitor banks function by creating a control system that is based on microprocessors. They solely used single phase capacitor banks for household purposes when designing their products.

(Rana et al., 2013) suggested utilizing a microcontroller to improve the power factor automatically. Because of the ease of programming as well as usage of resistors in place of potential transformers, their low-cost microcontroller IC (ATmega8) makes their automatic power factor correction system a highly cost-effective single phase power factor improvement regulating system available. The authors of this paper used static capacitors for power factor improvement but using static capacitor system has the following disadvantages, their service life is short ranging from 8 to 10 years, they are easily damaged if the voltage exceeds the rated value and once the capacitors are damaged, their repair is uneconomical.

(Alhasnawi, 2018) proposed Automated Power Factor Correction for Smart Home. In their design they e used the technique of relay switching method with a capacitor so that any drop in power factor can be sensed by the controller and switch the capacitor as required.

(Science et al., 2021) the process of raising a three-phase system's power factor through reactive power compensation. They demonstrate how to automatically fix the power factor in a three-phase system by adding capacitor banks that automatically achieve the desired value using binary coding (0–7). The entire circuit diagram is not apparent in their suggested system, and the source code they utilized is not included.

(Kumar et al., 2020) suggested Automatic Power Factor Correction Technique using Capacitive Bank Simulation Analysis. In this suggested work, the coding approach and topology are improved, and the power factor is enhanced to provide a better, more energy-efficient solution. It also regulates the power system's transient disturbances including additive harmonics.

(Nanda et al., 2020) proposed Automatic Power Factor Correction Using ATmega328. The proposed technique is based on using of ATmega328. The Emon library is used to code the Arduino controller ATmega328 to perform automatic power factor correction, making it a simpler and more effective solution than alternative approaches. They also went over the benefits of improving power factor, the drawbacks of lagging power factor, the functioning methods, and the potential applications. The results section of their paper was not very clear.

(Pukale et al., 2021) suggested utilizing an Arduino UNO for automatic power factor control. This study demonstrates how to easily and affordably build an automatic power factor correction (APFC) system for single-phase household loads. Using a relay to switch the capacitor banks, the proposed system modifies the power factor of inductive loads. The relay's switching is managed by an Arduino board.

(Dhameliya et al., 2017) suggested Using Arduino Uno for Automatic Power Factor Monitoring. The hardware part of the project was constructed utilizing the Arduino Uno board that employs ATmega328 as its main microcontroller. This study proposes a computationally efficient technique to create and build of a single-phase power factor correction utilizing Arduino Uno micro-controlling chip.

(Pandhare et al., 2018) suggested An APFC Loop-Based Industrial energy use Minimization Penalty.The suggested system makes use of four capacitors, each of which is powered by four relay circuits and controlled via an ATMEGA 328. While the power factor falls below 0.9, a single capacitor is added to the circuit, as well as another is added based on what level the power factor has become. The power factor controllers then command the relay as well as capacitor to remain connected in the circuit, improving the power factor.

(Devman et al., 2023) created the AFPC Unit Project for Industry Power Use Penalty Minimization. Both interrupt ports on the microcontroller receive the time lag that exists between zero-voltage as well as zero-current pulses that are appropriately produced by appropriate operational amplifier circuits operating in comparator modes in the suggested system. It uses an LCD to show the temporal lag between the voltage and current. In order to insert shunt capacitors entering the load circuit and raise the power factor until it approaches unity, the program assumes control and they didn't used thyristor instead of relay for control switching of capacitors as shown in their block diagram. They used four relays for controlling purpose as they put on block diagram.

(Kokate et al., 2018) Suggested Using APFC Unit to Reduce Penalties in Industry Power Factor Correction. In this study, many small rating capacitors are connected in parallel and a reference power factor is set as desired value into the microcontroller. The starting of capacitor is more impracticable than they used appropriate number of static capacitors are automatically connected according to the directive of microcontroller be corrected the power factor near to unity.

(Pukale et al., 2021)(Kamble et al., 2016) Proposed Power Factor Improvement of Industrial Load by Mat lab Simulation. This study; discusses how to calculate the correct value of capacitors.

(Raut, 2022),(Rossetto et al., 2000), (B et al., 2016) and (Shinge et al., 2018) were proposed Programming of PIC Microcontroller for Improvement of Power Factor. They describe the layout and development of a one-phase power factor corrector using PIC (Programmable Interface Circuit) micro- controlling chip unit, after determining their zero crossing locations of load voltage and current waveforms.

(Kumar et al., 2020) suggested reducing the penalty for industrial power use by using the APFC device at the Thermal Power Station- NLCIL's micro distribution. In this work, zero crossing detectors, opto-couplers, an EXOR gate, and some fundamental Arduino microcontroller functions are used to determine the phase difference between voltage and current. Phase angle and accompanying power factor are calculated from the phase difference between the voltage and current measurements. However, they omitted the source code, did not specify the project's application, and obscured the values.

(Rode et al., 2019) proposed Minimizing Penalty in Industry by Automatic Power Factor Correction (APFC). The operating amplifier devices in comparison mode in this suggested system are what create the time lag that separates zero current along with zero voltage pulses, which are supplied to a few alarm pins onto the microcontroller. The LCD displays the lag as time passes between the voltage as well as current.

(Ashokkumar, 2022) and (Devman et al., 2023) were proposed Arduino Uno Based Power Factor Corrector. Dual zero convergence investigators are employed in this suggested structure to detect the absence of a current as well as voltage crossing point. The Micro Controller used in this endeavor is ATMEGA 328 embedded in ARDUINO UNO.

This project will implement Investigation and Design of Power Factor Correction Using Static VAR Generator for Wonji/Shoa Sugar Factory and keep the power factor at 0.99 as well as the final result were simulated by using MATLAB/Simulink.

2.2 Power Factor

The way incoming electricity is utilized measured by the power factor, which an effective manner in our electrical system and defined as True power refers to the total of the vectors representing reactive plus effective power.

Real power (KW) is the actual power source that drives the machinery and produces fruitful, profitable work.

Reactive Power (KVAR) is the power required by certain machinery, such as transformers and motors, to produce a magnetic field that will allow actual work to be done.

Apparent power (KVA) is the total of the actual (active) power plus the power that is reactive combined.

Some equipment's such as motors in sugar industries are used real and reactive currents, while such as heater use only real current. The real currents are the components that are converted by the equipment's in to necessary operations, like the heater's heat production elements. Ampere (A) is the unit of measurement for this current while Watt (W) is for power(Hande et al., 2020).

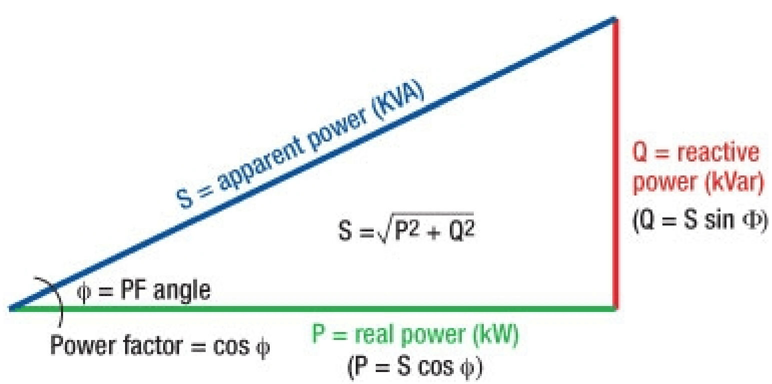

Figure2. 1Power triangle

2.3 Importance of power factor

Within a system of electrical power supplies, a large power factor is kind of advised to reduce losses and boost the importance of voltage management.

To make an appropriate element near an electrical load will minimize the apparent power demand on the power supply. As I described in introduction part, most of loads in sugar industries are inductive load. Because of this inductive load always cause an inadequate power factor as a result of using greater reactivity. In addition to penalizing the sugar sector, these inductive loads' poor power factor results in wasted energy in the power grid. It is agreed up on increasing and decreasing the mechanical load in sugar factory during operation is bringing changes in power factor. In sugar industry, since many inductive loads (motors, fans, belt conveyors, compressors, lathe machines, mills etc.) change due to different applications, the power factor is changes and becomes lower, which is necessarily to be taken care of. To solve this problem reactive power compensation is provided by the user. In the previous time capacitor bank is the solution for reduce reactive power. But in the recent time static VAR generator is the most preferred and important equipment used for correction power factor (compensation reactive power). The research shows that the reactive power formula is a suitable method for determining the correct power factor required in an electrical system.

In this method, two components including actual power and perceived power, or actual power and reactive power (reactive power and apparent power) have main role finding power factor. Once these two parameters are acquired the formula for power factor correction calculates reactive power and fixes the system.

Several methods are available to find these two values. The first method is, measure the voltage, current and change them to wave forms. Then use zero crossing sensors to find their angles. Hence by having voltage, current and cosine angle, the apparent power and power factor are determined. The second methods are installing power analyzer on the system and measure all parameters any loading point.

In my project I use MATLAB/Simulink, which is able to model, simulate and measure the power factor from the designed system. Accordingly, once those values are found, the method of finding PF correction as well as preserving reactive power at any point is easy.

2.4 The Advantages Power Factor Correction

- Avoid the fines from the utility due to the low power factor.
- Reduce electric energy loss and boost the electrical system's capacity.
- Increasing transmission capacity of the power grid and improve the utilization rate of equipment
- Reduce line loss and transformer active loss by heating
- Improve the quality of the voltage, avoid arise voltage drop due to reactive power

2.5. Static VAR Generator (SVG) Benefits

Compared to more conventional reactive power correction techniques like capacitor banks and synchronous condenser Static VAR generators have a number of advantages. Among these benefits are:

Quick Response: Static VAR Generators are useful for balancing dynamic disturbances and loads because they react quickly to changes in the power system.

Continuous Monitoring:

With the constant monitoring that static VAR generators offer over reactive power compensate on, fine tuning and enhanced power quality are possible. The load current either leads or lags the voltage when it generates capacitive or inductive current. SVG creates a leading or lagging current into the system based on its detection of the difference of phase angle. Resulting in a phase angle difference between the current and the transformer side voltage that is nearly the same, indicating a nearly unity basic power factor.

Stability of Voltage: Static VAR Generators inject or absorb reactive power to help control voltage levels, thereby avoiding variations in voltage, disparity in load and keeping the system operating steadily. It offers immediate step-free reactive power adjustment to address low power factor-related power quality issues and harmonic currents generated by extremely dynamic, non-linear changing loads, like inverters, drilling machine, Fiberizer machine, apparatus used in the chemical industry, Aluminum factories, paper industries and sugar factories etc.

Filtration in Harmonic: SVGs can be fitted with extra filters to reduce harmonics and enhance the system's overall power quality. A more economical option PFC and the removal of distorted currents and voltages can be found in hybrid systems that combine SVG and Thyristor.

Condensed Construction: As opposed to customary ways of recompense, smaller physical area is needed for Static VAR Generator. Thus, they can be used small area for building.

2.6 Power Factor correction

A method of generating leading current to offset delaying current with the aid of power electronics devices (Capacitor, IGBT, Diode …) is called power factor correction. These devices are connected as depend on their design and capacities of they were improve.
Power factor correction (PFC) can be implemented by the electrical user to lower expenses from the electrical supplier or implemented by the electrical company to increase the reliability and effectiveness of the transmission lines.
Power factor correction can be used by individual electrical consumers to lower the costs associated with their electricity supplier, or it can be implemented by an electrical power transmission utility to enhance the stability and efficiency of the transmission network.
(Rossetto et al., 2000). Most of an electrical load in the industry are requires both reactive and actual power.

Reactive power is regularly required by the load and is backed up by the origin of power supply. Its cyclical cause occurs when reactive current flows across the load.

Incremental of reactive power within the system cause the decrement of real power and make less than one system power factor

Similarly, incremental Reactive power in the system results in a rise of the amount of current travelling among the load and the electrical source, which raises power flow losses along the distribution and transmission networks. Result causes the problem significant economic and operational declines for Used Power Company. As a result, the power generating firm needed to keep the power factor beyond the required level for their customer, especially for those used high power consumption. The Electrical Engineers must involve in power because engineers were able to reduce power loss in the system through design, the generation, transmission, and distribution of power system, as well as advice on secure electrical system use and design power factor correction for generation companies and customer.

2.7 Improving Power Factor by using SVGs

Static VAR Generators (SVGs) are a family of the transverse FACTS devices. The essential functions of Static VAR Generators are taken, accurate, quick-acting with a capable being quantity of power reactive to the linked alternate current power system. Static VAR Generator is functions as a real-time, regulated Voltage Source Inverter (VSI), supplying any type of current waveform.

SVG works as a controlled Voltage Source Inverter (VSI) providing any kind of current waveform in real time. It is able to accomplish this by continuously modifying magnitude & phase (polarity) of the elements reactive of current passing via of their alternative current set. In the event that the load produces capacitive or inductive current, it results in equilibrium between the current and voltage waveform. It immediately injects after detecting the phase angle discrepancy, resulting to or trailing current into the electrical power systems, bringing the basic (original) power factor to unity by almost matching the phase angle of the current and the voltage.

Internal controller analyses data and the SVG produces the same reactive current, only inverted, the equivalent reactive current of the load, which is fed into grid (S. V. Generator, n.d.).

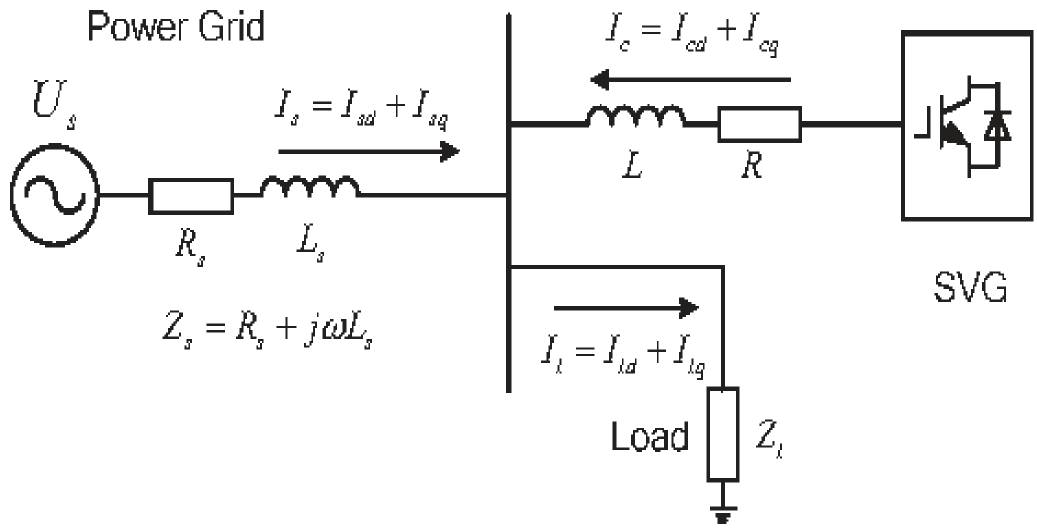

Figure2. 2 Single phase arrangement of Static VAR Generator

2.8 Methods of Power Factor Correction

Adjusting the power factor is possible corrected in several ways. Using capacitor and synchronous condensers are the two well known.

- **Capacitor Banks:** This kind of power factor correction involves installing a bank of capacitors shunt to the load to reduce reactive power while simultaneously raising power factor.
- **Synchronous Condenser:** To rectify the synchronous condenser, it is placed parallel with the amount of load on the system, while the power factor corrects by supplying the capacitive current that neutralizes the reactive power midway.
- **Phase Advancer**: For correcting the phase advancer and power factor are connected via the motor's circuit rotors to strengthen ampere-turns and it helps to gain a leading power factor.
- **Static VAR Compensators (SVCs):** It uses control the reactive power by quickly absorbing or supplying from the system and this was employed to adjust for power factor.
- **Active filter:** In this system at the connection point the filter generates currents in order to cancel harmonics content in the alternative current and to raise the power factor.

- ❖ **STATCOM:** is a suitable correct power factor to mitigate the duty that inductive loads cause on the system.
- ❖ **Hybrid Power Filters:** in this system the active filtering and passive filtering were combined and used for compensating reactive power.

2.9 Common Power Factor Correction Methods in Electrical System

2.9.1 Static capacitor

The static Capacitor to cause to move continuously toward Reactive load current's following component is entirely or partially neutralized by a leading current. The load's power factor rises as a result. For three-phase loads in this system, the capacitors can be connected in a delta or star configuration. To increase the device efficiency, those capacitors are to present nearer to mark by extra ordinarily great of inductive loads.

2.9.2 Synchronous Condenser

Synchronous Condenser is an over-excited synchronous motor above a fixed degree of its exciting work. It is also working like a capacitor whenever a synchronous motor produces leading current due to over excitation. In this case, the losses in the capacitor bank are less than Synchronous Condenser when it was compared. A separate DC source is used to excite the field winding in a synchronous motor. The power factor varies from lagging to unity and leading by increasing the DC excitation. When the field windings are over magnetized DC excitation is increases.

2.9.3 Static VAR Compensator (SVC)

A high voltage power system is used to create the static VAR compensator. It is a combination of both shunt capacitors and reactors. Reactors with thyristor-controlled reactors were used for restraining the voltage increases in low-load or idle situations. While shunt capacitors and thyristor switched capacitors were used for stopping under conditions of peak load, the voltage sags.

2.10 Power Factor Correction Using Static VAR Generator

At recent time most of the research in power system is investigating and designing the system used for reduce reactive power in our day-to-day activities of energy consumption. In general, the load centers are far away from the power generation plant, because of that there are so many power loss factors till it reaches behind customer. During transmission time the overloaded transmission line guide to declination voltage profile, hence diminishing the system stability. For the level of power use, the power factor of the loads linked to the network is significant. Because of consume much of reactive power; the majority of loads in the distribution networks (behind the customers) are inductive. Though it is necessary to control this reactive power by improving power factor. So Static VAR Generator is the most suitable equipment to mitigate this problem for all customers (domestic customer to industrial customer).Static VAR Generator is accomplish this by altering the reactive element of the current passing through their alternate current side virtually continually in terms of both amplitude and polarity (phase). This facilitates the SVGs' nearly constant control over the quantity and trajectory of reactive power interchange with the AC power system. Voltage is compensation by using SVGs parallel the loads in place of electrical distribution links at the ac receiver side. Because of this, SVGs are superior to banks of shunt capacitors in a number of ways, including being immune to harmonic noise. The SVG is ideal for places with rapidly shifting reactive power demands since it is unaffected by harmonic resonance, has a fast speed reaction of less than 15 ms, and a dynamic response period of less than 50 us. It also increases line reliability throughout load variations.

Similarly, in commercial facilities and SVGs are frequently used for dynamic Power Factor Correction, also known as dynamic reactive power compensation, in industrial plants that operate with significant, time-dependent spikes of reactive power demand.

A Static VAR Generator increases the Power Factor of the source where it is applied, minimizes ultimately lowers the operational costs of the facility by minimizing the voltage variations at the source input (which guards against equipment damage). SVG is become a successful method of lowering voltage swings that cause flicker with the availability of forced-commutated components.

In case of those and one of the major reason I select static VAR Generator is, it is the latest technology and used for compensation both capacitive and inductive power in instantly and in a couple of milliseconds adapts to demand. In imbalanced systems, it also makes up for phase-to-phase differences. In a similar vein, SVG is ideal for setups with severe consequences for reactive power use.

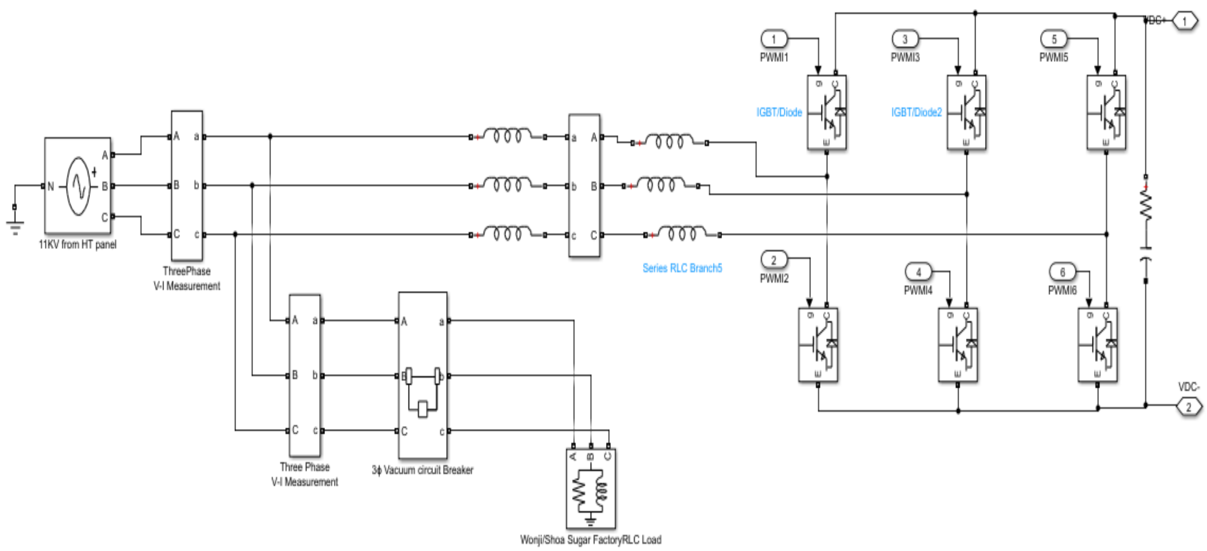

Figure2. 3 Model of Static VAR Generator

Sinusoidal PWM, the basis for controlling the static VAR generator, necessitates measuring current rather than reactive power.

2.10.1 Controller of Static VAR Generator

Constantly maintaining the power factor amount is the fundamental function of the monitoring system when the systems are varied depends on the load. The primary circuit is a three-phase bridge inverter that is connected to the electricity grid via the reactor, as the schematic diagram illustrates. The inverter charges the DC bus capacitor C by regulating the switches PMW1–PWM6 in the main circuit, absorbing a tiny quantity of active current from the AC system so that its voltage is maintained without the need for an external power source.

The SVG control mechanism can generate the necessary reactive power in the grid controlling to make up for the reactive power of the grid by varying the current or voltage at the output of the bridge inverters. The AC data in a three-phase constant coordinate system is converted into a two-phase rotating d-q coordinate system in order to implement both active and passive decoupling regulation. Figure 2.3 illustrates the compensating principle for the Voltage Source Inverter Control approach, which is commonly employed in active filter moderate with low voltage SVG. Both the load and the SVG are regarded as current sources as they are under control. Reactive power compensation is accomplished by controlling the iC to have the identical magnitude but in the opposite polarity of the reactive component of the load current (iL) that requires to be adjusted. This allows the reactive parts of the electrical side of the current to be balanced.

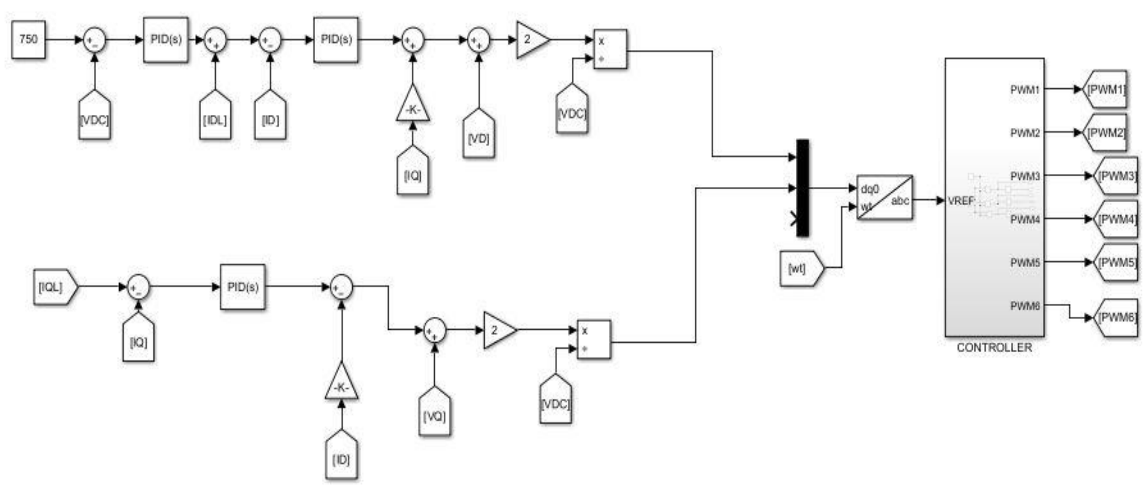

Figure2. 4 Static VAR generator controlling system

2.10.2 The benefits of employing the Static VAR Generator for power factor adjustment over alternative approaches

- Accurate Recompense: Reactive power is constantly output and adjusted to keep a power factor greater than 0.99.Compared to a conventional compensation device (capacitor), the amount of compensation effectiveness is 1.2 times higher.
- **Put an End to Harmonics:** adjusts the reactive power to eliminate superior harmonics and sets the necessary reactive current in instantaneously.
- **Quick Reaction**: Quick analysis and reaction times are made possible by quick configuration capability. Offers dynamic reaction <200us and cycle reaction <5ms.

- **Advantages of Low Voltage:** The primary voltage is supported steadily by output current, which is unaffected by fluctuations in supply voltage.
- **Reduced Losses and Increased Energy Efficiency:** Uses modern, standard IGBT that consumes less power and increases total equipment efficiency to 97%. The mechanism uses little electricity.
- **Simple Expansion and Modular Architecture:** There's no need for extra reactors or capacitors, and the small design saves 20–30% on weight. With a specifically created air path that makes module assembling and expansion easier, it is simple to maintain.
- **Superior Dependability and Safety:** Resonance issues are resolved by robust power system layout, which also removes the need for enhanced harmonic current as well as voltage. It increases the longevity of the system's parts and protects it.
- Its ability to independently regulate voltage leads to a far quicker adjustment of the power factor.
- It is capable of producing an output that is constantly changing without harmonics that are transients, or steps.
- In relation to the system voltage, it has the ability to produce as well as absorb reactive power. In contrast, the reactive electrical output from an AC capacitor is an exponential function for the system voltage.
- Regardless of what each of the phases might require, a traditional switched-capacitor form PFC technology monitors one phase & concurrently supplies step reactive power mitigation across all three phases. The three phases receive separate dynamic reactive power adjustment from the SVG, which also measures them.
- It is capable of controlling Voltage Flicker.
- Its compensatory role is diverse - It has the ability to adjust for both negative-sequence electrical currents and overall reactive power, that arise from imbalanced load currents. Consequently, imbalanced loads can be adjusted and corrected for on the original side. (*Static Var Generator (SVG) Installation Guide*, n.d.).
- Less than 3% of power is lost.

From the various power factor adjustment techniques that have been mentioned Static VAR Generator power factor correction system is the best and most flexible for all customers. That is why I select Static VAR Generator Investigation and design power factor correction in my thesis work for Wonji/Shoa sugar factory.

2.11 Static VAR Generator Operating Principles

Harmonic and fundamental phase shifts are mainly occurred by reactive power. Static VAR Generator should compensate both harmonics and basic reactive power into the device's permitted range, including the exception of basic active elements. In order to accomplish this, SVG is operated as a parallel connected Reactive Power Compensator to the Load. The below figure 2.4 illustrate its working principle and the SVG is represented by the Compensator together with Reactor X(S. V. A. R. Generator, n.d.)

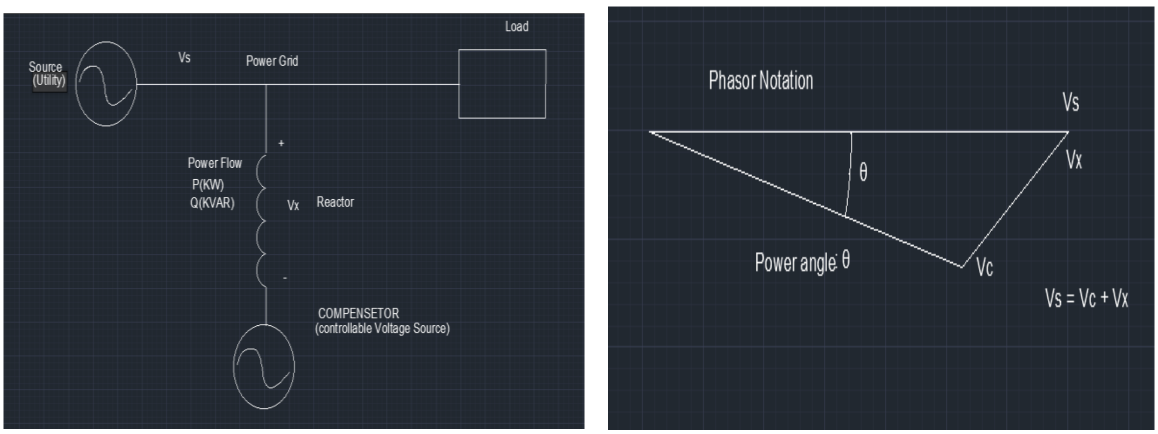

Figure2. 5 Static VAR Generator Operating Principles

The Compensator is a Controllable Voltage Source in which the magnitude of Vc is possible to alter the angle of incidence θ of the compensating voltage Vc in relation to the generating voltage Vs. θ is the angle between Vs and Vc is referred to as the Power Angle. Power in action (kW) and Reactive power (kVAR) can flow between Vs and Vc sources, to supply that there is a certain amount of reactance X between them. The following is an expression for the real power (P) flow among the source of power as well as compensator:

$$P = \frac{|Vs||Vc|}{X}\sin\theta \qquad (2.1)$$

Where |Vs| and |Vc| are the magnitudes of the Vs and Vc phasors respectively. Another way of expressing the reactive power (Q) flowing among the source as well as compensator is as follows:

$$Q = \frac{|Vs||Vc|}{X}\cos\theta - \frac{|Vs|^2}{X} \qquad (2.2)$$

For the reason Reactive Power Compensation, every Compensating device must function as a 100% reactive power origin, neither producing nor consuming any real power

Therefore, the goal is to have P = 0 in equation (2.1). To accomplish this, the Power Angle θ must be controlled on 0°. This means phasor Compensator voltage (Vc) must be controlled to be in phase with Source voltage (Vs) to have zero Real power flow between the Source and Compensator. Therefore, the term sin θ = 0 in equation (2.1) above, forcing P = 0.When using θ = 0° in equation (2.2), it simplifies to the following equation:

$$Q = \frac{|Vs|[|Vc| - |Vs|]}{X} \qquad (2.3)$$

Considering equation (2.3), It is evident a positive power reactive Q will positive result When

|Vc|> |Vs|, and negative when |Vc| < |Vs|. Therefore, by controlling Power Angle θ = 0° and The amplitude as well as direction of reactive electrical power(Q) can be adjusted by varying the value of the compensating voltage Vc in relation to the amplitude of the voltage from the source Vs.

This can be shown by simplified on figure 2.5 below(S. V. A. R. Generator, n.d.).

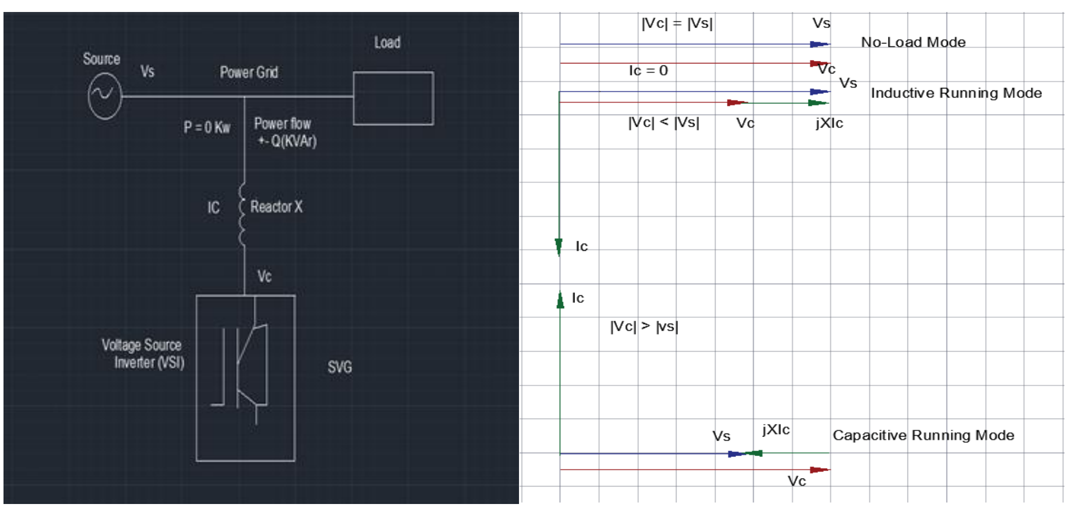

Figure2. 6 Static VAR Generator single line and Phasor diagrams

The Static VAR Generator (SVG) comprises an inverter with a voltage source (VSI) as well as line reactor X. The VSI is a typical static three-phase inverter which can used for DC link capacitor to provide filtering, minimizing fluctuation and generates three-phase pulse-width modulated (PWM) AC voltage waveforms from a single DC voltage, using high frequency switching power transistors called insulated-gate bipolar Transistor (IGBTs).

Through a pulse-width modulation technique The VSI's final voltage Vc is able to adjusted in terms of both phase angle as well as magnitude with respect to the supply voltage Vs. Together, the line reactor X and the VSI form the building blocks of the SVG.

By controlling phasor Vc to be in phase with Vs, the Power Angle θ = 0°. By doing this, the SVG will not generate or absorb any Real power P [kW]. By controlling the magnitude of Vc, the amount as well as direction reactive power Q [kVAR] is controlled, as is explained below:

No-Load Mode: By controlling |Vc| = |Vs|, over the line reactor, there will be a decrease in voltage that zero. Therefore, the Compensator current Ic that is generated by the SVG is zero. This is the No-Load mode as is illustrated in the top phasor diagram on the right. Vs is selected as the reference. In this mode the SVG does not absorb or generate Reactive power. Therefore Q = 0 KVAR.

Inductive Mode: By controlling |Vc| < |Vs|, there will appear a voltage drop across the line reactor, which will result in the Compensator current Ic to lag the Source voltage Vs. The SVG will take up delaying reactive power from electrical grid and function as an inductor. This is the Inductive Running Mode as is illustrated in the center phasor diagram on the right. Remember that current through a reactor always lags the voltage across the reactor by 90°.

Capacitive Mode: By controlling |Vc| > |Vs|, there will appear a voltage drop across the line reactor but opposite in direction as with the Inductive mode. This voltage across X will result in the Compensator current Ic to lead the Source voltage Vs. The SVG will serve as a capacitor and produce the majority of the reactive power entering the power grid. This is the Capacitive Running Mode as is illustrated in the bottom phasor diagram on the right. Because the voltage across X has now shifted by 180° compared to the Inductive Mode, the Compensator current Ic has also shifted by 180°.The SVG is therefore able to correct both leading and lagging Power Factors. When the Load's Power Factor is lagging (i.e., an Inductive Load), the SVG will operate in Capacitive Mode, as is shown in the left box below.

When the Load's Power Factor is leading (i.e., a Capacitive Load), the SVG will operate in Inductive Mode, as is shown in the right box below. And the SVG can change from Inductive Mode to Capacitive Mode in a matter of milli-second(S. V. A. R. Generator, n.d.).

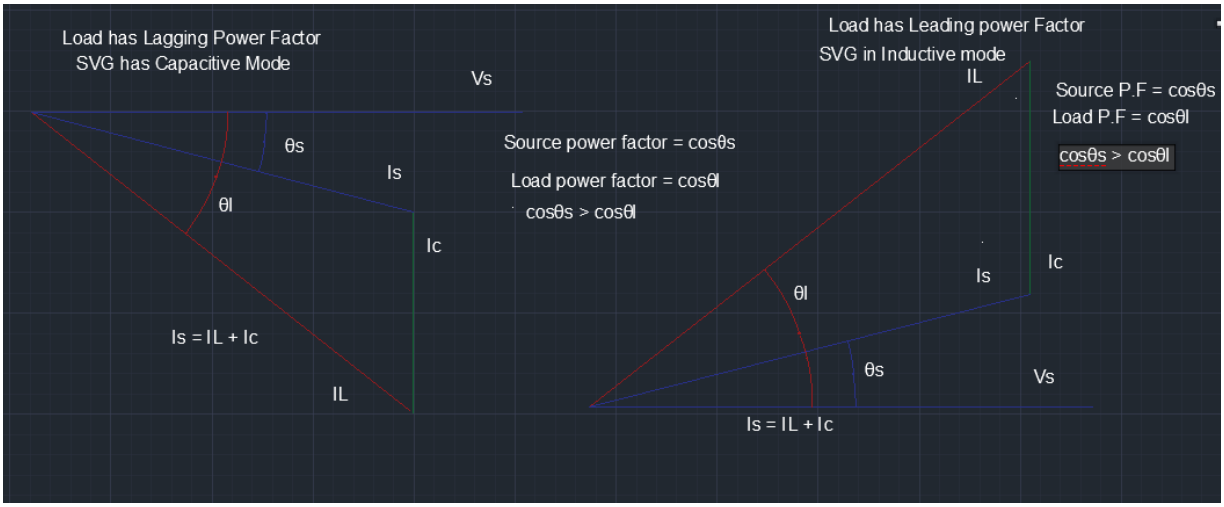

Figure2. 7 Static VAR Generator Operating Mode systems

Structurally Static VAR Generator is a device based on a voltage-source inverter (VSI) that injects or absorbs reactive currents into or out of the power grid by converting a DC input voltage into an AC output voltage. Below is an example wiring diagram for an SVG system that is linked to a power supply.

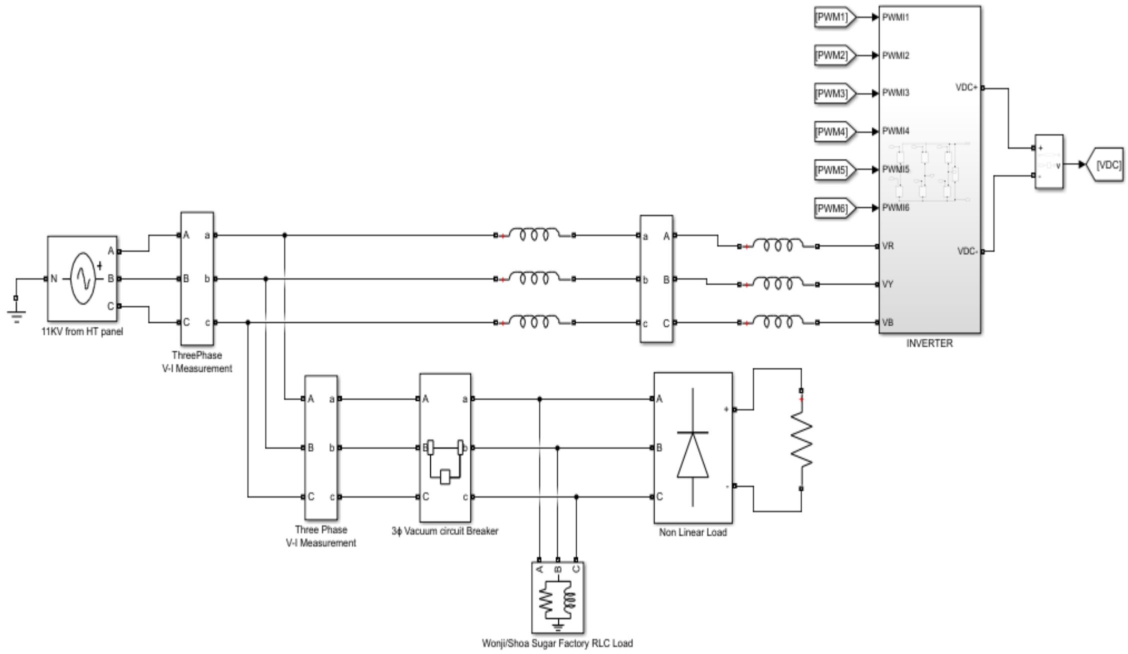

Figure2. 8 Typical wiring diagram of an SVG System connected to a power system

An SVG can provide instantaneous and continuously variable Reactive power in response to reactive power requirements. The SVG operates according to voltage source principles, which together with unique PWM switching of power transistors gives it unequalled performance in terms of effective rating and response speed. This unique performance can be assigned to Active Harmonic Filtering and Voltage Flicker mitigation, but it also allows for dynamic correction of a load's Displacement Power Factor and stabilization of fluctuating system voltages

2.12 Basic Components of Static VAR Generator

The following components are the basic parts of Static VAR Generator which makes the system functionally.

- ✓ Voltage source inverter
- ✓ IGBT
- ✓ Controller system block
- ✓ Phase – Locked Loop

I. Voltage source inverter

Voltage-source inverter (VSI) is the most basic component of a Static VAR Generators. It is used for converts DC power into AC power and is controlled by a sophisticated control system. The control system adjusts the SVG's operation by constantly measures the power system parameters, such as voltage and current. It is also used for DC link capacitor to provide filtering, minimizing fluctuation and generates three-phase pulse-width modulated (PWM) AC voltage waveforms from a single DC voltage, using high frequency switching power transistors called insulated-gate bipolar (IGBTs).

II. Insulated-Gate Bipolar (IGBT)

IGBT are used for timing selection and length could control inverter to generate accurate reactive power compensation current. It is also Compensating inductive reactive power or capacitive reactive power by controlling inverter induction to generate a capacitive current or inductive current to achieve bidirectional reactive power compensation.

III. Controller system block

The main function of the controller system block is used to how the controller processes inputs signals and generates the output signals to control the systems. In this control system the controller system block is measure the root mean square voltage at the load point and no requirements of reactive power measurements. At this system sinusoidal pulse width modulation technique is used for switching the voltage source inverter pose 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. Pulse width modulation generator, generates the sinusoidal PWM waveform or signal.(Mount, n.d.).

IV. Phase – Locked Loop

The main function of a Phase - Locked Loop (PLL) circuit in this system is synchronizing an output value with a reference (input) value. The system is "locked" whenever the phase variation among the two Variables is zero. A PLL is a closed-loop system that has a mechanism for controlling to lessen potential phase errors.

CHAPTER THREE

METHODS AND MATERIALS

3.1 Methodology for Data Collections

The relative item data were gathered from different sources of Wonji/Shoa sugar factory for doing this thesis. The relative data includes

- ✓ Annual average power consumption of wonji/shoa sugar factory during production time (operation season).
- ✓ The consumption of power cost for production during operation in different seasons.
- ✓ Different measured values recorded in one year, such as power factor, currents, reactive power, active power etc.

The increment of power factor & decrement of power loses are depending on the estimated data. The final conclusions, analyzing and suggestions are made depending on the recorded data.

Table3. 1 Wonji/Shoa sugar factory power factor charges.

No.	Sample taken year	Payment amount by power factor	Alive(operation) power factor
1	18/01/2022	114,069.9	0.7598
2	10/02/2022	114,455.05	0.722
3	11/04/022	146,288.69	0.75
4	12/05/2022	157,409.08	0.729
5	06/06/2022	146,019.53	0.746
6	05/12/2022	163,499.74	0.726
7	05/01/2023	92,036.56	0.776
8	04/04/2023	163,499.74	0.726
9	04/05/2023	109,920.54	0.773
10	04/07/2023	138,591.48	0.748
11	03/11/2023	121,021.05	0.757
12	05/12/2023	140,138.95	0.754

The total energy consumed by factory in 12 months as in table appendix B is

$$E_T = \frac{P_T \times t}{1000} \tag{3.1}$$

Where E_T =energy measured in KWh

P = power units in watts (w) and

t = time over which energy consumed

P_T = (9,405+7,063+8,346+7,657+8,071+7,784+6,572+7,784+7,634+7,782+7,310+8,258) KW

= 93,666 KW or 93,666,000 W

t = 8,760 hours in a 12 months or in a year, so by using equation 3.1 we can calculate the result of E_T

$E_T = P_T*t/1000$

= 93,666,000 W * 8,760hr/1000

= 820,514,160 KWh per year

As it was shown on the above equations total active power factory use in 12 months or one year is 93,666 KW or 93,666,000 W.

3.2 Mathematical Modeling of Static VAR Generator

Under this topic the value of Static VAR Generator is accomplished depending on the factory gathered data and the mathematical modeling of static VAR generator is designed for power factor correction systems. From the required for the power factor correction the load reactive power rating, the component rating of the Static VAR Generator such as the compensation Reactive power improvement are obtained. The power output factor adjustment is mathematically constructed and simulated using MAT lab software for before as well as following the system correction, based on the characteristics of the Static VAR Generator.

Table3. 2The given data from Wonji/Shoa Sugar Factory

Types of given data	Values
Load Voltage (VL)	11000 V
Load Current (IL)	6,581.245 A
Average Existing power factor during operation	0.747
Average of Total Energy consumed during operation	820,514,160 KWh per year

3.2.1 Analysis of Electrical Parameters Mathematically of Wonji/Shoa Sugar Factory

As it was shown on equation 3.1 result, the lowest energy consumption of wonji/shoa sugar factory in 12 selected months (during operations) is 820,514,160 KWh while its lowest exiting power factor during operation is 0.722. Considering this result Reactive power and apparent power during this time can be computed by calculating the mean power factor from appendix A, 0.722. We know that,

$$P = \sqrt{3} \times V \times I \times \cos\theta \qquad (3.2)$$

= 93,666,000 = √3*11000 V*I*0.722 from this we get" I" Value

I = 93,666,000 W/√3*11000 V * 0.722

= 93,666,000W/13,755.95 V

I = 6,809.13 A

$$Q = \sqrt{3} \times V \times I \times \sin\theta \qquad (3.3)$$

While Q is reactive power in VAR

To get Sin value we know that from mathematical equation

$$\mathrm{Cos}^2 + Sin^2 = 1 \qquad (3.4)$$

$$Sin^2 = 1 - Cos^2 \qquad (3.5)$$

$$Sin = \sqrt{1 - \mathrm{Cos}^2} \tag{3.6}$$

$= (\sqrt{1} - 0.722^2)$

$= (\sqrt{1} - 0.521284)$

Sin = 0.692

Q = √3 * 11,000 V * 6,809.13 *0.692

Q = 89,774,094.4 VAR or 89,774.0944 KVAR

$$S^2 = P^2 + Q^2 \tag{3.7}$$

$S^{2\,=}$ 93, 666^2 KW $^+$89,774.0944 ^{2} KVAR

S = 8,773,319,556 + 8,059,388,025.3401 16,832,707,581.34

S = 129,740.925 KVA OR 129,740,925 VA

Even if our country (Ethiopia) acceptable standard of power factor is greater than 0.85 most of the countries on the world standard power factor is greater than 0.9 and above of it. From perspective of this, to design Static VAR Generator for Wonji/Shoa Sugar Factory the power factory must be greater than 0.9. This means 0.99

3.2.2 Designing Static VAR Generator Size and Parameter for Wonji/Shoa Sugar Factory

The goal of this thesis project is to improve the power factor of the Wonji/Shoa sugar factory, which was working at the low lagging of 0.722 until recently. The target is now between 0.85 and 0.99. According difference revised papers, researchers etc. the performance of correcting power factor of static VAR Generator is ≥ 0.99. Depending on these parameters, when the power factor of wonji/shoa sugar factory is corrected from 0.722 to 0.99 is as follows.

$$P = \sqrt{3} \times V \times I \times pf \tag{3.8}$$

93,666,000 = √3*11000 V*I*0.99

$$I = 93{,}666{,}000\ W/\sqrt{3}*11000\ V * 0.99$$

$$= 93{,}666{,}000W/18{,}862.033\ V$$

$$I = 4{,}965.85\ A$$

$$Q = \sqrt{3} \times V \times I \times \text{Sin}\,\theta \qquad (3.9)$$

To get Sin value we know that from mathematical equation

$$Cos\theta^2 + Sin\theta^2 = 1 \qquad (3.10)$$

$$Sin\theta^2 = 1 - Cos\theta^2 \qquad (3.11)$$

$$\text{Sin}\ \theta = \sqrt{(1 - \text{Cos}\theta^2)}$$

$$= \sqrt{(1 - 0.99^2)}$$

$$= \sqrt{(1 - 0.9801)}$$

$$= \sqrt{(0.0199)}$$

$$\text{Sin} = 0.141$$

$$Q = \sqrt{3} * 11{,}000\ V * 4{,}965.85\ A * 0.141$$

$$Q = 13{,}340{,}313.084\ VAR \text{ or } 13{,}340.313084\ KVAR$$

$$S^2 = P^2 + Q^2$$

$$S^2 = 93{,}666^2\ KW + 13{,}340.313084^2\ KVAR$$

$$S^2 = 8{,}773{,}319{,}556 + 947{,}508{,}376.08$$

$$S^2 = 8{,}951{,}283{,}509.1793$$

$$S = 94{,}611.222956\ KVA \text{ OR } 94{,}611{,}222.956\ VA$$

From equation 3.3 and 3.9 results we get that compensated reactive power as

$$Q_{comp} = Q_{of\ o.722} - Q_{of\ \ 0.99} \qquad (3.12)$$

= 89,774,094.4 VAR - 13,340,313.084 VAR

= 76,433,781.316VAR or 76,433.781316 KVAR

So as it was shown on (3.12) equation the new designed Static VAR Generator is compensating reactive power (correct power factor) of the system.

When the power factor value is increased to 0.99 by SVG the real power value is 112,850,602.1009W, from this we can calculate Energy consumption like follow.

$E_T = P_T$*t/1000

= 112,850,602.1009*8,760hr/1000

= 988,571,274.404KWh per year

Therefore Upon raising the power factor from 0.722 to 0.99 is the saved energy is

$E_{Tnew} = E_{T0.99} – E_{T0.722}$

= 988,571,274.404KWh KWh per year - 820,514,160 KWh per year

= 168,057,114.04 KWh per year

3.2.3Design of Voltage source Inverter

In this case the system receives power from the DC voltage source. The source is connected to a low-voltage (230 Vrms) 50 Hz grid system. The AC voltage source is a low-voltage grid is represented as a stiff. For grid connection system it is common to choose the grid-connecting inductive reactance is to be 5 to 10 % of the base impedance rating. Additionally the connecting reactance is 10 % of the base impedance. The desired power rating of 10 kW at unity power factor is based on initialized inductor currents. There would be a transient during start-up until the steady state operating conditions are reached when the inductor currents were not initialized.

3.2.4 Design of Controller system block

In order to take command the static VAR generator system to generate active and reactive power, is the source voltage and correct values of the total resistance and inductors the system is achieve the feed forward control system. Errors in these parameters will precede impaired dynamic response and steady state systems. To avoid the problem a PID is used for control active and reactive system of the static VAR generator. In this system, the PID gain is arbitrary designed to satisfy the desired response, while the system under control is simplified to the first order transfer function.

3.2.5 Design of Capacitor Filter

Because of the capacitor impedance is a function of frequency it is used as in analog electronic filters. Frequency-dependent signal capacitor can be affects a signal. Because of this property capacitor is widely used in designing the filter. The basic important of this filter is to block high frequencies and allow low frequencies. In general, the signals which have a low frequency are filter out by capacitor. The value of these signals frequency is near to 0Hz, which is also known as DC signals. So unwanted harmonics are filtered by using this capacitor can be adjusted in power supply circuits to guarantee the least amount of output ripple.

$$C = \frac{I}{2\times f \times Vpp} \tag{3.13}$$

Where 'I' is load current, 'f' is i/p frequency of AC and 'Vpp' is the minimum ripple.

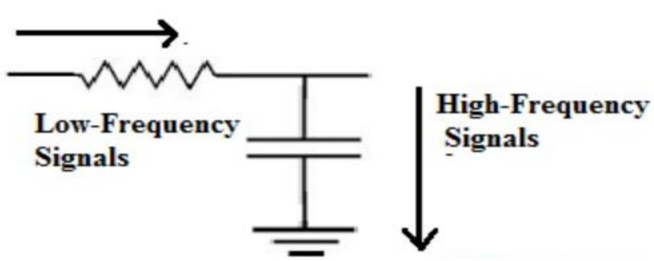

Figure3. 1 Filter Capacitor Circuit

In this circuit, the capacitor works as blocks direct current and like a high pass filter that allows high frequencies. Similarly, they can also work as block AC and low pass filter to allow DC.

For this system C is calculated as

C =I/2fVpp = 4,965.85A/2*50*11000V = 4,965.85/1,100,000

C = 0.0045144 F

3.2.6 Selection of AC inductor for SVG design purpose

The selection of AC inductor for the Static VAR Generator purpose is reduce current in a system to the desired value without loss of power and it is also used for calculating the value of apparent power in the systems. The computation of the current ripple and the selection of a core material that can withstand the estimated current ripple determine its design. The voltage across the inductor is given as below.

$$V = L_i \times \frac{di}{dt} \quad (3.14)$$

$$D = m \times \sin\theta \quad (3.15)$$

$$\sin\theta = \frac{1}{2m} \quad (3.16)$$

While m is the modulation index of ripple (m=1)

For inverters with an AC output, the equation is given as:

$$V_{bus} - V_o = Li \times \frac{i_{pp}}{D \times T_s} \quad (3.17)$$

Where $T_s = 1/f_{sw}$ is switch period

$$i_{pp} = \frac{D \times T_s (V_{bus} - V_0)}{L_i} \quad (3.18)$$

By rearranging the equations

$$i_{pp\,/\,\max} = \frac{V_{bus} \times T_s}{4L_i} \qquad (3.19)$$

$$L = \frac{V_{bus}}{4 \times f_{sw} \times i_{pp}} \qquad (3.20)$$

Where the ripple value in VSI is 15-20% and by taking the switching frequency $f_{sw} =$ 20 KHz we can calculate" L" as follow.

$I_{peak} = \sqrt{2} * I_{lod} = \sqrt{2} * 4965.65 = 7{,}022.5A$

$I_{pp} = I_{peak} * 20\% = 7{,}022.5A * 0.2$

$= 1{,}404.5A$

$L = \frac{11000V}{4 * 20000 * 1{,}404.5A}$

$= 0.097899mH$

3.2.7 Modeling of Static VAR Generator

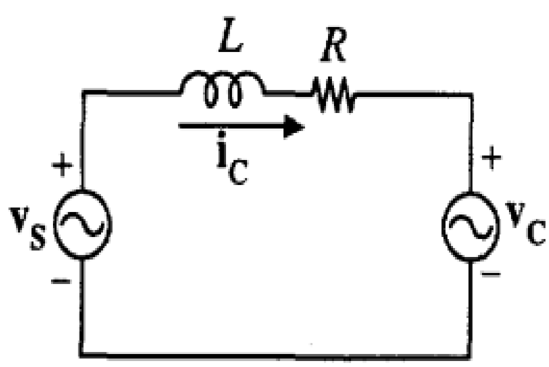

Figure3. 2 Equivalent circuit of static VAR Generator

As it was shown in the circuit of static VAR Generator system, the source voltage is Vs.

, Vc is the static VAR generator's generated voltage, I is the current drawn by Static VAR Generator, where the total inductance and resistance are denoted by L and R. Instantaneous quantities, Ic (static VAR generator current), Vc (static VAR generator voltage), and Vs (static

VAR generator source voltage) are expressed in the αβ-phase frame using the abc-to-αβ transformation [C].

$$Vs = \begin{bmatrix} vS\alpha \\ vS\beta \end{bmatrix} = [C] \begin{bmatrix} vSa \\ vSb \\ vSc \end{bmatrix} \tag{3.21}$$

$$Vc = \begin{bmatrix} vC\alpha \\ vC\beta \end{bmatrix} = [C] \begin{bmatrix} vCa \\ vCb \\ vCc \end{bmatrix} \tag{3.22}$$

$$ic = \begin{bmatrix} iC\alpha \\ iC\beta \end{bmatrix} = [C] \begin{bmatrix} iCa \\ iCb \\ iCc \end{bmatrix} \tag{3.23}$$

Where

$$[C] = \sqrt{\frac{1}{2}} \begin{bmatrix} 1 - \frac{1}{2} - \frac{1}{2} \\ 0 \frac{\sqrt{3}}{2} - \frac{\sqrt{3}}{2} \end{bmatrix} \tag{3.24}$$

From fig 3.2 we have

$$L\frac{dic}{dt} + Ric = Vs - Vg \tag{3.25}$$

Representing those Vs is sinusoidal source voltage,

$$Vs = vs \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix} \tag{3.26}$$

Where vs is the line-to-line voltage's root mean square value and θ is the phase angle.. Additionally we can get dq – coordinate from equation (3.17) and (3.18). By using frame transformation [T]

$$Vs = \begin{bmatrix} vsd \\ vsq \end{bmatrix} = [T]vs \tag{3.27}$$

$$Vc = \begin{bmatrix} vcd \\ vcq \end{bmatrix} = [T]vc \tag{3.28}$$

$$Ic = \begin{bmatrix} Icd \\ Icq \end{bmatrix} = [T]ic \tag{3.29}$$

$$T = \begin{bmatrix} \cos\theta \sin\theta \\ -\sin\theta \cos\theta \end{bmatrix} \tag{3.30}$$

The from the above equations it becomes

$$L\frac{dIc}{dt} + L\varpi \times Ic + RIc = Vs - Vc \tag{3.31}$$

$$L\frac{d}{dt}\begin{bmatrix} Icd \\ Icq \end{bmatrix} + \varpi L\begin{bmatrix} -Icq \\ Icq \end{bmatrix} + R\begin{bmatrix} Icd \\ Icq \end{bmatrix} = \begin{bmatrix} vsd - vcd \\ vsq - vcq \end{bmatrix} \tag{3.32}$$

$$Vs = \begin{bmatrix} vsd \\ vsq \end{bmatrix} = \begin{bmatrix} Vs \\ 0 \end{bmatrix} \tag{3.33}$$

Fig 3.1 is the dqω coordinates where ω=dθ/dt while ω and θ are vectors. When Vsd = Vs and Vsd =0, the active power P, flowing into Reactive Power and Static VAR Generator Q drawn by Static VAR Generator are Calculated as follows.

$$P = VsIcd \tag{3.34}$$

$$Q = VsIcq \tag{3.35}$$

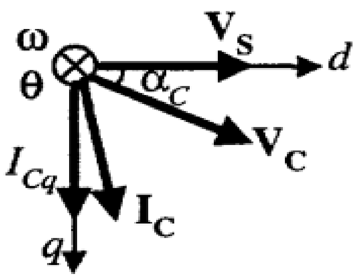

Figure 3. 3 dqω coordinates

From the figrure 3.2 Icd and Icq are the currents that are reactive and active components of Static VAR generator. While Icq is positive Reactive power is falling behind as well as when Icq is negative subsequently reactive power is being led by the static VAR Generator. (*Static Var Generator User Manual*, 2021).

3.2.8 Static VAR Generator Cost analysis

As we discussed in the previous topics, the wonji/shoa sugar factory is paid annually 40,827,858 birr for Ethiopia electric utility (EEU). From this 1,606,950.3 birr is the penalties paid by poor power factor. To improve this problem for Wonji/Shoa sugar the factory needs to increase the power factor from 0.747 to 0.99. By designing Static VAR Generator and installed for the factory.

As conclusion, by using Static VAR Generator the reactive power compensation and power factor correction is used for minimizing operation cost and losses for the factory. When the factory is using Static VAR Generator the total saving cost is about 1,606,950.3 birr per year, while the value of power factory is increased from 0.747 t0 0.99. Because according to our country (Ethiopia Electric Utility) rule, there is no penalty if the power factor value is ≥0.85. Therefore from the popular methods of capital budgeting technique examination this technique of financial appraisal is utilized to evaluate capital investments and determine the annual return from the project's inception until the total returns equal the investment's cost. At this point, the investment is considered to have been provided back, and the amount of time needed to accomplish this payback is known as a payback period (Femi & Olawale, 2008).

Payback period = initial Investment/ Operational Cash Flow for the year

Initial investment is an installation costs, test and commissions etc. while Annual operational Cash Flow is the annual benefit minus annual expenses like operating cost and maintenance costs.

Table3. 3Cost analysis of Static VAR Generator Component

Static VAR Generator components and their costs					
no	Name of components	Specification	Their piece price	No of needed	Total cost in Ethiopian birr
1	Three phase VI measurement	11kv rate VI measurement	Rs100,000	3	1.27*3*100,000 =381,000
2	Three phase breaker	11kv Vacuum circuit breaker	$2,755.16	1	275,516
3	IGBT	11KV, 50Hz indoor installation	100,000 birr	6	6*100,000 =600,000
4	Phase locked loop	For high voltage	$550	1	550*100 =55,000
5	Capacitor Filters	11kv high voltage capacitor	$1000-2200	3	3*2200*100 = 660,000
6	Static VAR Generator controller	Indoor installation	$1,500	1	1500*100 =150,000
7	Static VAR Generator cabinet	3 m by 1.2m	40,000 birr	1	40,000
	Total cost				2,161,516 birr

So as it shown on the table 3.3 the project cost to install for wonji/Shoa sugar factory is 2,161,516 birr. Starting from this we can calculate the repayment duration as follows.

Payback period (repayment duration) = Cost of Project/ yearly cash flow

= 2,161,516/40,827,858 = 0.053 year or 19.345 days

CHAPTER FOUR

RESULTS AND DICUTIONS

4.1 Power Feeder systems For Wonji/Shoa Sugar Factory

The sugar factory power systems is supplied by Awash Melkasa substation with 3Ø, 132kv lines are fed to wonji/shoa sugar factory then step down to 3Ø, 11kv and enters to High tension(HT) of the factory. After it was entered the HT, there were 11kv Diesel generator (DG) and 11kv steam turbine output Vacuum circuit breakers with synchronize which is used for synchronization each other's to Access them for the operation systems. After their were synchronized here, there were distributed by different Vacuum circuit breakers to different plants like, power generation plant, mill plant, pan house plant, Evaporation plant and boiling plant transformers for step down and drive the systems according to their supply needed.

According to Wonji/shoa sugar factory the total designed producing by their own steam power generation is 31.5 MW electric powers and the contribution to national grid is 21.5 MW with around 10 MW for their own consumption. But the turbine was failed before 10 years and they got supply from the Ethiopia power corporation. Because of this they paid more than 40,827,858 annually during operation times for Ethiopia electric utility (EEU) and from this 1,606,950.3 birr is the penalties paid by poor power factor. Reactive power compensation as well as power factor modification must be designed for in order to prevent this issue wonji/shoa sugar factory by using Static VAR Generator.

4.2 MATLAB Simulation and Result before the Static VAR Generator is connected to Wonji/Shoa Sugar Factory Load.

Due to the many inductive loads are present in sugar factory, the factory is forced for low power factor. Similar to this there is so many faults, such as short circuits, phase to phase, phase to ground, and ground faults over loaded etc. this happened in factory during operations are also forced the power system to become unstable and which is supporting it for low power factors. For simulation purposes, these loads are connected before the systems are phased in relation to the static VAR generator. Design as well as investigation for Wonji/Shoa sugar plant below, in figure 4.1, is the load. In this simulation, the operating current's three-phase waveforms, as well as voltage are shown figure 4.2 on the scope out puts and the power factor result is shown on figure 4.1 display.

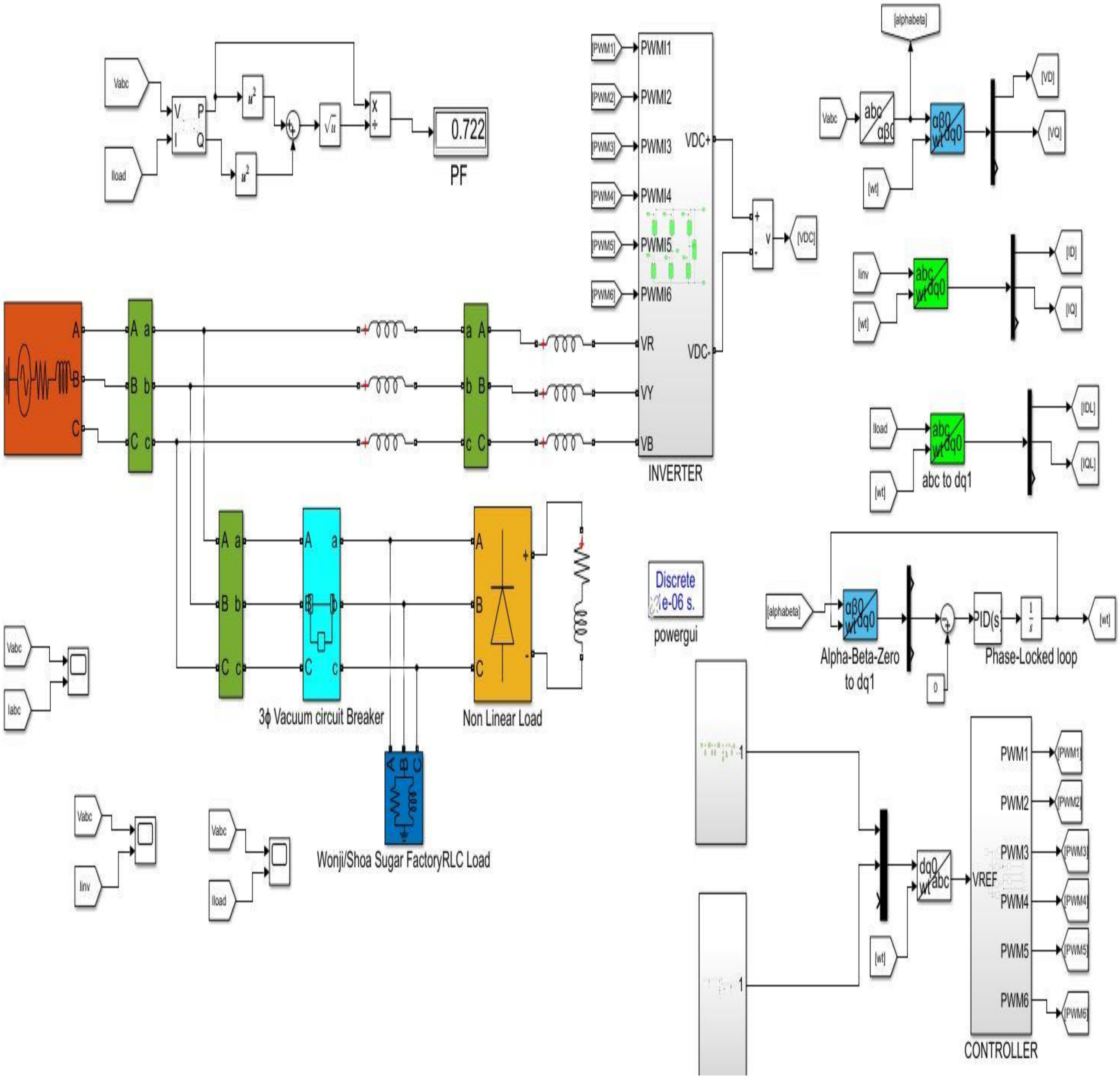

Figure4. 1 The Design and Simulation Diagram of Wonji/Shoa Sugar Factory load without Static VAR Generator connection by using Mat lab Software.

Three phase the voltage and current waveform simulation result from MATLAB before the power factory is corrected.

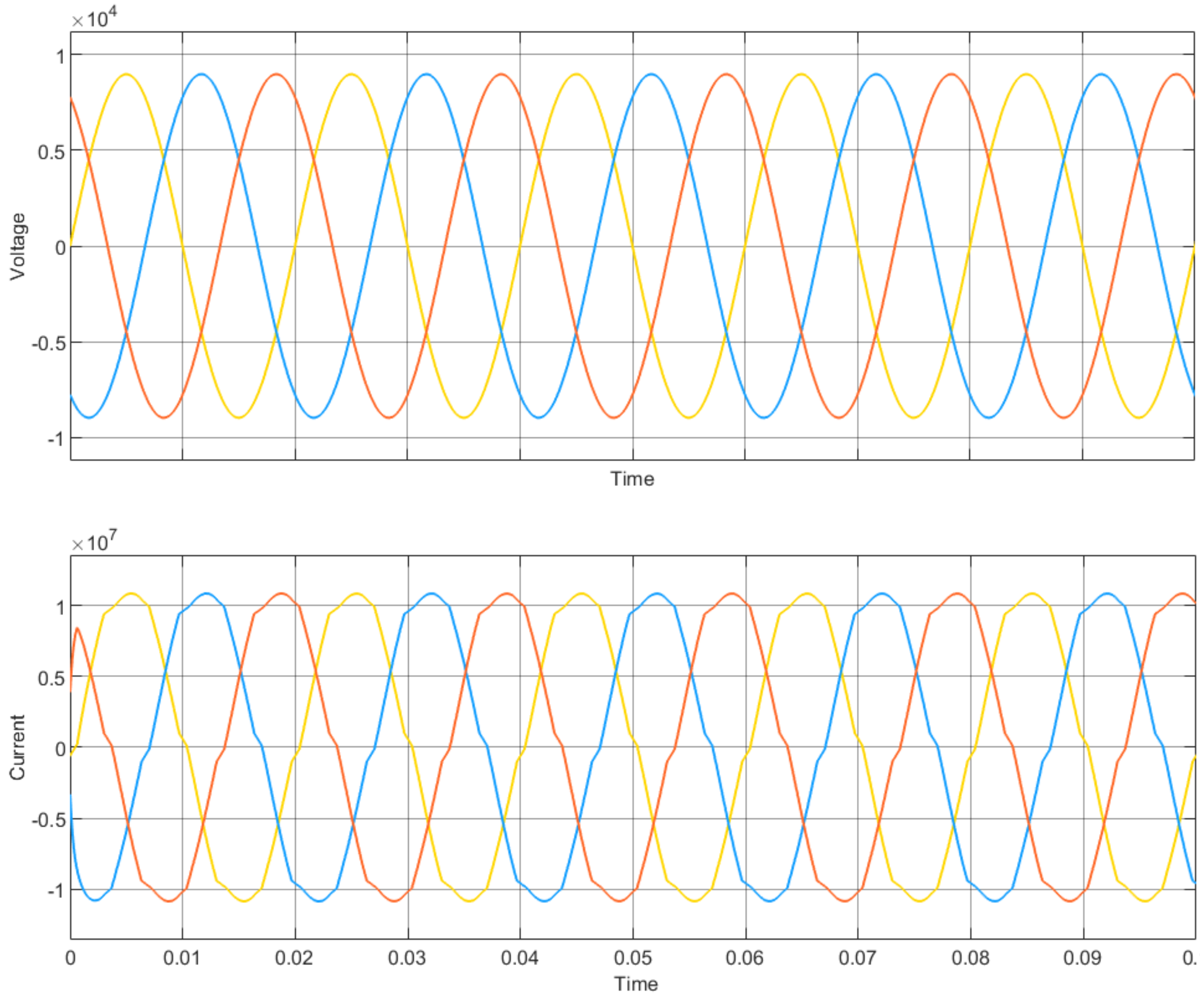

Figure4. 2 Voltage as well as Current Compared to Time Waveform Simulation Results in MATLAB before Static VAR Generator was Connected to Wonji/Shoa Sugar Factory.

As shown on fig 4.2 the three phase current waveform (load current) is distorted, which the factory was forced for low power factor. To solve this problem the Wonji/ Shoa sugar factory had to connect in parallel with Static VAR Generator. As it shown in figure 4.1 the nonlinear loads Couse distort in current waves. And these distorted systems were pushed it for harmonics, which can lead the power system vital for both the equipment's of distribution systems and the loads connected to it. When there are harmonics in the network, the loads are requires greater reactive power. By this reason the power factor becomes lower. Then the distorted output is connected to the V-I inverter and the inverter load output can be shown as figure 4.3 below.

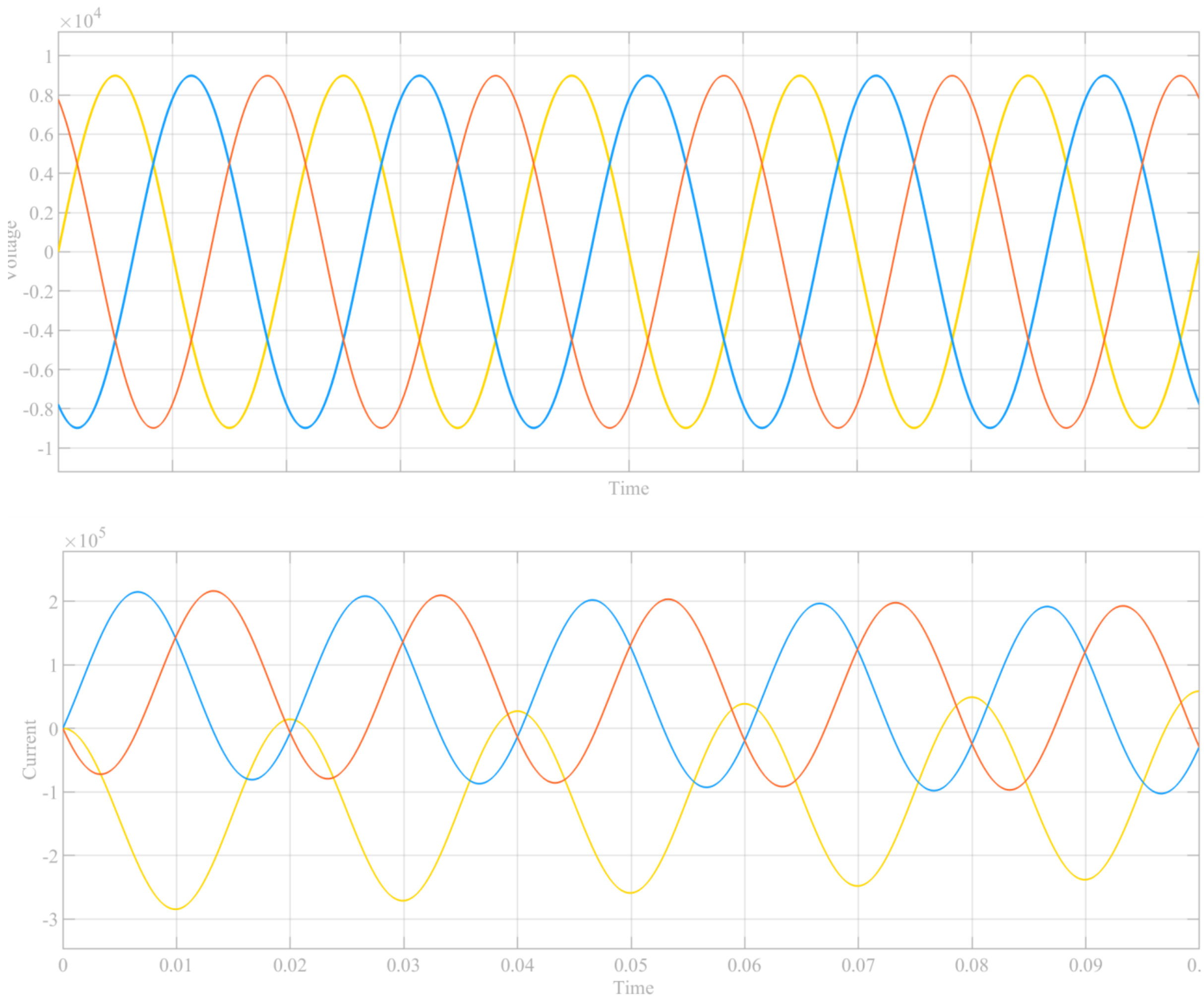

Figure4. 3 Results of a MATLAB simulation of the inverter load verses.

4.3 MATLAB Simulation and Result after the Static VAR Generator is connected to Wonji/Shoa Sugar Factory Loads systems.

As it was discussed on topic 4.2 before the Static VAR Generator is connected to wonji/shoa Suagar Factory systems, the occurred distorted systems was follows the low power factor (0.722).

The load of Wonji/Shoa Sugar Factory represented in this Simulink is adjusted by connecting the SVG as shown in the following Figure 4.4. The simulated load's three-phase waveform in this simulation distorted system is removed and it was same to as the voltage wave system, because of this the power factor is also corrected to provide point (0.99).

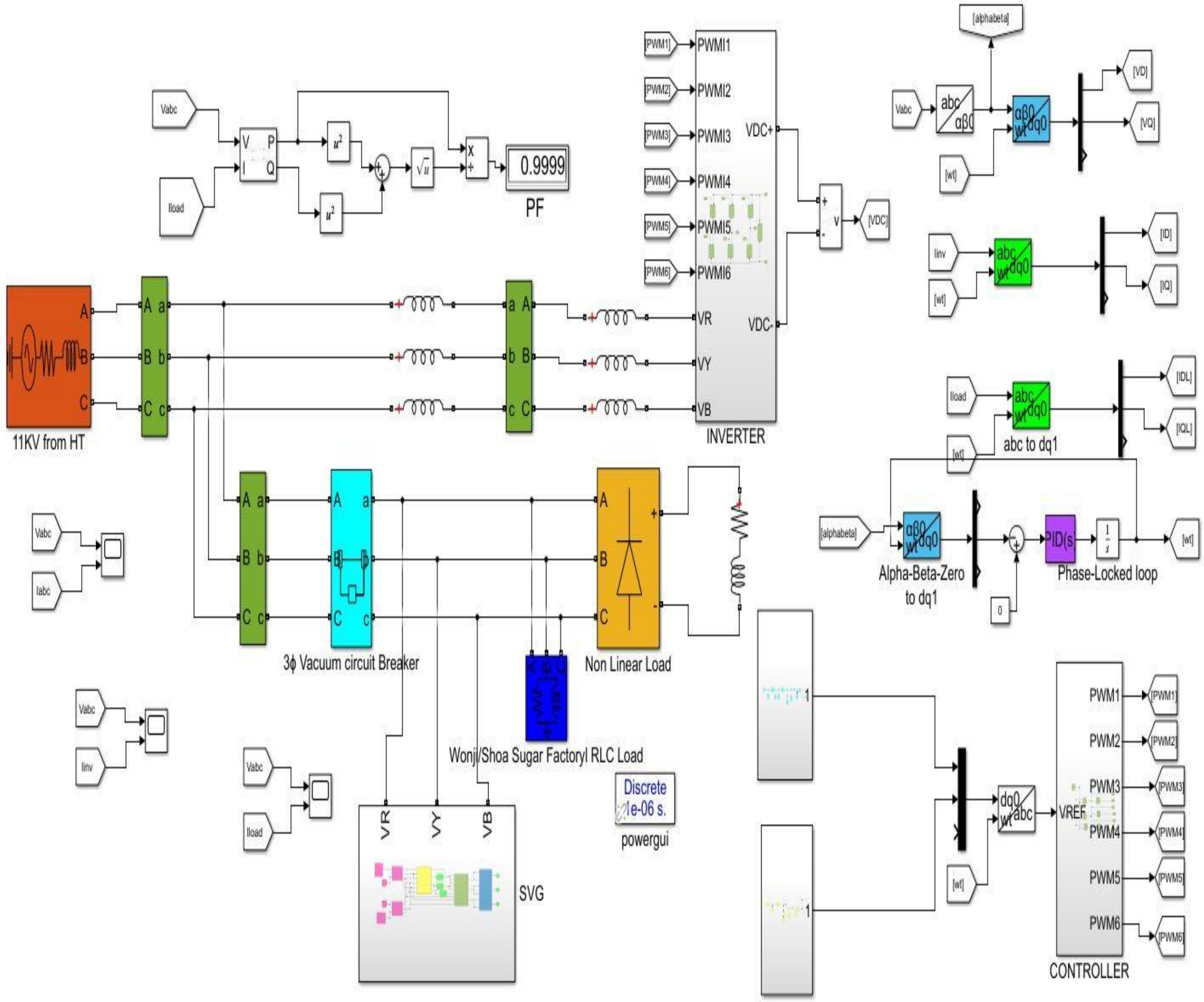

Figure4. 4 The Modeled circuit Diagram and connected of Static VAR Generator for Wonji/Shoa Sugar Factory in MATLAB Simulink with its Load.

For this correction system in order to attain bidirectional reactive power compensation, IGBT regulates the induction of the inverter to produce either a capacitive current of an inductive current control mechanism applied to generate gate pulses. Static VAR Generator is utilized on this distribution reduces distorted current waveform on by nonlinear loads. Figure 4.5 shows the current waveform after compensated and the figure 4.4 also shows the power factor result out put on displays (0.99).

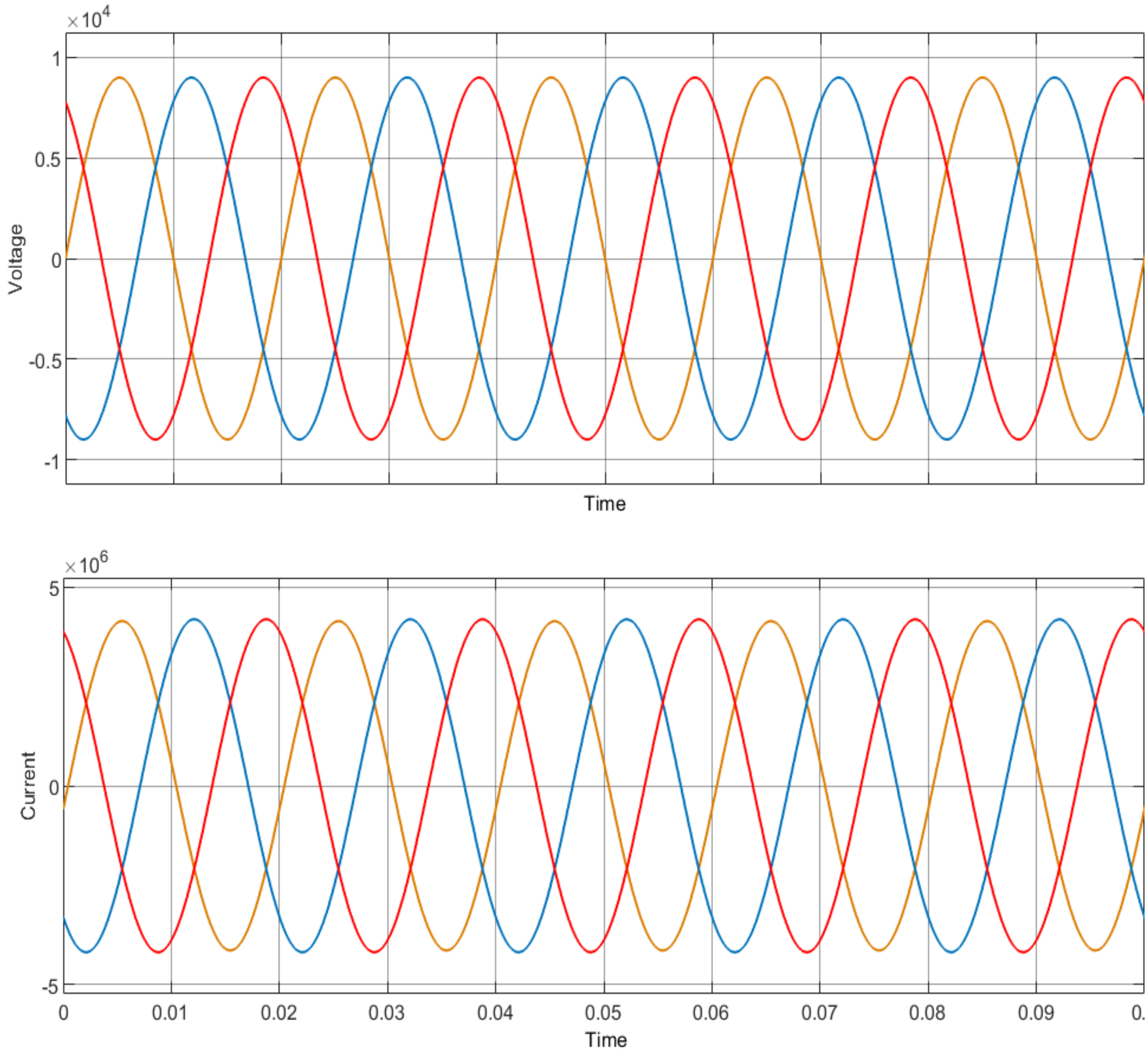

Figure4. 5 the Result of MATLAB Simulation Current and Voltage vs Time Waveform following the Static VAR Generator is connecting to Wonji/Shoa Sugar Factory Load.

The Static VAR Generator is connected in parallel to rectify the distorted three-phase load current seen in Figure 4.2. Of Wonji/Shoa Sugar factory loads, and the load voltage is controlled in same similar input Values. So it was seen that the three-phase inverter waveform Figure 4.3. Take a quick corrective action to manage the distorted current and power factor correcting system in factory loads by provided Static VAR Generator.

4.4. Discussions

Static VAR Generator is based on high power Voltage Inverter. This means that the needed reactive power can be adjusted by varying the amplitude as well as phase of the load's outputs current can be quickly absorbed or released. It is also a, superior dependability and quality of power, high performance and appropriate to active compensating of capacitive as well as inductive loads can resolve challenging issues in the reactive power compensation industry. With a power factor following compensation of greater than 0.99, SVG reactive power converter may accomplish accurate compensation with short response times, surpassing the accuracy of SVC compensator by 99.9%.

The wonji/Shoa Sugar factory Power distribution network system is studied as well as modeled with MATLAB/SIMULINK. Three-phase sinusoidal voltage supply with linear and When using non-linear loads to simulate factory's network distribution system. While the real power of the loads is taken into consideration, the active and reactive power of a series R load defines the linear loads to model nonlinear loads, a three-phase rectifier with R loads is employed. Finally, a simulation of the modeled distribution network is accomplished with and without the using of Static VAR Generator.

Upon connecting the Static VAR Generator to the electrical system, the waveform of the source current transforms into a pure sinusoidal wave. So the mentioned Static VAR Generator can correct the power factor which is 0.722 exists in the system.

CHAPTER FIVE

CONCLUSION, RECOMMENDATION AND FUTURE WORK

5.1. Conclusions

Regarding this thesis project, a Static VAR Generator is used for investigation, design and power factor correction at Wonji/Shoa Sugar Factory using IGBT inductive reactive power compensation or regulating the inverter's induction to produce capacitive current to provide capacitive reactive electrical power gate pulses are produced using a bidirectional reactive power compensation control system that uses inductive current. Various power factor adjustment methods were examined and researched. Among those methods, the Static VAR Generator power factor correction technique was chosen, and thanks to the low power factor, the 0.722 lagging was greatly corrected to fall between 0.85 and 0.99 lagging.

The different function of Static VAR Generator in nonlinear and linear distribution system such as elimination of harmonics, compensation the current sources and balancing the load were showed clearly as anticipated in the power factor correction system. Under all different loads, the Static VAR Generator's dc voltage output was controlled.

The details of the Static VAR Generator elements utilized in this thesis project are investigated and developed in accordance with the factory's required reactive power. Based on these studies and plans, the poor power factor in the Wonji/Shoa Sugar plant was adjusted from 0.722 lagging to 0.99 lagging in the MATLAB simulation results of the Static VAR Generator

Because of this Power factor was corrected; the factory will save 133,912.525 birr per month penalty bill of charges. Similarly the Ethiopian Electrical Utility (EEU) saves 70,043,742.916 KVAR powers which were consumed by Wonji/Shoa Sugar Factory each and every second.

Depend on the results of the MATLAB Simulation test, it's determined that the Investigated and Designed Static VAR Generator and its control mechanism of the inductive inverter to produce a capacitive current or Power factor correction in dynamic loads can be achieved with inductive current used to produce gate pulses in order to provide bidirectional reactive power compensation.

5.2. Recommendations

The flexible and proper technology is succeeding to use the efficient electrical power, which is achieved through minimizing electrical power consumption and changing the process of production. For Wonji/Shoa Sugar Factory, the Static VAR Generator Technique of power factor correction was investigated, designed and simulated in this thesis.

As it was shown on simulated results of the low power factor correction of factory was corrected, which is saving 168,057,114.04 KWh per year electrical energy. The factory will advise the following points from this thesis work of stand point. The majority of the sugar industry machines have a large inductive load, which causes low power factors, though to control these inductive loads the factory have to change the milling system to diffuser systems, install steam turbines and redesign the power factor correction of the factory by using the latest technologies like Static VAR Generator.

5.3. Suggestions for Future Work

This thesis is used to finding the point a number of topics for further investigation and research which is done under huge factories. As it was discussed this thesis summarizes research done on the Wonji/Shoa Sugar Factory specifically for the purpose of power factor adjustment. Further study can be conducted if a thorough Harmonics mitigation and controlling fluctuating power issues are undertaken. Power interruption (instability) was happened more times. Because of this the factory was lost many sources. So this may require more research.

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APPENDICES

Appendix A: power factor of Wonji/Shoa Sugar Factory recorded on different months

No	Date of recorded	Taken from energy meter
1	12/05/2021	0.7598
2	17/11/2021	0.722
3	18/01/2022	0.75
4	10/02/2022	0.729
5	11/04/022	0.746
6	12/05/2022	0.726
7	06/06/2022	0.776
8	12/05/2022	0.726
9	05/01/2023	0.773
10	06/03/2023	0.748
11	04/04/2023	0.757
12	04/01/2024	0.754
Average		0.747

Appendix B: Wonji/Shoa Sugar Factory Energy consumption on different months

Table B-1 Energy Consumption recorded at factory and billed by Ethiopia Electric Utility

No.	Invoice date	Active energy (KWH)	Max. demand (KW)	Power factor	Active energy cost ETB birr	Max. demand cost ETB birr	Power factor cost ETB birr	Total energy cost ETB birr
1	12/05/2021	198,000	9,405	0.7598	3,178,180.96	618,190.65	114,069.9	3,910,495.54
2	17/11/2021	704,035	7,063	0.722	556,962.09	464,250.99	114,455.05	1,135,722.13
3	18/01/2022	4,353,204	8,346	0.75	4,039,773.31	731,443.44	146,288.69	4,917,559.44
4	10/02/2022	3,218,195	7,657	0.729	2,986,484.96	671,059.48	157,409.08	2,986,484.96
5	11/04/022	3,828,083	8,071	0.746	3,552,461.02	707,342.44	146,019.53	4,405,876.99
6	12/05/2022	3,171,696	7,784	0.726	2,943,333.89	682,189.76	163,499.74	3,789,077.39

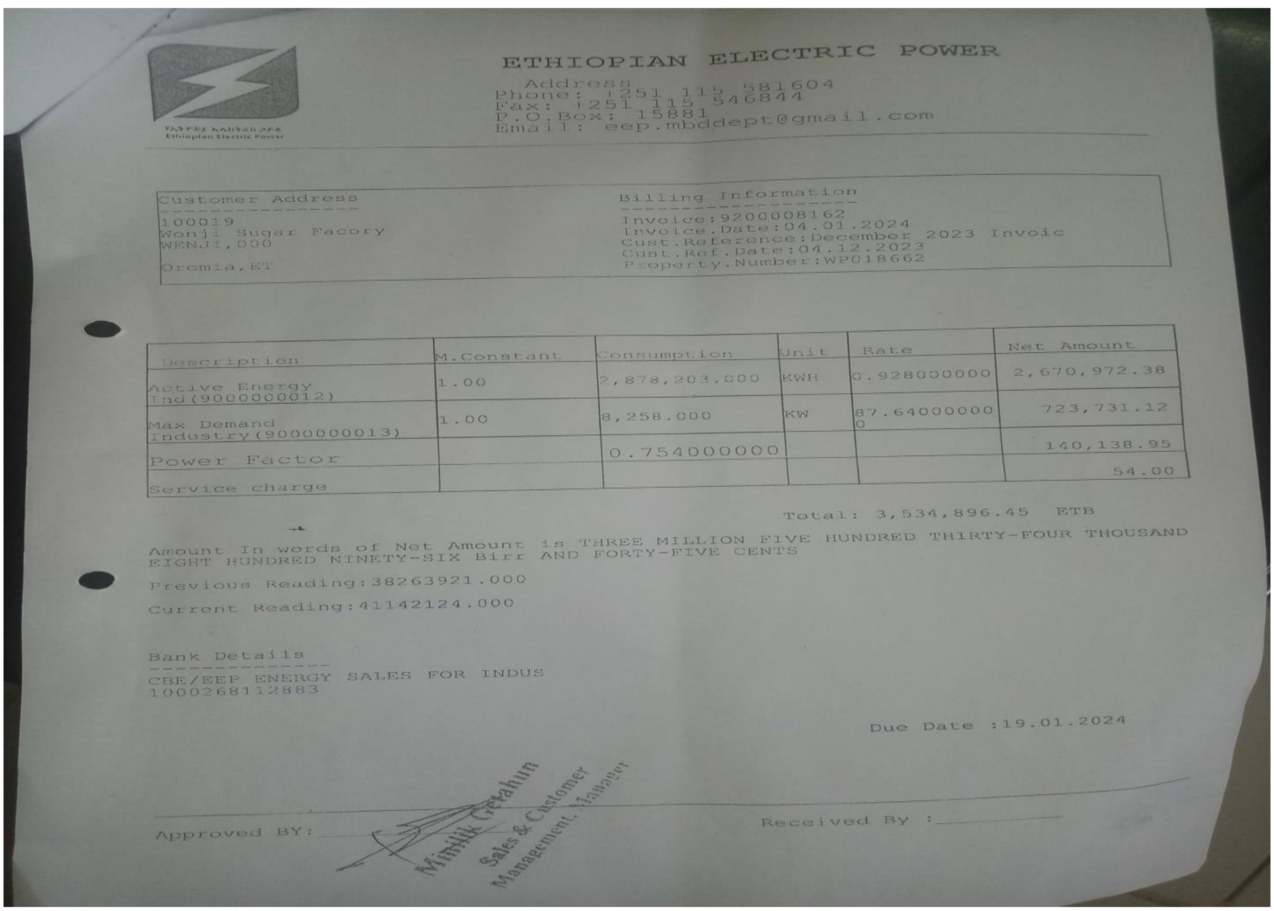
7	06/06/2022	788,157	6,572	0.776	731,409.70	575,970.08	92,036.56	1,399,470.34
8	12/05/2022	3,171,696	7,784	0.726	2,943,333.89	682,189.76	163,499.74	3,789,077.39
9	05/01/2023	3,994,721	7,634	0.773	3,707,101.09	669,043.76	109,920.54	4,486,119.39
10	06/03/2023	3,597,609	7,782	0.748	3,338,581.15	682,014.48	138,591.48	4,159,241.11
11	04/04/2023	1,672,536	7,310	0.757	1,552,113.41	640,648.40	121,021.05	2,313,836.86
12	04/01/2024	2,676,203	8,258	0.754	2,670,972.38	723,731.12	140,138.95	3,534,896.45
Total							1,606,950.3	40,827,858

Appendix C: Wonji/Shoa Sugar Factory Major Transformers with their ratigs.

Name	Purpose (used for)	Quantity	High side Voltage(V) and Current(A)		Low side Voltage (V)and Current(A)		Rating (KVA)	Type of their connections	
								High side	Low side
Substation Transformer	Feed supply to factory and grid	1	32000	105.97 -131.2	11000	1260-1575	30,000	star	delta
Utility and power Generation Transformer	Feed supply to Utility and power Generation	1	11000	165	400	4546	3150	delta	star
Pan house Transformer	Feed supply to Pan house	1	11000	165	400	4546	3150	delta	star
Boiling and Evaporation house Transformer	Feed supply to Boiling, RO Evaporation plants	1		165	400	4546	3150	delta	star
Mill house Transformer	Feed supply to	5	11000	66	690	509	1250	delta	Star and delta

ID and FD Fans transformer	Feed supply to ID and FD fans	1	11000	163	690	1318	3150	delta	Star and delta
Earthing Transformer	Feed supply to Power generation	1	11000	2500	-	-		star	-
Diesel Generator Transformer	Feed supply to Power generation	1	11000	-	400	-	3250	delta	star

Appendix D: Wonji/Shoa Sugar Factory Consumed Energy and Power Factor Charge Bill.



ETHIOPIAN ELECTRIC POWER

Address
Phone: +251 115 581604
Fax: +251 115 546844
P.O.Box: 15881
Email: eep.mbddept@gmail.com

Customer Address
100019
Wonji Sugar Facory
WENJI,000
Oromia,ET

Billing Information
Invoice:9200008162
Invoice.Date:04.01.2024
Cust.Reference:December 2023 Invoic
Cust.Ref.Date:04.12.2023
Property.Number:WP018662

Description	M.Constant	Consumption	Unit	Rate	Net Amount
Active Energy Ind(9000000012)	1.00	2,878,203.000	KWH	0.928000000	2,670,972.38
Max Demand Industry(9000000013)	1.00	8,258.000	KW	87.64000000 0	723,731.12
Power Factor		0.754000000			140,138.95
Service charge					54.00

Total: 3,534,896.45 ETB

Amount In words of Net Amount is THREE MILLION FIVE HUNDRED THIRTY-FOUR THOUSAND EIGHT HUNDRED NINETY-SIX Birr AND FORTY-FIVE CENTS

Previous Reading:38263921.000

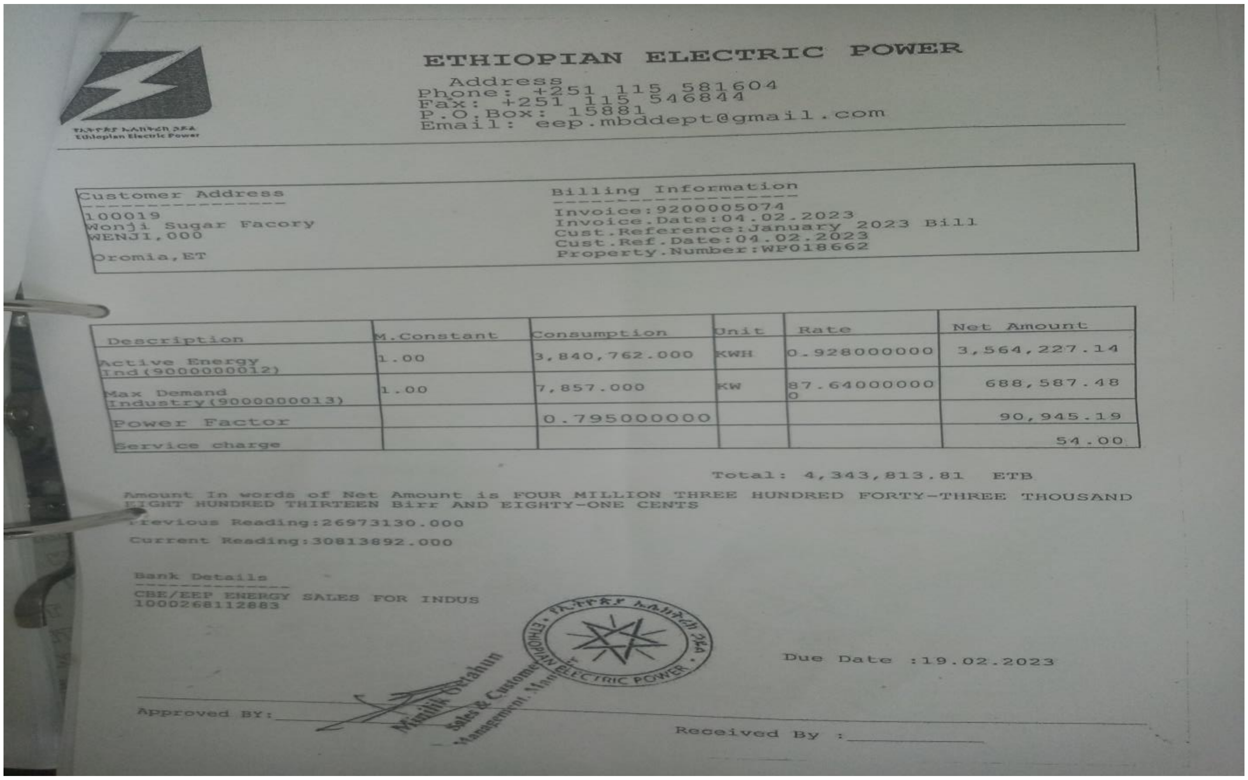
Current Reading:41142124.000

Bank Details
CBE/EEP ENERGY SALES FOR INDUS
1000268112883

Due Date :19.01.2024

Approved BY: Minilik Getahun Sales & Customer Management Manager

Received By :



ETHIOPIAN ELECTRIC POWER

Address
Phone: +251 115 581604
Fax: +251 115 546844
P.O.Box: 15881
Email: eep.mbddept@gmail.com

Customer Address	Billing Information
100019 Wonji Sugar Facory WENJI,000 Oromia,ET	Invoice:9200005074 Invoice.Date:04.02.2023 Cust.Reference:January 2023 Bill Cust.Ref.Date:04.02.2023 Property.Number:WP018662

Description	M.Constant	Consumption	Unit	Rate	Net Amount
Active Energy Ind(9000000012)	1.00	3,840,762.000	KWH	0.928000000	3,564,227.14
Max Demand Industry(9000000013)	1.00	7,857.000	KW	87.64000000 0	688,587.48
Power Factor		0.795000000			90,945.19
Service charge					54.00

Total: 4,343,813.81 ETB

Amount In words of Net Amount is FOUR MILLION THREE HUNDRED FORTY-THREE THOUSAND EIGHT HUNDRED THIRTEEN Birr AND EIGHTY-ONE CENTS

Previous Reading:26973130.000

Current Reading:30813892.000

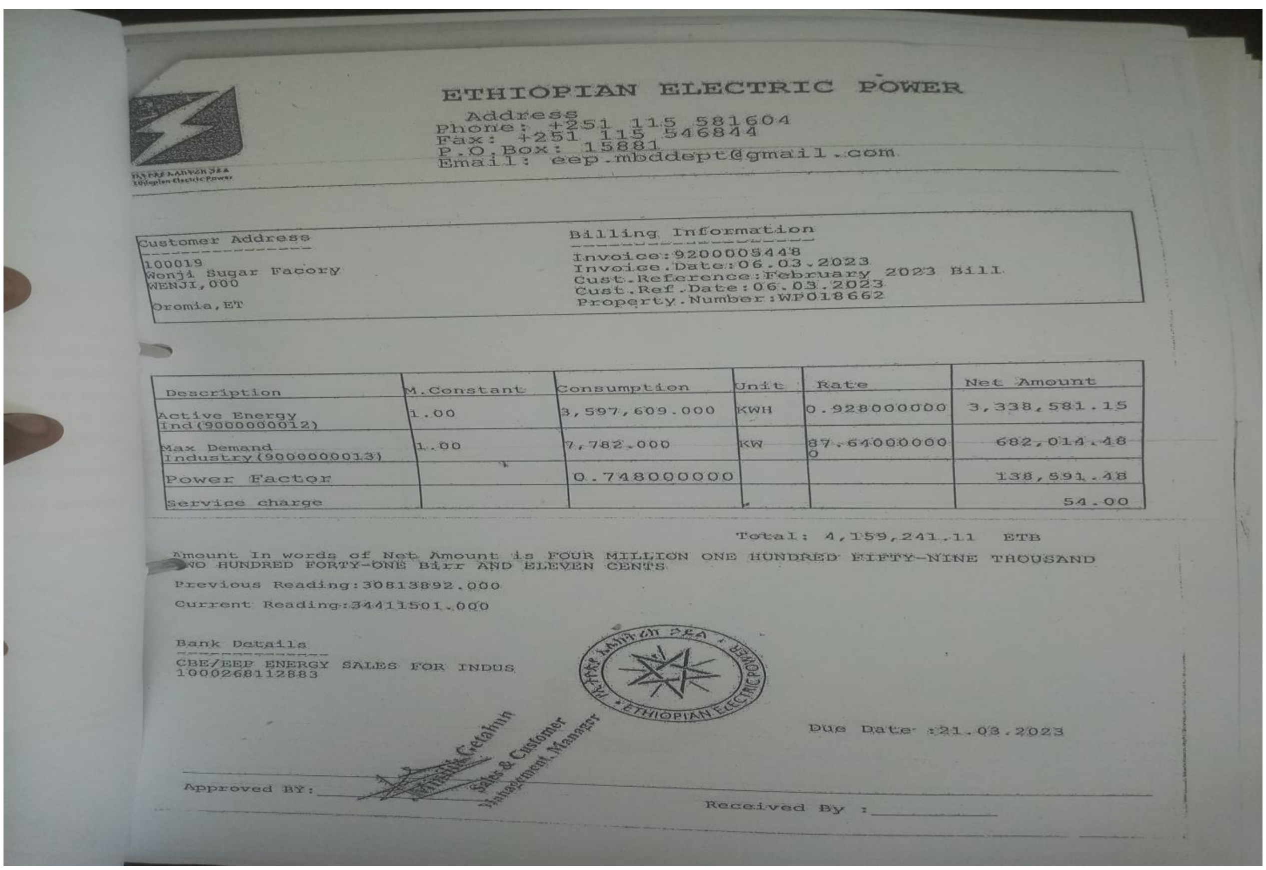
Bank Details

CBE/EEP ENERGY SALES FOR INDUS
1000268112883

Due Date :19.02.2023

Approved BY: Minilik Getahun Sales & Customer Management Manager

Received By :



ETHIOPIAN ELECTRIC POWER

Address
Phone: +251 115 581604
Fax: +251 115 546844
P.O.Box: 15881
Email: eep.mbddept@gmail.com

Customer Address	Billing Information
100019 Wonji Sugar Facory WENJI,000 Oromia,ET	Invoice:9200005448 Invoice.Date:06.03.2023 Cust.Reference:February 2023 Bill Cust.Ref.Date:06.03.2023 Property.Number:WP018662

Description	M.Constant	Consumption	Unit	Rate	Net Amount
Active Energy Ind(9000000012)	1.00	3,597,609.000	KWH	0.928000000	3,338,581.15
Max Demand Industry(9000000013)	1.00	7,782.000	KW	87.64000000 0	682,014.48
Power Factor		0.748000000			138,591.48
Service charge					54.00

Total: 4,159,241.11 ETB

Amount In words of Net Amount is FOUR MILLION ONE HUNDRED FIFTY-NINE THOUSAND TWO HUNDRED FORTY-ONE Birr AND ELEVEN CENTS

Previous Reading:30813892.000

Current Reading:34411501.000

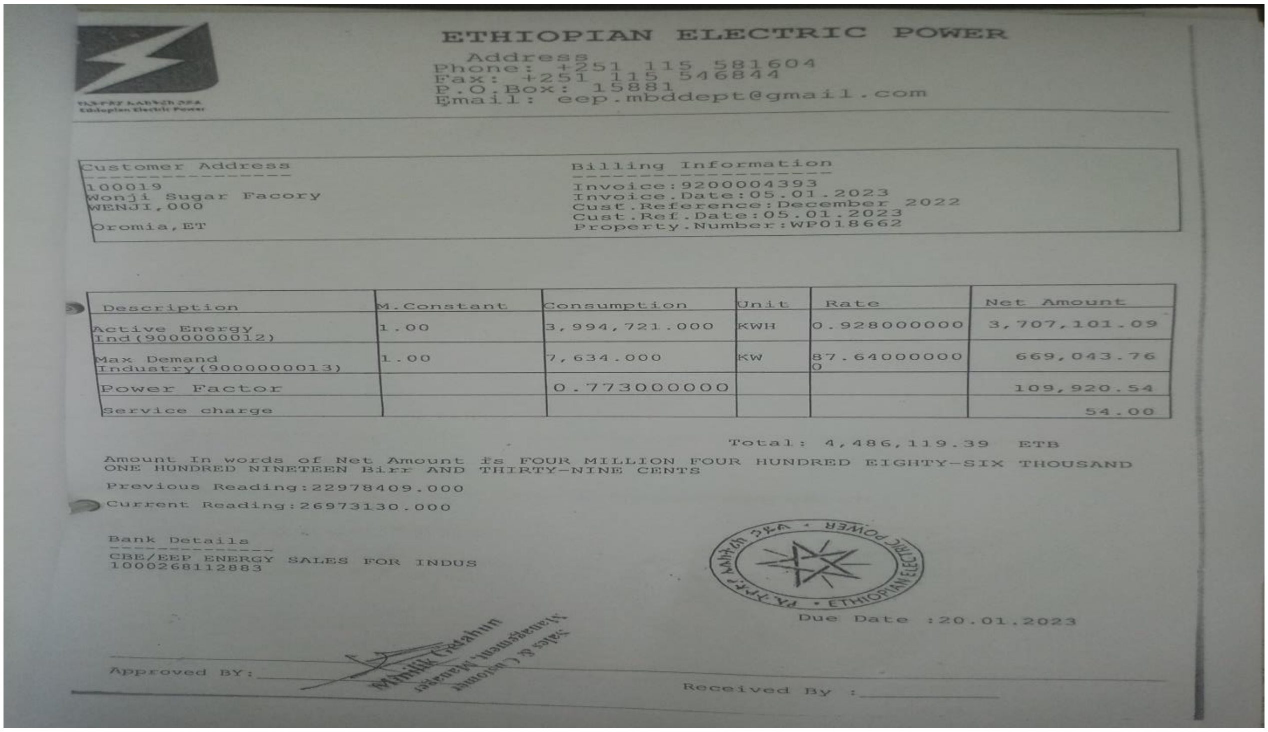
Bank Details

CBE/EEP ENERGY SALES FOR INDUS
1000268112883

Due Date :21.03.2023

Approved BY: Minilik Getahun Sales & Customer Management Manager

Received By :



ETHIOPIAN ELECTRIC POWER

Address
Phone: +251 115 581604
Fax: +251 115 546844
P.O.Box: 15881
Email: eep.mbddept@gmail.com

Customer Address
100019
Wonji Sugar Facory
WENJI,000
Oromia,ET

Billing Information
Invoice:9200004393
Invoice.Date:05.01.2023
Cust.Reference:December 2022
Cust.Ref.Date:05.01.2023
Property.Number:WP018662

Description	M.Constant	Consumption	Unit	Rate	Net Amount
Active Energy Ind(9000000012)	1.00	3,994,721.000	KWH	0.928000000	3,707,101.09
Max Demand Induatry(9000000013)	1.00	7,634.000	KW	87.640000000	669,043.76
Power Factor		0.773000000			109,920.54
Service charge					54.00

Total: 4,486,119.39 ETB

Amount In words of Net Amount is FOUR MILLION FOUR HUNDRED EIGHTY-SIX THOUSAND ONE HUNDRED NINETEEN Birr AND THIRTY-NINE CENTS

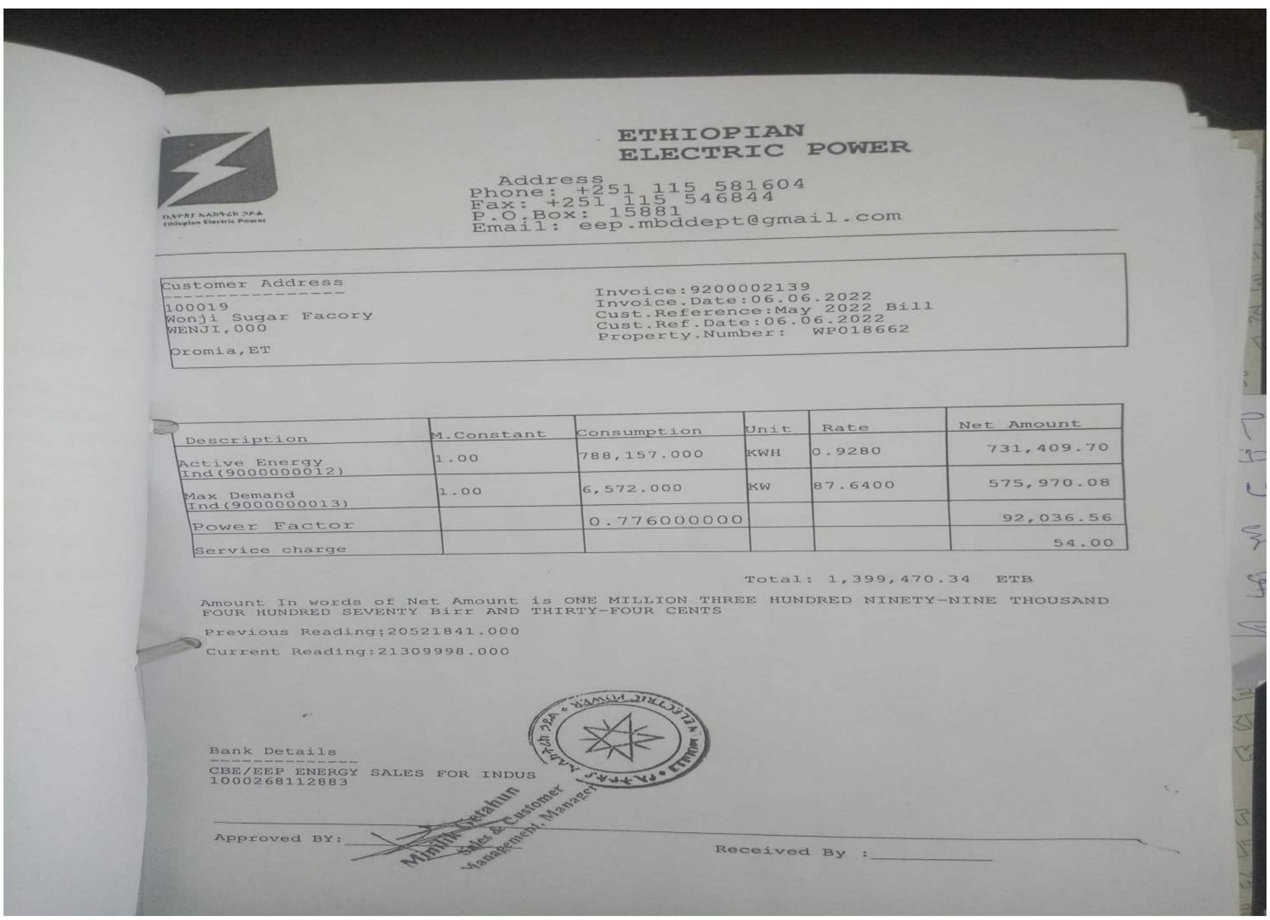
Previous Reading:22978409.000
Current Reading:26973130.000

Bank Details
CBE/EEP ENERGY SALES FOR INDUS
1000268112883

Due Date :20.01.2023

Approved BY: Minilik Fetahun, Sales & Customer Management Manager

Received By :



ETHIOPIAN ELECTRIC POWER

Address
Phone: +251 115 581604
Fax: +251 115 546844
P.O.Box: 15881
Email: eep.mbddept@gmail.com

Customer Address
100019
Wonji Sugar Facory
WENJI,000
Oromia,ET

Invoice:9200002139
Invoice.Date:06.06.2022
Cust.Reference:May 2022 Bill
Cust.Ref.Date:06.06.2022
Property.Number: WP018662

Description	M.Constant	Consumption	Unit	Rate	Net Amount
Active Energy Ind(9000000012)	1.00	788,157.000	KWH	0.9280	731,409.70
Max Demand Ind(9000000013)	1.00	6,572.000	KW	87.6400	575,970.08
Power Factor		0.776000000			92,036.56
Service charge					54.00

Total: 1,399,470.34 ETB

Amount In words of Net Amount is ONE MILLION THREE HUNDRED NINETY-NINE THOUSAND FOUR HUNDRED SEVENTY Birr AND THIRTY-FOUR CENTS

Previous Reading;20521841.000
Current Reading:21309998.000

Bank Details
CBE/EEP ENERGY SALES FOR INDUS
1000268112883

Approved BY: Minilik Fetahun, Sales & Customer Management Manager

Received By :