CUSTOMIZED INTERLINE POWER FLOW CONTROLLER FOR VOLTAGE PROFILE IMPROVEMENT AND POWER LOSS MINIMIZATION OF TRANSMISSION LINE (CASE STUDY: SOUTHERN REGION FROM SHASHEMENE TO BUKULUGUMA TRANSMISSION SYSTEM)

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN

POWER SYSTEM AND ENERGY ENGINEERING

By

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SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

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A thesis proposal submitted to Hawassa university institute of technology, school of graduate studies, for the partial fulfillment of the requirement for the degree of masters of Science in electrical and computer engineering (power system and energy engineering).

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Proposal Approval Sheet

This is to certify that, the thesis prepared by ASRAT LEMMA entitle of "CUSTOMIZED INTERLINE POWER FLOW CONTROLLER FOR VOLTAGE PROFILE IMPROVEMENT AND POWER LOSS MINIMIZATION OF TRANSMISSION LINE IN SOUTHERN REGION FROM SHASHEMENE TO BUKULUGUMA TRANSMISSION SYSTEM". Submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN POWER SYSTEM AND ENERGY ENGINEERING complies with the regulation of the university and meets the accepted standards with respect to originality and quality signed by the Advisors.

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EXAMINER'S APPROVAL SHEET

We the under signed Board of examiners of the final open defense by Asrat Lemma have read and evaluated his thesis entitled **"CUSTOMIZED INTERLINE POWER FLOW CONTROLLER FOR VOLTAGE PROFILE IMPROVEMENT AND POWER LOSS MINIMIZATION OF TRANSMISSION LINE IN SOUTHERN REGION FROM SHASHEMENE TO BUKULUGUMA TRANSMISSION SYSTEM"** and examined the candidate. This is therefore, to certify that the thesis has been accepted in partial fulfilment of the requirements for the degree.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the school of graduate studies (SGS) through the department Graduate Committee (DGC) of Electrical and Computer Engineering.

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Declaration

I the undersigned hereby declare that this MSc work **Customized Interline Power Flow Controller for voltage profile improvement and power loss minimization of transmission line in case study of Southern Region from Shashemene to Bukuluguma.** Neither this university nor any other completed my original work, and I gave credit to all of the materials and resources I used for the thesis in order to fulfill the requirements for a degree. All Advisor's comments and suggestions are correctly incorporated.

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Dedicated to my beloved family

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ABSTRACT

An electrical system is a collection of components that are used to supply, transmit, and consume electricity. Transmission lines effectively transfer the electricity produced by different power plants. Nevertheless, the generated electricity is not entirely supplied to customers because of voltage drop and power loss. Uncontrolled bus voltage profile caused problems for industries that were developing quickly. Interline power flow controller (IPFC) is a type of flexible AC transmission system (FACTs) devices applicable to reduce power loss and enhance voltage profiles of the transmission networks from Shashemene to Bukuluguma transmission system. Load flow analysis on nine buses were performed by Newton Raphson load flow analysis technique using MATLAB R2016a. The analysis showed that out of nine buses four buses are out of voltage limit. On the system as a whole, there has been a loss of 8% real power and 10.42% MVAr reactive power, or 7.322MW and 4.530 MVAr, respectively. To minimize the loss problems, grey wolf optimization (GWO) techniques were proposed to search optimal place and size of interline power flow controller (IPFC), placed on bus 5, and sized 27MVAr. GWO techniques are compared with Antlion optimization, but GWO gives a good performance. After analysis data 4 buses bus number 4, 7, 8, and 9 are out of permissible values, the remaining buses are within acceptable limits. GWO techniques suggest implementing the lowest voltage stability index bus. After installing IPFC in optimal power flow place the network problem is improved by GWO 6.1% and ALO 3.9%, the lowest case voltage profile improved from 0.937pu to 0.978pu and 59.7% of active power and 40% of reactive power are saved. Finally, the reduction result suggest that the recommended approach is operative to regulate all buses voltage magnitudes within the NEC and IEEE permissible boundary and to minimize power loss considerably.

Key words: - Customized IPFC, GWO, Newton Raphson, Power loss, Voltage profile

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ACRONYM

AC	Alternating current
ALO	Antlion optimization
B	Susceptance
Bc	Charging Susceptance
USD	US Doller
C	Capacitance
DC	Direct Current
DFC	Dynamic Flow Controller
DLUF	Disparity Line Utilization Factor
DSTATCOM	Distribution static compensator
EEP	Ethiopian Electric Power
EEPCO	Ethiopia Electric Power System corporation
EEU	Ethiopian Electricity Utility
ETB	Ethiopian Birr
FACT	Flexible AC transmission System
G	Conductance
GWH	Giga Watt Hour
GWO	Grey Wolf Optimization
I	Current
IEEE	Institute of Electrical and Electronics Engineering
IGBT	Insulated gate bipolar transistor
IGCT	Insulated gate commutated thyristor
IPFC	Interline Power Flow Controllers
KV	Kilo Volts
KVAr	Kilo Volt Ampere Reactive
KWh	Kilo Watt Hours
L	Inductance
MATLAB	Matrix laboratory
NEC	National Electrical Code
NGCC	National Grid Control Center
NR	Newton Raphson
OPF	Optimal Power Flow
PLRI	Real Power Loss Reduction Index
PU	Per unit
QLRI	Reactive Power Loss Reduction Index

R	Resistance
RPL	Real power loss
Si	Injected power
SSSC	Static Synchronies series compensator
STATCOM	Static Synchronous Compensator
SVC	Static VAR compensator
TCSC	Thyristor controller series capacitor
UPFC	Unified power flows controllers
Vinj	Injected Voltage
Vr	Receiving end voltage
Vs	Sending end voltage
VSC	Voltage Source Convertor
VSI	Voltage Stability Index
X	Reactance
Y	Admittance
Z	Impedance
δ	Angle Delta

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Power availability must be sufficient for economic expansion to take place. Ethiopian Electric Power (EEP) has worked hard for many years to provide its consumers with minimum power loss and sufficient power.

As a public sector instituted in 1956 was called Ethiopia Power Corporation. The corporation contain different sectors like, distribution, transmission, power generation system; energy sales service system in country and national grid maintenance. Subsequently in December 2023, this EEPCo organization was classified into two i.e. Ethiopian Electricity Utility (here in after called 'EEU') which is responsible for distribution, and Ethiopian Electric Power (here in after called 'EEP') which is in authority for power generation and transmission in [1].

Power generators, power transmissions, power distributions, and loads are constitute the electric power system. An electric power used for different purposes, as a basic need it founds every manufacturing industry area and now a day from food preparation to every activity is per day is supporting by electricity in [2]. The power generated in low voltage and stepped up by step up by power transformer within high voltage to transmission network. By its inter connectivity a power system transmission network is very vast, considerable distance to the electrical distribution network.

The current GTP II has a new board to increase capacity of generation to over 17,000 MW by 2020, with a general possible of 35,000 MW by the year of 2037 in [3]. Totally, there are 155 numbers of substations under the transmission substation operations subdivision, and 19 numbers of power plant substations managed by the Generation operation department in [4]. In Ethiopia the number of substation including exporting power to neighbor country grid system 500KV/400KV/230KV/132KV/66KV/45KV/33KV/15KV.

The country National Grid Control Center (NGCC) is accountable for the efficiently procedures for national grid reliable coordination's and operations.

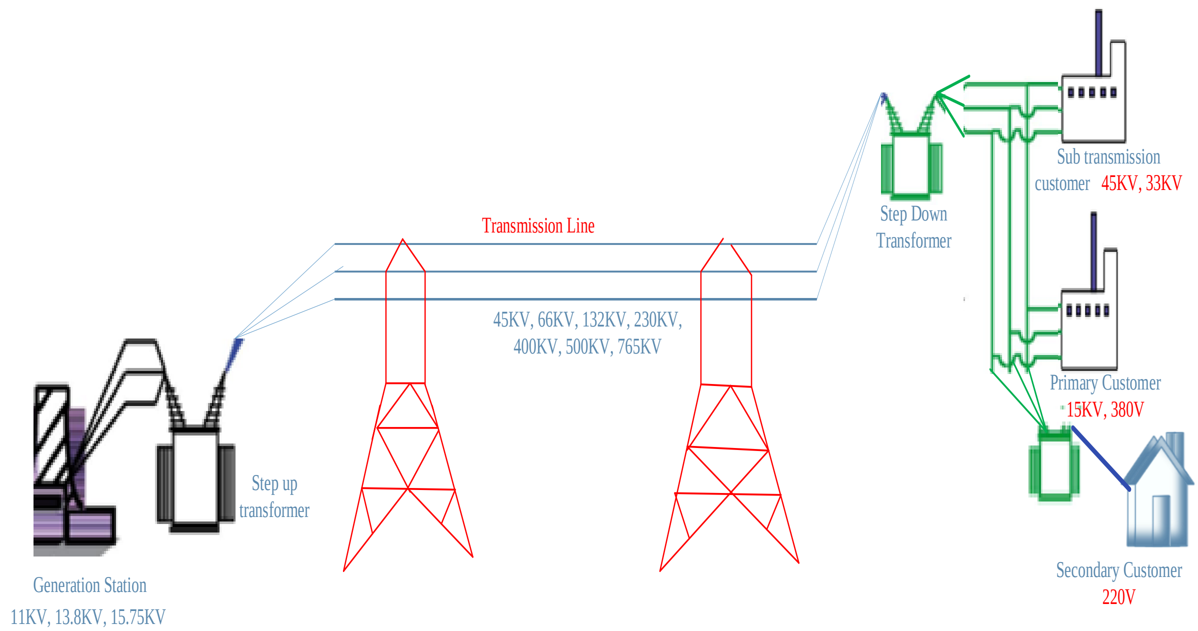

Figure 1.1: Electric power system schematic diagram **[5]**

Shashemene to Hawassa II, two buses connected branch of 132KV transmission network and have similar impedance, over loading and under loading capacity. On the Shashemene to Bukuluguma transmission system network, there are primarily two electric power generation plants. These are the Melka wakana and Genale dawa III power plants. Melka wakana is located 119.19 kilometers from Shashemene and has three generating units with a total capacity of 153 MW. Genale dawa III hydropower plant is located 274 kilometers from Yirgalem II has three producing units with a total maximum generating capacity of 254 MW. The transmission voltage from power plants to the Yirgalem II is 400 KV. The focus of this thesis is the placement of IPFC fact devices for voltage profile improvement, power loss reduction and enhances power transfer capacity in the existing Shashemene to Bukuluguma transmission network. The transmission lines connecting Genale dawa III substation to Yirgalem substation II, Hawassa substation II to Hawassa substation I, Hawassa substation I to Yirgalem substation I, Yirgalem substation I to Dilla substation, Dilla substation to Hagere Mariam substation, and Hagere Mariam substation to Yabelo, Yabelo substation to Bukuluguma substation.

Increasing transmission line capacity can be accomplished by constructing new transmission lines of existing transmission facilities. However, it is not economically feasible to develop transmission systems solely by laying new transmission lines due to a variety of environmental factors such as regulatory requirements and land uses. As a result, some transmission lines are heavily burden, and power system stability becomes a limiting factor in power transfer in [6]. As a result, the alternative option is to use existing transmission resources up to their maximum operating capacity. Different organization define a FACT device in different ways, IEEE define as "alternating current transmission system incorporating power electronics based and other static controls to improve line capacity and enhance power transferring capacity in [7]. The flexible AC transmission system controller defined as "AC transmission network parameters perfectly manageable and gives an ultimate function for demand and supplier" in [8].

FACT devices are effectively used to control the flow of energy through transmission lines and to improve system control by and enhancing voltage profile. The FACT controllers can accomplish the function of series compensates shunt compensators and phase shifting assembly multiple controllers. Although based on customer interest the power generating units in Ethiopia are impulsively increasing, consistently transmission system not upgraded. Most of Ethiopian region existing transmission network has more power losses due to overloading and aging problems in [7].

Power flows in a transmissions network concept is a huge and needs a carefully meaning of the sending Vs and receiving V_R end voltages the phase angle difference δ between the voltage and the line impedances Z. The procedure known as compensation can be used to help manage the power flow by adjusting any of the parameters mentioned above.

1.2 Electric system Power Loss

In power, system there is a power transmission, in the transferring process there is power losses due to different factors the sending end voltage does not exactly arrives to the receiving end.

The major issues of power system is handling problems. The classification of electric power system loss makes the investigation easy and create good understanding on the blow flow chart.

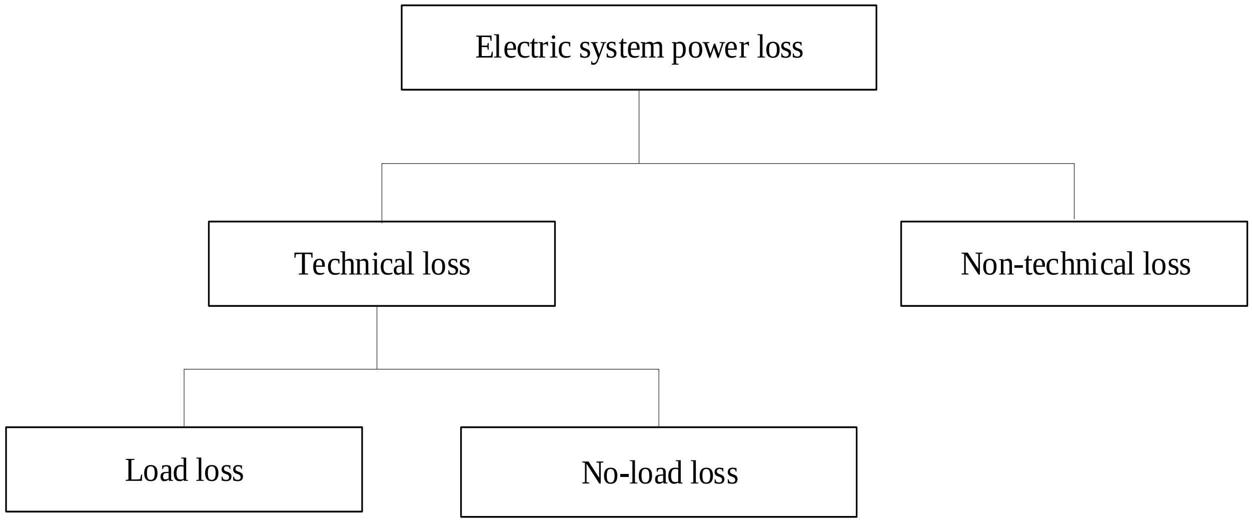

Figure 1. 2 Power loss classification

Technical Loss

A physical devices or components in a power system most of the time generates technical power loss in [9], [10]. The power that lost in a transformer and transmission line is a result of internal electrical resistance is the most striking examples. Technical losses mostly consists of power indulgence in electrical system components such as power transformer, transmission line etc.

Load Losses

In the load flow system load loss is happened in any electric power network element through current flow of the system. Truly, Loss is unnecessary in the technologized country company.

No-Load Losses

No load loss is a fixed loss it is not depend up on the distribution of power system equipment. It is also a percentage of losses that can be dielectric loss in the cable. The prepared state, or the existence of electric voltage on elements, is what causes no-load losses. The continuous losses constitute a very small part of the total peak load losses.

Non- technical Losses

This type loss is happen outside of system network or by condition. It is very difficult because they are often unaccounted on system operation. Because most people in industrialized nations can have enough money to pay prices that reflect source cost, non-technical loss in the power sectors, for example, are either nonexistent or very small.

1.3 Transmission line network and limitation of IPFC

A transmission system is like a human blood muscle of power system. The movement of electrical energy from single bus to other buses through a transmission network of power system. They are capable of carrying either alternating current, direct current, or a combination of the two. The IPFC is a series FACTS device that can control the power flow and voltage profile of multiple transmission lines.

However, it also has some limitations and effects on the transmission line network. The limitation of IPFC has some effect on the voltage profile and power loss of the transmission line network. According to some study, the IPFC can improve the voltage profile by providing series compensation and reactive power injection to the lines. However, the IPFC also introduces additional power loss due to the convertor loss and the circulating current between the lines. The distance of a transmission networks can affected by a distance.

In addition, overhead or underground wires can both carry electric current. The overhead alternative current transmission lines can be classified into three groups concerning on their length and operational voltage, this are

Long Transmission network

An overhead transmission lines is considered to be long transmission lines if it is longer than 150 km and has a voltage of greater than or equal to 100 kV in [11], [10]. Numbers are assumed chosen equally distribute along the entire length when analyzing line performances. Long lines with voltage uncontrolled bus at the receiving end in power system cause serious voltage issue under light or heavy load conditions.

When the loads is light, voltage at the receiving end rises while in a heavy load condition, voltage at the receiving end decreases. As an alternative to overhead power transmission, the HVDC is more frequently utilized in long-distances subterranean and overhead transmission networks. Moreover, it is employed to link AC systems with various frequencies.

Under conditions of excessive loading, the series reactive drop may be quite high causing voltage despair at the receiving ends. In exciting circumstance, the series reactive loss for the line reactive power demand may be enormously high, causing a serious voltage management issue in [11].

Medium transmission network

When the line's length falls between 50 and 150 kilometers and its voltage falls within 20 and 100 kilovolts, the line with this information said to be a medium transmission lines. It is impossible to ignore the capacitance impact in this kind of line. Therefore, the capacitance impact needs to been taken into account when analyzing the line's performance in [11].

Short Transmission network.

While the distance of the line is to about 50 km, the line said to be a short transmission lines. Voltage of the line becomes lower than 20,000V. The capacitance effect in short overhead line is neglected, Because of the small length and lower voltage, the capacitance effect is very small in [11]. Hence, in short, overhead transmissions line, the 6 capacitances effects is neglect. Consequently, only the resistance and inductance are taken into consideration while planning, modeling, and researching the short line's performance.

1.4 Statement of problems

The power transmission system is the heart of the power system networks, delivering electricity to the distribution system. In the southern region of Ethiopia, due to urbanization and industrialization, there is a daily increase in the consumption of electrical energy consequently; the transmission system network is not improving in terms of efficient operation and reliability. Most of line of transmission exposed to power loss, which in required amount power delivering side challenging in negative impact of generated power to the receiving end. Furthermore, the voltage profile of buses are out of IEEE standard permissible limit and transmission line losses have increased in case study transmission line network because of overloading and missing of versatile FACT device problems.

EEP is now using conventional methods to improve the power network by upgrading a new generation sites, transmission lines, and substations, as well as shunt capacitor/reactors for reactive power compensation. However, to construct such infrastructures is difficult in that one it is costly secondly it consumes time. In addition, compensation using shunt capacitor/reactor has some disadvantages like slow operations, low efficiencies and low voltage regulations beyond a certain level of compensation.

The electrical power system requires new equipment that improves a transmission system issues. A power grid to be protected, fault tolerant, self-healing, to make it smart and aware, and dynamically and statically controllable, IPFC FACT device is alternative solution. Therefore the proposed the proposed FACT device IPFC deploying in optimal place using grey wolf optimization technique the mentioned matters in the Shashemene to Bukuluguma transmission network can be repair.

1.5 Objective of the Thesis

1.5.1. General Objective

The general objective of the thesis is improving voltage profile and minimization of power loss in transmission line using customized IPFC in the Southern Region from Shashemene to Bukuluguma transmission system.

1.5.2 Specific objectives

- To evaluate the existing transmission system voltage profile and power losses using load flow analysis techniques of Newton Raphson
- To model IPFC and analysis a load flow with and without IPFC fact devices
- To determine the sizing and optimal placing of IPFC using grey wolf optimization
- To Compare a Proposed GWO algorithms results with Antlion algorithms

1.6 Scopes of study

The thesis focuses on systematic analysis, design, modelling, simulation and evaluation of the performances of the transmission lines through IPFC and without IPFC appropriate to minimize power loss and enhance line voltage profiles of the 132KV of the southern region from Shashemene to Bukuluguma transmission network

1.7 Significances of the Study

The loss of power in the power system will cost the electric utility a lot of money, thus assessing and reducing it is crucial. In this time power, handling problems is boldly challenging in the EEU. When some buses voltage profiles drop below the allowable threshold, it will result in a complete collapse and leads to blackout of the system. As a result, this thesis is important for avoiding such scenarios on the power system chosen as a case study, because IPFC is a relatively new device, it compensates the system's reactive and real power independently by installing series in a multiline configuration. As a result, the voltage profile and power loss issues will minimized, and EEP becomes economical.

1.8 Motivation

There are numerous indicator in Ethiopia electric power transmission line expose that concerns with electric performance, for instance power loss, voltage profile problems, and power transferring capability of line. These performance issues above mention parameter cause the Power loss and voltage profile problems. In addition to these at this time EEP challenging is a new constricting line theft that stealing very costy power transferring devices. Therefore, the analyzed case study transmission line requires advancements in the area stated above.

1.9 Research Methodology

A thesis works identifies the method of dissimilar tasks to satisfy problems of questions and follows A methodology consists of multiple separate work to accomplish the thesis, which are techniques/methods, materials, and manufacturers to conduct the suggested research works. These studies contain the next investigation approaches as exposed in Table 1.1

Table 1. 1 Thesis methodology

Methods	Descriptions
Literature reviews	- Published papers from the previous six and seven years that are connected to my study are reviewed from a variety of sources, including books, articles, talks, journals, materials, and unprinted papers. - The interrelated paper are discus about different optimization algorithms of transmission networks.
Data collection methods	- The appropriate and exact primary datas and secondary data's are composed from, EEP of southern region and Addis Abeba National Grid. - The data that are gathered through Directing discussions with the respective expert of transmission line employees of the substations
Power flow analysis modelling	- The transmission system and convergence problems faced in Newton Raphson methods, modelling of new line helps to fix the existing power flow problems of the system.
Formulation of objective functions and constraints	- The formulation of functions by respect to problem in the case study area system are; - Objective function. - Equality and inequality operational constraints and IPFC constraint.
Modeling a proposed methodology	- Southern region transmission system from Shashemene to Bukuluguma transmission line with IPFC modeled to analysis the system.
Simulation result and discussion	- Afterward the load flow analysis with optimal IPFC settlement has computed in the transmission system.

	- The simulation results based on MATLAB R2016a software, optimization algorithms and for sketching Microsoft Vision 2016 and others.

1.10 Organizations of the Thesis

The thesis has totally stated five chapter. All chapter concerned on general objective of the thesis and summarized as below.

Chapter One: States the introduction, background statements of the problem, general and specific objective motivation and significance of study

Chapter Two: Focuses on theoretical understanding and literature review of the study, transmission line loss, voltage drop and detail discussion and classification of fact devices are stated.

Chapter Three: Describe research methodology data collection, mathematical modelling of IPFC and transmission line, problem formulation of the thesis and objective function finally, optimization techniques are discussed.

Chapter Four: System simulations and result discussions with installing without and IPFC and cost estimation of the project with the payback period are proposed.

Chapter Five: In these final chapter future works, conclusions and recommendations has discussed.

CHAPTER TWO

2. THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 FACT Devices

The FACTS devices are nothing but the device used to increase the efficiency of the transmission

System. In modern power system technology Fact device has a vital tasks to manage a power in the transmissions network. Even though the high amount of supplied power to the system from different source, missing versatile fact devices makes an institute less Profit Company. This chance get up through the capability of FACT controller to regulate the power system network electrical parameters with series and shunt impedances, current, voltage, phase angle, and the damping oscillation in [12]. In the advanced power system, the system needs new and very controllable and feasible devices. The components of a FACT device are insulated gate bipolar transistors (IGBT), insulated gate commutated thyristors (IGCT) and thyristor gate turn offs (GTO) by changing position of and polarity of each element it can control a high voltage system. This all mentioned controller can give very fast response; create on the controlling system and different optimization algorithm approach to different simulation. FACTS technology has much benefit; these are the ability of larger power flow controls and helps to run a voltage at permissible standard limit of the existing transmission network.

In general, the various applications of FACTS devices can be summarized as below in [13].

- power flow controls in high voltage transmission line
- optimizing a transmission line power caring capacity
- controls a voltage profile of a bus
- stability improvements of active and reactive power
- Avoid a poor power quality problem.

A real and reactive power are major components in the power system. Because of these reasons, the parameters of components affect a system. When control a basic parameters of a transmission line we can called that a controlled power. Load flow in transmission lines refers to the flow of both active power and reactive power or power flow of a line in [14]. A mathematical methodology for determine distinct bus of voltage, their phases angle, active power and reactive power flow through various transmission line and generators of the conditions of steady state obtainable by power study of power system.

The primary goal of power analysis is to determine a power system networks in steady state operating condition and after all, we choose an appropriate fact device with the help of optimization to the system.

High power electronic controllers, which may inject or absorb reactive and real power according to system requirements, are a useful solution to this problem. The FACTS (Flexible AC transmission system) device is one of the most significant sources of reactive electricity. Therefore, we must employ various compensators in order to regulate and enhance the performance of ac power systems. By managing both kinds of powers and increasing the useable capacity of current transmission lines, the FACTS technology creates new possibilities.

2.1.1 FACTS Devices Classification

Depending on the wattage of the used electronic devices, FACT device can categorized in to two group; Thyristor valves or convertors and voltage source convertor employed FACTS in [15]. The main aims of a FACT devices placement and sizing can also to increase the total blocking rental or to improve the community well-being**.** FACT is commonly well known that the most influential and versatile devices are UPFC and IPFC, But while IPFC is designed to manage power flow in a multi-line transmission system, UPFC is intended to compensate a single transmission line. FACTS devices allows for the flow of electricity along the selected pathways though taking into account loss mitigation, preventing losses brought on by system trips or outages. For instance, extremely flexible FACTS controllers include UPFC and IPFC. However, IPFC is the most recent FACTS device that has the capacity to manage and regulates the power flow of several line at the second. Its tool has various benefits and is unique because of its capabilities in [16] . Due to these characteristics, it also offers the benefits of excellent system administration and control, as well as adequate financial rewards for the owners of power transmission systems in [16].

When the network is in a steady state, IPFC is utilized to boost line power transfer capacity, regulate and control power flow, account for reactive power, stop loop current, and prevent overloading. IPFC FACT devices is considered as the most flexible out of all devices and versatile as it employs at least two voltage source converter with a common DC link. Fact devices can be divided into four main categories. It basically classified into thyristor valve convertor and voltage source convertor.

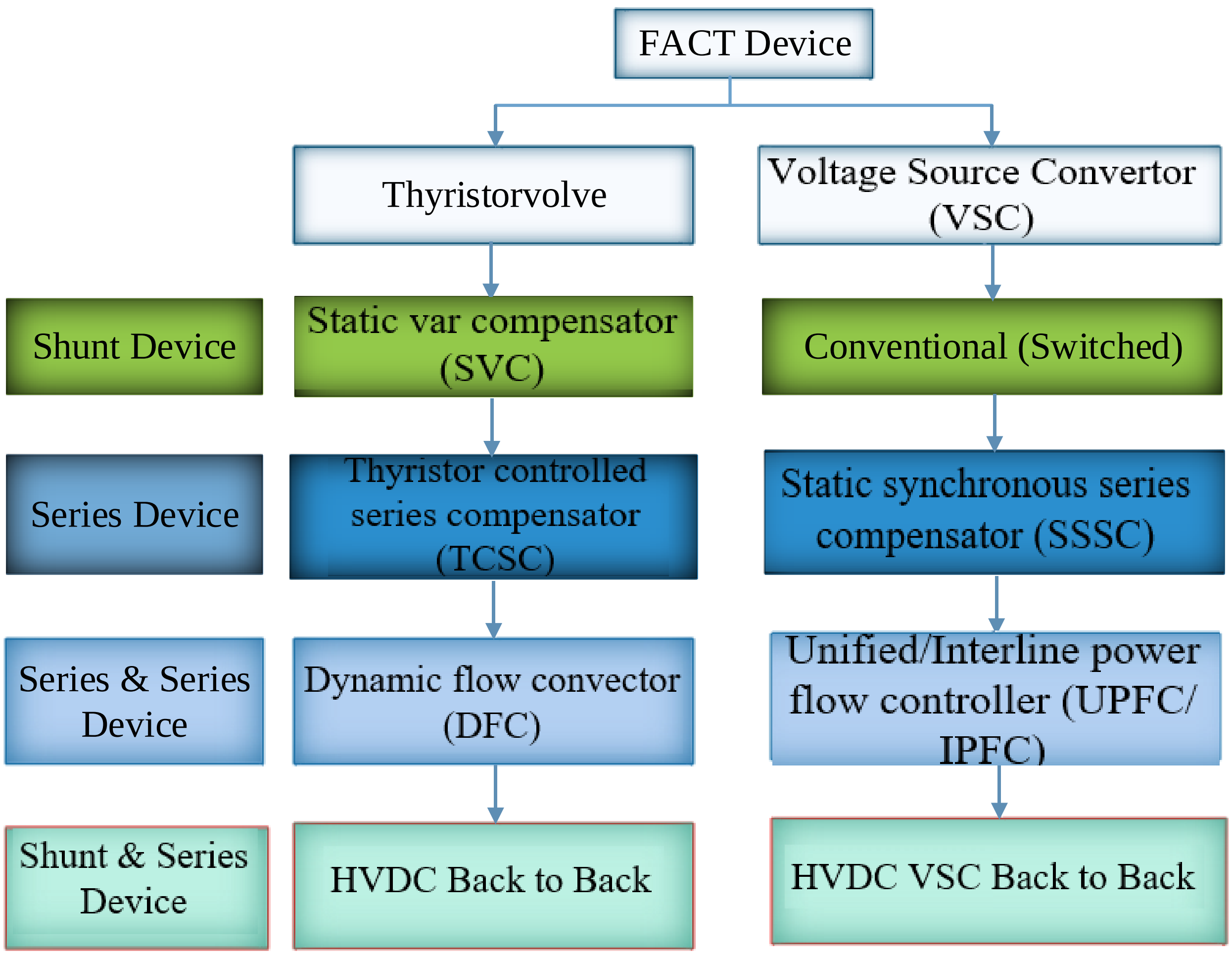

Figure 2. 1 Types of FACTS devices based on power electronics devices in **[17]**

2.1.2 Interline Power Flow Controller (IPFC)

In the modern day development of power system, the concentration of fact device is increased special the interest of IPFC is increasing. It is a series-series type FACT device. Which is used for exchange reactive and real power between two or more melt-line associated to the same bus. This device can constructed with two or more series-series type of fact device and, can construct two or more TCSC and SSSC and each are connects series to line in [18]. Every SSSC is able gradually compensate for the reactive power it contributes to the shared DC link by providing real powers starting its own line.

In nature fact device generate a reactive power in their controlling mechanism. In generally the IPFC can employs a quantity of DC to AC converters. These converters are provided that a series compassion for each transmission lines.

The fundamental objectives of an IPFC is to transfer power optimal and mutually real power and reactive power flow between two or more lines and allocate power from very loaded to under loaded line. In its overall form, the IPFC services a figure of convertor from DC to AC, individually providing for one of the lines in a multiline system, series compensation like to that utilized in the UPFC in [16]. The IPFC is reflect a new generation of FACT controller. The groupings of two or more capacitor linked to the transmission in series where joined by means of a common DC link to give the structure of IPFC [19].

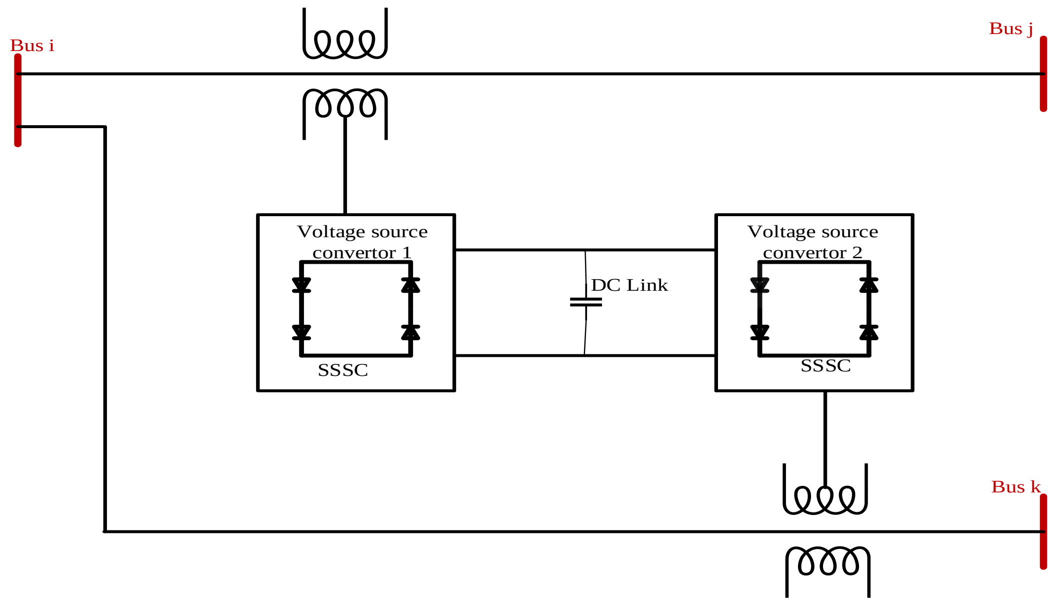

Figure 2 2 Schematic representation of IPFC in **[19]**.

2.1.3 Operational principle of IPFC

When the magnitude of a line and angle are convert, the series injecting voltage Vse laid on the challenge. The intention of this voltage injection is to affect the power flow on the line either directly or indirectly. However, Vse is dependent on the operating mode designated for the IPFC to control power flow [19]. The following subsection lists the main mode of operation.

Table 2.1 principal operating modes of IPFC

Operational mode	**Descriptions**

Mode of direct voltage injection	Mode of direct voltage injection principle is a voltage phase angle and magnitude can be adjusted to regulate the flow of both active and reactive power. The entire voltage vector Vse needs is the phase angle and magnitude specified by the reference input, which is what the series converter provides. When the IPFC's operation is coordinated by a different system optimization control, this operating mode might be useful and other FACTS controllers employed in the transmission system. Particular use cases for direct voltage injection are those with specific control goals. For instance, when the injected voltage vector Vse maintained in phase or in quadrature with the system voltage to regulate voltage magnitude, or when it is in quadratures with the line current vectors of IL to offer well-disciplined reactive series compensation.
Mode of Lines Impedance Compensations	The value of the injection voltages vector Vse are modulated by the series injection in relation to the line currents, IL, to replicate impedance as seen from the perspective of the lines. In general, a complex impedances with specific electric resistance and can be the essential impedance, as specified by the reference input. In order to compete capacitive or inductive compensation, a specific case of impedance compensation arises when the injected voltage quadratures of remain constant in relation to the line current. This operating mode can be chosen to work with the system's current series capacitive line compensation.
Model of the of phase angle regulation	In order to phase shift the output bus voltage vector, Vo, without changing its amplitude, the Vse, is regulated in relation to Vs. When Vse and Vs are maintained in quadrature to simulate a quadrature booster, a unique instance of phase shifting takes place.
Mode of Automatic Power Flow Control	To induce the desired real and reactive power flow in the line, the amplitude and Vse is attuned. Control of electricity flow automatically

	mode maintains the appropriate P and Q even in the event of power supply changes by automatically and continually determining the series injected voltage through a closed loop control system.

2.1.4 Static Synchronous Series Compensator

Compact states VSC serves as the foundation for the Static Synchronous Series Compensator, a VSC series fact device that produces the required voltages magnitude regardless current of line. A converter-coupling transformer and DC bus (storage unit) make up an SSSC. With the help of the inverter, the DC bus creates a waveform of AC then put into series transmission lines via the transformers at the right Angle of phases and line currents. A real power exchange occurs when the injected voltage is in phase with the line of current; a reactive power exchange occurs when the voltages injected in phase with the line current. Simply put, a series capacitor's job is to raise the voltage across an inductive line impedance at the frequency of the AC system in order to enhance transmitted power and line current. A series capacitor at the fundamental frequency can provide series compensation if this voltage is injected capacitor linked to the transmission in series. As a result, it can switch between reactive and actual power in a transmission line in [20].

Functional Control of SSSC Converter

Through connecting fitting voltages with a changeable phase angles and magnitude in series with the system of transmissions network, the actual and the flow of reactive power can be used to regulate the series convertor. In series with the transmission lines, capacitor linked converter generates voltage, Vse that is amplitude and angle controlled in [20]. There are numerous modes of operations in series converter. The functional control of SSSC is as a listed in the series connected operation of interline power flow controller.

2.2 Voltage Injecting Series Devices

As seen in figure 2.3, this device could be an adjustable impedance such as a reactor, capacitor, and variable based electronics sources that inject series voltage with in the line. In this instance, the device being used needs an outside energy supply.

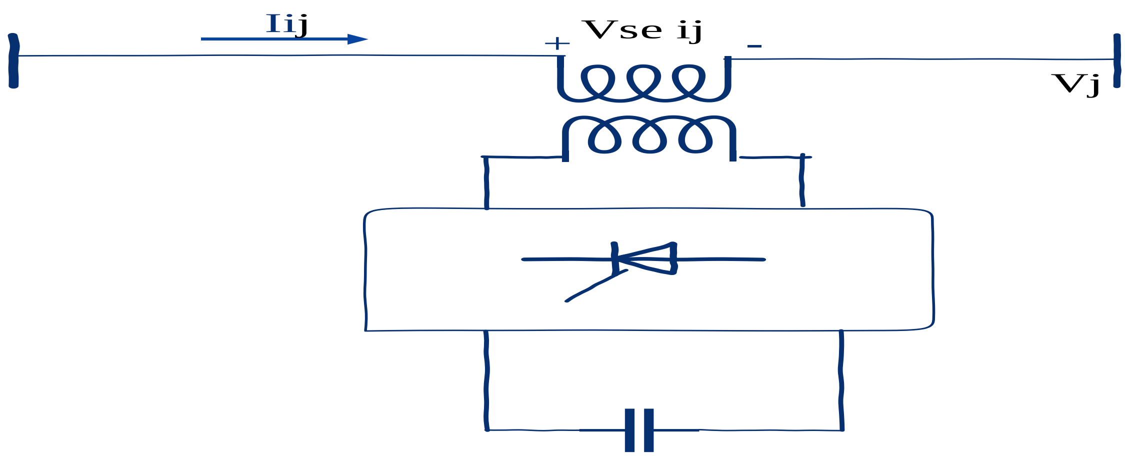

Figure 2. 3 Basic Series SSSC configuration in **[21]**

It functions SSSC configuration is very similar to STATCOM and a variables capacitors or an iron core impedance that can be modified in with series transmissions line to damp oscillators in the system as explained in the figure 2.3, the ultimate uses of fact device to improve utilization quality of voltage profile enhancement and power loss minimization. This is observed as the voltages transversely an impedances in series with the line and is achieved by injects a suitable voltages phasor in serie with the transmission line. The controller sinks or produces reactive power if the line current and voltages are in phase quadrature's; otherwise, the device sinks or produces both active power and reactive power.

Table 2. 1 A series controller advantage and disadvantage

Controller	Advantage	Disadvantage
Series controller	✓ Improve voltage profile at receiving end bus	✓ Occurrences of sub synchronous resonance(SSR)

	✓ Reduce reactive power consumed by transmission line ✓ Increase transmission power at receiving end bus ✓ Damping oscillation system under disturbance	

2.3 Factors that Affect a Power Loss

Flowing current, power factor, phase angle balance, and voltage regulation are variables that affect power system losses. Flowing current occurs when modern, highly linked networks fail to maintain a flat voltage profile in [22]. Consequently, it is crucial to keep voltage restrictions for a transmission networks at their designated levels in order to reduce losses. Phase balancing systems, with the variation from the average values below 10%, can be used to balance heavily loaded lines with other phases. At unity power factor, current flow will be at its lowest level, but any reactive component will raise the current, which will also increases real power losses in [8].

Transmission system voltage decreases at the end of receiving side when compared to unity power factor but current in the transmission system increases due to extreme voltage drop caused by line resistance.

2.4. Voltage Drop In Transmission Line

Finding the voltage drop, line loss, and transmission efficiency are essential factors to take into account while designing and administration a transmission line. The transmission line's R, L, and C line constants have a significant impact on these values. For example, the line's voltage drop is dependent on the values of the parameter of line constants mentioned above. Similar to this, the main factor causing power loss in a transmission line and affecting its transmission efficiency is its conductor's resistance in [23].

2.4.1. Voltage Regulation

In transmission line current currying, the line has a voltage drop because of inductance and resistance of networked line. Voltage drop is the difference of sending end voltage and receiving end voltage expressed in percentage. Voltage regulation or determining the best way to set the control parameters of power systems to maintain the voltage at all user-feeding points. Network nodes within a narrow range around a referred to as nominal value, is one of the most crucial tasks in power grid management. Both electric power utilities and grid management cooperating they can minimize a voltage collapse of a line, the end user manage the utilize energy in base load period and a grid management minimize a tariff of energy during base load period, doing these it can improve a service quality and minimize a voltage drop in[24].

This is relate to the powerlessness of the grid to transport the satisfactory reactive power. Note that the voltage at a quantified bus rises as much as the injection of the reactive power is increase in [25].

$$\text{Percent regulation} = \frac{|V_{RO}| - |V_{RL}|}{|V_{RL}|} \text{ X } 100\% \qquad (2.1)$$

Where V_{RO} = Magnitudes of voltage at the receiving end without any load

V_{RL} = Magnitude of the voltage at the receiving end full load voltage

For short line $|V_{RO}| = |V_S|$, $|V_{RL}| = |V_R|$

$$\text{Therefore, percent regulation} = \frac{|V_{RO}| - |V_{RL}|}{|V_{RL}|} \qquad (2.2)$$

$$= \frac{|I|\text{R}\cos\theta\text{r} + |I|\text{R}\sin\theta\text{r}}{|V_R|} \text{ x } 100\% \qquad (2.3)$$

2.5 Transmission Line Modeling

A transmission line model using the calculated average sample of impedance of line. Different line models where used to simulate all transmission line$Z_s = R_s + jx_s$ in this study, a π transmission line model with series impedance has been studied. Usually, the complex power flow complete the exact transmission system amid bus i and j is governed by the below mentioned equations,

$$S_{I-J}^{fl} = P_{I-J}^{fl} + jQ_{I-J}^{fl} \tag{2.4}$$

To understanding more, examining the hypothetical power transfer from bus I to j in Figure 2.5

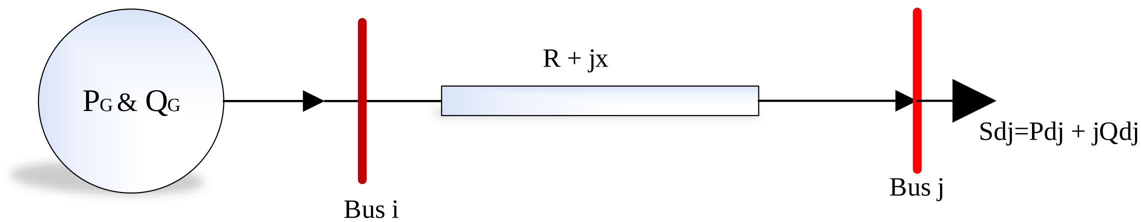

Figure 2 4 Representation of power flow i to j. **[26]**

2.5.1 Transmission Line Network from Shashemene to Bukuluguma.

The tasks of transmission line is transferring a power with in minimum loss, in my case from Shashemene to Bukuluguma system the voltage should be serve in acceptable limit. Using a computer approach, the first power system flows issue in my case study location had been identified. These assist us in determining the point at which supply power is least efficient relative to demand power. In the Genale Dawa III to Yirgalem II from Yirgalem II to Hawassa II there is 230 KV network the other is 132KV transmission network includes from Shashemene to Hawassa I, from Hawassa I to Yirgalem I and from Yirgalem I to Bukuluguma.

Overhead transmission network pi model is depicted figure blow admittance j_{BC} is a function no- load current I_o admittance y is dependent on short circuit voltage [27].

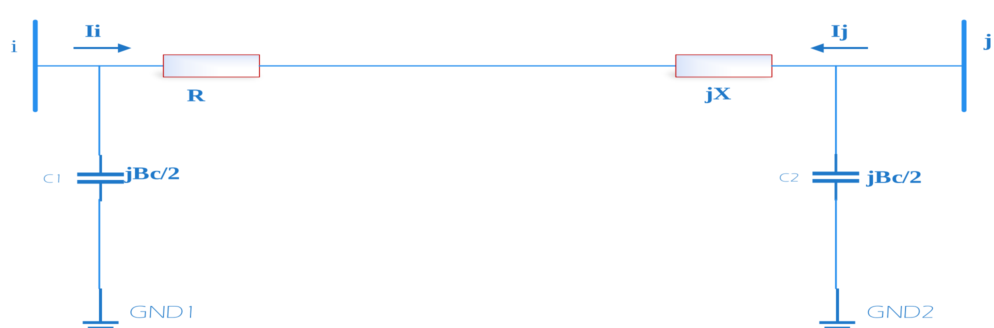

Figure 2 5 Transmission line modelling. **[26]**

In addition to this, there are limitation on the amount of power that a transmission line can transmit, which gives by equation 2.4 and 2.5 for sending end and receiving end respectively.

These restrictions brought on by the transmission line thermal limit.

$$S_{ij} \leq S_{max} \qquad (2.5)$$

$$S_{ji} \leq S_{max} \qquad (2.6)$$

Where Sij, Sji and Smax are apparent and max apparent power, correspondingly of lines among bus-i and bus-j balanced two ports chain matrix and its consistent two port nod admittances equation describes this Pi-models are given below

$$\begin{bmatrix} Vi \\ Ii \end{bmatrix} = \begin{bmatrix} 1 + j\frac{Bc}{2}z & Z \\ j\frac{Bc}{2}(2 + j\frac{Bc}{2}Z) & 1 + j\frac{Bc}{2}z \end{bmatrix} \begin{bmatrix} Vi \\ Ij \end{bmatrix} \qquad (2.7)$$

$$\begin{bmatrix} Ii \\ Ij \end{bmatrix} = \begin{bmatrix} y + j\frac{Bc}{2} & -y \\ -y & y + j\frac{Bc}{2} \end{bmatrix} \begin{bmatrix} Vi \\ Vj \end{bmatrix} = \begin{bmatrix} yii & yij \\ yji & yjj \end{bmatrix} \begin{bmatrix} Vi \\ Vj \end{bmatrix} \qquad (2.8)$$

Vi = Vi< δ_i, Vj = Vj< δ_j, z = R + jx and y = $\frac{1}{Z}$

$Y_{ii} = Y_{jj} = G_{ii} + jB_{ii} = y + j\frac{Bc}{2}$

$Y_{ij} = Y_{ji} = G_{ij} + jB_{ij} = -y$

Where

G = Conductance — Vi = Voltage at bus i

Bc = Capacitive susceptance — Vi = Voltage at bus j

Z = Impedance — δ_i = Angle delta at bus i

X = Reactance — δ_j = Angle delta at bus j

R = Resistance — $Y_{ii} = Y_{jj}$ = Admittance at the bus I and bus j

Apparent power Si and Sj injected ant bus i and bus j are given by.

$$S_i = ViI_I^* \text{ and } S_i = VjI_j^* \qquad (2.9)$$

Where I_I^* = conjugated current at bus i

I_I^* = conjugated current at bus j

Substituting the values of Ii and Ij the ejected power can be written as follows.

$S_i = Vi(\, Y_{ii}Vi + Y_{ij}Vj)^*$ and $S_j = Vj(\, Y_{ij}Vi + Y_{jj}Vj)^*$ (2.10)

Therefore, the injected real power Pi and reactive power Qi flow at bus I can be respectively expressed as

$$P_i = G_{ii}V_I^2 + Vi\, Vj(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}) \quad (2.11)$$

$$Q_i = B_{ii}V_I^2 + Vi\, Vj(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}) \quad (2.12)$$

Similarly, the injected real and reactive power at bus j can be spoken as

$$P_j = G_{jj}V_j^2 + ViVj(G_{ji}\cos\delta_{ji} + B_{ji}\sin\delta_{ji}) \quad (2.13)$$

$$Q_j = -\, B_{jj}V_j^2 + ViVj(G_{ji}\sin\delta_{ji} - B_{ji}\cos\delta_{ji}) \quad (2.14)$$

Since $\delta_{ij} = \delta_i - \delta_j = -\,\delta_{ji}$

Where P_i and P_j active or real power at bus i and bus j

Q_i , and Q_j reactive power at bus i and bus j

The reactive power flow and real power flow between bus i and bus j of the line having a series impedances.

Z = R + jx can be calculated using above equation 2.13 and 2.14

2.6 Literature Review

Most researchers focuses on this because of very interesting. The problems of enhancement profiles of voltage and power loss mitigation in transmission network have been approached in a number of different ways by researchers. The researchers' most important works are listed below.

The works focused on voltage stability improvement, voltage profile improvement, active power control, and reactive power control, power transferring capacity enhancement and transmission line loading minimization.

Bindeshwar Singh, Garima Agrawa [28]. The ultimate goals of this thesis work is to decrease the system's real and reactive power loss and to enhance line voltage profiles. The FACTS device

Static VAR Compensator (SVC) are being used to manage voltage profiles of the system. This study examines and evaluates SVC technology for the purposes of suppressing fluctuations, lowering system losses, and enhancing voltage. The IEEE-9 and IEEE-30 bus systems have been used to test the efficacy of the suggested approach. This is an excellent and resolvable piece of work. Voltage source convertors, on the other hand, are more acceptable since they adjust for real power and reactive power and voltage profiles issues by coordinating two or more transmission lines.

Y.N.Vijayakumar, Dr. Sivanagaraju, [29]. Controllers for Flexible AC Transmissions System (FACTS) consume primarily been used to address different power system steady state control issues. An adaptable tool called an interline power flow controllers can be used to regulate the power flows in subnetworks or multiline systems. In this investigation transmission, system in detail discussed and different mechanism of fact device based on power loss minimization techniques are proposed. A different mathematical modeling of IPFC and transmission network this are a two convertor, a three convertor of GUPFC and comprising convertors of IPFC are proposed. A work more focuses in only damping of low frequency oscillations investigation only, it does not includes the sizing and pacing techniques of IPFC to improve a voltage profile.

Manoj Asati, Sachin Tiwari, [30]. This work examines the influences of IPFC on the power network and looks into a number of variables, including the voltage profile and the actual and reactive power flows in the system transmission lines. The Inter line Power Flow Controllers power injection model has been introduced. The line charging susceptance and the complex impedances of the series-connecting transformers are included in this model. This research proposes a new method for power flow management in transmission systems using IPFC, and it creates and tests an IPFC model with MATLAB R2016a software. The load flow analysis, on the other hand, is dependent on the IEEE 9 bus system. There is not mentioned the any optimization algorithm techniques.

Worku Abera, [7]**.** The transmission line's Unified Power Flow Controller were proposed to boost power transfer capacity, lower power loss, and enhance voltage profile. Software called

DIgSILENT Power Factory has been used to simulate the UPFC. According to the results of the simulation, placing the UPFC will minimize power losses and improve the bus voltage profile and power flow. A comparison analysis was conducted and the numerical findings for the EEP transmission network in the eastern region of Ethiopia were need a report both with and without UPFC. This work is very similar with this thesis the difference is utilized fact devices and the big difference is compensation mechanism of the problem of that concerns voltage profile and losses. For this case, it is supportive and easily can dig gaps. However, the UPFC is connected on the single transmission line.

In these, investigation missed programming approach optimization techniques. Since it is better than DIgSILENT software, because it gives an iterative best function. In addition, cost estimation, and payback period of the project are not calculated.

Akanksha Mishra, G. Venkata Nagesh Kumar [31]. This research proposes a disconnected long-terms investigation strategies for interline power flow controller deployment that safeguards the power system against unanticipated events.

To increase system stability and loadability while lowering system loss and power flow on heavily loaded lines, utilize an IPFC. To control transmissions line congestion, this research suggests using for optimal placement, a Disparity Line Utilization Factor and optimal tuning of IPFC based on the Gravitational Search algorithm. According to relative line congestion, DLUF assigns a ranking to the transmission lines. The study used the IEEE 14 bus system as the basis and suggested 57 buses utilizing GA optimization techniques for bus sizing and placement; however, the feasibility of the project are not mentioned

Mbunwe Muncho and Josephine, Nohu Mark Nubuka [32]**.** The study suggests a method to address voltage issues by strategically placing static synchronous compensator device, aiming to minimize power losses and enhance the voltage profile within a mult-machine power network. In order to minimize losses and enhance bus voltage profile, this study proposes a methodology for solving voltage problems at appropriately sited STATCOM devices. However, based on the line with the greatest reactive power losses, a straightforward heuristic method used for identify the best place for STATCOM. In modern era, IPFC is better than STATCOM for transmission network. New understandings in related domains or technology breakthroughs can cause research to become out of date. To close the ensuing technological or knowledge gaps, more research is required to expand on the current understanding like IPFC.

Apoorv H. Prajapati, Piyush R. Patel, Himalay V. Patel [17]**.** This investigation proposed on four buses system. For IPFC Phase compensation (IPFC-P) and Quadrature compensation (IPFC-Q), there are two models available. In order to prevent the series VSC from using any real power in steady state between two signals compensations schemes use the injected voltages by the sequences VSC to maintain a two signals advance relationships with the source currents. This is a big benefit when sag conditions reduced via IPFC. The VSC is decreased since both the series VSC and the shunt-VSC share the load's volt ampere reactive (VAr).

Minale Birlie [8]**.** In this investigation the possible of minimizations of power loss and enhancement of voltage level in a transmission line, Fuzzy Logic Controller (FLC) based UPFC is proposed. The works including load flow analysis using newton Raphson methods also comparison of the result of after implementation of IPFC becomes better after added FLC the results becomes improved, but the cost analysis and payback period is not mentioned.

This task consists of multipurpose features, including reducing active power loss. Many researcher have been concentrated on different techniques to overcome the power transmission system issues, most of them proposed used different fact devices. However, some researcher has not consider a latest and versatile IPFC fact devices and fuzzy logic system controller also newton Raphson load flow analyze. In my thesis, the voltage profile and power loss issues will composite using IPFC and GWO optimization techniques to sizing and placing of a device. It consisting comparison of antlion optimization techniques are proposed and address the existing issues on the southern region transmission system from Shashemene to Bukuluguma.

2.7. Identified Research Gap.

A number of researcher proposed voltage profile improvement and power loss minimization using different optimization techniques and FACT devices. Their research finding are not evaluated in terms of cost and optimization algorithms are complicated.

Grey wolf optimization programing approach is simple compare to other GA, WO and PSO. It needs less memory requirement and has fast response time. Several papers cost of the project are not estimated and final proposed payback period not estimated.

In this investigation, the improved voltage magnitude and minimized power loss based on optimal placing and sizing with the help of GWO. The achieved improvement of the bus voltage profiler is improved from 0.937pu to 0.969pu and real and reactive power loss are minimized from 7.322 MW to 4.3.93 MW and 5.693 MVAr to 2.294 MVAr respectively. IPFC is very effective FACT device for high voltage transmission line compare to other, it compensate a multiline line issues and optimize both active and reactive power overload to underload also project implementation cost are calculated and final proposed project payback period calculated.

For more comparison, the following table more explain the gaps and the techniques

Table 2.3 Research gap and utilized techniques

Author	**Objectives of investigation**	**Utilized Techniques**	**Limitation**
Asresahegn Tsehay [2]	Using UPFC device to reduce transmission line power loss and enhance the bus voltage profile	Particle swarm optimization techniques for sizing and placing of UPFC and newton load flow analysis for power flow solution	Searching capabilities of PSO dealing with strongly constraint problems and need another comparison algorithms.

Worku Abera [7]	Using UPFC, reduce transmission line loss, improve voltage profile, and increase the current transmission line's capacity for power transmission.	To identify the weakest bus. Utilize DIgSILENT Power Factory results	The techniques values are not considered an optimization algorithm
Minale Birlie [8]	To investigate the possibility of employing UPFC to reduce power loss and raise voltage levels in a transmission line	using fuzzy logic controller based	The objective function and its constraint is not mentioned. It doesn't utilized Optimization techniques
Tokuma Zeleke [13]	Assess the effectiveness of Ethiopian transmission lines at voltage levels between 400 and 230 kV in order to lower line loss and enhance voltage profile with the use of capacitors banks and STATCOM.	PSO optimization techniques to size and placing of STATCOM, and NR load flow analysis.	The utilized PSO algorithm is older than GWO. A versatile IPFC has a better performance compare to STATCOM
Gezahegn Shituneh	Investigate and evaluate the possibilities for improving Ethiopia high-voltage grid	The technique of contingency-based analysis is commonly	For sizing and optimal placing of UPFC using

[26]	security using the Unified Power Flow Controller.	employed to examine the security of power systems and collaboratively	different algorithm techniques is better than contingency analysis
Bindeshwar Singh [28]	Minimize the system's actual and reactive power loss in order to enhance the voltage profile.	The best site is at bus number nine, and the best arrangement for SVC makes use of Newton Raphson	The utilized fact device SVC is not supplementary compare with the latest versatile IPFC
Vishnu Charan Thippana, et al [33]	By employing an IPFC fact device, reduce the network's average transmission loss overall and bus voltage drop.	Firefly optimization algorithm for optimal location and NR load flow analysis	Very expensive techniques to achieve, but it gives better result. Reactive power losses minimization doesn't considered
The proposed this thesis	To minimize a power loss and improve voltage profile in the transmission line	Grey wolf optimization and compared with antlion optimization techniques	The latest versatile IPFC cost is high

CHAPTER THREE

3. MODELING OF POWER SYSTEM

3.1 Introduction

In this thesis, customized IPFC will be performed on the networks of southern region transmission line at different system operating conditions. MATLAB software is used for finding power flow analysis results for different loading conditions that performs in base case and after implementation. The ultimate goal of thesis test is to demonstrate the helpfulness of IPFC for power loss control and bus voltage profiles. The following activities will be carried out.

3.2 Methodology

In generally, the methodology that were used in this work can summarized in the following approach.

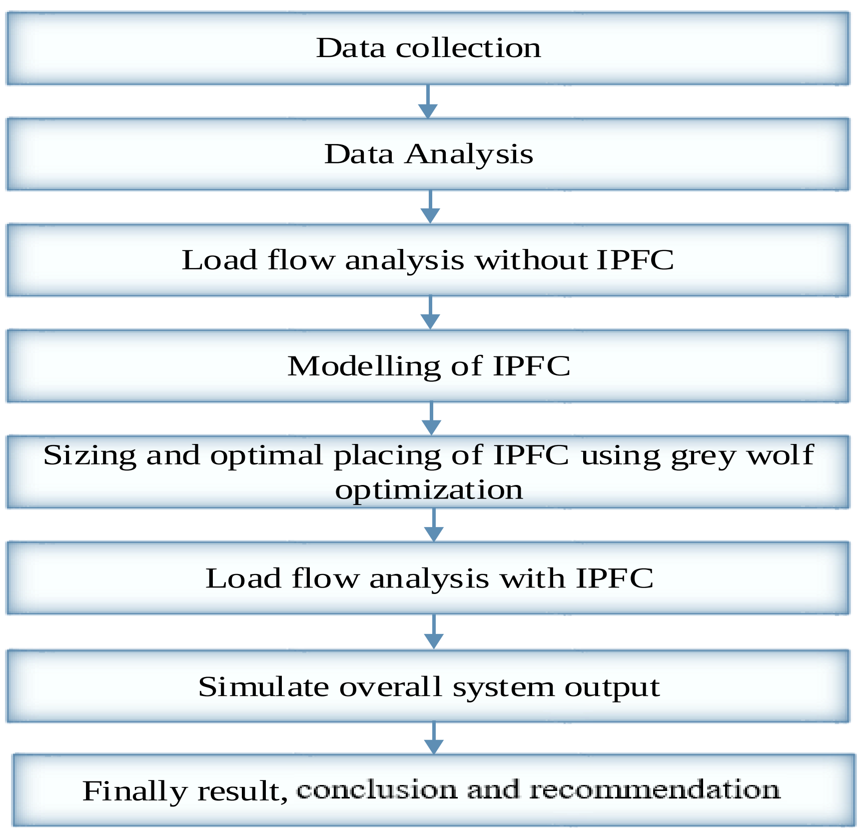

Figure 3. 1 The thesis methodology flows process

3.3 Data collection and analysis

Interviewing the appropriate staff members of the southern transmission networks and generations.

The information gathered will been used to clearly examine the issues with the systems under investigation. The recent and necessary data for the transmission network is collected from the Ethiopian Electric Power through their recorded technical data regarding the transmission network. The data collected includes

- The transmission line parameters.
- The load demand data of the Southern Region Transmission System network
- The generation capacity of the power plants Power Generation.

Three categories can be used to categorize power systems buses based on the initial data provided

1. Slack Bus: In power flow study one slack node, defined by a phase angles voltage constant and in voltage magnitudes, should be present in the power system. Consequently, at the swing node, V and θ are identifiable variables, whereas the variables that need to be solved are P active powers and Q reactive powers. The network receives its losses from the power generated at this node. This is crucial since, until the present computation is finished the extent of the loss won't be recognized. Additionally, if one node has power constraints, the system cannot accommodate the necessary losses, therefore the goal cannot be attained. The slack node closest to a large AGC power station should be selected since the position of the slack node can affect how complex the computations are.
2. PQ Bus: For PQ buses, the complex voltage must be resolved while the reactive power Q and real power P are supplied as known values. Substations are often regarded as PQ node where the load power are specified as constants. This node can be used as PQ nodes in power plants where output real power or reactive power are fixed. The majority of nodes in power systems are PQ types when considering load flow.
3. PV Bus: Some time it call a generative bus. For PV nodes, it is essential to determine the reactive power Q and voltage angle, while the voltage magnitude V and active power P are already established variable. Usually, the node voltage magnitude can be keep at a standard

level by the reactive power sources that should be present in PV buses. Power plant buses can function as photovoltaic nodes since their generator's reactive power capacity allows for the management of the voltage at these buses. When an electrical substation possesses sufficient reactive power compensation devices to regulate voltage, it can classified as a photovoltaic node. The summarized table as shown blow.

Table 3. 1 Generations data

No	Generation name	P_G(MW)	Q_G(MVAr)	Qmin(MVAr)	Qmax(MVAr)
1	Genale Dawa III	254	30	-38	38
2	Melka Wakena	153	17.2	-20	20
3	Gilgal Gibe II	180	67.2	-22.4	22.4

Table 3.3 Data of two winding transformer

From bus name	To bus name	Winding MVA Base	Pri (KV) winding nominal	Sec (KV) winding nominal
Hawassa I	Hawassa I	25	132	15
Bukuluguma	Bukuluguma	25	132	33
Hagere Mariam	Hagere Mariam	25	132	33
Shashemene	Shashemene	50	132	15

Table 3.4 Data of three winding transformer

Node 1	Node 2	Node 3	Prim KV	Sec KV	Teri KV	Pri Winding 1-2 MVA	Sec Winding 2-3 MVA	Ter Winding 3-1 MVA
Hawassa I	Hawassa I	Hawassa I	132	33	15	16	8	8
Shashemene	Shashemene	Shashemene	132	33	15	12.5	12.5	12.5
Dilla	Dilla	Dilla	132	33	15	25	12.5	12.5

Yirgalem I	Yirgalem I	Yirgalem I	132	33	15	25	12.5	12.5
Yirgalem II	Yirgalem II	Yirgalem II	230	33	15	125	125	125
Yabelo	Yabelo	Yabelo	132	33	15	10	10	10
Hawassa II	Hawassa II	Hawassa II	230	132	15	125	125	125

Table 3. 5 Transmission line data

S.no	**From bus**	**To bus**	**KV**	**R(pu)**	**X(pu)**	**B(pu)**
1	Shashemene	Hawassa II	132	0.036902	0.043833	0.00804
2	Hawassa II	Hawassa I	132	0.0040846	0.0076874	0.0014893
3	Bukuluguma	Yabelo	132	0.1730659	0.3462130	0.0665771
4	Dilla	H/Mariam	132	0.1157403	0.2315349	0.0445244
5	Yirgalem I	Dilla	132	0.0428260	0.0856721	0.0164748
6	H/Mariam	Yabelo	132	0.1106624	0.2213766	0.0425710
7	Yirgalem II	Yirgalem I	132	0.0073416	0.0146866	0.0028243
8	Hawassa I	Yirgalem I	132	0.0524819	0.0854493	0.0163851
9	Hawassa II	Yirgalem II	230	0.008083176	0.024	0.0770756

Table 3. 6 Load data

S.No	**Bus name**	**Pload (MW)**	**Qload (MVAr)**
1	Shashemene	14.91	7.16
2	Hawassa II	19.36	9.98
3	Yirgalem II	8.49	5.90
4	Hawassa I	24.21	16.44
5	Yirgalem I	4.71	2.26
6	Dilla	8.43	5.99
7	Hagere Mariam	5.27	3.68

8	Bukuluguma	3.09	2.27
9	Yabelo	1.99	0.95

Table 3. 7 Bus data

No	Bus name	Voltage (Pu)	Angle (deg)
1	Shashemene	1.0096	-38.59
2	Hawassa II	1.0094	-38.56
3	Yirgalem II	1.0227	-37.15
4	Hawassa I	0.9873	-11.90
5	Yirgalem I	0.9614	-12.44
6	Dilla	0.9026	-20.26
7	Hagere Mariam	0.9408	-48.06
8	Yabelo	0.9741	-14.69
9	Bukuluguma	0.972	-12.05

In the case study network system at list one generation bus setup as a swing bus. The proposed network is addressed on a 132KV transmission system a line network has different line KVs. The swing bus also known as the reference bus contains two power plants on the single line diagram: Melka Wakana and Gilgel Gibe II, which are considered single generation. Additionally, at PV bus Genale Dawa III, a third power plant in the case study area network, this line are externally linked to the Wolaita sodo line. Nine busses total, with two of them having exterior lines that are shown on a single line diagram: Yirgalem I to the Shakiso line and Yirgalem II to the Wolaita sodo line.

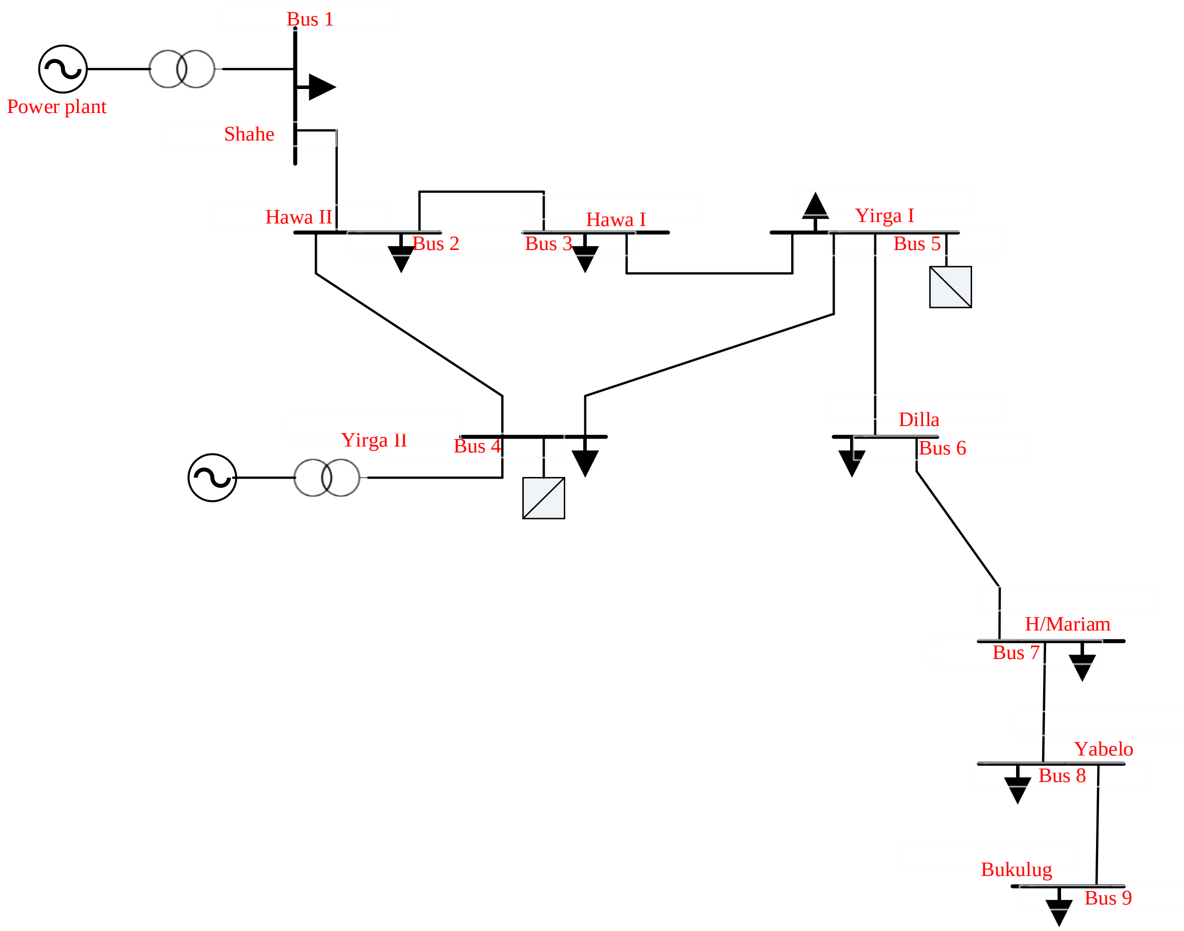

Figure 3. 2 Single line diagram of southern region from Shashemene to Bukuluguma transmission line network.

Distance of a transmission line networks

My case study area total the transmission line network distance from Shashemene to Bukuluguma is totally 623.9 Kilometer. Bus name and bus number are indicated or assigned on each bus. The external grid signed in diagonal shaded box. This external grid network represented as an equivalent generator to reflect the influence of the external grid network on the component of the network for which studies are being conducted and total in this system two external grid. For load, used symbol is a bold black arrow.

The IPFC are incorporated on the fifth bus name called Yirgalem I and it located between Hawassa I on bus II and Dilla bus on bus six. The IPFC fact devices problem compensator where implemented on the 115.68 Kilometer from reference bus to Yirgalem I bus.

3.4. Per unit value of the system

A per unit value of the system is displaying the quantities of the arrangement as fraction of defined bases unit measures. The complex transformation of all impedances to a single VA system is necessary to solve the problem of interconnected power systems with multiple voltage levels. This allows for the expression of each reactance in the system as a percent or as a unit. To fully define a per-unit system, at least four base quantities must be present: Volt-ampere, impedance, voltage, and current in [34].

$$\text{Per unit} = \frac{Actual\ value\ of\ quantity}{Base\ value\ of\ quantity} \tag{3.1}$$

For the purpose of characterizing the per unit system the voltage, current, power and impedance values must be defined

$$V_{pu} = \frac{V}{V_{base}},\ I_{pu} = \frac{I}{I_{base}},\ S_{pu} = \frac{S}{S_{base}},\ Z_{pu} = \frac{Z}{Z_{base}} \tag{3.2}$$

Two of four base values V_{base}, I_{base}, S_{base}, and Z_{base}.

3.5 Using the Newton-Raphson Method to Flow Power

For large power systems, load flow analysis utilizing the Newton Raphson (NR) approach is more practical and efficient. The primary benefits of this approach are its rapid processing speed and The number of iteration requireds to find a solution remains unchanged regardless of the size of the problems.

The most fundamental study to be carried out in a power system is a power flow analysis, every now and then discussed to as load flow. Analysis of power system an important part. Methods of newton Raphson load flows are required for controlling an existing system, minimizing power loss, and improving the voltage profile.

The issue consists of figuring out the voltage levels and angles of phase at each bus in addition to the reactive as well as active power flows in each lines. When addressing a power flow issue, compute the system's power loss. A single phase model is employed, and the systems are considered to be functioning under balanced conditions in [35].

In computer-assisted electrical power system analyses, such analysis of load flow, performance problems are solved by an analysis of mathematics based on the solution of arithmetic simultaneous equations in [36]. A grid power system's nodal equation resembles

Y bus:-

$$I = Y_{bus} * V \tag{3.3}$$

For an n bus system, the node equation can be written in a thorough form.

$$I_i = \sum_{j=1}^{n} y_{ij} V_j \quad \text{for i = 1, 2 ... n} \tag{3.4}$$

The complicated power supplied to bus I is

$$P_i + Q_i = V_I I_i^* \tag{3.5}$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{3.6}$$

Replacing for I_i in terms of P_i and Q_i, the equation given

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=1}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} - V_j \qquad j \neq 1 \tag{3.7}$$

This equation 3.7 employing iterative methods to address the load flow issue

Newton Raphson methods

The equation pertaining to currents entering a power system can written using the admittance matrix. Equation 3.5 can be stated polarly, with j including bus i.

$$I_i = \sum_{j=1}^{n} |y_{ij}| \, |V_{ij}| < Q_{ij} + \delta_j \tag{3.8}$$

At bus i, the real and reactive power is

$$P_i - jQ_i = V_i^* \; I_i \tag{3.9}$$

Substitutes for I_i in equations 3.9 for equation 3.10

$$P_i - jQ_i = |V_i| < -\delta_i \sum_{j=1}^{n} |y_{ij}| \, |V_j| < \delta_{ij} + \delta_j \tag{3.10}$$

The two imaginary and real part

$$P_i = \sum_{j=1}^{n} |V_i| \left|V_j\right| \left|y_{ij}\right| \cos\left(Q_{ij} - \delta_i + \delta_i\right) \quad (3.11)$$

$$Q_i = \sum_{j=1}^{n} |V_i| \left|V_j\right| \left|y_{ij}\right| \sin\left(Q_{ij} - \delta_i + \delta_i\right) \quad (3.12)$$

The two above equation 3. 11 and 3.12 a real power and reactive power establish a set of nonlinear algebraic equation in the per unit $|V|$ and in radianδ.

In Taylor's series, equations 3.11 and 3.12 are extended with respect to the first estimation, disregarding any higher order terms. The sets of linear equation obtained are as follows.

$$\begin{bmatrix} \Delta P_2^k \\ \vdots \\ \Delta P_n^k \\ \Delta Q_2^k \\ \vdots \\ \Delta Q_n^k \end{bmatrix} = \begin{bmatrix} \frac{\Delta P_2^k}{\partial \delta_2} & \cdots & \frac{\Delta P_2^k}{\partial \delta_n} & \frac{\Delta P_2^k}{\partial |V_2|} & \cdots & \frac{\Delta P_2^k}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\Delta P_n^k}{\partial \delta_2} & \cdots & \frac{\Delta P_n^k}{\partial \delta_n} & \frac{\Delta P_n^k}{\partial |V_2|} & \cdots & \frac{\Delta P_n^k}{\partial |V_n|} \\ \frac{\Delta Q_2^k}{\partial \delta_2} & \cdots & \frac{\Delta Q_2^k}{\partial \delta_n} & \frac{\Delta Q_2^k}{\partial |V_2|} & \cdots & \frac{\Delta Q_2^k}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\Delta Q_n^k}{\partial \delta_2} & \cdots & \frac{\Delta Q_n^k}{\partial \delta_n} & \frac{\Delta Q_n^k}{\partial |V_2|} & \cdots & \frac{\Delta Q_n^k}{\partial |V_n|} \end{bmatrix} \begin{bmatrix} \Delta \delta_2^k \\ \vdots \\ \Delta \delta_n^k \\ \Delta \left|\frac{V_2^K}{V}\right| \\ \vdots \\ \Delta \left|\frac{V_n^K}{V}\right| \end{bmatrix} \quad (3.13)$$

The magnitude and voltage angles values for the slack bus system are previously known, so they are not included in the previous equations. A linearized links between minute variations in voltage magnitude and angle is established by the element of the Jacobian matrix that is generated subsequently partial derivations of equation 3.13 are expressed. The equation in the following matrix expression in 3.14.

$$\begin{bmatrix} \triangle P \\ \triangle Q \end{bmatrix} = \begin{bmatrix} H & M \\ N & L \end{bmatrix} \begin{vmatrix} \triangle \delta \\ \triangle \frac{|V|}{V} \end{vmatrix} \quad (3.14)$$

Where: H, N, M, and L are Jacobian matrix element. And

H = $\frac{\partial P}{\partial \delta}$, N = $\frac{\partial P}{\partial V}$, M = $\frac{\partial Q}{\partial \delta}$, and L = $\frac{\partial Q}{\partial V}$

The discrepancy among the scheduled and calculated figures known as power residual for the term of ΔP_i^k and ΔQ_i^k are characterized as

$$\Delta P_i^k = \Delta P_i^{sche} - \Delta P_i^k \; ; \quad i = 2, \ldots n-1 \qquad (3.15)$$

$$\Delta Q_i^k = \Delta Q_i^{sche} - \Delta Q_i^k \; ; \quad i = n - 1 \text{ --------- } n-1-m \qquad (3.16)$$

The updated bus voltage estimations are

$$\delta^{k+1} = \delta_i^k + \Delta\delta_i^k \qquad (3.17)$$

$$|V^{k+1}| = |V_i^k| + \Delta|V_i^k| \qquad (3.18)$$

Newton Raphson Algorithm

After quadratic mathematical problem formulation, equation algorithm procedure depends on above formulated equations. The load flow problem can resolved iteratively by its convergence undoubtedly Newton Raphson approach with the following ways:

1. With angle and voltage (typically δ = 0 at reference or swing bus, expected │V│, δ, at all PQ bus and phase angle at entirely PV bus. In the nonappearance of any supplementary statistics flat voltage start are suggested.
2. Determine ΔQi for each PQ bus and ΔPi directed at PV and PQ bus using the equations, 3.15 and 3.16. The iteration should be terminated P1 and Q1, should be calculated, and either the line flows or the entire solution should be printed since all values are below the predetermined ability.
3. Consider evaluating Jacobian elements using if the convergence criteria is not met. Equation. 3.14.
4. For corrections of voltage angles and magnitudes, solve Equation 3.17.
5. After making the necessary adjustments to the prior values, update the voltage angles and magnitudes and go back to step 2.
6. If there are restrictions on the controlled Q source at PV buse in step 2,

Every time Q calculated, if it exceeds the limitations, it is set to the restrictive values, and in that iteration, the conforming PV bus converted to a PQ bus. The bus changed back to a PV bus if Q does fall inside the allowed bounds in the ensuing computation.

A PV bus was created from a PQ bus with voltage limitations if any of these limitations were exceeded in that iterations, with the voltage locked at the restrictive value.

The Newton Raphson load flows technique diagram is displayed in Figure 3.3

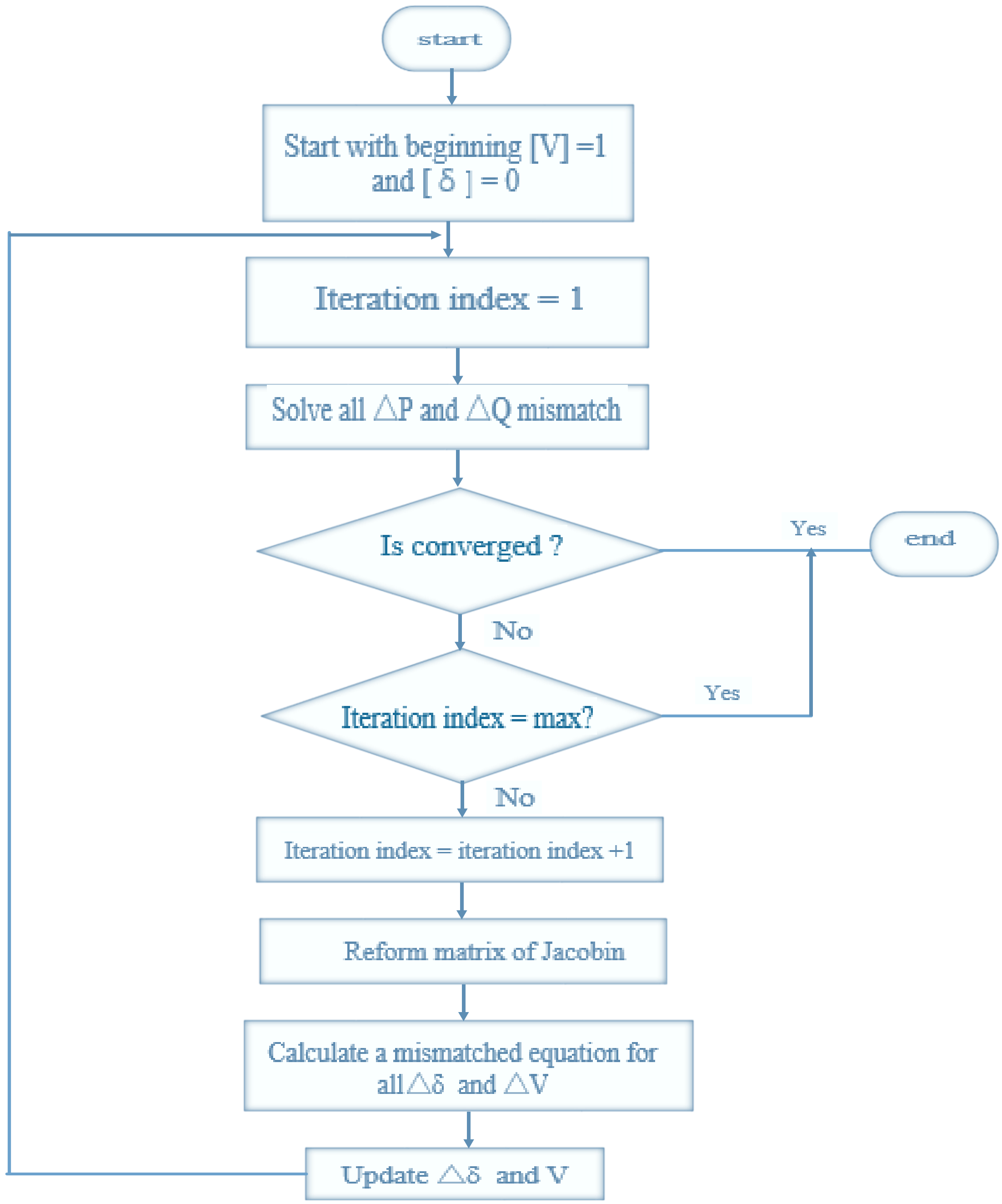

Figure 3. 3 Newton Raphson load flow analysis flowchart.

3.6. Voltage Stability Index

First recognized by powerful IPFC with the whole system loading size at all nodes at a time, and then the equation 3.20 used to compute the VSI. The IPFC is located at the node with the lowest VSI. The most sever bus profile identified by voltage stability index in [37]. The stabilities of power system networks can examined by VSI. There are two categories for these voltage stability indices: system variable-based and Jacobian matrix-based.

The capacity of a power system network to sustain constant voltage magnitudes at every network bus both before and after a disturbance is referred to as voltage stability. The loss of this ability frequently results in voltage instability, which is characterized by a persistent fluctuation in the network's voltage magnitude.

To evaluate the power system's steady state voltage stability under changing load conditions, a voltage stability index has been devised. The Bus Voltage profile Improvement Index (VPII) is defined as equation (3.19).

$$VSI = (K+1) = |Vk|^4 - 4\,[P_{k+1} \times X_k - Qk+1 \times Rt]^2 - 4[P_{k+1} \times R_k - Qk+1 \times Xt]|Vt|^2 \qquad (3.19)$$

$$VSI = \frac{1}{\lambda + max_{i=2}^{n}(|1 - V(IPFC)|)} \qquad (3.20)$$

Where; - VSI - is the voltage values after IPFC installations.

λ - is a scalar value

3.6.2. Real Power Loss Reduction Index

The objective of IPFC size and placement is to reduce the actual power system loss. When an IPFC is deployed at a bus, the active Power Loss Reduction Factor Index per node is the ratio of the active power loss reductions in terms of percent from a base configuration. The active Power Loss Reduction Index (PLRI) is considered as follow:

$$PLRI = \frac{PL(base) - PL(IPFC)}{PL(base)} \qquad (3.21)$$

Where, (Base):-is active power loss before IPFC installation. PL (IPFC):- is the real power loss in study scheme after connection of IPFC.

3.6.3 Reduction Index of Reactive Power

An industrial machines most of the time motors run by reactive power and this power is utilized by inductive load. The Factor for reduction index of reactive power loss has been included in the independent functions to determine the influence of IPFC on reactive power losses. When an IPFC is put on a bus, this is the percentage decrease in reactive power loss as opposed to the default value.

The QLRI, or the index for reducing reactive power loss has been expressed as flows.

$$\text{QLRI} = \frac{QL(base) - QL(IPFC)}{PL(base)} \tag{3.22}$$

(base) : The reactive power loss before IPFC installation.
QL (IPFC) : Reactive power loss in the research systems following IPFC connection

3.7 Modeling of IPFC

Both actual and reactive power exchanges with the line are made possible by the IPFC framework. By using a DC connection to exchange power between the SSSCs in separate lines, this active power can be provided. The voltages produced by the voltage source converters (VSC) differ in both phase angle and amplitude. Examine an example bus in a power system networks; the equivalent transmission lines are used there. A system's properties, such as voltage magnitude, line impedance, and transmission angle, can be changed to manage power flow. A device that attempts to alter scheme constraints in order to regulate the flow of power is known as a power flow-controlling device in [17].

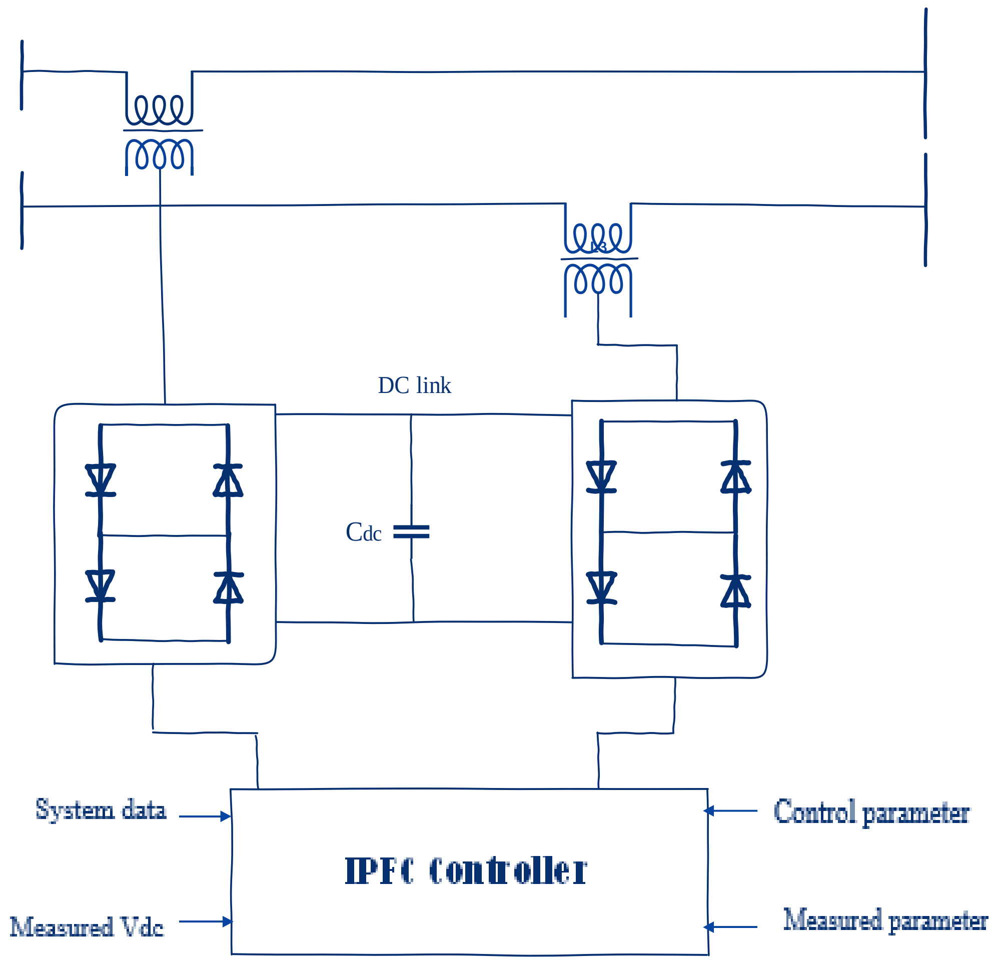

Figure 3. 4 Two-converter IPFC Series Controller schematic diagram **[38]**

Static Synchronous Series Compensator (SSSC)

In the modelling of IPFC, considering SSSC is very necessary things because of IPFC is a serial connected result of SSSC in [39]. It is possible to regulate the output voltage in two side with the help of DC link between them control a line power structure without affecting the system's current. It makes it possible to absorb oscillations and regulate power flow in both directions. It is similar to a regulated series capacitor device, but significantly more perfect and efficient.

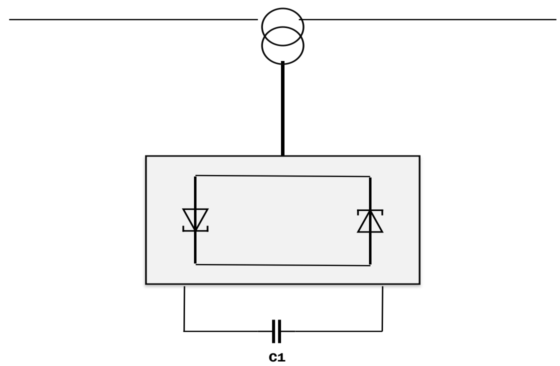

Figure 3. 5 Static synchronous series controller without power source **[39]**

3.7.1. Control Strategy of IPFC

An essential component of an interline power transmission system is the control system. By controlling reactive power, this control system keeps the system voltage within an acceptable range. Reactive power support is ensured by the control tasks for the surrounding AC system, which improves power quality and reliability during regular operation and keeps the system stable in the event of an interruption. By adjusting the phase angles of the converter output voltage or by injecting series voltage in series with the transmission line, active power can be regulated. Conversely, reactive power can be managed by adjusting the converter's output voltage magnitude. The converter is capable of freely absorbing or creating responsive electricity in [29].

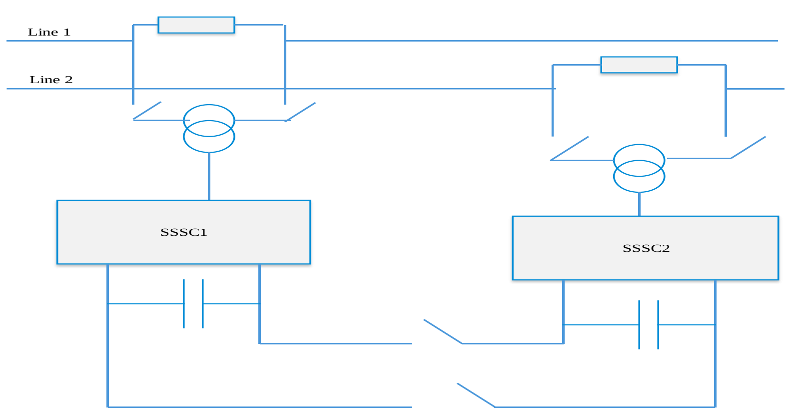

Figure 3. 6 IPFC Control strategy **[29]**

3.7.2 Operational Principle of IPFC

The series conversion controls the amount and direction of the injected voltage. Directly or indirectly influencing the power flows on the line is the goal of this voltage injection. Examine a basic IPFC design with two AC convertors placed back-to-back that each use series voltage injection to compensate a transmission line in [40].

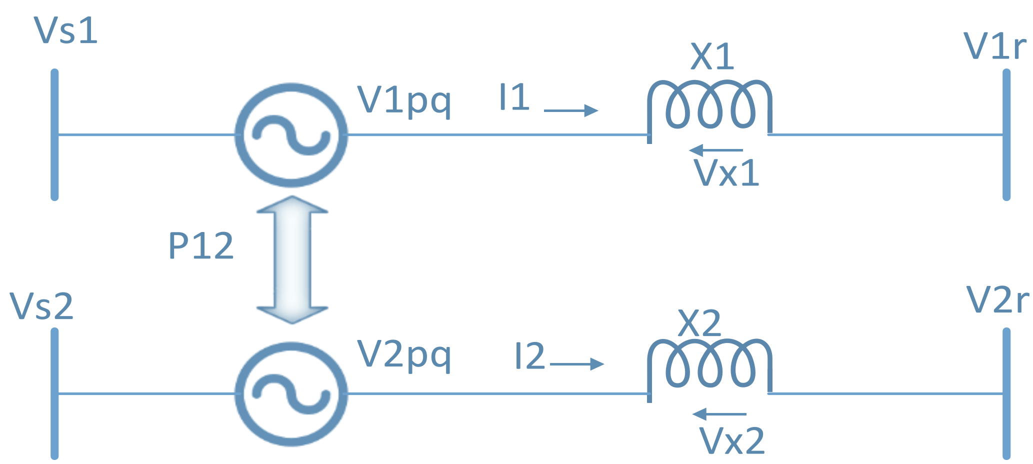

Figure 3. 7 Voltage compensation of two line **[40]**

To ensure clarity, we will assume that both the sending and receiving ends have constant voltages, with fixed amplitudes (V1s = V1r = V2s = V2r = 1.0pu) and fixed angles that produce equal transmission angles (δ1 = δ2 (30) for both systems. System phasor diagram showing the link between angle ($0^\circ < P1pq \leq 360^\circ$) and V1s, V1r, and V1x. The phasor Vpq relationship to angle P1pq causes a cyclical variation in the phasor V1x's magnitude and angle.

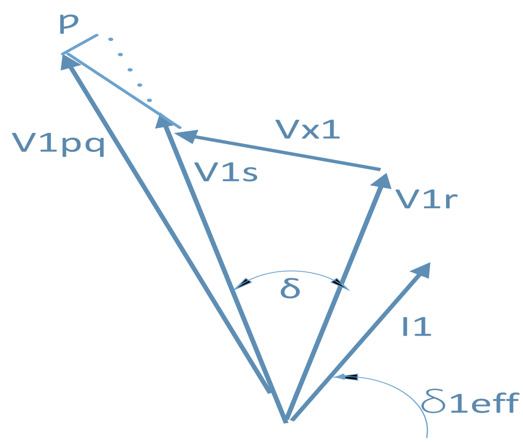

Figure 3. 8 Voltage convertor vector diagram **[40]**

3.7.3 Mathematical modeling of IPFC

The IPFC is represented mathematically by a model that will be called the power injection model. Understanding how the IPFC affects the power system in a steady state is made easier with the use of this model.

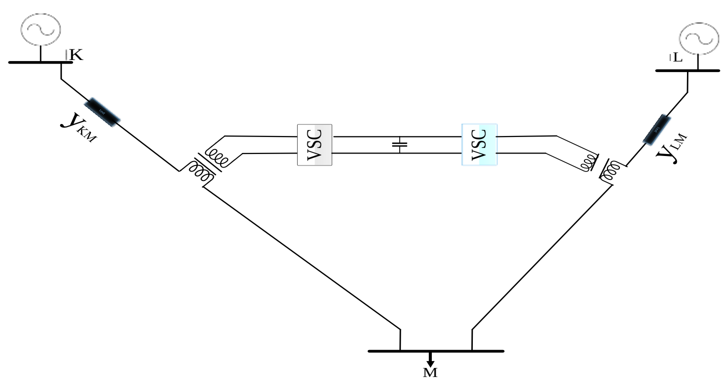

Fig. 3.9 IPFC incorporation in transmission line

Furthermore, integrating the IPFC model with the power flow model may be simple. When studying power systems in their steady state, usually, the VSC is regarded as a synchronous voltage source that injects a controlled-magnitude, almost sinusoidal voltage and angle Fig. 3.9 illustrates IPFC comparable circuit based on the system's power flow concept. IPFC is able to regulate two transmissions line parameter with three buses voltage. Equivalent circuit of IPFC is exposed V_i, V_j and V_k Bus voltage.

V_1, δ_1 Magnitudes and angles.

Vsein intricate manageable series injection voltages. Active power can exchanged between the two active power exchange results in zero when one or more series convertors are connected to the DC link in [41].

$$\text{Re}\,(V_{seij}\, I_{ji}^{*} + V_{seik}\, I_{ki}^{*}) = 0 \tag{3.23}$$

Power flow mathematical equations for load flow studies that use IPFC are given blow

Bus i

$$Ii = Iij + Iik \tag{3.24}$$

$$Ii = \frac{V_i - V_{seij} - V_j}{Z_{seij}} + \frac{V_i - V_{seik} - V_k}{Z_{seik}} \tag{3.25}$$

Complex power can be obtained from the equation above, and the results are given here.

$$Si = V_i\, I_{ij}^{*} = P_i + jQ_i \tag{3.26}$$

The complex power in terms of voltage and impedance is given blow

Considered as flows for the purpose of solving load flow with IPFC under operating restrictions

$$\left.\begin{matrix} V_{sein}^{min} \le V_{sein} \le V_{sein}^{max} \\ \pi \le \theta_{sein} \le -\pi \end{matrix}\right\} \tag{3.27}$$

The active power exchanges between the two convertor DC link is deliver in the flowing equations

$$Pi = \sum P_{sum} = 0 \tag{3.28}$$

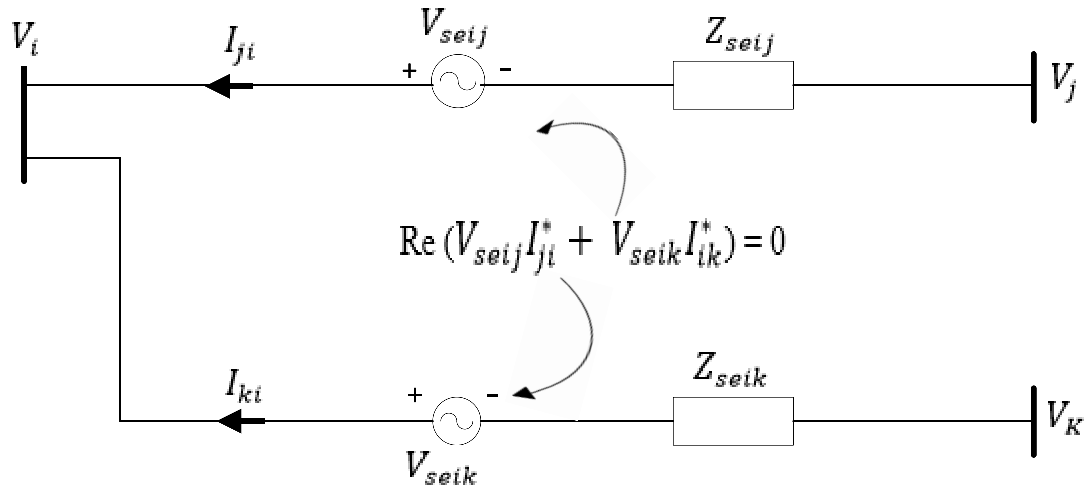

Figure 3. 9 Mathematical modeling of IPFC **[41]**

$Z_{seij} = Z_{seik}$ are the transformer's series impedance. Pi, Qi and Pji, Qji, respectively, are the active and reactive powers injected by the series convertor linked with respect to buses i, j. The IPFC branch currents Iji and Iki are what leaves bus j and k when line j_i and k_i exit.

$$P_i = V_i^2 g_{ii} - \sum_{j=1,j\neq 1}^{n} V_i V_j (g_{ij}cos\delta_{ij} + b_{ij}sin\delta_{ij}) - \sum_{j=1,j\neq 1}^{n} V_i V_{seij}(g_{ij}cos(\delta_i - \theta_{seij}) - b_{ij}sin(\delta_i - \theta_{seij})) \quad (3.29)$$

$$Q_i = V_i^2 b_{ii} - \sum_{j=1,j\neq 1}^{n} V_i V_j (g_{ij}sin\delta_{ij} - b_{ij}cos\delta_{ij}) - \sum_{j=1,j\neq 1}^{n} V_i V_{seij}(g_{ij}sin(\delta_i - \theta_{seij}) - b_{ij}cos(\delta_i - \theta_{seij}) \quad (3.30)$$

$$P_{ji} = V_j^2 g_{jj} - \sum_{j=1,j\neq 1}^{n} V_i V_j (g_{ij}cos\delta_{ij} + b_{ij}sin\delta_{ij}) + \sum_{j=1,j\neq 1}^{n} V_i V_{seij}(g_{ij}cos(\delta_i - \theta_{seij}) - b_{ij}sin(\delta_i - \theta_{seij})) \quad (3.31)$$

$$Q_{ji} = -V_j^2 b_{jj} - \sum_{j=1,j\neq 1}^{n} V_i V_j (g_{ij}cos\delta_{ji} - b_{ij}sin\delta_{ji}) + \sum_{j=1,j\neq 1}^{n} V_i V_{seij}(g_{ij}cos(\delta_j - \theta_{seij}) - b_{ij}sin(\delta_j - \theta_{seij})) \quad (3.32)$$

Where $g_{ij} + jb_{ij} = g_{jj} + jb_{jj} = \frac{1}{Z_{seij}} = Y_{seij}$ (3.33)

$$g_{ii} + jb_{ii} = (g_{ij} + g_{ik}) + j(b_{ij} + b_{ik}) \quad (3.34)$$

In order to maximize the use of the transmission system, underloaded lines can share power with overloaded lines by applying the IPFC concept, which is applied to two lines, to numerous lines. All of the converters' combined real power exchange must be zero.

Re $(V_{seij} I_{ji}^* + V_{seik} I_{ik}^*) = 0$

Transmission system is not simply modeled as a visualized it needs a very clear and detail calculated model and digital system analysis management to control voltage active power and reactive powers of the system. The IPFC has the ability to regulate the basic power system parameters.

This part derives a mathematical model for IPFC, which we'll call the power injection model. Understanding how IPFC affects a power system in steady states is made easier with the use of this above mathematical models. The power injection model is the mathematical representation of the IPFC that is derived in this section. The model makes it easy to understand how the IPFC influences the power system in a steady state. A synchronous voltage basis that injects a nearly sinusoidal voltage with adjustable magnitude and angle is typically used to approximate the VSC in the steady state study of power system.

In Figure 3.7, the functional arrangement is demonstrated by connecting the output of two consecutive in series with transmission lines 1 and 2 are DC to AC converters, which generate voltages phasor V1pq and V2pq, respectively. All voltages at the sending and receiving ends are assumed to be constant and have a fixed amplitude for the sake of clarity in the illustration: V1s = V1r = V2s = V2r = 1.0 pu in [42].

Additionally, it is believed that the two lines' impedances and transmission angles, as well as the ratings of the two compensating voltage sources the converters create are indistinguishable, that is $X1 = X2 = 0.5$ p.u., $\delta 1 = \delta 2$ (= 30°), and $V1pq_{max} = V2pq_{max} = 0.25$ p.u. For both lines, this means that the maximum increase in real or reactive power is V Vpq per X = 0.5 p.u. To clarify the relationships that regulate the IPFC's operation, lines 1 and 2's operational identities are maintained throughout this section, despite the possibility that they will differ in practice due to differences in transmission line voltage, impedance, and angle.

Meanwhile a real power transfer between the two lines occurs asynchronously through the DC link of the converters; their operational identities do not compromise their presumptive independence. In fact, they may even represent distinct systems with an arbitrary phase relationship. A series capacitive or inductive line compensator is what the IPFC will do if the injected voltage (Vse) is in phase-quadrature with a line current in Figure 3.7 below

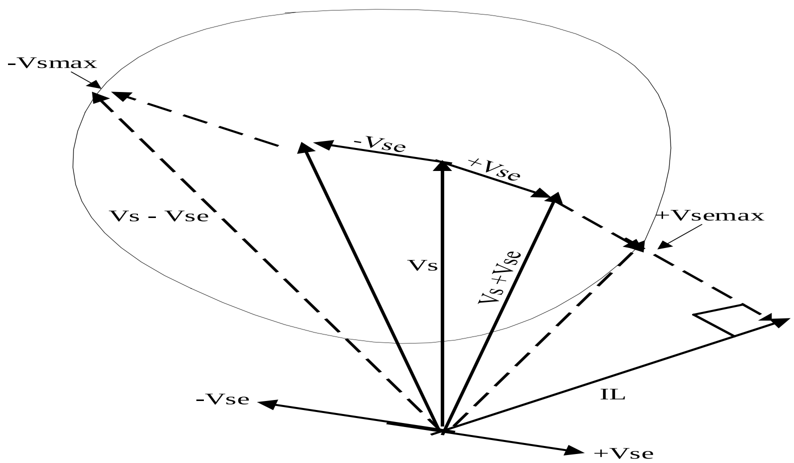

Figure 3. 10 Phasor diagram for series impedance compensation in **[42]**

3.8 Mathematical Problem Formulations of Optimal Power Flows

The optimum power flow problems method's steady state performance of a power system. Transmission system is not simply modeled as a visualized it needs a very clear and detail calculated model and digital system analysis management and also to address optimally voltage, active power and reactive powers for the system.The target function is to minimize reactive power loss, enhance voltage profile, and minimize active power losses while complying with various constraints of equality and inequalities. The perfect situation power flow problems stated mathematically as follow.

Minimize f(x, u)

Subject to the constraint

$g(x, u) = 0$

$h(x, u) \leq 0$

Where : f is the desired function that needs to be reduced.

g : are the equality constraint

h : is inequality constraint

x : is the collection of state variables, including bus power slack, P_g. Load bus voltage V_l. Generators reactive power $Q_{g.,}$ u is a collection of regulating factors, like the generator voltage V_g generator real power P_g. except the swing bus power productivity

3.8.1 The constraint of IPFC fact devices

Constraints of active power and reactive power flows are

$$\left.\begin{aligned} P_{ni} - P_{ni}^{Spec} = 0 \\ Q_{ni} - Q_{ni}^{spec} = 0 \end{aligned}\right\} \quad (3.35)$$

Where Ni and Nj bus i and bus j active and reactive power

P_{ni}^{Spec} and Q_{ni}^{spec} are defined reactive and active powers for every buses.

3.8.2 Objective function

The optimal power flow in this investigation has the main objectives to keep the voltage profile within the acceptable voltage profile and to minimize the function line losses.

Minimize $F_1 = P_{loss}$

Minimize $F_2 = Q_{loss}$

Minimize F_2 = Voltage drop

The first objective function is minimization of power loss

$$\text{Minimize } F_1 = \sum_{k=m,n}^{lk} P_{loss} \quad (3.36)$$

These functions is first objective functions of the problems it applied based on

$$Pl = \sum_{i=1}^{Nb} P_i = \sum_{i=1}^{Nb} P_{iGi} - \sum_{i=1}^{Nb} P_{Di} \quad (3.37)$$

Where: - N_b is number of bus

P_G is generated power

P_D is a demand power

The second objective function is minimization of reactive power loss.

$$\text{Minimize } F_2 = \sum_{k=m,n}^{lk} Q_{loss} \quad (3.38)$$

$$Ql = \sum_{i=1}^{Nb} Q_i = \sum_{i=1}^{Nb} Q_{iGi} - \sum_{i=1}^{Nb} Q_{Di} \quad (3.39)$$

Where: - N_b is number of bus

P_G is generated power

P_D is a demand power

The third objective function is improve bus voltage drop

Minimization of voltage drop and each bus voltage drop are expresses as

$$F_3 = \text{mini}\sum_{i=1}^{Nb} \left|\frac{VNi-Vrated}{VNi}\right|^2 \quad (3.40)$$

Where Nb = is number of bus

V_{Ni} = Voltage of at bus Ni

V_{rated} = is voltage of rated or bus voltage

Equality constraints

The conventional load flow equation is represented by the equality restrictions, which to formulate and helps to balance a power system.

$$\left.\begin{aligned} P_k^{net} - P_k^{cal} = 0 \ \ where\ (k = n, m) \\ Q_k^{net} - Q_k^{cal} = 0 \ \ where\ (k = n, m) \end{aligned}\right\} \quad (3.41)$$

P_k^{cal} and Q_k^{cal} (k = m, n) the evaluated Power in the bus K, both active and reactive that are expressed as.

$$P_k^{cal} = |V_k|^2 G_{lk} - |V_k|\,|V_l|[G_{lk}\cos\theta_{lk} + B_{lk} + \sin\theta_{lk}] + |V_k|\,|V_{slk}|\,[G_{lk}\cos\theta_{kslk} + B_{lk}\sin\theta_{kslk}] \quad (3.42)$$

$$Q_k^{cal} = -|V_l|^2 B_{lk} - |V_k||V_l|\,[G_{lk}\sin\theta_{lk} - B_{lk}\cos\theta_{lk}] + |V_k|\,|V_{slk}|\,[G_{lk}\sin\theta_{kslk} - B_{lk}\cos\theta_{kslk}] \quad (3.43)$$

Where: - $P_k^{net} = P_k^{gen} - P_k^{load}$ (3.44)

is the net programmed active power at node k

$$Q_k^{net} = Q_k^{gen} - Q_k^{load} \quad (3.45)$$

is the remaining programmed power of reactive at bus k, P_k^{gen} and Q_k^{gen} the powers that are both active and reactive P_k^{load} and Q_k^{load}, which are produced at bus K, the powers that are both active and reactive used by the load there.

According to the IPFC's operating concept, the active power requisite by each converter and the active powers supplied to it are equal. IPFCs are often used in steady state operations to regulate the flows of both active and reactive power through the transmission lines in which they are installed.

Therefore, this condition formulated as in.

Real ($V_{slm}I_{lm}^{*}$ + $V_{sln}I_{ln}^{*}$) = 0 or

$\sum_{k=m,n}(|V_{slk}|\ G_{lk}$ - $|V_l||V_{sk}|[G_{lk}\cos\theta_{lslk}$ - $B_{lk}\text{sine}\theta_{lslk}]$ + $|V_k||V_{slk}|[G_{lk}\cos\theta_{kslk}$ - $B_{lk}\sin\theta_{kslk}]$) = 0

Inequality constraint

The problem of inequality constraining optimal power flow indicates the state of variable limit and control. The upper and lower limits of the generator's active power generation constitute the system's variable restriction or operation limitations, load bus voltage and transmission line loading which are described as in [43].

$$\left.\begin{array}{l} p_{Gs}^{min} \le P_{Gs} \le P_{Gs}^{max}\ (s = slack) \\ Q_{Gi}^{min} \le Q_{Gs} \le Q_{Gi}^{max}(i = 1, \dots . NG) \\ V_{di}^{min} \le V_{di} \le V_{di}^{max}(i = 1, \dots . . NB \\ \\ S_i \le S_i^{max}(i = 1, \dots \dots Ni \end{array}\right\} \qquad (3.46)$$

Consider from the above equation real power outputs, generator voltage, and control variables are constrained by

$$\left.\begin{array}{l} P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}\ (\mathrm{i} = 1, \dots N_G) \\ V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max}\ (\mathrm{i} = 1, \dots N_G) \end{array}\right\} \qquad (3.47)$$

The operating constraint limit of the IPFC is specified for the series injected voltage source convertors as

1. Voltage injection with a regulated magnitudes V_{slk} and angles, θ_{slk}

$$\left.\begin{aligned} V_{slk}^{min} \le V_{slk} \le V_{slk}^{max}\ (\mathrm{k} = \mathrm{m, n}) \\ \theta_{slk}^{min} \le \theta_{slk} \le \theta_{slk}^{max}\ (\mathrm{k} = \mathrm{m, n}) \end{aligned}\right\} \tag{3.48}$$

2. Line current magnitude through the series voltage source convertor

$$I_{lk}^{min} \le I_{lk} \le I_{lk}^{max}\ (\mathrm{k = m, n})$$

3. power injected by voltage source convertor

$$|S_{slk}| = S_{slk}^{max}\ (\mathrm{k = m, n}) \tag{3.49}$$

S_{slk} Represents the complicated power that the service voltage source convertor injects into the line.

4. The circulating real power, P_{slk}

$$|P_{slk}| \le P_{slk}^{max}\ (\mathrm{k = m, n}) \tag{3.50}$$

3.9 Grey wolf optimization techniques

An optimization gray wolf algorithm is a population-based optimization have been applied in the power transferring transmission line transmission line to optimize economic problems and sizing and placing of fact devices. IPFC based power loss minimization and enhancement of voltage was suggested because of its capacity for independent power flow regulation and grey wolf optimization (GWO), which was chosen because of its quicker reaction, lower memory demand, and easier programming, allowed for the modification of its ideal parameters in [44].

Grey wolf mostly prefers to occupy a pack. The group’s sizes are five to twelve on Fig. 3.9 illustrates the extreme social dominance hierarchy that on average certain interests hold.

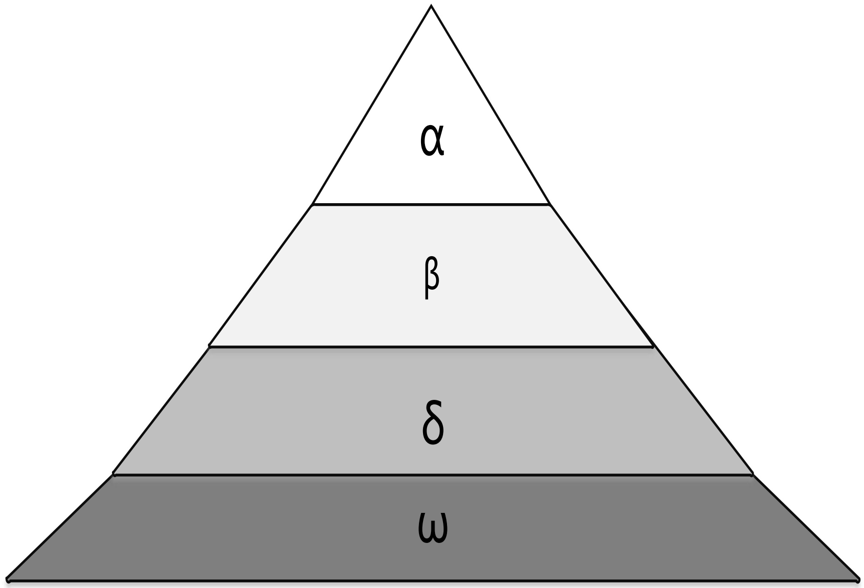

Figure 3. 11 Gray wolf dominances decreases up to down in **[45]**

Alphas, both male and female, are the leaders. The alphas is mostly in charge of making decision on hunting, where to sleep, what time to wake up, and additional problems. Alpha gives orders, and the pack must to obey. Nevertheless, an alpha can also act democratically by deferring to the other wolves in the packs. During gatherings, the whole pack fields their extensions down in submission to the alpha. Since his or her commands should be obeyed by the entire pack, the alpha wolf also named the dominant wolves in [45]. These demonstrate how a pack's discipline and structure is much more important than strength.

The greatest candidate to succeed as alpha in the situation that one of the other wolves clearances away or grows too old is probably the beta wolves, which can be either female or male. Even though the alpha is the superior wolf, the beta wolf is still required to submit to it. It also acts as a disciplinarian for the pack and advisor to the alpha. The beta both responds to the alpha and spreads the pack obeys the alpha's orders.

The gray wolf with the lowest rating is Omega. This is a result of the omega(s) releasing the fury and ferocity that all wolves possess. The pack's babysitters might also be the omega in certain situations.

In certain allusions, A wolf is called a delta or subordinate if they are not an alpha, beta, or omega. Alphas and betas must subject to delta wolves, but they rule the omega. This group includes scout, sentinel, elder, hunter, $\boldsymbol{\alpha}\ \boldsymbol{\beta}\ \boldsymbol{\delta}\ \boldsymbol{\omega}$ and caretaker. The group's security is guaranteed by guards acting as sentinels and sentinels guard. The seasoned wolves that were once beta or alpha are known as elders. Hunting animals and supplying the pack with food requires hunters to assist the alphas and betas in [45].

3.9.1 Mathematical models of GWO algorithms

The fittest solution is taken into consideration as the alpha even though structure grey wolf optimization in order to statistically describe the social structure of wolves as the alpha ($\boldsymbol{\alpha}$). Accordingly, the third and second greatest solution name are beta ($\boldsymbol{\beta}$) and delta ($\boldsymbol{\delta}$) correspondingly. The other possibilities assumed omega ($\boldsymbol{\omega}$). In the grey wolf optimization algorithm, the hunting's (optimization) are directed by alpha. The other wolf follows these three wolves.

Acceptable to accurately surrounding model performance, the equations are projected:

$$\vec{D} = \left| \overrightarrow{C} \, . \, \overrightarrow{Xp}(t) - \vec{X}(t) \right| \tag{3.51}$$

$$\vec{X}(t+1) = \vec{X}p(t) - \vec{A} \, . \, \vec{D} \tag{3.52}$$

The current iteration is denoted by t, the position vectors of the prey are represented by $\vec{X}p$, the vectors of a grey wolf are indicated by $\vec{X}$, and $\vec{A}$ and $\overrightarrow{C}$ are a coefficients.

$\vec{A}$ and $\overrightarrow{C}$ vectors are designed as:

$$\vec{A} = 2\vec{a} \, . \, \overrightarrow{r1} - \vec{a} \tag{3.53}$$

$$\vec{C} = 2. \, \vec{r}2 \tag{3.54}$$

In the above situation the values of a drop linearly from 2 – 0 during iterations with $\overrightarrow{r1}$, and $\vec{r}$ representing random vectors in (0, 1).

3.9.2 Hunting

Assuming that beta and deltas have superior information about the likely location of prey, we assume that the alpha is the strongest candidate solution mathematically simulating the forceful behavior of grey wolves optimization. These three prayers do very strong and straggling with hunting animals. We keep the first of the three best solutions we have identified so far, and keep informed the position of the outstanding search agents, which include the omegas, based on the position of the top search agent. The algorithms offer recommendations for size and position in this affections.

$$\vec{D}\alpha = \left|\vec{C}1 \,.\, \vec{X}\alpha - \vec{X}\right|, \quad \vec{D}\beta = \left|\vec{C}2 \,.\, \vec{X}\beta - \vec{X}\right|, \quad \vec{D}\delta = \left|\vec{C}3 \,.\, \vec{X}\delta - \vec{X}\right| \qquad (3.55)$$

$$\vec{X}1 = \vec{X}\alpha - A_1.\,(\vec{D}\alpha), \quad \vec{X}2 = \vec{X}\,\beta - A_2.\,(\vec{D}\beta), \quad \vec{X}3 = \vec{X}\,\delta - A_3.\,(\vec{D}\delta) \qquad (3.56)$$

$$\vec{X}\,(t+1) = \frac{\vec{X}1 + \vec{X}2 + \vec{X}3}{3} \qquad (3.57)$$

Stated differently, alpha, beta, and delta wolves determine the prey's location while other wolves update their positions at random surrounding the target.

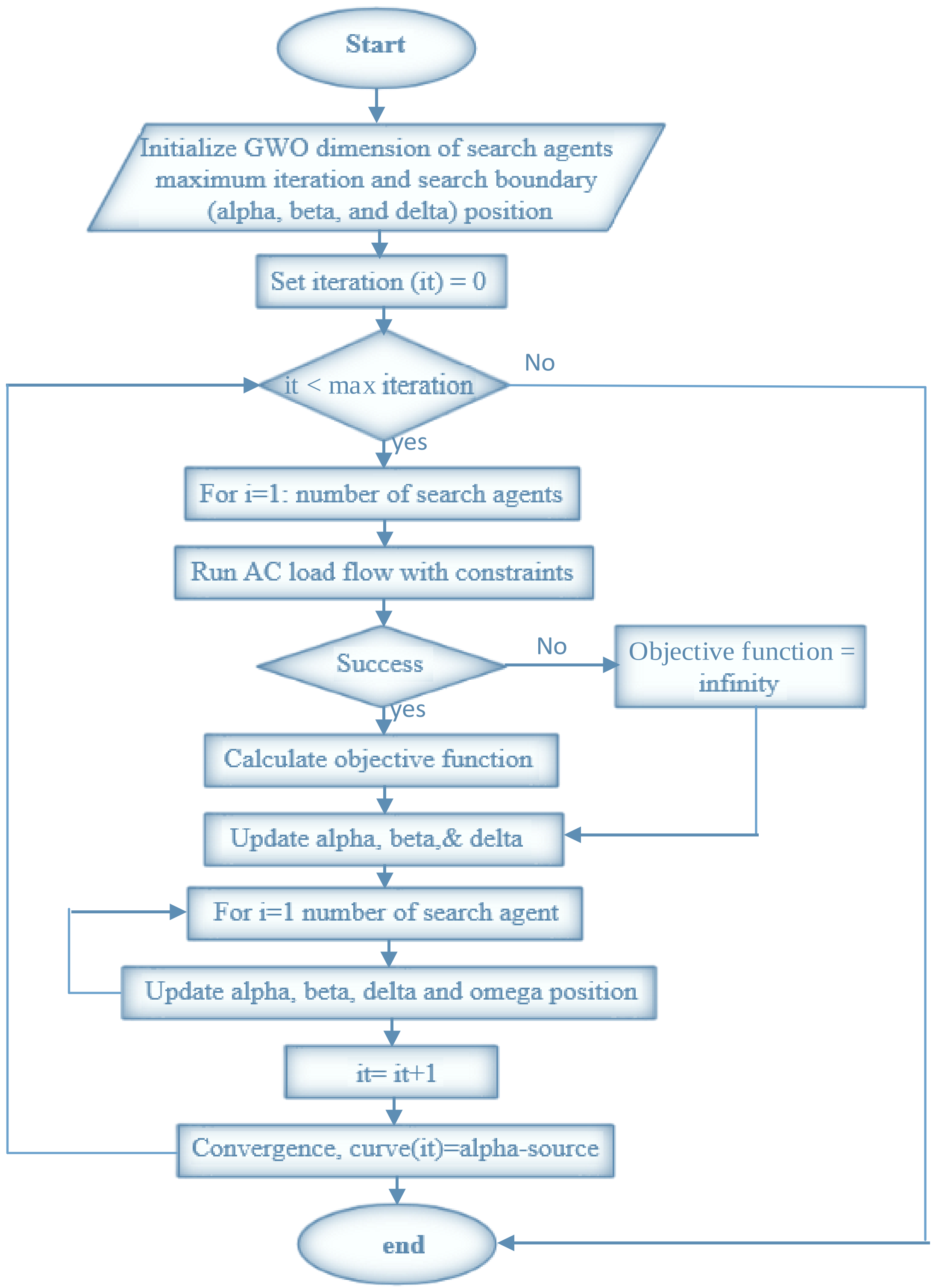

Figure 3. 12 Flow chart of Grey wolf optimization algorithm.

3.10. Ant lion Optimization Problem

With a better programming approach, antlions optimization algorithm helps a controlling system with in good manor computing system. One innovative Meta heuristic optimization technique is the recently developed Ant Lion Optimizers (ALO) algorithm. Seyedali Mirjalili introduces antlion optimization for the first time (2015) The physical life assessments of ants' natural hunting methods served as the model for the Antlion optimization algorithms. The ALO approach imitates the antlions' natural hunting tactics. Five step of stalking techniques of casual movement of ant, structure trap, set-up of ant in traps, catching preys, and transformation trap in [46].

3.10.1 Elitism

Rather from being a literal description, the claim that the "elite is the rightest antlion" and that it influences every ant's movement across iterations appears to be a metaphor or analogy. If we take a metaphorical interpretation. The elite is the most correct antlion and should influence the movements of every ant throughout iterations. Elitism is an appearance of the evolutionary algorithm that enables them to maintain the finest solutions to achieve at any stages of the optimization process.

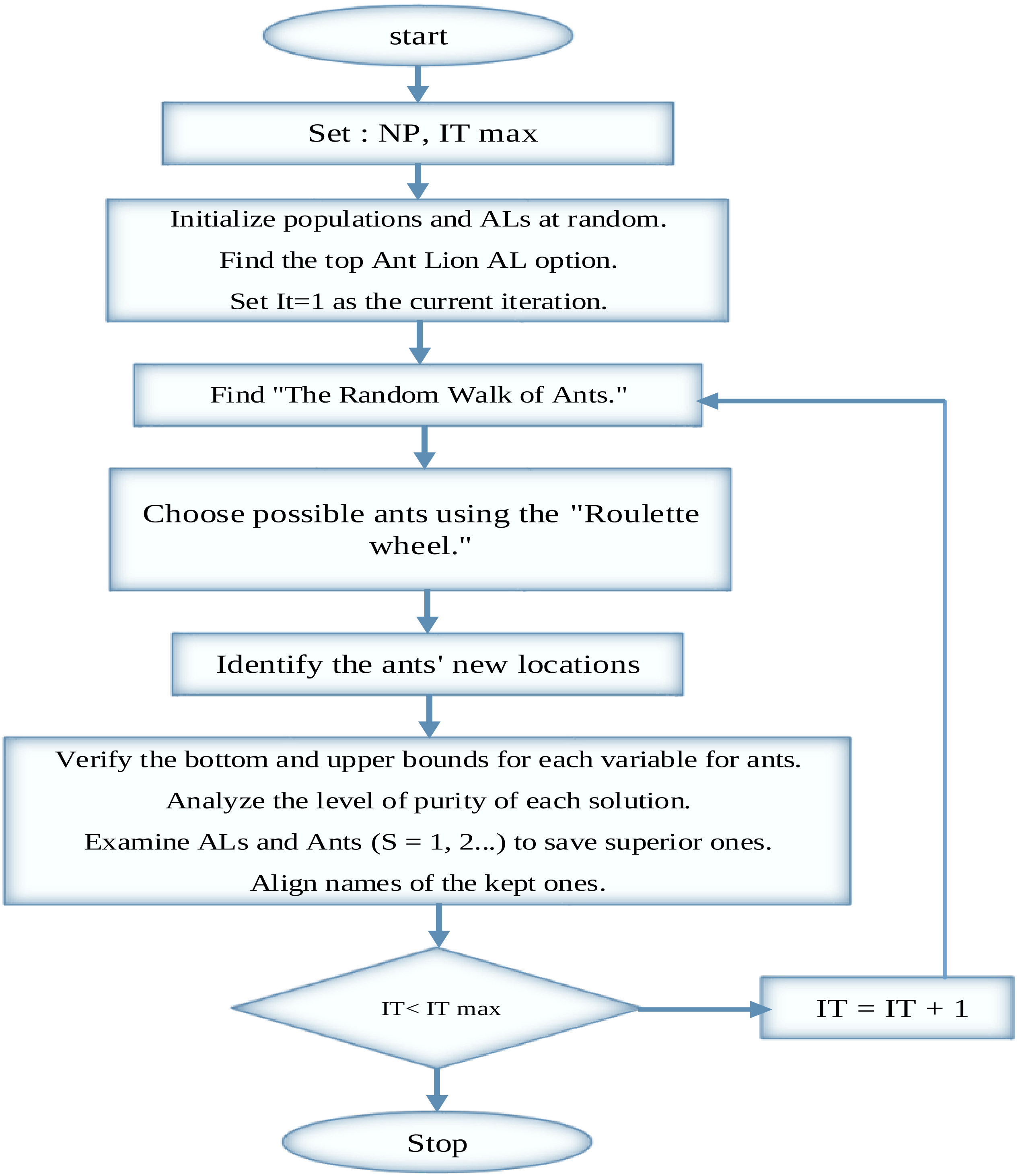

Figure 3. 13 Antlion optimization techniques flow chart.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. INTRODUCTION

This thesis work performed on the transmission network of the Shashemene to Bukuluguma transmission system. The effectiveness of the existing system from Shashemene to Bukuluguma transmission network without the installation of IPFC is described at the beginning of this chapter. The overall active and reactive powers supply of the system is 90.460 MW and 54.630 MVAr correspondingly.

The findings of a load flow analysis of a Shashemene to Bukuluguma transmission network done in the MATLAB environment to determine the system steady state and compare it to IEEE standards are shown in Table 4.1.

Table 4. 1 Existing networks load flow analysis

% Power flow solution By Newton-Raaphson method

Maximun Power Mismach =0.00042629

NO. of iterations =5

Bus No.	Voltage Mag.	Angle degree	Load MW	Load MVar	Generation MW	Generation MVar	Injected MVAr
1	1.000	0.000	0.000	0.000	90.469	54.6300	0.000
2	0.956	-21.670	21.680	9.450	0.000	0.000	0.000
3	0.963	-31.216	18.500	14.220	0.000	0.000	0.000
4	0.945	-13.150	13.130	11.120	0.000	0.000	0.000
5	0.957	-36.220	8.180	3.820	0.000	0.000	0.000
6	0.955	-49.440	2.987	2.100	0.000	0.000	0.000
7	0.944	-39.490	11.110	5.215	0.000	0.000	0.000
8	0.947	-39.610	6.570	2.250	0.000	0.000	0.000
9	0.937	-37.670	0.990	0.762	0.000	0.000	0.000
Total			83.147	48.937	90.469	54.6300	

Total system Loss =7.322MW

The suggested technique is employed in this chapter for optimal customized interline power flow controller placement and size at the node with the least amount of power loss and the lowest bus voltage, as shown in the following result analysis. MATLAB R2016a used to implement and program the methods described in the preceding chapter. Sections of the results and discussion are presented according to the sizes of the optimally placed customized interline power flow controller in the network and its impact on the investigating parameters of the system that on the fitness function scheme under consideration.

Different comparisons have also been made between GWO algorithm and ALO algorithms in the open literature to show the algorithm's consistency in lowering reactive and actual power network losses while raising bus voltages.

4.1.1. Explanation of Optimization Algorithm Parameters

With the preferred objective functions, the proposed algorithm is used to reduce power loss and improves the voltage profile. The optimization based technique is run multiple times on different optimal parameter settings, as illustrated in Table 4.2.

Table 4. 2 Shows the GWO algorithm's parameters.

The size of populations	Maximum number of iterations	Grey Factors	Variables of design
100	100	Round[1 + round(0 , 1) {2 - 1}	Vary

4.1.2. Shashemene to Bukuluguma Transmission System Simulations Results

Utilizing the load flow analysis methods the Newton Raphson load flow method, and the initial power losses bus voltages and voltage stability indices of the system were determined utilizing a parameters data of the transmission system. A bus based voltage index study prompted the grey wolf algorithm to find the best position and size for the customized interline power flow controller. Two possible situations are examined for the implementation of the stated method based on the simulation results for the suggested system, as shown below.

Case 1: Analysis of Load Flow before Installation of IPFC Devices in System.

Load flow Newton Raphson analysis method is applied to find the bus voltage magnitudes, Stability indexes of line and transmission line loss. To study and acquire the steady state bus voltages, active and flow of reactive powers in the network, Newton Raphson power flow where used. The voltage magnitude and line losses were noted for discussion and are now provided. The bus voltage magnitude results for the network's power flow study are shown in Table 4.3.

It was noted in Table 4.3, that the voltage magnitudes at 4, 7, 8, and 9 are out of voltage limit. This was not connected with lack of load connection at bus 4, 7, 8, and 9. This situation must be disallowed to avoid cascading bus voltage defilement, which strength leads to system collops. Consequently, there is need to integrate Customized interline power flow Controller to control this bus voltage stability hence, the buses whose terminal voltages are violated are the candidates for Customized interline power flow Controller device placements.

Figure 4.1 depicts the graphical interpretation of bus voltage magnitude after the simulation without Customized interlines power flow Controller device. The low bus voltage occurs at bus 4, 7, 8 and 9 as earlier stated. Apart from swing bus whose value remains constant at 1.00 volts even after the simulation, other bus voltages are within the allowable limits.

Table 4. 3 Voltage Profile of existing network

Bus No	Buses	Magnitudes of bus voltage (p . u)
1	Slack	1.000
2	P-V	0.956
3	P-V	0.963
4	P-Q	0.945
5	P-V	0.957
6	P-Q	0.955
7	P-Q	0.944
8	P-Q	0.947
9	P-Q	0.937

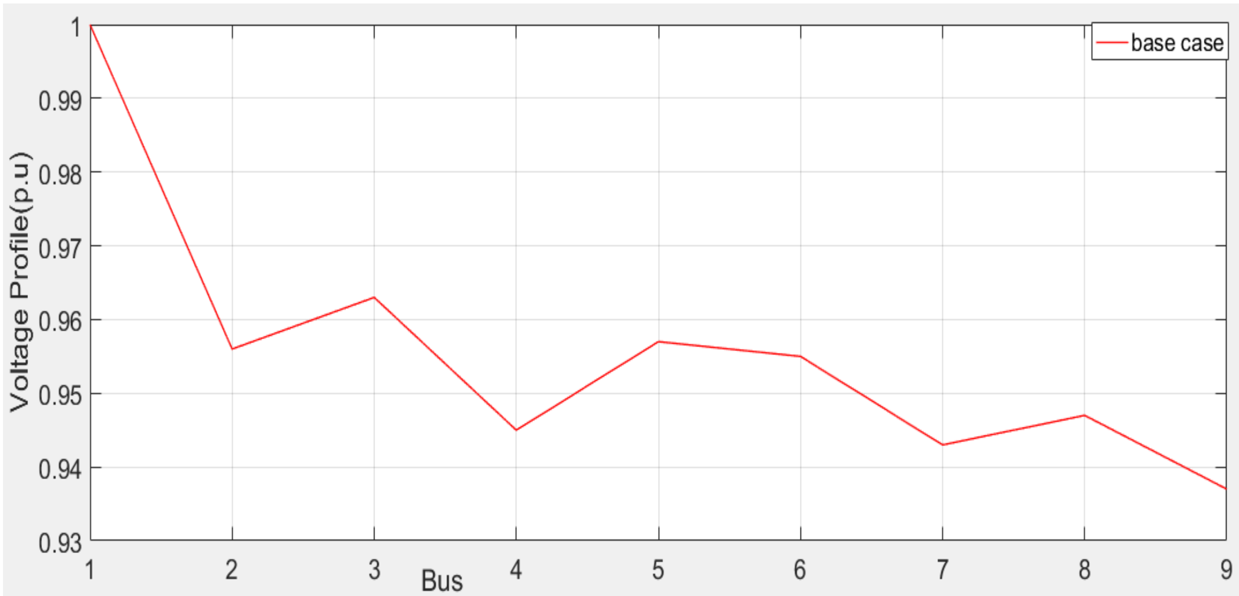

Figure 4. 1 Voltage profile of System before Placement IPFC Device

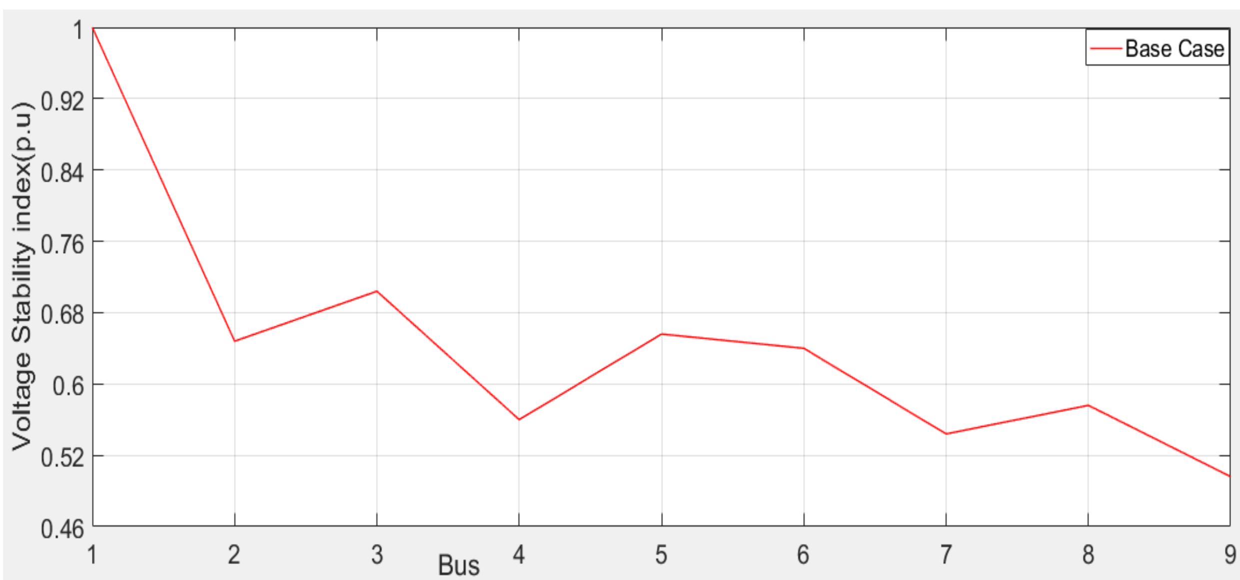

Figure 4. 2 Base case voltage stability index before compensation

Table 4.4 includes the following values. The transmission network from Shashemene to Bukuluguma has total loss of real power is 7.322 MW and loss of reactive power is 5.693MVAr. For a better understanding, consider Figure 4.4, which illustrates the graphical representation of losses in Table 4.4. There is a power loss on lines 1–2, 2–3, 3–4, 4–5, 5–6, 6–7, 7–8, and 8–9. These losses are having a negative effect on the network's performance.

Table 4. 4 Without customized interline power flow controller line loss

Bus number		Base Case	With IPFC
From Bus	To bus	MW	MVar
1	2	0.6857	0.4969
2	3	0.8255	0.6993
3	4	0.9862	0.5542
4	5	0.8768	0.6937
4	6	0.9764	0.6956
6	7	0.9755	0.6988
7	8	0.9861	0.6899
8	9	0.9896	0.6727
Total Power Losses		7.322	5.693

4.2. Real and Reactive Power Loss before IPFC Placement without IPFC placement

In this study under the normal load conditions, the results obtained using the GWO techniques optimization techniques.

The minimum bus voltage magnitude (0.937 p. u) that found at bus 9 with the proposed GWO algorithm approaches, the base case and existing analysis was enhanced to 0.979 p . u, and 0.968 p . u.

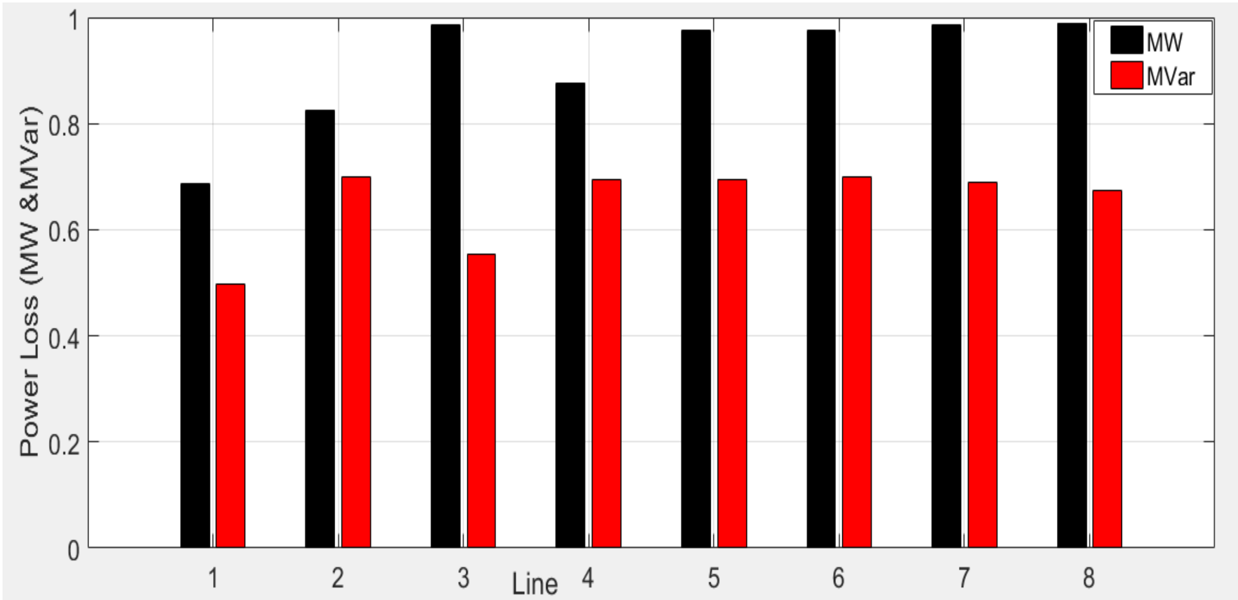

Figure 4. 3 Before IPFC installation, Real and Reactive Power Losses.

The status of transmission system main parameters within lower and upper boundary are proposed in the table 4.5. Before analyzing with best optimizing techniques the lower boundary magnitudes of voltage is out of standards permissible limits.

Table 4. 5 The status of the transmission system before analyzing with best optimizing techniques.

Parameter	
Losses of Active Power (MW)	7.322
Losses of Reactive Power Loss (MVAr)	5.693
Min. Bus Voltage profile (p.u)	0.937
Min. voltage stability index (p.u)	0.50
Max. Bus Voltage profile (p.u)	1.000
Max. voltage stability index (p.u)	1.000

Case 2: Analysis of Load Flow after Installation IPFC Devices in System

This section illustrates the results of simulations that explains how individual IPFC allocations in the network affects voltage process improve and minimize a power loss. Following the base case analysis, the conventional GWO provided to evaluations for the proper size and position of IPFC in the existing networks. For each bus level, the optimal IPFC size was determined to be 27MVar, and the best locations have been founding on the bus 5.

After installing the devices, taken result is very ambiguous as industry developing country and this, much power loss is not necessary. A right place installed device it makes profitable the southern region power transmission management should implements to become a cost effective company.

The IPFC device installed improved network bus voltage magnitude by allowing voltage magnitudes at the majority of the buses to be within a (0.95 - 1.05) range. As a result, the GWO algorithm was utilized to best position and size IPFC device in order to restore this terminal voltage within the limit.

Table 4. 6 Voltage profile of System after IPFC Placement

Bus No	Bus Type	Voltage profile (p.u)
1	Slack	1.000
2	P-Q	0.978
3	P-Q	0.985
4	P-V	0.967
5	P-Q	0.979
6	P-Q	0.977
7	P-Q	0.965
8	P-Q	0.967
9	P-Q	0.969

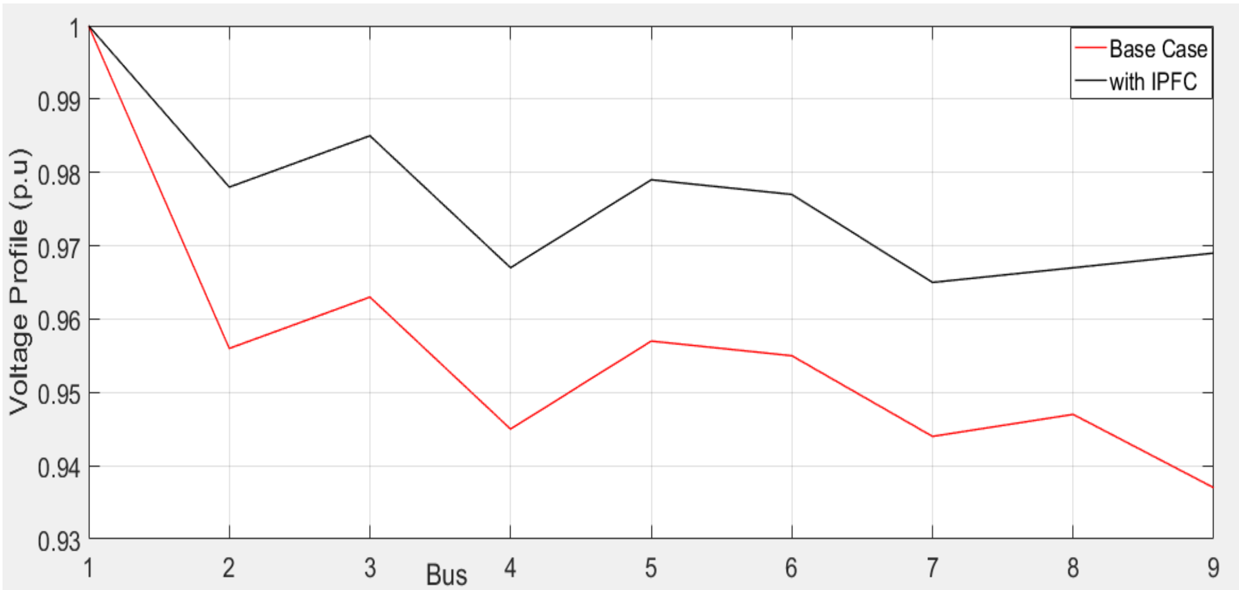

Figure 4. 4 Bus Voltage Profile Comparison Without and with IPFC Placements

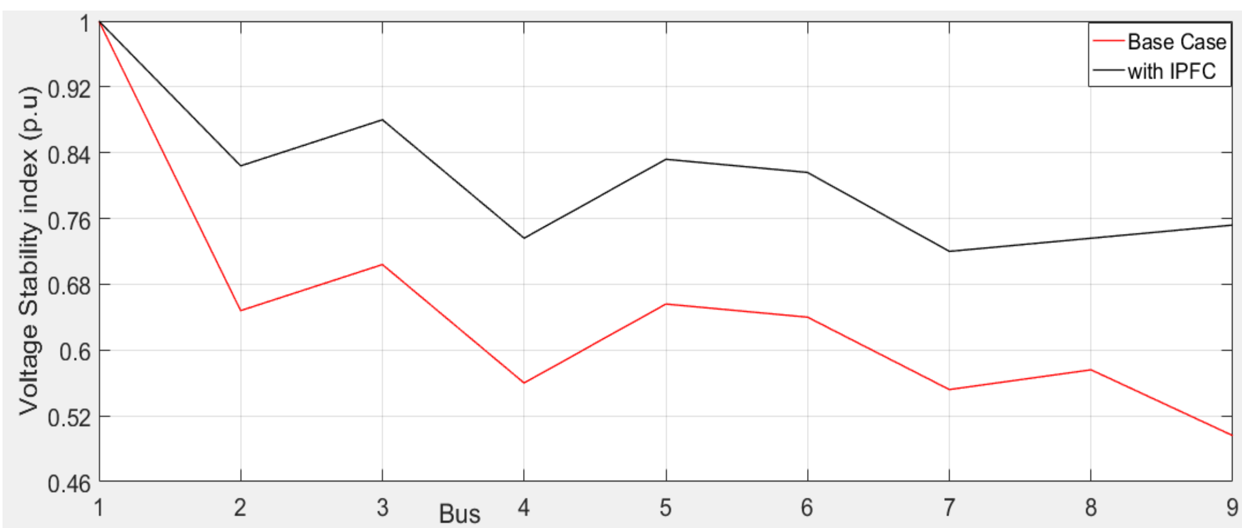

Figure 4. 5 Index of voltage stability both before and after modification.

4.3. Minimization of Active Power Loss

IPFC device was able to minimize real power losses by using optimization algorithms for placement technique.

Table 4.7 proposed that the active power losses details on the base case on each lines, GWO placed IPFC device. The total real power loss without any device is 7.322 MW in the base case, but it was reduced to 4.393 MW in the advanced case.

Table 4. 7 Active power Loss Reduction result for IPFC case

Bus number		Stead state Case	GWO Case
From Bus	To bus	MW	MW
1	2	0.6857	0.3216
2	3	0.8255	0.4624
3	4	0.9862	0.6221
4	5	0.8768	0.5137
5	6	0.9764	0.6123
6	7	0.9755	0.6124
7	8	0.9861	0.6220
8	9	0.9896	0.6265
Total Active Power Losses		7.322	4.393

When using the GWO optimization algorithm to install the IPFC, a reduction of 2.929 MW was realized. The usage of GWO to integrate the IPFC device resulted in a 59.7% reduction in active power loss.

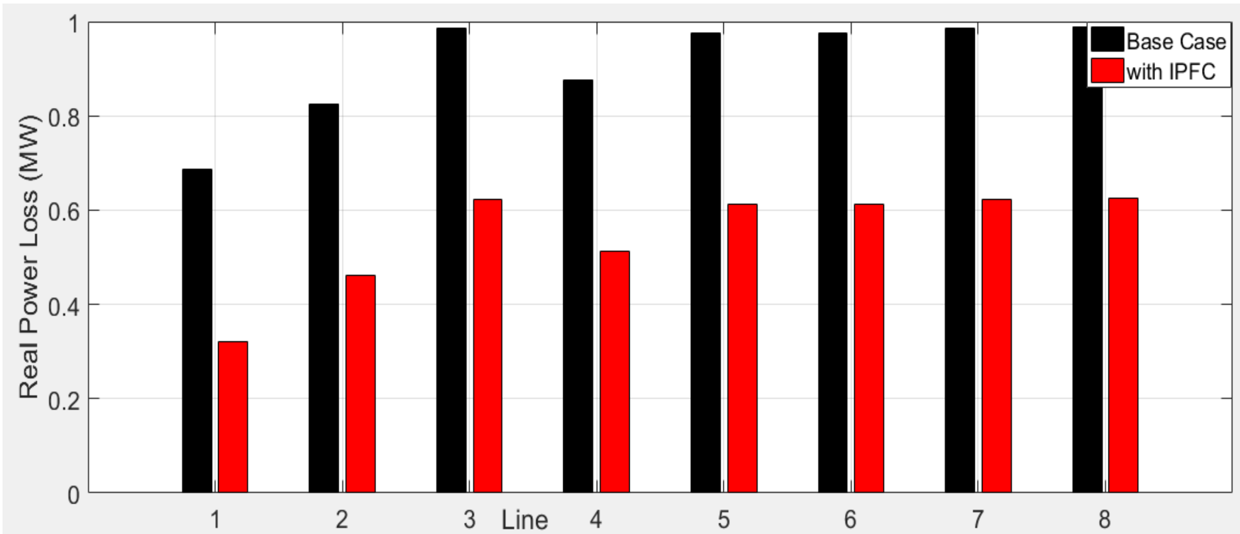

Figure 4. 6 Real power loss wit IPFC

4.4. Minimization of Reactive Power Loss

IPFC device was able to minimize reactive power losses by using optimization algorithms for placement technique. Table 4.8 shown the reactive power loss details for the base case, GWO placed IPFC device. The total reactive power loss without any device is 5.693MVAr in the base case, but it was reduced to 2.294 MVAr in the advanced case.

Table 4.8 Reactive power Loss Reduction result for IPFC case

Bus number		Stead state Case	GWO Case
From Bus	To bus	MVAr	MVAr
1	2	0.4969	0.1335
2	3	0.6993	0.3350
3	4	0.5542	0.1900
4	5	0.6937	0.3306
4	6	0.6956	0.3325
6	7	0.6988	0.3357

7	8	0.6899	0.3268
8	9	0.6727	0.3096
Total reactive Power Losses		5.693	2.294

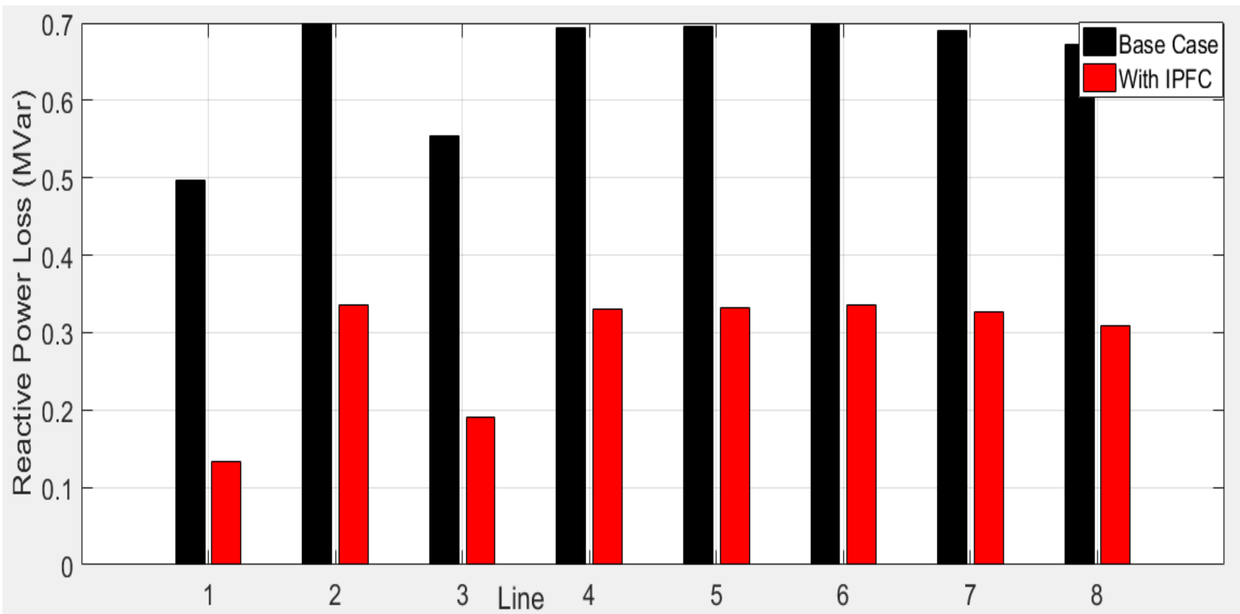

Figure 4. 7 Reactive power loss with IPFC

When IPFC was placed under case two study, the reactive loss, which was 5.693 MVAr without the device, When IPFC was optimally installed using GWO, and this was reduced to 2.294 MVAr. When GWO was used to put the device, 0.597 MVAr were achieved, resulting to 40.3% overall reductions, respectively.

4.5. Comparison of GWO with AL optimization algorithms with IPFC placement

In this study under the normal load conditions, the results obtained using the GWO techniques are compared with ALO optimization techniques.

After installing the IPFC, by both optimization techniques of the whole bus voltages magnitude of the networks has increased by 3.9% by ALO and 6.1% by GWO.

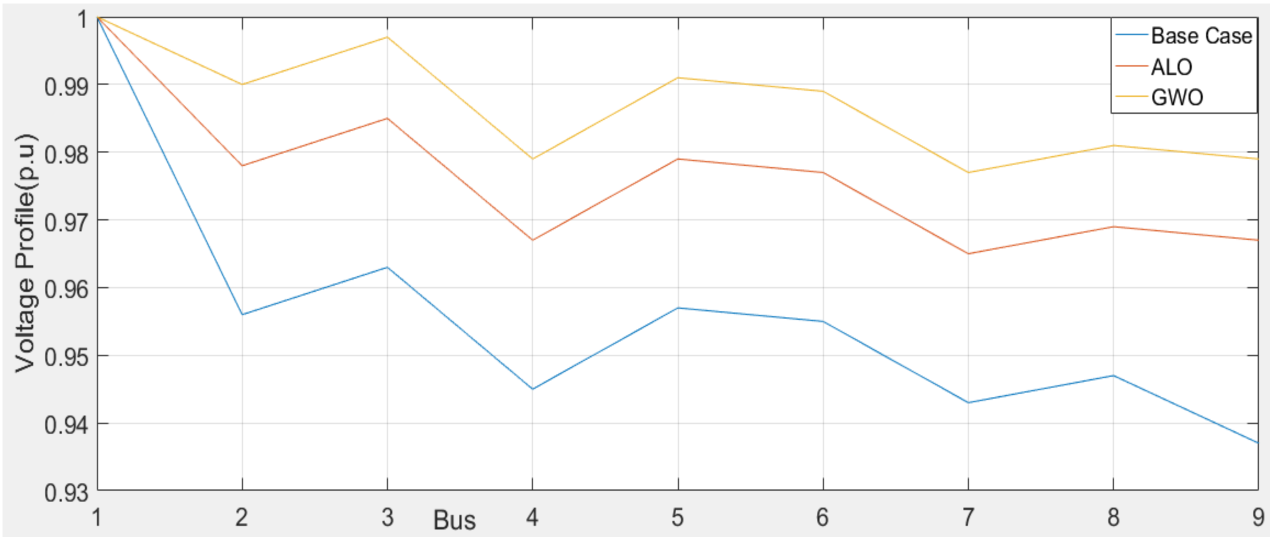

Figure 4. 8 Comparison of GWO with ALO algorithm

4.6. Cost Calculation

Siemens industry gives up to date information about building electronic FACT device. Cost calculation consists of installation cost and cost of fact device. In the digital economy, the advanced electronics market found online to calculate the values based on their rating size. To decide on it for cost of installation, cost of maintenance and other has its own methods. The cost of installations for IPFC device also taken from the Siemen business databases together with the ideal power flow. The following formulas have been used to calculate the cost of installing IPFC devices:

$$IC = CIPFC * S * 1000 \quad (4.1)$$

Where,

IC is the cost of installation of IPFC device in US$

CIPFC is the costs of IPFC devices valued in $US / KVAr.

The IPFC installation cost is extracted from the Siemens database. The IPFC cost function is constructed as follows:

Where,

$$C_{IPFC} = 0.0003S^2 - 0.2691S + 188.22 US\$/kVAR \quad (4.2)$$

Where, C_{IPFC} is the costs of IPFC in US$ / kVA and S is functioning ranges of IPFC in MVAr

$$S = Q2 - Q1 \quad (4.3)$$

$Q1$- before inserting the IPFC device, the MVAr flows through the branch.

$Q2$ - after inserting the IPFC device, the MVAr flows through the branch.

4.6.1. Financial Losses Analysis

It splits into two parts: the cost associated with energy loss and the cost associated with the FACTS device's initial expenditure. As it is possible to reduce but eliminate power loss. For the two scenarios considered in this study that is before and after, the annual energy of power losses of the following formula can be used to compute:

Case 1: Financial loss caused by the system before the IPFC implementation.

Scenario 1: Annual MWh loss for 7.322 MW

= (peak Loss in MW) *8760h

= 64,140.720MWh

Case 2: Financial loss caused by the system after the IPFC implementation.

Scenario 2: Annual MWh loss for 4.393MW

= (peak Loss in MW) *8760h

= 38,482.680MWh

4.6.2. Cost Implication

Based on Ethiopian Electric Utility's ETB / kWh energy rates under the new power tariff, the cost analysis is conducted. This tariff changed at the necessity time for across a country and domestic utilizers. Up to December 1, 2021, the cost of energy will be calculated by averaging all tariff class energy unit costs ($US / kWh). When the total energy consumed exceeds 500kWh (0.02944$/kWh) or 29.44 $/MWh, the cost of energy will be rated at 1.385 ETB/kWh. Using 29.44 $US / MWh, the total annual revenue loss due to disruption is computed as follows:

Case 1: The system's financial implications before the IPFC installation.

The annual financial loss in scenario 1 is 64,140.720MWh * 29.44 $US per MWh = 1,888,302.8

Case 2: The system's financial implications after the IPFC installation

For scenario 1, the annual financial loss is 38,482.680MWh * 29.44 $US per MWh = 1,132,930.1

Table 4. 8 Cost comparisons before and after embedding IPFC

Cos before IPFC ($/Year) (X)	Cost after IPFC ($/Year) (Y)	Saving ($/year) (X-Y)	Cost of IPFC ($/Year)
1,888,302.8	1,132,930	755,372.8	1,350,000

4.6.3. The cost of an IPFC in rating

Although IPFC controllers can offer real and reactive power control for enhancing electric power system voltage profile improvements and minimizations of power loss, a recognized and known disadvantages of electronic device is as its quality based on rating of usage in a power system is high parallel its cost also become very high in [46], [47].

Table 4. 9 Costs of different power electronics FACTS controller

FACTs Controller	**Costs in $US**
DSTATCOM	$36 / kVAr
SVC	$40 / kVAr
UPFC	$50 / kVAr
TCSC	$40 / kVAr
IPFC	$50 / kVAr

Table 4.13 indicates that as of April 28, 2023 G.C., one US dollar is worth 54.28 Ethiopian Birr (ETB). This exchange rate is based on the Commercial Bank of Ethiopia.

Paybacks period

A case study of companies in the southern region transmission and generation authority focuses on increasing customer satisfaction and their profits. The Payback Period is the length of time in that benefit must accrue before a project breaks even. Shorter payback periods are often favored for projects and investments since they show that the initial investment will be returned sooner, and cash flows that exceed payback periods are indicative of pure profit or positive cash flow. It shows how much time is needed for the cumulative net cash flows (benefits) to equal the initial investment outlay.

$$\text{Payback Period} = \frac{\text{Net investment cost of IPFC}}{\text{Net annual return}} \tag{4.4}$$

The time frame following the original investment is recouped is established using this strategy. The overall cost of the investment is made up of the 10% installation cost and the 2% maintenance cost.

Costs of investment can be designed as

Installation cost (10%) = 0.1 * 1,350,000 = 135000$

Cost of operations and maintenance (2%) = 0.02*1,350,000 = 27000$

Total Costs of investment = IPFC cost + installation costs + maintenance costs

Total Costs of investment = 1,350,000$ + 135000$ + 27000$ = 1512000$

$$\text{Payback Period} = \frac{\text{Net investment cost of IPFC}}{\text{Net annual return}} = \frac{1512000}{755372.8} = 2.00166 \approx 2 \text{ Year}$$

CHAPTER FIVE

5. CONCLUSION, RECOMMENDATIONS AND THE FUTURE WORKS

5.1 Conclusion

This investigation presents an optimization approach for minimizing and managing power loss of transmission network and improving voltage profiles by properly sizing and locating IPFC device. The fundamental concerns that exist in the Shashemene to Bukuluguma transmission system were addressed in this thesis, which included transmission network optimization and voltage profiles improvement. An objective function and a set of constraints are part of the optimization procedure. The implementation of grey wolf optimization method and antlion optimization algorithm is primarily done to expand the scope of the search, which in turn increases the exploitability and robustness of the algorithm. It has been noted that the suggested optimization methods, such as grey wolf, offer more precise and trustworthy direction for the best possible synchronization of other sources of reactive electricity for FACTS devices in the power network.

Load flow analysis, voltage stability analysis, and GWO. To calculate the essential parameters in the existing transmission system, Newton Raphson load flow analysis was utilized. The approach's efficacy and suitability for a steady state constant load model were shown on a conventional IEEE 9 bus network in Shashemene to Bukuluguma transmission network. The findings were compared to those produced using the traditional (ALO) algorithms. The existing system's total real power losses in the base case are 7.322 MW. The GWO algorithm is utilized to choose design variables based on IPFC's optimal placement and size. In terms of reducing both real and reactive power losses, the algorithm is found effective.

With the comparison of different system cases, the result demonstrates that loss reduction is significant. The reduction of real power losses in the system is 59.7 percent, whereas the reduction of reactive power losses in network is 40 percent.

For all bus levels, the operated network's bus voltage has improved to within the allowed limit of IEEE range. After IPFCs integration, the voltage stability index of the operating network improved compared to the base case. When compared to the network base-case results, the overall power loss was reduced by 59.7 percent and the bus voltage improved using the GWO approach; for the ALO approach, 37.5 percent reduction in total power loss was achieved.

The applicability of GWO and ALO for IPFC location and parameter settings for the attainment of defined objectives was demonstrated by their successful independent implementation. IPFC also played an important role in reducing network power loss and controlling bus voltage magnitude. However, the result showed using GWO and ALO to optimize the IPFC device has increased the transmission system's efficiency without the need for physical power infrastructure expansion. However, GWO outperformed ALO in terms of performance to be more successful for IPFC device optimization to reduce power loss and improve bus voltage magnitude. It was shown that various research issues were properly addressed and that the implemented GWO and ALO approaches were effective for optimal IPFC device placement as compared to the uncompensated approach.

5.2 Recommendation

According the thesis result, EEP should strongly advised to use this device in the southern region from Shashemene to Bukuluguma transmission system to improve the voltage profile and to minimize transmission line loss of existing network. The implementation payback period is below five year these means feasible work. Doing these, the EEP Company become profitable also increase the customer satisfaction. The constructing new transmission line consuming time is very long because it needs new route. Therefore, the investigator recommend the EEP to install the IPFC at the specified places with its optimal rating.

5.3 Future works

The future works considering Ethiopian power handling problems focuses on the following points.

- Different latest and best optimization approaches will be used to address optimal power flow issues in a network of long and medium transmission lines in Ethiopia while keeping IPFC's implementation costs as low as possible.
- To make a more stable and reliable power supply for consumer use more advanced power controller IPFC fact device to high voltage transmission line for the next study scopes will wide.
- Transmission line reduction of power loss and enhancement of voltage profile investigation can be taken into an account when performing the possible analysis

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APPENDEX A

Newton Raphson Load Flow Analysis

```
%This program is used in conjunction with lf Newton raphson
%for the computation of line flow and line losses.
%Copyright  (c)  Asrat L.
SLT = 0;
Fprintf ('\n')
Fprintf ('                           Line Flow and Losses \n\n')
Fprintf (' --Line-- Power at bus & line flow    --Line loss Transformer\n')
fprintf('     Bus      MW      Mvar     MW      Mvar      Injected\n')

for n = 1:nbus;
busprt = 0;
   for L = 1:nbr;
       if busprt == 0
       fprintf('     \n'),  fprintf('%6g',  n),  fprintf('           %9.3f',
P(n)*basemva)
       fprintf('%9.3f', Q(n)*basemva), fprintf('%9.3f\n', abs(S(n)*basemva))

       busprt = 1;
       else, end
       if nl(L)==n      k = nr(L);
       In = (V(n) - a(L)*V(k))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(n);
       Ik = (V(k) - V(n)/a(L))*y(L) + Bc(L)*V(k);
       Snk = V(n)*conj(In)*basemva;
       Skn = V(k)*conj(Ik)*basemva;
       SL  = Snk + Skn;
       SLT = SLT + SL;
       elseif nr(L)==n  k = nl(L);
       In = (V(n) - V(k)/a(L))*y(L) + Bc(L)*V(n);
       Ik = (V(k) - a(L)*V(n))*y(L)/a(L)^2 + Bc(L)/a(L)^2*V(k);
       Snk = V(n)*conj(In)*basemva;
       Skn = V(k)*conj(Ik)*basemva;
       SL  = Snk + Skn;
       SLT = SLT + SL;
       else, end
         if nl(L)== n | nr(L)==n
         fprintf ('%12g', k),
         fprintf ('%9.3f', real(Snk)), fprintf('%9.3f', imag(Snk))
         fprintf ('%9.3f', abs(Snk)),
         fprintf ('%9.3f', real(SL)),
             if nl(L) ==n & a(L) ~= 1
             fprintf('%9.3f', imag(SL)), fprintf('%9.3f\n', a(L))
             else, fprintf('%9.3f\n', imag(SL))
             end
         else, end
  end
end
SLT = SLT/2;
```

```
Fprintf ('   \n'), fprintf('    Total loss                          ')
Fprintf ('%9.3f', real(SLT)), fprintf('%9.3f\n', imag(SLT))
clear Ik In SL SLT Skn Snk
```

APPENDEX B

Grey Wolf optimization algorithm

%%proposed Grey Wolf optimization algorithm code for optimal sizing and placing of IPFC

```
clear all
clc
nbus=9;
voltage_minimum=0.937;
voltage_maximum=1.0;
capmaxsij_maximum=100;
IPFCmaxij_maximum=10.8;
QMIN_VALUE=120;
QMAX_VALUE=1200;
data_pass_to_loadflow{1}=voltage_minimum;
data_pass_to_loadflow{2}=voltage_maximum;
data_pass_to_loadflow{3}=capmaxsij_maximum;
data_pass_to_loadflow{4}=IPFCmaxij_maximum;
N=100;
T=100;
%X=9;
UB=1200;
LB=100;
lb=1;
ub=9;
dim=2;
SearchAgents_no=100; % Number of search agents

Max_iteration=100; % Maximum numbef of iterations
[fobj]=Get_Functions_details();

[Best_score,Best_pos,GWO_cg_curve]=GWO(SearchAgents_no,Max_iteration,lb,ub,
dim,fobj);
[finalres_base_case]=bold_flow_before(voltage_minimum,nbus,data_pass_to_loa
dflow);

display(['The best solution obtained by GWO is : ', num2str(Best_pos)]);
display(['The best optimal value of the objective funciton found by GWO is :
', num2str(Best_score)]);

finalresult_val=Best_pos(1:dim) ;
         IPFC_loc=round( finalresult_val(1));
         IPFC_SIZE=finalresult_val(2);
         IPFC_place=[IPFC_loc;IPFC_SIZE];
```

```
[finalres_after_comp]=bold_flow_after(voltage_minimum,IPFC_place,data_pass_
to_loadflow);
   % display final result display('GWO RESULTS ');

POWER_LOSS_BASE_CASE=finalres_base_case{2};
VSI_MINIMUM_BASE_CASE=finalres_base_case{5};
Reactive_power_loss_base_case=finalres_base_case{6};
IPFC_LOCATION=IPFC_loc
IPFC_SIZE_kVAr=IPFC_SIZE
POWER_LOSS_WITH_IPFC=finalres_after_comp{2}
Reactive_power_loss_with_IPFC=finalres_after_comp{6}
VSI_MINIMUM_WITH_IPFC=finalres_after_comp{5}
Active_power_loss_percantage_reduction=(POWER_LOSS_BASE_CASE-
POWER_LOSS_WITH_IPFC)/(POWER_LOSS_BASE_CASE)*100
Reactive_power_loss_percenatge_reduction=(Reactive_power_loss_base_case-
Reactive_power_loss_with_IPFC)/(Reactive_power_loss_base_case)*100%
Minimum_voltage_base_case=finalres_base_case{8}
%Annual_loss_expense_base_case=finalres_base_case{1}
%Annual_loss_expense_after_dstatcom=finalres_after_comp{1}
voltage_profile_base_case=finalres_base_case{7} ;
voltage_profile_after_dstatcomG=finalres_after_comp{7};
min_voltage_profile_after_IPFCG=finalres_after_comp{8}
max_voltage_profile_after_IPFCG=finalres_after_comp{9}
voltage_stablity_index_base_case=finalres_base_case{4};
voltage_stablity_index_after_IPFCG=finalres_after_comp{4};
Active_power_loss_buses_WITH_OUT_IPFC=finalres_base_case{1};
Active_power_loss_buses_WITH_IPFC =finalres_after_comp{1};
Reactive_power_loss_buses_WITH_OUT_IPFC=finalres_base_case{2};
Reactive_power_loss_buses_WITH_IPFC =finalres_after_comp{2};
voltage_before_compensation=finalres_base_case{3} ;
voltage_stab_index_before_compensation=finalres_base_case{4};
voltage_after_compensation=finalres_after_comp{3} ;
voltage_stab_index_after_compensation=finalres_after_comp{4};
%figure,plot(1:nbus,voltage_before_compensation,'r')
%hold on,plot(1:nbus,voltage_after_compensation,'k')
%xlabel('Bus Number')
%ylabel('Voltage')
%grid on;
%legend('BASE CASE','WITH IPFC')
%title('Voltage Profile of the System Before and After Compensation')
%figure,plot(1:nbus,voltage_stab_index_before_compensation,'r')
%hold on,plot(1:nbus,voltage_stab_index_after_compensation,'k')
%xlabel('Bus Number');
%ylabel('Voltage Stability Index')
%grid on;
%legend('BASE CASE','WITH IPFC')
%title('Voltage Stability Index for All Buses')
figure,plot(1:nbus,Active_power_loss_buses_WITH_OUT_IPFC,'r')
hold on,plot(1:nbus,Active_power_loss_buses_WITH_IPFC,'k')
xlabel('Bus Number');
ylabel('Active power loss')
```

```
grid on;
legend('BASE CASE','WITH GWO IPFC')
title('Active power loss for All Buses')
legend('BASE CASE','WITH ALO IPFC')
%xlswrite('voltage_stability_index_value_before_compensation_GWO.xls');
%xlswrite('voltage_stability_index_value_after_compensation_GWO.xls');
%xlswrite('voltage_profile_before_compensation_GWO.xls');
%xlswrite('voltage_profile_after_compensation_GWO.xls');
```