(6th Semester Internship Report)

FINAL PROJECT REPORT ON:

FAMILIARIZATION WITH ELECTRIC EQUIPMENT AND POWER FLOW ANALYSIS IN AC-DC MICROGRID

Submitted By:

NAME- NISHANT
ROLL N0.-12014014
DEPARTMENT - ELECTRICAL ENGINEERING

Under the Guidance of…

Faculty Mentor:

NAME- DR. PRADEEP KUMAR

DESIGNATION- ASSISTANT PROFESSOR

Department of Electrical Engineering

NIT KURUKSHETRA

DECLARATION

Department of Electrical Engineering, NIT KURUKSHETRA

I hereby declare that the content presented in this Power Flow Analysis of Microgrid project report, titled **"FAMILIARIZATION OF ELECTRIC EQUIPMENT AND POWER FLOW ANALYSIS IN AC-DC MICROGRID"**, is the result of my independent work and research. All information,data, and findings presented in this report are based on my own efforts and are accurately represented to the best of my knowledge. This project is in requirementof my 6th semester that I had done under the guidance of

FACULTY MENTOR:

Dr. Pradeep Kumar
Assist. Prof. EE Department
NIT Kurukshetra

DATE:

NISHANT
12014014

CERTIFICATE

This is to certify that project work embodied in this report entitled **"FAMILIARIZATION OF ELECTRIC EQUIPMENT AND POWER FLOW ANALYSIS IN AC-DC MICROGRID"** was carried out by *Nishant*, roll no.: *12014014*, studying in 6th semester at NIT Kurukshetra. This project work has been carried out under my guidance and supervision and it is up to my satisfaction.

Date:

Place: Kurukshetra

Faculty Mentor:

NAME- DR. PRADEEP KUMAR

DESIGNATION-ASSISTANT PROFESSOR EED

NIT KURUKSHETRA

ACKNOWLEDGEMENT

I would like to express my sincere, grateful and warm thanks to all those who were integral to the successful completion of the design within the given timeframe. Without their devoted devotion, this bid would not have achieved its pretensions. I'm thankful to each individual involved for their unvarying support and donation, which acted as the prop of this design. This is a seasonable moment for me to extend my thanks to everyone. During the design timeline, my associates played a necessary part by furnishing backing and guidance. Their involvement was pivotal in icing the design's successful capstone.

I want to convey my boundless appreciation to **DR. Pradeep Kumar, Professor of the EE Department at NIT Kurukshetra,** and the project's mentor. His practical and theoretical knowledge, along with his necessary guidance, played a pivotal role in steering this endeavour towards triumph.

Nishant

12014014

ABSTRACT

Industrial equipment and their training are the most important prerequisites before entering in any industry. It all started with the basic hand tool training and grabbing the knowledge of electrical equipment at Siemens Centre of Excellence (SCOE). Here, we get to know about the working of equipment and construction as well as their operational understanding, some of the most important equipment was the ac-dc drive. Drives are very necessary in case of we are expecting a desirable speed of motor.

Power system studies encompass power flow analysis, a vital aspect in planning, design, and operation of a power system. Essentially, it involves simulating the system during a steady-state condition to ascertain the operating point. This operating point is used subsequently to initialize variables in transient and dynamic system simulations.

To effectively represent the operating state of a mixed AC-DC power system, significant modifications are necessary in the conventional load flow analysis. These modifications should account for the specific conditions of load, generation, and DC system control strategies.

The presence of DC link within power system necessitates the inclusion of DC link modelling in the power flow analysis. Although the designing of DC systems in power flow is generally standardized, the specific solution methodologies employed can vary. This dissertation focuses on the integration of HV-DC links into the power flow analysis, exploring mathematical models and solution techniques. Additionally, a comprehensive review of different algorithms proposed in the literature is presented.

A C++ program is developed for AC-DC load flow analysis. AC load flow analysis is done using NEWTON RAPHSON method and the program is followed by having BUSDATA and LINEDATA. For the dc load flow analysis, we have used the Sequential Approach. Program has been applied to IEEE 14 bus system.

Contents

CHAPTER- 1: ***INTRODUCTION TO SCoE***

Siemens Centre of Excellence (SCOE) is an esteemed division of the National Institute of Technology, Kurukshetra, which holds the status of an Institution of National Importance. Its primary objective is to enhance expertise in design and manufacturing by leveraging cutting-edge and highly reliable technology-driven solutions.

The centre is devoted to executing solution-oriented projects for both industry and academia. Its infrastructure is well-equipped to undertake real-time projects, and the team consists of skilled professionals with practical experience in industrial processes and troubleshooting. Additionally, the centre benefits from the expertise of the esteemed faculty from NIT Kurukshetra, thereby enhancing the quality of deliverables.

SCOE is committed to promoting technological advancements on both regional and national levels, contributing to the development of a technology-driven society.

Vision:

To establish SCOE as a globally recognized and leading centre for skill development, training, and translational research, thereby empowering indigenous manufacturing.

Mission:

- Empower Indian youth with industry-relevant skills in manufacturing technologies through education and training, ensuring lucrative employment opportunities.

- Foster the development of capabilities and capacity for indigenous manufacturing by collaborating with industry, academia, and government agencies.
- Facilitate access to state-of-the-art machinery and software tools for innovative design and the development of new manufacturing technologies.

CHAPTER- 2: *FAMILIARIZATION WITH ELECTRICAL TOOLS AND EQUIPMENT TRAINING.*

1. PAC (Programmable Automation Controller) meter:

Figure 1: PAC METER (Record all parameters i.e., voltage, current, power, energy, power factor.

- It combines the features of a PC and a PLC, offering the advantages of both in a single package, resembling a "Mashup" system. This integration results in reduced operating and maintenance costs.
- With its multi-discipline control capabilities, it can handle complex motion instructions and includes integrated safety functionality.
- By consolidating multiple utility meters into a single enclosure, it saves valuable wall space.
- It enhances energy efficiency.
- Some examples of this technology are the PAC4200, PAC1600, PAC2200, and PAC1200.
- The PAC4200 model excels in delivering highly accurate measurements of power, energy, and demand.
- To utilize the device, the wire is connected to the PAC, and the PAC plug is inserted into the power socket. This setup allows users to conveniently record values such as instantaneous current, voltage, power factor, active power, etc.
- A large graphic LCD display on the device presents all the readings, complete with appropriate units, phase angle, and measurements.

2. Tachometer:

Figure 2: Tachometer (For the measurement of speed (RPM) of shaft.

- Tachometers are electromechanical devices that generate a voltage proportional to the speed of their shaft.
- To measure the speed, we connected or positioned the tachometer's tip, and the speed was displayed on a small screen.
- These devices were commonly used in laboratories with motors and spindles.
- The tachometer operates on the measuring principle, using voltage to determine the rotational speed. It is attached to the object which is being measured and assesses the power-generated voltage to calculate the object's rotational speed.
- The formula $V_o = K_t * W_s$
- represents the relationship between output voltage (Vo), tachometer constant (Kt) in volts per radian, and angular speed (Ws) in radians per second.
- Additionally, the tachometer constant is derived as
  - $K_t = \varphi P / (60 * Z * a)$
- where φ is flux per pole in webers, P is number of poles and Z is number of conductors in the armature windings, and ‘a’ represents number of parallel paths in the armature windings.

3. Multimeter:

Figure 3: Multimeter (To measure multiple parameters like-V, I, R etc).

- A digital multimeter is a testing tool utilized to measure various electrical values, primarily voltage (volts), resistance (ohms) and current (amps).
- It is alternatively referred to as a volt-ohm meter.
- In the CNC Controller lab, we employed the digital multimeter on the 840 DSL training rack.
- A standard multimeter typically measures voltage (AC and DC), resistance and current (AC and DC). However, more advanced models of multimeters can also assess additional values such as:

  - AC voltage and amperage

  - DC voltage and amperage

  - Resistance, capacitance, and conductance

  - Decibels, frequency, temperature, and more.

4. Sound level Tester:

Figure 4: Sound level tester (To measure audio frequency (hz) & intensity (db)).

- A sound level meter, also called a sound pressure level meter (SPL), is a device utilized for acoustic measurements.
- It consists of a microphone that captures and measures the variations in air pressure caused by the sound source.
- The sound level meter calculates a single value referred to as the "Broadband value." It incorporates measurements from across the audio frequency range (20Hz to 20kHz) to determine the overall sound level.
- The measurement is typically expressed in decibels (dB), a logarithmic unit used to quantify sound intensity.
- Sound level meters find application in various areas, including:

  - Analysing sound and noise levels for community noise assessment.
  - Assessing the acoustics of buildings.
  - Controlling industrial noise.
  - Analysing machinery noise, and more.

  - In the lab, we employed the sound level meter to measure the noise produced by various machines.

5. Clamp meter:

Figure 5: Clamp meter (A kind of current sensor without having direct contact with wire)

- Clamp meter is a test tool that integrates a basic digital multimeter with a current sensor.
- Clamps in the meter are designed to calculate current. The hinged jaw incorporated into the electrical meter enables technicians to clamp it around a wire or conductor without the need for disconnection.
- This feature ensures safety as there is no direct contact with the wires.
- It offers convenience since there is no requirement to shut off the device or interrupt the electrical circuit during measurements.
- There are three types of clamp meters available:

  1. Current transformer clamp meter: Utilizes a current transformer to measure current.

  2. Hall effect clamp meter: Relies on the Hall effect principle to measure current.

  3. Flexible clamp meter: Incorporates a flexible clamp for measuring current, providing greater flexibility in accessing confined spaces or irregularly shaped conductors.

6. Digital Thermometer:

Figure 6 Digital Thermometer (It senses infra-red radiation to measure temperature)

- In various industrial and clinical environments, infrared (IR) thermometers are employed to measure temperature.
- They are particularly suitable for measuring temperature in delicate or fragile objects.
- IR thermometers operate based on the principle of IR radiation. They enable the determination of surface temperature without any physical contact with the object being measured.
- These thermometers utilize a lens that focuses infrared light from an object to a detector is called a thermopile.
- A thermopile consists of multiple thermocouples connected either in series or in parallel. It captures the focused IR light and generates an electrical signal proportional to the temperature.
- This allows for non-invasive and accurate temperature measurements across a wide range of applications.

CHAPTER- 3 ***WORKING, CONSTRUCTION AND OPERATIONAL UNDERSTANDING OF INDUSTRIAL EQUIPMENTS.***

1 Air Circuit Breaker:

The air circuit, a safeguard for electrical circuits, utilizes air to shield from current's excess, preventing damage from overloads or shorts, A primary guardian, its purpose is to bless.

In two forms it appears,

3WL and 3WT

Each with distinct traits, their roles set apart. Together they serve, ensuring safety's plea,

With air as their ally, they guard the circuit's heart.

3WL TYPE

- Protection range = 630-6300A
- In SCoE lab, we saw 3WL921-1AC31-1BP1 ACB having In(max)= 1000A and Un(max)= 690V

Parts

- Charging handle liver
- Reset
- ETU
- Teethes
- Auxiliary bus
- Arc chutes
- Ready-to-close
- Servomotor
- Spring
- Indicators
- Auxiliary connectors

Figure 7: 3WL ACB (uses air to shield from excess current and their damages to equipment)

Working

The ETU's role is to measure current's flow, when abnormalities arise, it alerts the breaker,

Air serves as the medium, quenching the arc's glow, ensuring safety, preventing electrical wrecker.

A spring enables contact's make or break, Operated by handle or automatic servomotor,

Manually or automatically, actions it takes, Controlling the flow, like a skilled conductor.

This ACB defends against five fault types,

L: Overload release, cautioning when limits exceed,

S: Delayed short circuit release, patience in its sights,

I: Instantaneous short circuit release,

N: Neutral fault protection, keeping balance intact,

G: Ground fault release, safeguarding the earth

With these protections, the ACB proves its worth,

Rating:

- In(max) = 6300A
- Ics(short) = 66kA 50kA
- Icv = 66kA 50kA
- Ve = 1000V
- Ui(rated voltage) = 1000V
- Vimp(max imp voltage) = 12 KV
- Ve(min voltage) = 440V 690V

3WT TYPE:

Figure 8 3WL ACB (a kind of advanced version of 3WL ACB)

- New generation ACB used for current range 400-4000A
- In SCOE lab, 3WT 8061-6UA34-5AB2
- 3WT don’t have a rating plug
- It has more user-friendly display
- It is more economical and has high performance

Circuit Breaker Application

- Motor protection
- Generator protection
- For fault protection, it is used in substation.

2. FUSES

It is a protection/ safety device that protects electrical equipment from overcurrent. It is used as backup protection.

It has two types:

1. HRC Fuses
2. Semiconductor fuses

Figure 9 Fuses (breaks off when overcurrent flows, to protect the appliances)

HRC fuse (High Rupturing Capacity)

- In SCoE, 3NA7804-0RC, 4A ○ Operating voltage= 500V AC
  - Breaking Capacity= 120KA
- Current range= 2A-800A (500V AC)
  - 2A-500A (690AC)
- Gg
  - g: Complete range protection
  - G: Cable & conductor protection (general purpose fuse)

Working

The conductor elements inside fuse melts easily and break connection when current exceeds a particular limit

- Red colour: normal condition
- White: faulty condition

Figure 10 Semiconductor type fuses

Semiconductor type fuses

- In SCoE: 3NE1 020-2, 690V AC, 80A
- gR: general purpose semiconductor protection
- It is used generally for protection of semiconductor device

Working

- As the current increases, its heat energy also increases.
- After crossing a thermal limit of ARC, the fuse will melt down and the circuit brakes.

3 Super Switch

- As touching a high voltage switch directly can be dangerous, a combination of switch and fuse came in place, known as super switch.
- It is also a backup protection, works with MCCB and fuses.
- In SCoE: 3KA8151-3TE00 (63A, 690V AC 50Hz)
- It has long shaft, so user can operate the device from a larger distance.

Figure 11 Super Switch (preferred if there is high voltage)

4. Contactors

● It is an electrically controlled switch utilized for exchanging an electrical power circuit.

● It is operated by another circuit having low power level than switch, such as 24V coil is used as electromagnet to control 230V supply.

Parts

● Fixed contact

● Moving contact

● Coil

● Terminal

Making & Breaking Capacity

● The current value, which can switch ON the contactor safely without damaging itself is called making capacity.

● The current value, which can switch OFF the contactor safely without damaging itself is called breaking capacity.

- We use contactor to connect the PLC to motor indirectly and safely because if there is any surge in the motor it can also damage the PLC with the motor which will increase the maintenance expenditure.
- The contactors have a low voltage coil, to which PLC output is connected. ➢The coils work with 24DC signals.
- Asthe coil is energized, EMF will be created and the moving coil will be attracted toward the fixed coil.
- The current of the coil and contacts are electrically isolated. The contacts will open and close via EMF created by the coil.

Figure 12 Contactors (switching device)

5. MPCB

● It stands for Motor Protection Circuit Breaker.

● MPCB is a protection device used to secure electrical motors.

● It protects motor against faults like: short circuit, line to line, ground to ground, overload protection

● It is mostly used for Induction motor

● If the motor draws current more than its rated value, it provides overload protection.

Principle

Like another circuit breaker it protects or works in some limited range and breaks circuit in an abnormal condition.

Application

● Elevators
● Conveyor Belts

Figure 13 MPCB (used to protect electrical motors)

6. MCCB

● It stands for Moulded Case Circuit Breaker

● It is a progressed version of MCB which protects electrical equipment from overload & short circuit current and instantaneous over current.

● Range available: 16-1600A

● It is compact in size and it's modular.

3VT (3VT1,3VT2…….3VT5)

● 16-1600A with breaking capacity: 25kA, 36kA, 65kA at 415V AC

● Used upto 50'C

● Attached on DIN rail

● Used for DC Application

3VA

● Have separate option for overload & short circuit
● Protection against overload, short circuit and ground fault, protection of neutral conductor.

Application

● Industries

● Office building

Figure 14 MCCB (advanced version of MCB)

7. Induction Motor

A 3phase induction motor is an asynchronous motor that rotates at less than synchronous speed.

Parts

- Rotor
- Fan
- Stator winding
- Stator slots

➢Laminated slots are used to reduce eddy current

➢Windings are insulated with varnish

Working

- The 3 phase AC supply on the stator produces a rotating magnetic field that cuts the rotor conductors and induces an EMF in rotor causing a current to flow in rotor and hence energy flows from stator to rotor by means of mutual induction
- The rotor current produces another magnetic field.
- As a result, a torque is produced because of interaction of those two magnetic fields.

8. DC Motor

- A device which converts DC electrical energy into mechanical output.
- **In SCoE**:2KW, 220V, 4A, shunt excited, B insulation
- **Rating**: 440V (armature), 1500rpm, D.P. type

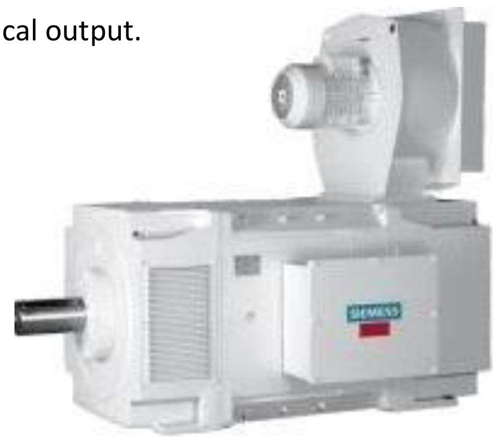
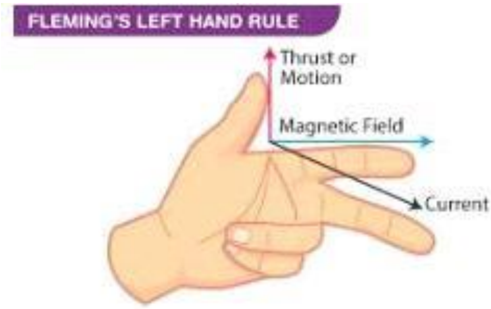


Figure 15 DC Motor

Working Principle

It works on **'Lorentz law'**, which states that conductors carrying current put in a magnetic field experience a force whose course is decided by Fleming Left-hand rule.



Tachogenerator

A tachogenerator is fitted on the rotor of DC motor to measure the speed of the DC motor. It converts mechanical input to electrical output (in terms of voltage) and then tells us speed.

➢The main reason, induction motor is used in industries over DC is, DC motor is difficult to open and maintenance is also difficult

➢There were 2 interpoles in SCoE motor to reduce armature reaction.

9. PAC Meter

● In SCoE: PAC4200

● It is used for external or embedded automatic meter reading in panels, switchboard, switchgear, transformer, etc., to allocate energy costs on a building-by-building basis.

● PAC4200 offers high accuracy power, energy and demand measurements

● It measures parameters like:

○ Vph-ph Inst = 230V (l1)
○ Amp. Inst = 0.13A
○ Power factor = 0.37
○ 230V (l1)

Figure 16 PAC METER (Record all parameters i.e. voltage, current, power, energy, power factor.)

Application

● Ideal for replacing multiple analog meters

● It has high accuracy power etc measurements

10. Type 1 & Type 2 coordination

- Fuse (HRC) - Contactor - Relay (thermal)
- MPCB (primary) - Contactor (secondary)
- Soft starter (primary) - MPCB (secondary)

11. Timer & Relay Panel

- ON Relay: After switching ON, it will actually start after some time.
- OFF Relay: Gives pause to OFF signal for a time defined by us.
- 555 timer: Here we can define time for which we want delay.
- Star-Delta: We set time for which we want delay in circuit from changing of star to delta

Application

- On Delay: Washing machine (Auto)
- Off Delay: Elevator doors

Figure 17 Timer & Relay Kit (fault or any malfunction like overcurrent, sensing unit)

12 AC/ DC Drive

● Drive is a power electronic converter during a mechanical load such as a motor.

● If it is controlling an AC motor, it is called an AC drive.

● If it is operated over DC motor, it is DC drive

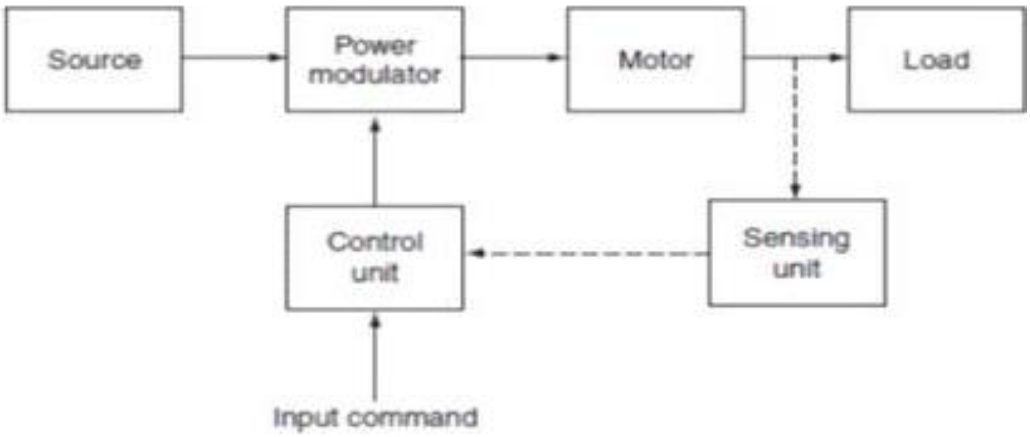


Figure 18 Drive System (control diagram)

DC Drive

● DC drive uses rectifier & chopper

● Requires comparatively more maintenance

● Because of commutation, they are more heavy and costly

● Rectifying the circuit is necessary.

● Produces high starting torque

● Circuit is less complex because of the single power consumption/ conversion process from AC to DC.

● Single-phase DC drive: ○ DC motor is run from single AC source using rectifier

1 phase full wave converter

1 phase semiconductor

1 phase half wave convertor

● 3Phase DC Drive: 3 phase rectifier drives a DC motor. It is used for large DC motors

13. Energy Saving Panel

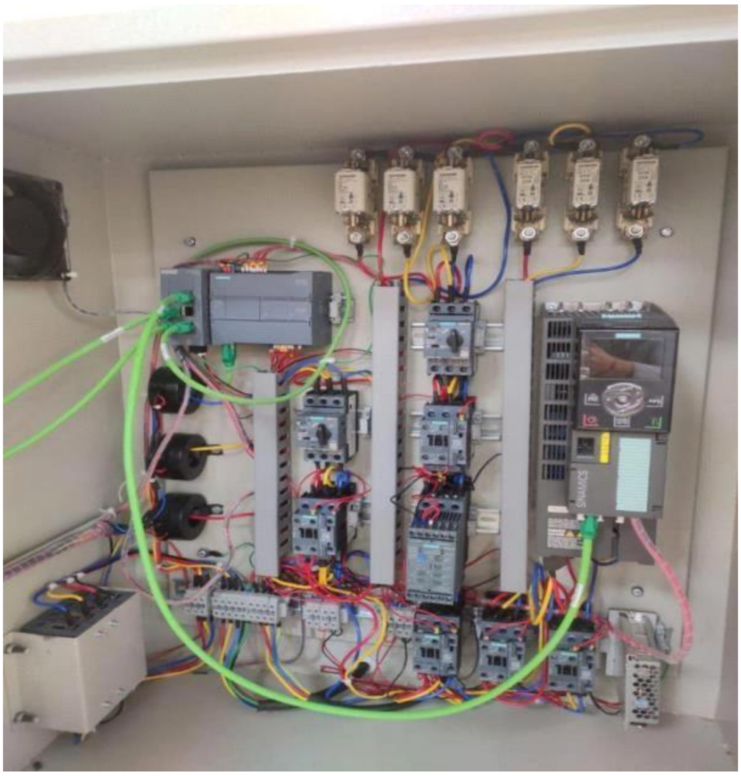


Figure 19 Energy Saving Panel (reduces energy consumption & improve energy efficiency of equipment used)

14. Star Delta Starter Kit

● This type of starting technique is used when we need a low starting current and high voltage is needed during starting.

● There are two different types of star-delta kits available in older & newer versions.

● The older one has large size but newer is compact.

● New one has an inbuilt timer circuit in it but it is not there in old one.

Figure 20 Star Delta Starter Kit (to reduce starting current and interference of supply)

15. Automation Lab

● Automation is control of machinery & processes utilized in different industries by independent systems through the use of innovations like robotic & computer program.

● Advantages: ○ High productiveness ○ High quality & flexibility ○ High information accuracy

● Disadvantages: ○ High initial cost ○ Maintenance can be costly as experts need to repair.

PLC

● It stands for Programmable Logic Control

● It is an electronic device that can be programmable and reprogrammable by logic to control some output.

● In SCoe: 1214C CPU
● PLC Component: ○ Power module ○ CPU ○ I/O module ○ Memory unit
○ Programming device

● **Types:**

○ **Fixed PLC:**

■ Relay/AC/DC

■ Relay/DC/DC

■ If there is an integrated input, then also it is fixed PLC

■ External power source not needed for input, output in fixed PLLC

■ Fixed PLC does not require memory card initially

○ **Modular PLC:**

■ Rather than AC/DC/Relay etc; communication protocol is written like PN/DP

■ There is no integrated I/O

■ Memory card is mandatory like simatic card which is highly secure

■ PLC need external power source of DC type

○ **Combination of both**

● IC Standard: 61131-3

● Type of PLC language:

○ Ladder diagram

○ Function block diagram

○ Sequential flow chart

○ Structure text (like C, C++)

○ Instruction list (mnemonics)

● Ways to achieve automation (programming software are mentioned below):

○ TIA portal: Totally Integrated Automation

○ WinCC Professional (for HMI): Window Control Centre Professional

○ WinCC Professional RT (for SCADA): WinCC Professional Runtime

● Block diagram of PLC ○ Here power supply is SMPS (Switch Mode Power Supply) that converts 1 phase (220V AC) to 24V DC

● PLC CPU memory

Load memory

Work memory (like RAM)

System memory

Non-volatile memory

● PIR (Process Image Registrar)

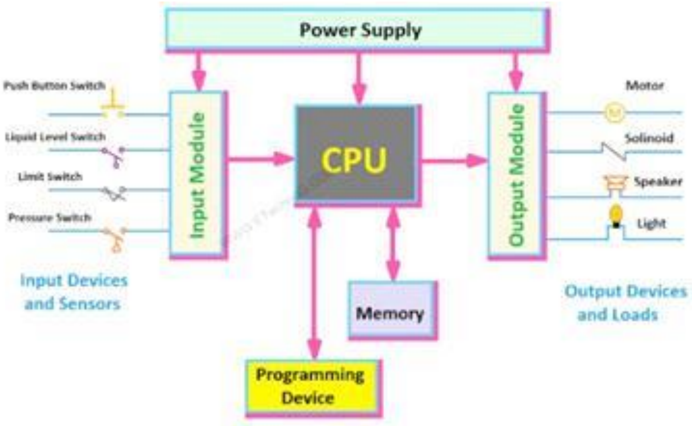


Figure 21 Block diagram of PLC

This memory registrar is always in bytes and divided into two sub parts i.e., PII and PIQ equally.

● PLC scan cycle

● ○ PLC executes a series of task repetitively

CHAPTER 4: *POWER FLOW ANALYSIS IN MICROGRID*

INTRODUCTION:

HVDC transmission has emerged as cost-effective alternative to AC transmission, especially for long-distance lines exceeding 600 Km.AC transmission is commonly used in industries and residential areas, its complexity and dependence on voltage phasor angles make it less suitable for extended lines. HVDC technology, utilizing High Voltage Direct Current, overcomes these limitations and enables power transfer over substantial distances.

HVDC transmission involves the conversion of DC to AC at the receiving end & AC to DC at the sending end, which is achieved through converter stations. By employing basic control actions, these converters may be seamlessly exchanged between rectifier and inverter modes, allowing for power reversal as needed.

The development of HVDC transmission was pioneered by the discovery of the high voltage mercury valve, which laid the foundation for its advancement. In 1954, the primary commercial HVDC framework connected with two AC systems through a submarine cable linking the Swedish mainland with the island of Gotland. Since then, HVDC has gained widespread adoption worldwide.

Traditionally, HVDC systems based on thyristors utilized the Current Source Converter (CSC) arrangement. However, recent advancements have introduced a new type of HVDC transmission that employs Insulated Gate Bipolar Transistors (IGBTs) as semiconductors and operates with voltage source converters (VSCs) at higher switching freq. of around 1 to 2 kHz using pulse width modulation (PWM) technique. This technology, in industries known as HVDCPLUS (Power Link Universal Systems) or HVDC Light, offers improved performance and is readily available for deployment.

AC-DC LOAD FLOW ANALYSIS

AC-DC load flow analysis is a crucial technique in power systems engineering for studying and analysing the steady-state behaviour of AC and DC power networks. It involves solving a set of non-linear power flow equations to determine the voltage magnitudes, voltage angles, and power flows in the system.

The AC load flow analysis focuses on AC power networks, where generators, transformers, transmission lines, and loads are interconnected. By solving the load flow equations, it provides valuable information about the system's operating conditions, such as active and reactive power flows, voltage profiles, and line losses. This analysis helps in assessing system stability, voltage regulation, and identifying potential issues like overloads and voltage violations.

On the other hand, DC load flow analysis is specifically used for analysing high-voltage direct current (HVDC) transmission systems. HVDC systems have become increasingly important for long-distance power transmission due to their advantages over AC systems. The DC load flow analysis considers the converter stations, transmission lines, and loads in the HVDC system. It helps in determining the DC voltage levels, power flows, and converter operating points. The analysis aids in optimizing power transfer, controlling power flow, and ensuring stability in HVDC systems.

Both AC and DC load flow analyses involve iterative numerical techniques such as the Newton-Raphson method or Gauss-Seidel method to solve the non-linear equations. These techniques iteratively update the voltage magnitudes and angles until convergence is achieved. The load flow analysis considers various factors such as power generation, load demand, network topology, and system constraints to determine the steady-state operating conditions.

In conclusion, AC-DC load flow analysis is a vital tool for power system planning, operation, and optimization. It provides critical insights into system performance, helps in identifying potential issues, and aids in making informed decisions to ensure efficient and reliable power system operation.

The strategy for understanding AC-DC power systems can be categorized as follows:

1. Simultaneous or unified method

This approach acknowledges the interdependency of AC and DC system conditions and solves the complete system simultaneously. The best execution of this approach includes combining all the conditions for the DC and AC systems into a single set of nonlinear logarithmic equations. A Jacobian matrix is at that point made, and Newton's method is utilized to unravel this condition set. An alternative variation of this method is the "fast decoupled" method used to solve the AC system equations. Several commonly used methodologies in the literature include:

- Duane A. Braunagel's Approach

- J. Arrillaga's Approach

- R.M. Mathur's Approach

2. Sequential or alternating method

The sequential method is a further simplification of the unified method. In this method, the AC system equations are calculated while the DC system is modelled as real & reactive power injections at the significant terminal bus bar. For DC solution, the AC system is modelled as a constant voltage at the converter's AC terminal bus bar. Following methodologies are commonly used in the literature:

- J. Reeve's Approach

- C.M. Ong's Approach

There are two main solution approaches: the sequential solution approach and the unified solution approach. In this sequential approach, the AC & DC equations are solved independently at every iteration. In contrast, the unified approach combines the DC & AC systems and solves them like a single set of equations during each iteration.

Modelling of HVDC system using sequential approach (C.M. Ong's Approach)

To accurately model a HVDC system, several assumptions are made:

a. At the terminal bus bar, the three AC voltages are symmetrical and sinusoidal.

b. The converter operates in a balanced manner.

c. Both voltages and direct currents are smooth.

d. The magnetizing admittance is neglected since the converter transformer is assumed to be lossless.

e. In AC system having injection of reactive & active power constant at two terminal buses so that the DC connection get integrated to ac load flow.

Based on these assumptions, the equivalent circuit of a system with a HVDC link (with a converter at the ith bus and an inverter at the jth bus) is depicted. The equations related to the HVDC link are as follows:

.

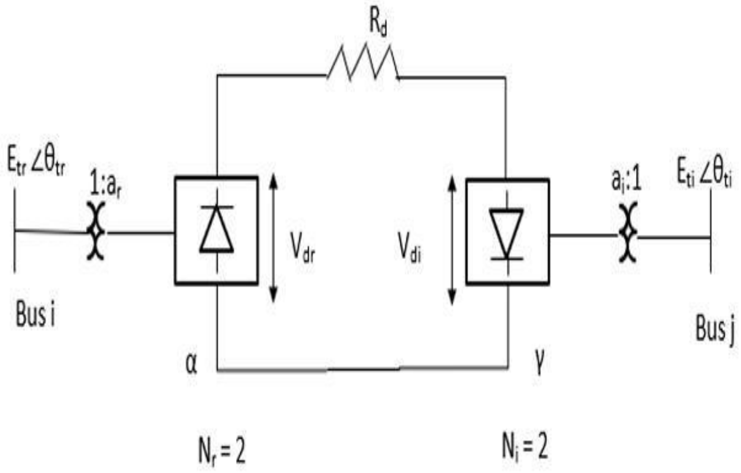


Figure 22 HVDC TRANSMISSION LINE MODELLING

Vdr = $(\frac{3\sqrt{2}}{\pi})$*Nr*ar*Etr*$\cos\varphi r$ =Vdor*$\cos\varphi r$ ……………………..1

Vdr = Vdor*$\cos\alpha$ – $(\frac{3}{\pi})$*Xcr* Nr*Id ……………………2

Vdi = $(\frac{3\sqrt{2}}{\pi})$* Ni* ai* Eti*$\cos\varphi i$ = Vdoi*$\cos\varphi i$ ..……………………3

Vdi = Vdoi*cosγ – $(\frac{3}{\pi})$*Xci*Ni*Id ……………………4

Id = $\frac{(Vdr - Vdi)}{Rd}$ ……………………5

r for rectifier side and I for inverter side….

Where ,

Et : AC terminal voltage

a : Transformer tap ratio

N: Number of 6 pulse converters connected in series

X: Individual transformer leakage impedance

ϕ: Power factor angle

α : Firing angle

γ : Extinction angle

Rd : DC link resistance

Set of variables we have => [Vdr Vdi Id ar ai cosα cosγ ϕr ϕi]

-

Here, we have 9 variables and 5 equations. So, to find the values of the variables we need to assume any 4 variables values and then try to solve the equations.

So, we some combinations of control specifications……

Control 1: γ , Vdi α , Pdr

Control 2: ai , Pdi , ar , Vdr

Within the sequential approach, the AC system and DC systems are solved independently, and the connection between them is built up by infusing equal amounts of active and reactive power at the terminal AC buses. In different words, the impact of an HVDC connection between buses i and j (with the rectifier at bus i and the inverter at bus j) is introduced into the AC system through power injections P(R)DCi and Q(R)DCi at the rectifier bus i, and P(I)DCj and Q(I)DCj at bus j (where the superscripts R and I denote rectifier and inverter, respectively).[5]
Hence, at buses i and j, the net injected power is calculated as follows:

For bus i: PTotali = PACi + P(R)DCi and QTotali = QACi + Q(R)DCi

For bus j: PTotalj = PACj + P(I)DCj and QTotalj = QACj + Q(I)DCj

AC system is then equated again using net injected power values, and the corresponding injected powers (P(R)DCi, Q(R)DCi, P(I)DCj, Q(I)DCj) and total injected powers (PTotali, QTotali, PTotalj, QTotalj) are modified. This way of solving the DC and AC systems alternately continues until the discrepancies between the quantities of two subsequent iterations in the DC and AC
systems are smaller than a predefined threshold value.

Although the simultaneous approach provides a system solution without exchanging b/w DC and AC, the sequential strategy is relatively straightforward to implement. Similar to how Gauss-Seidel (G-S) and Newton-Raphson methods are utilized to calculate power flow problems in purely AC systems, these methods can also be employed to calculate power flow problems in AC-DC systems.

Power Flow Algorithm –

Here we are considering only combination 1 for power flow analysis….

Here is the breakdown of the steps involved in AC-DC power flow calculation:

Step 1: from DC and AC system read the given data to initialise the values.

Step 2: initialize the values for α, Pdr, γ, and Vdi. then find Id and Vdr

Step 3: as we get Vdr and Vdi, then Calculate ϕr and ϕi

Step 4: after getting ϕr and ϕi find (Pdi, Qdr, Qdi)

Step 5: Get the total injected power at both the end.

Step 6: Form the Ybus matrix for the AC system.

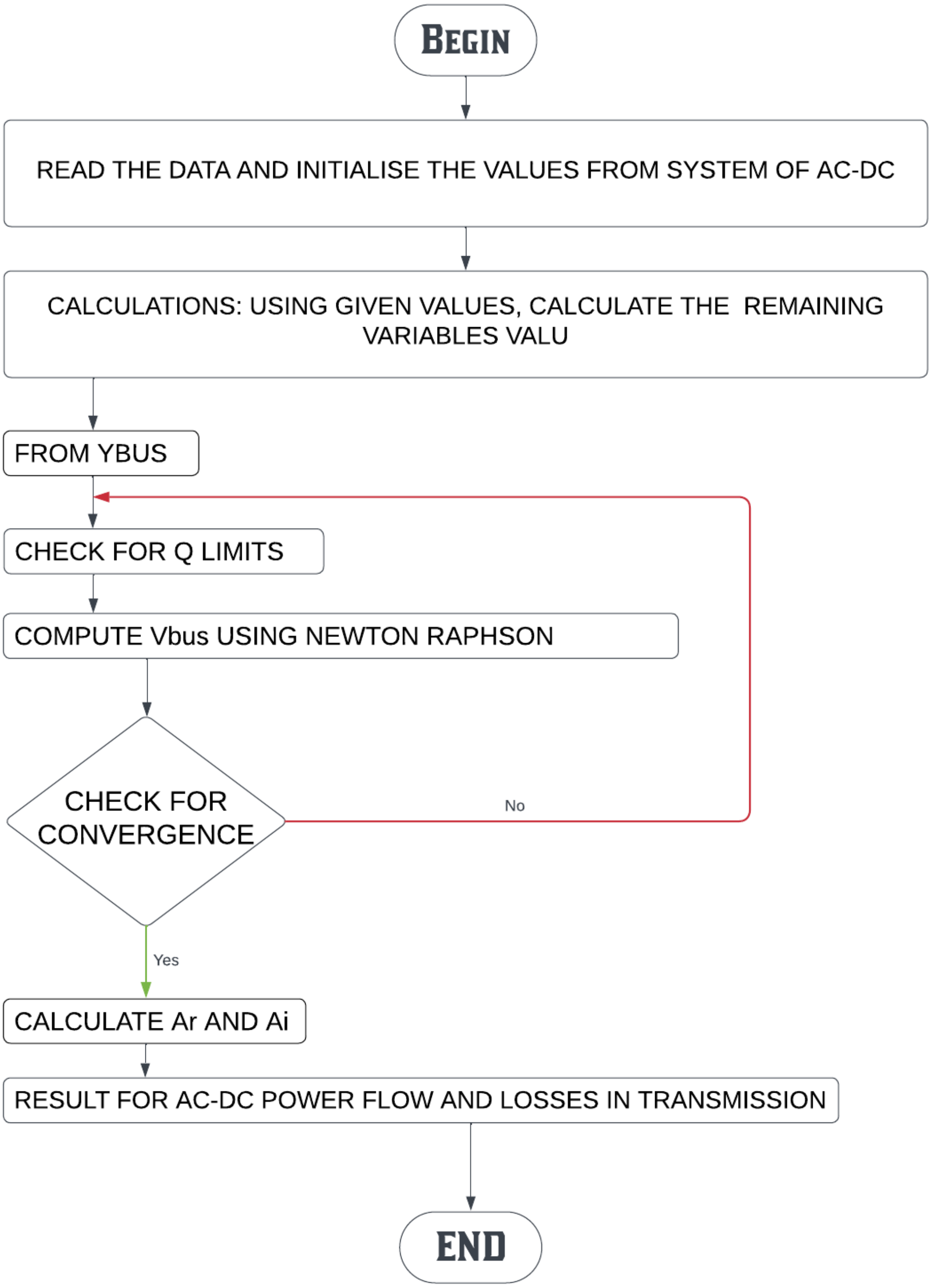
Step 7: Calculate Qg (reactive power generated) for generator buses and check for Q limit violations.

Step 8: Using newton Raphson find Vbus and check for convergence. If convergence is not achieved, go back to Step 7.

Step 9: After finding the final solutions for voltage magnitudes, calculate ar and ai.

Step 10: Obtain the results for the AC-DC power flow, including the transmission losses.

FLOW CHART


BEGIN
READ THE DATA AND INITIALISE THE VALUES FROM SYSTEM OF AC-DC
CALCULATIONS: USING GIVEN VALUES, CALCULATE THE REMAINING VARIABLES VALU
FROM YBUS
CHECK FOR Q LIMITS
COMPUTE Vbus USING NEWTON RAPHSON
CHECK FOR CONVERGENCE
No
Yes
CALCULATE Ar AND Ai
RESULT FOR AC-DC POWER FLOW AND LOSSES IN TRANSMISSION
END

CHAPTER 5: TEST SYSTEM AND RESULTS

Having a data of IEEE 14 Bus System on which AC and DC load flow analysis is done.

We are having the bus data, line data and corresponding to that getting power flow results.

AC and DC analysis is done separately, we have taken system values for dc bus to calculate the power flow data is referred from thesis on ac-dc analysis and IJRAR.

By performing a C++ program _

- Bus data
- Line data
- Ybus
- Load flow
- DC load flow analysis (main file 2)
- Load flow analysis
- Newton Raphson load flow (as a main file 1)

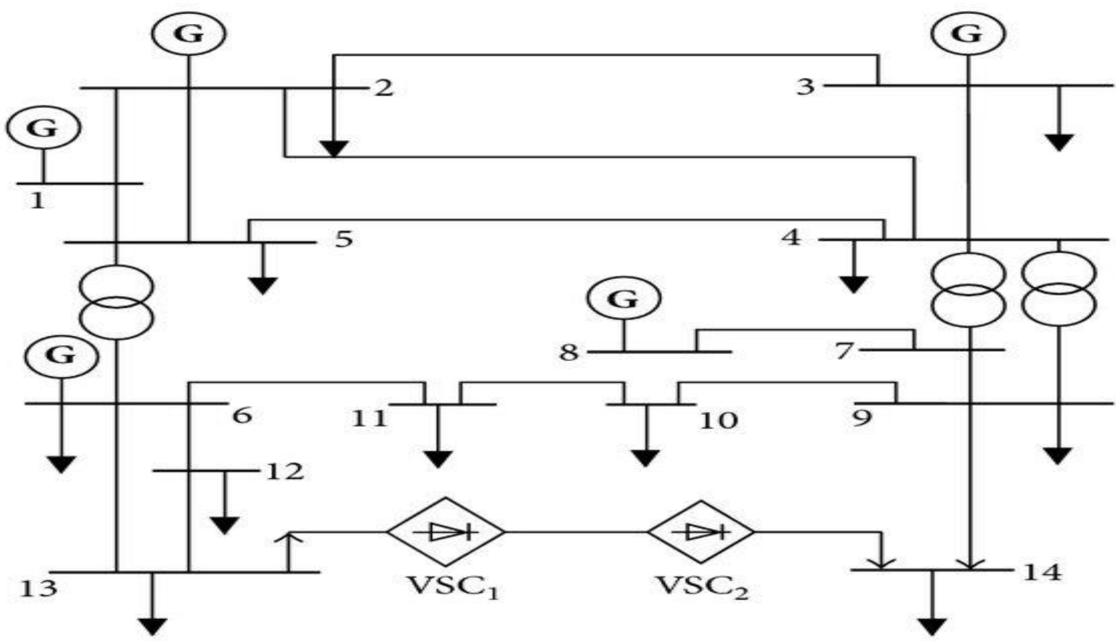


Figure 23 IEEE 14 Bus Network with VSC at bus terminal 13 and 14.

BUS DATA

%	Bus	Type	Csp	Theta	PGi	QGi	PLi	Qli	Qmin	Qmax
1	1	1	1.060	0	0	0	0	0	0	0
2	2	2	1.045	0	40	42.4	21..7	12.7	-40	50
3	2	2	1.010	0	0	23.4	94.2	19.0	0	40
4	3	1	1.0	0	0	0	47.8	-3.9	0	0
5	3	1	1.0	0	0	0	7.6	1.6	0	0
6	2	2	1.070	0	0	12.2	11.2	7.5	-6	24
7	3	1	1.0	0	0	0	0.0	0.0	0	0
8	2	2	1.090	0	0	17.4	0.0	0.0	-6	24
9	3	1	1.0	0	0	0	29.5	16.66	0	0
10	3	1	1.0	0	0	0	9.0	5.8	0	0
11	3	1	1.0	0	0	0	3.5	1.8	0	0
12	3	1	1.0	0	0	0	6.1	1.6	0	0
13	3	1	1.0	0	0	0	13.5	5.8	0	0
14	3	1	1.0	0	0	0	14.9	5.0	0	0

Bus data and line data are taken from the MATLAB to get the same output to ensure that the python code is running well.[11]

LINE DATA

From Bus	To Bus	R(pu)	X(pu)	B/2(pu)	X'mer TAP(a)
1	2	0.001938	0.05917	0.0264	1
1	5	0.05403	0.22304	0.0246	1
2	3	0.04699	0.19797	0.0219	1
2	4	0.05811	0.17632	0.0170	1
2	5	0.05695	0.17388	0.0173	1
3	4	0.06701	0.17103	0.0064	1
4	5	0.01335	0.04211	0.0	1
4	7	0	0.20912	0.0	0.978
4	9	0	0.55618	0.0	0.969
5	6	0	0.25202	0.0	0.932
6	11	0.09498	0.19890	0.0	1
6	12	0.12291	0.25581	0.0	1
6	13	0.006615	0.13027	0.0	1
7	8	0	0.17615	0.0	1
7	9	0	0.11001	0.0	1
9	10	0.03181	0.08450	0.0	1
9	14	0.12711	0.27038	0.0	1
10	11	0.08205	0.19207	0.0	1
12	13	0.22092	0.19988	0.0	1
13	14	0.17093	0.34802	0.0	1

Newton Raphson Load flow Analysis

Bus No	V pu	Angle Degree	Injection MW	Injection MVar	Generation MW	Generation Mvar	Load MW	Load MVar
1	1.0600	0.0000	232.59	-15.23	232.59	-15.23	0.00	0.00
2	1.0450	-4.9891	18.30	35.23	40.00	47.93	21.70	12.70
3	1.0100	-12.7492	-94.20	8.76	0.00	27.76	94.20	19.00
4	1.0132	-10.2420	-47.80	3.90	0.00	0.00	47.80	-3.90
5	1.0166	-8.7601	-7.60	-1.60	0.00	0.00	7.60	1.60
6	1.0700	-14.4469	-11.20	15.53	0.00	23.03	11.20	7.50
7	1.0457	-13.2368	0.00	0.00	0.00	0.00	0.00	0.00
8	1.0800	-13.2368	-0.00	21.03	-0.00	21.03	0.00	0.00
9	1.0305	-14.8201	-29.50	-16.60	-0.00	-0.00	29.50	16.60
10	1.0299	-15.0360	-9.00	-5.80	0.00	0.00	9.00	5.80
11	1.0461	-14.8581	-3.50	-1.80	-0.00	-0.00	3.50	1.80
12	1.0533	-15.2973	-6.10	-1.60	0.00	0.00	6.10	1.60
13	1.0466	-15.3313	-13.50	-5.80	0.00	0.00	13.50	5.80
14	1.0193	-16.0717	-14.90	-5.00	-0.00	-0.00	14.90	5.00
Total			13.593	31.009	272.593	104.509	259.000	73.500

To match the result output of the program, a problem on IEEE 14 bus system data is taken from the outside sources (MATLAB).[11]

Line Flow and Losses

From Bus	To Bus	P MW	Q MVar	From Bus	To Bus	P MW	Q MVar	Line Loss MW	Line Loss MVar
1	2	160.05	-17.48	2	1	-149.89	30.64	10.16	13.15
1	5	78.28	7.98	5	1	-70.20	3.46	8.08	11.45
2	3	75.79	5.94	3	2	-68.83	3.89	6.96	9.83
2	4	57.80	2.94	4	2	-52.53	2.13	5.27	5.07
2	5	43.62	4.74	5	2	-39.02	-1.93	4.60	2.81
3	4	-22.48	7.75	4	3	24.19	-6.75	1.70	1.00
4	5	-59.58	11.57	5	4	60.06	-10.06	0.48	1.51
4	7	28.30	-16.10	7	4	-27.67	5.69	0.62	-10.41
4	9	16.47	-2.81	9	4	-15.96	-2.25	0.51	-5.06
5	6	52.83	-24.00	6	5	-49.24	-7.00	3.59	-31.00
6	11	8.29	8.90	11	6	-8.16	-8.64	0.12	0.26
6	12	8.06	3.18	12	6	-7.98	-3.01	0.08	0.17
6	13	18.34	9.98	13	6	-18.09	-9.49	0.25	0.50
7	8	0.00	-20.36	8	7	-0.00	21.03	0.00	0.67
7	9	27.07	14.80	9	7	-27.07	-13.84	0.00	0.96
9	10	4.39	-0.90	10	9	-4.39	0.92	0.01	0.02
9	14	8.64	0.32	14	9	-8.55	-0.13	0.09	0.19
10	11	-4.61	-6.72	11	10	4.66	6.84	0.05	0.12
12	13	1.88	1.41	13	12	-1.87	-1.40	0.01	0.01
13	14	6.46	5.08	14	13	-6.35	-4.87	0.11	0.21
Total Loss								42.688	1.448

##

Characteristics of DC Link

Characteristic	Converter 1	Converter 2
A.C. Bus Bar	Bus 5	Bus 4
D.C. Voltage Base	100 kv	100 kv
Transformer Reactance	0.126	0.0728
Commutation Reactance	0.126	0.0728
Filter Admittance (Bf)	0.478	0.629
DC-Link-Resistance	0.334 Ω	------

Control Parameters for case

DC Link Power	58.6	----------
Rectifier Firing Angle (deg)	7.0	----------
Inverter Extinction Angle (deg)	----------	10.0
Inverter DC Voltage	----------	-128.87 kv

This dc data is taken from the M.Tech thesis of a student at Nit Kurukshetra [6]

By using DC load flow program, we calculated the net real and reactive power injection on the buses which have HVDC.[1]

RESULT:

```
Vdr 129.0216985144774
Id 0.4541871690940196
Vdor 171.28354483694932
fr 0.7177859024618372
fdr 51.16707039844909
Vdoi 171.02108456793943
fi 0.717376829142717

Pdr     Qdr     Pdi                     Qdi
58.6     0     58.53110048114631    51.06472711340028
```

Future Scope of Research

The current study centered on the steady-state analysis of AC-DC systems. Based upon the discoveries, several areas for further research and advancements in HVDC transmission systems can be identified:

1. Analysis of transient behaviour: Future research can delve into studying the transient behaviour of interdependent AC-DC systems at the time of switching and fault conditions. This analysis would provide insights into system response and stability during dynamic events.

2. Generic modelling of HVDC systems: Developing a comprehensive and generic modelling approach for all kinds of HVDC systems, considering every possible configuration, would be beneficial. Such a model would help reduce the complexity involved in analysing and simulating power systems with HVDC components.

3. Utilization of Voltage Source Converters (VSC): Exploring the effective utilization of VSC in interdependent AC-DC systems is an area of interest. This would involve inquiring the integration of DC sources with the utility grid using VSC technology, which can enhance power system flexibility and control.

By focusing on these future research areas, further advancements can be made in understanding and optimizing the performance of AC-DC systems. This, in turn, would contribute to the development of more efficient, reliable, and sustainable power transmission networks.

References and Bibliography

1. Novel Approach to AC- DC Load Flow Analysis Hemant Kumar S. Barotand S.K. Joshi, NATIONAL POWER SYSTEMS CONFERENCE, NPSC 2002.
2. Article: A Full-Newton AC-DC Power Flow Methodology for HVDC Multi-Terminal Systems and Generic DC Network Representation.
3. HadiSaadat: ‘Power system Analysis’ (Tata McGraw-Hill, New York, 2010, 2nd edn.).
4. Power Flow Studies of an AC-DC Transmission System(thesis) by Ummaiah Bondhala (IITH).
5. Power Flow Analysis of AC – DC Power Network Using Numerical Methods by Reshma Muralidharan and Rajeswari Ramachandran Department of Electrical and Electronics Engineering Government College of Technology, Coimbatore, Tamilnadu, India. (IJRAR)
6. AC DC power flow analysis by M. Tech student (2016) Thesis paper at NIT Kurukshetra.
7. C.M. Ong and Fudeh M., ‟A simple and efficient AC-DC load flow method for multi-terminal hvdc systems ‘, IEEE Trans. on Power apparatus and systems, Vol. PAS-100, pp. 4389-96,1981
8. Power System Restructuring and Deregulation- Book Edited by L.L. Lie, John Willey & Sons.
9. Prof. Biswarup Das., NPTEL course on “Computer Aided Power System Analysis”,
10. Kothari, I.J., Nagrath, D.P.: ‘Modern power system Analysis’ (Tata McGraw Hill, New York, 2003, 3rd edn.)
11. MATLAB program by HAFIZ KASHIF KHALEEL on Newton Raphson power flow analysis version 1.0.0.0
12. Power System Analysis by John J. Grainger and William D. Stevenson