COLLEGE OF ENGINEERING & TECHNOLOGY

LABORATORY MANUAL

POWER SYSTEM PLANNING AND DESIGN

SUBJECT CODE: 2180903

ELECTRICAL ENGINEERING DEPARTMENT

B.E. 8th SEMESTER

NAME:______________________________

ENROLLMENT NO: ______________________________

BATCH NO: ______________________________

YEAR: ______________________________

Amiraj College of Engineering and Technology,
Nr.Tata Nano Plant, Khoraj, Sanand, Ahmedabad.

COLLEGE OF ENGINEERING & TECHNOLOGY

Amiraj College of Engineering and Technology,
Nr.Tata Nano Plant, Khoraj, Sanand, Ahmedabad.

CERTIFICATE

This is to certify that Mr. / Ms. ____ Of class___________________ Enrolment No _________________________has Satisfactorily completed the course in __________________________________as by the Gujarat Technological University for ____ Year (B.E.) semester___ of Electrical Engineering in the Academic year_________.

Date of Submission:-

Faculty Name and Signature
(Subject Teacher)

Head of Department
(Electrical)

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List Of Experiments

Sr. No.	Title	Date of Performance	Date of submission	Sign	Remark
1.					
2					
3					
4					
5					
6					
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9					

Laboratory Experiment – 1

Aim of Experiment: Study the behavior of terminated coaxial transmission lines in frequency domain.

Requirement:

You have to install a Lab VIEW Run time Engine on your computer to run the exe file in order to perform the experiment.

Knowledge Required for the Experiment:

- Transverse Electromagnetic wave.
- Transmission-Line.
- General Transmission-Line equations.
- Transmission-Line parameters.
- Reflection Coefficient.

Objective of Experiment:

This experiment gives the vision by which we can see the voltage wave travelling toward the load, voltage reflected wave from the load end and the voltage standing wave, by which we can understand the concept behind the transmission of analog signal in the lossless transmission line. In a transmission-line operating at high frequency, due to impedance mismatch between the source, transmission-line, and load there is a loss of energy transfer from source to load. The effects due to mismatch of the load and characteristic impedance can be studied here in frequency domain. This can be done by sending a wave on the line with its load mismatched and watching the reflected wave along with voltage standing wave over transmission line. By varying various parameters of transmission line their effects can be visualized accordingly.

Theory:

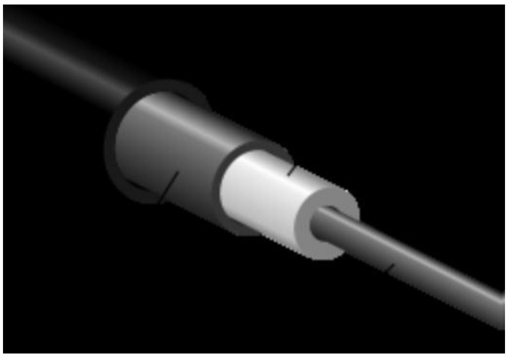
Transmission line: It is a device designed to guide the electrical energy from one point to another. It is used, for example, to transfer the RF energy from source to antenna. For efficient point-to-point transmission of power and information the source energy must be directed or guided. Transmission line that consists of two or more conductors may support transverse electromagnetic (TEM) waves, characterized by the lack of longitudinal field components. The TEM mode of guided waves is one in which **E** and **H** are perpendicular to each other and both are

Transverse to the direction of propagation along the guiding line. TEM waves have uniquely defined voltage, current, and characteristic impedance.

The three most common types of guiding structures that support TEM waves are:

1. Parallel-plate transmission line
2. Two-wire transmission line.
3. Coaxial transmission line.

Coaxial transmission line: This type of transmission line consists of an inner conductor and outer conductor separated by a dielectric medium. This structure has the important advantage of confining the electric and magnetic fields entirely within the dielectric region. No stray fields are usually generated inside a coaxial transmission line, and little external interference is coupled into the line.



In this experiment at the generator terminal we have AC voltage source, and transmission line is considered as lossless. Therefore the characteristic impedance becomes pure resistance (= √).

Since we know that the general solution for the transmission lines are:

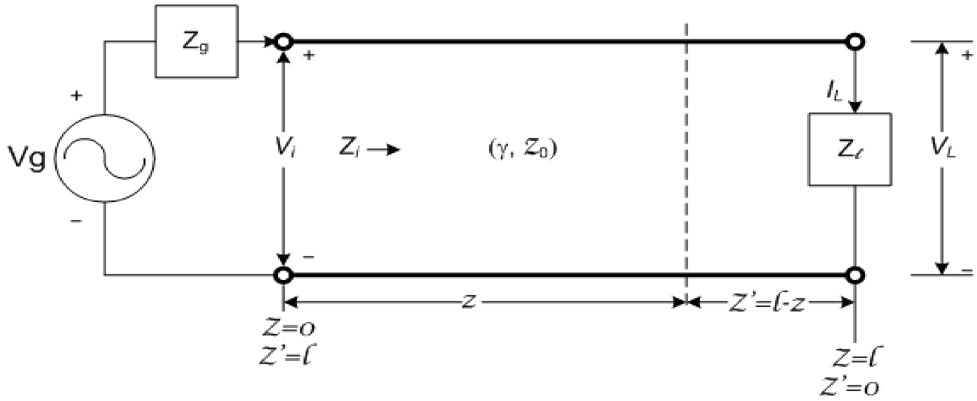
( ) (1)

( ) (2)

Where,

— — (3)

A transmission-line of finite length having characteristic impedance terminated in arbitrary load impedance as shown in the Fig. 2, the length of the line is *l*. A sinusoidal voltage with internal impedance is connected to the line at Z = 0.



The incident voltage travels down the line +z direction. When the finite transmission line is terminated with its own characteristic impedance (when a finite transmission line is matched), there is no reflected wave thus, we get 0 voltage reflection in the reflected voltage plot.

Standing wave ratio (SWR): Standing wave ratio (SWR) is defined as the ratio of the maximum to the minimum voltages along a finite, terminated transmission-line.

Lab VIEW Programming:

In the LabVIEW programming of the experiment incident voltage is plotted. Incident voltage wave is given as. As = , soon this incident voltage reaches at the load End, if the load is not matched to the characteristic impedance of the transmission-line, the voltage wave gets reflected. The reflected voltage wave is given by . Presence of Reflected wave leads to standing waves where the magnitude of the voltage on the line is not constant. In the third plot of vi standing wave has been plotted, the value of it can be seen in the column of output parameter at the front panel.

Procedure:

Please download the files shown on the left to perform the actual experiment. The exe file is the Lab VIEW file that will run on Lab VIEW Run time Engine

Step 1: Set the incident voltage ( ) in volts and frequency (*f*) of incident wave in GHz.
Step 2: Set the number of cycles, number of points in distance scale and location of point (in meter) at which voltage has to be measured w.r.t. time.
Step 3: Enter the values of properties of transmission-line i.e. length of transmission line (*l*) in meter, characteristic impedance of transmission line ( ) in Ohm and relative dielectric constant (epsilon) of transmission line.
Step 4: Enter the value of load resistance ( ) in Ohm.

Step 5: In the output you will see three plots first one showing the incident voltage travelling along transmission line, second plot shows the reflected voltage wave travelling along transmission line and the third plot shows the voltage standing wave along the transmission line.
Step 6: Run the VI to see the results. In case, you wish to see the result for different values then Click STOP and repeat steps 1 – 5 before running the program again.

Task:

1. By specifying source and load values and giving the properties of transmission line, observe the travelling wave, reflected voltage wave and standing wave ratio.
2. Observe the waves in case of matched and mismatched impedance.
3. Observe the waves for short circuited and open circuited transmission line by specifying –0‖ value to load reactance and for load resistance specify the value –0‖ for short circuited and –inf‖ for open circuited transmission line.

Summary: This experiment gives a vision to see the high frequency voltage wave travelling in the transmission-line. This experiment helps in building concept of waves travelling in transmission line, reflected waves from the load end and the standing wave generated in case of impedance mismatch.

Laboratory Experiment – 2

Aim of Experiment: Visit of substation and draw its lay out plan

Objective: To see firsthand apparatus that we will be studying in this course and learn about their role in operation and protection of power systems.

Laboratory Task: Visit a local substation.

Report:
Write a few sentences about each apparatus you saw, include its photograph if you were allowed to take it (of course with permission and always reference the source), and state its role, as you understand it at this stage in your study, in operation and protection of power systems. State the approximate physical size and the electric ratings in terms of voltage, current, power, kVA etc. These apparatus may include transmission line towers and their structure, transmission line conductors, their size and bundling, transformers, circuit breakers, surge arresters, relays, line traps for line-carrier communication, microwave towers, bus bars and their arrangement, substation grounding, battery backup as uninterruptible power supplies and so on.






Laboratory Experiment – 3

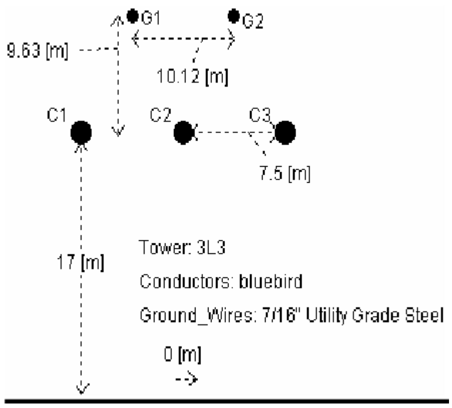
Aim of Experiment: Design of transmission line tower

Objectives: Obtaining the parameters of a 345 kV transmission line and modeling

Laboratory Tasks and Report:

Tasks

1. Consider a 345-kV transmission line consists of three-conductor-flat towers shown in Figure. This transmission system consists of a single-conductor per phase, which is a Bluebird ACSR conductor with a diameter of 1.762 inches. The *PSCAD/EMTDC* file for this 345-kV single-conductor line is **Line Parameters .psc** , which is located in this folder. Double click on it to open it and execute it to calculate line constants. Compare the results with those given in Example



A 345-kV, single-conductor per phase, transmission system

2. The *PSCAD/EMTDC* file for a 345-kV double-conductor line is **LineParameters_Bundled.psc**, which is located in this folder. Double click on it to open it and execute it to calculate line constants. Compare the results with those in Task 1.

3. A 200 km long 345-kV line has the parameters given in the Table below. Neglect the resistance. Measure the reactive power at both ends under the following two levels of loading if both ends are held at the voltages of 1 per unit: (a) 1.5 times *SIL*, and (b) 0.75 times *SIL*. The *PSCAD/EMTDC* file for modeling this transmission line is **Transmission Line. psc** , which is located in this folder. Double click on it to open it and execute it.

Table

Transmission Line Parameters with Bundled Conductors at 60 Hz

Nominal Voltage	*R*(Ω/ *km*)	ω*L*(Ω/ *km*)	ω*C*(⌠ ı/ *km*)	*Zc* (Ω)	*SIL*(*MW*)
345 kV	0.037	0.376	4.518	280 (use 288.48)	425 MW (use 412.16)

Help with Transmission Line Constants in PSCAD/EMTDC:

Task 1:
1) Take **T-Line** i.e. transmission line from toolbar.
2) Double click on T-Line, in the configuration parameters dialog select Termination style as Direct connection
3) Set other parameters as per requirement
4) Click on edit to edit tower and conductor data
5) Select and delete _frequency dependent model‘block. Right click on blank area and select Bergeron model
6) Again right click on blank area to select type of tower. There are 12 tower types to choose from
7) Double click on Tower structure to edit the data as below

Component	**Properties**
Line constants 3 conductor flat tower	**Tower Data:** Here you can edit Height of conductors, Horizontal Spacing between conductors etc. Also you can specify no. of ground wires and transposed lines or untransposed lines. **Conductor Data:** In this either you can select conductor from a library or can specify conductor radius and DC resistance. **Ground Wire Data:** As in conductor data you can specify ground wire data using library or inputting radius and resistance of ground wire. Also you can specify sag for ground wires, height of ground wires and spacing between ground wires. Conductor bundling X, Y data: If bundled conductors are used, then their X, Y positions can be specified here.

8) Right click on blank space and click on additional options. After pasting it, double click on additional options and change the output file display settings in the dialog box appropriately.
9) To solve the line constants, right click on blank space and select _solve constants‘.
10) Click on _output‘at the bottom to see the results.

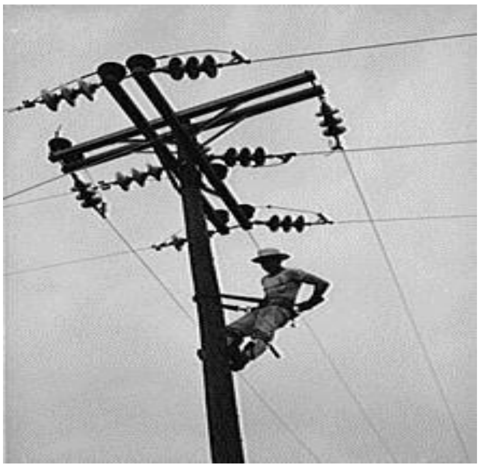
Laboratory Experiment – 4

Aim of Experiment: Survey of rural electrification and draw single line diagram.

Objectives: Obtaining the survey of Rural Electrification in INDIA

Report :

- **Rural electrification** is the process of bringing electrical power to (that is, electrifying) rural and remote areas. Electricity is used not only for lighting and household purposes, but it also allows for mechanization of many farming operations, such as threshing, milking, and hoisting grain for storage. In areas facing labor shortages, this allows for greater productivity at reduced cost. One famous program was the New Deal's Rural Electrification Administration in the INDIA, which pioneered many of the schemes still practiced in other countries.
- At least a billion people worldwide still lack household electric power - a population equal to that of the entire world in the early 19th century.
- As of the mid 2010s an estimated 200 to 300 million people in India (15 to 20 percent of the total population) lack electricity as well as seven out of eight rural Sub-Saharan Africans. Many more receive only intermittent and poor quality electric power. In 2012 Some 23% of people in East Java, Indonesia, a core region, also lack electricity, as surveyed in 2013.
- It is estimated that the absolute number of people without power was growing until the late 1980s when rural electrification programs, particularly in East Asia, outpaced the growth of human populations. Up from about 1.84 billion in 1970, approximately 2.01 billion (equal to the world population in 1927) people in developing countries still lacked household electric power in 1990 (the year the World Wide Web was invented) - about 38 percent of the world's population at that time, 51 percent of the population of so-called developing countries, and 67 percent of rural parts of the developing world.



A Rural Electrification Administrationlineman at work in INDIA in 1998

Social and economic benefits:

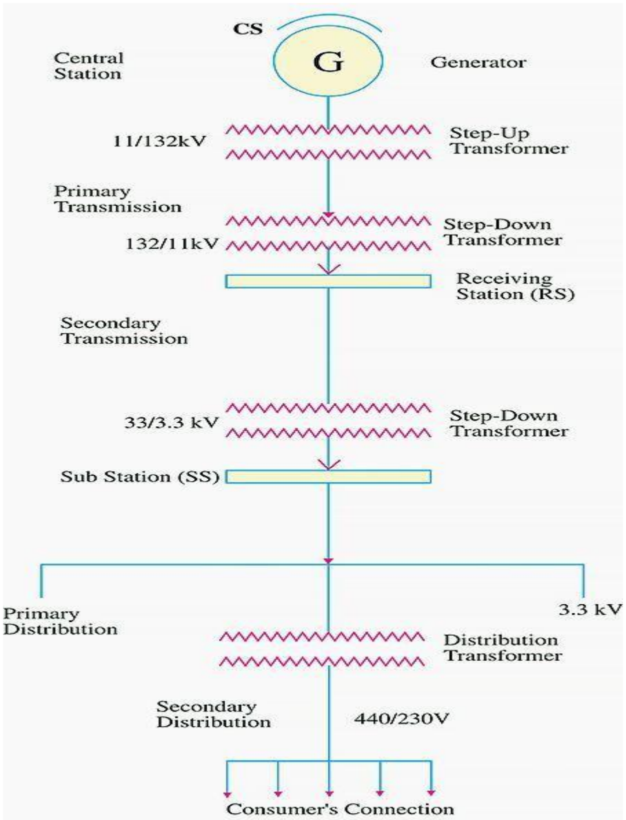
- Allow activities to occur after daylight hours, including education. In impoverished and undeveloped areas, small amounts of electricity can free large amounts of human time and labor. In the poorest areas, people carry water and fuel by hand, their food storage may be limited, and their activity is limited to daylight hours.
- Reduce isolation through telecoms
- Improve safety with the implementation of street lighting, lit road signs.
- Improve healthcare by electrifying remote rural clinics.
- Reduces the need for candles and kerosene lamps with their inherent fire safety risks and improves indoor air quality.
- Improve productivity, through the use of electricity for irrigation, crop processing, and other activities.

Continental and national initiatives of **India**

- 304 million Indians (24 percent of the population) are still without electricity. [17] India has 20% of the world's population but 40% of the world's population without electricity.[18]Rural areas in India are electrified non-uniformly, with richer states being able to provide a majority of the villages with power while poorer states still struggling to do so. The Rural Electrification Corporation Limited was formed to specifically address the issue of providing electricity in all the villages across the country. Poverty, lack of resources, lack of political will, poor planning, and electricity theft are some of the major causes which has left many villages in India without electricity, while urban areas have enjoyed growth in electricity consumption and capacity. The central government is increasingly trying to improve the dire conditions by investing heavily in bio-gas, solar as well as wind energy.Programs such as The JNN solar mission, Pradhan Mantri Gram Vidyut yojna to fasten the pace of electrification and diversify the procedure.The work is also on-going for reducing wastage, providing better equipments and improving the overall infrastructure for electrical transmissions in villages. Currently, more than 95% of villages in India have been electrified with a further goal of providing complete electrification by 2020. Northern and North-Eastern states in India are lagging behind the national average bringing the numbers down, primarily due to inefficient state governments and lack of economic resources; these states are currently the focus of many NGOs as well as state programs. It is estimated that 1-2 GW of solar power will be required for the 1 lakh un-electrified villages in the country, not to mention the solar power requirements of un-electrified households of electrified villages.[19] A breakdown is provided below on the number of states and UTs (Union Territories) that have been electrified :

Rural electrification rate	State/UT (Electrification rate, Unelectrified villages)
100%	20 states and 6 union territories
99.00-99.99%	Himachal Pradesh (99.81%, 34), Uttar Pradesh (99.77%, 224), Uttarakhand (99.52%, 76), Rajasthan (99.26%, 332), Madhya Pradesh (99.51%, 258), Karnataka (99.86%,39), West Bengal (99.96%, 14)
95.00-98.99%	Jammu & Kashmir (98.31%, 107), Tripura (98.03%, 17), Bihar (97.46%, 993), Chhattisgarh (96.55%, 675), Odisha (95.33%, 2210)
90.00-94.99%	Jharkhand (93.98%, 1775), Assam (92.31%, 1950), Manipur (91.55%, 201), Mizoram (94.03%, 42), Nagaland (94.14%, 82)
80.00-89.99%	Meghalaya (85.9%, 42), Andaman & Nicobar Islands (86.11%)
Below 80%	Arunachal Pradesh (73.3%, 1404)

- <u>**Single Line Diagram**</u>



Laboratory Experiment – 5

Aim of Experiment: Study pipe earthing and plate earthing

Objectives: to study the Pipe earthing and Plate earthing

Theory:

❖ **Introduction:**

- Earth behaves as an Electrical conductor but its characteristics is that its conductivity is variable and unpredictable. The resistance of an earth connection varies with earth's composition, chemical contents, moisture, temperature, season of the year, depth and diameter of rod and other reasons. The resistance offered to AC and DC also differs considerably. Theoretically, it is possible to calculate the resistance of any system of earthing electrodes. However as there are too many variables such as temperatures, season, moisture contents etc., it is usually measured in practice rather than calculated.

❖ **OBJECT OF EARTHING**

- The object of earthing system is to provide a surface under and around a station, which shall be at a uniform potential (nearly zero or absolute earth potential). This Earth surface should be as nearly as possible to the system. This is in order to ensure that, all parts of apparatus other than live parts and attending personnel shall be at earth potential at all times. Due to this there exists no potential difference, which could cause shock or injury to a person, when short circuit or any other type of abnormalities takes place

✓ Pipe Earthing

- Pipe earthing is the best form of earthing and is very cheap in cost. In this method of earthing, a galvanized and perforated pipe of approved length and diameter is placed up right in a permanently wet soil.

- The size of the pipe depends upon the current to be carried and the type of the soil. Usually the pipe used for this purpose is of diameter 38 mm and 2.5 meters in length for ordinary soil or of greater length in case of dry and rocky soil. The depth at which the pipe must be buried depends upon the moisture of the ground. The pipe is placed at a depth of 3.75 meters (minimum). The pipe is provided with a tapered casing at the lower end in order to facilitate the driving. The pipe at the bottom is surrounded by broken pieces of coke to increase the effective area of the earth and to the earth and to decrease the earth resistance respectively. Another pipe of 19 mm diameter and minimum length 1.25 meter is connected at the top to G I pipe through reducing socket.

- In our country in summer the moisture in the soil decrease which cause increase in earth resistance. So a cement concrete work, is done in order to keep the water arrangement accessible, and in summer to have an effective earth, 3 or 4 buckets of water are put through the funnel connected to 19 mm diameter pipe, which is further connected to G I pipe.

- The earth wire (either G I wire or G I Strip of sufficient cross section to carry faulty current safely) is carried in a G I pipe of diameter 13 mm at a depth of about 60 mm from the ground).

- Care should be taken that earth wire is well protected from mechanical injury, when it is carried over from one machine to another.

✓ Plate Earthing

- In plate earthing an earthing plate either of copper of dimensions 60 cm x 60 cm x 3 mm or of galvanized iron of dimensions 60 cm x 60 cm x 6 mm is buried into the ground with its face vertical at a depth of not less than 3 meters from ground level. The earth plate is embedded in alternate layers of coke and salt for a minimum thickness of 15 cm. The earth wire (G I wire for G I plate earthing and copper wire for copper plate earthing) is securely bolted to an earth plate with the help of a bolt, nut and washer made of material of that of earth plate (made of copper in case of copper plate earthing and of galvanized iron in case of G I plate earthing).

- A small masonry brick wall enclosure with a cast iron cover on top or an R C C pipe round the earth plate is provided to facilitate its identification and for carrying out periodical inspection and tests.

- For smaller installations G I pipe earthing is used and for larger stations and transmission lines, where the fault current, likely to be high, plate earthing is used.

Laboratory Experiment – 6

Aim of Experiment : Including an HVDC Transmission Line for Power Flow Calculations in PowerWorld and Modeling of Thyristor Converters in PSCAD/EMTDC

Objectives: 1. To include an HVDC transmission line and see its effect on power transfer on other transmission line.
2. To understand the operating principle of 12-pulse thyristor converters used in HVDC transmission systems.

Laboratory Tasks and Report:

1. The transmission line between buses 1 and 3 is an HVDC line, as described in the *PowerWorld* file **PowerFlow_HVDCline.pwb** (see video clip# 8), which is located in this Folder. Double click on this file or open it through *PowerWorld*. Look at various characteristics of this HVDC system by examining its parameters; see dialog boxes below. Compare this case with that in Example 5-4 for the various bus voltages and the power flow on various lines due to this HVDC line. Change the set point from 200 MW to 300 MW and then to 400 MW. Explaing what you see.

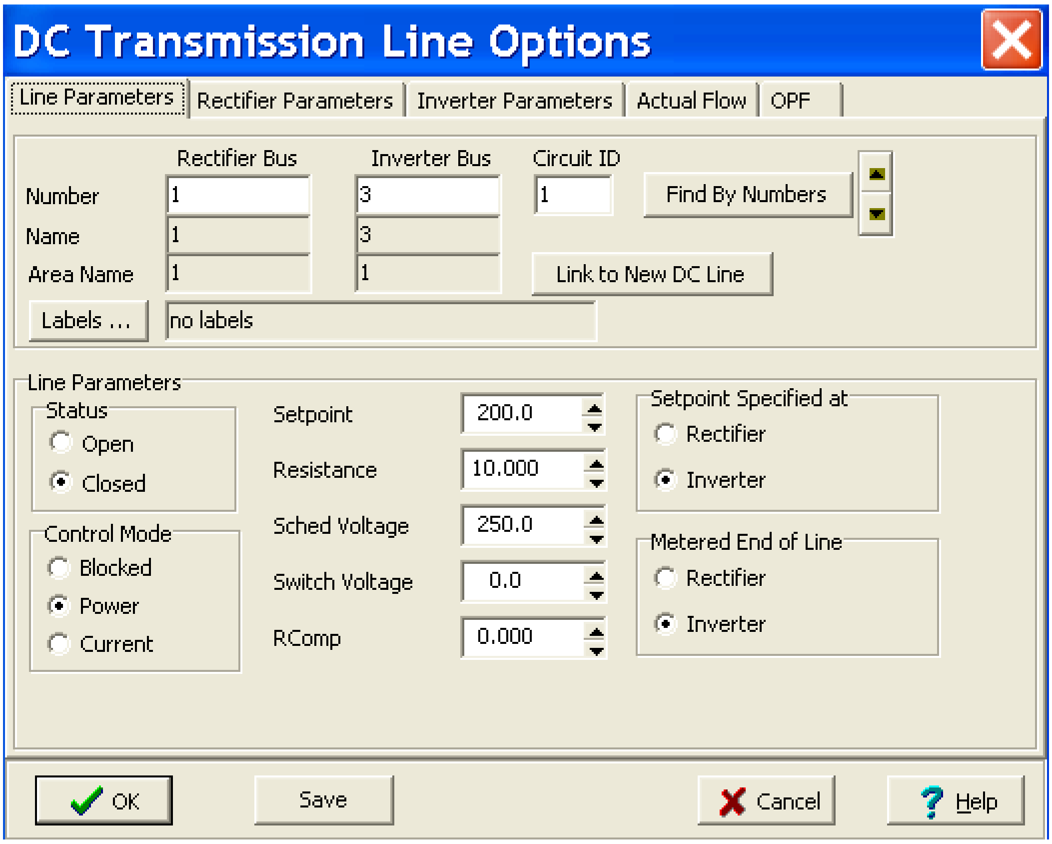
2. Obtain the waveforms of individual Rectifier DC voltage and combined 12-pulse DC voltage output , for different firing angles , in a 12-pulse thyristor converter operating in a rectifier-mode described by the PSCAD/EMTDC file in this folder called **HVDC_Rectifier.psc** (see video clip# 9). Source: Courtesy of Prof. Ani Golé of the University of Manitoba
.

3. Obtain the waveforms of individual inverter DC voltage and combined 12-pulse DC voltage input ,for different firing angles in a 12-pulse thyristor converter operating in the inverter-mode described by the PSCAD/EMTDC file in this folder called **HVDC_Inverter.psc** (see video clip# 9). Source: Courtesy of Prof. Ani Golé of the University of Manitoba.

4. By using the formula (7-12) and (7-13), for different firing angles, calculate the DC voltage and match with the value obtained from the waveform. For Rectifier: w*Ls = 13.6791 ohm, VLL=213 kV, Id= Obtain from simulation For Inverter: w*Ls=13.1843 ohm, VLL=207 kV, Id= Obtain from simulation.

5. Obtain the waveforms of the input and output currents for both the transformers in rectifier and inverter. Observe the phase shift between the primary and secondary of Wye-Delta transformer. Explain what you see.

6. Obtain harmonic components of secondary line current of Wye-Delta Transformer and harmonic components of the DC line voltage in the rectifier and inverter. What is the significance of the harmonics that appear?


DC Transmission Line Options
Line Parameters
Rectifier Parameters
Inverter Parameters
Actual Flow
OPF
Rectifier Bus
Inverter Bus
Circuit ID
Number
1
3
1
Find By Numbers
Name
1
3
Area Name
1
1
Link to New DC Line
Labels ...
no labels
Line Parameters
Status
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Closed
Setpoint
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Resistance
10.000
Sched Voltage
250.0
Switch Voltage
0.0
RComp
0.000
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Rectifier
Inverter
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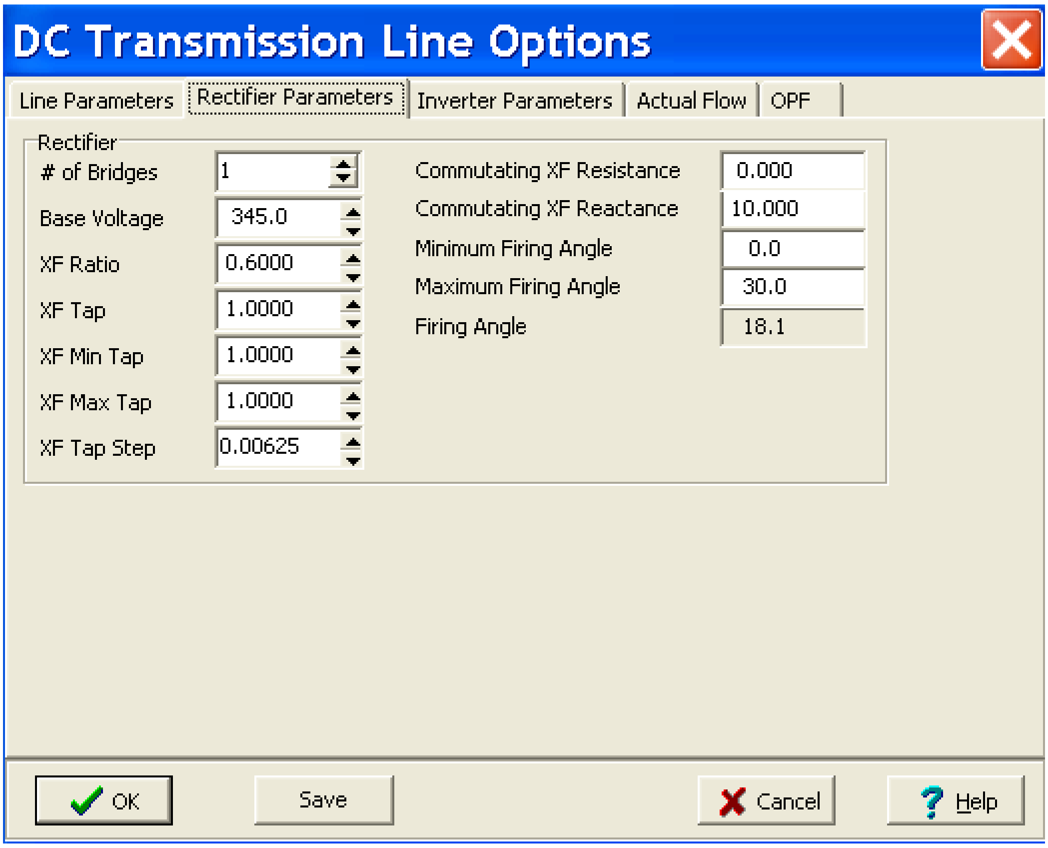
Blocked
Power
Current
Metered End of Line
Rectifier
Inverter
OK
Save
Cancel
Help


DC Transmission Line Options
Line Parameters
Rectifier Parameters
Inverter Parameters
Actual Flow
OPF
Rectifier
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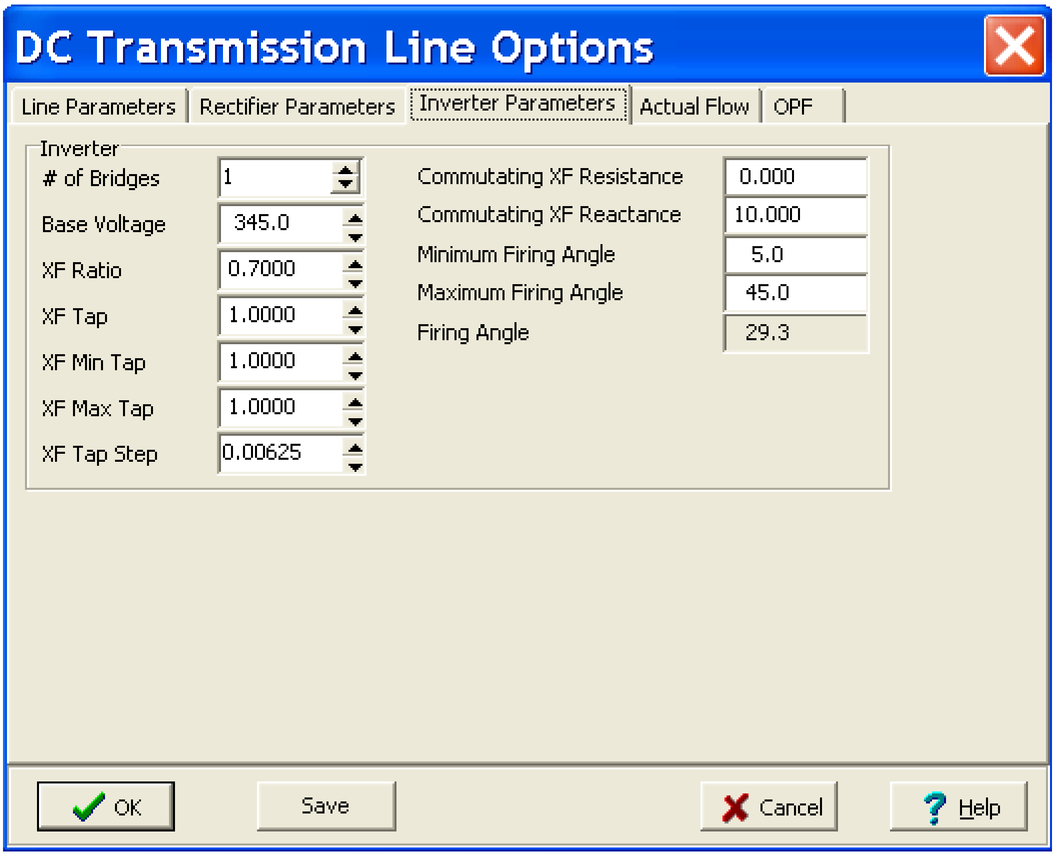
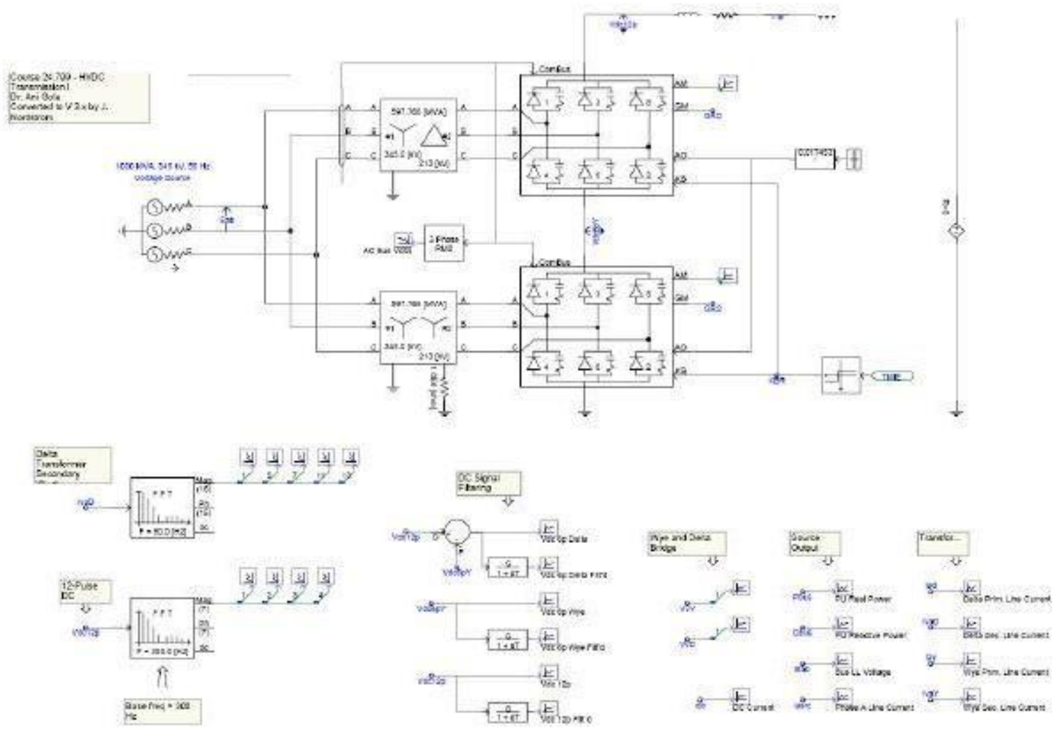
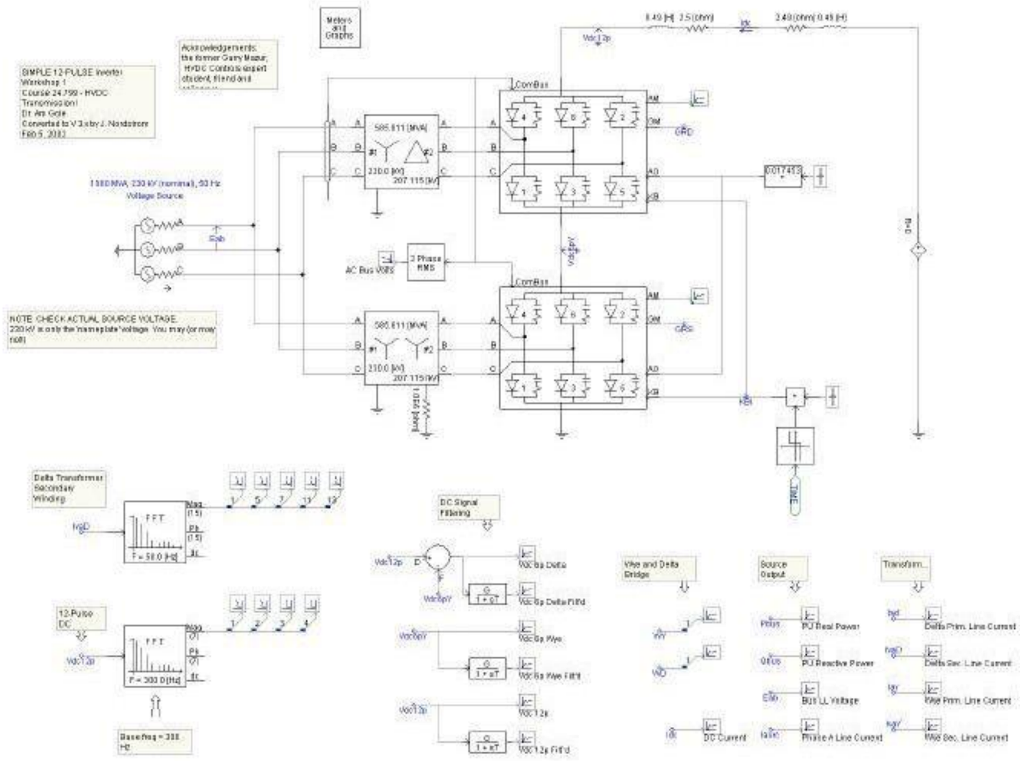
Base Voltage
345.0
XF Ratio
0.6000
XF Tap
1.0000
XF Min Tap
1.0000
XF Max Tap
1.0000
XF Tap Step
0.00625
Commutating XF Resistance
0.000
Commutating XF Reactance
10.000
Minimum Firing Angle
0.0
Maximum Firing Angle
30.0
Firing Angle
18.1
OK
Save
Cancel
Help



HVDC_Rectifier.psc



HVDC_Inverter.psc



Laboratory Experiment – 7

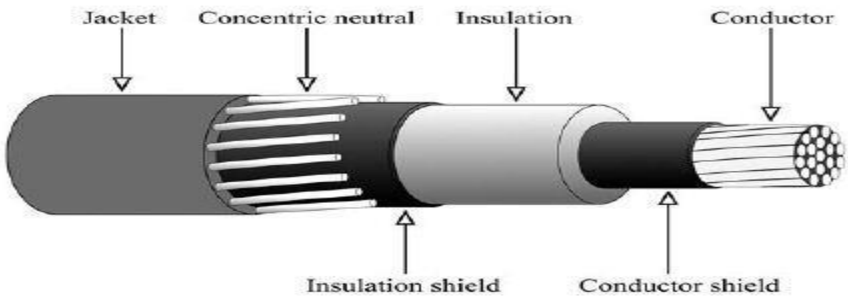
Aim of Experiment : Survey of cables/conductors used in transmission and distribution system

Objectives: to study the Cables / Conductor in Transmission and Distribution System

Theory :

❖ Cables

➢ At the center of a cable is the phase conductor, then comes a semiconducting conductor shield, the insulation, a semiconducting insulation shield, the neutral or shield, and finally a covering jacket. Most distribution cables are single conductor. Two main types of cable are available: concentric-neutral cable and power cable. Concentric-neutral cable normally has an aluminium conductor, an extruded insulation, and a concentric neutral (Figure shows a typical construction). A concentric neutral is made from several copper wires wound concentrically around the insulation; the concentric neutral is a true neutral, meaning it can carry return current on a grounded system. Underground residential distribution normally has concentric-neutral cables; concentric-neutral cables are also used for three-phase mainline applications and three-phase power delivery to commercial and industrial customers. Because of their widespread use in URD, concentric-neutral cables are often called URD cables. Power cable has a copper or aluminum phase conductor, an extruded insulation, and normally a thin copper tape shield. On utility distribution circuits, power cables are typically used for mainline feeder applications, network feeders, and other high current, three-phase applications. Many other types of medium-voltage cable are available. These are sometimes appropriate for distribution circuit application: three-conductor power cables, armored cables, aerial cables, fire-resistant cables, extra flexible cables, and submarine cables.



❖ Cable Insulation

➢ A cable‘s insulation holds back the electrons; the insulation allows cables with a small overall diameter to support a conductor at significant voltage. A 0.175-in. (4.5-mm) thick polymer cable is designed to support just over 8 kV continuously; that‘s an average stress of just under 50 kV per in. (20 kV/ cm). In addition to handling significant voltage stress, insulation must withstand high temperatures during heavy loading and during short circuits and must be flexible enough to work with. For much of the 20th century, paper insulation dominated underground application, particularly PILC cables. The last 30 years of the 20th century saw the rise of polymer-insulated cables, polyethylene-based insulations starting with high-molecular weight polyethylene (HMWPE), then cross-linked polyethylene (XLPE), then tree-retardant XLPE and also ethylene-propylene rubber (EPR) compounds.

➢ Some of the key properties of cable insulation are:

- *Dielectric constant* (e, also called permittivity) — This determines the cable‘s capacitance: the dielectric constant is the ratio of the capacitance with the insulation material to the capacitance of the same configuration in free space. Cables with higher capacitance draw more charging current.
- *Volume resistivity* — Current leakage through the insulation is a function of the insulation‘s dc resistivity. Resistivity decreases as temperature increases. Modern insulation has such high resistivity that very little resistive current passes from the conductor through the insulation.
- *Dielectric losses* — Like a capacitor, a cable has dielectric losses. These losses are due to dipole movements within the polymer or by the movement of charge carriers within the insulation. Dielectric losses contribute to a cable‘s resistive leakage current. Dielectric losses increase with frequency and temperature and with operating voltage.
- *Dissipation factor* (also referred to as the loss angle, loss tangent, tan d, and approximate power factor) -- The dissipation factor is the ratio of the resistive current drawn by the cable to the capacitive current drawn (*IR*/*IX*). Because the leakage

current is normally low, the dissipation factor is approximately the same as the power factor:

$$Pf = \text{—} \quad \frac{\quad}{\sqrt{\;}} \quad \text{—} = \textit{Dissipation Factor}$$

Paper-Insulated Lead-Covered (PILC) Cables. Paper-insulated cables have provided reliable underground power delivery for decades. Paper-insulated lead-sheathed cable has been the dominant cable configuration, used mainly in urban areas. PILC cables have kraft-paper tapes wound around the conductor that are dried and impregnated with insulating oil. A lead sheath is one of the best moisture blocks: it keeps the oil in and keeps water out. Paper cables are normally rated to 85_C with an emergency rating up to 105_C . PILC cables have held up astonishingly well; many 50-year-old cables are still in service with almost new insulation capability. While PILC has had very good reliability, some utilities are concerned about its present day failure, not because of bad design or application, but because the in-service stock is so old. Moisture ingress, loss of oil, and thermal stresses — these are the three main causes of PILC failure. Water decreases the dielectric strength (especially when the cable is hot) and increases the dielectric losses (further heating the cable). Heat degrades the insulating capability of the paper, and if oil is lost, the paper‘s insulating capability declines. PILC use has declined but still not disappeared. Some utilities continue to use it, especially to supply urban networks. Utilities use less PILC because of its high cost, work difficulties, and environmental concerns. Splicing also requires significant skill, and working with the lead sheath requires environmental and health precautions.

Polyethylene (PE). Most modern cables have polymer insulation extruded around the conductor — either polyethylene derivatives or ethylene-propylene properties. Polyethylene is a tough, inexpensive polymer with good electrical properties. Most distribution cables made since 1970 are based on some variation of polyethylene. Polyethylene is an ethylene polymer, a long string or chain of connected molecules. In polyethylene, some of the polymer chains align in crystalline regions, which give strength and moisture resistance to the material. Other regions have nonaligned polymer chains — these amorphous regions give the material flexibility but are permeable to gas and moisture and are where impurities locate. Polyethylene is a thermoplastic. When heated and softened, the polymer chains break apart (becoming completely amorphous); as it cools, the crystalline regions reform, and the material returns to its original state. Polyethylene naturally has high density and excellent electrical properties with a volume resistivity of greater than 1014 W-m and an impulse insulation strength of over 2700 V/mil.

Within each voltage rating, more than one insulation thickness is available. Standards specify three levels of cable insulation based on how the cables are applied. The main factor is grounding and ability to clear line-to-ground faults in order to limit the overvoltage on the unfaulted phases. The standard levels are *100 percent level* — Allowed where line-to-ground faults can be cleared quickly (at least within one minute); normally appropriate for grounded circuits *133 percent level* —Where line-to-ground faults can be cleared within one hour; normally can be used on ungrounded circuits

❖ Conductors

- For underground residential distribution (URD) applications, utilities normally use aluminum conductors; Boucher (1991) reported that 80% of utilities use aluminum (alloy 1350); the remainder, copper (annealed, soft). Copper is more prevalent in urban duct construction and in industrial applications. Copper has lower resistivity and higher ampacity for a given size; aluminum is less expensive and lighter. Cables are often stranded to increase their flexibility (solid conductor cables are available for less than 2/0). ASTM class B stranding is the standard stranding. Class C has more strands for applications requiring more flexibility. Each layer of strands is wound in an opposite direction.