Course Title: Power systems principles

Course Code: ELE 401

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Primary sources of energy

Various Sources of energy;

1. Water – Hydro plant
2. Coal - Steam power plant
3. Nuclear Material, e.g. Plutonium, uranium (Nuclear Power Plant)
4. Wind – Wind Power Plant
5. Gas – Gas turbine plant
6. Sunlight – Solar Power Plant
7. Oil – Oil fired power station etc.

Electricity Generations (Power Stations)

Power station is basically a gigantic energy conversion site or centre e.g. kainji jebba, shiroro, Afram, Eghin etc. Electrical energy is the final farm of conversion within power station.
Power contained in the (primary source) e.g. water, coal, nuclear etc. is converted into final form of electrical energy.
Power stations are classified under two main headings i.e.

(i) Thermal (steam) and
(ii) Hydro-power stations.

STEAM POWER STATIONS

Primary energy(source) → Heat energy → Mechanical energy → electrical energy

Fig 1: Sequence of energy conversion a thermal or (steam) power stations.

SUMMMARY OF STEAM (THERMAL) POWER STATION

In a thermal or steam power stations, the primary energy source may be either coal, oil natural gas a nuclear material such as uranium or plutonium teat energy is produced in a station by either a chemical reaction combustion of coal, oil (fossil fuel) or natural gas or by a nuclear

reaction involving fission uranium or plutonium material. The heat energy produced is used to boil water in oricle of tubing to generate steam under very high pressure. The heat energy contained in the steam is then converted into mechanical energy by using a turbine. As turbine shaft turns, the rotor of the generator also turns since it is coupled to the turbine shafts. The rotor of a generator is electro-magnetic and therefore as it turns its magnetic fields cut across the stationary conductors of the generator stator inducing e.m.f. in them. The induced e.m.f. is then stepped-up using a transformer to the required transmission voltage.
(Note: The voltage maintained there is line-to-line voltage)

The steam is produced in BOILER.

PRODUCTION OF STEAM

The heat energy released from the primary energy source is used to boil pure water contained in miles of tube, within the boiler to generate stream under high pressure. These tubes are usually suspended in the furnace. If the water is to receive maximum heat; Pure water is used to prevent corrosion, wear and blockage due to collection of organic materials (impurities).

THE TURBINE SYSTEM

The turbine is the main equipment involved in the conversion of heat energy (contained in the steam) into mechanical energy or work. This is the least efficient of all the stages involved in the product if electrical energy. The conversion of heat into work is done in a coaxial expansion chamber, made up of 3 parts i.e. the high pressure (HP), intermediate pressure (IP) and low pressure (LP) chambers.

The steam enters turbine through the H.P. chamber. It then piped back to be reheated out of turbine and since drying factor decrease on leaving H.P chamber, the steam has to be piped back to be reheated before it goes to the IP chamber. The re-heated steam is then fed into the IP chamber from where it goes straight to L.P. chamber from the Low Pressure L.P. chamber, the steam then condense and turns into liquid. The liquid then turns to water and returns to the boiler.

COOLING SYSTEM

The steam coming out of the LP chamber still contains a lot of heat energy. (More than half of heat energy for oil or coal and more that 2/3 for nuclear power stations) which must be disposed off.

The condenser is connected to the low pressures (L.P.) chamber and this contains tube filled with water thus allowing the steam to condense on the water filled tubes (condenser). The liquid water formed is the pumped back to the boiler to be heated. Also water coming out of the condenser tubes is at higher temperature than that going in and this heat is disposed off in several ways.

The waste heat energy from the L.P chamber of the turbine is disposed off in two ways: either by

(i) Direct cooling system
(ii) By the use of cooling towers.

1. In the direct cooling system, water is taken from large reservoir such as sea or Large River and pumped into the condenser. The water in the condenser tubes absorbs heat energy from the steam and the steam is then pumped back into the source at lower temperature.

Note: Direct cooling is used where there is large river or sea.

ADVANTAGE

(1) Cost of very low (water is free)

DISADVANTAGES

1. Salt and salt contents of the sea can cause corrosion of the pipes.
2. Tidal effect can aggravate fouling of the cold water intake due to weeds and other marine life.
3. The high temperature of the water in the outfall channel encourages the growth of algae which can produce blockage.

COOLING TOWER (Indirect Cooling System)

The water from the condenser is passed into the cooling tower before returning into the condenser in this method. Two type of tower, usually involved are;

(i) The dry cooling tower
(ii) The wet cooling tower.

DRY COOLING TOWER

In the dry cooling tower the water from the condenser flows downward through an array of pipes which are cooled by the outwards flow of air. In this type, the flow of air is generally fan-assisted. Dry tower operates with a close cycle water circulation system and their “make-up” requirement is for purging purpose.

Note: Cooling tower are used when supply of water is not plentitude (Both wet and dry)

WET TYPE COOLING TOWER

In this method of cooling method, water from the condenser is allowed to flow down the tower through a series of open lattices to collect in a pond at the base of the tower. The leeward drift of air through the tower base cools the falling water from the condenser. The top of the tower is usually characterized by the presence of water vapour due to the evaporation and drift losses.

Disadvantages

(1) Make up water is continuous due to evaporation and drift closes.
(2) Humidity increases in the areas of location of cooling however result always into rain falling (Humidity).

COAL FIRED POWER

This is one of the steam power plants. Primary source of energy is coal. Two type of boiler associated with it:

(i) chain grate stoker
(ii) Pulverizing mill boiler

In chaining grate striker coal is feed into the moving conveyor into the furnace. The main disadvantage here is that the amount of coal burnt depends on the speed of the conveyor.

In pulverizing mill boiler, coal is fed into pulverizing mill which crushed ground them into fine powder. This is mixed with preheated air and blown into the furnace to be burnt like a gas. Here, any type of coal may be used. Although, those with high sulphur contents must be avoided due to stringent environmental conditions.

The furnace of a coal powered station produces a large amount of ash, an oxide of Nitrogen Carbon, Sulphur, and water vapour. The combustion products are passed through an electrostatic precipitator, where the dust and ash are attracted by plates or electrodes as the products passes through the precipitator. The ash and dust can then be removed and sold off to be used in highway embarkment, building industry (cement factory), and land reclamation manure.

OIL FIRED POWER STATION

The primary source here is oil which is pumped from nearby oil refinery or deport through pipeline direct to the BOILER of the power station. The oil is passes through nozzles and comes out as a fine spray or droplets into the “boiler burner” or furnace. The waste products are similar to that of coal fired power station except that here, no ash or dust is produced. Also wastes due to sulphur are very low compared to that of coal fired power stations.

HYDRO POWER STATIONS

The primary energy source is water. The energy conversion sequence in Hydro power station is as follows:

Water power (KE) ⟶ **Mech. Power** ⟶ **Electrical energy**
(Primary energy source free) **Turbine system** **(generator system)**

NB: The primary energy source is water which is free in cost. Water from the reservoir is allowed to fall through a height (head) into the turbine blades. The kinetic energy associated with the falling water is impacted to the turbine bladdes making them turn. The turbine in turn drives the generator coupled with it to produce electricity.

Different turbines are used here, depending on the head of water above the turbine.

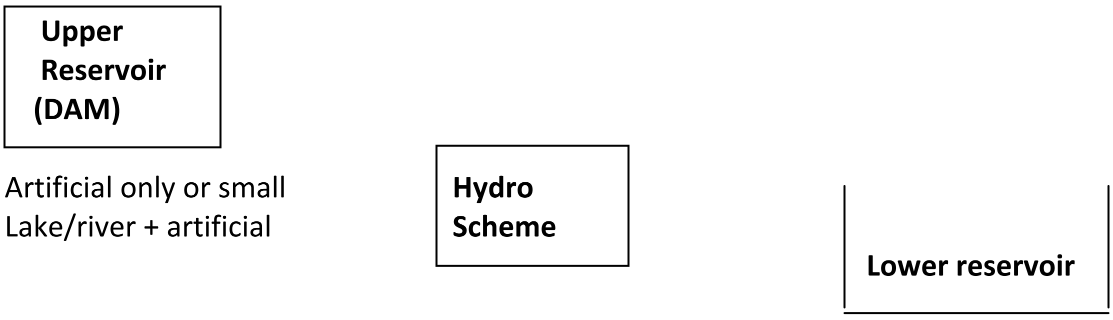
These are hydro-turbines examples;

(1) **Kaplan wheels**: For head up to 50m. It can be used for pumped storage schemes run off-the river with or without pondage.

(2) **Francis wheels Turbine**- For heads from 20m – 250m. Also good for pumped storage schemes.

(3) **Pelton wheel Turbines**: - For heads from 250m – 1800m. It is used for schemes with reservoir (dams) only.

PUMPED STORAGE SCHEMES



Artificial only or small
Lake/river + artificial

May be river or lake.

Pumped storage scheme is used basically during the peak demand period. The scheme is mainly a hydro power station with reservoir or dams. The lower reservoir may be a natural river or lake and upper reservoir may not have any source of natural water. This scheme is used only during period of peak system demand.

In the off-peak period the unit acts as the motor pumping water from lower reserviour into the upper reservoir.

The water in the upper reservoir is used for generating purpose in the usual way during the peak demand. If the unit (turbine-generator) performs both pumping and generation functions then, it refers to as reversible turbine schemes. In other cases separate units are used for pumping and generation respectively.

GAS TURBINE SETS

In the schemes, the primary energy source is oil or natural gas. The oil is mixed with compressed air and burnt in combustion chamber. The resultant hot gases are used to drive the gas turbine set which in turn drives the rotor of the generator.

Gas turbine sets are very fast in operation taken about a minute from stand still to achieve fall output. But they are less economical to run and they are in the main restriction for period of peak demand.

NUCLEAR-FIRED POWER STATION

In nuclear-fired power station the primary energy source is nuclear materials such as uranium and plutonium. These are made to undergo a process called nuclear fission to release a great amount of heat.

In nuclear-fired power station the primary energy source is the controlled fission of uranium or plutonium nucleic, a process that is capable of librating larger amount of heat energy than the purely chemical combustion of coal or oil. A nuclear reactor consists of the nuclear fuel surrounded by a moderator in which the heat is evolved. The moderator may be graphite, heavy water or ordinary water. There are also movable control rods in the moderator which absorbs neutrons and this exerts control over the fission process. Both fuel and moderator are enclosed in a steel pressure tight vessel surrounded by very thick reinforced concrete wall. Heat from the reactor is transferred by a coolant (carbon dioxide, water, liquid sodium) to the boiler which in turn supply steam to the turbo generator.

TYPES OF REACTORS

(i) **Magnox**

- Magnox alloy cans carry the uranium nuclei.
- Natural uranium rods are used as fuel.
- Coolant – CO_2
- Moderator – Graphite

(ii) **Advanced Gas-Cooled Reactor (AGR)**

- Stainless steel cans carry the nuclear fuel.
- Uranium Dioxide pellets are used as fuel.
- Coolant –CO_2
- Moderator – Graphite

(iii) **Pressurized Water Reactor (P.W.R)**

- Stainless steel tubes carry nuclear fuel.
- Uranium Dioxide pellets used as fuel
- Coolant –water (ordinary or light)
- Moderator –Heavy water of D_2O

(iv) **Fast Breeder Reactor (FBR)**

- Here, no attempt is made to control or slow down the neutrons and therefore the power per kg of fuel is higher.
- Plutonium fuel is used (in the form of pins)
- Highly toxic.
- Moderator –none (no control rods)
- Coolant – liquid sodium

N.B.:Here very small amount of material (plutonium) is neede

EXCITATION SYSTEM

These provide variable direct current to the field circuit of the power station generators. They are classified into two main groups
(i) d. c (ii) a.c

In the d.c. type, the exciter is a d.c generator with its field winding fed from the station battery.

In the a.c type, the exciter is subsidiary synchronous generator (different from main generator), whose a.c output is rectified and then fed to the main generator field circuit.

The brushless type of exciter is preferred these days owning to the elimination of slip rings and the reduced maintenance cost. Here, the field winding of the exciter is put on the stator while the armature winding is found on the rotor. The armature output is fed into a rectifier system (also shaft mounted) which in turn supplies the field circuit of the main generator.
Factors to be taken into consideration before choose a site for hydro power stations are;

(1) Transportation in a degruate form
(2) Availability of Hydro
(3) Objection of people in the area.
(4) Cost of whole project.

SITING OF POWER STATIONS

(A) **Hydro Power Station:-**

(i) Here, the choice of site is restricted to the vicinity of the rive/lake.
(ii) Adequate load network must be near to facilitate transportation of parts and supplies
(iii) Environmental impact and objections of people must be taken into account.

(B) **Nuclear Power Station:-**

(i) It must be sited away from population centres.
(ii) Subject to (i) it must be close enough to the area it is intended to supply to minimize the transmission cost.
(iii) It must be near a source of water for cooling purposes.
(iv) Because of heavy machinery involves the land (soil) must be able to support the heavy machinery and equipment involved.
(v) The land must be big enough for present and future need i.e. availability of enough land.
(vi) Proximity of adequate transportation facilities for fuel elements (both in and out (used one)).
(vii) Environment impact and objection of people must be considered.
(viii) Means of quick evaluation of people around the site in case of accident must be provided.

(C) **Coal Power Station:-**

(i) Sited away from population centres.
(ii) There must be adequate supply of cooling water.
(iii) It is sited either at the coal mining centre (to minimize transportation costs) or at the load centre. If sited away from area, transportation (rail preferable) facilities must be provided.
(iv) Environmental impact and objections of people must be taken into consideration.

(D) **Oil Power Station:-**

(i) It must be sited close to an oil refinery or oil depot to minimize pumping cost.

(ii) It must be near an adequate source of water for cooling purpose.
(iii) Environmental impact and objectivities of people must be taken into consideration.
(iv) There must be adequate available transportation facilities.

N.B.: Nuclear and Hydro power station are usually sited away from load centres.

Magneto Hydrodynamic (MHD) generation

Attempts have been made to generate electricity without prime moves or rotating generator. In this method, called magneto hydrodynamics, gases at 2500oc are passed through a chamber in which a strong magnetic field has been created as shown in fig 1.8 below. If the gas is hot enough, it is electrically slightly conducting (it is seeded with potassium to improve the conductivity) and constitutes a conductor moving in the magnetic field. An emf is thus induced which can be collected at suitable electrode to make it more practicable, it is usually used in conjunction with traditional power plant

UNCONVENTIONAL ENERGY SOURCES

1. Solar energy to generate electricity

Due to load demand fluctuation, these are needed to provide a sufficient back-up supply to customers through solar. Here, solar energy panel water heater is built to provide the steam needed for steam turbine. The main component is the ray collector.

The energy received by the collector per square meter (Net) = q

$$\mathbf{q = I\,\alpha\tau - (\varepsilon_F + \varepsilon_B)\,\sigma(T^4 - T^4_o)}$$

Where ;

ε_F and ε_B = front and back emissivities of panel
σ = Stefan – Boltzmann cash = 5.67 x 10^{-8}/K^4-m2
τ = Transmittance of cover plate (e.g 0.93)
T_o = Temperature of cover plate (K)
I = Incident radiation normal to surface
T(K) and α = Temperature and absorptive of absorbing panel.

In a direct conversion to electricity approach, photovoltaic conversion occurs in a thin layer of suitable material, e.g. silicon when have election pairs are created by incident solar photons and the separation of this holes and electrons at a discontinuity in electrochemical potential created a potential difference.

2. Wind energy for generating electricity

The wind mills are age-old. For electric generation purposes there are three scales of operation;

(a) Small, 0.5-10KW for isolated single premises
(b) Medium, 10-100KW for communities
(c) Large say 1.5 MW for connection to power supply systems.

The types of rotor used are the two-or three-bladed propeller with horizontal axes. Energy output can be increased by a larger rotor and hence larger tower that can with stand wind speeds up to 180km/hr. The theoretical power in a wind stream is given by

$$P = \tfrac{1}{2} \rho A V^3 \text{ (watts)}$$

Where **ρ** = density of air (120 gm/m^3 at N.T.P.)
V = mean air velocity (m/s)
A = Swept area (m^2)

For example, for a rotor of 17m diameter and a velocity of 48km/hr, the theoretical power

$$P = \tfrac{1}{2} \rho A V^3 = 265\text{KW}$$

NB: The practical values obtainable are usually above half the theoretical value.

LOAD CURVES

A load curve is pictorial representation showing the relationship between system demand and time. This is usually done for daily cycle.

A load curve is composed of a base load (made of industrial/commercial/transportation loads) and a weather sensitive component (consisting of lighting, heating and ventilation)

A load curve is always affected by some factors:
(i) Time of the day
(ii) Time of the weak and
(iii) Time of the year
(iv) Routine mates in some factories.
(v) Special events-like weakened parties, programs on T.V etc.

(vi) Promotional activities-giving tariff discount to people to encourage them using power always for proper smoothing of the load curve.

NB: The shape of a load curve may be affected by the following factors.
Time of the day, time of the week, time of the year, the weather, special event (especially on T.V). promotional activities by utilities (example, Night storage heater) can also affect the shape of load curve.

Load curve varies from day-day, week-week and weekday to weekend.

LOAD FORECASTING

Post load curves are primarily used in forecasting what the demand must be in the future. Since the act of load forecasting is not exact, the spinning reserve (synchronize generator ready to take up the inaccuracies in forecast demand of the load) is usually added to take account of the inaccuracies in forecast demand.

The demand x say is made up of the following;

$$\mathbf{X = a + d + G}$$

X = demand
a = base load
d = day of the week correction
g = weather dependent load.

Three (3) main methods are involved in Forecasting these are:

(i) WEATHER WEIGHTING TECHNIQUE

The weather weighting method assign each item of the weather such as temperature, cloud cover, wind velocity, rain etc. a weighting factor. Weighting factors are deduced from previous load and weather data. The factors are applied as a percentage of the forecast base load as (w factor = 2% of base load).

(ii) Regression Analysis

This technique involves the use of regression analysis to predict the demand linear regression assumes that the load is linearly dependent on each of the weather factor such that

$$\mathbf{X = a + d + b_1 T + b_2 W + b_3 L + b_4 P + f (t)}$$

T = temperature
W = wind
L = Lighting
P = precipitation
f (t) = accounts for the variation in the base load for the time of the year.
Constant b_1-b_4 is found by fitting previous data of this equation.
This method is similar to that in (i) and both are accurate only for the weather forecast and must be outdated progressively.

(iii) **Pattern Recognition**:

This method utilizes past load data only for example if several years data are available, with a repeated pattern every day, it is possible to consider the time series for each day as being ensemble of time series. Excessive data storage is required to classify all sample point. It has very limited use for normal load prediction.

POLYPHASE SYSTEMS

Polyphase system being proposed for future transmission purposes are 6 and 12 phase systems.

Their advantages over existing 3 phase system are;
(a) Increase the thermal loading capacity of lines.
(b) Reduces corona effect due to less conductor surface stress.
(c) Higher transmission efficiency: for example an existing double circuit 3-phase line on each tower can easily be converted to a single let of 6-phase lines.
(d) The line-line voltage relative to the line to neutral voltage becomes smaller at the higher number of the phases. Hence less phase-phase insulation is required. Result to an increased utilization .

Since balanced system is assume then:
$V_{ab} = V_{am} + V_{nb}$
$= V_{an} - V_{bn}$

Using cosine rule
$Vac^2 = Van^2 + Vcn^2 - 2\ Van\ Vcn \cos 60^o$
$= 2\ Van^2 - 2\ Van^2 x\ ½$
$= Van^2$
$Vac^2 = Van^2$

Or $V_{\text{line-to-line}} = V_{\text{line-to neutral}}$ for a 6-phase system.

12-phases

$V_{ab} = V_{am} + V_{nb} = V_{am} - V_{bn}$
$V_{ab2} = V_{an2} + V_{bn2} - 2 V_{an} V_{bn} \cos 30^{o}$
$= 2 V_{an2} - 2 V_{an2} \times 0.866$
$= Van^{2} - 2Van2 \times 0.866$
$= Van^{2} (21 - 72)$
$= 0.268 Van^{\underline{2}}$
$Vab = 0.52V_{an}$

Or for a 12-phase system the $V_{\text{line-to-line}} = 52\%$ of $V_{\text{line-to-line}}$
$V_{LL} < V_{LN}$

Polyphase systems are usually described in terms of the phase voltage (L-N) rather than line-line at the case for 3 –ϕ system.

Example: Consider a 12-phase 300kv transmission system. Find V_{L-L} and V_{L-N} Solution

Here = $V_{LN} = 300kV$
$V_{LL} = 0.52V_{L-N}$
$= 0.52 \times 300kV$
$= 156kV$

(b) Consider a 3-phae 300kv transmission system find V_{LL} and V_{LN}

Solution
Here = $V_{L-L} = 300k\ V = 3 \surd V_{L-N}$

$$V_{L-N} = \frac{300kv}{\sqrt{3}} = 173kV$$

Power supply systems

In determining the design and construction of transmission and distribution systems, three broad classification of choices need to be considered:

The type of electric systems
a.c d.c and if a.c, single phase or poly-phase
The type of delivery system; radial,loop, or network.
The type of constructed: overhead or underground.

FACTORS TO BE TAKEN INTO CONSIDERATION IN ENERGY (POWER) DISTRIBUTION AND TRANSMISSION

As said above, electrical energy may be distributed over two or more wires. The principal factors desired are:

I. Safety
II. Smooth and even flow of power,
III. Economy and types of loads to be supplied.

D.C. supply system is obtained form a D.C. generators and rrectifiers. D.C. supply systems is usually at a fixed (or constant) voltage
AC supply is to obtained generally from synchronous generators at fixed frequency.

TYPES OF DC SUPPLY SYSTEMS

Direct current systems usually consist of two or three wires

a) 2-wire with 1- wire eartheed

b) 2-wire , with midpoint earthed

c) 3- wire system

This type is used for distribution purposes. There are choices of two voltages V/2 and V. Here, more power can be handled compared to a 2-wire system for distribution.

Exercise 1

A four-wire distributor, 400m long is fed at one end at 240V. at the points 250m and 400m from the feeding end there are loads 200A and 160A respectively. Calculate the cross-sectional area of each core in order that the voltage at 160 A.A load may be 96% of that at the feeding point. Also , determine the cost of energy loss in the distribution over a period of 6 hours if the above load were maintained constant during that time. Assume the resistivity of the conductor at working temperature to be 0.02μΩm, and the cost of electrical energy to be 0.5 kobo per KWhr

Sollution

I. Let R' be the Ω/m of the conductor.

Total voltage drop along the conductor = 240 – (0.96 x 240) = 9.6 V

$9.6 = 2\ I_{AB}\, R' \times AB\ x + 2 I_{BC} R' x\ BC$

$= 2R' \left[(200+160)\ A \times 250 + 160 \times 150\right]$

$$R' = \frac{9.6}{228 \times 10^3}\ \Omega/m$$

But $R' = \frac{\rho l}{A}$

And $\frac{R}{A} = R' = \frac{\rho}{L}$

$$A = \frac{\rho}{R'} = \frac{0.02 \times 10^{-6}\Omega m}{9.6\Omega/m}$$

$=475mm^2$

II. Total Energy Cost = I^2Rt

$$= \frac{9.6}{228 \times 10^3}\left(2 \times 360^2 \times 250 + 2x\ 160^2 \times 150\right) \times 6$$

Total Energy Lost = 18.31 KWh

Cost of energy loss $= \frac{0.5k \times 18.31}{KWhr}$ KWhr

= 9.16 Kobo

AC SUPPLY SYSTEM

1 phase 2 – wire with one wire Earthened

1 ϕ 3 wire system

NB: Basically it is used for distribution of power. The power is distributed at two voltage levels V/2 and V. Common in the U.S. for distribution of power to domestic premises

3-ϕ, 3 wire System

Used for transmission and subtransmission purposes. Also can be found in distribution to large loads (e.g. 11KV, 33KV distribution)

Assignment
State 3 reasons for using the three – phase 4 - wire system inpreference to a single phase for the distribution purposes. Also, explain the significance for using the 5-wire when street lighting is desired.

3- ϕ, 4 wire

Used mainly for distribution purposes in domestic, commercial/ industrial premises. Can handle small as well as large loads due to existence of the two voltage levels(i.e. line- line and line – to phase)

3-ϕ, 5 wire

This is used for power distribution for domestic premises and street lighting purposes. The 5th wire is taken from the any of the three phases at the sub-stationor generating station. This is to ensure security of the supply to the street lamps at all lines and also to ensure separate metering for the street lightings

DISTRIBUTION NETWORK

The delivery of electric energy from the generating plant to the consumer may consist of several more or less distinct parts that are nevertheless somewhat interrelated. The part considered "distribution, i.e. from the bulk supply substation to the meter at the consumer's premises, can be conveniently divided into two subdivisions."

(i) Primary distribution which carries the load at higher than utilization voltages from the substation (or other source) to the point where the voltage is stepped down to the value at which the energy is utilized by the consumer.
(ii) Secondary distribution which includes that part of the system operating at utilization voltages, up to the meter at the consumers premises.

PRIMARY DISTRIBUTION FEEDERS DESIGN

Primary distribution feeders are usually
(i) Radial lines or

(ii) loop/ring system.

In distribution feeders design, first of all load survey must be carried out to establish the magnitude of the load to be serving. Once this is done, a decision must be made as to what type of feeders system to be used i.e. radial line or loop system. The choice made is based upon the type and characteristics of the load to be serving and also the cost.

(i) **RADIAL SYSTEM DESIGN**

The radial type system is the simplest and the most commonly used. It consist of separate feeders or circuits radiating out of the substation or source, each feeder usually serving a given area.

Design procedures

Assumption

(i) The same conductor everywhere
(ii) The same voltage level at all points
(iii) Let Z = 0.05 + j0.5 Ohms/km of conductor

Question: Determine the voltage of distribution, voltage drops and losses in feeder.

Procedure

(i) Choose a voltage level e.g. II KV for instance
(ii) Assume no losses within the system; determine the voltage drops at all load points.
(iii) If voltage drop at load pt is greater than or equal to 10-12% of the nominal voltage level choosen (in this case 10-12% off IIkV) then, choose the next higher voltage level e.g. 33kV etc.
(iv) If (iii) is true go to step (2) to (iii) until otherwise.If (222) is not true, i.e. volt drop all within 10-12% go to (v)
(v) Calculate power losses and determine actual voltage drops

How, for this exercise, Let us choose IIKV for the feeders.

Volt drop, $\Delta V = \frac{(P.R + Q.X)}{V} L$ **volts**

Where **P** = active power (KW) in the line
Q = Reactive Power (KVAR) in the line

R + JX = impedance /KW of the line (S^2/km)
L = Length of the line in km
V = Line-to-line voltage (kV)

Now, voltage drop per unit (p.u.)

$$= \frac{\text{volt drop}}{\text{Nominal voltage}}$$

Voltage drop p.u, $\Delta V = \frac{(P.R + Q.X)\, L}{V^2}$ **p.u.**

Step 1:
Assume IIKV distribution voltage along all feeders.

Step 2:
Assume P.F, 0.8 lagging

$$P = S \cos \Theta, \qquad Q = S \sin \Theta$$
$$P = 15 \times 0.8, \qquad Q = 15 \times 0.6$$

S_{Bc} = 15MVA

$$\Delta V_{Bc} = \frac{15(0.8 \times 0.05 + 0.6 \times 0.5)12}{II^2}$$

S_{AR} = (10 + 15) MVA = 25MVA

$$\Delta V_{AB} = \frac{25\ (0.8 \text{ X } 0.05 + 0.6 \text{ X } 0.5)15}{II^2} \text{ p.u}$$

= 1.05p.u.or 5% rise

S_{OA} = (3 + 10 + 15) MVA = 28MVA

$$\Delta V_{OA} = \frac{28\ (0.8 \text{ X } 0.05 + 0.6 \text{ X } 0.5)10}{II^2} \text{ p.u.}$$

= 0.79 or 79%

Step 3

Let $\Delta V_{max} = 12\%$

$\Delta V_{BC} > \Delta V_{max}$

$$\Delta V_{OA} > \Delta V_{Max}$$

So we choose the next higher voltage is 33KV. Then calculate volt drops assuming no losses in the system.

$$\Delta V_{BC} = \frac{15\,(0.8 \times 0.05 + 0.6 \times 0.05)12}{33^2} = 0.056 \text{ pu}$$

$$= 5.6\% \text{ drop}$$

$$\Delta V_{AB} = \frac{25\,(0.8 \text{ X } 0.05 + 0.6 \text{ X } 0.05)15}{33^2}$$

$$= 0.116\text{pu}$$

$$= 11.6\%$$

$$\Delta V_{OA} = \frac{28\,(0.8 \times 0.05 + 0.6 \times 0.5)10}{33^2} = \frac{0.79}{9}$$

$$= 0.088\text{pu}$$

$$= 8.8\%$$

Hence, $\Delta V_{BC,}$ $\Delta V_{AB,}$ $\Delta V_{OA,}$ $<$ $\Delta V_{Max,}$ **(12%)**

Therefore the 33kv distribution voltage acceptable for the feeders.

Step 4

Calculate losses within the system

Power Loss $\Delta S = |I|^2|Z| \times L$ **MVA**

While $\Delta P = |I|^2R,$ $Q = |I|^2X$

But $|I| = \frac{|3|}{|V|}$

$$\Delta S = \left(\frac{|S|}{|V|}\right)^2 |Z| \times L \quad \text{MVA}$$

Assume Transforms losses to be 1% of normal rating

$\Delta S_T = 1\%$

NODE C

$$\Delta S_{TC} = 0.01\,(15MVA) = 0.15MVA$$

$$\Delta S_C = 0.15 + 15 = 15.15MVA$$

$$\Delta S_{BC} = \left(\frac{|S_C|}{|V|}\right)^2 X\ |Z|\ X\ L$$

$|Z| = (0.052 + 0.5)^{1/2} = 0.502$

$$\Delta S_{BC} = \left(\frac{15.15}{33}\right)^2 x\ 0.502\ x\ 12$$

$$= 1.27MVA$$

To compensate for losses, S_{BC} should be

$S_{BC} = 15 + 0.15 + 1.27 = 16.42MVA$

NODE: B

ΔS_{TR} (transformer loss at point B) = 0.01 x 10MVA = 0.1MVA

$S_B = 16.42 + 0.1 + 10 = 26.52\ MVA$

$$S_{AN} = \left(\frac{26.52}{33}\right)^2 x\ 0.502\ x\ 15$$

$$= 4.68MVA$$

$S_{AB} = S_B + S_{AB} = 26.52 + 4.86 = 31.38MVA$

NODE A:

$\Delta S_{TA} = 0.01\ x\ 3MVA = 0.03MVA$

$S_A = 6.03 + 3 + 31.38 = 34.41MVA$

$$\Delta S_{OA} = \left(\frac{34.41}{33}\right)^2 x\ 0.502\ x\ 10 = 5.46MVA$$

S_O = capacity of source or indeed

$S_{OA} = S_O = 5.46 + 34.41 = 39.87$ MVA

Now that we know the power flow loses everywhere along the line, we use these flows to calculate the true voltage drops at each node.

$$\Delta V_{OA} = S_{OA}\,\frac{(R\ \text{Cos}\ Q + X\ \text{Sin}\ Q)}{V^2}\,L_{OA}$$

$$= 39.87\,\frac{(0.05 \times 0.8 + 0.05\ \text{x}0.6)}{33^2} \times 10$$

=0.124 p.u. or 12.4% of 33KV

$$= \Delta V_{OA} = \left(\frac{124}{100}\right)^2 \text{x } 33\ \text{KV} \quad = 4\text{KV}$$

4KV drop

O ———————————— A

$$\Delta\ V_{AB} = \frac{31.38}{35^2}\,(0.05 \times 0.08 + 0.5 \times 0.6) \times 15\ \text{p.u}$$

= 0.146 p.u or 14.6% of 33KV

= 4.83KV

Volt drop = 4.83KV

O ———————————————— O

$$\Delta\ V_{BC} = S_{BC}\,\frac{(0.8 \times 0.05 + 0.06 \times 0.5)}{33^2} \times 12$$

$$= 16.\ 42\,\frac{(0.8 \times 0.05 + 0.06 \times 0.5)}{33^2} \times 12 \quad \text{p.u}$$

= 0.062 p.u or 2.03KV drop

Exercise:

It is proposed to supply electric power to the 5 major load points within the union campus – using a ring Network as shown below, show your design proposal including choice of distribution voltage and power losses determination. Use initial distribution voltage of IIKV

Choose:

Z = (0.1 + J0.4) Ω/km

PF = 0.8 lagging

S_T = 1% of rated capacity or transformer

Solution: To solve the problem, split-point where effect of $S_A' + S_B' = 0$

STEP 1: Break loop at in feed point.

Find S_A', S_B' (break at injection point)

To find S_A', Take moment about B′

$$S_A' = \sum_i \frac{S_i\ L_{Bi}}{L_{A'B'}} = \frac{S_1LB_1 + S_2LB_2 + \ldots + S_5LB_5}{L_{A'B'}}$$

$$= \frac{(3 \times 10) + (10 \times 10.5) + (1 \times 13.5) + (7.5 \times 20) + (5 \times 23)}{27}$$

$$S_A' = 15.315 \text{ MVA}$$

Also take moment About A′ to find S_B'

$$S_B' = \sum_i \frac{S_iL_{Ai}}{L_{A'B'}} = \frac{S_1LA_1 + S_2LA_2 + \ldots + S_5LA_5}{L_{A'B'}}$$

$$S_B' = \frac{(3 \times 17) + (10 \times 16.5) + (1 \times 13.5) + (7.5 \times 7) + (5 \times 4)}{27}$$

$$S_O = S_A' + S_B' = 26.50 \text{ MVA}$$

Step 2

Find the split point i.e. where the power from both ends meets. This is done by assuming zero losses in the system.

From this diagram as indicated above the two load arrows meet at node 2 which is summed up to **1.815 + 8.185 MVA**

Node 2 is our "Split point" so we can effect two radial lines as follows

Step 3:
Analyze each radial line as done previously.

N.B.: it is usual to allow a loop circuit to operate with a uniform voltage.

Assume no losses

Use **IIKV** for preliminary calculations.

$$\Delta V_{A'5} = \frac{15.315(0.8 \times 0.1 + 0.6 \times 0.4)}{11^2} \times 4 \text{ p.u.} = 0.16$$

Since **$\Delta V_{A'5}$ > 0.12 or 12%**, we therefore go to next high voltage is **33KV**.
Check if **33KV** will be O.K

$$\Delta V_{A'5} = \frac{15.315(0.8 \times 0.1 + 0.6 \times 0.4)}{33^2} \times 4 \text{ p.u} = 0.018 \text{ p.u} = 1.8\%$$

$$\Delta V_{A'5} = \frac{8.185(0.8 \times 0.1 + 0.6 \times 0.4)}{33^2} \times 4 \text{ p.u} = 0.0012 \text{ p.u} = 0.12\%$$

Here all **Δ** V'S are less than 12%. Hence, the 33KV is acceptable as distribution voltage.

Step (iv): Calculate the losses and Power flow

Step (v): Using information from (iv) calculate actual volts drops.

SUBSTATIONS

It is a layout if power supply circuits for bulk transmission of power or distribution of power. The choice of layout is based on the following considerations;

(a) Character or nature of the load (1MV, 8MV, or 8MV load, steel works, hospitals, etc.)
(b) Necessary for maintaining continuity of service.
(c) Flexibility in operation. Must provide proper facilities for equipment incorporation,

Substations may be for outer transmission, sub-transmission or distribution purposes.

The distribution is based on the level of primary voltage.

(i) Unit Scheme

Unit = Source + Breaker + Line

In unit scheme, substation interruptions to consumers are relatively unimportant for example distribution of power to houses or homes.

Below is another type of unit scheme:
This type of Unit scheme incorporate flexibility .Here, a whole unit may be dropped without affecting supply to the loads.

Quite common in primary distribution substations (i.e. IIKV or 33KV)

Cheapest substation evaluation is unit scheme.

(ii) Double Bus Bar Scheme)

In the double bus bar scheme, flexibility is achieved by using duplicate bus and switchgear. It is costly, though!

Whole sections may be removed for inspection or maintenance purpose without interrupting supply to consumers. It is Common in sub-transmission and distribution substation. It is also, common in transmission substations.

(iii) BREAKER-AND-A-HALF SCHEME

Advantage of this scheme is that the scheme provides considerable flexibility with the fewest number of breakers.

(iv) DOUBLE RING BUS BAR SCHEME

Reactor: To limit here effecting fail current by increasing the effective impedance.

DRB scheme – used for high load denitrify areas, very flexible and reliable.

Breaker Interrupts fault current and bring so doing, the equipment and working/maintenance men are safe.

A TYPICAL TRANSMISSION SUBSTATION

ARC HORN: Interrupts magnetizing in rush current only.

WAVE TRAP: Low pass filter. Allow 50Hz (or electric power) signals to pass though but blocks any communication figural (which are high frequency).

SURGE/LIGITING ARRESTER: Allows the discharge of any dangers over voltage (e.g. lightening) before it does any damage to the equipment and then restores the line to normal operation if after the discharge.
The arc Gap does not break down under normal voltages. Early breakdown when an over voltage surge passes through.

The Thyrite is a NON-LINEAR RESISTOR which reduces current at gap until it is extinguished.

Lighting Arrester is also called surge diverters.

CIRCUIT BREAKER (CB)
It interrupts fault (short circuit) currents on feeders live or bus bars, thus protecting them against damage.

ISOLATOR/SERIES SWITCH/DISCONNECT SWITCH
It serves as additional back-up protection for personnel in the circuit breaker opens. It enables the circuit breaker to be completely isolated for maintenance and inspection purposes.

REACTOR
Basically, for limiting short circuit current at a bus usually connected in series in this case.

Fault MVA = $\sqrt{3}$ KV I_{SC}

I_{SC} supposed to be limited which is done by reactor

CURRENT TRANSFORMER

Used for obtaining currents which are portioned to the system currents for use in various ways e.g. metering and relaying.

VOLTAGE TRANSFORMAER/POTENTIAL TRANSFORMAER (PT/VT)

It is a two winding Transformer which gives a measure of nominal voltage. It is used for providing voltage much lower than system normal voltage for metering or relaying purposes. It is actually a-2 winding transformer with the secondary having a nominal voltage of 110v.

CAPACITOR VOLTAGE TRANSORMER (CVT)

It serves same purpose as VT. In addition, u-provides complying of wave trap to the system conductor.

RELAYS

Devices which indicate abnormal system conductors. They are responsible for energizing circuit breaker's trip circuit.
ARC HORN: interrupts magnetizing in-rush current only.

Wave Trap: Low pass filter. Allows 50Hz (or electric power) signals to pass through but blocks any communication signals (which are high frequency)

SURGE/LIGHTNING ARRESTER: Allows the discharge of any dangerous over voltage (e.g. lightning) before it does any to the equipment and then restores the line to normal operation after the discharge.

ECONOMICS IN POWER SUPPLY

Considered charge for consumption of electricity is based on the two-part tariff nowadays.
The two-part-tariff is given as:

Consumption charge = a + b x energy consumed (KWH)

Where **a**= fixed charge in (₦) and depends on the size/cost of generating plant and transmission system.

b= the charge ($^{₦}/_{KW}$) per unit energy used. This is depends upon duration of use of consumer equipment.

The fixed charge **a**, is payable whether energy is used or not, **b** is levied only when energy is consumed.

It is usual to express the fixed charge in terms of the size of equipment i.e. the KVA of maximum demand used.

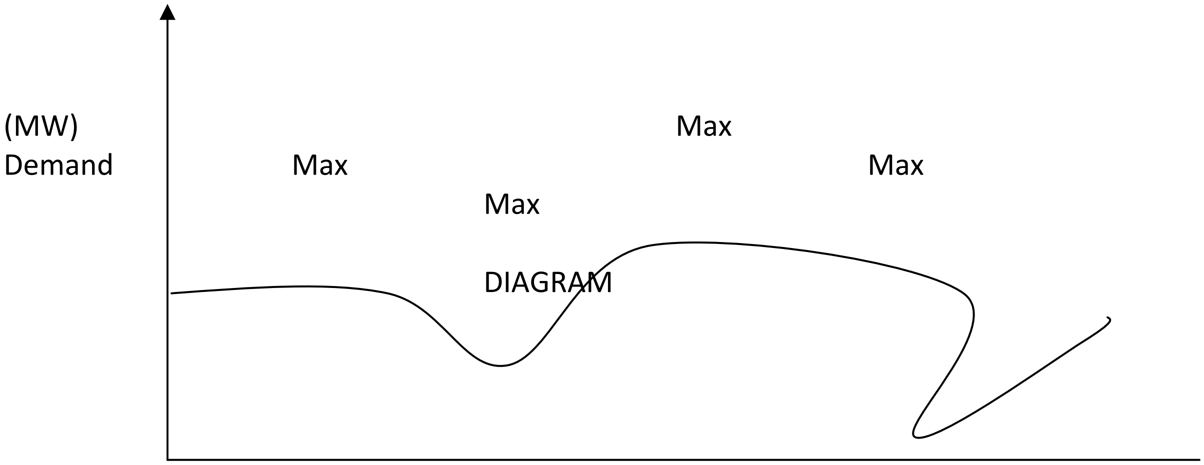
DIVERSITY FACTOR (D.F) = $$\frac{\textbf{sum of max demand of all consumers}}{\textbf{Maximum Demand upon generating plant.}}$$

Or **D.F. =** $$\frac{\textbf{Total connected load}}{\textbf{Max. Load is use at any instant}}$$

Diversity factor is generally greater than unit (1)

The D.F takes into account that it is most unlikely that all connected plant will be in use at any one time.

Maximum Demand (M.D) = the average load over the half-hour of maximum output



Load factor: (L.F) = $$\frac{\textbf{Units in use during a given period}}{\textbf{Units when M.D is in use for the same period}}$$

= 0-100%

DIAGRAM

Units used in 24Hr period = A

Units used If M.D. had been in use for 24hrs = A + B

Example:

A consumer of max demand of 500KW consumer 4,800KWh unit of electricity per day.

What is load factor (L.F)?

If the load factor is improved to $66\frac{2}{3}\%$ what will be the savings on the max demand charge if the half charge is N10/KW of max demand the energy used remaining unchanged.

Soln:

M.D = 500KW
Unit used/day = 4800KWh
Unit use/day when M.D is in service is given by 500KW x 24hrs = 12000KWh

(a) Cal. L.F = $\frac{4800kwh}{12000kwh}$ x 100% = 40%

(b) L.F = 662/3% = 4800kwh x 100% = Energy use unit used with M.D KWh in 24hrs
unit used with M.D. $\frac{kwh}{L.F}$ = $\frac{4800kwh}{66^{2}/_{3}\%}$

$=\frac{4800kwh}{0.667}$

= MD = $\frac{7200}{24}$ - $\frac{kwh}{h}$ = 300kw
Saving in MD = (500-300) = 200kw.
Saving expected = 200kw x 10 N/kw
=₦2000

POWER FACTORS (P.F.)

Note: Power (watts) = $\sqrt{3}$ x volts x amps x PF

= $\sqrt{3}\,V_1\,5\cos\phi$

Or KW = KVA x PF

KVA = $\sqrt{3}\,V_1 \times 10^{-3}$

In power supply system, voltage is usually assumed constants.

Watts = K x amp x cos ф

Where K = constant = $\sqrt{3}$ volts (line)

This we assume that the purer dram by load (i.e. waft, remain constant). Them for load open tiny at low power factor i.e. cos ϕ = O, the current drawn by the load is high.

$$= amp = \frac{Watts}{K\cos \phi}$$

Now if load operates at high power factor cos ϕ – I then the current taken by the load is small

In summary:

Amps = high if Cos ϕ = 0

Amp = Low if Cos ϕ = 1

Note:- It is obvious that operating at load p.f. results in the system capacity being reached. Operating at an improved P.F. result in spare capacity being released within the system (i.e. lower current demand for the same load)

This if a consumer operates with high P.F. then spare capacity will be available for additional system load.

Due to the above reason supply authority penalizes consumer for operating with low P.F. the tariff charge here is based on KVA rating of max Demand rather than the KW.

KW = (KVA X PF)

KVA = KW/PF

For a given KW load KVA demand depends upon the P.F.

KVA is small when PF is high

KVA is large when P.F. is low for the same KW load.

Question

A 50hp 415v 3- ϕ motor operates on full load at 0.7 p.f. lagging at efficiency of 85%. What will be the KVA demand and the current taken from the supply? By how much will the KVA demand and the current be reduced if the P.F. is improved to 0.95 lagging.

(a) Output if motor = 50hp = $\underline{50 \times 0.746kw}$
37.3kw

$$\text{Motor input} = \frac{\text{output}}{\text{Efficiency}} = \frac{37.3}{0.85}$$

$$= 43.9\text{KW}$$

$$\text{KVA} = \frac{\text{KW}}{\text{PF}} = \frac{43.9}{0.7}$$

$$= 62.7\text{KVA}$$

$$\text{KVA} = 3\ \text{KV line X I} = \sqrt{3}\ \text{volt x amps x } 10^{-3}$$

$$= \sqrt{3}\ \text{volt x amps}$$

$$\text{Amps} = \frac{\text{KVA}}{\sqrt{3}\text{KV line}} = \frac{62.7}{\sqrt{3} \text{ x } 0.45}$$

$$= 87.2\ \text{A}$$

(b) PF is improved to 0.95

$$\text{KVA input} = \frac{\text{input kw}}{\text{p.f.}}$$

$$= \frac{43.9}{0.95}$$

$$= 46.2\ \text{KVA}$$

$$\text{I} = \frac{\text{KVA}}{\sqrt{3}\ \text{KV line}} = \frac{46.2}{3 \text{ x } 0.415}$$

$$= 64.3\text{A}$$

Reduction in KVA = 62.7 – 46.2
= 16.5 KVA

Reduction in current taken = 87.2 – 64.3
= 22.9A

POWER FACTOR IMPROVEMENT

Most loads are inductive in nature and therefore absorbs vars (volts ampere reactance) leading to lagging power factor.

If a load is capable of supply leading var is connected in parallel or across the induction load, the the P.F correction of inductive load will be improved. P.F correction equipments in use are shunt-connected capacitor, synchronous compensator (condenser)

A synchronous compensator is synchronous motor with no load coupled with the system shaft. It generates or absorbs vars; depending on level of excitation which also depends on voltage level on the line.

Note that in a pure capacitive reactive load the capacitor current leads the voltage by π/2 or 90^o since it is purely reactive.
The current I_2 drawn from the supply is less than. I1 and ϕ_1 reduces to O

$$= \text{Cos } \phi_2 > \text{Cos } \phi_1$$

The P.F of the load is thus improved from cos ϕ_1 to cos ϕ_2 (since $\phi_2 < \phi_1$). As a result I_2 is less that I_1 thus releasing spore capacity.

Note that in the above phasor diagram the capacitor is purely reactive and therefore its current I^2 leads V by 90^o

N.B $OG = I_1 \cos \phi_1 = I_2 \cos \phi_2$

$I.B = I_1 \cos (90 - o^1)$

$= I_1 \sin \phi_1$

$I,B = I^2 \text{Cos } (90 - \phi_2) = I_2 \sin \phi_2$

Now $Ic = I_1 \sin \phi_1 - I_2 \sin \phi_2$

$Xc = \frac{V}{Ic} = \frac{10^6}{2\pi fc}$ where C in µF. (i.e 10^{-6})
i.e $Xc = 1/2\pi fc$

DIAGRAM

In power system is assumed the voltage to be remain constant. Therefore by multiplying all axis by V: the new phasor diagram is obtained.

$Q_c = Q_1 - Q_2$

$Q_c = \quad V I_c$

$Q_1 = V I_1 \sin \phi_1$

$Q_2 = VI^2 \sin \phi_2$

Therefore improving power fascine leads to reduction in KVA demand i.e. saving in KVA demand = $S^1 - S^2$

* Power factor improvement may also be done by connecting a synchronous compensator (synchronous motor) instead of the shunt capacitor

Example 1:

A current of 35A is taken from 240v single phase 50Hz a.c supply at P.F. of 0.75 lagging if a capacitor is installed to improve P.F. to 0.96 lagging find:

(a) Current taken from the supply

(b) The capacitor current

(c) The capacitance of the capacitor

(a)$I_1 \cos \phi_1 = I_2 \cos \phi_2$

$$I_2 = I \frac{\cos \phi_1}{\cos \phi_2} = \frac{35 \times 0.75}{0.95}$$

(b) $I_c = I_1 \sin \phi_1 - I_2 \sin \phi_2$

$= 35 \sin 41.4^o - 27.3 \sin 16.30^o$

$I_c = 15.5A$

(c) $C = \frac{10^6 I_c}{2\pi fV} \quad \mu F$

$= \frac{10^6 \times 15.5}{2\pi \times 50 \times 240}$

$= 205\mu F$

Example 2

A 414V, 33-4, 50H2 motor 150kw output operates on full load at lagging P.F. of 0.707 with an efficiency of 85.6%. Find the rating if a capacitor required to improve the P.F. to 0.98 lagging and its capacitance per phase, if it is delta connect.

If the maximum demand charge in the tariff is N8.00 per KVA per annum, what will be the annual reduction is the cost of electricity?

Solution:

$$\text{Motor Input} = \frac{\text{output}}{\eta}$$

$$= \frac{150\text{KW}}{0.856} \quad =175.2\text{kw}$$

$\phi1 = \quad \text{Cos}^{-1}(0.707) \quad = 45^0$

$\phi2 = \quad \text{Cos}^{-1}(0.98) \quad = 11.5$

$Q1 = P \tan \phi_1 = 175.2 \tan 45^o = 175.2\text{KVAR}$

$Q2 = P \tan\phi_2 = 175.2 \tan 11.5^o = 35.6\text{KVA}$

$Q2 = Q_1 - Q_2 = 139.6\text{KVA}$

= total rating of capacitor

$$\text{Capacitor rating per phase} = \frac{139.6}{3} = 46.5\text{KVA}$$

$$Ic = \quad \frac{\text{KVAr}}{\text{Volt}} \times 10^3 \qquad = \frac{46.5 \times 103}{415}$$

$$= 112.0\text{A}$$

NB $V_{L\text{-}L} = V_{L\text{-}N}$ for Δ connection

$$C = \frac{10^6 I_C}{2\pi fV} \mu F$$

$$= \frac{106 \times 112}{2\pi \times 50 \times 415} \qquad = 859\text{MF per phase}$$

But $S_1 = \quad p \quad = \quad 247.8\text{KVA}$

$$\overline{\qquad}\atop \cos \phi_1$$

$$S_2 = \frac{p}{\cos \phi_2} = 178.8KVA$$

Reduction in KVA = $S_1 - S_2$ = 69.04KVA

Annual reduction = $(S_1\text{-}S_2)$ x tariff

= 69.04 x 8 = N552.32

Synchronous Motor for Power Factor Improvement

The power factor at which machines operate is an economically important features because of the cost of reactive KVA. Low power factor adversely affect system operation in three principal ways.

1. Power equipments (generators, transformer etc) are rated in KVA rather than kilowatts, because their losses and heating are very nearly determined by voltage and current.

2. Low power factor means more current and greater copper losses in generating and transmitting equipment.

$$P = 3\, V_L\, I_L \cos \phi = \qquad I = \frac{P}{\sqrt{3}\, V \cos \phi}$$

$$= \frac{P}{\sqrt{3} \times V \times PF}$$

If P = Costant , V = Costant, i.e $\frac{P}{\sqrt{3}\, V} = K$ = Costant

$$I = \frac{K}{P.F}$$

3. Low power factor leads to poor voltage regulation. But most industrial load (e.g. induction motor) are inductive in nature and therefore absorbs vars leading to lagging power factor. If a load capable of supplying leading power factor vars is connected in parallel or across the inductive load, then the power factor will be improved.

One of the P.F. correction equipment in use is synchronous condensers or synchoronous compensator. A synochronous compensator is a synchronous motor running without mechanical load, and depending on level of excitation, it can absorb or generate reactive power. If under excited it absorbs vars from the system (i.e. produces leading vars). i.e. current leads the voltage. If over excited, it generates vars into the system (i.e. generating at lagging P.F).

Since synchronous motor is not purely inductive it does not lead by 90^o but at certain angle $<90^o$ inductive load (e.g. induction motor)

$I_2 = I_1 + I_m$
Q_1 = Phase angle b/4 correction

Q_2 = Phase angle after correction

Q_m = Phase angle of motor.

Multiplying each phasor by V to get terms in power

Solution:

Actual load of the factory

$= \frac{P}{\eta} = \frac{800KW}{0.80} = 1000KW$

Factory load in KVA = KW = $\frac{1000}{PF}$ =1176.5KVA

0.85 = S1

DIAGRAM

Load phasor Diagram for with lagging load.

Actual Load of synchronous = $\frac{\text{Motor } Pm}{\eta}$ = $\underline{200KW}$

$Q_2 = \text{Cos}^{-1}(0.98)$
$= 11.5^o$
$Q_m = ?$

But $S_2 = \frac{P_2}{\text{Cos } Q_2} = \frac{1235.3}{\text{Cos } 11.5^o} = \frac{1235.3}{0.98}$

= 1260.5 KVA

$Q_2 = P_2 \tan Q_2 = 1235.3 \tan 11.5^o = 215.3$KVA

$Q, = Q_1 - Q_3 = (619.7 - 251.3)$KVA

$\text{Tan } \phi_m = \quad Q_m \quad = 368.4 \quad = 1.6$

$$\overline{P_m} \qquad \overline{235.3}$$

$\phi_m = \tan^{-1}(1.6) = 58^o$

$Pf_m = \cos\phi_m = \cos 58^o = 0.53$ leading

Power factor at which the sychronous motor operates to improve the P.F. of the load to 0.98 lagging = 0.53 loading

Exercise

A three-phase induction motor deliver 500 hp at an efficiency of 0.71, the operating power factor being 0.76 lagging. A loaded synchronous motor with a power consumption of 100KW is connected in parallel with a motor. Calculate the necessary KVA and the operating power factor of the synchronous motor if the overall power is to be Unity.
(Answer = 365 KVA, 0.274)

TRANSMISSION LINES AND CABLE

CABLES

Cables used in electrical circuit are of many types but all consists of the following main parts:

a. Conductor
b. Insulator
c. Mechanical protection

a. **Conductor:** are usually made of copper, the conducting cores being formed from strands of copper wire so that the cable is more flexible that if solid cores were used. If vulcanized rubber insulation is to be used the copper conductors are tinned to prevent corrosion of the copper by sulphur which is present is vulcanized rubber.

b. Insulation of Cables used in domestic installations is normally of vulcanized rubber (V.R.I.) or poly-vinyl-chloride (P.V.C.). Where mineral insulation (magnesia) is employed the cable has a copper cluster sheath, the type of cable h\being known as mineral insulated copper Sheathed cable (MICS).

1. **Mechanical Protection**: This is provided to prevent damage to the cable during insulation and throughout its subsequent service.

Note: For overhead lines, the aluminium conductors or various sizes are used. The insulation is air end no mechanical protection is required. Although it is not such as good as copper, its light weight and absence of copper losses are advantages, in many situation, lower prices and larger diameter are another advantages.

Overhead Lines

Types and Parameters

Overhead Lines are suspended from insulators which are themselves supported by toward or poles. The span between two towers is dependent upon the allowable sag in the line, and for sheet towers with very high voltage lines the span in normally 370-460m (1200-1500ft). Typical supporting structures are shown in figures 3a-3h.

There are two main types of tower:
a. Those for straight runs in which the stress due to the weight of the line alone has to be withstood.
b. those for changes in route, called deviation towers; these withstand the resultant forces set up when the line changes direction.

When specifying towers and lines, wind loadings as well as extra forces due to a break in lines on one side of a tower; are taken into account. For lower voltages and distribution circuit wooden or reinforced concrete poles are used with conductor supported in horizontal formations.

The line conductors are insulated from the towers by insulation which take two basic forms, **the pin type** and **suspension type**. The pin type is used for lines up to 33KV whole the suspension type is used for lines up to 400KV.

Insulations of Overhead Lines

Overhead lines conductors are not themselves insulated. Insulators mounted on suitable cross-arm are required to give necessary clearances between conductors and between conductors and earth. The insulator must provide the necessary mechanical support for conductors against mechanical loading.

Porcelain and toughened glass are the only two materials generally used for insulating bare overhead lines conductors.

Conductor Materials

Hard drawn (HD), high conducting (HC) copper, hard drawn *** copper, hard drawn aluminium and aluminium, alloy and cored aluminium (Aluminium Cable Steel reinforced ACSR) are conductor materials.

For high voltages ≥ 230KV, it is not possible to use a round single conductor due to corona. Bundle conductors of two, three or four conductors per phase spaced about 11/2ft apart are used. This also reduces the line reactance and give added advantage of increased transmission capacity.

Sag and Stress Calculation

There is overhead line regulation for the minimum height for lines above ground. The regulation states that sag must be calculated under the specified worst conditions line temp = 22^0F, covered with ice of radial thickness of 3/8" with ice weighing 57Lbf/ft^3 and to the end such that the pressure on line is 8lbf/ft^2 of total projected area.

a. Consider Parabola shape line with relation

$Y = ax^2$ - (1)
L = span
S = Sag at mid-span

At mid pt, y = s and x = µ2.

This gives from (1)

$$A = \frac{4s}{l^2} \qquad - \qquad (2)\backslash$$

$$y = 4s\left(\frac{x}{l}\right)^2$$

With 0 as origin.

Let T = tension (lbf) at 0 (assume) constant over the whole span).
W = conductor or weight lbf/ft.

Taking moment about A gives

$$TS = \left(\frac{wl}{2}\right)\left(\frac{l}{4}\right)$$

$$S = \frac{wl^2}{8T}$$

$$\text{Or} \quad y = \frac{wx^2}{2T}$$

b. If Support at different level,

Let Lc = Span of complete parabola
L = Actual span

Then let $x_L = L - \frac{L_E}{2}$

The equation $y = ax^2$ holds and

$$S = \frac{wx^2}{8T}$$

$X_l^2/(S - h) = lc^2/4S$

(from $\frac{x^2}{Y} = \frac{l^2}{4S}$

Which gives $Lc = L + 2Th/wl$

LINE PARAMETERS CALCULATIONS

The parameters of interest for circuit analysis are inductance, capacitance, and resistance, and leakage resistance. These four parameter affect the ability of T/L to fulfill its function as part of power system.

A. Inductance

Assignment
Prove that

I. Inductance due to an internal flux (Internal inductance) of a conductor is given by

$$L_{int} = \frac{\phi_{int}}{I} = \tfrac{1}{2} \times 10^{-7} \text{ henry/meter.}$$

II. Flux Linkage between two pt External to an Isolated Conductor is

$$\phi_{12} = 2 \times 10^{-7} I \ln D_2/n$$

or $L_{12} = \phi_{12} = 2 \times 10^{-7} \ln D_2/ D_1$

Inductance of a single-phase two wire line

Let $I_1 = -I_2$.
A line of flux set up by current set up by current in conductor to a distance equal to or greater than D + r_2 from the centre of conductor 1 does not link the current (since total current enclosed is zero).

Inductance due to conductor 1

$L1_{ext} = 2 \times 10^{-7}$ Lin D/r_1 (H/m)

For internal

Lint = $\frac{1}{2} \times 10^{-7}$ (H/m)

Total inductance = $(1/2 + 2\ln.D/r_1) \times 10^{-7}$ (H/m)

= $2(1/2 + \ln D/r_1) \times 10^{-7}$.

Or L1 = $2 \times 10^{-7} (\ln 2^{1/4} + \ln D/r_1)$
= $2 \times 10^{-7} \ln D/r_1e^{-1/4})$
= $2 \times 10^{-7} \ln D/r_1'$ (H/m)

Where $r_1' = r_1e-^{1/4}$

In some text books;
The Inductance of a single-phase two wire line is given as $\frac{\mu}{4\pi}[1 + 4\ln \left(\frac{d-r}{r}\right)]$ (H/m)

Where d = distance between the centres
r = radius of the conductors (assume r1 = r2)

Example 3.1
A single phase circuit comprises two parallel conductors 0.25inch diameter spaced 3ft apart. Calculate the inductance/loop/mile; if the material of the conductor is
(a) Copper (b) Steel of effective relative permeability of 59

Solution

L = $\frac{\mu_0 \ln D/r_1'}{2\pi}$ (non-magnetic material r1 = $(re^{1/4})$

Or $L = \frac{\mu_0}{\pi}\left[\frac{\mu_r}{4} + \mathrm{In}\,(D/r)\right]$ H/m

for a magnetic material of relative permeability μ_r.

a. For copper,

$L = \frac{\mu 0}{\pi}\,\mathrm{In}\,(D/r_1')$

$r' = re^{-1/4}$

$r = \frac{0.25}{2} = 0.125$inches

$D = 3$ft $+ 0.25$ inches

$D = 36.25$inches

Therefore $r' = 0.125e\text{-}^{1/4}$

$= 0.125 \times 0.7788$

$D = 36.25$ inches.

therefore $L = \frac{4 \times \pi \times 10^{-7}}{2\pi}\,\mathrm{In}\,\left(\frac{36.25}{0.125 \times 0.7788}\right)$ H/m

$= 4 \times 10^{-7}\mathrm{In}\,\left(\frac{36.25}{0.09735}\right)$ H/m

$= 4 \times 10^{-7}\,\mathrm{In}\,(372.36)$ H/m

$= 2.368 \times 10^{-6}$ H/m

For a mile,

$L = (2.368 \times 10^{-6})(1000)(8/5)$H

$= 0.003788$

$= 0.0038$H

b. For steel, $\mu_r = 50$

$L = \frac{\mu_0}{\pi}\left[\frac{\mu_r}{4} + \mathrm{In}\,(D/r)\right]$

$D = 36.25$ inches

$r = 0.125$ inches

$$L = \frac{4 \times 10^{-7} \times \pi}{\pi} [\underline{50} + \text{In}(36.25/0.125)]$$
$$= 4 \times 10^{-7}(18.16988) \text{ H/m}$$
$$= 7.268 \times 10^{-6} \text{ H/m}$$

For a ***,

$$L = 7.268 \times 10^{-6} \times 1000 \times 8/5$$
$$= 0.01168\text{H}$$

B. Line Capacitance

The overhead line conductors without insulation between them constitutes a capacitance which when connected to an alternating voltage supply will take a charging current which will flow even under no local condition. The changing current will be greatest at sending end and will diminish to zero at the receiving end.

The line construction may consist of double – circuit lines with two conductors/phase. In effect the capacitance is a leading power factor on the line current. These leakage currents are proportional to the line voltage. At high voltages (300KW and above) and lines in excess of 200miles, the impact of these shunt elements becomes of primary concern to the system engineers.

Capacitance of Single Phase Line

We will prove this with our basic knowledge in integral calculus

Recall, $\frac{dZ}{Z^2 + r^2}$; Let $Z = r\tan\theta$

$$\frac{dZ}{d\theta} = r\sec^2\theta$$

$$\frac{dZ}{Z^2 + r^2} = \frac{r\sec^2\theta d\theta}{r\sec\theta} = \sec\theta d\theta$$

Assume we carry ± ep C/m of the wire

$$= Q\text{Sec}\theta_1 d\theta_1 + -Q\text{Sec}\theta_2 d\theta_2$$

Note $\text{Sec } x\, dx = \log(\sec x + \tan x)$

$$Q\log(\sec\theta_1 + \tan\theta_1) - Q\log(\sec\theta_2 + \tan\theta_2)$$

Tan $\theta = 2/r$

Sec $\theta = 1/\text{Cos}\ \theta = \frac{Z^2 + r^2}{r}$

$$= \text{Qin}[\frac{Z + Z^2 + r_1^2}{r1}] \quad - \quad \text{Qln}[\frac{Z + Z^2 + r^2}{r2}]$$

$$= \text{Qin}\ \frac{L + L^2 + r_1^2}{r1} \ - \ \text{Qin}\ [\ \frac{-L + L2 + r_1^2}{r1}]$$

$$= \text{Qin}\ \frac{L + L2 + r2}{r2} + \text{Qin}\ [\frac{L + L^2 + r_2^2}{r_2^2}]$$

$$= \text{Qin}\ \frac{(L + L2 + r_1^2)}{(L+L^2+r_2^2)}\ \frac{(-L + L^2 + r_2^2)}{(-L + L^2 + r_1^2}$$

Again, the wire carry ± Qe/m of the wire with opposite signs. The electric potential at an arbitrary pt P i.e.

$V \quad lo= \quad \frac{q}{4\pi\pounds or}$ Volts

Since $a = Z^2 + r_1^2$

$b = Z^2 + r_2^2$

We obtain by summation for the potential at p

$$Vp = \frac{QdZ}{4\pi\pounds o\ Z^2 + r_1^2} \quad + \quad \frac{-QdZ}{4\pi\pounds o\ Z^2 + r_2^2}$$

where 2L is the total line height.

$$Vp = \frac{Q}{4\pi\pounds o}\ \ln\ [\frac{(L + L^2 + r_1^2\ (-L + L^2 + r_2^2)}{L + L^2 + r_1^2)\ (-L + L^2 + r_1^2)}$$

If L $\rightarrow\infty$, then (L +)/(L +) $1\rightarrow$

But

$(-L + L^2 + r^2)/(-L + \quad)$ takes indeterminate value, but

$$-^{1}L + L2 + r_2^2 \quad = \quad \frac{-1 + [1 + ½(r_2/L)^2 + ...]}{-1 + [1 + ½(r_1/L)^2 + ...]} \quad = \quad (r_2/r_1)^2$$

This term varnishes with increasing L, therefore for L $\rightarrow \infty$

$$Vp = \frac{Q}{4\pi\pounds o} \text{In } (r_2/r_1)^2 \quad = \quad \frac{Q}{2\pi\pounds o} \text{In}(r_2/r_1) \qquad - \qquad (1)$$

Note:

a. Vp is constant along the contour for which the ratio r_2/r_1 is unchanged. The equipotential surfaces are these cynlinders.
b. In close proximity of the line charges the ratio r2/r1 is either very large or very small.

The potential V_1 on the cylinder of radius R1 equals

$V_1 = \frac{Q \text{ In}}{2\pi\pounds o} D/R1$ D = distance between wires

R1 is the immediate neighbourhood of the +ve wire.

$$\text{And } \; V2 = \frac{Q}{2\pi\pounds o} \text{In} R_2/D$$

Likewise, p.d. between the two cylindrical surfaces as

$$V1 - V2 \quad \approx \frac{Q}{2\pi\pounds o} [\text{In } D/R_1 - \text{In } R_2/D]$$

$$= \frac{Q}{\pi\pounds o} [\text{In } D/R_1R_2] \qquad - \qquad (2)$$

$$\text{But} \quad C \quad = \quad \frac{Q}{V1 - V2} \quad = \quad \frac{\pi\pounds o}{\text{In } (D/R_1R_2)}$$

If the conductor have equal radii R1 = R2, then

$$C \quad = \quad \frac{\pi\epsilon_0}{\text{In}(D/R)}$$

For transmission (over head transmission) line, it is usual to assume the lines are fully transposed such that phase inductances are equal to each other and capacitances to ground are also the same.

Transmission lines generally carry balanced. It is normal to assume transmission lines to be balanced. Hence, it can be represented on per phase basis. The representation of Transmission Lines is limited by the length of the line.

A. Short Transmission Lines

These spans from 0-80kms in length. Here, capacitances are negligible and the series independence is lumped together.

R = line series Resistance
X = line series reactance (inductance).

The four terminal network constant (to be discussed later) are A = 1, B = Z, C = 0, D = 1. The voltage drop along a line is important and the regulation is defined as:

$$\frac{\text{Received voltage on no load – Received voltage on load}}{\text{Received voltage on load } (V_R)}$$

2. Medium Length Transmission Lines

These characteristics lines with length between 80-240km. Here, the capacitances to ground are appreciable and therefore incorporated. Lines in this categories are represented by their π-equivalent or T-equivalent

a. Medium – Length – π-equivalent category
b. Medium – length line – T-equivalent

Where R = line series
X = impedance
Ysh – line capacitance to ground in admittance form

Note: For π-equivalent ext,

$Vs = V_R + IZ = V_R + (V_RY/2 + I_R)Z$ - (1)

But $I = I_R + Y/2.V_R$

$Vs = (1 + ZY/2)V_R + ZI_R$ - (2)

$Is = VsY/2 + (V_RY/2 + I_R)$ - (2a)

$Is = [(1 + ZY/2)V_R + ZI_R]Y/2 + V_RY/2 + I_R$ (2b)

$Is = [(1 + ZY/2)Y/2 + Y/2]V_R + (ZY/2+1)I_R$ (3)

Combining (2) and (3), we have

$$\begin{matrix} Vs \\ Is \end{matrix} = \begin{matrix} A & B \\ C & D \end{matrix} \begin{matrix} V_R \\ I_R \end{matrix}$$

where A = (1 + ZY/2); B = Z

$C = [(1+Zy/2)y/2 = Y/2]$

$D = ZY/2 + 1$

$WC = Y(1+ZY/4)$

These are ABCD or general parameters of *** lines.

Similarly, for T-equivalent Network

$Vs = Vc + ZI_S/2$

$Vc = VR + ZI_R/2$ (2)

$Is = I_R + VcY$ (3)

Solve out, will give

$A = D = 1 + ZY/2$

$B = (1 + ZY/d)Z$

$C = y$

Long Transmission Lines

These are lines spanning above 240kms in length. Here the line parameters are assumed distributed. The changes in voltage and current over an element length 4x of the line, x metres from the sending end are determined and conditions for the whole line obtained by integration,

That is we normally use relations

$\frac{d^2I}{dx^2}$, $\frac{d^2V}{dx^2}$ etc in the analysis and parameters are in per unit length.

For lines less than 500km in length, the following expressions for the ABCD constants hold approximately.

$A = D = 1 + ZY/2$

$B = Z(1 + ZY/6)$

$C = Y(1 + ZY/6)$

Let R = resistance/unit length
L = Inductance/unit length
G = Conductance/unit length
C = Capacitance/unit length
z = Impedance/unit length
Y = Shunt admittance/unit length
Z = Total Series Impedance of the
Y = total shunt admittance of line

The voltage and current x metres from the sending end are given by

$$V_x = V_s \text{Cosh}\gamma x - I_s Z_o \text{Sinh}\gamma x$$

$$I_x = I_s \text{Cosh}\gamma x - \frac{V_s}{Z_o}\text{Sinh}\gamma x$$

Where γ = propagation constant $= (\alpha + j\beta)$

$= (R + JwL)(G + JwC) = \sqrt{2}y$

Where Zo = characteristics impedance

$$= \frac{R + JwL}{G + JwC} \quad - \quad (4)$$

OVERHEAD CONDUCTORS

The overhead three phase power transmission line is the main energy corridor in a power system. The lines are usually suspended from insulators which are themselves supported by towers or poles. That is, the conductors are bare (no insulating veering) for heat dissipation reasons; the phase conductors insulated from each other and the tower by suspension from insulator strings.

Apart from the phase conductors, there are usually overhead neutrals (sky wires0. The neutrals are electrically in contact with the tower and therefore grounded. They are primarily exist to provide lightening shielding for the phase conductors and also to carry zero sequence and harmonic currents that help to maintain balances sinusoidal voltages. They are usually steel or aluminium and are small in (diameter above 1cm). The phase conductors are much larger (diameter, 15cm), and are typically stranded aluminium surrounding a stranded steel cable (for increased) tensile strength). Sometimes more than one (a "bundle") comprise a phase.

The span between two towers is dependent upon the allowable sag in the line, and for steel towers with very high voltage lines the span is normally 370 – 460m (1200 – 1500ft). Typical supporting structures are shown in figures A and figure B below. There are two main types of tower:

a. Those for straight runs in which the stress due to the weight of the line has to be withstood.
b. Those for changes in route, called deviation towers; these withstood the resultant forces set up when the line changes direction.

When specifying towers and lines, wind, loadings as well as extra forces due to break in the lines on one side of a tower. For lower voltages and distribution circuits wooden or reinforced. Concrete poles are used with conductors supported in horizontal formations,

INSULTATIONS OF OVERHEAD LINES

The line conductors are insulated from the towers by insulators which take two basic forms, the pin type and the suspension type. The pin type is used for lines up to 33KV, while the suspension type is used for lines up to 400KV.

The line conductors are not themselves insulated. Insulators mounted on suitable cross-arm are required to give necessary clearance between conductors and earth. The insulators must provide the necessary mechanized support for conductors against mechanical loading.

Porcelain and toughened glass are the only two materials generally used for insulating bare overhead lines conductors.

CONDUCTORS MATERIALS

Overhead line conductors usually comprise a standard steel core (for mechanical strength) surrounded by aluminium wires which form the conductor. It should be noted that aluminium and AC & R (aluminium conductor steel reinforced) conductors are sometimes described by area of a copper conductor having the same d.c resistance, i.e. their copper equivalent.

It is to be noted that at high voltages transmission above 230KV, it is not possible to use a round single conductor due to corona. Bundle conductors of two, three or four conductors per phase spaced about $1^1/_2$ ft apart are used. This also has that advantage of reducing the line reactance and thereby gives added advantage of increased transmission capacity.

Sag and Stress Calculation

There is overhead line regulation for minimum clearance height for lines above the ground. The regulation states that sag must be calculated under specified "worst conditions" – varying from place to place and for a country to a country.

Consider the line-parabola.

Consider the equation of parabola,
$Y = ax^2$ - (1)
Given that l is a span
S = Sag at mid-span.

At mid point, y = S and x = L/2
From eqn, by substituting the above in (1), we get

a =4S/l2 (2)
y = 4s(x/l)2 (3)
With 0 as origin
Let T = tension (lbf) at 0, [assume constant over the whole span].

W = Conductor weight lbf/ft

Taking moment about A, gives

TS = w x l/2
S = wl/2T (4)

DETERMINATION (CALCULATION) OF OVERHEAD LINES PARAMETERS

The line parameters are of a great interest for circuit analysis. These include line inductance (L), Capacitance (C), resistance (R), and leakage resistance. These parameters affect the ability of the transmission line to fulfill its function as part of power system.

The formula for calculating these parameters will be briefly highlighted.

INDUCTANCE (L)

Here, we will consider the inductance of single-phase, two wiore line. The multiphase system will be considered at higher studies.

Consider a single phase 2-wire

Let $I_1 = -I_2$

A line of flux is set up by the current in conductor 1 to a distance equal to or greater than D + r2 from the centre of conductor 1.

Inductance due to conductor 1

$L1 = 2 \times 10^{-7} D/r1 (H/m)$ - (1)

For internal

$Lint = ½ \times 10^{-7} (H/m)$

Total inductance $= (1/2 + 2In\ D/r1) \times 10^{-7} (H/m)$

$= 2[1/4 + In\ D/r1) \times 10^{-7}$

Or

$L1 = 2 \times 10^{-7}(In\ e^{1/4} + In\ D/r1)$

$= 2 \times 10^{-7}\ In\ D/r1e^{-1/4}$ (2)

$= 2 \times 10^{-7}\ In\ D/r_1'$ (3)

Where $r_1' = r_1e^{-1/4}$

Or $L = \frac{\mu o}{\pi} In\ D/r_1'$ (non-magnetic material) (4)

or $L = \frac{\mu o}{\pi}[\mu r + In(D/r)]H/m$ (5)

for a magnetic material of relative permeability μr

Example 1

A single phase circuit comprises two parallel conductor 0.25inch diameter spaced 3ftt apart. Calculate the inductance/loop/mile, if the material of the conductor is

(a) Copper (b) steel of effective relative permeability of 50

Solution

$L = \frac{\mu o}{\pi} In\ D/r_1'$ (non-magnetic material) (4)

where $r_1' = re^{-1/4}$

and for a magnetic material of relative permeability, μr,

or $L = \frac{\mu o}{\pi}[\frac{\mu r}{4} + In(D/r)]H/m$ (5)

(a) For copper,

$L = \frac{\mu o}{} In\ D/r_1'$

π

where $r_1' = re^{-1/4}$

$r = \frac{0.25}{2} = 0.125\text{incheas}$

$D = 3\text{ft} + 0.25 \text{ inches}$

$= 36.25\text{inches}$

$r_1' = 0.125e^{-1/4}$

$r_1' = 0.125 \times 0.7788$

$D = 36.25\text{inches}$

$$L = \frac{4 \times \pi \times 10^{-4}}{\pi} \ln\left(\frac{36.25}{0.125 \times 0.7788}\right)$$

$= 4 \times 10^{-4}\ln(372.36) \text{ H/m}$

$= 2.368 \times 10^{-6} \text{ H/m}$

For a mile,

$L = 2.368 \times 10^{-6} [1000] \times 8/5 \text{ H}$

$= 0.003788$

$= 0.0038\text{H or } 3.8\text{mH}$

b. For Steel, $\mu r = 50$

$$L = \frac{\mu o}{\pi}[\mu r + \ln(D/r)]\text{H/m} \qquad (5)$$

$D = 36.25$ inches

$r = 0.125$ inches

$$L = \frac{4 \times 10^{-7} \times \pi}{\pi}[50/4 + \ln(36.25/0.125)]$$

$= 4 \times 10^{-7} (18.16988) \text{ H/m}$

$= 7.268 \times 10^{-6}\text{H/m}$

For a mile,

L = $7.268 \times 10^{-6} \times 1000 \times 8/5H$

= $0.01168H$

W = $11.68mH$

2. Capacitance

Two overhead line conductors with air insulation between them constitutes a capacitance which when connected to an alternating voltage supply which will take a charging current which will flow even under no load conduction. The charging current will be greatest at the sending end and will diminish to zero at the receiving end. The line construction may consist of double circuit lines with two conductors/phase. In effect the capacitance is a leading power factor on the line. It represents a leading path for the line current. These leakage currents are proportional to the line voltage. At high voltages (say about 300kv and above) and lines in excess of 200 miles, the impact of these shunt elements becomes of primary concern to the system engineer.

Again, let briefly consider a single phase, 2-wire conductors with radius R1 and R2 and distance D apart

D = Distance between wires

The potential difference between the two wires

$$= \quad V1 - V2 = \frac{Q}{2\pi £o}(\ln {}^{D}/_{R1} - {}^{R2}/_{D}) \quad - \quad (1)$$

$$\approx \quad \frac{Q}{\pi £o}(\ln {}^{D}/_{R1R2}) \quad - \quad (2)$$

but the capacitance between the wires

$$C = \frac{Q}{V1-V2} = \frac{\pi £o}{(\ln {}^{D}/_{R1R2})} \quad - \quad (3)$$

If the conductors have equal radii R = R1 = R2

$$\text{Therefore } C = \frac{\pi £o}{(\ln {}^{D}/_{R})} \quad - \quad (4)$$

CORONA

Air at normal pressure and temperature breaks down at 330KV/cm (peak or crest value). Smooth cylinders this stress may be determined from the expression;

$$\frac{V}{rIn(d/r)} \text{ (Volts/cm)} \qquad (1)$$

where v = voltage between line and a neutral
d = spacing between line
r = radius of conductor (cm)

If the visual critical voltage Vv of a line conductor system is reached is if the line conductor is subject to a stress above the value above in (i), the discharge will occur in the air surrounding a conductor. This is easily detected by a missing sound and at night by a blue glow (or a violet glow) around the conductors, and this is called corona.

Corona is established at a stress £v called the visual critical stress (corresponding to a voltage Vv) which is greater than the basic breakdown value £o. Assume a smooth conductor surface,

$$£v = £o(1 + 0.3/\sqrt{r} \qquad (2)$$

$$£v = \frac{Vv}{rIn(d/r)} \qquad (3)$$

Effects of Corona

1. The power loss due to corona especially cut abnormal weather condition is really significant.
2. Racho Interference (RI) or radio noise. Although the presence of corona results in a power loss, a more important effect is that the discharge causes radiation, to be propagated in the frequency bands used by radio and television.

3. The corona discharges occur at discontinuities on the conductor surface and random generation of purpose occurs.

Control of Corona

1. Use of Bundle Conductor: The most effective way to reduce or avoid corona and radio interference is the use of bundle conductors; i.e. several conductors per phase suspended from common insulators and separated mechanically by spacers of various designs. On some systems four – conductor bundles are in use. The configuration of

conductors forming a bundle modifies the single conductor surface electric field such that the maximum stress is lower than with a single conductor. This also increases the current rating of the circuit thereby increasing line thermal capacity.

2. Since corona discharges are more pronounced at discontinuities, good contact and smooth surfaces at [points will greatly reduce corona.