Transmission and Distribution of Electrical Power

By

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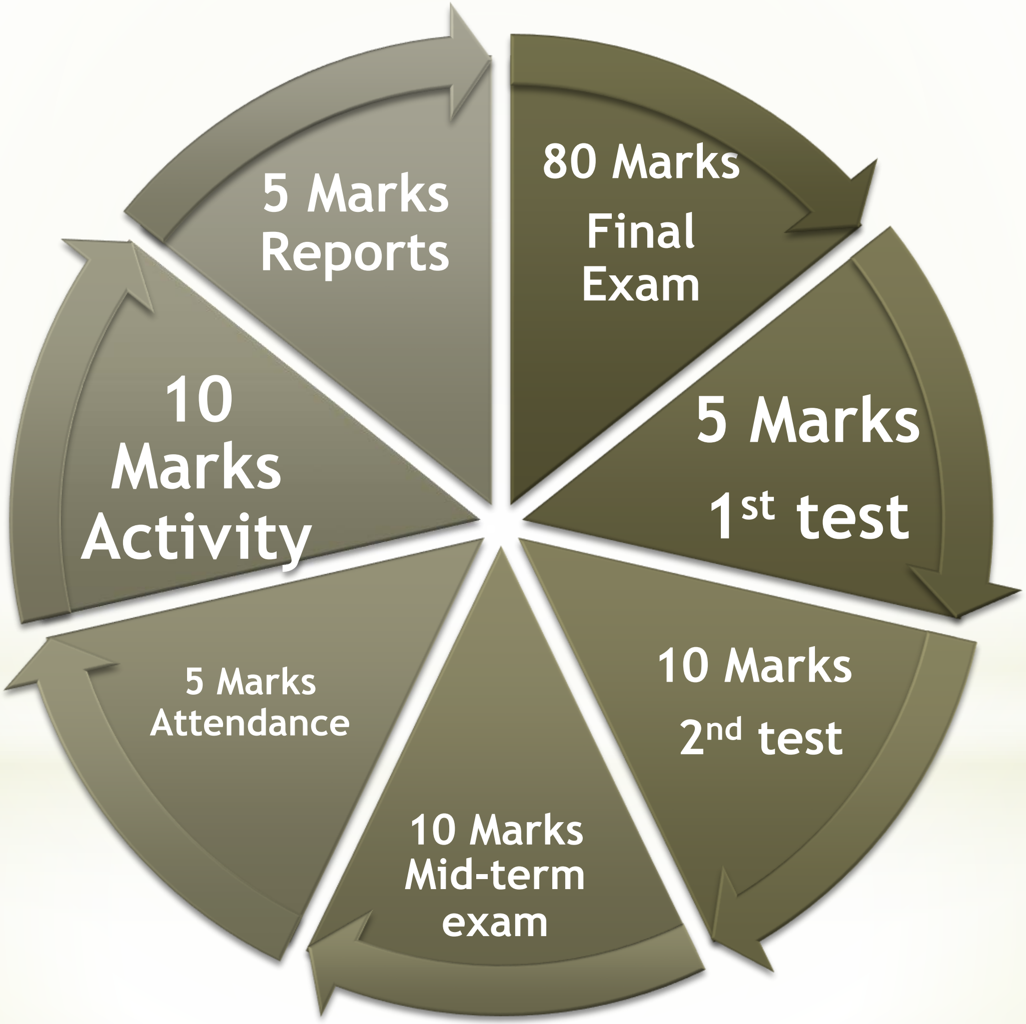
Lecture (1)

Syllabus

1. Introduction.
2. Fundamentals of Electrical Power Engineering.
3. Transmission Line Constants Calculation.
4. Transmission Line Models and Calculations.
5. Mechanical Design of Overhead Transmission Line.
6. D.C. Power Transmission Technology.
7. Overhead Line Insulator.
8. Corona
9. Underground Cables
10. Electrical Power Distribution

Marks Distribution Chart



Engineering Definition

What is Engineering?

Engineering is the application of math and science by which properties of matter and the sources of energy in nature are made useful.

Engineering Design Definition

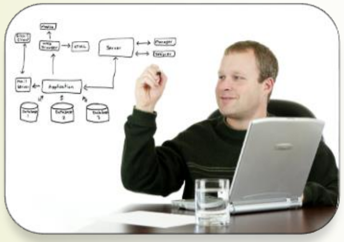
What is Design?

So, Engineering design is………

Applications & Examples

Why Engineering Design?

Betterment of society through



Design

Manufacturing

Research & Development

Management

Continual Improvement

Logistics

Engineer Definition

Who is Engineer?

Creative

Iterative

Integrated

Innovation is the key Oven Story!!!!!!!!!

So, Engineer is………

Engineering Process Cycle

The engineering process cycle is achieved by following 10 stages.

1-Identify the problem/product innovation

2-Define the working criteria/goals

3-Research and gather data

4-Brainstorm / generate creative ideas

5-Analyze potential solutions

Engineering Process Cycle

6-Develop and test models.

7-Make the decision.

8-Communication and specify.

9-Implement and commercialize.

10-Perform post-implementation review and assessment.

Electricity

Changes

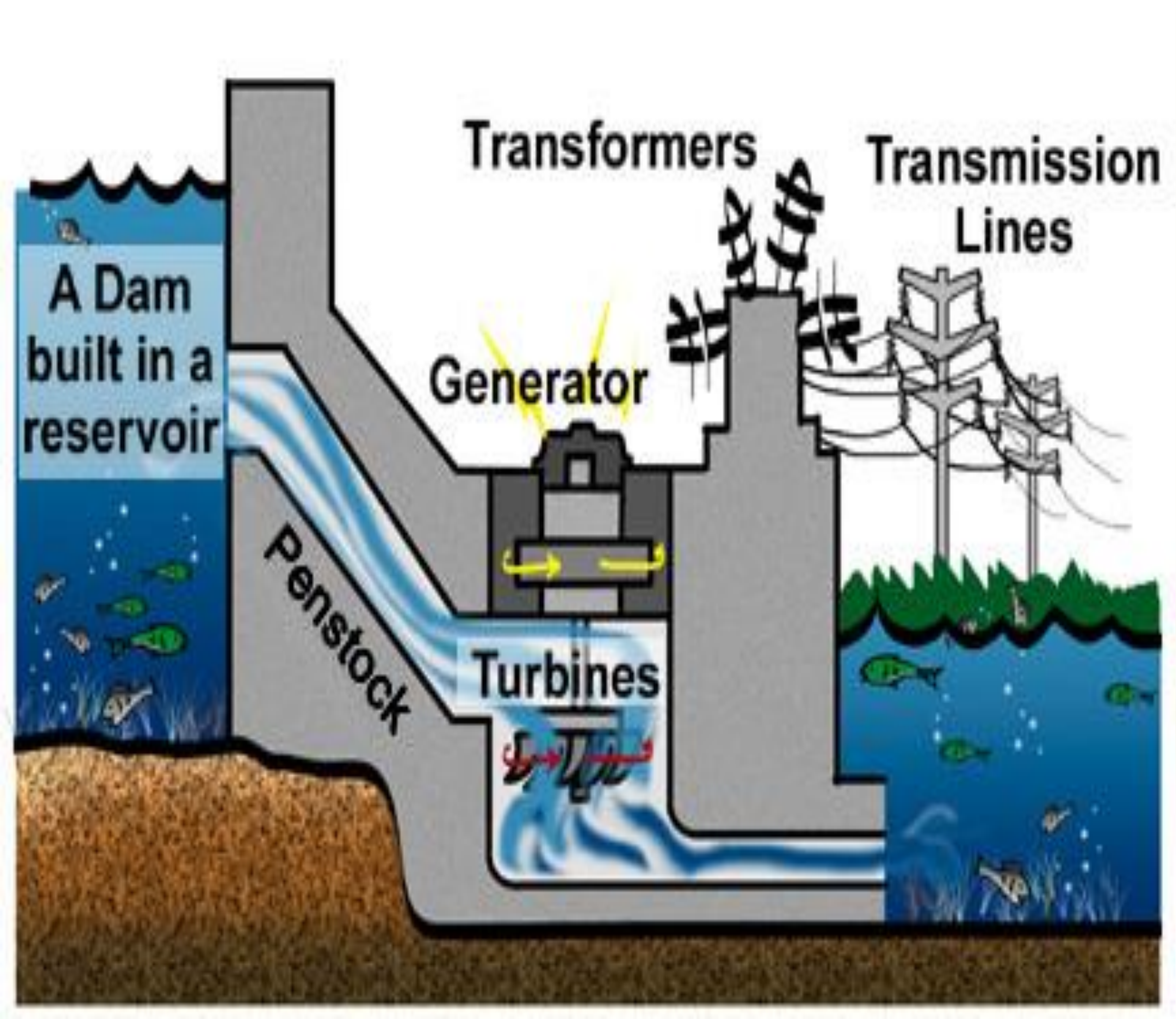
Lifestyle

Six key questions

- What is the electrical energy?
- How do we produce electric energy?
- Why do we think the electrical energy is important?
- What are the resources of electrical energy?
- What about renewable energy resources?
- What about the concept of smart grid?

TYPES Of Power plants

Hydroelectric Power Plants



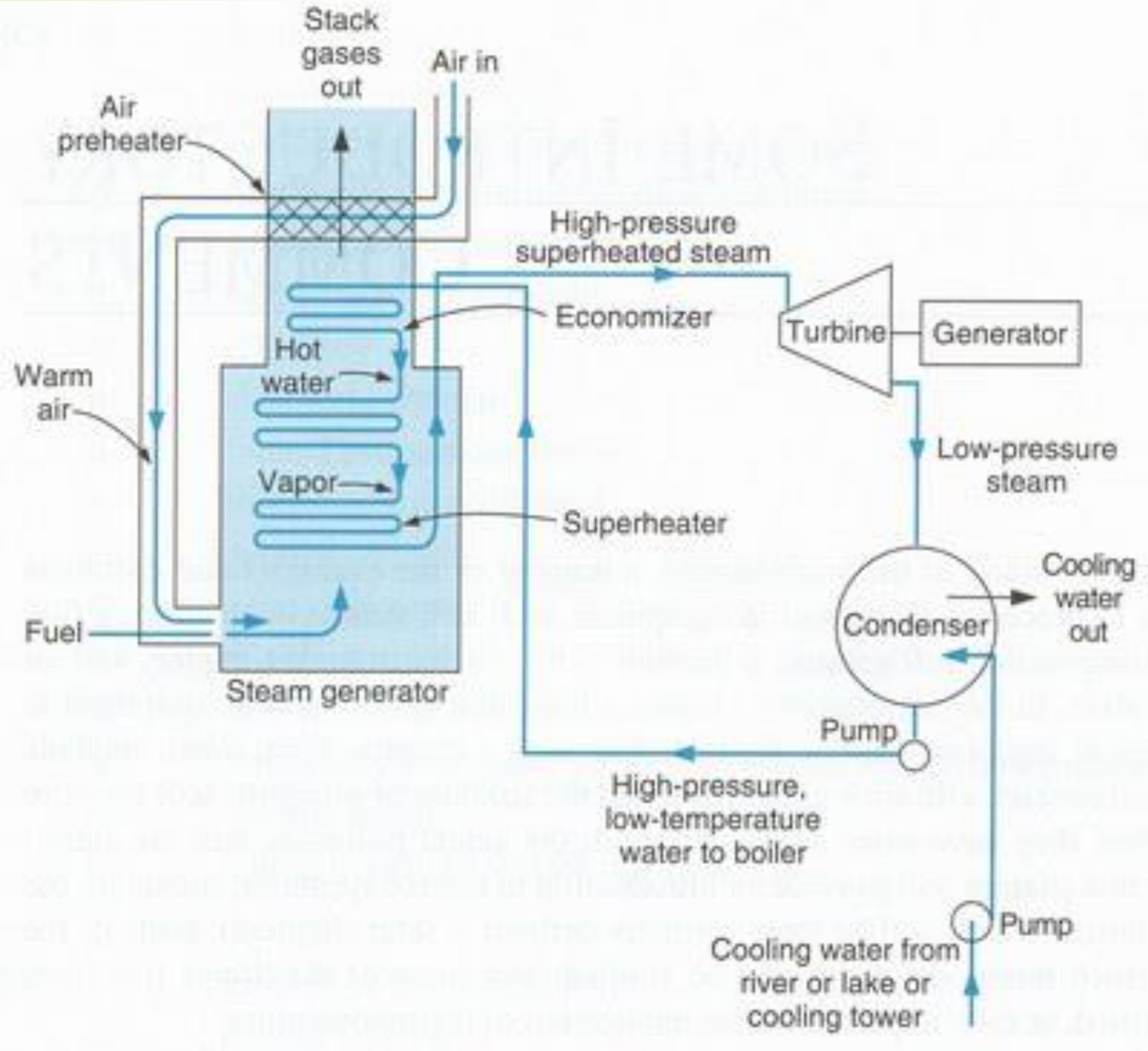
*Theory of Operation

Hydroelectric Power Plants

* Advantages of hydroelectric power plant

* Disadvantages of hydroelectric power plant

Steam Power Plants



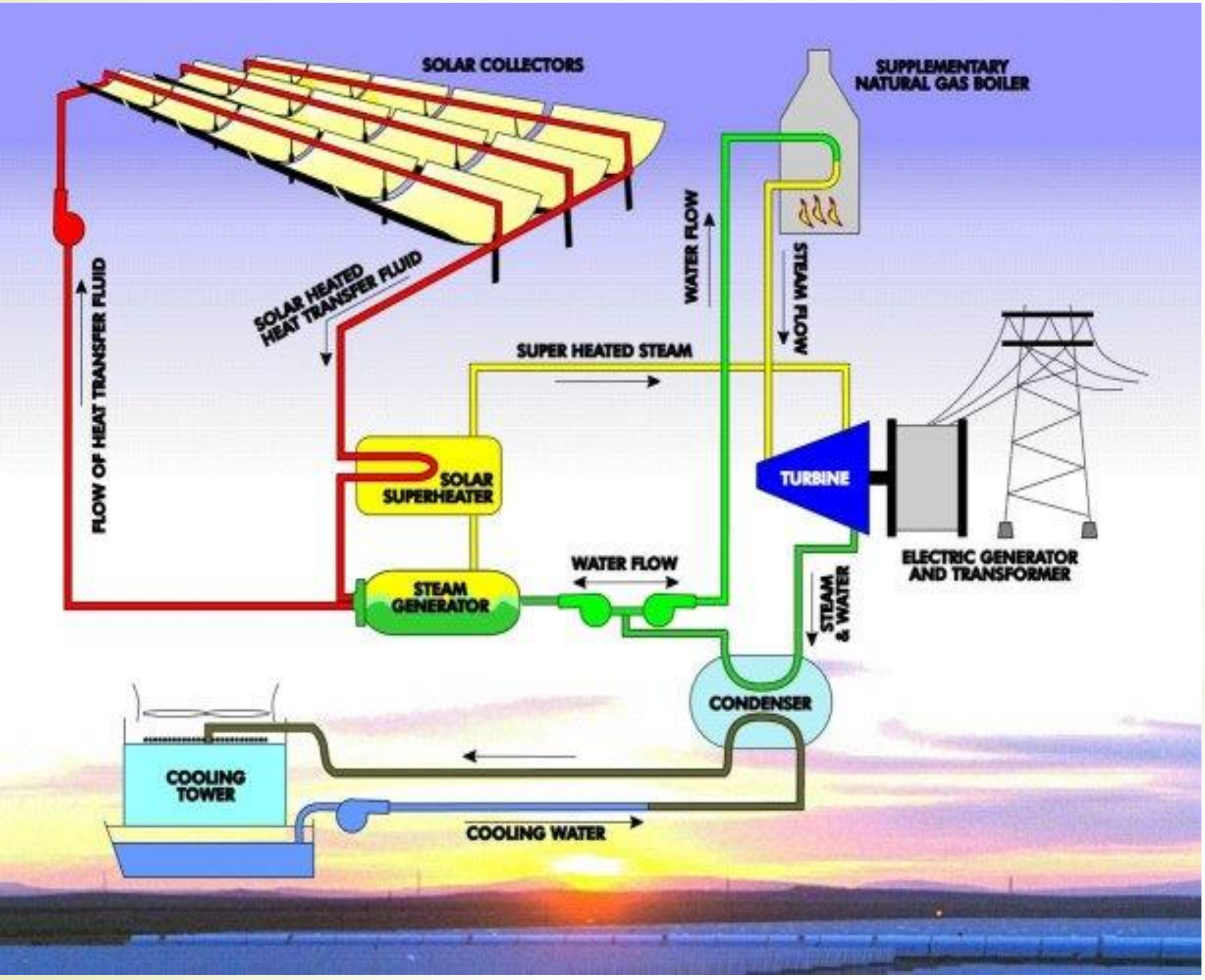
* Theory of Operation

Steam Power Plants

* Advantages of Steam Power Plants

* Disadvantages of Steam Power Plants

Solar Power Plants

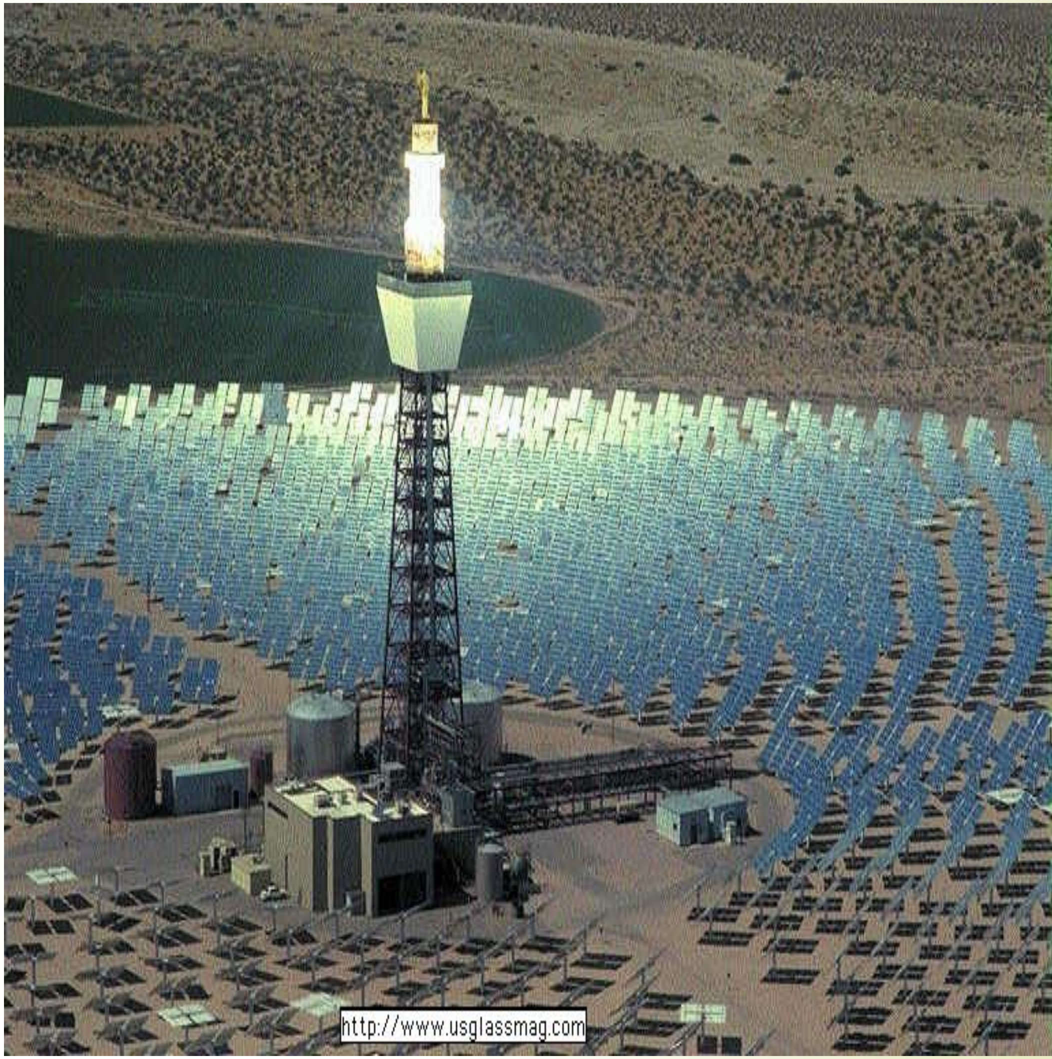


* Theory of operation

Solar Power Plants

* **Advantages of Solar Power Plants**

* **Disadvantages of Solar Power Plants**



Diesel Power Plants

* Theory of Operation

Diesel Power Plants

* Advantages of Diesel Power Plants

* Disadvantages of Diesel Power Plants

Gas turbine Power Plants

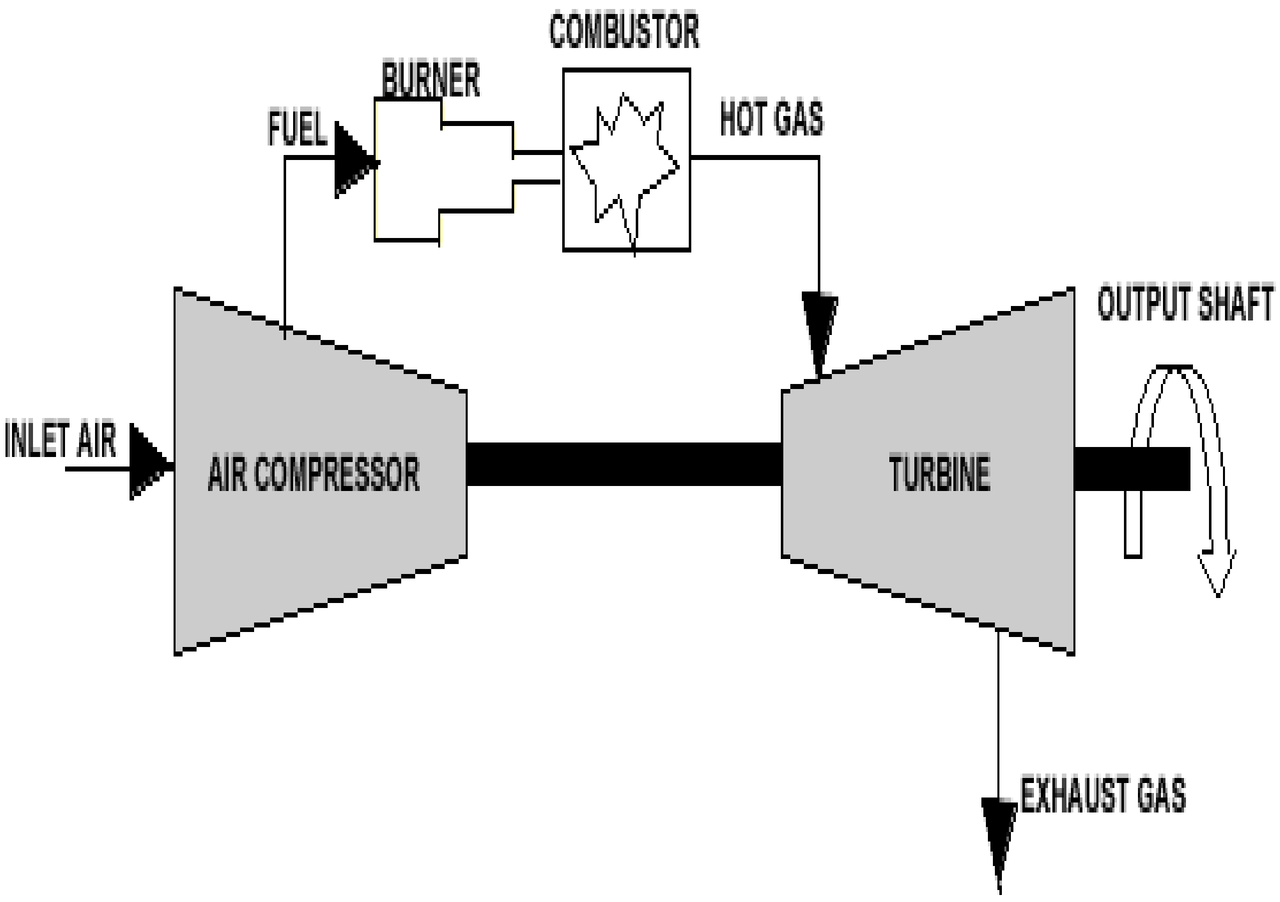


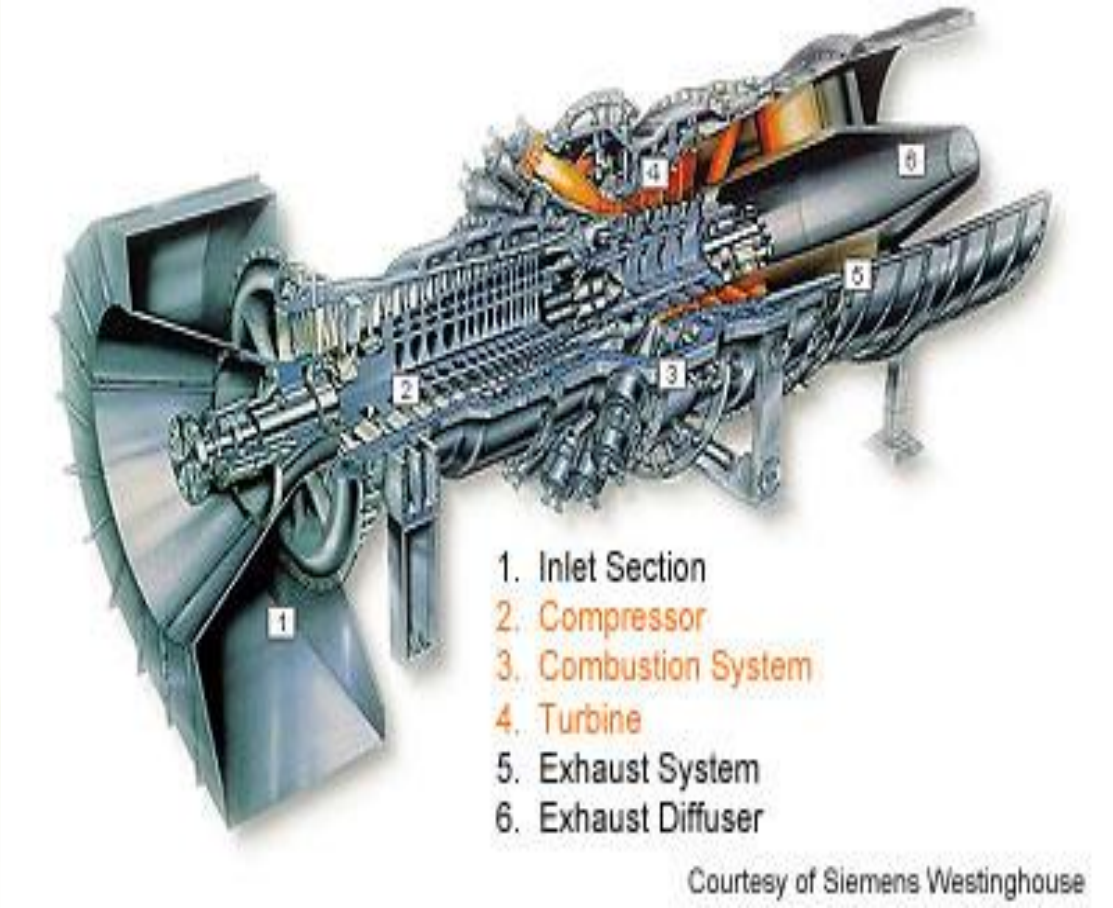
DIAGRAM OF TYPICAL LARGE GAS TURBINE

* Theory of operation

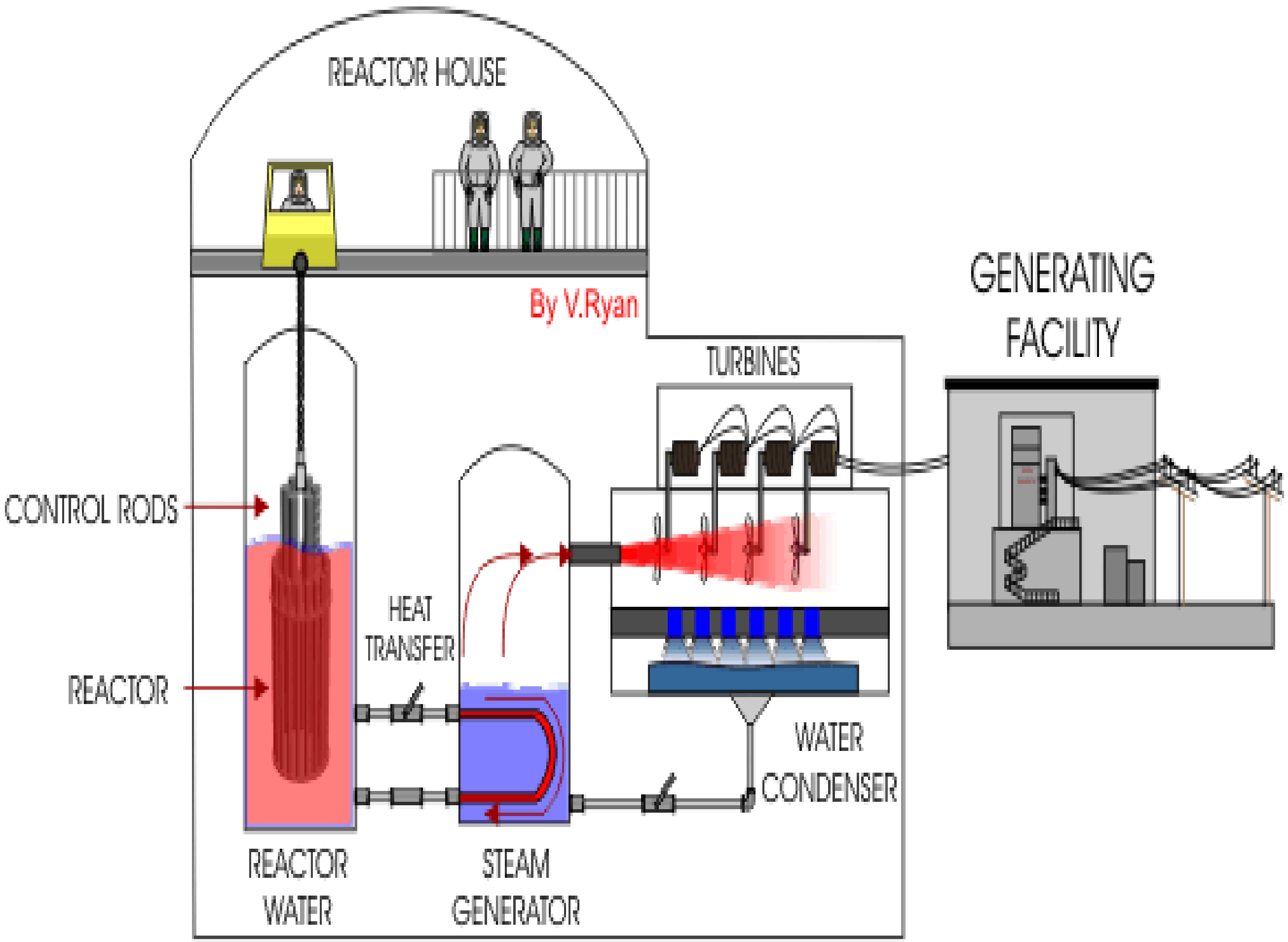
Gas turbine Power Plants

* Advantages of Gas-turbine Power Plants

* Disadvantages of Gas-turbine Power Plants



Nuclear Power Plants



* Theory of Operation

Nuclear Power Plants

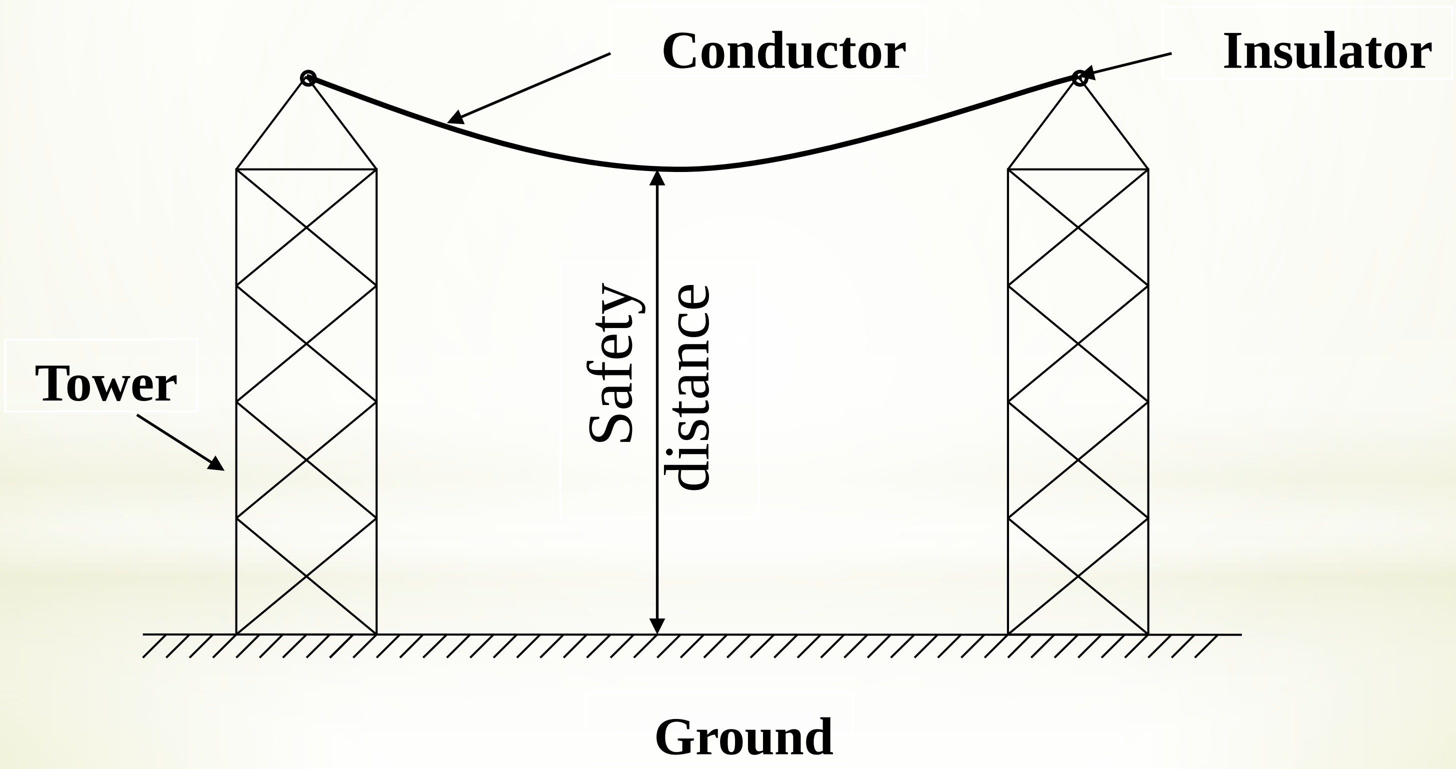
* Advantages of nuclear power plant

* Disadvantages of nuclear power plant

Contents

Chapter 1: Transmission Line Constants

1. **Main parts of over head T .L.**



Types of conductors

* Hard –drawn copper conductors .
* Aluminum- core steel–rein forced (ACSR).
* For rural electrification , all – aluminum conductors are used.
* Steel wires are used as earthing wires for over head T. L.

The main constants required are

* Resistance (R “ohm”).
* Inductance (L “hennery”) & corresponding X_L.
* Capacitance (C “ farad “) & corresponding X_c.

Resistance of over head T . L

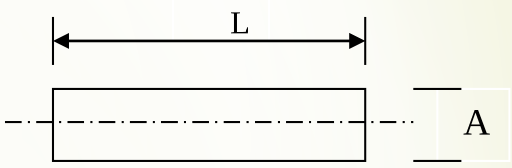
* $R = \rho L/A$ Ω
* Where :

  R: resistance of T.L (Ω)

  ρ : resistivity of T.L conductor (Ω .m)

  L : length of T.L (m)

  A : cross -section area (m^2)

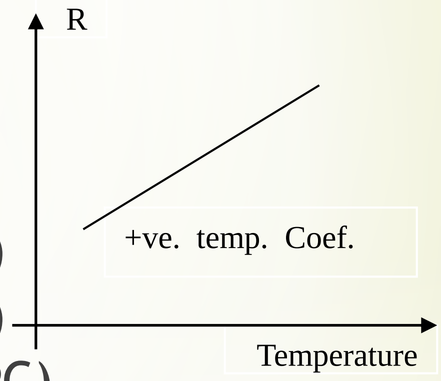


* For hard -drawn conductors : $\rho = 1.724 * 10^{-8}$ Ω.m at 20 °C
* For all – aluminum conductors : $\rho = 2.860 * 10^{-8}$ Ω.m at 20 °C

Effect of Temperature on Resistance

* The resistance of T.L increases with Temperature
* The rise in resistance depends on the Temperature coefficient of conductor material (α).

$$\frac{R_{t2}}{R_{t1}} = \frac{1/\alpha_0 + t_2}{1/\alpha_0 + t_1}$$



Where :

R_{t2} : Resistance of T .L at t_2 (Ω)

R_{t1} : Resistance of T .L at t_1 (Ω)

α_0 : Temperature coefficient at 0 °C (1/°C)

T_1 : First temperature (°C)

T_2 : Second temperature (°C)

* For hard – drawn copper α_0 = 0.0041 °/ C
  For aluminum α_0 = 0.0038 °/ C

Skin Effect on Conductors

when alternating current is passing through conductors, there is an unequal distribution of current in any cross – section of the conductor, the current density at the surface being higher than the current density at the center of the conductor . this causes larger power loss for a given r.m.s alternating current than the loss when the same value of DC is flowing in the conductor.

* $R_{ac} > R_{dc}$

$$R_{ac} = \frac{\text{Average power losses}}{I^2_{rms}}$$

$$\text{Skin effectratio} = \frac{R_{ac}}{R_{dc}}$$

Which depends on

* Permeability (Type of material).
* Area of cross section of the conductor.
* Frequency of the supply.

Inductance & Reactance of O.H.T.L

Inductance of overhead transmission line depends on:

* Size of conductor.
* Distance between conductors.
* Material of conductors.

Inductance & Reactance of O.H.T.L

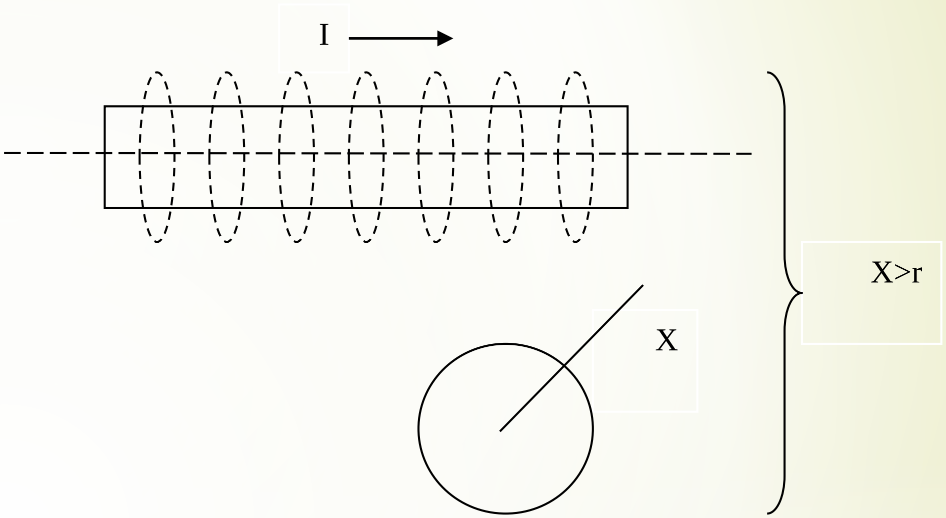
H = $\dfrac{I}{2\pi x}$ A.turn/m

H : electric field intensity.

B = $\dfrac{2*10^{-7}}{x} I$ wb/m²

H = $\dfrac{Ix}{2\pi r^{2}}$ A.turn/m

B = $\dfrac{2*10^{-7}}{r^{2}} Ix$ wb/m²



Inductance of Two Conductor (Single Phase)

$\lambda_{total} = \lambda_{inside} + \lambda_{outside}$

$$\lambda_{inside} = \int_0^r \frac{2*10^{-7} xI}{r^2} * \frac{\pi x^2}{\pi r^2} dx$$

$$\lambda_{inside} = \int_0^r \frac{2*10^{-7} x^3}{r^4} dx = \frac{2*10^{-7} I}{r^4} \frac{1}{4} x^4 \Big|_0^r$$

$$= \frac{2*10^{-7} I}{4r^4} * r^4 = \frac{1}{2} * 10^{-7} I \quad \text{linkages /m}$$

Continue

$$\lambda_{outside} = \int_r^D \frac{2*10^{-7} xI}{r^2} * \frac{\pi r^2}{\pi x^2} dx$$

$$= \int_r^D \frac{2*10^{-7I}}{X} dx = 2*10^{-7} I \ln \frac{D}{r}$$

$$\lambda_{outside} = 2*10^{-7} I \ln \frac{D}{r} \quad \text{linkages/m}$$

$$\lambda_{total} = \lambda_{inside} + \lambda_{outside}$$

$$= \frac{1}{2} *10^{-7} I + 2*10^{-7} I \ln \frac{D}{r}$$

Continue

$L_1 = \frac{\lambda_1}{I} = 10^{-7}(2\ln\frac{D}{r} + \frac{1}{2})$ H/m

In case of non magnetic or hollow conductor

$L_t = L_1 + L_2 = 2L_1$ (Two identical conductors)

−7

In Case of Magnetic Conductor

$$L = 10^{-7}(\ln\frac{D}{r} + \frac{1}{2}\frac{\mu}{\mu_o})$$

μ : permeability

μ_r : relative permeability

$$X_t = 2\pi f L_t \quad \Omega$$

$$\lambda = 10^{-7} I(2\ln\frac{D}{r} + \frac{1}{2}) = 2*10^{-7} I(\ln\frac{D}{r} + \frac{1}{4})$$

Continue

$$\lambda = 2*10^{-7} I \ln \frac{D}{re^{-0.25}}$$

Where:

r e $^{-.025}$: geometric mean radius (GMR)

or self – geometric mean distance.

D : distance bet. Two conductors

or mutual distance between two conductors

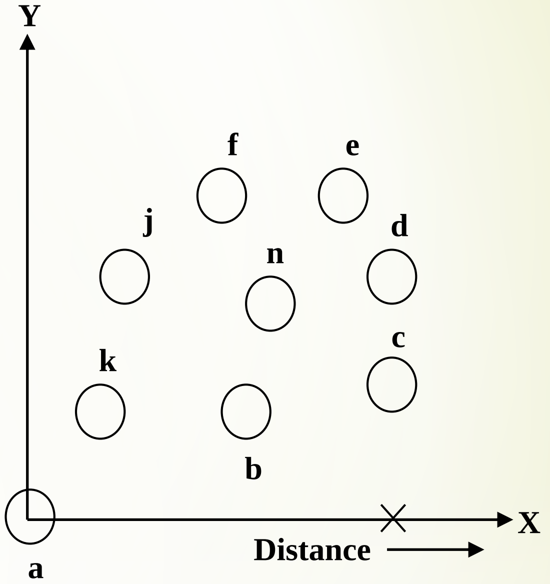
General Expression for Inductance of a Group of Parallel Wires

$$\lambda_a = 10^{-7}\left(\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{D_{ax}}{r}\right)$$

$$\lambda_{total} = 10^{-7}\left(\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ \ln\frac{D_{ax}}{r}\right.$$

$$+ 2I_p \ln\frac{D_{bx}}{D_{ab}}$$

$$\left. + .. + 2In \ \ln\frac{D_{nx}}{D_{an}}\right)$$



$$I_a + I_b + I_c + ... + I_n = 0$$

" Closed loop"

$$I_n = -(I_a + I_b + I_c + ... + I_{n-1})$$

by substitution

Continue

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a(\ln\frac{D_{ax}}{r} - \ln\frac{D_{nx}}{D_{an}})$$

$$+ 2I_b(\ln\frac{D_{bx}}{D_{ab}} - \ln\frac{D_{nx}}{D_{ab}})$$

$$+ \ldots\ldots\ldots + 2I_{n-1}(\ln\frac{D_{nx}}{D_{an}})]$$

$$\text{since}, \ln A - \ln B = \ln\frac{A}{B}$$

Continue

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a(\ln\frac{D_{ax}}{r}.\frac{D_{an}}{D_{nx}}))$$

$$+ 2I_b(\ln(\frac{D_{bx}}{D_{ab}}.\frac{D_{an}}{D_{nx}}))$$

$$+ ... + 2I_{n-1}(\ln(\frac{D_{n-1x}}{D_{an-1}}.\frac{D_{an}}{D_{nx}}))]$$

Continue

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a(\ln\frac{D_{ax}}{r}.\frac{D_{an}}{D_{nx}}))$$

$$+2I_b(\ln(\frac{D_{bx}}{D_{ab}}.\frac{D_{an}}{D_{nx}}))$$

$$+\ldots+2I_{n-1}(\ln(\frac{D_{n-1x}}{D_{an-1}}.\frac{D_{an}}{D_{nx}}))]$$

Continue

When X approaches infinity,

$$\frac{D_{ax}}{D_{nx}} = \frac{D_{bx}}{D_{nx}} = \ldots\ldots\ldots = \frac{D_{n-1}}{D_{nx}} = 1$$

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{D_{an}}{r}$$

$$+ 2I_b \ln\frac{D_{an}}{D_{ab}}$$

$$+ \ldots + 2I_{n-1} \ln\frac{D_{an}}{D_{an-1}}]$$

Continue

$$\text{Since,}\quad -\ln A = \ln(A)^{-1} = \ln\frac{1}{A}$$

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{1}{r} + 2I_b \ln\frac{1}{D_{ab}}$$

$$+ \ldots + 2I_{n-1}\ln\frac{1}{D_{an-1}}$$

$$+ 2\ln D_{an}(I_a + I_b + \ldots + I_{n-1})]$$

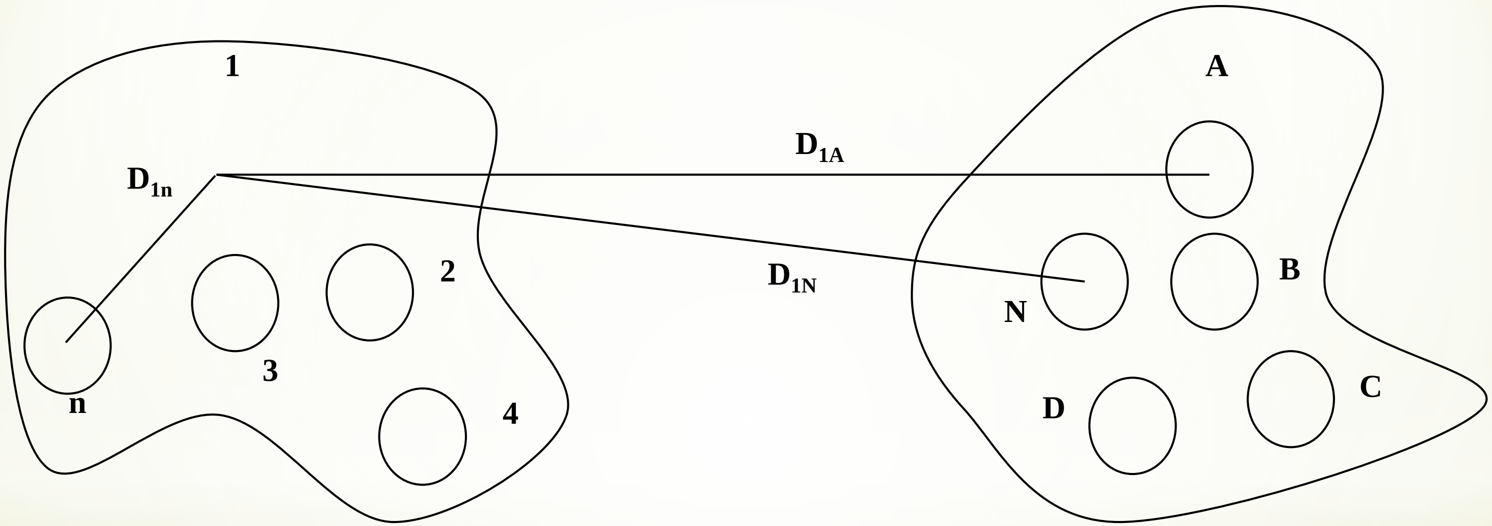
Continue

$$\lambda_a = 10^{-7}[\frac{I_a}{2}\frac{\mu}{\mu_0} + 2I_a \ln\frac{1}{r} + 2I_b \ln\frac{1}{D_{ab}} + \ldots + 2I_f \ln\frac{1}{D_{af}} + 2I_n \ln\frac{1}{D_{an}}]$$

$$L_a = \frac{\lambda_a}{I_a} \quad \text{m/H}$$

$$X_{La} = 2\pi f L_a \quad \Omega$$

General Expression for Inductance of Two Parallel Conductors of Irregular Cross-Section



Continue

The linkages about the small element I can be obtained by,

$$\lambda_1 = 2 * 10^{-7} * \left(\frac{I}{n}\right)\left(\frac{1}{4} + \ln\frac{1}{r_1} + \ln\frac{1}{D_{12}} + \ln\frac{1}{D_{13}} + \ldots + \ln\frac{1}{D_{1n}} - \ln\frac{1}{D_{1a}} - \ln\frac{1}{D_{1B}} \ldots - \ln\frac{1}{D_{1n}}\right) \quad \text{Linkage/m}$$

Similarly, $\lambda_2, \lambda_3, \ldots\ldots, \lambda_n$ can be obtained

$$\lambda_{total} = \lambda_1 + \lambda_2 + \lambda_3 + \ldots\ldots + \lambda_n$$

The linkages about the conductor are given by (λ_{total})

$$\lambda_{total} = \frac{2*10^{-7}}{n^2} I[\frac{1}{4} + \ln\frac{1}{r_1} + \ln\frac{1}{D_{12}} + \ldots + \ln\frac{1}{D_{1n}}$$

$$+\frac{1}{4} + \ln\frac{1}{r_2} + \ln\frac{1}{D_{21}} + \ldots + \ln\frac{1}{D_{2n}}$$

$$+\frac{1}{4} + \ln\frac{1}{r_n} + \ln\frac{1}{D_{n1}} + \ldots + \ln\frac{1}{D_{nn}}$$

$$-\ln\frac{1}{D_{1A}} - \ln\frac{1}{D_{1B}} - \ldots - \ln\frac{1}{D_{1n}}$$

$$-\ln\frac{1}{D_{2A}} - \ln\frac{1}{D_{2B}} - \ldots\ldots - \ln\frac{1}{D_{2n}}]$$

Continue

$$\text{since}\ \ln\frac{1}{D_1} - \ln\frac{1}{D_2} = \ln\frac{1/D_1}{1/D_2} = \ln\frac{D_2}{D_1}$$

$$\frac{1}{n^2}\ln X = \ln\sqrt[n^2]{X}$$

$$\lambda_{total} = 2*10^{-7} I[\frac{1}{4n} + \ln\frac{\sqrt[n^2]{D_{1A}D_{1B}\ldots\ldots\ldots D_{1n}D_{2A}D_{2B}\ldots\ldots\ldots\ldots D_{2n}}}{\sqrt[n^2]{r_1 D_{12}\ldots\ldots D_{1n} r_2 D_{21}\ldots\ldots D_{2n}\ldots\ldots r_n D_{n1}\ldots}}]$$

Continue

If n is taken as infinity, the term $\frac{1}{4n}$ is negligible and approaches to zero, thus,

$$\lambda = 2*10^{-7} I \ln \frac{\sqrt[n^2]{D_{1A}D_{1B}\ldots\ldots D_{1n}D_{2A}D_{2B}\ldots\ldots D_{2n}\ldots\ldots}}{\sqrt[n^2]{r_1 D_{12}\ldots\ldots D_{1n} r_2 D_{21}\ldots\ldots\ldots\ldots\ldots\ldots D_{2n} r_n}}$$

$$\lambda = 2*10^{-7} I \ln \frac{D_m}{D_s} \quad H/m$$

Continue

$$L = \frac{\lambda}{I}$$

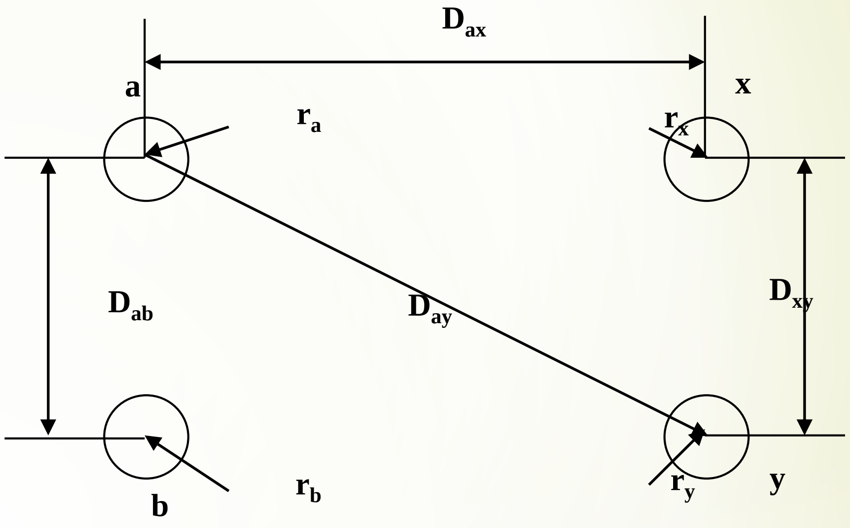
Definitions:

D_m : (Geometric mean distance) “GMD“ : is the distance between the one conductor in coil side and the other conductors in the other coil side.

Ds : (self – geo metric mean distance) “SGMD“ or (Geometric mean radius)”GMR” is the distance between the one conductor in coil side and the other conductors in the same coil side

Inductance of Two Parallel Wires with Single–Phase Circuit

Using general expression



$$D_m = D$$

$$D_s = re^{-0.25}$$

$$L = L_a + L_b$$ H/m (For both conductors)

Inductance of Single-Phase Line with Multi–Conductors

using general expression

$$L = 2*10^{-7} \ln \frac{D_m}{D_s}$$ H/m

For identical conductors, $r_a = r_b = r_x = r_y = r$

$$D_m = \sqrt[2*2]{D_{ax}.D_{ay}\ .D_{bx}.D_{by}}$$

Where;

$$D_{ay} = \sqrt{(D_{ax})^2 + (D_{xy})^2}$$

Continue

$$D_s = \sqrt[(2)^2]{r_a . D_{ab} . r_b . D_{ba}} = \sqrt[4]{r_a D_{ab} r_b D_{ba}}$$

$$r_a = r_b = r \qquad D_{ab} = D_{ba}$$

$$\boxed{Note: r_a = re^{-0.25}} \qquad D_s = \sqrt{r D_{ab}}$$

If $D_{ab}=D_{xy}$, then D_s of the conductors on the left-hand side as well as on the right-hand side is equal.

With Our Best Wishes

Transmission and Distribution of Electrical Power

Course Staff

Thank You

For Your Attention

Mohamed Ahmed Ebrahim