MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS **L1**

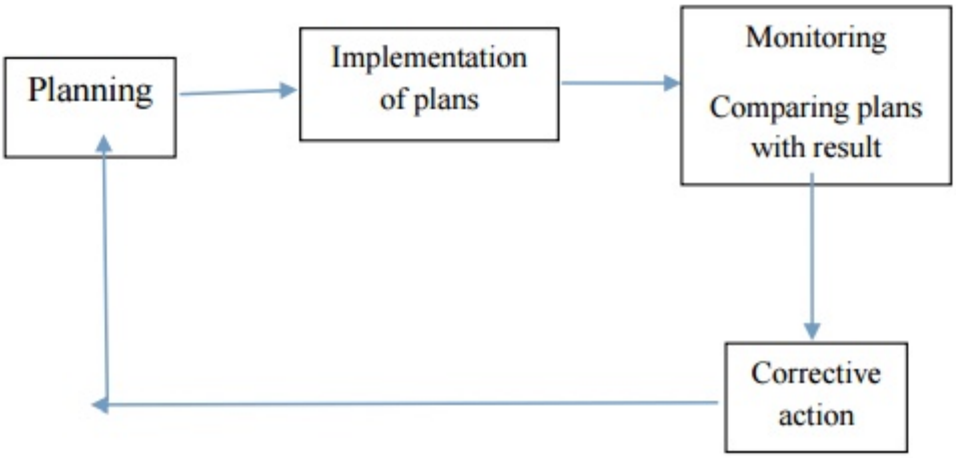
EEE **III/V**

Course Name with Code :**Power System Analysis/ 19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **I – Introduction** **Date of Lecture:**

Topic of Lecture: Need for system planning and operational studies
Introduction: Planning and operation of power system - Operational planning covers the whole period ranging from the incremental stage of system development. The system operation engineers at various points like area, space, regional & national load dispatch of power
Prerequisite knowledge for Complete understanding and learning of Topic: ✓ System ✓ Components of power system ✓
Detailed content of the Lecture: **Planning and operation of power system:** Power system planning and operational analysis covers the maintenance of generation, transmission and distribution facilities **Steps:** ➢ Planning of power system ➢ Implementation of the plans ➢ Monitoring system ➢ Compare plans with the results ➢ If no undesirable deviation occurs, then directly go to planning of system ➢ If undesirable deviation occurs then take corrective action and then go to planning of the system



Planning and operation of power system

Planning and operation of power system the following analysis are very important

(a). Load flow analysis

(b). Short circuit analysis

(c). Transient analysis

(a) Load flow analysis

- Electrical power system operate - Steady state mode
- Basic calculation required to determine the characteristics of this state is called as Load flow
- Power flow studies - To determine the voltage current active and reactive power flows in given power system

(b) Short circuit studies

- To determine the magnitude of the current flowing throughout the power system at various time intervals after fault
- The objective of short circuit analysis - To determine the current and voltages at different location of the system corresponding to different types of faults

(c) Transient stability analysis

- The ability of the power system consisting of two (or) more generators to continue to operate after change occur on the system is a measure of the stability
- In power system the stability depends on the power flow pattern generator characteristics system loading level and the line parameters

Video Content / Details of website for further learning (if any):

https://www.brainkart.com/article/Analysis-For-System-Planning-and-Operational-Studies_12398/

Important Books/Journals for further learning including the page nos.:

John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp.1-2

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L2

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **I – Introduction** **Date of Lecture:**

Topic of Lecture: Introduction to Restructuring

Introduction:

Restructuring of power industry aims **at abolishing the monopoly in generation and trading sectors**, thereby introducing competition at various levels, wherever possible. ... Thus the electricity in restructured power market, is dispatched with the help of either power exchange or the pool/system operator.

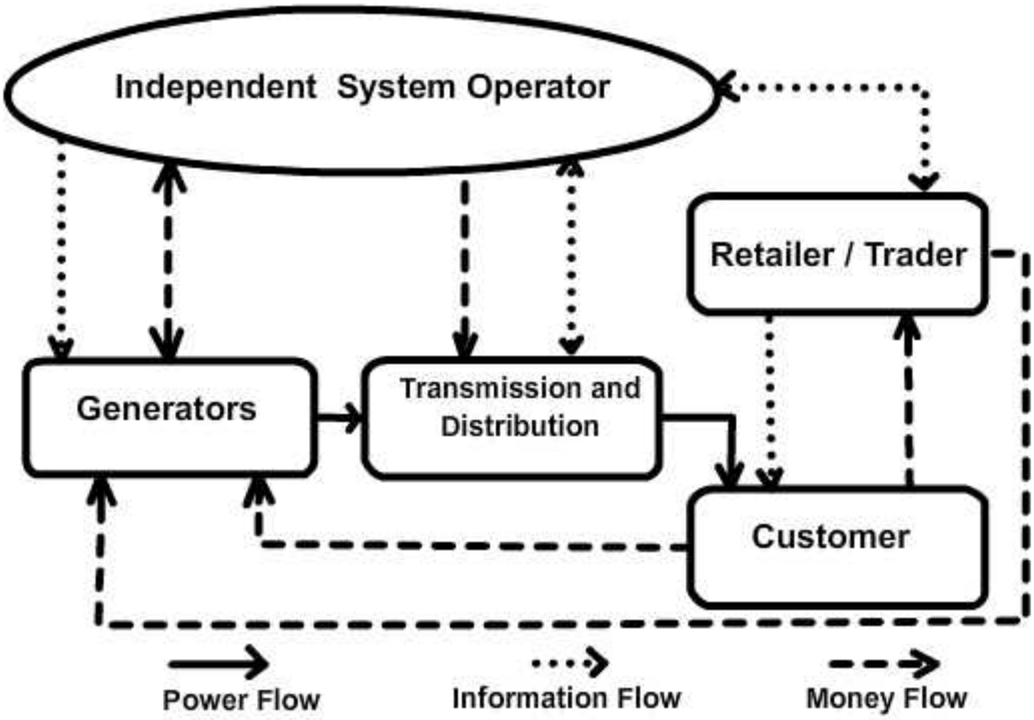
Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Power system
- ✓ Transmission system

Detailed content of the Lecture:

- The process of deregulation has taken different formats in different parts of the world. Also, the reasons for power sector to adopt the reforms vary from country to country. For the developed countries, introduction of competition to achieve social welfare was probably the most important reason.
- On the other hand, the developing countries mainly banked on the capacity addition through entry of private players.
- It is observed that neither, there is lone reason for driving deregulation of power industry nor is there a single objective of the same. The restructuring process starts with the unbundling of the originally vertically integrated utility.
- This essentially leads to separate the activities involved in an integrated power system leading to creation of functional partition amongst them.
- For example, the unbundling of power industry involves separating transmission activity from the generation activity. Further, distribution can be separated from transmission.
- In contrast to the vertically integrated case where all the generation is owned by the same utility, there is a scope for private players to sell their generation at competitive prices.

- The generators owned by the earlier vertically integrated utility will then compete with these private generators.
- The transmission sector being a natural monopoly is most unlikely to have competing players in the sector. This is because for natural monopolies like transmission companies, the business becomes profitable only when output is large enough.
- Figure shows the representative structure of deregulated power system. In contrast to the vertically integrated utility structure, it can be seen that there are many alternative paths along which the money flows.
- It is evident that there are many more other entities present, apart from the vertically integrated utility and the customers. It should be noted that there can be many more versions of deregulated structure.



Various Entities Involved in Deregulation:

The introduction of deregulation has introduced several new entities in the electricity market place and has simultaneously redefined the scope of activities of many of the existing players. Variations exist across market structures over how each entity is particularly defined and over what role it plays in the system. However, on a broad level, the following entities can be identified:

1. **Genco (Generating Company):** Genco is an owner-operator of one or more generators that runs them and bids the power into the competitive marketplace. Genco sells energy at its sites in the same manner that a coal mining company might sell coal in bulk at its mine.
2. **Transco (Transmission Company):** Transco moves power in bulk quantities from where it is produced to where it is consumed. The Transco owns and maintains the transmission facilities, and may perform many of the management and engineering functions required to ensure the smooth running of the system.

Discom (Distribution Company): It is the owner-operator of the local power delivery system, which delivers power to individual businesses and homeowners. In some places, the local distribution function is combined with retail function.

3. **Resco (Retail Energy Service Company):** It is the retailer of electric power. Many of these will be the retail departments of the former vertically integrated utilities. A Resco buys power from Gencos and sells it directly to the consumers. Resco does not own any electricity network physical assets.
4. **Market Operator:** Market operator provides a platform for the buyers and sellers to sell and buy the electricity. It runs a computer program that matches bids and offers of sellers and buyers. The market settlement process is the responsibility of the market operator. The market operator typically runs a day-ahead market. The near-real-time market, if any, is administered by the system operator.
5. **System Operator (SO):** The SO is an entity entrusted with the responsibility of ensuring the reliability and security of the entire system. It is an independent authority and does not participate in the electricity market trades.
6. **Customers:** A customer is an entity, consuming electricity. In a completely deregulated market where retail sector is also open for competition, the end customer has several options for buying electricity. It may choose to buy electricity from the spot market by bidding for purchase, or may buy directly from a Genco or even from the local retailing service company.

Video Content / Details of website for further learning (if any):
https://nptel.ac.in/courses/108/101/108101005/

Important Books/Journals for further learning including the page nos.:
George Hondroyiannis, “Economic Change and Restructuring”, Hybrid (Transformative Journal), volume 54, Issue 3, August 2021.

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L3

EEE

III/V

Course Name with Code :Power System Analysis/19EEC10

Course Faculty : Dr.N.Mohananthini

Unit : I – Introduction **Date of Lecture:**

Topic of Lecture: Single line diagram

Introduction:

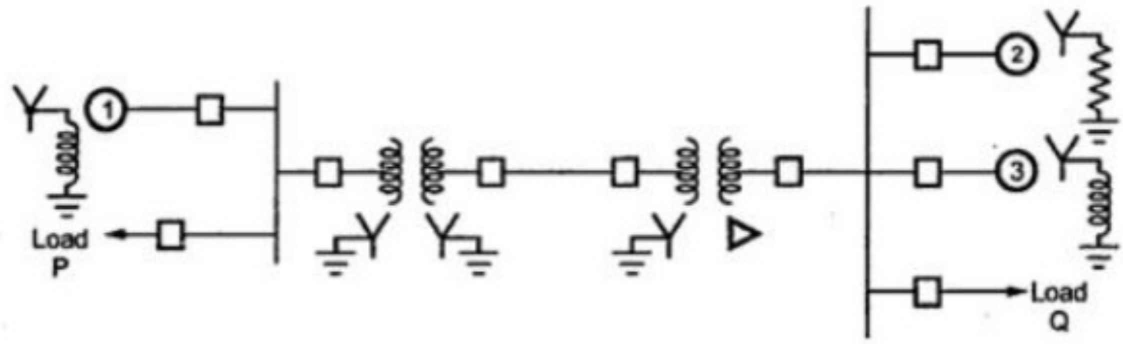
- Single line diagram is a diagrammatic representation of power systems in which the components are represented by their symbols and interconnections between them are shown by a straight line

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Transmission system
- ✓ Distribution system

Detailed content of the Lecture:

- The purpose of the single line diagram is to supply in shortest form the significant information about the system. Above Figure show single line diagram of power system



- One line diagram of a very simple power system
- Two generators one grounded through a reactor and one through a resister connected to a bus and through a step up transformer to a transmission lines
- Another generator grounded a reactor is connected a bus and through a transformer to the opposite end of the transmission line

- A load is connected to each bus
- On the diagram information about the loads the ratings of the generators and transformers and reactance of different components of the circuit is often given
- It is important to know the location of points where a system is connected to ground to calculate the amount of current flowing when an unsymmetrical fault involving ground occur

IMPEDANCE DIAGRAM

The impedance diagram on single-phase basis for use under balanced conditions can be easily drawn from the SLD. The following assumptions are made in obtaining the impedance diagrams.

Assumptions:

- The single phase transformer equivalents are shown as ideals with impedance on appropriate side (LV/HV),
- The magnetizing reactance of transformers are negligible,
- The generators are represented as constant voltage sources with series resistance or reactance,
- The transmission lines are approximated by their equivalent Models,
- The loads are assumed to be passive and are represented by a series branch of resistance or reactance and
- Since the balanced conditions are assumed, the neutral grounding impedance do not appear in the impedance diagram.

REACTANCE DIAGRAM

With some more additional and simplifying assumptions, the impedance diagram can be simplified further to obtain the corresponding reactance diagram. The following are the assumptions made.

Additional assumptions:

- The resistance is often omitted during the fault analysis. This causes a very negligible error since, resistances are negligible
- Loads are Omitted
- Transmission line capacitances are ineffective &
- Magnetizing currents of transformers are neglected.

Video Content / Details of website for further learning (if any):

https://www.brainkart.com/article/Single-Line-diagram-of-an-Electrical-system_12402/
https://www.brainkart.com/article/Reactance-Diagram_12404/

Important Books/Journals for further learning including the page nos.:

John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp. 34-37

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS **L4**

EEE **III/V**

Course Name with Code :**Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **I – Introduction** **Date of Lecture:**

Topic of Lecture: Per Phase and Per Unit Analysis

Introduction:

- During the power system analysis, it is a usual practice to represent current, voltage, impedance, power, etc., of an electric power system in per unit or percentage of the base or reference value of the respective quantities.
- The numerical per unit (pu) value of any quantity is its ratio to a chosen base value of the same dimension.
- Thus a pu value is a normalized quantity with respect to the chosen base value.

Prerequisite knowledge for Complete understanding and learning of Topic:

1. Per Unit
2. Impedance

Detailed content of the Lecture:

Per unit value.

- The per unit value of any quantity is defined as the ratio of the actual value of the any quantity to the base value of the same quantity as a decimal.
- The percent value is 100 times the pu value. Both the pu and percentage methods are simpler than the use of actual values.
- Further, the main advantage in using the pu system of computations is that the result that comes out of the sum, product, quotient, etc. of two or more pu values is expressed in per unit itself.

Advantages of per unit system

- Per unit data representation yields valuable relative magnitude information.
- Circuit analysis of systems containing transformers of various transformation ratios is greatly simplified.

- The p.u systems are ideal for the computerized analysis and simulation of complex power system problems.
- Manufacturers usually specify the impedance values of equivalent in per unit of the equipment rating. If the any data is not available, it is easier to assume its per unit value than its numerical value.
- The ohmic values of impedances are refereed to secondary is different from the value as referee to primary. However, if base values are selected properly, the p.u impedance is the same on the two sides of the transformer.
- The circuit laws are valid in p.u systems, and the power and voltages equations are simplified since the factors of √3 and 3 are eliminated.

- In an electrical power system, the parameters of interest include the current, voltage, complex power (VA), impedance and the phase angle.
- Of these, the phase angle is dimensionless and the other four quantities can be described by knowing any two of them. Thus clearly, an arbitrary choice of any two base values will evidently fix the other base values.
- Normally the nominal voltage of lines and equipment is known along with the complex power rating in MVA. Hence, in practice, the base values are chosen for complex power (MVA) and line voltage (KV).
- The chosen base MVA is the same for all the parts of the system. However, the base voltage is chosen with reference to a particular section of the system and the other base voltages (with reference to the other sections of the systems, these sections caused by the presence of the transformers) are then related to the chosen one by the turns-ratio of the connecting transformer.
- If Ib is the base current in kilo amperes and Vb, the base voltage in kilo volts, then the base MVA is, Sb = (VbIb). Then the base values of current & impedance are given by

Base current (kA), Ib = MVAb/KVb

= Sb/Vb

Base impedance, Zb = (Vb/Ib) = (KVb2 / MVAb)

Hence the per unit impedance is given by Zpu = Zohms/Zb

= Zohms (MVAb/KVb2)

In 3-phase systems, KVb is the line-to-line value & MVAb is the 3-phase MVA. [1-phase MVA = (1/3) 3-phase MVA].

Video Content / Details of website for further learning (if any):

https://www.brainkart.com/article/Per-Phase-and-Per-Unit-Representation_12405/

Important Books/Journals for further learning including the page nos.:

John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp. 25-29

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L5

EEE

III/V

Course Name with Code :**Power System Analysis/ 19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **I – Introduction** **Date of Lecture:**

Topic of Lecture: Primitive network and Bus Incidence matrix

Introduction:

- The primitive network is a set of uncoupled elements of the network.
- These network equations can be formed either in the bus frame of reference, or loop frame of reference using either impedance or admittance parameters.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Network
- ✓ Impedance
- ✓ Reactance

Detailed content of the Lecture:

- The matrices of the interconnected network have been defined. These matrices contain complete information about the network connectivity, the orientation of current, the loops and cut sets. However, these matrices contain no information on the nature of the elements which form the interconnected network.
- The complete behaviour of the network can be obtained from the knowledge of the behaviour of the individual elements which make the network, along with the incidence matrices.
- An element in an electrical network is completely characterized by the relationship between the current through the element and the voltage across it.
- General representation of a network element: In general, a network element may contain active or passive components.
- Figure 2 represents the alternative impedance and admittance forms of representation of a general network component.

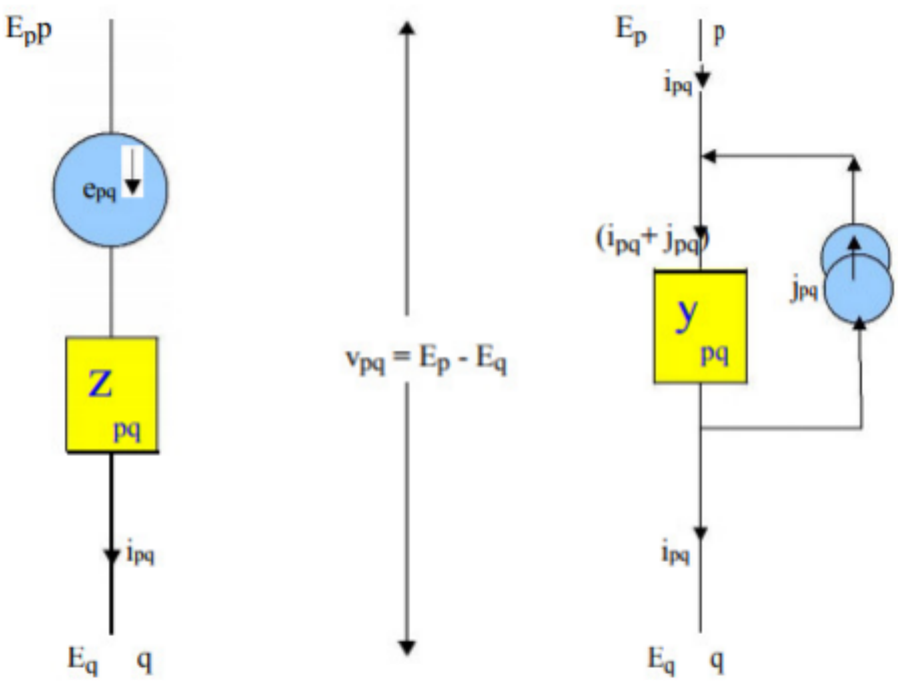


Fig.2 Representation of a primitive network element

(a) Impedance form (b) Admittance form

Performance equation: Each element p-q has two variables, vpq and ipq. The performance of the given element p-q can be expressed by the performance equations as under:

$$v_{pq} + e_{pq} = z_{pq} i_{pq} \qquad \text{(in its impedance form)}$$

$$i_{pq} + j_{pq} = y_{pq} v_{pq} \qquad \text{(in its admittance form)}$$

- A set of non-connected elements of a given system is defined as a primitive Network and an element in it is a fundamental element that is not connected to any other element.
- In the equations above, if the variables and parameters are replaced by the corresponding vectors and matrices, referring to the complete set of elements present in a given system, then, we get the performance equations of the primitive network in the form as under:

$$v + e = [z]\, i$$

$$i + j = [y]\, v$$

- Primitive network matrices: A diagonal element in the matrices, [z] or [y] is the self impedance $z_{pq\text{-}pq}$ or self admittance, $y_{pq\text{-}pq}$.
- An off-diagonal element is the mutual impedance, $z_{pq\text{-}rs}$ or mutual admittance, ypq-rs, the value present as a mutual coupling between the elements p-q and r-s.
- The primitive network admittance matrix, [y] can be obtained also by inverting the primitive impedance matrix, [z]. Further, if there are no mutually coupled elements in the given system, then both the matrices, [z] and [y] are diagonal.

Video Content / Details of website for further learning (if any): http://www.gvpcew.ac.in/LN-CSE-IT-22-32/EEE/3-Year/PSA-Unit-1.pdf
Important Books/Journals for further learning including the page nos.: John J.Grainger and W.D.Stevenson Jr., “Power System Analysis”, Tata Mc Graw-Hill, Sixth reprint, 2010, pp. 239-245

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

LECTURE HANDOUTS

L6

EEE

III/V

Course Name with Code **:Power System Analysis/19EEC10**

Course Faculty **: Dr.N.Mohananthini**

Unit **: I – Introduction** **Date of Lecture:**

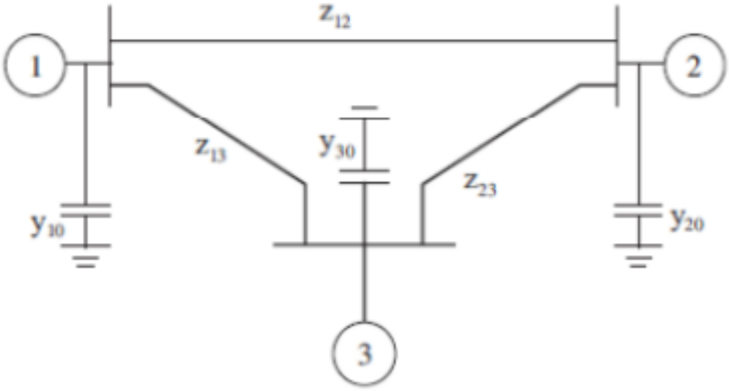
Topic of Lecture: Formation of Y-bus using inspection method and Gaussian elimination method
Introduction: ➢ Y-bus may be formed by inspection method, only if there is no mutual coupling between the lines. ➢ Every transmission line should be represented equivalent. Shunt impedances are added to diagonal element corresponding to the buses at which these are connected. ➢ The off diagonal elements are unaffected.
Prerequisite knowledge for Complete understanding and learning of Topic: ✓ Impedance ✓ Admittance
Detailed content of the Lecture: **BUS** ➢ The meeting point of various components in a power system is called a bus. The bus is a conductor made of copper or aluminum having negligible resistance. The buses are considered as points of constant voltage in a power system. **BUS IMPEDANCE MATRIX** ➢ The matrix consisting of driving point impedances and impedances of the network of a power system is called bus impedance matrix. It is given by the inverse of bus admittance matrix and it is denoted as Zbus . The bus impedance matrix is symmetrical. **BUS ADMITTANCE MATRIX** ➢ The matrix consisting of the self and mutual admittances of the network of a power system is called bus admittance matrix. It is given by the admittance matrix Y in the node basis matrix equation of a power system and it is denoted as Y_{bus}. The bus admittance matrix is symmetrical. ➢ Bus admittance matrix (Y_{Bus}) for an n-bus power system is square matrix of size n × n. The diagonal elements represent the self or short circuit driving point admittances with respect

to each bus.

- The off-diagonal elements are the short circuit transfer admittances (or) the admittances common between any two number of buses. In other words, the diagonal element y_{ii} of the Y_{Bus} is the total admittance value with respect to the i^{th} bus and y^{ik} is the value of the admittance that is present between i^{th} and k^{th} buses.

DIRECT INSPECTION METHOD

- Formulation of Y_{Bus} by direct inspection method is suitable for the small size networks. In this method the Y_{Bus} matrix is developed simply by inspecting structure of the network without developing any kind of equations. Let us consider a 3-bus power system shown in figure below:



Since $[B]^T * i$ is zero because, algebraic sum of all the currents meeting at a node is zero. The source current matrix [j] can be partitioned into,

$$[j] = \begin{bmatrix} j_b \\ j_\ell \end{bmatrix}$$

Where j_b is the source acting in parallel across the branches

$$\therefore [B]^T * [j] = [B]^T * [j_b] = I_{BR}$$

$$I_{BR} = [B]^T * y * [B] * V_{BR}$$

$$I_{BR} = [Y_{BR}] * V_{BR} \quad \text{(or)} \quad I_{BR} = Y_{BR} * V_{BR}$$

$$Y_{BR} = B^T * [y] * B \text{, and}$$

$$Z_{BR} = Y_{BR}^{-1} = \{ B^T * [y] * B \}^{-1}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=-1I_24vO6pM

Important Books/Journals for further learning including the page nos.:
John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp. 245-257

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L7

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **I – Introduction** **Date of Lecture:**

Topic of Lecture: Tutorial Hour – single line diagram

Introduction:

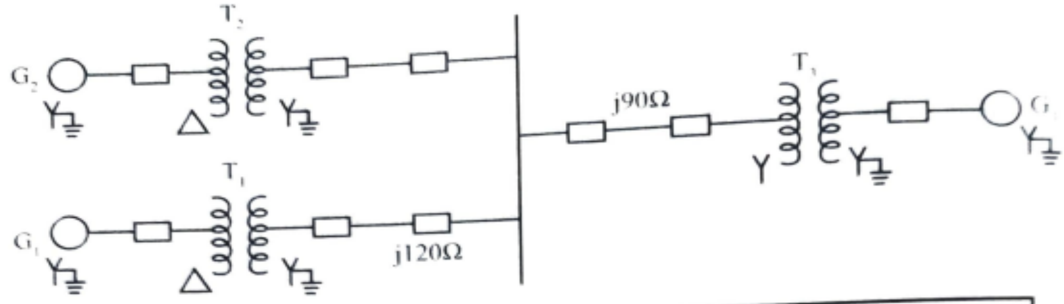
- Single line diagram is a diagrammatic representation of power systems in which the components are represented by their symbols and interconnections between them are shown by a straight line

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Transmission system
- ✓ Distribution system

Detailed content of the Lecture:

Example : Fig shows a single line diagram of unloaded three generator power system with inter connection between the generators by means of 3 transformers & a transmission line. With two sections with their impedences marked on the diagram. The Ratings of the transformers & generators are given below.



Generator	MVA	KV	Reactance in Permit
1.	25	6.6	0.2
2.	15	6.6	0.15
3.	30	13.2	0.15

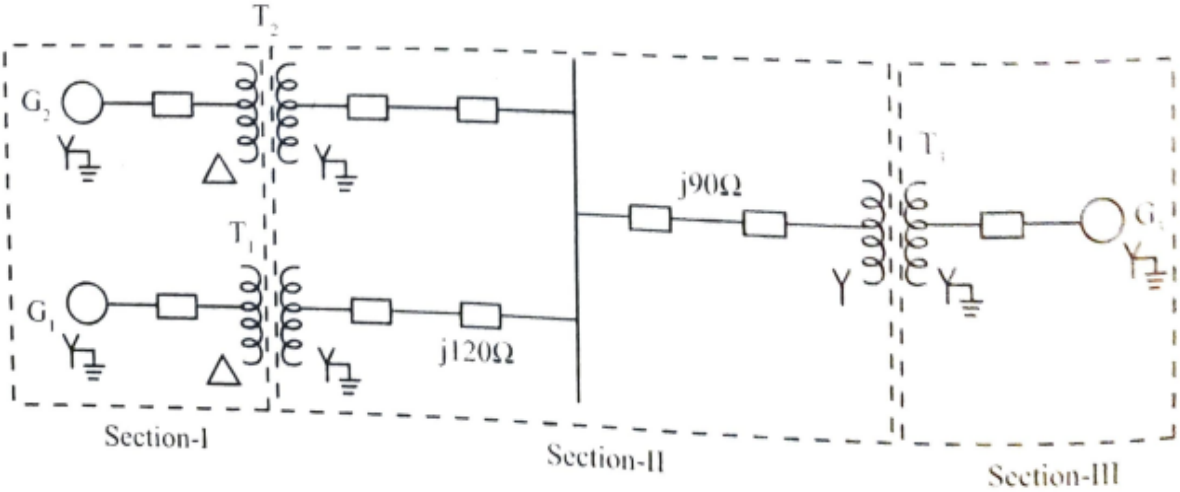
Transformer 1 : 30 MVA, 6.9 Δ - 115 Y KV, X = 10%

Transformer 2 : 15 MVA, 6.9 Δ - 115 Y KV, X = 10%

Transformer 3 : Single phase units, each Rated 10 MVA, 6.9 / 69 KV, X = 10%

Draw an impedance diagram & mark all values p.u choosing a base of 30 MVA, 6.6 KV in generator 1 circuit.

Solution :



Section - I	Section - II
$MVA_{B\ new}$ = 30 MVA $KV_{B\ new}$ = 6.6 KV To find : XG_1, XG_2 XT_1, XT_2	$MVA_{B\ new}$ = 30 MVA To find : XT_3 Transmission line j120 Ω Transmission line j90 Ω

Section - III
$MVA_{B\ new}$ = 30 $KV_{B\ new}$ = 6.6 KV To find : XG_3

Section - I

$MVA_{B\,new} = 30\ MVA$

$KV_{B\,new} = 6.6\ KV\ (G_1)$

Generator 1 :

$$Zp.u_{\,new} = Z\,p.u\ given \times \left[\frac{KV_B\ given}{KV_{B\,new}}\right]^2 \times \left[\frac{MVA_B\ new}{MVA_B\ given}\right]$$

$$= j\,0.2 \times \left[\frac{6.6}{6.6}\right]^2 \times \left[\frac{30}{25}\right] = j\,0.24\ p.u.$$

$$\boxed{XG_1 = j\,0.24\ p.u.}$$

Transformer T_1 : (Refer to Primary side)

KVB new = 6.6 KV

$$Z\,p.u.\ new = j\ 0.1 \times \left[\frac{6.9}{6.6}\right]^2 \times \left[\frac{30}{30}\right]$$

$$\boxed{Z^T_{p.u} = j\,0.109\ p.u}$$

Transformer T_2 :

$KV_{B\,new} = 110\ KV$

$$Z\,p.u_{\,new} = j\ 0.1 \times \left[\frac{115}{110}\right]^2 \times \left[\frac{30}{15}\right]$$

$$\boxed{XT_{2\ (p.u)} = j\,0.218\ p.u}$$

Generator (G_2) :

$MVA_{B\,new} = 30\ MVA$

$$KV_{B\,new} = 110 \times \frac{6.9}{115} = 6.6\ KV$$

$$Z\,p.u_{\,new} = j\,0.15 \times \left[\frac{6.6}{6.6}\right]^2 \times \left[\frac{30}{15}\right]$$

$$\boxed{ZG_{2\ p.u} = j\,0.3\ p.u}$$

Section : 2

Transmission line j 120 Ω,

$$KV_{B\,new} = KV_{B\,old} \times \left[\frac{H.V\ Rating\ of\ T_1}{L.V\ Rating\ of\ T_1}\right]$$

$$= 6.6 \times \left[\frac{115}{6.9}\right]$$

$KV_{B\,new} = 110\ KV$

$$Z_{Base} = \frac{(KV_{B\,new})^2}{MVA_{B\,new}}$$

$$= \frac{(110)^2}{30}$$

$ZB = 403.3\ \Omega$

$$Z_{p.u} = \frac{Z_{act}}{Z_{Base}}$$

$$= \frac{j120}{403.3}$$

$$\boxed{Z_{L2} = j\,0.298}$$

Transmission Line j 90 Ω

$KV_{B\,new} = 110\ KV$

$$Z_B = \frac{110^2}{30}$$

$$= 403.3\ \Omega$$

$$Z_{p.u} = \frac{j90}{403.3} = j\,0.223\ p.u$$

$$\boxed{ZL_1 = j\,0.223\ p.u.}$$

Transformer T_3 :-

(Refer to Primary side)

3 Single phase units are used.

$$\text{Voltage Rating } \frac{\sqrt{3} \times 6.9}{\sqrt{3} \times 6.9} = 119.5 / 11.95\ KV$$

MVA_B given = 3 × 10 = 30 MVA

$KV_{B\,new} = 119.5\ KV$

$$Z\ p.u\ new = j\,0.1 \times \left[\frac{119.5}{119.5}\right]^2 \times \left[\frac{30}{30}\right]$$

$$\boxed{ZT_{3\,p.u} = j\,0.1\ p.u}$$

Section : 3

Generator 3 :

$$KV_{B\,new} = KV_{B\,given} \times \left[\frac{\text{H.V rating of } T_3}{\text{L.V rating of } T_3}\right]$$

$$KV_{B\,new} = 119.5 \times \frac{11.95}{119.5}$$

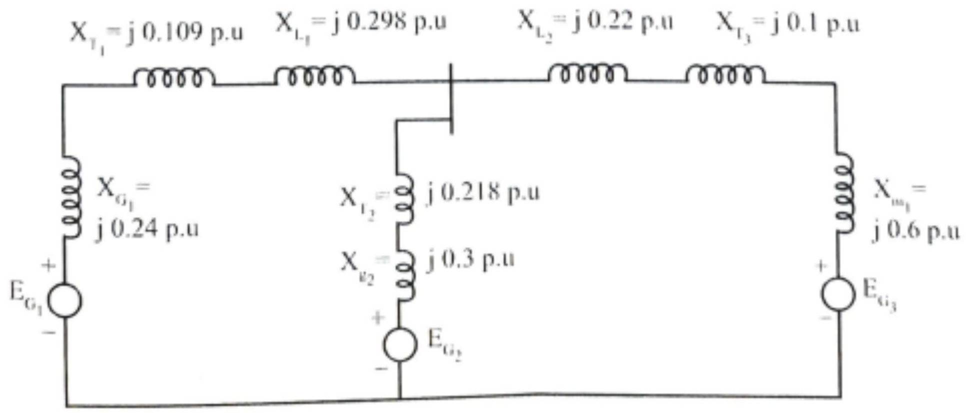
$$= 11.95\ KV$$

$$Z_{p.u\,new} = Z_{p.u\,given} \times \left[\frac{KV_{B\,given}}{KV_{B\,new}}\right]^2 \times \left[\frac{MVA_{B\,new}}{MVA_{B\,given}}\right]$$

$$Z\ p.u = j0.15 \times \left[\frac{13.2}{11.95}\right]^2 \times \left[\frac{30}{30}\right]$$

$$\boxed{Z_{G3\,p.u} = j0.183\ p.u}$$

Impedance Diagram :



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=IOprzZJ4ARc

Important Books/Journals for further learning including the page nos.:
John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp.34 - 35

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L8

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **I – Introduction** **Date of Lecture:**

Topic of Lecture: Tutorial Hour –Bus admittance matrix

Introduction:

- The matrix consisting of the self and mutual admittances of the network of a power system is called bus admittance matrix. It is given by the admittance matrix Y in the node basis matrix equation of a power system and it is denoted as Y_{bus}. The bus admittance matrix is symmetrical.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Impedance
- ✓ Admittance

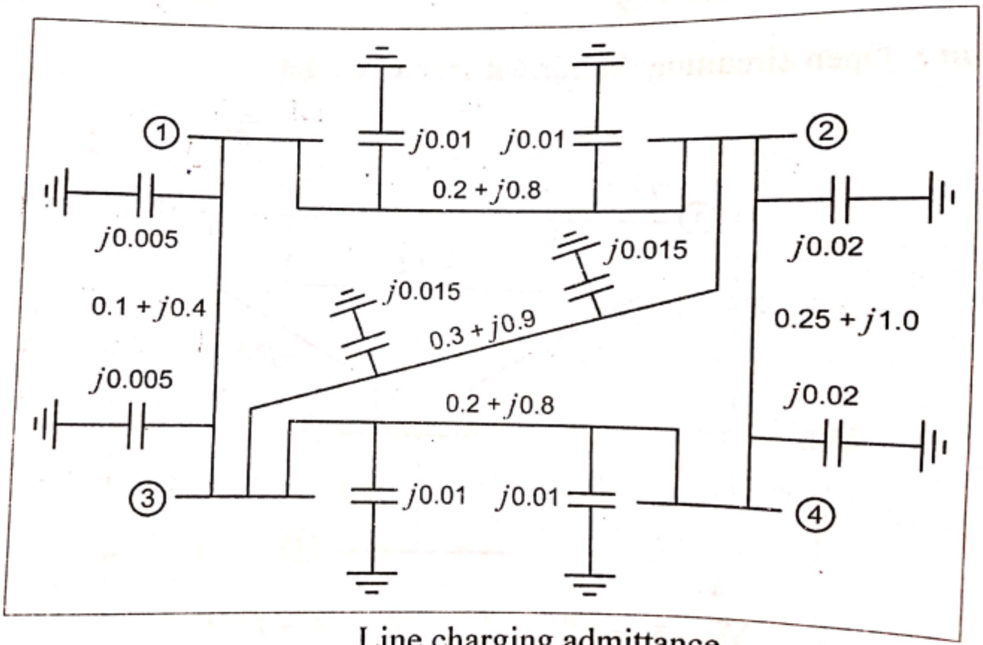
Detailed content of the Lecture:

Example *The parameters of 4 bus system are as follows :*

Bus code	Line impedance (p.u)	Line charging admittance (p.u)
1 – 2	0.2 + j0.8	j0.02
2 – 3	0.3 + j0.9	j0.03
2 – 4	0.25 + j1.0	j0.04
3 – 4	0.2 + j0.8	j0.02
1 – 3	0.1 + j0.4	j0.01

Draw the network and find bus admittance matrix.

☺ ***Solution :***



$$\text{Half line charging admittance} = \frac{\text{Line charging admittance}}{2}$$

$$Y_{11} = Y_{12} + Y_{13} + Y_{10}$$

$$= \frac{1}{0.2 + j0.8} + \frac{1}{0.1 + j0.4} + j0.01 + j0.005$$

$$= 0.294 - j1.176 + 0.588 - j2.353 + j0.015$$

$$= 0.882 - j3.514$$

$$Y_{21} = Y_{12} = \frac{-1}{0.2 + j0.8} = -0.294 + j1.176$$

$$Y_{31} = Y_{13} = \frac{-1}{0.1 + j0.4} = -0.588 + j2.353$$

$$Y_{41} = Y_{14} = 0$$

$$Y_{22} = Y_{21} + Y_{24} + Y_{23} + Y_{20}$$

$$= \frac{1}{0.2+j0.8} + \frac{1}{0.25+j1.0} + \frac{1}{0.3+j0.9} + j0.01 + j0.02 + j0.015$$

$$= 0.294 - j1.176 + 0.235 - j0.941 + 0.333 - j1 + j0.045$$

$$= 0.862 - j3.072$$

$$Y_{32} = Y_{23} = \frac{-1}{0.3+j0.9} = -0.333 + j1$$

$$Y_{42} = Y_{24} = \frac{-1}{0.25+j1} = -0.235 + j0.941$$

$$Y_{33} = Y_{31} + Y_{34} + Y_{32} + Y_{30}$$

$$= \frac{1}{0.1+j0.4} + \frac{1}{0.2+j0.8} + \frac{1}{0.3+j0.9} + j0.005 + j0.015 + j0.01$$

$$= 0.588 - j2.353 + 0.294 - j1.176 + 0.333 - j1 + j0.03$$

$$= 1.215 - j4.499$$

$$Y_{34} = Y_{43} = \frac{-1}{0.2+j0.8} = -0.294 + j1.176$$

$$Y_{44} = Y_{42} + Y_{43} + Y_{40} = \frac{1}{0.25+j1} + \frac{1}{0.2+j0.8} + j0.02 + j0.01$$

$$= 0.235 - j0.941 + 0.294 - j1.176 + j0.03 = 0.5294 - j2.088$$

$$\text{Y-bus} = \begin{bmatrix} 0.882 - j3.514 & -0.294 + j1.176 & -0.588 + j2.353 & 0 \\ -0.294 + j1.176 & 0.862 - j3.072 & -0.333 + j1 & -0.235 + j0.941 \\ -0.588 + j2.353 & -0.333 + j1 & 1.215 - j4.499 & -0.294 + j1.176 \\ 0 & -0.235 + j0.941 & -0.294 + j1.176 & 0.529 - j2.088 \end{bmatrix}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=scxbH1D8RW8

Important Books/Journals for further learning including the page nos.:
John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp.284 - 287

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L9

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **I – Introduction** **Date of Lecture:**

Topic of Lecture: Tutorial Hour – Y bus using singular transformation

Introduction:

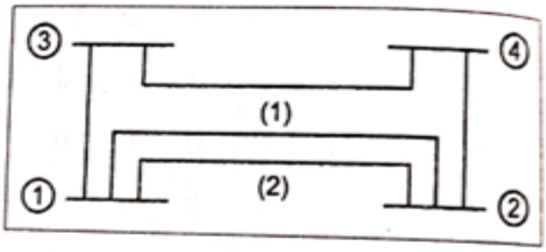
- The matrix consisting of the self and mutual admittances of the network of a power system is called bus admittance matrix. It is given by the admittance matrix Y in the node basis matrix equation of a power system and it is denoted as Y_{bus}. The bus admittance matrix is symmetrical.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Impedance
- ✓ Admittance

Detailed content of the Lecture:

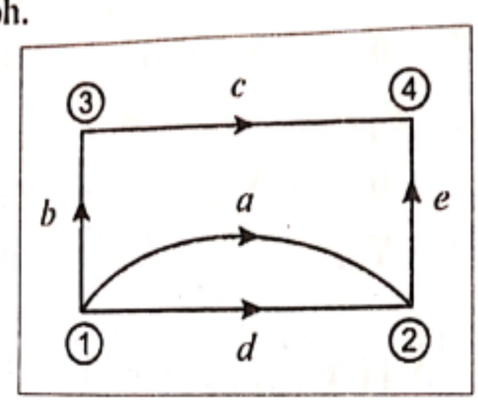
Example *Form Y_{bus} by singular transformation for the network shown in Fig. The impedance data is given in Table. Take (1) as reference node.*



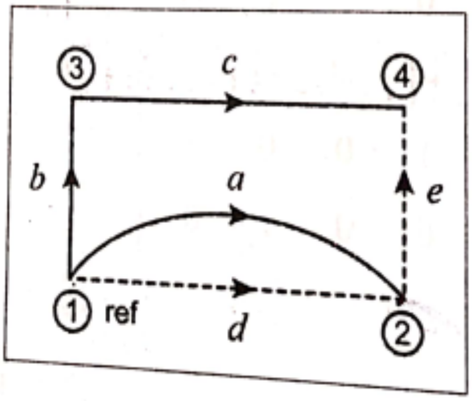
Element No.	Self	
	Bus code	Impedance
1	1 – 2 (1)	0.6
2	1 – 3	0.5
3	3 – 4	0.5
4	1 – 2 (2)	0.4
5	2 – 4	0.2

☺ ***Solution :*** Oriented Graph.

☺ ***Solution :*** Oriented Graph.



Take (1) as reference. Draw a tree.



$$\text{Incidence matrix } [A] = \begin{array}{c} (2) \\ (3) \\ (4) \end{array} \overset{\begin{array}{ccccc} a & b & c & d & e \end{array}}{\begin{bmatrix} -1 & 0 & 0 & -1 & 1 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 & -1 \end{bmatrix}}$$

$$[A]^T = \begin{array}{c} a \\ b \\ c \\ d \\ e \end{array} \overset{\begin{array}{ccc} (2) & (3) & (4) \end{array}}{\begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 0 \\ 1 & 0 & -1 \end{bmatrix}}$$

$$\text{Primittive impedance matrix } [Z_{\text{Primittive}}] = \begin{array}{c} a \\ b \\ c \\ d \\ e \end{array} \overset{\begin{array}{ccccc} a & b & c & d & e \end{array}}{\begin{bmatrix} j0.6 & 0 & 0 & 0 & 0 \\ 0 & j0.5 & 0 & 0 & 0 \\ 0 & 0 & j0.5 & 0 & 0 \\ 0 & 0 & 0 & j0.4 & 0 \\ 0 & 0 & 0 & 0 & j0.2 \end{bmatrix}}$$

Primittive admittance matrix $[Y_{Primittive}] = [Z_{Primittive}]^{-1}$

$$= \begin{array}{c} \\ a \\ b \\ c \\ d \\ e \end{array} \begin{array}{c} \begin{array}{ccccc} a & b & c & d & e \end{array} \\ \begin{bmatrix} -j1.667 & 0 & 0 & 0 & 0 \\ 0 & -j2.0 & 0 & 0 & 0 \\ 0 & 0 & -j2 & 0 & 0 \\ 0 & 0 & 0 & -j2.5 & 0 \\ 0 & 0 & 0 & 0 & -j5 \end{bmatrix} \end{array}$$

Bus admittance matrix $[Y_{bus}] = [A][Y_{Primittive}][A]^T$

$$[Y_{Primittive}][A]^T = \begin{array}{c} a \\ b \\ c \\ d \\ e \end{array} \begin{bmatrix} j1.667 & 0 & 0 \\ 0 & j2 & 0 \\ 0 & -j2 & j2 \\ j2.5 & 0 & 0 \\ -j5 & 0 & j5 \end{bmatrix}$$

$$[Y_{bus}] = [A][Y_{Primittive}][A]^T = \begin{array}{c} \\ (1) \\ (2) \\ (3) \end{array} \begin{array}{c} \begin{array}{ccc} (1) & (2) & (3) \end{array} \\ \begin{bmatrix} -j1.667-j2.5-j5 & 0 & j5 \\ 0 & -j2-j2 & j2 \\ j5 & j2 & -j2-j5 \end{bmatrix} \end{array}$$

$$= \begin{bmatrix} -j9.167 & 0 & j5 \\ 0 & -j4 & j2 \\ j5 & j2 & -j7 \end{bmatrix}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=qVTiUXhEwUw

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Third Edition,2011.P- 194

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Importance of power flow analysis in planning and operation of power systems

Introduction :

- The study of various methods of solution to power system network is referred to as “load flow study”. The solution provides voltages at various buses power flowing in various lines and line loses

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

- Load flow studies are one of the most important aspects of power system planning and operation.
- The load flow gives us the sinusoidal steady state of the entire system - voltages, real and reactive power generated and absorbed and line losses.
- Since the load is a static quantity and it is the power that flows through transmission lines, the purists prefer to call this **Power Flow studies** rather than load flow studies.
- Through the load flow studies we can obtain the voltage magnitudes and angles at each bus in the steady state. This is rather important as the magnitudes of the bus voltages are required to be held within a specified limit. Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be computed.
- Also based on the difference between power flow in the sending and receiving ends, the losses in a particular line can also be computed.
- Furthermore, from the line flow we can also determine the over and under load conditions.
- The steady state power and reactive power supplied by a bus in a power network are expressed in terms of nonlinear algebraic equations.

- We therefore would require iterative methods for solving these equations. In this chapter we shall discuss two of the load flow methods. We shall also delineate how to interpret the load flow results.

➢ Power balance equation is

$$P_D = \sum_{i=1}^{N} PG_i \,, \quad i=1,2.......N$$

Total demand=sum of real power generation

➢ The Generation should be such a way that to meet out the required demand. When the relation is satisfied it gives good economy and security. Electrical areas are larger in size.

➢ So planning for future expansion of a P.S is essential. More network data must be collected for planning a P.S n/w. For planning of P.S, power engineer use computer programme.

Importance of P.S planning and operation analysis covers the maintenance of generation, transmission and distribution network.

Steps for Load Flow Study:

1.Representation of the s/m by the single line diagram
2.Determining the impedance diagram using the single line diagram
3.Formulation of network equations
4.Solution of network equations

Video Content / Details of website for further learning (if any):

https://nptel.ac.in/content/storage2/courses/108104051/chapter_4/4_1.html

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Third Edition,2011,pp.39.

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Statement of power flow problem

Introduction :

- The information obtained from a load flow study is magnitude and phase of voltages, real and reactive power flowing in each line and line losses.
- The load flow solution also give the initial conditions of the system when the transient behaviour of the system is to be satisfied

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

Need for Load Flow Study:

- The load flow study of the P.S is essential to decide the best operation of existing system & for planning the future expansion of the system. It is also essential for designing the new P.S.

Assumptions for Load Flow Analysis

- Since the power flow analysis calculates the steady-state operation of the power system, the study is bound to have constraints, limitations, and assumptions that make the calculations precise.
- Every electrical element are three-phase symmetric components, which makes it possible to assume that currents and voltages in a system are balanced.

- There are three assumptions when performing a load flow analysis:

1. The power system is in a steady state, which means no transient changes are present.
2. Three-phase systems are assumed to have a balanced loading.

The per-unit power system is used to calculate the load flow in the simplest terms.

Significance of a power flow analysis

- Provides a benchmark to compare changes in voltages and network flows under abnormal conditions
- Helps in the design of protective devices and investigates a system's capability to handle disturbances of any kind and size
- Reveals how new lines to be added can mitigate overloads that occur on adjacent lines
- Facilitates crucial economic assessments that show how much of the losses are reduced by installing the new line
- Plays a fundamental role in the planning, control, operation, and economic scheduling of existing power systems
- Enables future expansions by understanding the effect of adding new components to the infrastructure
- Helps determine the most favorable capacitor size and location to improve the power factor and increasing bus voltages in the network

Video Content / Details of website for further learning (if any):

https://presentgroup.com.au/load-flow-or-power-flow-analysis-what-you-must-know/

Important Books/Journals for further learning including the page nos.:

John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp.329

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Classification of buses

Introduction :

- In a power system the buses becomes nodes (i.e) the buses are meeting points of various components.
- The generation will feed energy to buses and loads will draw energy from buses.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

- In a network of a P.S, the buses become nodes and a voltage can be specified for each bus.

The power flow equation is

$$P_i+jQ_i = V_i \sum_{j=1}^{N} Y_{ij}{}^* V_j{}^* \text{ , } i=1,2.........N \quad (1)$$

and the complex bus voltage

$$V_i = |V_i| < \delta \quad (2)$$

Each bus in power system (P.S) is associated with four quantities and they are

1.Real power(P)

2.Reactive Power(Q)

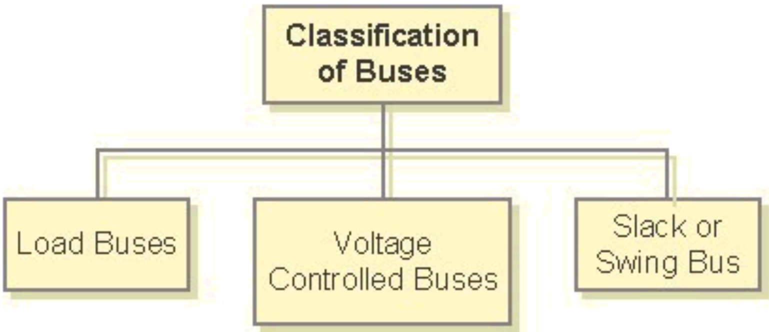
3.Voltage magnitude |V|

4.Phase angle voltage

- The buses are classified based on the variables specified.

- There are 3 types of buses

  1.Slack bus (or) Swing bus (or) Reference bus
  2.Generator bus (or) Voltage controlled bus (or) P.V bus
  3.Load bus (or) PQ bus



- In load flow problem, two quantities are specified for each bus and the remaining two quantities are obtained by solving the load flow equation.

$$\text{Where } P=P_G-P_L$$
$$Q=Q_G-Q_L$$

P_G=Real power generated by generator connected to the bus
Q_G=Reactive power generated by generator connected to the bus
P_L=Real power drawn by the load
Q_L=Reactive power drawn by the load

$$P_L = \sum_{i=1}^{N} P_I = \sum_{i=1}^{N} P_{GI} - \sum_{i=1}^{N} P_{DI}$$

Types of bus	Known (or) specified quantities	Unknown (or) quantities to be determined
1.Stack bus	$\lvert V\rvert,\delta$	P, Q
2.Generator bus	P,$\lvert V\rvert$	Q , δ
3.Load bus	P,Q	$\lvert V\rvert,\delta$

- The slack bus is needed to account for transmission line losses. In a PS the total power generated will be sum of power consumed by loads and losses.
- In a PS only the generated power and load power are specified for buses. The stack bus is assumed to generate the power required for losses. Since the losses are unknown the real & reactive power are not specified for stack bus.

1.Slack bus (or) Swing bus (or) Reference bus

- The bus is called “Slack bus” if the magnitude and phase of bus voltages are specified for the bus.
- The slack bus is the reference bus for load flow solution and usually one of the generator is selected as the slack bus.

2. Generation Bus (Or) Voltage Controlled Bus Or PV

- The bus is called “generation bus” ,if the real power (P) and the magnitude of bus voltages are specified for the bus.
- The load flow equations can be solved to find the reactive power & phase angle(δ) The load flow equations can be solved to find the reactive power & phase angle(δ)

3.Load bus(or) PQ bus:

- The bus is called ”Load bus”. When real power(P) and reactive power(Q) are specified for the bus.
- The load flow equations can be solved to find the magnitude |V| & phase angle of bus voltage(δ).

Video Content / Details of website for further learning (if any):

https://nptel.ac.in/content/storage2/courses/108104051/chapter_4/4_3.html

Important Books/Journals for further learning including the page nos.:

John J.Grainger and W.D.Stevenson Jr., “Power System Analysis”, Tata Mc Graw-Hill, Sixth reprint, 2010, pp. 332-335

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Development of power flow model in complex variables form and polar variable form

Introduction :

- The complex power injected by the source into the ith bus of a power system

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

Conditions for Successful Operation of a Power System

1. There should the adequate real power generation to supply the power demand at various load buses and also the losses
2. The bus voltage magnitudes are maintained at values very close to the rated values.
3. Generators, transformers and transmission lines are not over loaded at any point of time or the load curve

From figure power injected into the bus i

$$S_{i=}S_{Gi} - S_{Di}$$

$$= P_{Gi} + j\,Q_{Gi} - P_{Di} - j\,Q_{Di}$$

$$= (P_{Gi} - P_{Di}) + j\,(Q_{Gi} - Q_{Di})$$

$$S_i = P_i + j\,Q_i = V_i I_i^* \quad i = 1, 2, \ldots \ldots . n$$

Taking complex conjugate on both sides we get

$$P_i - j\,Q_i = V_i^* I_i - - - - - - (1)$$

In general, the net current entering into the ith bus,

$$I_i = Y_{i1}V_1 + Y_{i2}V_{21} + \cdots Y_{ii}V_i + \cdots Y_{in}V_n$$

$$I_i = \sum_{k=1}^{n} Y_{ik}V_k - - - - - - -(2)$$

Substitute 2 in 1

$$P_i - j\,Q_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k$$

$$P_i = Real\,\{V_i^* \sum_{k=1}^{n} Y_{ik}V_k\} \qquad Q_i = -\,Imag\,\{V_i^* \sum_{k=1}^{n} Y_{ik}V_k\}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=2Ryn9R89fnA

Important Books/Journals for further learning including the page nos.:
John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp. 329-332

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Power flow solution using Newton -Raphson method

Introduction :

- **Newton Raphson Method** is an iterative technique for solving a set of various nonlinear equations with an equal number of unknowns. There are two methods of solutions for the load flow using Newton Raphson Method.
- The first method uses rectangular coordinates for the variables while the second method uses the polar coordinate form. Out of these two methods the polar coordinate form is used widely.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

Iterative Solution using Newton-Raphson Method

- Newton raphson method is mathematically superior to the gauss – seidal method because of the following advantages

  1. Quick Convergence (ie., Quadratic Convergence)
  2. Less prone to divergence with conditioned problems

- The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required at each iteration.
- Newton- raphson method used to solve a system of non-linear algebraic equations of the form f(x) = 0.

Consider a set of n non-linear algebraic equations given by

$f_i(x_1, x_2, \ldots\ldots x_n) = 0 \qquad i = 1, 2 \ldots\ldots n$

Let $x_1^0, x_2^0, \ldots\ldots x_n^0$ be the initial guess of unknown variables and

$\Delta x_1^0, \Delta x_2^0, \ldots\ldots \Delta x_n^0$ be the respective corrections.

Therefore

$f_i(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots x_n^0 + \Delta x_n^0) = 0 \qquad i = 1, 2, \ldots\ldots n$

The above equation can be expanded using Taylor's series to give

$f_i(x_1^0, x_2^0 \ldots\ldots x_n^0) + \; +$Higher order terms$=0 \qquad i = 1, 2, \ldots\ldots n$

$\ldots \qquad \left(\frac{\partial f_i}{\partial x_1}\right)^0, \left(\frac{\partial f_i}{\partial x_2}\right)^0, \ldots\ldots \left(\frac{\partial f_i}{\partial x_n}\right)^0$

- If the higher order terms are neglected then above equation can be written in matrix form as

$$\begin{bmatrix} f_1^0 \\ f_2^0 \\ \cdot \\ \cdot \\ \cdot \\ f_n^0 \end{bmatrix} + \begin{bmatrix} \left(\frac{\partial f_1}{\partial x_1}\right)^0 & \left(\frac{\partial f_1}{\partial x_2}\right)^0 & \cdot\;\cdot\;\cdot & \left(\frac{\partial f_1}{\partial x_n}\right)^0 \\ \left(\frac{\partial f_2}{\partial x_1}\right)^0 & \left(\frac{\partial f_2}{\partial x_2}\right)^0 & \cdot\;\cdot\;\cdot & \left(\frac{\partial f_2}{\partial x_n}\right)^0 \\ \cdot & \cdot & \cdot\;\cdot\;\cdot & \cdot \\ \cdot & \cdot & \cdot\;\cdot\;\cdot & \cdot \\ \cdot & \cdot & \cdot\;\cdot\;\cdot & \cdot \\ \left(\frac{\partial f_n}{\partial x_1}\right) & \left(\frac{\partial f_n}{\partial x_2}\right) & \cdot\;\cdot\;\cdot & \left(\frac{\partial f_n}{\partial x_n}\right) \end{bmatrix} \begin{bmatrix} \Delta x_1^0 \\ \Delta x_2^0 \\ \cdot \\ \cdot \\ \cdot \\ \Delta x_n^0 \end{bmatrix} = 0$$

$$F^0 + J^0 \, \Delta X^0 = 0$$

$$F^0 = -J^0 \, \Delta X^0$$

$$\Delta X^0 = |J^0|^{-1} F^0$$

$$X^1 = X^0 + \Delta X^0$$

Video Content / Details of website for further learning (if any):

https://nptel.ac.in/content/storage2/courses/108104051/chapter_4/4_10.html

Important Books/Journals for further learning including the page nos.:

John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp.347-352

Course Faculty

LECTURE HANDOUTS **L15**

EEE **III/V**

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Tutorial Hour – Gauss –Seidel Method

Introduction :

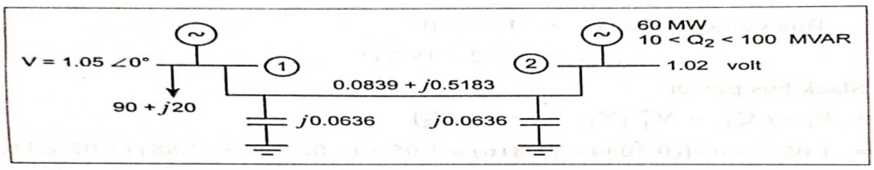
Gauss-Seidel (G-S) method is one of the simplest iterate method. It is a modification **of** Gauss-Iterative method. This modification will reduce the numbers of iterations. So, it is suitable for the power flow study of small power system

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

Using Gauss –Seidel Method,determine busvoltages ,for the Fif.shown.Take Base MVA-100,α=1.1



☺ ***Solution :***

Step 1 : Formulate Y_{bus}.

$$Y_{bus} = \begin{bmatrix} 0.3044 - j1.816 & -0.3044 + j1.88 \\ -0.3044 + j1.88 & 0.3044 - j1.816 \end{bmatrix}$$

Step 2 : Initialize bus voltages.

$$V_1^{old} = 1.05 \angle 0° \quad \text{p.u}$$
$$V_2^{old} = 1.02 \angle 0° \quad \text{p.u}$$

Step 3 : Calculate Q value for generator bus.

$$Q_2^{cal} = -\text{Im}\{V_2^* [V_1 Y_{21} + V_2 Y_{22}]\}$$
$$= -\text{Im}\{1.02 [1.05 \angle 0° \times (-0.3044 + j1.88) + 1.02 \angle 0° (0.3044 - j1.816)]\}$$
$$= -0.124 \quad \text{p.u}$$

Check for Q_{limit} violation :

$$Q_{2\,(min)} = 10 \text{ MVAR}, \quad Q_{2\,(min)} = \frac{10}{100} = 0.1 \quad \text{p.u}$$
$$Q_2^{cal} < Q_{2\,(min)}$$

i.e., $-0.124 < 0.1$

∴ Bus 2 will act as load bus.

$$Q_2 = Q_{2\,(min)} = 0.1 \quad \text{p.u}$$
$$V_2^{old} = 1.0 \angle 0° \quad \text{p.u}$$
$$P_2 = 60 \text{ MW} = 0.6 \quad \text{p.u}$$

Step 4 : Calculate V_2^{new}

$$V_2^{new} = \frac{1}{Y_{22}}\left[\frac{P_2 - j\,Q_2}{V_2^{old\,*}} - Y_{21}\,V_1^{new}\right]$$

$$= \frac{1}{0.3044 - j1.816}\left[\frac{0.6 - j0.1}{1.0\,\angle 0°} - (-\,0.3044 + j1.88)\,1.05\right]$$

$$= \frac{1}{1.842\,\angle -\,80.49°}\,[0.9196 - j2.074]$$

$$= \frac{1}{1.842\,\angle -80.49°}\,[2.2687\,\angle -66.087°]$$

$$= 1.2316\,\angle 14.403° = 1.193 + j0.306$$

Step 5 : Using acceleration factor.

$$V_{2\,acc}^{new} = V_2^{old} + \alpha\,[\,V_2^{new} - V_2^{old}\,]$$

$$= 1 + 1.1\,[1.193 + j0.306 - 1]$$

$$= 1.2098 + j0.33$$

$$= 1.254\,\angle 15.26°$$

Bus voltages are $V_1 = 1.05\,\angle 0°$

$V_2 = 1.254\,\angle 15.26°$

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=qWuiOkO9-AA

Important Books/Journals for further learning including the page nos.:
John J.Grainger and W.D.Stevenson Jr., "Power System Analysis", Tata Mc Graw-Hill, Sixth reprint, 2010, pp. 335-341

Course Faculty

Course Name with Code : Power System Analysis/19EEC10

Course Faculty : Dr.N.Mohananthini

Unit : II – Power flow Analysis **Date of Lecture:**

Topic of Lecture: Power flow solution using Fast decoupled method

Introduction :

- The fast decoupled load flow (**FDLF**) program which employing sparse matrix techniques needs less computer storage and running time, but makes it harder by modifying the program to adapt to further study such as power system security and continuation power flow.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

- An important characteristic of any practical electric power transmission system operating in steady state is the strong interdependence between real powers and bus voltages angles and between reactive powers and voltage magnitudes.
- This interesting property of weak coupling between P- δ and Q-V variables gave the necessary motivation in developing the Fast Decoupled Load Flow, in which P- δ and Q-V problems are solved separately.

Decoupled Newton Methods:

- In any conventional Newton method, half of the elements of the Jacobean matrix represent the weak coupling referred to above, and therefore may be ignored.
- Any such approximation reduces the true quadratic convergence to geometric one, but there are compensating computational benefits.
- A large number of decoupled algorithms have been developed in the literature. However, only the most popular decoupled Newton version is presented here.
- In Eq. (6.67), the elements to be neglected are submatrices [N] and [J]. The resulting decoupled linear Newton equations become

$$[\Delta P] = [H]\ [\Delta \delta] \quad (6.76)$$

$$[\Delta Q] = [L] \left[\frac{\Delta |V|}{|V|}\right] \quad (6.77)$$

where it can be shown that

$$H_{ij} = L_{ij} = |V_i|\ |V_j|\ (C_{ij} \sin\ \delta_{ij} - B_{ij} \cos\ \delta_{ij}). \quad i \neq j \quad (6.78)$$

$$H_{ii} = -\ B_{ii}\ |V_i|^2 - Q_i \quad \text{(Eq. (6.65))} \quad (6.79)$$

$$L_{ii} = -\ B_{ii}\ |V_i|^2 + Q_i \quad \text{(Eq. (6.65))} \quad (6.80)$$

- Equations (6.76) and (6.77) can be constructed and solved simultaneously with each other at each iteration, updating the [H] and [L] matrices in each iteration using Eqs (6.78) to (6.80).
- A better approach is to conduct each iteration by first solving Eq. (6.76) for Δδ, and use the updated δ in constructing and then solving Eq. (6.77) for Δ|V|.
- This will result in faster convergence than in the simultaneous mode. The main advantage of the Decoupled Load Flow Methods (DLF) as compared to the NR method is its reduced memory requirements in storing the Jacobean.
- There is not much of an advantage from the point of view of speed since the time per iteration of the DLF is almost the same as that of NR method and it always takes more number of iterations to converge because of the approximation.
- Further physically justifiable simplifications may be carried out to achieve some speed advantage without much loss in accuracy of solution using the DLF model described in the previous subsection.

Video Content / Details of website for further learning (if any):

https://www.eeeguide.com/fast-decoupled-load-flow/

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Third Edition,2011,pp.222-225

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Tutorial Hour - Newton Raphson using power flow solution

Introduction :

- **Newton Raphson Method** is an iterative technique for solving a set of various nonlinear equations with an equal number of unknowns. There are two methods of solutions for the load flow using Newton Raphson Method.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

Example 5.13 *Perform two iteration of Newton Raphson load flow method and determine the power flow solution for the given system. Take base MVA as 100.*

☺ ***Solution : Line Data :***

Line	Bus		R (p.u)	X (p.u)	Half line charging admittance $\left(\frac{Y_P}{2}\ \text{(p.u)}\right)$
	From	To			
1	1	2	0.0839	0.5183	0.0636

Bus Data :

Bus	P_L	Q_L
1	90	20
2	30	10

$$Y_{bus} = \begin{bmatrix} 0.3044 - j1.816 & -0.3044 + j1.88 \\ -0.3044 + j1.88 & 0.3044 - j1.816 \end{bmatrix}$$

$$Y_{bus} = \begin{bmatrix} 1.842 \angle -1.405 & 1.904 \angle 1.7314 \\ 1.904 \angle 1.7314 & 1.842 \angle -1.405 \end{bmatrix}$$

[*Note :* Use in rad mode]

Assume the initial value *i.e.*, $\delta = 0,\ V = 1.0$.

$$[X] = \begin{bmatrix} \delta_2 \\ V_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 1.0 \end{bmatrix}$$

Step 3 : Calculate P_2^{cal}, Q_2^{cal}, ΔP_2 and ΔQ_2.

$$P_2^{cal} = |V_2| \{|V_1||Y_2| \cos(\theta_{12} + \delta_2 - \delta_1) + |V_2||Y_{22}| \cos(\theta_{22} + \delta_2 - \delta_2)\}$$
$$= 1.0 [1.05 \times 1.904 \cos(1.7314) + 1.842 \cos(-1.405)]$$
$$= 1.05 \times 1.904 (-0.15991) + 1.842 (0.16503)$$
$$= -0.015 \text{ p.u}$$

$$P_{2\,(spec)} = P_{G2} - P_L$$
$$= 0 - \frac{30}{100} = -0.3 \text{ p.u}$$

$$\Delta P_2 = P_{2\,(spec)} - P_2^{cal}$$
$$= -0.3 - (-0.015) = -0.285$$

$$Q_2^{cal} = -V_2 \{|V_1||Y_{21}| \sin(\theta_{12} + \delta_1 - \delta_2) + |V_2||Y_{22}| \sin(\theta_{22} + \delta_2 - \delta_2)\}$$
$$= -1.0 [1.05 \times 1.904 \sin(1.7314) + 1.0 \times 1.842 \sin(-1.405)]$$
$$= -0.157 \text{ p.u}$$

$$\Delta Q_2 = Q_{2\,(spec)} - Q_2^{cal} = -0.1 - (-0.157)$$
$$= 0.057$$

Step 4 : **Form Jacobian matrix.**

$$\begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & V_2 \frac{\partial P_2}{\partial V_2} \\ \frac{\partial Q_2}{\partial \delta_2} & V_2 \frac{\partial Q_2}{\partial V_2} \end{bmatrix} \begin{bmatrix} \Delta \delta_2 \\ \frac{\Delta |V_2|}{|V_2|} \end{bmatrix} = \begin{bmatrix} \Delta P_2 \\ \Delta Q_2 \end{bmatrix}$$

$$\frac{\partial P_2}{\partial \delta_2} = |V_2||V_1||Y_{12}| \sin(\theta_{12} + \delta_1 - \delta_2) + |V_2|^2 |Y_{22}| \times 0$$
$$= 1.0 \times 1.05 \times 1.904 \sin(1.7314)$$
$$= 1.973$$

$$|V_2| \frac{\partial P_2}{\partial V_2} = |V_1||V_2||Y_{21}| \cos(\theta_{12} + \delta_1 - \delta_2) + 2|V_2|^2 |Y_{22}| \cos(\theta_{22})$$
$$= 1.05 \times 1.904 \cos(1.7314) + 2 \times 1.842 \cos(-1.405)$$
$$= 0.289$$

$$\frac{\partial Q_2}{\partial \delta_2} = |V_2||V_1||Y_{21}| \cos(\theta_{12} + \delta_1 - \delta_2) - |V_2|^2 |Y_{22}| \times 0$$
$$= 1.05 \times 1.904 \times \cos(1.7314)$$
$$= -0.3197$$

$$|V_2| \frac{\partial Q_2}{\partial V_2} = -|V_1||V_2||Y_{21}| \sin(\theta_{12} + \delta_1 - \delta_2) - 2|V_2|^2 Y_{22}| \sin(\theta_{22})$$
$$= -1.05 \times 1.904 \sin(1.7314) - 2 \times 1.842 \sin(-1.405)$$
$$= 1.66$$

Step 5 : Compute Δx,

$$\begin{bmatrix} \Delta\delta_2 \\ \dfrac{\Delta V_2}{|V_2|} \end{bmatrix} = \begin{bmatrix} \dfrac{\partial P_2}{\partial \delta_2} & |V_2|\dfrac{\partial P_2}{\partial V_2} \\ \dfrac{\partial Q_2}{\partial \delta_2} & |V_2|\dfrac{\partial Q_2}{\partial V_2} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \Delta P_2 \\ \Delta Q_2 \end{bmatrix}$$

$$= \begin{bmatrix} 1.973 & 0.289 \\ -0.3196 & 1.66 \end{bmatrix}^{-1} \times \begin{bmatrix} -0.285 \\ 0.057 \end{bmatrix}$$

$$= \begin{bmatrix} 0.493 & -0.086 \\ 0.0949 & 0.586 \end{bmatrix} \begin{bmatrix} -0.285 \\ 0.057 \end{bmatrix} = \begin{bmatrix} -0.145 \\ 0.0064 \end{bmatrix}$$

$$\delta_2^1 = \delta_2^\circ + \Delta\delta_2 = 0 + (-0.145) = -0.145$$

$$V_2^1 = V_2 + |V_2| \cdot \frac{\Delta V_2}{|V_2|} = 1.0 + 0.0064 = 1.0064$$

Iteration 2 : Compute mismatch vectors.

$$P_2^{cal} = 1.0064\,[1.05 \times 1.904 \cos(1.7314 + 0 + (-0.145)) + 1.0064 \times 1.842 \cos(-1.405)]$$

$$= -0.297$$

$$\Delta P_2 = P_{2\,(spec)} - P_2^{cal} = -0.3 - (-0.297) = -0.003$$

$$Q_2^{cal} = -\{1.0064\,[1.05 \times 1.904 \times \sin(1.7314 + 0 - (-0.145)) + 1.0064 \times 1.842 \times \sin(-1.405)]\}$$

$$= -0.078$$

$$\Delta Q_2 = Q_{2\,(spec)} - Q_2^{cal}$$

$$= -0.1 - (-0.078) = -0.021$$

Compute Jacobian matrix.

$$\frac{\partial P_2}{\partial \delta_2} = 1.0064 \times 1.05 \times 1.904 \sin(1.7314 + 0.145) = 1.919$$

$$|V_2|\frac{\partial P_2}{\partial V_2} = 1.05 \times 1.0064 \times 1.904 \cos(1.7314 + 0.145) + 2 \times 1.0064^2 \times 1.842 \times \cos(-1.405) = 0.015$$

$$\frac{\partial Q_2}{\partial \delta_2} = 1.0064 \times 1.05 \times 1.904 \times \cos(1.7314 + 0.145) = -0.605$$

$$|V_2|\frac{\partial Q_2}{\partial V_2} = -1.05 \times 1.904 \sin(1.7314 + 0.145) - 2 \times 1.0064 \times 1.842 \times \sin(-1.405) = 1.76$$

$$\begin{bmatrix} \Delta\delta_2 \\ \frac{\Delta V_2}{|V_2|} \end{bmatrix} = \begin{bmatrix} 1.919 & 0.015 \\ -0.605 & 1.76 \end{bmatrix}^{-1} \begin{bmatrix} \Delta P_2 \\ \Delta Q_2 \end{bmatrix}$$

$$= \frac{1}{3.3865} \begin{bmatrix} 1.76 & -0.015 \\ 0.605 & 1.919 \end{bmatrix} \begin{bmatrix} \Delta P_2 \\ \Delta Q_2 \end{bmatrix}$$

$$= \begin{bmatrix} 0.5197 & -0.0044 \\ 0.1786 & 0.566 \end{bmatrix} \begin{bmatrix} -0.003 \\ -0.021 \end{bmatrix} = \begin{bmatrix} -0.0015 \\ -0.0124 \end{bmatrix}$$

$$\delta_2 = \delta_2^{old} + \Delta\delta_2$$

$$= -0.145 + (-0.0015) = -0.1465 \text{ rad}$$

$$V_2 = V_2^{old} + |V_2^{old}| \cdot \frac{\Delta V_2}{|V_2^{old}|}$$

$$= 1.0064 + 1.0064 \times (-0.0124) = 0.994 \text{ p.u}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=CrrfwNplMvE

Important Books/Journals for further learning including the page nos.:
John J.Grainger and W.D.Stevenson Jr., “Power System Analysis”, Tata Mc Graw-Hill, Sixth reprint, 2010, pp.347-352

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **II – Power flow Analysis** **Date of Lecture:**

Topic of Lecture: Tutorial Hour – Fast decoupled power flow

Introduction :

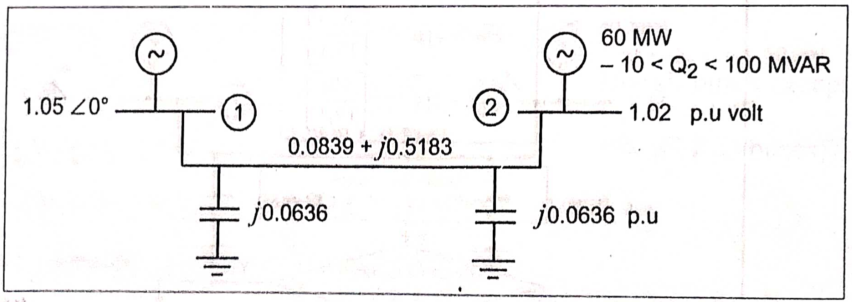
Fast decoupled power flow method is faster ,simple to program ,more reliable and requires less memory than Newton Raphson load flow method.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Operation of power systems

Detailed content of the Lecture:

Perform two iterations of decoupled load flow method and determine the power flow solution for the system as shown in Fig. Take base MVA -100



☺ ***Solution :***

Step 1 : Form Y_{bus} matrix ; $Y_{bus} = \begin{bmatrix} 0.3043 - j1.817 & -0.3044 + j1.88 \\ -0.3044 + j1.88 & 0.3043 - j1.817 \end{bmatrix}$

$$Y_{bus} = \begin{bmatrix} 1.842\angle -1.405 & 1.904\angle 1.7314 \\ 1.904\angle 1.7314 & 1.842\angle -1.405 \end{bmatrix}$$

Step 2 : Initialize bus voltages.

$$V_1^{old} = 1.05 \angle 0 \text{ p.u} \qquad \text{(slack bus)}$$

$$V_2^{old} = 1.02 \angle 0 \text{ p.u} \qquad \text{(P-V bus)}$$

Step 3 : Check for Q-limit violation.

$$Q_2^{cal} = -\{ |V_2||V_1||Y_{21}| \sin(\theta_{21} - \delta_2 + \delta_1) + |V_2|^2 |Y_{22}| \sin \theta_{22} \}$$

$$= -[1.02 \times 1.05 \times 1.904 \times \sin(1.7314) + 1.02^2 \times 1.842 \times \sin(-1.405)]$$

$$= -0.1228 \text{ p.u}$$

$$Q_{2\,(min)} = 10 \text{ MVAR} = \frac{10}{100} \text{ p.u} = 0.1 \text{ p.u}$$

$$Q_2 < Q_{2\,(min)}; \quad \therefore Q_2 = Q_{2\,(min)} = 0.1 \text{ p.u}$$

and the bus 2 will act as load bus, $V_2 = 1 \angle 0$ p.u

Step 4 : Calculate ΔP and ΔQ.

$$P_2^{cal} = |V_2||V_1||Y_{21}| \cos(\theta_{21} - \delta_2 + \delta_1) + |V_2|^2 |Y_{22}| \cos \theta_{22}$$

$$= 1.0 \times 1.05 \times 1.904 \times \cos(1.7314) + 1.0^2 \times 1.842 \times \cos(-1.405)$$

$$= -0.0157$$

$$P_{2\,(spec)} = P_{G2} - P_{L2} = \frac{60}{100} = 0.6 \text{ p.u}$$

$$\Delta P_2 = P_{2\,(spec)} - P_2^{cal} = 0.3 - (-0.0157) = 0.6157$$

$$\Delta Q_2 = Q_{2\,(spec)} - Q_2^{cal} = 0.1 - (-0.1) = 0.2$$

Step 5 : Bus susceptance matrix

$$[B'] = \begin{matrix} & 2 \\ 2 & [-1.817] \end{matrix}$$

$$[B']^{-1} = \frac{1}{-1.817} = -0.5504$$

$$[B''] = \begin{matrix} & 2 \\ 2 & [-1.817] \end{matrix}, \quad [B'']^{-1} = -0.5504$$

Note B′ matrix is the imaginary part of Y_{bus} for the buses except slack bus.

B″ matrix is the imaginary part of Y_{bus} for the load buses.

Step 6 : Calculate $\Delta\delta$ and ΔV.

$$[\Delta\delta_2] = -[B']^{-1} \left[\frac{\Delta P_2}{|V_2|} \right] = -(-0.5504) \left[\frac{0.6157}{1.0} \right] = 0.34$$

$$[\Delta V_2] = -[B'']^{-1}\left[\frac{\Delta Q_2}{|V_2|}\right] = -(-0.5504)\left[\frac{0.2}{1.0}\right] = 0.1226 \text{ p.u}$$

$$\delta_2^1 = \delta_2^0 + \Delta\delta_2 = 0 + 0.34 = 0.34 \text{ rad}$$

$$V_2^1 = V_2^0 + \Delta V_2 = 1.0 + 0.1226 = 1.1226 \text{ p.u}$$

$$V_2^1 = 1.1226 \angle 0.34$$

Iteration 2 : Check for Q-limit

$$Q_2^{cal} = -\{1.1226 \times 1.05 \times 1.904 \sin(1.7314 - 0.34) + 1.1226^2 \times 1.842 \times \sin(-1.405)\}$$

$$= -(-0.0812) = 0.0812$$

$$0.0812 < 0.1, \; Q_2^{cal} < Q_{2\,(min)}$$

$$\therefore Q_2 = Q_{2\,(min)} = 0.1 \text{ p.u MVAR}$$

Bus 2 again act as load bus $V_2^{old} = 1.1226 \angle 0.34$.

$$P_2^{cal} = 1.1226 \times 1.05 \times 1.904 \times \cos(1.7314 - 0.34) + 1.1226^2 \times 1.842 \times \cos(-1.405)$$

$$= 0.7836 \text{ p.u.}$$

$$P_{2\,(spec)} = P_{G2} - P_{L2} = \frac{60-0}{100} = 0.6 \text{ p.u}$$

$$\Delta P_2 = P_{2\,(spec)} - P_2^{cal} = 0.6 - 0.7836 = -0.1836$$

$$\Delta Q_2 = Q_{2\,(spec)} - Q_2^{cal} = 0.1 - 0.0812 = 0.0188$$

Step 5 : Bus susceptance matrix.

$$[B'] = [B''] = [-1.817]$$

$$[B']^{-1} = [B'']^{-1} = -0.5504$$

Step 6 : Calculate $\Delta\delta$ and ΔV.

$$[\Delta\delta_2] = -[B']^{-1}\left[\frac{\Delta P_2}{|V_2|}\right] = -(-0.5504)\left[\frac{-0.1836}{1.1226}\right]$$

$$= -0.09$$

$$[\Delta V_2] = -[B'']^{-1}\left[\frac{\Delta Q_2}{|V_2|}\right] = -(-0.5504)\left[\frac{0.0188}{1.1226}\right]$$

$$= 0.0092$$

$$\delta_2^2 = \delta_2^1 + \Delta\delta_2 = 0.34 + (-0.09) = 0.25 \text{ rad} = 14°$$

$$V_2^2 = V_2^1 + \Delta V_2 = 1.1226 + 0.0092 = 1.1318$$

$$V_2^{new} = 1.1318 \angle 14°$$

Video Content / Details of website for further learning (if any):

https://www.eeeguide.com/fast-decoupled-load-flow/

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Third Edition,2011,pp.222-225.

Course Faculty

Course Name with Code : **Power System Analysis/19EEC10**

CourseFaculty :**Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced FaultsDate of Lecture:**

Topic of Lecture: Importance of short circuit analysis

Introduction:

A short-circuit study is an analysis of an electrical system that determines the magnitude of the currents that flow during an electrical fault.Comparing these calculated values against the equipment ratings is the first step to ensuring that the power system is safely protected.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Fault
- ✓ Fault current
- ✓ Fault voltage

Detailed content of the Lecture:

Short Circuit Analysis:

"Whenever a fault occurs on a network such that a large current flows in one or more phases, a short circuit is said to have occurred".

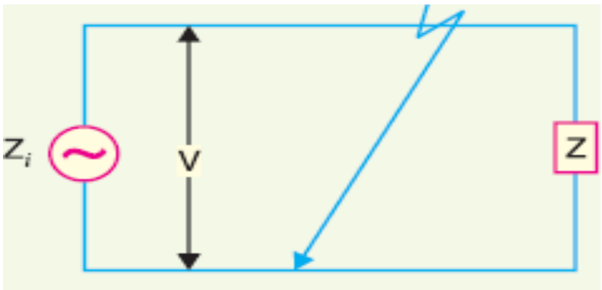


Fig.short circuit

Causes of short-circuit:

Internal effects are caused by breakdown of equipment or transmission lines, from deterioration of insulation in a generator, transformer etc. Such troubles may be due to ageing of insulation, inadequate design or improper installation.

External effects causing short circuit includeinsulationfailuredueto lightningsurges,overloading of equipment causingexcessive heating; mechanical damage by public *etc*.

Effects of short-circuit:

- When a short-circuit occurs, the current in the system increases to an abnormally high value while the system voltage decreases to a low value.
- Short-circuit causes excessive heating which may result in fire or explosion. Sometimes short-circuit takes the form of an arc and causes considerable damage to the system
- Low voltage created by the fault has a very harmful effect on the service rendered by the power system. If the voltage remains low for even a few seconds, the consumers' motors may be shut down and generators on the power system may become unstable.

Short-Circuit Current Calculations

The calculations of the short-circuit currents are important for the following reasons:

(i) A short-circuit on the power system is cleared by a circuit breaker or a fuse. It is necessary, therefore, to know the maximum possible values of short-circuit current so that switchgear of suitable rating may be installed to interrupt them.

(ii) The magnitude of short-circuit current determines the setting and sometimes the types and location of protective system.

(iii) The magnitude of short-circuit current determines the size of the protective reactors which must be inserted in the system so that the circuit breaker is able to withstand the fault current.

(iv) The calculation of short-circuit currents enables us to make proper selection of the associated apparatus (*e.g*. bus-bars, current transformers etc.) so that they can withstand the forces that arise due to the occurrence of short circuits.

Faults in a Power System:

Symmetrical faults :

That fault which gives rise to symmetrical fault currents (*i.e*. equal faults currents with 120^o displacement) is called a symmetrical fault.

Example: when all the three conductors of a 3-phase line are brought together simultaneously into a short-circuit condition.

Unsymmetrical faults:

Those faults which give rise to unsymmetrical currents (*i.e*. unequal line currents with unequal displacement) are called unsymmetrical faults.

- Single line-to-ground fault
- Line-to-line fault
- Double line-to-ground fault

Common: a short-circuit from one line to ground

- ✓ Short circuit analysis essentially consists of determining the steady state solution of a linear network with balanced three phase excitation.
- ✓ Such an analysis provides currents and voltages in a power system during the faulted condition.
- ✓ This information is needed to determine the required interrupting capacity of the circuit breakers and to design proper relaying system.

- ✓ To get enough information, different types of faults are simulated at different locations and the study is repeated.
- ✓ Normally in the short circuit analysis, all the shunt parameters like loads, lime charging admittances are neglected.
- ✓ Then the linear network that has to be solved comprises of Transmission network Generator system and Fault.
- ✓ By properly combining the representations of these components we can solve the short circuit problemCarelabs allows you to perform a per unit calculation on any system you are working with.
- ✓ We automatically converts the entire system (panel boards, transformers, generators, motorized items and cables) into a unique impedance unit from which you can obtain the rating of the short circuit current at any given point.
- ✓ The process is simple, efficient and will save you both money and time.

Short Circuit Analysis Needs:

- ✓ The first short-circuit analysis should be performed when a power system is originally designed, though this should not be the only time.
- ✓ These studies need to occur with any facility expansion or with the addition of any new electrical equipment such as circuit breakers or new transformers and cables.
- ✓ Without any new additions or changes, short circuit studies still need to occur on a regular basis of at least every 5-6 years.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=HcMh7ahJxfo

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011,pp.327-328.

CourseFaculty

Course Name with Code : **Power System Analysis/19EEC10**

CourseFaculty :**Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Assumptions in fault analysis

Introduction:

- ✓ There are several assumptions to made before we do electrical fault analysis study on a electrical system.
- ✓ Power systems are inherently dynamic which are subjected to constant voltage and current variations and therefore to maintain the stability of the system and also to choose appropriate switch gears and settings for the relays, we need to know the worst case scenarios.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Power flow analysis
- ✓ Bus system

Detailed content of the Lecture:

Basic Assumptions in Fault Analysis of Power Systems:

(i). Representing each machine by a constant voltage source behind proper reactance which may be X”, X’, or X

(ii). Pre-fault load current are neglected

(iii). Transformer taps are assumed to be nominal

(iv). Shunt elements in the transformers model that account for magnetizing current and core loss are
neglected

(v). A symmetric three phase power system is conducted

(vi). Shunt capacitance and series resistance in transmission are neglected (vii). The negative sequence impedances of alternators are assumed to be the same as their positive sequence impedance Z+ = Z-

Need for short circuit studies or fault analysis

Short circuit studies are essential in order to design or develop the protective schemes for various parts of the system .To estimate the magnitude of fault current for the proper choice of circuit breaker
and protective relays.

Bolted fault or solid fault

- ✓ A Fault represents a structural network change equivalent with that caused by the addition of
- ✓ impedance at the place of a fault.
- ✓ If the fault impedance is zero, the fault is referred as bolted fault orsolid fault.

Reason for transients during short circuits

- ✓ The faults or short circuits are associated with sudden change in currents.
- ✓ Most of the components ofthe power system have inductive property which opposes any sudden change in currents, so the faultsare associated with transients.

Doubling effect

- ✓ If a symmetrical fault occurs when the voltage wave is going through zero then the maximum
- ✓ momentary short circuit current will be double the value of maximum symmetrical short circuit
- ✓ current.
- ✓ This effect is called doubling effect.

DC off set current

The unidirectional transient component of short circuit current is called DC off set current.

Assumptions made in a Electrical Fault Analysis Study and the validation of those assumptions:

- ✓ In fault analysis study its necessary to make assumptions , because we cant predict 100% natural scenarios on this electrical energy. Following are some of the assumptions commonly made in three phase fault studies for the ease of calculations,
- ✓ Transformers are on nominal tap position. This will let us take nominal voltages of transformers in calculations.
- ✓ All sources are balanced and equal in magnitude and phase. We neglect the slight differences in magnitude and phase of the source voltages as it is nothing when compared with the fault.
- ✓ High Voltage Power Lines are assumed fully transposed and all 3 phase have same impedance. Transposed lines have more or less equal inductance's in all three phases.
- ✓ Loads currents are negligible compared to fault currents. Usually fault currents are about several kilo amperes, but load currents are mostly in ampere range. Therefore the effect of the load current on the final result is negligible.
- ✓ Sources represented by the Thevenin's voltage prior to fault at the fault point. Large systems may be represented by infinite bus bars.

- ✓ When comparing with large systems with a small one, effect from the small one will not make much effect on the larger system. Therefore there is not much different taking the large system as an infinite bus bar.
- ✓ Line charging currents can be completely neglected as line charging currents are smaller compared to load current.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=OveCTTEOnjE

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011, pp – 338.

CourseFaculty

LECTURE HANDOUTS

L21

EEE

III/V

Course Name with Code : **Power System Analysis/19EEC10**

CourseFaculty :**Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Analysis using Thevenin's theorem

Introduction:

Thevenin's Theorem states that "Any linear circuit containing several voltages and resistances can be replaced by just one single voltage in series with a single resistance connected across the load".

Prerequisite knowledge for Complete understanding and learning of Topic:

Thevenin's theorem

Detailed content of the Lecture:

FAULT ANALYSIS USING THEVENIN'S THEOREM :

Find the prefault voltage at the fault period using the prefault current. If the system is unloaded the voltage is 1 p.u. Select base value of power and voltage MVAb and KVb draw the reactance diagram of the given power system.

Prefault voltage at fault point in p.u

$$V_{pf} = \frac{actual\ voltage\ at\ fault\ point}{base\ volatge\ at\ fault\ point}$$

$$= \frac{KV_{fault\ point}}{KV_{b,fault\ piont}}$$

Determine the thevenin's impedance of the system at the fault piont.

- ✓ To determine the thevenin's impedance , replace all the source by zero value source
- ✓ That all the voltage source is shorted
- ✓ Then reduce the resultant network to single equivalent impedance.
- ✓ It is denoted by Zth.
- ✓

Symmetrical Fault analysis using Thevenin's Theorem :

- ✓ In symmetrical faults all the three phases are short circuited to each other and to earth.

- ✓ Suchfaults are balanced and symmetrical in the sense that the voltage and current of the systemremains balanced even after the fault and it is enough if we consider any one phase

Short circuit capacity of power system or fault level:

Short circuit capacity (SCC) or Short circuit MVA or fault level at a bus is defined as the product ofthe magnitude of the pre fault bus voltage and the post fault current

$$\text{SCC or Short circuit MVA} = |V_{prefault}| \times |I_f|$$

(OR)

$$\text{SCC} = \frac{1}{X_{th}} \quad p.u \ \ MVA$$

Short Circuit Capacity (SCC)

- ✓ It is the product of magnitudes of the prefault voltage and the post fault current.
- ✓ It is used to determine the dimension of a bus bar and the interrupting capacity of a circuit breaker.

$$|SCC| = |V_F^0| |I_F|$$

$$|I_F| = \frac{|V_T|}{|Z_T|}$$

$$|SCC|_{1f} MVA = \frac{|V_T|^2}{|Z_T|} = \frac{S_{b,1f}}{|Z_T|_{pu}} \qquad If$$

$$|SCC|_{3f} MVA = \frac{S_{b,3f}}{|Z_T|_{pu}}$$

$$I_f = \frac{|SCC|_{3f} * 10^6}{\sqrt{3} * V_{Lb} * 10^6}$$

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=W4UJlhMYHGU

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011, pp.341-343.

CourseFaculty

Course Name with Code : **Power System Analysis/19EEC10**

Course Faculty : **Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Z –bus building algorithm

Introduction:

Z Matrix or bus impedance matrix is an important tool in power system analysis. Though, it is not frequently used in power flow study, unlike Ybus matrix, it is, however, an important tool in other power system studies like short circuit analysis or fault study. The Zbus matrix can be computed by matrix inversion of the Ybus matrix. Since the Ybus matrix is usually sparse, the explicit Zbus matrix would by dense so memory intensive to handle directly.

Prerequisite knowledge for Complete understanding and learning of Topic:

Z –bus building algorithm

Detailed content of the Lecture:

- ✓ Consider a n bus network. Assume that three phase fault is applied at bus k through a fault impedance z_f Prefault voltages at all the buses are

$$V_{bus}(0) = \begin{bmatrix} V_1(0) \\ V_2(0) \\ . \\ V_k(0) \\ . \\ V_n(0) \end{bmatrix}$$

- ✓ Draw the Thevenin equivalent circuit i.e Zeroing all voltage sources and add voltage source at faulted bus k and draw the reactance diagram
- ✓ The change in bus voltage due to fault is

$$\Delta V_{bus} = \begin{bmatrix} \Delta V_1 \\ . \\ . \\ \Delta V_k \\ . \\ \Delta V_n \end{bmatrix}$$

- ✓ The bus voltages during the fault is

$$V_{bus}(F) = V_{bus}(0) + \Delta V_{bus}$$

- ✓ The current entering into all the buses is zero.the current entering into faulted bus k is –ve of the current leaving the bus k.

$$\Delta V_{bus} = Z_{bus} I_{bus}$$

$$\Delta V_{bus} = \begin{pmatrix} Z_{11} & . & Z_{1k} & . & Z_{1n} \\ . & . & . & . & . \\ Z_{k1} & . & Z_{kk} & . & Z_{kn} \\ . & . & . & . & . \\ Z_{n1} & . & Z_{nk} & . & Z_{nn} \end{pmatrix} \begin{bmatrix} 0 \\ . \\ -I_k(F) \\ . \\ 0 \end{bmatrix}$$

$$V_k(F) = V_k(0) - Z_{kk} I_k(F)$$

$$V_k(F) = Z_f I_k(F)$$

$$I_k(F) = \frac{V_k(0)}{Z_{kk} + Z_f}$$

$$V_i(F) = V_i(0) - Z_{ik} I_k(F)$$

- ✓ we need to use Z bus matrix for short circuit or fault calculation for large power systems. We had seen in the earlier lesson that we can obtain this Z bus matrix by inverting the Y bus matrix.
- ✓ But, inverting this Y bus matrix for a large power system is computationally very expensive and time consuming. Therefore, we most of the time try to build this Z bus matrix by a step by step algorithm.
- ✓ Just like Y bus, that we could build using or by just inspecting the network, we cannot do the same for Z bus. That is Z bus cannot be formed by inspection, just like the Y bus matrix formation that we had done earlier.

- ✓ Now, Z bus matrix requires building algorithm, where we add each element step by step to finally, form the Z bus for the complete system. Z bus matrix is basically describing the open circuit description of the network, we will see why this happens.
- ✓ Now, if you recall the network equation we can write as V bus is equal to Z bus into I bus. So, we have written this equation in expanded form, where we have a N bus power system. So, we have voltage at various buses as V 1, V 2 up to V n. And we have the current injections as I 1, I 2 up to I n. Now, these voltages or the bus voltages, that we have are measured with respect to a common reference, which can be the common neutral of the generators or the ground.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=rN6TvIJvGDg

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011.P-420

Course Faculty

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty :**Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Fault analysis using Z-bus Problems

Introduction:

when we talked about solving forsymmetrical faults, using the Z bus method. Here also, we will consider the system andthe study has n buses. It is initially operating in a symmetrical normal state. That is abalance three phase system state, is available before the fault. All pre-fault bus voltagesand power flows are assume to be known.

That is either we do a load flow analysis to get these values. Or we assume that all prefault voltages are 1 per unit. And all pre-fault currents are 0 in all the elements. Now, wewill assume that the fault has occurred at a bus q. This bus q can be any bus in thesystem.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Fault
- ✓ Z-bus

Detailed content of the Lecture:

- ✓ A fault is any abnormal condition in a power system. The steady state operating mode of apower system is balanced 3-phase a.c.
- ✓ However, due to sudden external or internal changesin the system, this condition is disrupted.
- ✓ When the insulation of the system fails at one or more points or a conducting object comesinto contact with a live point, a short circuit or a fault occurs.
- ✓ The majority of faults in power systems are asymmetrical. To analyse an asymmetrical fault,an unbalanced 3- phase circuit has to be solved.
- ✓ Since the direct solution of such a circuit isvery difficult, the solution can be more easily obtained by using symmetrical componentssince this yields three (fictitious) single phase networks, only one of which contains a driving emf.
- ✓ Since the system reactances are balanced the thee fictitious networks have no mutual couplingbetween them, a fact that is making this method of analysis quite simple.

Consider the four-bus system of Fig. 14.17, in which line impedances are shown in per unit. Using a generation-shift distribution factor based on the dc power-flow method, find the change in power flow in line ①–② when the power generation at bus ④ is incrementally increased by 0.1 per unit. Note: An appropriate bus should be selected as reference to find $\mathbf{Z}_{bus}$ of the system.

Solution:

Suppose we choose bus ① as reference. Then using the $\mathbf{Z}_{bus}$ building algorithm, we find

$$\mathbf{Z}_{bus} = \begin{matrix} ② & ③ & ④ \end{matrix} \begin{bmatrix} j0.19522 & j0.19304 & j0.19130 \\ j0.19304 & j0.46258 & j0.27825 \\ j0.19130 & j0.27825 & j0.34779 \end{bmatrix}$$

The incremental current injection into bus ④ causes current flow change in line ①–② as follows (See Eqs. (14.29) and (14.30))

$$\Delta I_{12} = K_{12,4}\Delta I_4 = \frac{(Z_{14} - Z_{24})}{Z_c}\Delta I_4 = \frac{(0 - j0.19130)}{j0.2}(0.1) = -0.09565 \text{ per unit}$$

Thus the current flow *increases* from bus ② to bus ①.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=rN6TvIJvGDg

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.pp – 360.

CourseFaculty

LECTURE HANDOUTS

L24

EEE

III/V

Course Name with Code **:Power System Analysis/19EEC10**

CourseFaculty **:Dr.N.Mohananthini**

Unit **: III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Post fault voltage , currents and line flows

Introduction:

Short circuit capacity available. kVA of a three phase transformer = V x A x 1.732, where 1.732 = the square root of 3. The square root of 3 is introduced for the reason that, in a three phase system, the phases are 120 degrees apart and, therefore, can not be added arithmetically.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Post fault
- ✓ Pre fault

Detailed content of the Lecture:

- ✓ Fault voltages and currents in a power system network is very important part of power system analysis for stable and economical operations of a Power System.
- ✓ The main objective of the short circuit fault analysis is to simulate short circuit faults on different buses of a power system network and to estimate the state of the power system before and after a fault, which includes various bus voltages and current flow on various transmission lines.
- ✓ The analysis of power systems under faulted condition provides information regarding circuit breaker selection,relay setting, and the stability of the systems operation.
- ✓ Two different MATLAB based programs were written; oneprogram was for Load Flow Studies to determine the pre-fault conditions based on Newton-Raphson method, while theother was for three-phase short-circuit studies.
- ✓ It was observed that the fault currents were mostly excessively high.

Video Content / Details of website for further learning (if any): https://www.youtube.com/watch?v=ENSTaD-Xk7E
Important Books/Journals for further learning including the page nos.: Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011, pp – 341

CourseFaculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS **L25**

EEE **III/V**

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty :**Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Tutorial - Computations of short circuit capacity problem

Introduction:

Short circuit capacity available. kVA of a three phase transformer = V x A x 1.732, where 1.732 = the square root of 3. The square root of 3 is introduced for the reason that, in a three phase system, the phases are 120 degrees apart and, therefore, can not be added arithmetically.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Short circuit
- ✓ 1phase system
- ✓ 3 phase system

Detailed content of the Lecture:

Short-Circuit Capacity (SCC):

- ✓ The short-circuit capacity of a bus is a measure of the strength of a bus. The SCC is defined as the product of the magnitudes of the rated bus voltage and the fault current. It is used to determine the size of the bus bar and to size the breaker used at the bus.

From the above definition we have for the short-circuit MVA at bus k:

$SCC \quad 3 V_{Lk} I_k \; F \quad 10^{-3}$MVA

where the line-to-line voltage is $V_{Lk}$is in kV and I_k(F) in A.

$$I_k(F)_{pu} = \frac{V_k(0)}{X_{kk}}$$

where $V_k \; 0$ is the per unit prefault bus voltage and $X_{kk}$is the per unit reactance at the point of fault. N.B. System resistance is neglected, thus the current computed is on the pessimistic (larger) side. The base current is given by

$$I_B = \frac{S_B \times 10^3}{\sqrt{3} V_B}$$

where S_B is the base MVA and V_B is the line-to-line base voltage in kV. Thus the fault current in ampere is

$$I_k(F) = I_k(F)_{pu} I_B$$

$$= \frac{V_k(0)}{X_{kk}} \frac{S_B \times 10^3}{\sqrt{3} V_B}$$

Thus we have for the SCC:

$$SCC = \frac{V_k(0)}{X_{kk}} \frac{S_B V_{Lk}}{V_B}$$

If we assume the base voltage is equal to the line voltage (i.e. $V_{Lk} = V_B$) then

$$SCC = \frac{V_k(0) S_B}{X_{kk}}$$

The prefault bus voltage is usually assumed 1.0 pu, thus we have the following approximate equation for the short-circuit capacity or the short-circuit MVA

$$SCC \approx \frac{S_B}{X_{kk}}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=gg4fllpVLdI

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011. pp – 349.

CourseFaculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L 26

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Tutorial - fault analysis

Introduction:

A fault is any abnormal condition in a power system. The steady state operating mode of apower system is balanced 3-phase a.c.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Power flow analysis
- ✓ Bus system

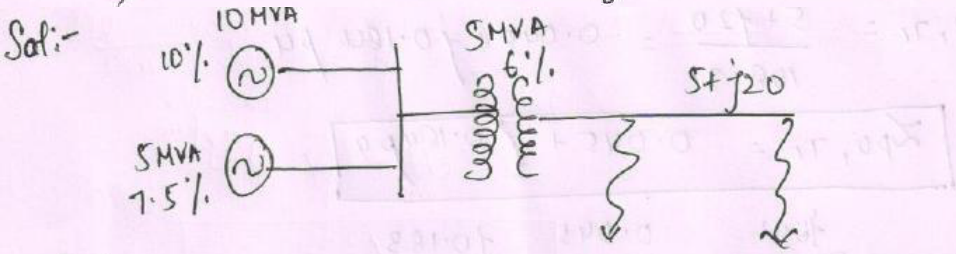
Detailed content of the Lecture:

Prob A 3φ transmission line operating at 33 kV and having a resistance & reactance of 5 Ω & 20 Ω resp. is connected to the generating station bus bar through a 5000 kVA step up transformer which has a reactance of 6%. Connected to the bus bar are two alternators, one 10,000 kVA having 10% reactance & another 5000 kVA having 7.5% reactance. Calculate the kVA at a short circuit fault b/w phases occurring

i) at the high voltage terminal of the T/f

ii) at load end of the transmission line

Sol:-



Let

$$MVA_b = 10 MVA \ , \ kV_b = 33 kV$$

Generator G_1 :-

$$Z_{T\,pu} = Z_{T\,pu\,old} \times \left(\frac{MVA_b\ new}{MVA_b\ old}\right) \times \left(\frac{kV_b\ old}{kV_b\ new}\right)^2$$

$$Z_{pu, G_1} = 0.1 \times \frac{10}{10}$$

$$\boxed{Z_{pu, G_1} = j0.1\ pu}$$

Generator G_2 :-

$$Z_{pu, G_2} = 0.075 \times \left(\frac{10}{5}\right)$$

$$\boxed{Z_{pu, G_2} = j0.15\ pu}$$

Transformer :-

$$Z_{pu, T} = 0.06 \times \frac{10}{5}$$

$$\boxed{Z_{pu, T} = j0.12\ pu}$$

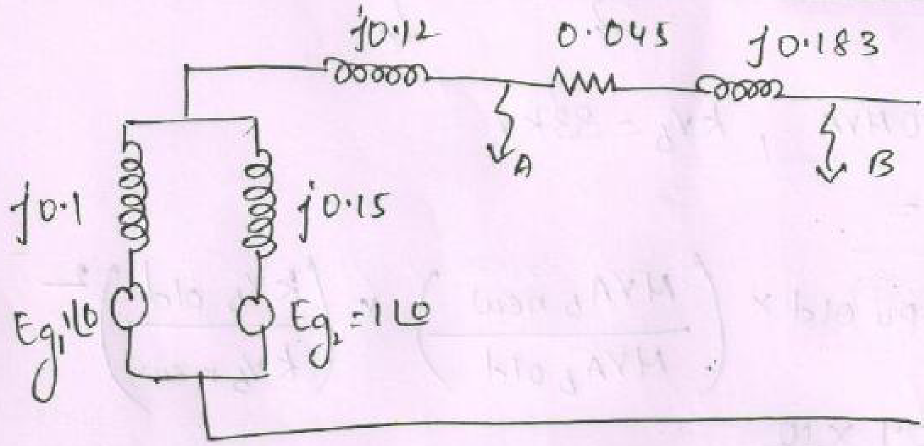
Tr. line

$$Z_{pu, T_l} = \frac{Z_T}{Z_b}$$

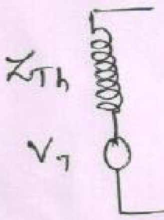
$$\boxed{Z_b = 108.9\,\Omega}$$

$$Z_{pu,TL} = \frac{5 + j20}{108.9} = 0.045 + j0.184\ pu$$

$$\boxed{Z_{pu,TL} = 0.045 + j0.184\ pu}$$



i) I_f at A



$$Z_T = \frac{j0.1 \times j0.15}{j0.1 + j0.15} + j0.12$$

$$\boxed{Z_T = j0.18\ pu}$$

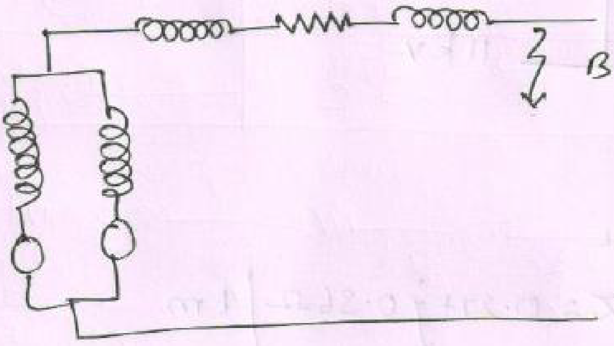
$$S_{cc} = \frac{S_b}{Z_{Tph}}$$

$$S_{cc} = \frac{10}{j0.18} = j55.5$$

$$I_f = \frac{S_{cc_{pu}} \times 10^6}{\sqrt{3} \times V_b \times 10^3} = \frac{j55.5 \times 10^6}{\sqrt{3} \times 33 \times 10^3}$$

$$\boxed{I_f = 971\ A\ pu}$$

ii) I_f at B :-



$$Z_T = \frac{j0.1 \times j0.15}{j0.1 + j0.5} + j0.12 + j0.183 + 0.045$$

$$\boxed{Z_T = 0.045 + j0.363}$$

$$S_{cc} = \frac{S_b}{Z_{pu}}$$

$$= \frac{10}{0.363}$$

$$\boxed{S_{cc} = 27.54 pu}$$

$$I_f = \frac{27.54 \times 10^6}{\sqrt{3} \times 33 \times 10^3}$$

$$\boxed{I_f = 481.1 A}$$

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=msd34MrSYiY

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.

Course Faculty

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty :**Dr.N.Mohananthini**

Unit : **III - Fault Analysis–Balanced Faults** **Date of Lecture:**

Topic of Lecture: Tutorial - Post fault voltage and currents problems

Introduction:

Short circuit capacity available. kVA of a three phase transformer = V x A x 1.732, where 1.732 = the square root of 3. The square root of 3 is introduced for the reason that, in a three phase system, the phases are 120 degrees apart and, therefore, can not be added arithmetically.

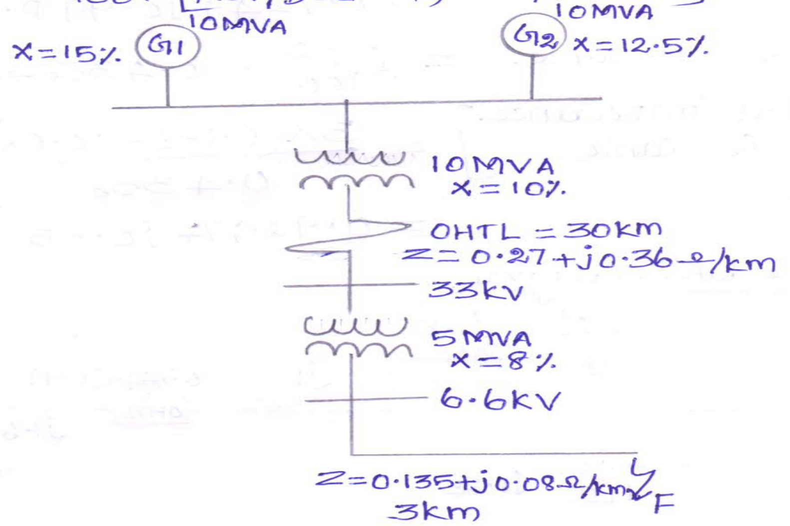
Prerequisite knowledge for Complete understanding and learning of Topic:

Post fault voltage and currents

Detailed content of the Lecture:

5

For the radial network shown, 3φ fault occurs at F. Determine the fault current and the line voltage at 11kV bus under fault conditions. Consider Base MVA = 100. [Nov/Dec-14, Nov/Dec-12]



Solution:

Base MVA = 100

Base kV on Generator side = 11 kV

Base kV on Overhead Tr. line = 33 kV

Base kV on cable = 6.6 kV

$$X_{g1} = 0.15 \times \left(\frac{100}{10}\right) \times \left(\frac{11}{11}\right)^2 = 1.5\ p.u$$

$$X_{g2} = 0.125 \left(\frac{100}{10}\right) \times \left(\frac{11}{11}\right)^2 = 1.25\ p.u$$

$$X_{T_1} = 0.1 \times \left(\frac{100}{10}\right) \times \left(\frac{11}{11}\right)^2 = 1\ p.u$$

$$X_{T2} = 0.08 \times \left(\frac{100}{5}\right) \times \left(\frac{33}{33}\right)^2 = 1.6\ p.u$$

43

$$Z_{base} \text{ in OHTL} = \frac{33^2}{100} = 10.89\ \Omega$$

$$\left.\begin{array}{l}\text{P.U impedance}\\ \text{of OHTL}\end{array}\right\} = \frac{30 \times [0.27 + j0.36]}{10.89}$$

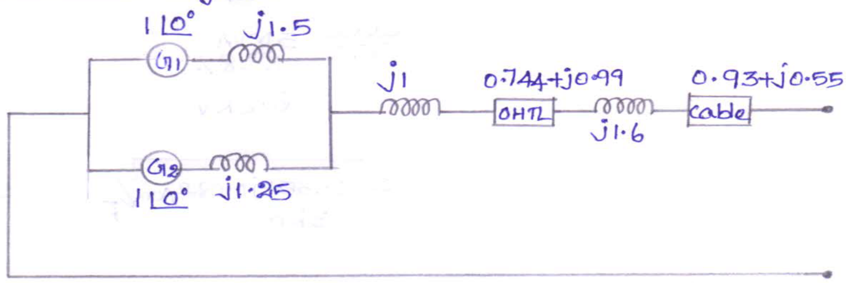
$$= 0.744 + j0.99\ p.u$$

$$Z_{base} \text{ in cable} = \frac{6.6^2}{100} = 0.4356\ \Omega$$

$$\left.\begin{array}{l}\text{P.U impedance}\\ \text{of cable}\end{array}\right\} = \frac{3 \times (0.135 + j0.08)}{0.4356}$$

$$= 0.9297 + j0.55$$

Impedance diagram



Fault occurs, when the generator are at no load condition. Therefore $V_t = 1\angle 0°$

$$X_{eq} = \frac{j1.5 \times j1.25}{j2.75} = j0.682$$

$$Z_{th} = j0.682 + j1 + 0.744 + j0.99 + j1.6 + 0.93 + j0.55$$

$$Z_{th} = 1.674 + j4.822$$

$$Z_{th} = 5.1\angle 70.8$$

Short circuit capacity

$$S_{cc} = \frac{100}{5.1} = 19.6\angle{-70.8}$$

$$I_f = \frac{S_{cc_{3\phi}} \times 10^6}{\sqrt{3}\, V_{lb} \times 10^3} = \frac{19.6\angle{-70.8} \times 10^6}{\sqrt{3} \times 6.6 \times 10^3}$$

$$I_f = 1714.55A$$

To find Line Voltage at 11kV bus during fault condition:

Total impedance between F and 11kV bus,

$$= 0.93 + j0.55 + j1.6 + 0.744 + j0.99 + j1$$

$$= 1.674 + j4.14$$

Total impedance between F & 11 kV bus $= 4.43\angle{67.8}$ p.u

Voltage at 11kV bus in p.u $= Z_{pu} \times I_{pu}$

$$= 4.43\angle{67.8} \times 0.196\angle{-70.8}$$

Voltage at 11kv bus during fault $= 0.88\angle{-3^\circ}$ p.u

Actual Voltage at 11kv bus during fault $= 0.88 \times 11$

$= 9.68$ kV

Line Voltage at 11kv bus during fault $= 9.68$ kV

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=ENSTaD-Xk7E

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.pp - 341.

CourseFaculty

Course Name with Code :**Power System Analysis / 19EEC10**

CourseFaculty : **Dr.N.Mohananthini**

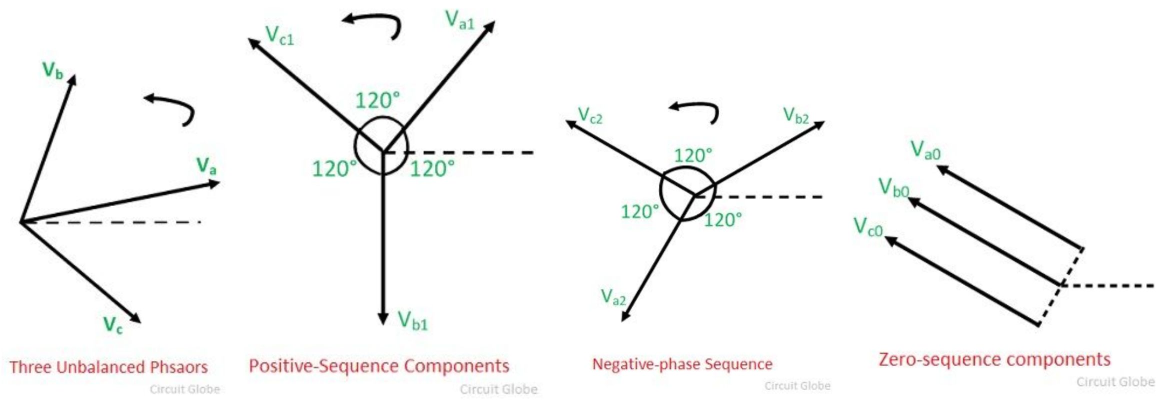
Unit : **IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Introduction to symmetrical components
Introduction: In electrical engineering, the method of symmetrical components simplifies analysis of unbalanced three-phase power systems under both normal and abnormal conditions.
Prerequisite knowledge for Complete understanding and learning of Topic: Symmetrical Analysis

Detailed content of the Lecture:

- ✓ When the system is unbalanced the voltages, currents and the phase impedances are in general unequal.
- ✓ Such a system can be solved by a symmetrical per phase technique, known as the method of symmetrical components.
- ✓ This method is also called a three-component method.
- ✓ The method of symmetrical components simplified the problems of the unbalanced three-phase system. It is used for any number of phases but mainly used for the three-phase system.
- ✓ The unbalanced three phase system is solved regarding symmetrical components, and then it can be transferred back to the actual circuit.
- ✓ The balanced set of components can be given as a positive sequence component, negative sequence component, and zero phase sequence component.
- ✓ Consider an unbalanced voltage phasor system shown in the figure below. Suppose that the phasors are represented by V_a, V_b and V_c and their phase sequence is V_a, V_b, and V_c.
- ✓ The phase sequence of the positive component is V_a, V_b and V_c and the phase sequence of negative components is V_a, V_c, and V_b.
- ✓ In positive phase sequence component, the set of three phasors are equal in magnitude, spaced 120° apart from each other and having the same phase sequence as the original unbalanced phasors.

✓ The positive sequence component of the unbalanced three phase system is shown below.



- ✓ In negative phase sequence component, the set of the three phasors are equal in magnitude, spaced 120° apart from each other and having the phase sequence opposite to that of the original phasors. The negative phase sequence is shown in the figure below
- ✓ In zero phase sequence components, the set of three phasors is equal in magnitude to zero phase displacement from each other. The zero phase sequence component is shown in the figure below.
- ✓ The three phase balanced system is a special case of a general three-phase system in which zero and negative sequencecomponents are zero.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=iLOfLIHLaqs

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-398

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L 29

EEE

III/V

Course Name with Code **:Power System Analysis/19EEC10**

CourseFaculty **: Dr.N.Mohananthini**

Unit **: IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Sequence Impedances

Introduction:

Sequence impedances and sequence networks are the fault analyzing and calculating parameters in power system networks. Sequence impedances are of three types. They are positive, negative and zero sequence impedances.

Prerequisite knowledge for Complete understanding and learning of Topic:

Sequence Impedances

Detailed content of the Lecture:

- ✓ Sequence impedances and sequence networks are the fault analyzing and calculating parameters in power system networks. Sequence impedances are of three types. They are positive, negative and zero sequence impedances.
- ✓ The sequence impedances in positive and negative sequences are equal in magnitude in case of transformers and transmission lines. Whereas these are not equals in case of rotating machines such as synchronous machines (alternators, synchronous motors).
- ✓ Consider the sequences networks for a synchronous machine.

Positive sequence network:

Figure 1 is the Positive sequence network for three phase system and its equivalent for single phase system.

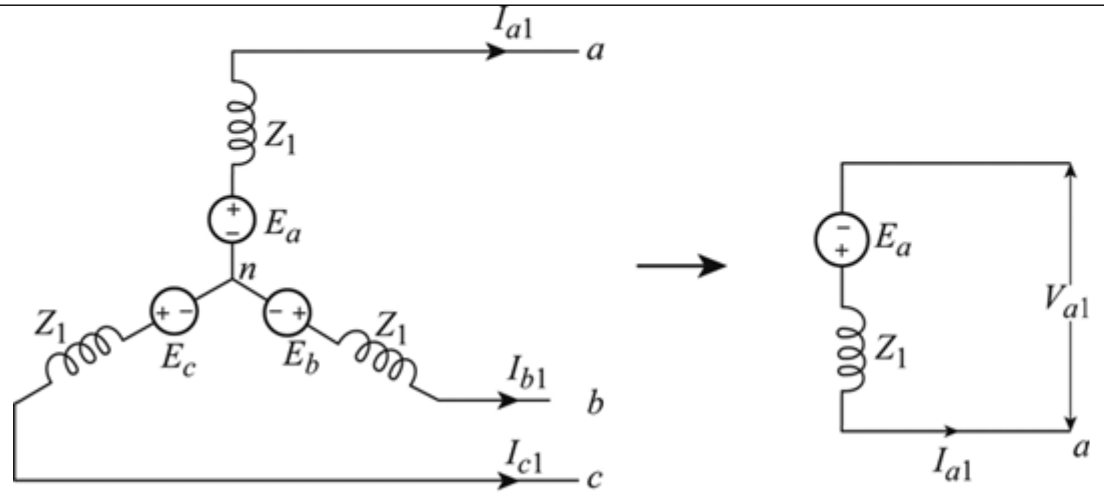


Figure 1

By analyzing this sequence network, the positive sequence voltage can be expressed as,

$V_{a1} = E_a - Z_1 I_{a1}$

Here, V_{a1}, I_{a1}, Z_1 are voltage, current and impedance of positive sequence network respectively, E_a is voltage magnitude in phase.

Negative sequence network:

Figure 2 is the negative sequence network for three phase system and its equivalent for single phase system.

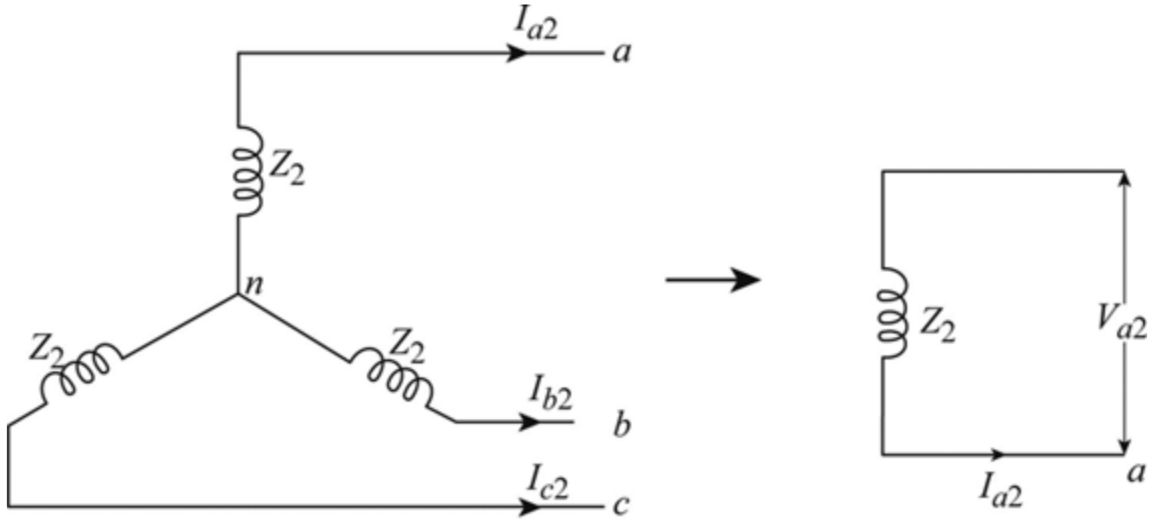


Figure 2

By analyzing this sequence network, the negative sequence voltage can be expressed as,

$V_{a2} = -Z_2 I_{a2}$

Here, V_{a2}, I_{a2}, Z_2 are voltage, current and impedance of negative sequence network respectively.

Zero sequence network:

Figure 3 is the zero sequence networks for three phase system and its equivalent for single phase system.

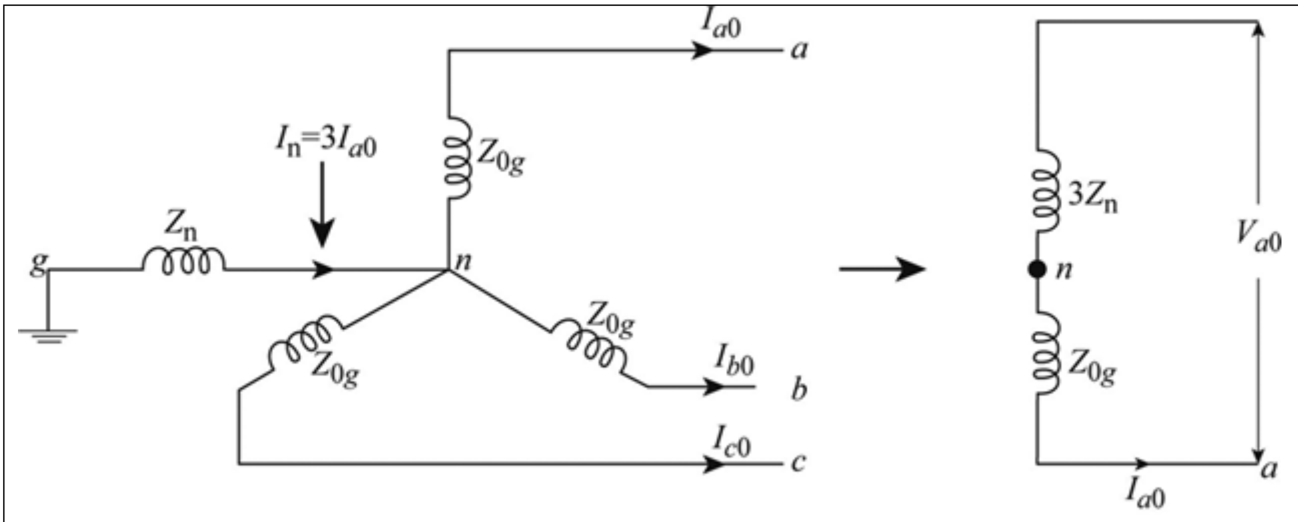


Figure 3

By analyzing this sequence network, the zero sequence voltage can be expressed as,

$V_{a0} = -Z_0 I_{a0}$

$Z_0 = 3Z_n + Z_{0g}$

Here, V_{a0}, I_{a0}, Z_{a0} are voltage, current and impedance of zero sequence network respectively and Z_n is neutral impedance.

The relation between three sequence impedances is $Z_0 < Z_2 < Z_1$. These symmetrical components play a significant role in the fault calculations and analysis of the power system networks.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=Tsyep7R5r38

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-399

Course Faculty

LECTURE HANDOUTS

L 30

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini**

Unit : **IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Sequence circuits of synchronous machine, transformer and transmission lines

Introduction:

The sequence impedance of the network describes the behavior of the system under asymmetrical fault conditions. The performance of the system determines by calculating the impedance offered by the different element of the power system to the flow of the different phase sequence component of the current.

Prerequisite knowledge for Complete understanding and learning of Topic:

Synchronous machine, transformer and transmission lines

Detailed content of the Lecture:

<u>Sequence Impedances of Transmission Lines:</u>

Sequence Impedances of Transmission Lines – Figure 10.9 shows the circuit of a fully transposed line carrying unbalanced currents. The return path for I_n is sufficiently away for the mutual effect to be ignored.

Let

X_s = self reactance of each line

X_m = mutual reactance of any line pair

The following KVL equations can be written down from Fig. 10.9.

$$V_a - V'_a = jX_sI_a + jX_mI_b + jX_mI_c$$

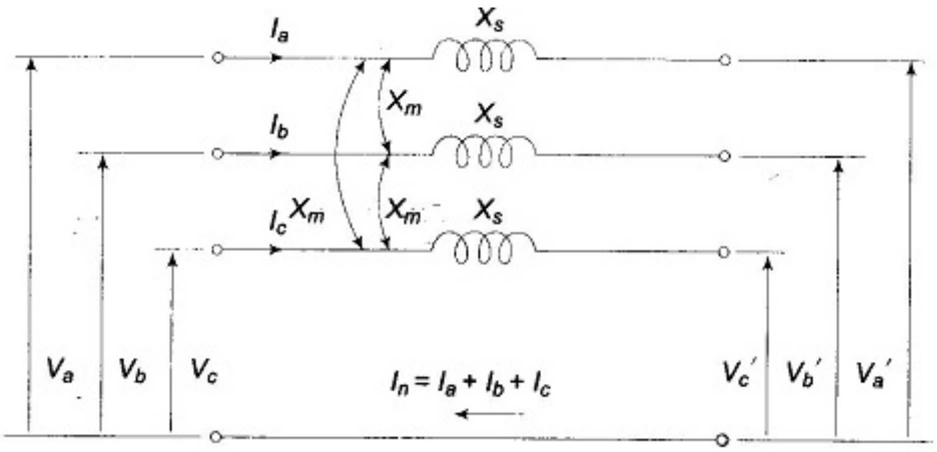


Fig. 10.9

$$V_b - V_b' = jX_mI_a + jX_sI_b + jX_mI_c \tag{10.35}$$

$$V_c - V_c' = jX_mI_a + jX_mI_b + jX_sI_c$$

or in matrix form

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - \begin{bmatrix} V_a' \\ V_b' \\ V_c' \end{bmatrix} = j \begin{bmatrix} X_sX_mX_m \\ X_mX_sX_m \\ X_mX_mX_s \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{10.36}$$

or $$V_p - V_p' = ZI_p \tag{10.37}$$

or $$A\ (V_s - V_s') = ZAI_s \tag{10.38}$$

or $$V_sV_s' = A^{-1}ZAI_s \tag{10.39}$$

Now

$$A^{-1}ZA = \frac{1}{3}\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} jX_s & jX_m & jX_m \\ JX_m & jX_s & jX_m \\ jX_m & jX_m & jX_s \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ \alpha^2 & \alpha & 1 \\ \alpha & \alpha^2 & 1 \end{bmatrix} \tag{10.40}$$

$$= j\begin{bmatrix} X_s - X_m & 0 & 0 \\ 0 & X_s - X_m & 0 \\ 0 & 0 & X_s + 2X_m \end{bmatrix}$$

Thus Eq. (10.37) can be written as

$$\begin{bmatrix} V_1 \\ V_2 \\ V_0 \end{bmatrix} - \begin{bmatrix} V_1' \\ V_2' \\ V_0' \end{bmatrix} = j\begin{bmatrix} X_s - X_m & 0 & 0 \\ 0 & X_s - X_m & 0 \\ 0 & 0 & X_s + 2X_m \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_0 \end{bmatrix} \tag{10.41}$$

$$= \begin{bmatrix} Z_1 & 0 & 0 \\ 0 & Z_2 & 0 \\ 0 & 0 & Z_0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_0 \end{bmatrix} \tag{10.42}$$

wherein

$$Z_1 = j(X_s - X_m) = \textit{positive sequence impedance} \quad (10.43)$$

$$Z_2 = j(X_s - X_m) = \textit{negative sequence impedance} \quad (10.44)$$

$$Z_0 = j(X_s + 2X_m) = \textit{zero sequence impedance} \quad (10.45)$$

We conclude that a fully transposed transmission has:

- equal positive and negative sequence impedances.
- zero sequence impedance much larger than the positive (or negative) sequence impedance (it is approximately 2.5 times).

It is further observed that the sequence circuit equations (10.42) are in *decoupled* form, i.e. there are no mutual sequence inductances. Equation (10.42) can be represented in network form as in Fig. 10.10.

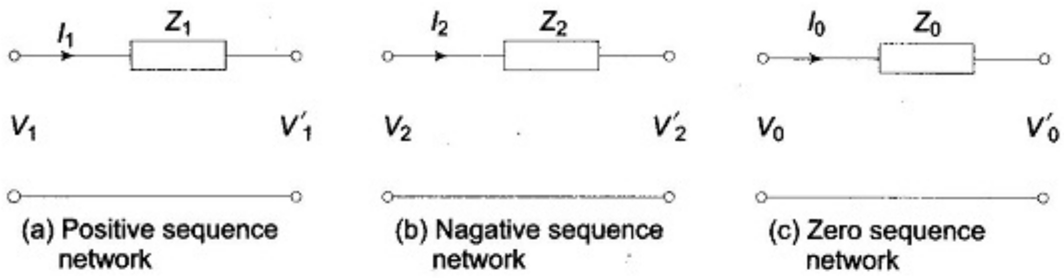


Fig. 10.10

The decoupling between sequence networks of a fully transposed transmission holds also in 3-phase synchronous machines and 3-phase transformers. This fact leads to considerable simplications in the use of symmetrical components method in unsymmetrical fault analysis.

In case of three static unbalanced impedances, coupling appears between sequence networks and the method is no more helpful than a straight forward 3-phase analysis.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Tsyep7R5r38

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011.P-399

Course Faculty

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini**

Unit : **IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Sequence networks analysis of single line to ground

Introduction:

The sequence impedance of the network describes the behavior of the system under asymmetrical fault conditions. The performance of the system determines by calculating the impedance offered by the different element of the power system to the flow of the different phase sequence component of the current.

Prerequisite knowledge for Complete understanding and learning of Topic:

Single line to ground

Detailed content of the Lecture:

Sequence networks

- ✓ In all respect, the positive sequence network is identical to the usual networks considered.
- ✓ Each synchronous machine must be considered as a source of EMF, which may vary in magnitude and phase position depending upon the distribution of power and reactive volt amperes, just prior to the occurrence of the fault.
- ✓ The positive sequence voltage at the point of fault will drop, the amount being dependent upon the type of faults; for three-phase faults it will be zero; for DLG fault, line-to-line fault, and single line-to-ground fault, it will be higher in the order stated.
- ✓ The negative sequence network is in general quite similar to the positive sequence network except that since no negative sequence voltages are generated, the source of EMF is absent.
- ✓ The zero sequence networks will be free of internal voltages, flow of current resulting from the voltage at the point of fault. The impedances to zero sequence current are very frequently different from positive or negative sequence currents. Transformer and generator impedances depend upon the type of star or delta connections.
- ✓ The zero sequence equivalent circuits of three-phase transformers require special attention because of the possibility of various combinations.
- ✓ A general circuit for any combination is given in Figure Z_0 is the zero sequence impedance of the windings of the transformer.

- ✓ These are two series and two shunt switches. One series and one shunt switch are for both the sides separately.
- ✓ The series switch of a particular side is closed if it is star grounded and the shunt switch is closed if that side is delta connected, otherwise they are left open. For example, consider the transformer Δ/Y is connected with star ungrounded, as shown in Figure 18.30b.
- ✓ The switching arrangement shown in Figure 18.30c, since the primary is delta connected, the shunt switch of the primary side is closed and series is left open.
- ✓ The secondary is star ungrounded, therefore the series switch is left open and the shunt switch is also left open. The zero sequence network is shown in Figure.

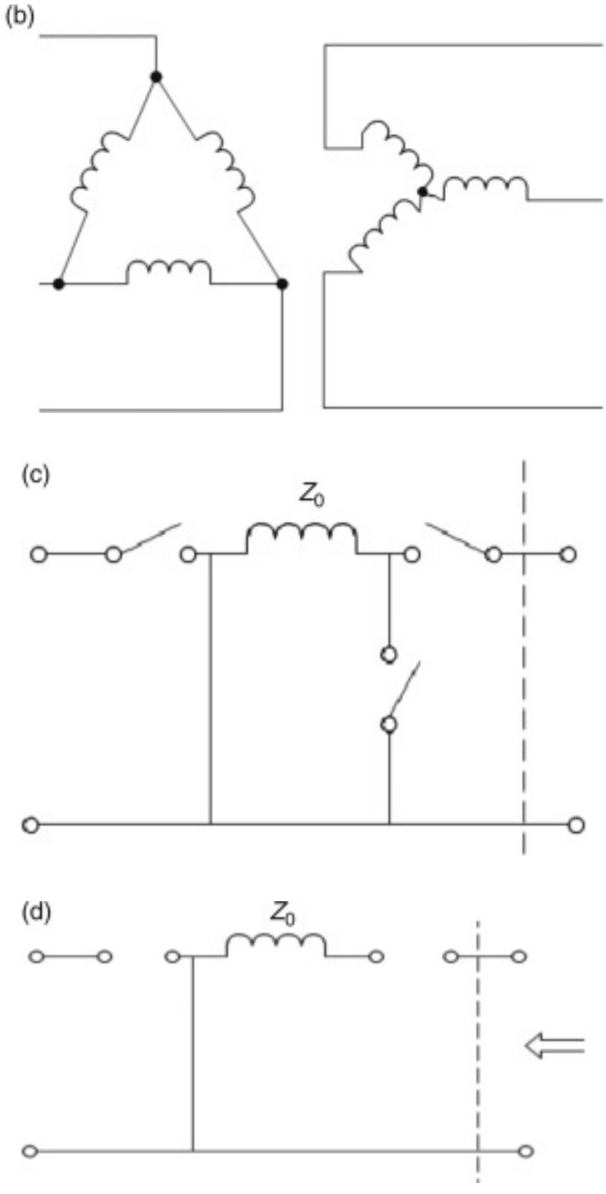
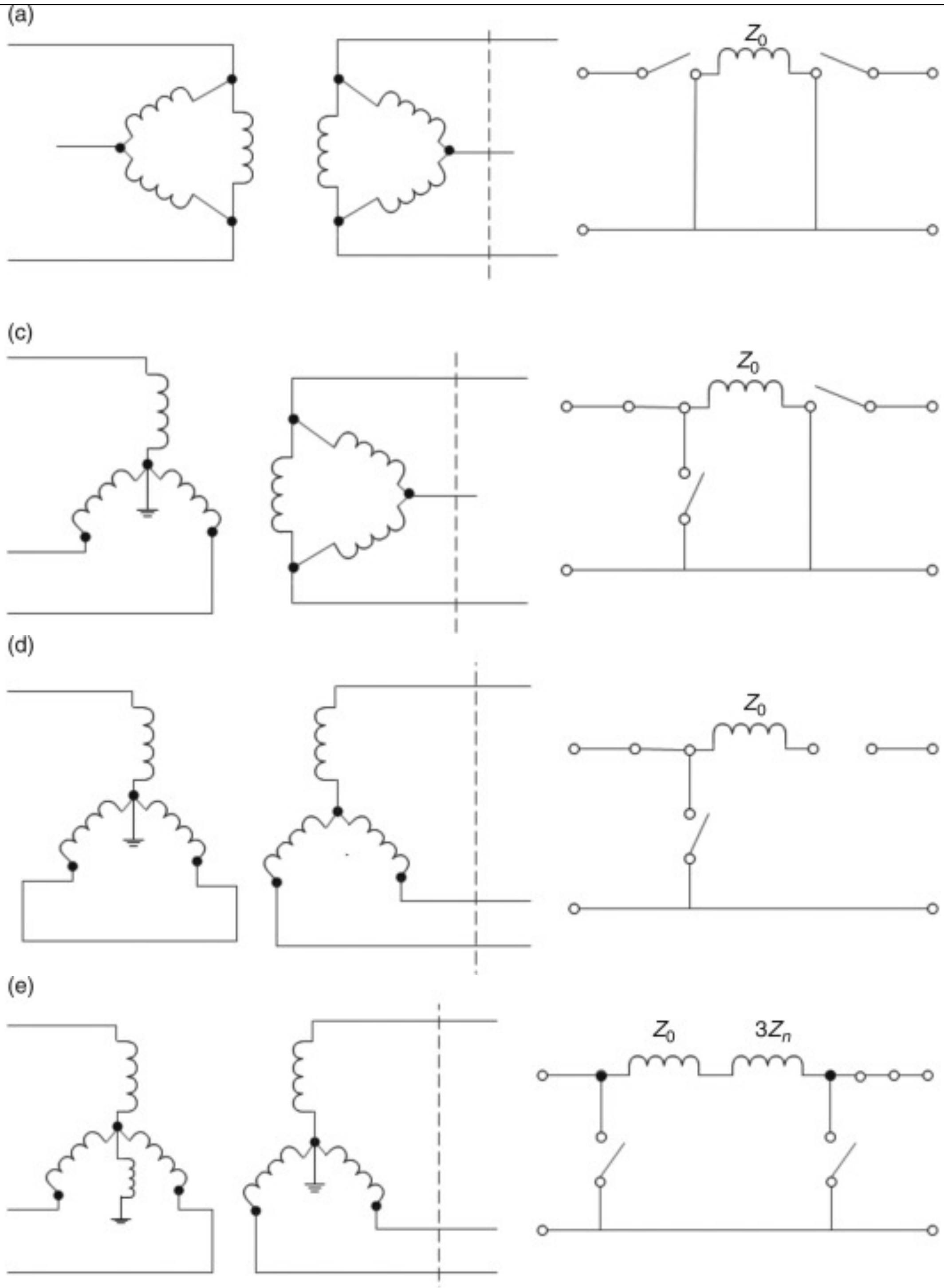


Figure 18.30. (a) General switching combination, (b) star–delta transformer, (c) its switch arrangements for zero sequence network of a Δ/Y transformer, (d) zero sequence equivalent of a Δ/Y transformer.

The zero sequence equivalent circuits for a few more combinations using this arrangement are shown in Figure



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Tsyep7R5r38

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-400

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

Estd. 2000

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS | **L 32**

EEE | **III/V**

Course Name with Code :Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini

Unit : IV - Fault Analysis–Unbalanced Faults **Date of Lecture:**

Topic of Lecture: Sequence networks analysis of line to line

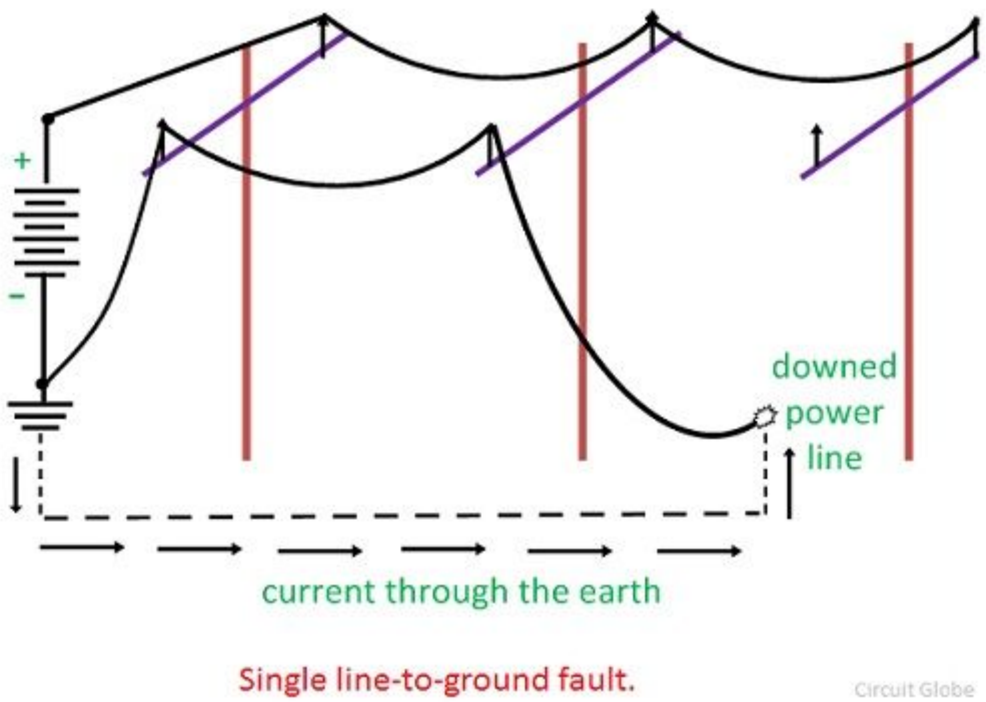
Introduction:
Single line-to-ground fault on a transmission line occurs when one conductor drops to the ground or comes in contact with the neutral conductor. Such types of failures may occur in power system due to many reasons like high-speed wind, falling off a tree, lightning,

Prerequisite knowledge for Complete understanding and learning of Topic:
line to line

Detailed content of the Lecture:

Single Line-to-Ground Fault

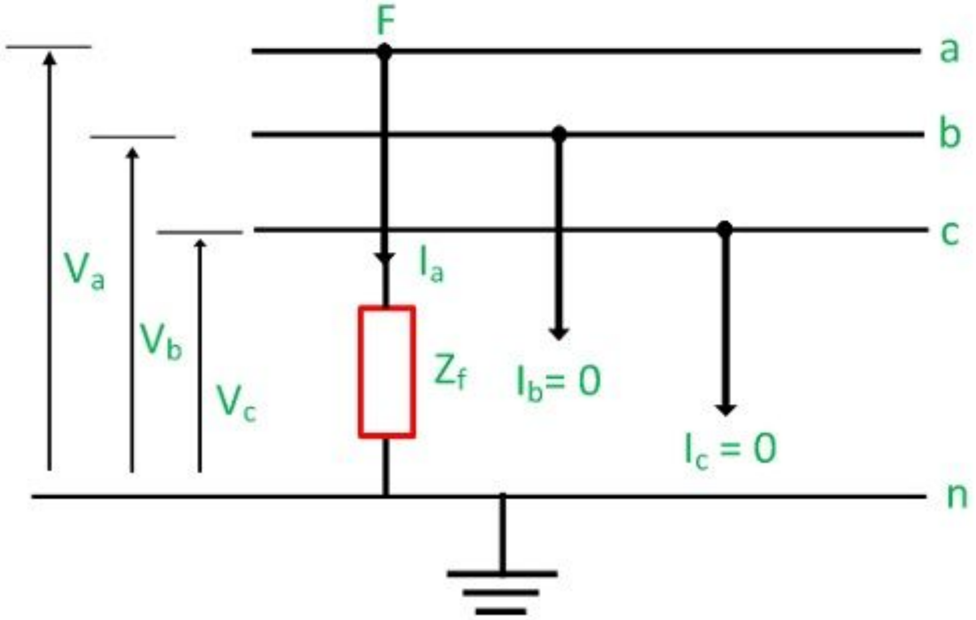
- ✓ Generally, a single line-to-ground fault on a transmission line occurs when one conductor drops to the ground or comes in contact with the neutral conductor. Such types of failures may occur in power system due to many reasons like high-speed wind, falling off a tree, lightning, etc.



Single line-to-ground fault.

Circuit diagram of single line-to-ground fault

- ✓ Suppose the phase **a** is connected to ground at the fault point F as shown in a figure below. I_a, I_b and I_c are the current and V_a, V_b and V_c are the voltage across the three phase line a, b and c respectively. The fault impedance of the line is Z_f.



Single line-to-ground fault

- ✓ Since only phase **a** is connected to ground at the fault, phase b and c are open circuited and carries no current; i.e fault current is I_a and $I_b = 0$, $I_c = 0$. The voltage at the fault point F is $V_a = Z_f I_a$.

- ✓ The symmetrical component of the fault current in phase "a" at the fault point can be written as

$$I_{a0} = \frac{1}{3}(I_a + I_b + I_c) = \frac{1}{3}(I_a + 0 + 0) = \frac{1}{3}I_a$$

$$I_{a1} = \frac{1}{3}(I_a + \alpha I_b + \alpha^2 I_c) = \frac{1}{3}(I_a + 0 + 0) = \frac{1}{3}I_a$$

$$I_{a2} = \frac{1}{3}(I_a + \alpha^2 I_b + \alpha I_c) = \frac{1}{3}(I_a + 0 + 0) = \frac{1}{3}I_a$$

$$I_{a0} = I_{a1} = I_{a2} = \frac{1}{3}I_a$$

This relation can also be found by matrix method as follows:-

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{I_a}{3}\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

$$I_{a0} = I_{a1} = I_{a2} = \frac{1}{3} I_a$$

- ✓ In the case of a single line-to-ground fault, the sequence currents are equal. The sequencevoltage at the fault point is determined by the equations:-

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Tsyep7R5r38

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., ‘Modern Power System Analysis’, Tata McGraw-Hill, Fourth Edition,2011.P-451

Course Faculty

LECTURE HANDOUTS

L 33

EEE

III/V

Course Name with Code **:Power System Analysis/19EEC10**

CourseFaculty **: Dr.N.Mohananthini**

Unit **: IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Z-bus Matrix

Introduction: (Maximum 5 sentences)

Z Matrix or bus impedance matrix is an important tool in power system analysis. Though, it is not frequently used in power flow study, unlike Ybus matrix, it is, however, an important tool in other power system studies like short circuit analysis or fault study.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Matrix

Detailed content of the Lecture:

FORMATION OF Z BUS MATRIX

To know about Z bus formation first of all we have to know about Z bus matrix.

Z BUS MATRIX:

- ✓ Z bus matrix contains the driving point impedance of each and every node with respect to a reference bus.
- ✓ And the driving point impedance of a node is equivalent impedance between it and the reference.
- ✓ The off diagnol are known as the transfer impedence between each bus of the network and with every other bus with respect to the reference bus.
- ✓ The Z bus are also known as bus impedence matrix which is built from the branch consisting data of the positive sequence,negative sequence and zero sequence impedence.During practical purposes,the positive and negative sequence are treated equally.

FORMATION OF Z BUS MATRIX:

- ✓ The whole system is assembled by starting with a single element connected to the reference bus,and if one element is added at a time ,we have to modify the matrix for that added element.
- ✓ Each of the element added should be connected to the system by a single node or two nodes.There are some types which are described below

TYPE 1: A branch from reference bus

Suppose current of 1.0pu is injected into a new bus Q ,connected to the reference but it will produce no voltage on other buses.And also injection of current into any bus of PN will produce no voltage on the new bus Q.

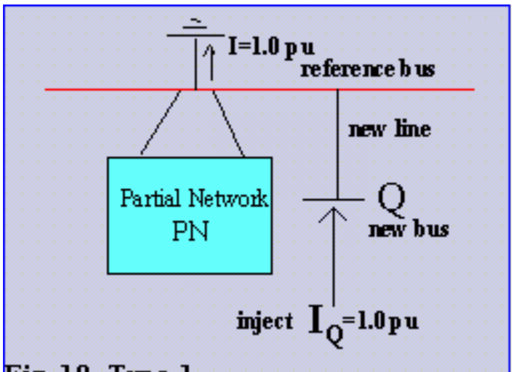


Fig_10. Type 1

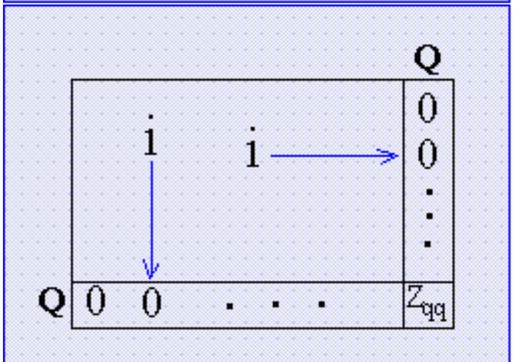


Fig_11. Resulting Zbus

- ✓ $Z_{i,q}$=$Z_{q,i}$=0 where i is not equal to q
- ✓ $Z_{q,q}$=$Z_{p,q}$
- ✓ Hence from above equation the driving point impedence of new bus is impedence of new element added.

TYPE2:A Branch not from reference bus

- ✓ Suppose a current of 1.0pu is injected into busQ which is same as injecting the current on bus P.
- ✓ A new axis is been added to the Z bus matrix corresponding to new bus Q.And the off diagnol elements of new row –coloum is same as the element of bus P.The diagnol element is Zq where q is Zp,P plus a series line impedence .

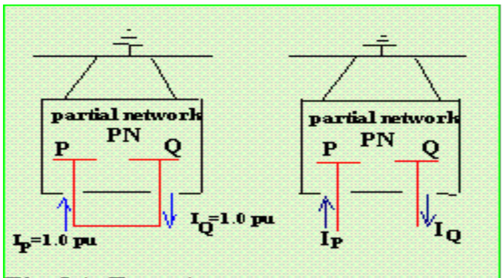


Fig_14. Type 4

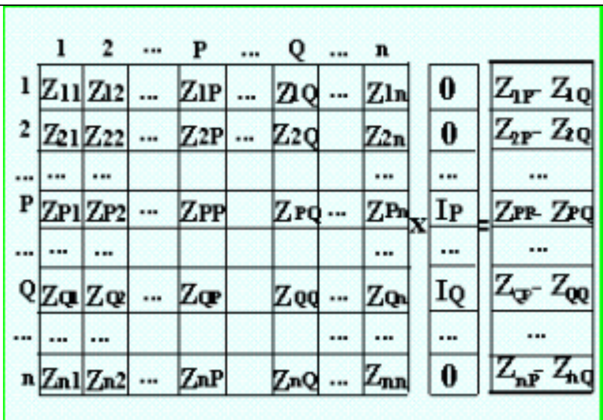


Fig_15 Ip=1.0, Iq=-1.0 pu

$$Z_{i,q}=Z_{i,p}$$

$$Z_{q,i}=Z_{p,i}$$

$$Z_{qq}=Z_{pp}+Z_{p,q}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Tsyep7R5r38

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-423

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L 34

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini**

Unit : **IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Sequence networks analysis of single line to ground problems

Introduction: (Maximum 5 sentences)

The sequence impedance of the network describes the behavior of the system under asymmetrical fault conditions. The performance of the system determines by calculating the impedance offered by the different element of the power system to the flow of the different phase sequence component of the current.

Prerequisite knowledge for Complete understanding and learning of Topic:

Single line to ground

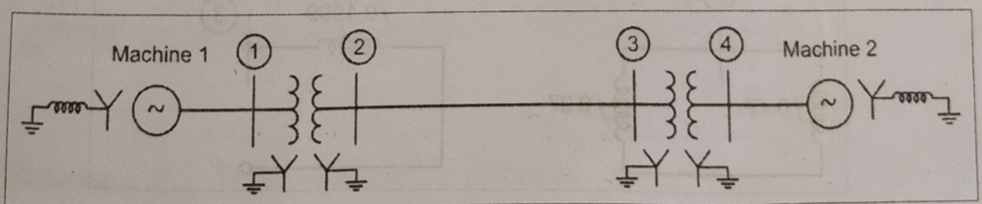
Detailed content of the Lecture

Example 10.1(a) Two synchronous machines are connected through three-phase transformers to the transmission line as given in Fig. The ratings and reactances of the machines and transformers are :

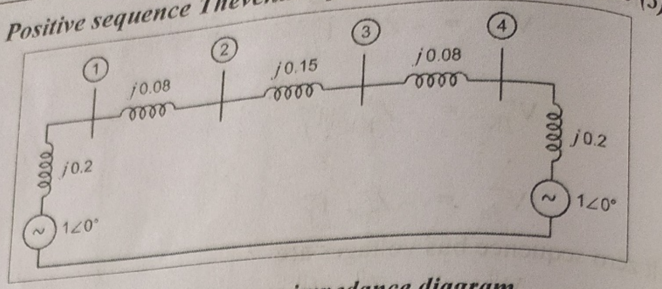
Machines 1 and 2 : 100 MVA ; 20 KV ; $X_d'' = X_1 = X_2 = 20\%$; $X_0 = 4\%$; $X_n = 5\%$

Transformers T_1 and T_2 : 100 MVA ; 20 Y / 345 Y KV ; X = 8%

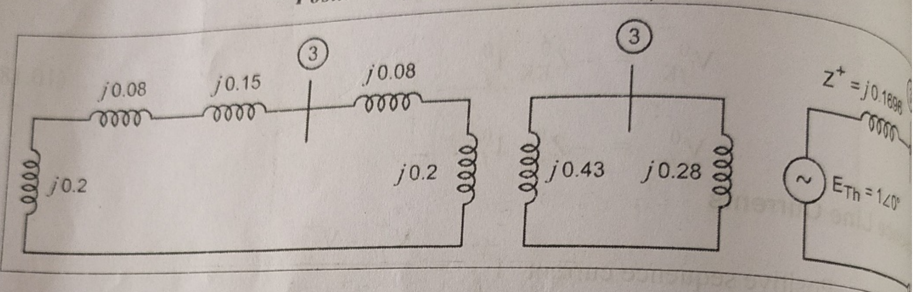
Both transformers are solidly grounded on two sides on a chosen base of 100 MVA, 345 KV in the transmission line circuit. The line reactances are $X_1 = X_2 = 15\%$ and $X_0 = 50\%$. The system is operating at nominal voltage without prefault currents when a bolted ($Z_f = 0$) single line-to-ground fault occurs on phase 'a' at bus 3. Determine the subtransient current to ground at the fault.



☺ **Solution :** ***Positive sequence Thevenin equivalent viewed from bus (3) :***

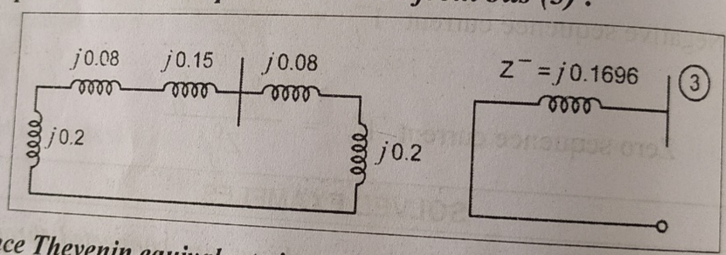


Positive sequence impedance diagram

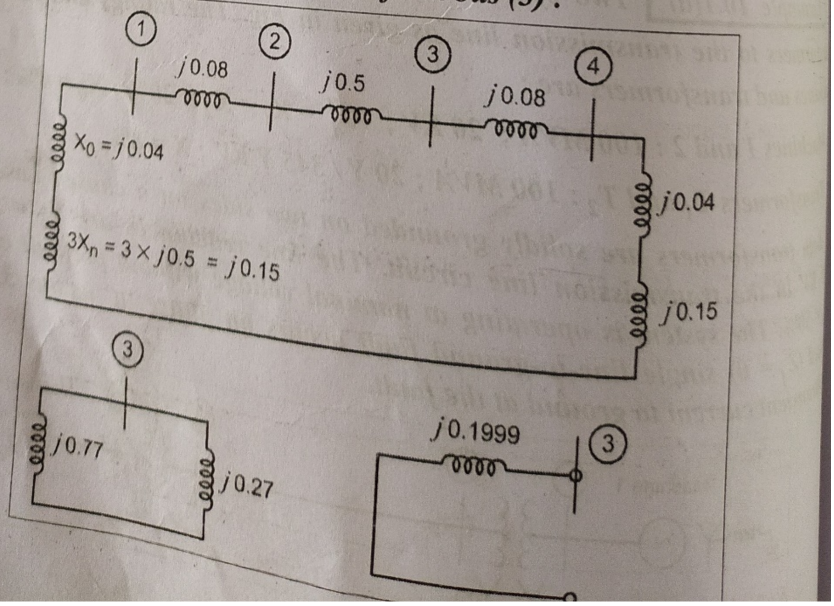


Thevenin's network for positive sequence

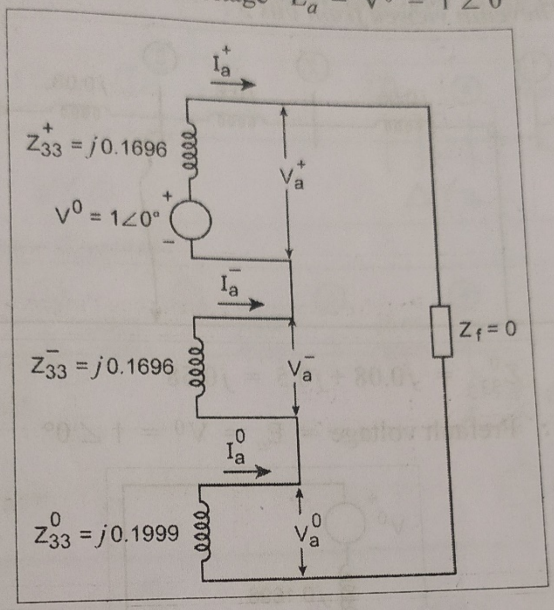
Negative sequence Thevenin equivalent viewed from bus (3) :



Zero sequence Thevenin equivalent viewed from bus (3) :



Draw Sequence Network : Prefault voltage $E_a = V^0 = 1\angle 0°$



From Fig., $$I_a^+ = I_a^- = I_a^0 = \frac{1\angle 0°}{Z_{33}^+ + Z_{33}^- + Z_{33}^0}$$

$$= \frac{1\angle 0°}{j0.1696 + j0.1696 + j0.1999} = -j1.8549 \text{ p.u}$$

Fault current in p.u $= 3 \times I_a^+$

$$= 3 \times -j1.854 = -j5.5648 \text{ p.u}$$

Base current at the fault point or secondary side of first transformer/line

$$= \frac{MVA_b}{\sqrt{3} \times KV_b} = \frac{100 \times 10^3}{\sqrt{3} \times 345} = 167.348 \text{ Amp}$$

Fault current in Amp $= I_{f\ p.u.} \times$ Base current

$$= -j5.5648 \times 167.348$$

$$= -j931.2576 = 931.2576\angle 270° \text{ Amp}$$

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=Tsyep7R5r38

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-435

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L 35

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini**

Unit : **IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Tutorial - Analysis of Double line to ground fault

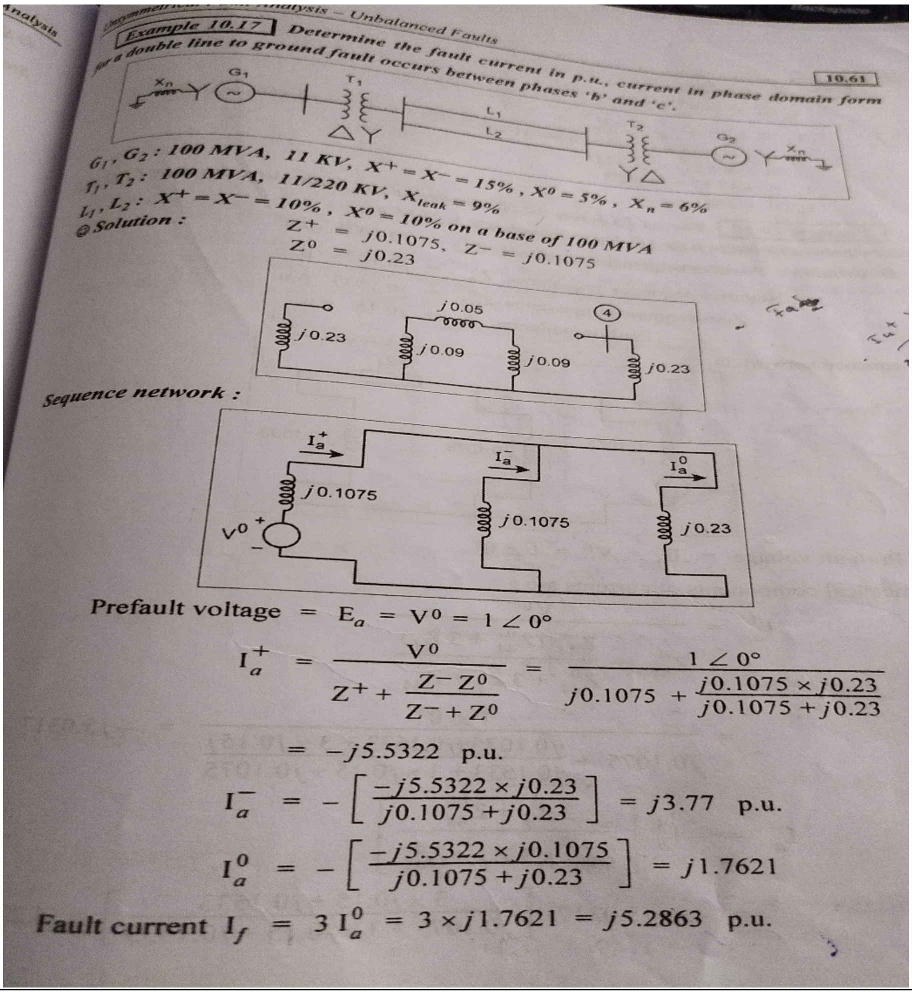
Introduction

Double line to ground fault occurs when any two phases of the power circuit is short circuited to ground or neutral. Following are some of the characteristic 'signatures' of a Phase to Phase to Ground fault or Double Line to Ground fault.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ line to ground fault

Detailed content of the Lecture:



Example 10.17 Determine the fault current in p.u., current in phase domain form for a double line to ground fault occurs between phases 'b' and 'c'.

G_1, G_2 : 100 MVA, 11 KV, $X^+ = X^- = 15\%$, $X^0 = 5\%$, $X_n = 6\%$

T_1, T_2 : 100 MVA, 11/220 KV, $X_{leak} = 9\%$

L_1, L_2 : $X^+ = X^- = 10\%$, $X^0 = 10\%$ on a base of 100 MVA

Solution :

$Z^+ = j0.1075$, $Z^- = j0.1075$

$Z^0 = j0.23$

Sequence network :

Prefault voltage $= E_a = V^0 = 1\angle 0°$

$$I_a^+ = \frac{V^0}{Z^+ + \dfrac{Z^- Z^0}{Z^- + Z^0}} = \frac{1\angle 0°}{j0.1075 + \dfrac{j0.1075 \times j0.23}{j0.1075 + j0.23}}$$

$$= -j5.5322 \text{ p.u.}$$

$$I_a^- = -\left[\frac{-j5.5322 \times j0.23}{j0.1075 + j0.23}\right] = j3.77 \text{ p.u.}$$

$$I_a^0 = -\left[\frac{-j5.5322 \times j0.1075}{j0.1075 + j0.23}\right] = j1.7621$$

Fault current $I_f = 3 I_a^0 = 3 \times j1.7621 = j5.2863$ p.u.

Current in phase domain : $I_a = I_a^0 + I_a^+ + I_a^- = 0$ $I_b = I_a^0 + a^2 I_a^+ + a I_a^-$ $= j1.7621 + (-0.5 - j0.866)(-j5.5322) + (-0.5 + j0.866) \times j3.77$ $= -8.0557 + j2.6431$ $I_c = 8.0557 + j2.6431$ $I_n = 5.286$ p.u.
Video Content / Details of website for further learning (if any): https://www.youtube.com/watch?v=Tsyep7R5r38
Important Books/Journals for further learning including the page nos.: Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-465.

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)

Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

LECTURE HANDOUTS

L 36

EEE

III/V

Course Name with Code :**Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini**

Unit : **IV - Fault Analysis–Unbalanced Faults** **Date of Lecture:**

Topic of Lecture: Tutorial Z-bus Matrix Problems

Introduction:

Z Matrix or bus impedance matrix is an important tool in power system analysis. Though, it is not frequently used in power flow study, unlike Ybus matrix, it is, however, an important tool in other power system studies like short circuit analysis or fault study.

Prerequisite knowledge for Complete understanding and learning of Topic:

- ✓ Z-bus Matrix

Detailed content of the Lecture:

FORMATION OF Z BUS MATRIX

To know about Z bus formation first of all we have to know about Z bus matrix.

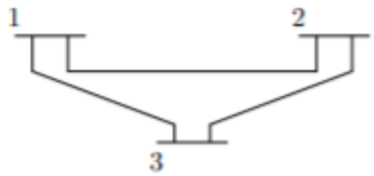
Z BUS MATRIX:

Z bus matrix contains the driving point impedance of each and every node with respect to a reference bus.And the driving point impedance of a node is equivalent impedance between it and the reference.The off diagnol are known as the transfer impedence between each bus of the network and with every other bus with respect to the reference bus.The Z bus are also known as bus impedence matrix which is built from the branch consisting data of the positive sequence,negative sequence and zero sequence impedence.During practical purposes,the positive and negative sequence are treated equally.

FORMATION OF Z BUS MATRIX:

The whole system is assembled by starting with a single element connected to the reference bus,and if one element is added at a time ,we have to modify the matrix for that added element.Each of the element added should be connected to the system by a single node or two nodes.There are some types which are described below

1. Form $\mathbf{Y}_{\text{Bus}}$ matrix for the network shown here.



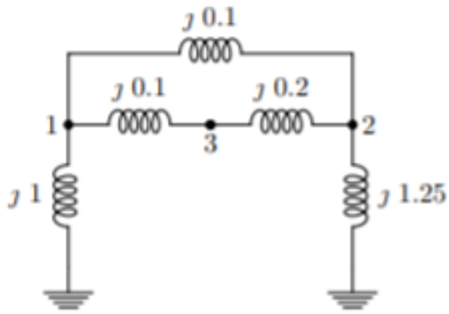
Line	Series Reactance p.u.	Shunt Admittance p.u
1–2	j 0.20	j 0.24
2–3	j 0.10	j 0.16
1–3	j 0.25	j 0.30

Ans: $\mathbf{Y}_{\text{Bus}} = \begin{pmatrix} -j8.73 & j5 & j4 \\ j5 & -j14.8 & j10 \\ j4 & j10 & -j13.77 \end{pmatrix}$

2. Modify $\mathbf{Y}_{\text{BUS}}$ if the line between 1 and 2 is removed.

Ans: $\mathbf{Y}_{\text{Bus}} = \begin{pmatrix} -j3.85 & 0 & j4 \\ 0 & -j9.92 & j10 \\ j4 & j10 & -j13.77 \end{pmatrix}$

3. Form $\mathbf{Z}_{\text{BUS}}$ matrix for the network shown here by building algorithm.



Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=rN6TvIJvGDg

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-463.

Course Faculty

Course Name with Code :Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini & Mrs.N.Sathya

Unit : V – Stability Analysis **Date of Lecture:**

Topic of Lecture: Steady state and transient Stability

Introduction:

Voltage instability stems from the attempt of load dynamics torestore power consumption beyond the capability of the combined transmission and generation system. The process by which the sequence of events accompanying voltage instability leads to a low unacceptable voltage profile in a significant part of the power system.

Prerequisite knowledge for Complete understanding and learning of Topic:

Stability

Detailed content of the Lecture:

- ✓ Voltage stability or voltage collapse deals with the ability of a power system to maintain acceptable voltage levels at all buses in the system in any condition whether it is normal or during disturbance.
- ✓ A heavily loaded system enters a state of voltage instability due to a sudden large disturbance or a change in system condition. It causes a progressive and uncontrollable decline in voltage.
- ✓ The main factor causing voltage instability in any power system is the inability of the system to meet its sudden growing demand for reactive power.

The two different approaches available as a tool to analyse the voltage collapse problem in a system are:

(a) The static approach and

(b) The dynamic approach.

(a) Static methods involve the static model of power systemcomponents. These methods are important when the power system is in operation and planning stages, in-order to prepare an ade- quate fool proof plan for meeting the power requirements during different types of contingencies arising during its operation.

(b) The dynamic methods use time domain simulations to re- veal the voltage collapse mechanism such as why and how the volt- age collapse occurs. Dynamic methods analyze the effect of dynam- ic loads, on load tap changes (OLTC), generator over excitation limiters (OXL) on voltage collapse.

- ✓ In most of the cases, the system dynamics affecting voltagestability are quite slow. The static approach effectively analyzes most of the problems. It can examine the viability of a specific operating point of the power system.

- ✓ In addition, static analysis method provides information such as sensitivity or degree of stability and involves the computation of only algebraic equations. It is much more efficient and faster than dynamic approaches.

- ✓ The static analysis approach is more attractive than the dynamic method and well suited to voltage stability analysis of power systems over a wide range of system conditions.

  Dynamic analysis provides the most accurate indication of the time responses of the system. Therefore, Dynamic analysis is extremely useful for fast voltage collapse situations, such as loss of generation and system faults, especially concerning the complex sequence of events that lead to the instability.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=ImqYGfEHe0Q

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.T-333.

Course Faculty

LECTURE HANDOUTS | **L 38**

EEE | **III/V**

Course Name with Code :Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini & Mrs.N.Sathya

Unit : V – Stability Analysis **Date of Lecture:**

Topic of Lecture: Introduction to voltage stability

Introduction:

Voltage instability stems from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission and generation system. The process by which the sequence of events accompanying voltage instability leads to a low unacceptable voltageprofile in a significant part of the power system.

Prerequisite knowledge for Complete understanding and learning of Topic:

Stability

Detailed content of the Lecture:

- ✓ Voltage stability or voltage collapse deals with the ability of a power system to maintain acceptable voltage levels at all buses in the system in any condition whether it is normal or during disturbance.
- ✓ A heavily loaded system enters a state of voltage instability due to a sudden large disturbance or a change in system condition. It causes a progressive and uncontrollable decline in voltage.
- ✓ The main factor causing voltage instability in any power system is the inability of the system to meet its sudden growing demand for reactive power.

  The two different approaches available as a tool to ana- lyse the voltage collapse problem in a system are:

  (a) The static approach and

  (b) The dynamic approach.

(a) Static methods involve the static model of power systemcomponents. These methods are important when the power system is in operation and planning stages, in-order to prepare an ade- quate fool proof plan for meeting the power requirements during different types of contingencies arising during its operation.

(b) The dynamic methods use time domain simulations to re- veal the voltage collapse mechanism such as why and how the volt- age collapse occurs. Dynamic methods analyze the effect of dynam- ic loads, on load tap changes (OLTC), generator over excitation limiters (OXL) on voltage collapse.

- ✓ In most of the cases, the system dynamics affecting voltagestability are quite slow. The static approach effectively analyzes most of the problems. It can examine the viability of a specific operating point of the power system.
- ✓ In addition, static analysis method provides information such as sensitivity or degree of stability and involves the computation of only algebraic equations. It is much more efficient and faster than dynamic approaches.
- ✓ The static analysis approach is more attractive than the dynamic method and well suited to voltage stability analysis of power systems over a wide range of system conditions.

  Dynamic analysis provides the most accurate indication of the time responses of the system. Therefore, Dynamic analysis is extremely useful for fast voltage collapse situations, such as loss of generation and system faults, especially concerning the complex sequence of events that lead to the instability.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=ImqYGfEHe0Q

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011. P-459

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L 39

EEE

III/V

Course Name with Code :Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini & Mrs.N.Sathya

Unit : V – Stability Analysis **Date of Lecture:**

Topic of Lecture: Single Machine Infinite Bus (SMIB) system

Introduction:

An SMIB system is a very simple model to understand theimportance of large or sustained angular disturbance stabilityproblem. It is simply a single generator connected to a largepower system represented by infinite bus having fixed voltageand constant frequency.

Prerequisite knowledge for Complete understanding and learning of Topic:

Bus system

Detailed content of the Lecture:

- ✓ Stability and control are one of the key elements in modern power system operations. Due to increasing growth in the consumption of electric power and complexity of the power system operations, viz. physical setups, interconnections, etc., a form of instability has emerged in the system inthe form of power oscillations of small amplitude and low frequency.

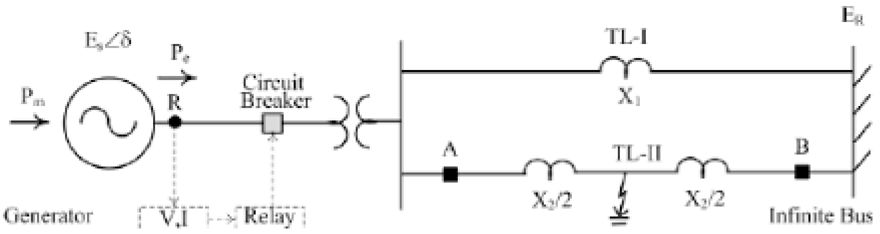


Fig. single machine bus system

- ✓ Suchlow frequency oscillations often last for long duration of time in the system and sometimes limit thesteady state power transfer. These oscillations arereferred to as small signal stability and they are mainly due to the insufficient damping in the system.
- ✓ To improve the small signal stability and dynamic quality of power system, the effects of excitation system control has been considered by many researchers. That is, the

excitation system which includes the exciter andAVR must be able to control the system voltage and keep its value within an acceptable threshold.

- ✓ The design of the IEEE Type-I based voltage regulators are widely accepted and known to be useful for power system operations.
- ✓ However,following a disturbance due to small variations in load or generations in the system dynamics, thesynchronous machines equipped with such regulators have the tendency to introduce negativedamping into the system and deteriorate its dynamic performance.
- ✓ To improve thedynamic performance of such system, other feedback loops are usually used in conjunction with theAVR. However, the regulator design based on feedback loops and other advanced techniques, such as variable structure control,linear quadratic regulator, artificial intelligence, etc., have their ownlimitations and drawbacks.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=aSwGUVqrBMQ

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011. P - 451

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

Estd. 2000

LECTURE HANDOUTS | **L 40**

EEE | **III/V**

Course Name with Code : Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini & Mrs.N.Sathya

Unit : V – Stability Analysis **Date of Lecture:**

Topic of Lecture: Development of swing equation

Introduction:

A power system consists of a number of synchronous machines operating synchronously under all operating conditions. Under normal operating conditions, the relative position of the rotor axis and the resultant magnetic field axis is fixed. The angle between the two is known as the power angle or torque angle.

Prerequisite knowledge for Complete understanding and learning of Topic:

Swing equation

Detailed content of the Lecture:

- ✓ During any disturbance, the rotor decelerates or accelerates with respect to the synchronously rotating air gap mmf, creating relative motion.
- ✓ The equation describing the relative motion is known as the swing equation, which is a non-linear second order differential equation that describes the swing of the rotor of synchronous machine.
- ✓ The power exchange between the mechanical rotor and the electrical grid due to the rotor swing (acceleration and deceleration) is called Inertial response.
- ✓ The stability of an interconnected power system is its ability to return to normal or stable operationafter having been subjected to some form of disturbance.
- ✓ With interconnected systems continually growing in size and extending over vast geographical regions, it is becoming increasingly more difficult to maintain synchronism between various parts of the power system.
- ✓ Modern power systems have many interconnectedgenerating stations, each with several generators and many loads.
- ✓ So our study is focused on multi-machinestability .

  The tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium is known as “STABILITY”.

- ✓ The problem of interest is one where a power system operating under a steady load condition is perturbed, causing the readjustment of the voltage angles of the synchronous machines.
- ✓ If such an occurrence creates an unbalance between the system generation and load, it results in the establishment of a new steadystate operating condition, with the subsequent adjustment of the voltage angles.
- ✓ The perturbation could be a major disturbance such as the loss of a generator, a fault or the loss of a line, or a combination of such events.
- ✓ It could also be a small load or random load changes occurring under normal operating conditions. Adjustment to the new operating condition is called the transient period.
- ✓ The system behavior during this time is called the dynamic system performance, which is of concern in defining system stability.
- ✓ The main criterion for stability is that the synchronous machines maintain synchronism at the end of the transient period.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=LX0xbvIWz7Q

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-459

Course Faculty

MUTHAYAMMAL ENGINEERING COLLEGE

(An Autonomous Institution)

(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS | **L 41**

EEE | **III/V**

Course Name with Code : **Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini & Mrs.N.Sathya**

Unit : **V – Stability Analysis** **Date of Lecture:**

Topic of Lecture: Tutorial - swing equation

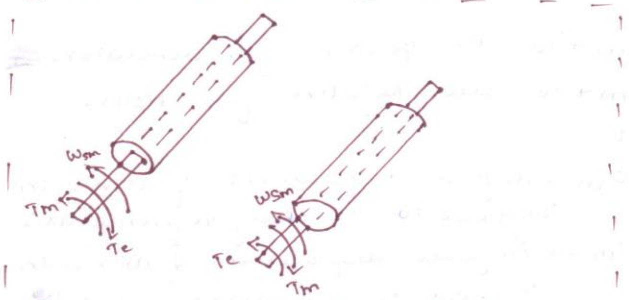
Introduction:
A power system consists of a number of synchronous machines operating synchronously under all operating conditions. Under normal operating conditions, the relative position of the rotor axis and the resultant magnetic field axis is fixed. The angle between the two is known as the power angle or torque angle.

Prerequisite knowledge for Complete understanding and learning of Topic:
Swing equation

Detailed content of the Lecture:

1. Derive swing Equation of a Synchronous Machine

The rotor of a Synchronous Machine is Subjected to two torques T_e and T_m which are acting in opposite directions



Torque acting on rotor of Synchronous Machine

where T_e => Net electrical (or) electromechanical torque in N-m

T_m => Mechanical (or) Shaft torque supplied by the prime mover in N-m

Under steady state operating condition the T_e and T_m are equal and the machine runs at constant speed known as Synchronous speed. If there is a difference between the two torques, then the rotor will have an accelerating (or) decelerating torque denoted as T_a.

$$\therefore T_a = T_m - T_e \quad \text{------} (1)$$

T_m & T_e are positive for Generators

T_m & T_e are negative for Motors.

Let.

θ_m => Angular displacement of rotor with respect to stationary reference axis

δ_m => Angular displacement of rotor with respect to synchronously rotating reference axis.

By Newton's IInd law of Motion,

$$T_a \propto \frac{d^2\theta_m}{dt^2}$$

(or)

$$T_a = J\frac{d^2\theta_m}{dt^2} \quad \text{------} (2)$$

Sub (1) in (2).

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=LX0xbvIWz7Q

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011. P-480

Course Faculty

Course Name with Code:Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini & Mrs.N.Sathya

Unit : V – Stability Analysis **Date of Lecture:**

Topic of Lecture: Step by step method

Introduction:
There are several sophisticated methods for solving the swing equation. The step-by-step or point-by-point method is conventional, approximate but well tried and proven method. This method determines the changes in the rotor angular position during a short interval of time.

Prerequisite knowledge for Complete understanding and learning of Topic:
Swing equation by modified Euler method

Detailed content of the Lecture:

SOLUTION OF SWING EQUATION USING STEP BY STEP METHOD

- Over a lossless line, the real power transmitted will be $P_e = P_m sin\delta$
- Consider a fault occurs in a synchronous machine which was operating in steady state. Here, the power delivered is given by $P_e = P_m$
- For clearing a fault, the circuit breaker in the faulted section should have to be opened up. This process takes 5/6 cycles and the successive post-fault transient will take an additional few cycles.

The Swings equation is given by

$$\frac{2H}{\omega_s}\left(\frac{d^2\delta}{dt^2}\right) = P_m - P_e \quad .....(1)$$

P_m → Mechanical power

P_e → Electrical power

δ → Load angle

H → Inertia constant

$\omega_s \rightarrow$ Synchronous speed

We know that,

$$\frac{d^2\delta}{dt^2} = \frac{\frac{d}{dt}\left(\frac{d\delta}{dt}\right)^2}{2\left(\frac{d\delta}{dt}\right)^2} \quad .....(2)$$

Putting equation (2) in equation (1), we get

$$\frac{H}{\omega_s}\frac{d}{dt}\left(\frac{d\delta}{dt}\right)^2 = P_m - P_e\left(\frac{d\delta}{dt}\right) \quad .....(3)$$

Now, multiply dt to either side of equation (3) and integrate it among the two arbitrary load angles which are δ_0 and δ_c. Then we get,

$$\int_{\delta 0}^{\delta c}\frac{H}{\omega_s}\left(\frac{d\delta}{dt}\right)^2 = \int_{\delta 0}^{\delta c}(P_m - P_e)\,d\delta \quad .....(4)$$

Assume the generator is at rest when load angle is δ_0. We know that $\frac{d\delta}{dt} = 0$

At the time of occurrence of a fault, the machine will start to accelerate. When the fault is cleared, it will continue to increase speed before it reaches to its peak value (δ_c). At this point, $\frac{d\delta}{dt} = 0$

So the area of accelerating from equation (4) is

$$A_1 = \int_{\delta 0}^{\delta c}(P_m - P_e)\,d\delta = 0 \quad .....(5)$$

Similarly, the area of deceleration is

$$A_2 = \int_{\delta c}^{\delta m}(P_m - P_e)\,d\delta = 0 \quad .....(6)$$

QUESTION

The value of $y(5)$ using Euler's method to solve the ordinary differential equation

$$\frac{dy}{dx} + 2y = x^2 \ , \ y(1) = 5$$

with a step size of $h = 2$ most nearly is

(A) -13.00
(B) 21.25
(C) 53.00
(D) 57.00

HINT

$y_{i+1} = y_i + f(x_i, y_i)h$. Note that the initial condition is given at $x = 1$.

SOLUTION

$$\frac{dy}{dx} + 2y = x^2, \ y(1) = 5$$

$$\frac{dy}{dx} = x^2 - 2y = f(x, y), \ y(1) = 5$$

$$y_{i+1} = y_i + f(x_i, y_i)h$$

$$y_1 = y_0 + f(x_0, y_0)h$$

$$x_0 = 1$$

$$y_0 = 5$$

$$\begin{aligned} y_1 &= 5 + f(1,5)(2) \\ &= 5 + \left(1^2 - 2(5)\right) \times 2 \\ &= 5 + (-9) \times 2 \\ &= -13 \end{aligned}$$

$$y_2 = y_1 + f(x_1, y_1)h$$

$$\begin{aligned} x_1 &= x_0 + h \\ &= 1 + 2, \\ &= 3 \end{aligned}$$

$$y_1 = -13$$

$$\begin{aligned} y_2 &= -13 + f(3,-13)(2) \\ &= -13 + \left(3^2 - 2(-13)\right) \times 2 \\ &= -13 + 35 \times 2 \\ &= 57. \end{aligned}$$

Video Content / Details of website for further learning (if any):
https://www.yutube.com/watch?v=ukNbG7muKho

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011. P480

Course Faculty

LECTURE HANDOUTS | **L 43**

EEE | **III/V**

Course Name with Code :Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini & Mrs.N.Sathya

Unit : V – Stability Analysis **Date of Lecture:**

Topic of Lecture: Equal area criterion

Introduction:
The equal area criterion is a simple graphical method for concluding the transient stability of two-machine systems or a single machine against an infinite bus. This principle does not require the swing equation for the determination of stability conditions. The stability conditions are recognized by equating the areas of segments on the power angle diagram between the p-curve and the new power transfer line of the given curve.

Prerequisite knowledge for Complete understanding and learning of Topic:
Equal area criterion

Detailed content of the Lecture:

- ✓ The principle of this method consists on the basis that when δ oscillates around the equilibrium point with constant amplitude, transient stability will be maintained.
- ✓ Starting with swing equation

$$M\frac{d^2\delta}{dt^2} = P_s - P_E = P_A$$

- ✓ where, M = Angular Momentum
  P_E = Electrical Power
  P_S = Mechanical Power
  δ= Load Angle
- ✓ Multiplying both sides of the above equation by dδ/dt, we get

$$M\frac{d^2\delta}{dt^2}.\frac{d\delta}{dt} = P_s\frac{d\delta}{dt} - P_E\frac{d\delta}{dt} = \frac{d\delta}{dt}(P_s - P_E)$$

or

$$\frac{1}{2}M\frac{d}{dt}\left(\frac{d\delta}{dt}\right)^2 = (P_S - P_E)\frac{d\delta}{dt}$$

- ✓ Rearranging, multiplying by dt and integrating, we have

$$\left(\frac{d\delta}{dt}\right)^2 = \int_{\delta_o}^{\delta}\frac{2(P_S - P_e)}{M}d\delta$$

$$\frac{d\delta}{dt} = \sqrt{\int_{\delta_o}^{\delta}\frac{2(P_S - P_e)}{M}d\delta}$$

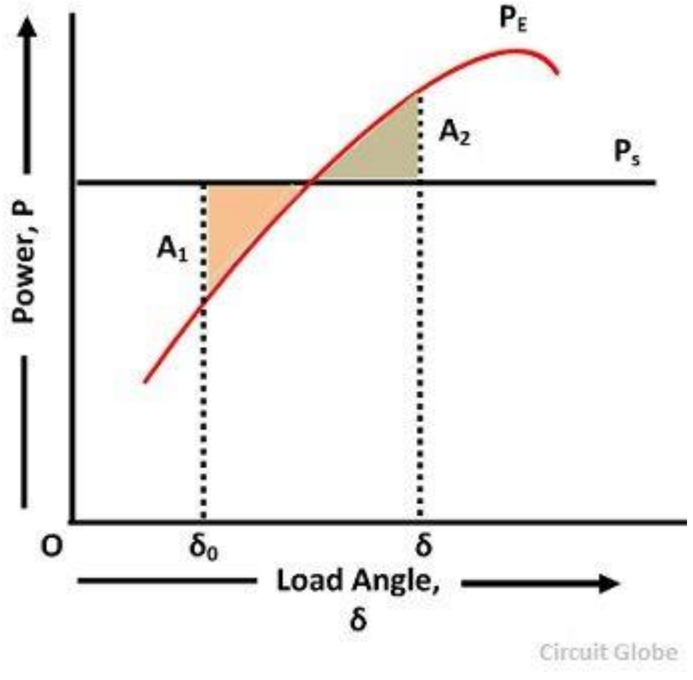
- ✓ Where δ_o, is the torque angle at which the machine is operating while running at synchronous speed under normal conditions. Under the above conditions, the torque angle was not changing

- ✓ i.e. before the disturbance. $\frac{d\delta}{dt} = 0$

$$\frac{d\delta}{dt} = 0$$

- ✓ Hence the condition for the transient state stability is given by the equation

✓ $$\sqrt{\int_{\delta_o}^{\delta}\frac{2(P_S - P_e)}{M}d\delta} = 0 \quad \int_{\delta_o}^{\delta}\frac{2(P_S - P_e)}{M}d\delta = 0 \quad \int_{\delta_o}^{\delta}P_A\,d\delta = 0$$



- ✓ The area A_1 represents the kinetic energy stored by the rotor during acceleration, and the A_2 represents the kinetic energy given up by the rotor to the system.

- ✓ The area under the curve $_{PA}$ should be zero, which is possible only when $_{PA}$ has both accelerating and decelerating powers, i.e., for a part of the curve $_{PS}> _{PE}$ and for the other $_{PE}> _{PS}$. For a generation action, $_{PS}> _{PE}$ for the positive area and $_{A1}> _{PS}$ for negative areas $_{A2}$ for stable operation. Hence the name equal area criterion.

- ✓ The equal area criterion is also used for determining the maximum limit on the load that the system can take without exceeding the stability limit. This can happen only when the area between the P_S line and the P_E curve is equal to the area between the P_S line, and the P_E curve is equal to the area between the initial torque angle δ_0 and the line P_S. In this case, the area A_2 is less than the area A_1; the system will become unstable.

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=h_FslR0vVd8

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011. P-864

Course Faculty

LECTURE HANDOUTS | **L 44**

EEE | **III/VI**

Course Name with Code : **Power System Analysis/19EEC10**

CourseFaculty : **Dr.N.Mohananthini & Mrs.N.Sathya**

Unit : **V – Stability Analysis** **Date of Lecture:**

Topic of Lecture: Tutorial - Equal area criterion

Introduction:
The equal area criterion is a simple graphical method for concluding the transient stability of two-machine systems or a single machine against an infinite bus. This principle does not require the swing equation for the determination of stability conditions. The stability conditions are recognized by equating the areas of segments on the power angle diagram between the p-curve and the new power transfer line of the given curve.

Prerequisite knowledge for Complete understanding and learning of Topic:
Equal area criterion

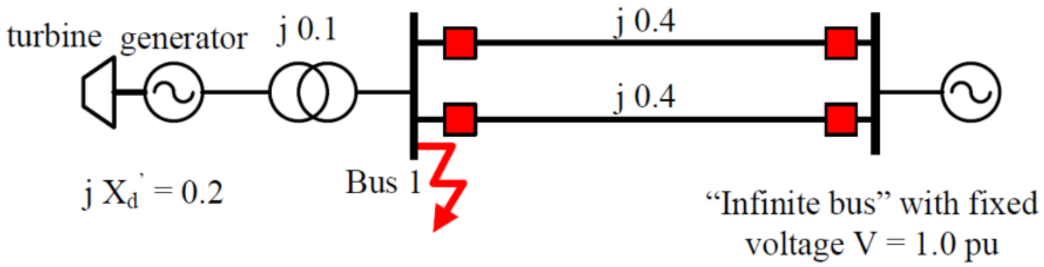
Detailed content of the Lecture:

Example for Equal-Area Criterion

Calculate the critical clearing time and clearing angle for the system shown below, when the system is subjected to a three-phase fault at point Bus 1. The 'inertia constant' H of the turbine-generator is 5 kWs/kVA.

$$H = \frac{\text{stored kinetic energy in megajoules at synchronous speed}}{\text{machinerating in MVA}} = \frac{\frac{1}{2}J\omega_s^2}{S_{rating}}$$

This H constant is used in the power industry in North America.



In the system of the generator has an inertia constant of 4 MJ/MVA, write the swing equation upon occurrence of the fault. What is the initial angular acceleration? If this acceleration can be assumed to remain constant for $\Delta t = 0.05$s, find the rotor angle at the end of this time interval and the new acceleration.

Solution

Swing equation upon occurrence of fault

$$\frac{H}{180 f}\frac{d^2\delta}{dt^2} = P_m - P_e$$

$$\frac{4}{180 \times 50}\frac{d^2\delta}{dt^2} = 1 - 0.694 \sin \delta$$

or

$$\frac{d^2\delta}{dt^2} = 2250\ (1 - 0.694 \sin \delta).$$

Initial rotor angle $\delta_0 = 33.9°$

$$\left.\frac{d^2\delta}{dt^2}\right|_{t=0^+} = 2250\ (1 - 0.694 \sin 33.9°)$$

$$= 1379 \text{ elect deg/s}^2$$

$$\left.\frac{d\delta}{dt}\right|_{t=0^+} = 0; \text{ rotor speed cannot change suddenly}$$

$$\Delta\delta \text{ (in } \Delta t = 0.05\text{s)} = \frac{1}{2} \times 1379 \times (0.05)^2$$

$$= 1.7°$$

$$\delta_1 = \delta_0 + \Delta\delta = 33.9 + 1.7° = 35.6°$$

$$\left.\frac{d^2\delta}{dt^2}\right|_{t=0.05s} = 2250\ (1 - 0.694 \sin 35.6°)$$

$$= 1341 \text{ elect deg/s}^2$$

Observe that as the rotor angle increases, the electrical power output of the generator increases and so the acceleration of the rotor reduces.

Video Content / Details of website for further learning (if any):
https://www.youtube.com/watch?v=3Cot5NW-36Q

Important Books/Journals for further learning including the page nos.:
Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011.P-373

Course Faculty

LECTURE HANDOUTS | **L 45**

EEE | **III/V**

Course Name with Code :Power System Analysis/19EEC10

CourseFaculty : Dr.N.Mohananthini & Mrs.N.Sathya

Unit : V – Stability Analysis **Date of Lecture:**

Topic of Lecture: Solution of swing equation by modified euler method and runge - kutta fourth order method

Introduction:

There are several sophisticated methods for solving the swing equation. The step-by-step or point-by-point method is conventional, approximate but well tried and proven method. This method determines the changes in the rotor angular position during a short interval of time.

Prerequisite knowledge for Complete understanding and learning of Topic:

Swing equation by modified Euler method

Detailed content of the Lecture:

STEP BY STEP METHOD

- ✓ The step by step method used for hand calculation is better and simpler than the methods used for the computers in this method of the hand calculation the angular position of the rotor is changed during the short interval of time and is computed using some assumptions and these assumptions are-:
- ✓ Accelerating power Pa which is doesnot change at the initial interval, which is the proceeding interval from the middle to middle of that interval.
- ✓ Throughout any interval angular velocity is constant at a value computed from the middle of the interval
- ✓ But the above assumptions are not accurate because delta is changing continuously and both Pa and w are functions of delta. As the time interval is decreased the computed swing curve tends to accuracy.

SWING EQUATION SOLUTION USING MODIFIED EULER METHOD

- ✓ Before we discuss the application of Euler's method for solving the swing equations we should know the basic Euler's method of numerical integration so the general form of the equation is –

  ✓ Y' = f (x,y)   Y(xo)= yo

- ✓ Where x is independent and y is dependent quantities whereas xo and yo
- ✓ Is the initial value of x and y respective here the independent axis that is the x-axis is divided to intervals of length 'h' so that the discrete points on the independent axis will be xo, xo + h, xo + 2h, etc.
- ✓ Our task is to calculate the values y1, y2, corresponding to the x co-ordinates after these values are calculated the curve representing the solution of differential equation given in equation can be plotted.
- ✓ In this method the y1, y2, values are calculated in two steps predictor and corrector and then it is determined.

SWING EQUATION SOLUTION BY RANGE KUTTA METHOD

In this method we consider two equation –

X1=f(x1,x2)

X2=f(x1,x2)

Video Content / Details of website for further learning (if any):

https://www.youtube.com/watch?v=3Cot5NW-36Q

Important Books/Journals for further learning including the page nos.:

Nagrath I.J. and Kothari D.P., 'Modern Power System Analysis', Tata McGraw-Hill, Fourth Edition,2011. P 461

Course Faculty