20 Jan 2019

⊛ Power System components:

It consists of 3 components:

1. Generation
2. Transmition
3. Distribution

- Generation:

Electrical energy is generated at power stations or plants, can be ~~cla~~ classified to:

- Thermal
- Hydro
- Renewable

• **Thermal Plants:** (non-salient) (cylindrical) (3000 rpm)

Can be classified according to:

1) fuel: fossil (oil, coal, gas), Nuclear, geothermal
2) Prime mover: steam turbine, gas turbine, combined cycle, internal combustion engine

• **Hydro Plants:** (non-cylindrical) (Salient) (1000 - 1400 rpm)

Kinetic ~~energy~~ energy of water can be used to drive hydroturbine

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- Renewable Plants:
  1) wind (induction generator)
  2) Solar
  3) Tidal

- Transmission:

→ Power stations generate voltages in the range (11-25) KV, in order to transfer this energy, the voltage is stepped-up through step-up transformers located at the power station substations.

→ In Jordan there are two transmission level 132 and 400 KV.

→ Since $p = vi$, - v ≡ is set by the required insulation level between conductors
- i ≡ is set by the thermal capacity of the conductors

→ Usually transmission lines are double circuit

- Distribution:

→ At the recieving ends of the transmission lines there are substations which include step-down transformers in order to step-down the transmitted voltages to distribution levels

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→ Although ~~the~~ distribution system is Passive, but now it became Active, because generating ~~units~~ units are connected directly to this system

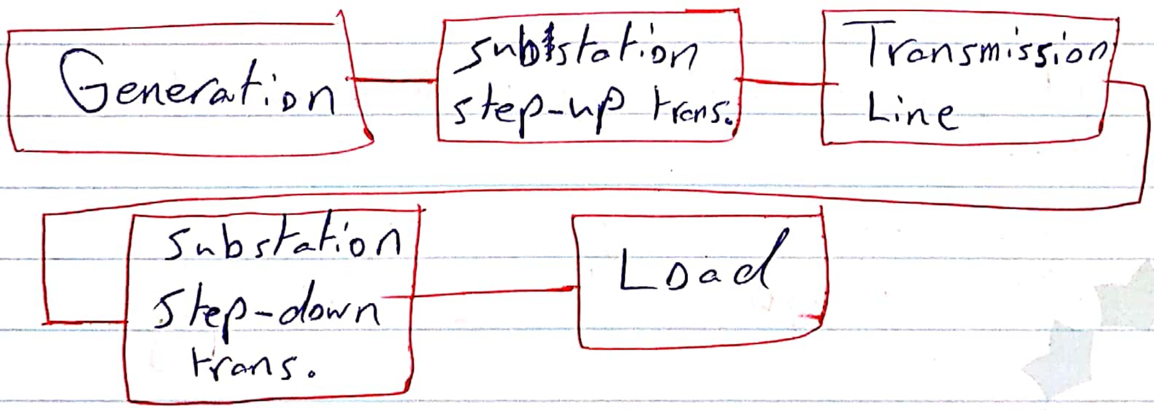
④ Power System Representation :

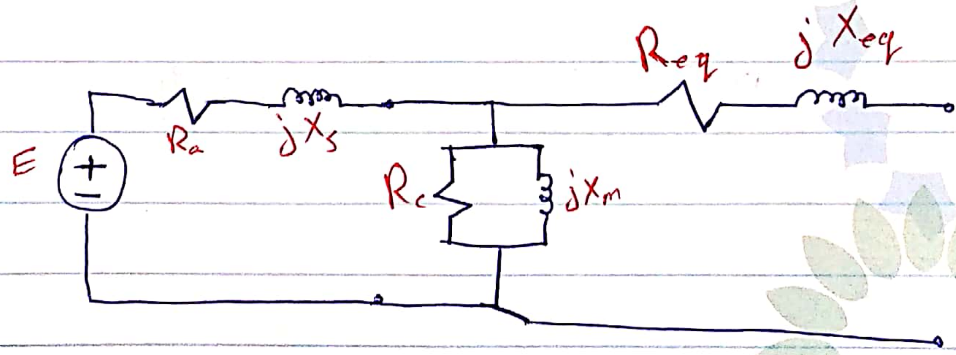
In order to perform analysis on a power system, then it should be represented as follows:-

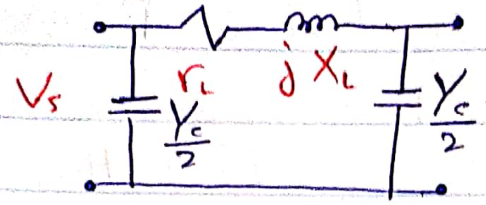
1) Graphical representation
2) Mathematical representation

← Graphical:

1) per phase circuit. This is used for balanced systems. Here each component is represented by it's equivalent circuit, illustrated as follows:-

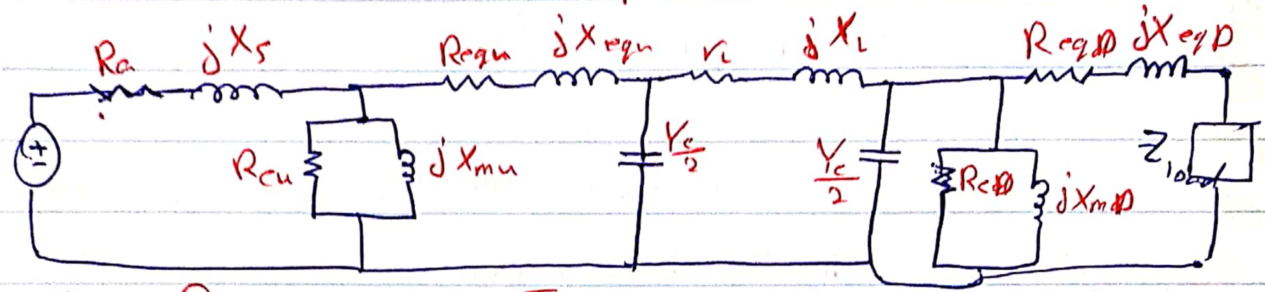






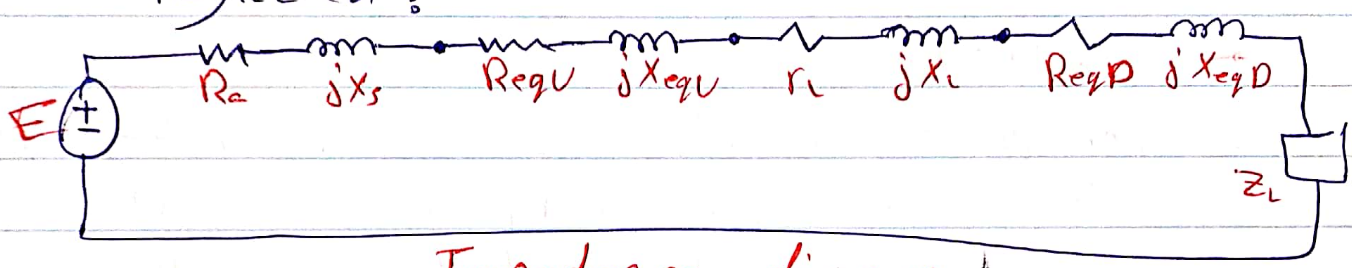
$Y_c = jwC$

this's called π-Representation of the line



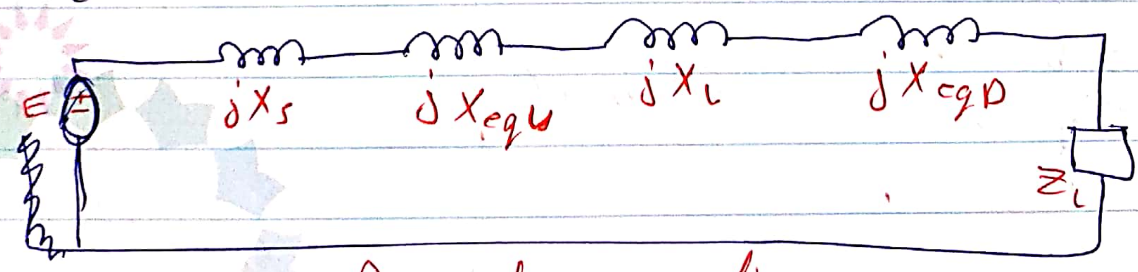
⟵ G ⟶ ⟵ Trans. ⟶ ⟵ Distribution ⟶

- To simplify the analysis, shunt elements are neglected:



Impedence diagram

- To simplify more, one may neglect resistive elements:



Reactance diagram

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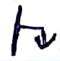
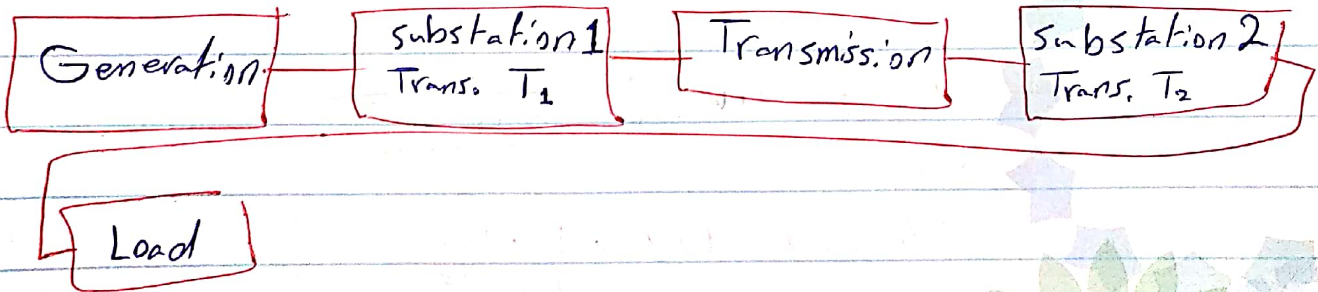
- Single-line or one-line diagram:

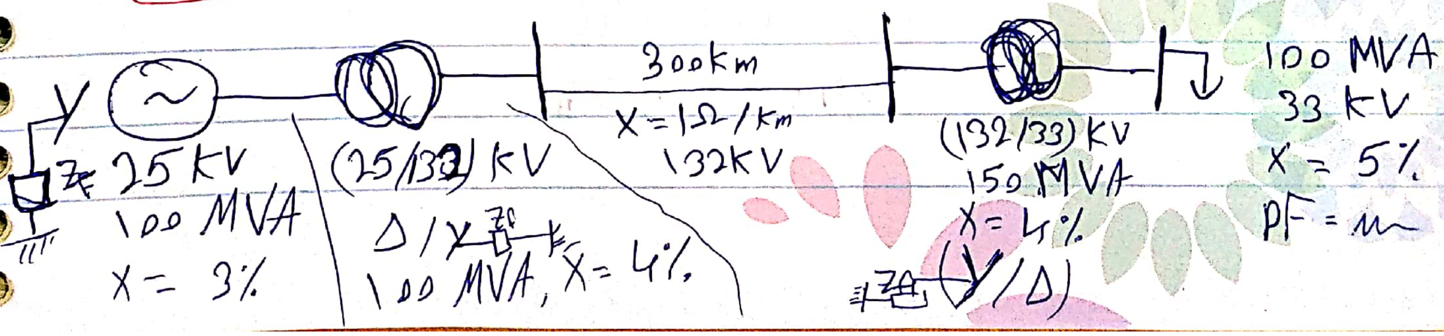
→ This diagram is used to show how the components of a given power system are connected to each other, by using only one-line.

→ Consequently each component is ~~repr~~ represented by a standard symbol as follows:-

Component	Symbol
Generator	
Motor	
Transformer	
Busbar	
Transmission line	
Circuit breaker	
Current trans.	
Load	

→ To illustrate, consider the previous system as follows
single line diagram





Type of Data given on the diagram depends on the required application (e.g: load flow, fault analysis, ..., etc)

$Z_f \equiv$ earthing impedence

Note: The give PU reactance of each component, it's base Values equals the rating of the component

To solve a given system, you should select a common base for all components.
Then update the given X_{PU} by ~~u~~ using

$$\boxed{X_{new} = X_{old} * \left(\frac{V_{old}}{V_{new}}\right)^2 * \frac{S_{new}}{S_{old}}}$$

Ex: If common base ~~Values~~ Values are selected at the gen. $V_B = 25\,KV$, $S_B = 100\,MVA$

at ~~gen~~ gen : 3%

at first trans.: 4%

~~at second trans.:~~

at trans line: $X_{PU} = \frac{X}{Z_B} = \frac{300}{\frac{(25/\sqrt{3} \times 10^3)^2}{\frac{100 \times 10^6}{3}}}$

at second trans: $X = 4\% * 1 * \frac{100}{150}$

load : $Z_L = |Z| \angle \cos^{-1} PF$

$|Z_L(PU) = Z_L / Z_B|$

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— Mathematical :

• Bus Admittance Matrix:

This is based on the node equation, and illustrated as follows :

Apply node analysis:

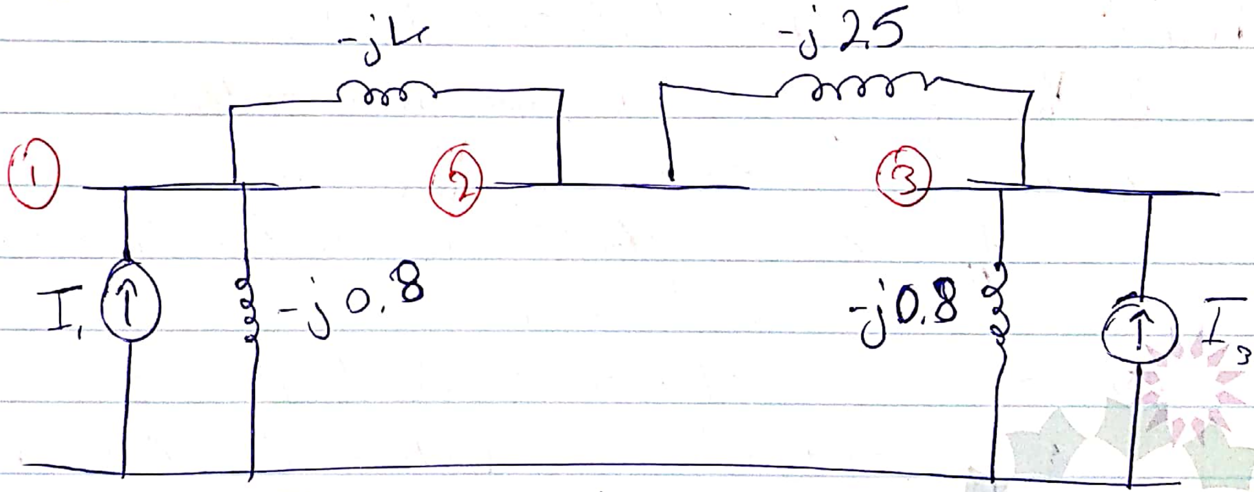
$$① \rightarrow V_1(-j0.8) + (V_1 - V_2)(-j4) = I_1$$

$$-j4.8V_1 + j4V_2 = I_1 \text{ —— } ①$$

$$② \rightarrow (V_2 - V_1)(-j4) + (V_2 - V_3)(-j2.5) = 0$$

$$j4V_1 - j6.5V_2 + j2.5V_3 = 0 \text{ —— } ②$$

$$③ \rightarrow V_3(-j0.8) + (V_3 - V_2)(-j2.5) = I_3$$



The given values are PU admittances

$$j2.5V_2 - j3.3V_3 = I_3 \text{ —— } ③$$

Now, rewrite the equations in a matrix form

$$\begin{bmatrix} -j4.8 & j4 & 0 \\ j4 & -j6.5 & j2.5 \\ 0 & j2.5 & -j3.3 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} I_1 \\ 0 \\ I_3 \end{bmatrix}$$

$$[Y][V] = [I] \quad \text{—— } (1)$$

Bus Admittance Matrix

Y_{Bus}

From (1), It can be deduced that:-

(1) Y_{Bus} is square and symmitrical matrix

(2) the diagonal element of Y_{Bus}, say

y_{ii} = sum of admittances connected directly to the i^{th} bus

(3) the non-diagonal elements of Y_{Bus}, say

y_{ij} = $-1 *$ admittance between i^{th} and j^{th} busses

SO, for given system Y_{Bus} can be written directly.

It will be seen that Y_{Bus} will be used in the load flow analysis.

If (1) is multiplied by $[Y]^{-1}$

$$[Y]^{-1}[Y][V] = [I][Y]^{-1}.$$

$$\therefore [V] = [Y]^{-1}[I]$$

Z_{Bus} Matrix

$$\therefore [V] = Z_{Bus}[I]$$

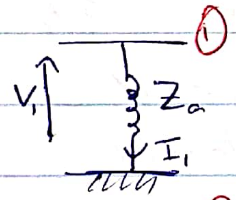
Z_{Bus} will be used in fault analysis

- Evaluation of Z_{Bus}:

1) by finding $[Y_{Bus}]^{-1}$
2) By direct method

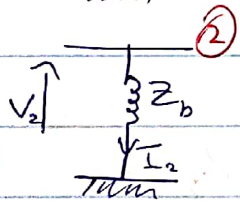
→ Direct method:

The busses are considired one at a time;



(1) consider Bus (1) $V_1 = Z_a I_1$, $[V_1] = [Z_a][I_1]$

(2) Add or conside the next bus (i.e connected to ref or connected to Bus (1))



$\therefore$ for the 2 busses together →

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \underbrace{\begin{bmatrix} Z_a & 0 \\ 0 & Z_b \end{bmatrix}}_{\text{Evolving } Z_{Bus}} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

(3) Then one proceed to modify evolving Z_{Bus} by adding other branches or busses, as follows ;-

(3.1) adding Z_b from a new bus, say P, to the ref. node

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \\ \hline V_p \end{bmatrix} = \left[\begin{array}{c|c} Z_{org} & \begin{matrix} 0 \\ \vdots \\ 0 \end{matrix} \\ \hline 0 \cdots 0 & Z_b \end{array}\right] \begin{bmatrix} I_1 \\ \vdots \\ I_N \\ \hline I_p \end{bmatrix} \quad (3.1)$$

(3.2) adding Z_b from a new bus, say P to existing bus K

$$\begin{bmatrix} V_1 \\ \vdots \\ V_N \\ \hline V_p \end{bmatrix} = \left[\begin{array}{c|c} Z_{original} & \begin{matrix} Z_{1k} \\ Z_{2k} \\ \vdots \\ Z_{kk} \end{matrix} \\ \hline Z_{k1} \cdots Z_{kN} & Z_{kk}+Z_b \end{array}\right] \begin{bmatrix} I_1 \\ \vdots \\ I_k \\ \hline I_p \end{bmatrix} \quad (3.2)$$

(3.3) adding Z_b from existing bus K to the ref.

(a) Create a new row and a column as in (3.2)

(b) eleminate the produced (N+1) row and the (N+1) column, to find each element in Z_{hi} (new) in the new matrix as follows:

added row, added column

$$Z_{hi}(new) = Z_{hi}(old) - \frac{Z_{h(N+1)} + Z_{(N+1)i}}{Z_{kk} + Z_b} \quad (3.3)$$

row, column

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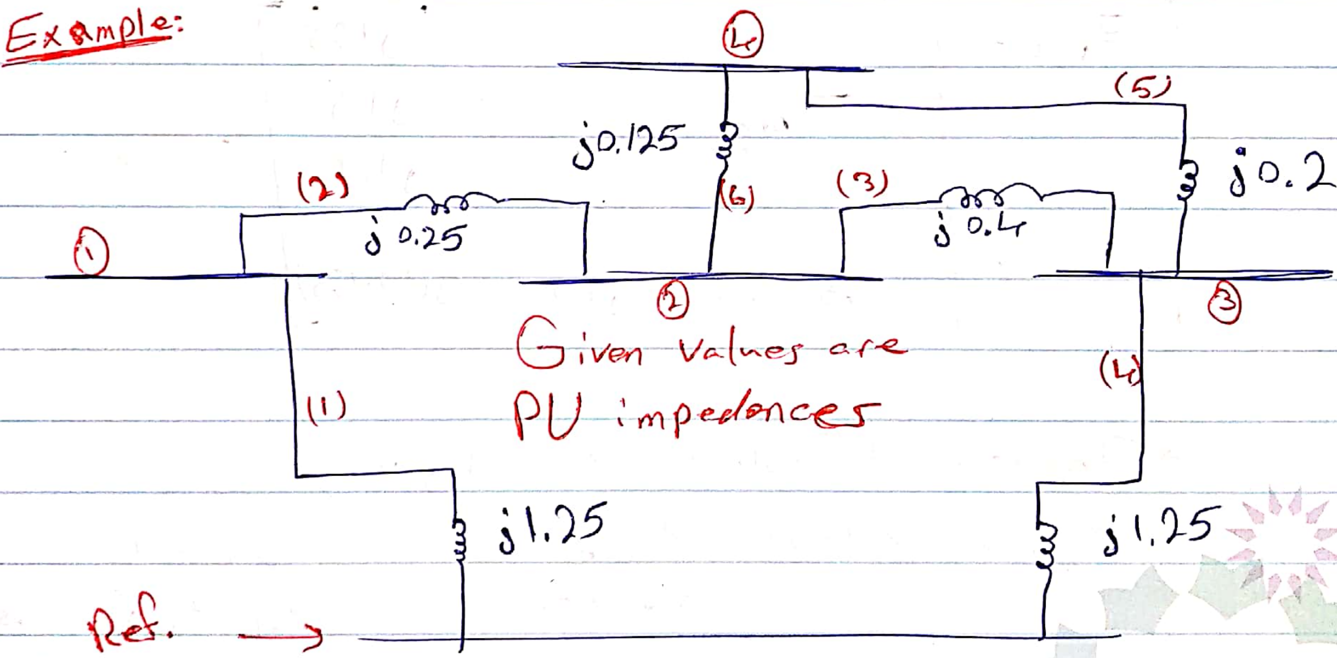
3.4 Z_b is added between two existing busses, say bus j and bus k

$$Z_{bus} = \left[\begin{array}{c|c} Z_{org} & \text{col } j - \text{col } k \\ \hline \text{row } j - \text{row } k & Z_{bb} \end{array}\right]$$

where $Z_{bb} = Z_{jj} + Z_{kk} - 2Z_{jk} + Z_b$

Eleminate the introduced new row and new column by using $Z_{hi}(\text{new}) = Z_{hi}(\text{old}) - \dfrac{Z_{h(N+1)} Z_{(N+1)i}}{Z_{bb}}$

Example:



For the given system find Z_{bus} by using Build-up algorithm:

Procedure: start by adding branche sequintially according to their number.

1) $Z_{bus\,1} = [j1.25]$

2) $Z_{bus\,2} = \begin{bmatrix} j1.25 & j1.25 \\ j1.25 & j(1.25+0.25) \end{bmatrix}$

3) $Z_{bus\,3} = \begin{bmatrix} j1.25 & j1.25 & j1.25 \\ j1.25 & j1.5 & j1.5 \\ j1.25 & j1.5 & j(1.5+0.4) \end{bmatrix} \leftarrow Z_{org.}$

4) $Z_{bus\,4} = \left[\begin{array}{c|c} Z_{org.} & \begin{matrix} j1.25 \\ j1.5 \\ j1.9 \end{matrix} \\ \hline \begin{matrix} j1.25 & j1.5 & j1.9 \end{matrix} & j(1.9+1.25) \end{array}\right]$

New Row →

← New column

→ Eliminate the 4^{th} column and row, by using:-

$$Z_{hi}(new) = Z_{hi}(old) - \frac{Z_{h(N+1)} Z_{(N+1)i}}{Z_{kk} + Z_b} \quad , \quad N+1 = 4$$

$$Z_{kk} + Z_{bb} = j(1.9+1.25) = j3.15$$

→ Illustration, consider Z_{11}.

$$Z_{11\,New} = Z_{11}(old) - \frac{Z_{14} Z_{41}}{Z_{33} + Z_b} = j1.25 - \frac{j1.25 * j1.25}{j1.9 + j1.25}$$

$$= j0.75397$$

→ Repeat for $Z_{12}, Z_{13}, \text{-- -- -- --}, Z_{32}, Z_{33}$

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5) $Z_{bus5} = \begin{bmatrix} j0.75397 & - & j0.49603 \\ - & - & - \\ j0.49603 & - & j0.75397 \end{bmatrix}$

6) $Z_{bus6} = \left[\begin{array}{c|c} Z_{bus5} & \text{3rd columns of } Z_{bus5} \\ \hline \text{3rd row of } Z_{bus5} & j(0.75397 + 0.2) \end{array}\right]$

7) $Z_{bus7} = \left[\begin{array}{c|c} Z_{bus} 6 & \text{col 2 of } Z_{bus}6 - \text{col 4 of } Z_{bus}6 \\ \hline \text{row 2 of } Z_{bus}6 - \text{row 4 of } Z_{bus}6 & Z_{55} \end{array}\right]$

between bus 2 and 4

where $Z_{55} = \underbrace{Z_{22} + Z_{44} - 2Z_{24}}_{\text{elements in } Z_{bus}6} + Z_b \ (= j1.25)$

8) Finally eliminate the 5^{th} column and row:

$$Z_{hi}(New) = Z_{hi}(old) - \frac{Z_{h(N+1)} Z_{(N+1)i}}{Z_{55}}, \quad N+1 = 5$$

→ It can be found that

$$Z_{bus}8 = \begin{bmatrix} j0.7166 & - & - & j0.5855 \\ j0.6099 & - & - & j0.6966 \\ j0.5334 & - & - & j0.6695 \\ j0.5805 & - & - & j0.7631 \end{bmatrix}$$

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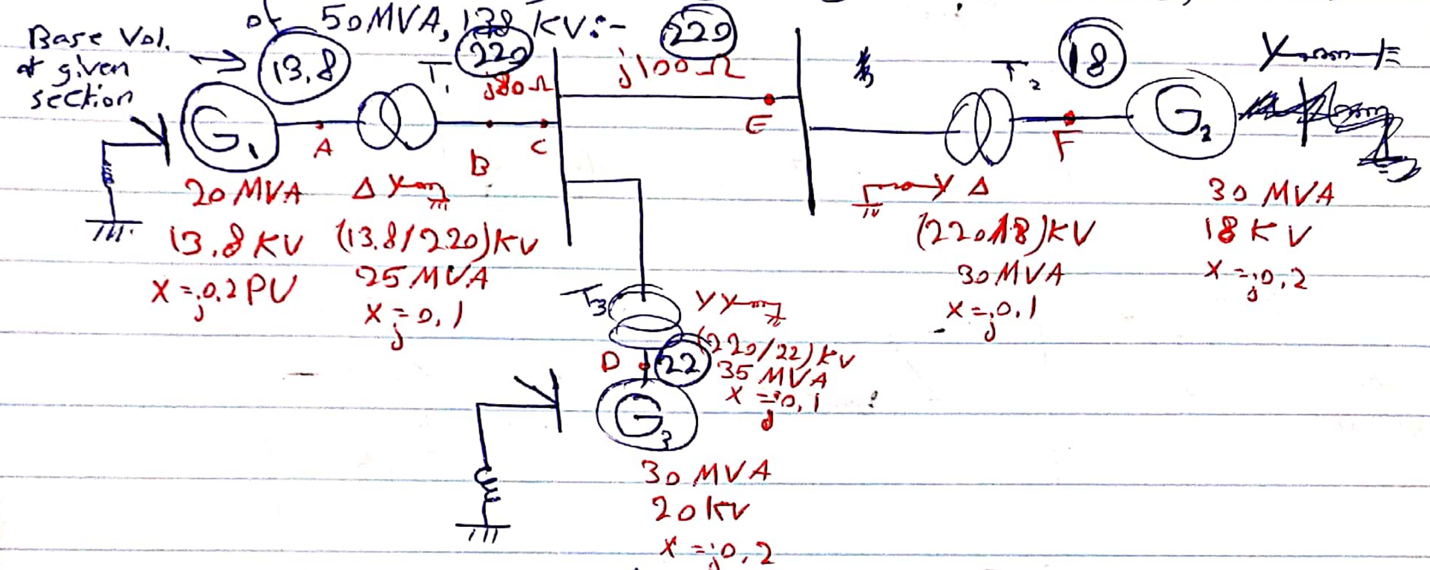
⊛ Revision of PU Systems:

Example: For the given single line diagram, evaluate it's reactance diagram, by using a common Base at (G_1) location of 50MVA, 13.8 KV:-



- The given X PU of a given component is Based on the Rating of that component.

- Modify the given PU X according to the System bas values using: $X_{new} = X_{old} * \left(\frac{V_{old}}{V_{new}}\right)^2 * \left(\frac{S_{new}}{S_{old}}\right)$.
  $S_{new} = 50 MVA$, $V_{new} = 13.8 KV$, S, V_{old} = Rating of the given component

- Identify the base voltage for each section of the system

Component	Xnew
G_1	$0.2 \left(\frac{13.8}{13.8}\right)^2 * \frac{50}{20} = 0.5$
T_1	$0.1 * 1 * \frac{50}{25} = 0.2$
line B-C	$Z_b = V_b^2/S_b = \frac{220^2}{50} = 968$, $X = \frac{80}{968} = 0.083$
line C-E	$\frac{100}{968} = 0.103$

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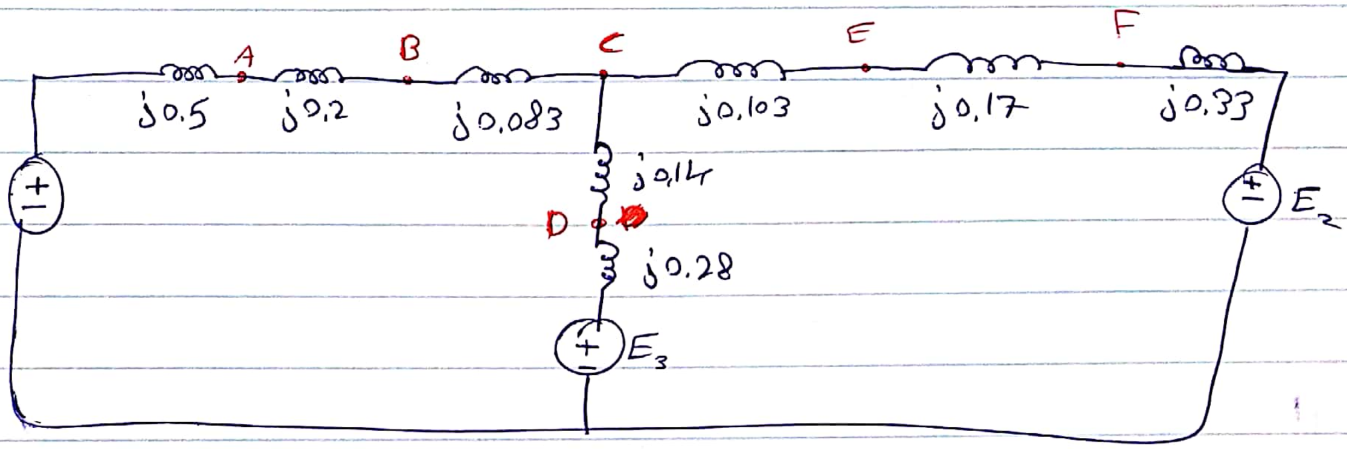
$T_2 \quad 0.1 * 1 * \frac{50}{30} = 0.17$

$T_3 \quad 0.1 * 1 * \frac{50}{35} = 0.14$

$G_3 \quad 0.2 * \left(\frac{20}{22}\right)^2 * \frac{50}{30} = 0.28$

$G_2 \quad 0.2 * 1 * \frac{50}{30} = 0.33$



PU Reactance Diagram

Comment: ① Knowing E_1, E_2, E_3. ~~one~~ we can solve the cct. to find PU Current and/or Voltage at any point.

② Knowing base Values, we can find actual current and voltage Values

⊛ Equivilalnt cct. of Power System component:

- 3Ph Sync. gen.:

① steady state