تلخيص

تحليل I

ابذل غاية الجهد ييسّر لك غاية الهدى
(والذين جاهدوا فينا لنهديَنّهم سبلنا)

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بسم الله الرحمن الرحيم

تحية طيبة وبعد ...

اخواننا الطلبة الكرام ...

فأننا في فريق #سبارك نضع بين ايديكم مجموعة من الاوراق "تلخيص" التي نأمل من الله عز وجل أن تكون في ميزان حسنات من قام بها وتعب عليها ...

حيث أننا نفيدكم انه من قام بعمل هذه التلاخيص هم ثلة رائعة من طلاب تخصص هندسة الطاقة الكهربائية في كلية الهندسة التكنولوجية / البوليتكنك ...

نود اعلامكم أن هذه الاوراق المختصرة لا تغني بأي شكل من الاشكال لأي مادة تخصصية ومرجعك الاول والأخير ألا وهو #الكتاب ...

اخوانكم في فريق #سبارك

لا تنسونا من صالح الدعاء

قام بالتلخيص الطالب

أحمد عيسى الحيح

Spark POLYTECHNIC

نظام الطاقة الحديث

1.3 MODERN POWER SYSTEM

The power system of today is a complex interconnected network as shown in Figure 1.1 (page 7). A power system can be subdivided into four major parts:

- Generation توليد
- انتقال Transmission and Subtransmission
- Distribution توزيع
- Loads أحمال

Important

1.3.1 GENERATION

Generators — One of the essential components of power systems is the three-phase ac generator known as synchronous generator or alternator. Synchronous generators have two synchronously rotating fields: One field is produced by the rotor driven at synchronous speed and excited by dc current. The other field is produced in the stator windings by the three-phase armature currents. The dc current for the rotor windings is provided by excitation systems. In the older units, the exciters are dc generators mounted on the same shaft, providing excitation through slip rings. Today's systems use ac generators with rotating rectifiers, known as *brushless* excitation systems. The generator excitation system maintains generator voltage and controls the reactive power flow. Because they lack the commutator, ac generators can generate high power at high voltage, typically 30 kV. In a power plant, the size of generators can vary from 50 MW to 1500 MW.

The source of the mechanical power, commonly known as the *prime mover*, may be hydraulic turbines at waterfalls, steam turbines whose energy comes from the burning of coal, gas and nuclear fuel, gas turbines, or occasionally internal combustion engines burning oil. The estimated installed generation capacity in 1998 for the United States is presented in Table 1.1.

Steam turbines operate at relatively high speeds of 3600 or 1800 rpm. The generators to which they are coupled are cylindrical rotor, two-pole for 3600 rpm or four-pole for 1800 rpm operation. Hydraulic turbines, particularly those operating with a low pressure, operate at low speed. Their generators are usually a salient type rotor with many poles. In a power station several generators are operated in parallel in the power grid to provide the total power needed. They are connected at a common point called a *bus*.

Transformers — Another major component of a power system is the transformer. It transfers power with very high efficiency from one level of voltage to another level. The power transferred to the secondary is almost the same as the primary, except for losses in the transformer, and the product VI on the secondary side is approximately the same as the primary side. Therefore, using a step-up transformer of turns ratio a will reduce the secondary current by a ratio of $1/a$. This will reduce losses in the line, which makes the transmission of power over long distances possible.

The insulation requirements and other practical design problems limit the generated voltage to low values, usually 30 kV. Thus, step-up transformers are used for transmission of power. At the receiving end of the transmission lines step-down transformers are used to reduce the voltage to suitable values for distribution or utilization. In a modern utility system, the power may undergo four or five transformations between generator and ultimate user.

1.3.2 TRANSMISSION AND SUBTRANSMISSION

The purpose of an overhead transmission network is to transfer electric energy from generating units at various locations to the distribution system which ultimately supplies the load. Transmission lines also interconnect neighboring utilities which permits not only economic dispatch of power within regions during normal conditions, but also the transfer of power between regions during emergencies.

Standard transmission voltages are established in the United States by the American National Standards Institute (ANSI). Transmission voltage lines operating at more than 60 kV are standardized at 69 kV, 115 kV, 138 kV, 161 kV, 230 kV, 345 kV, 500 kV, and 765 kV line-to-line. Transmission voltages above 230 kV are usually referred to as extra-high voltage (EHV).

Figure 1.1 shows an elementary diagram of a transmission and distribution system. High voltage transmission lines are terminated in substations, which are called *high-voltage substations*, *receiving substations*, or *primary substations*. The function of some substations is switching circuits in and out of service; they are referred to as *switching stations*. At the primary substations, the voltage is stepped down to a value more suitable for the next part of the journey toward the load. Very large industrial customers may be served from the transmission system.

The portion of the transmission system that connects the high-voltage substations through step-down transformers to the distribution substations are called the *subtransmission* network. There is no clear delineation between transmission and subtransmission voltage levels. Typically, the subtransmission voltage level ranges from 69 to 138 kV. Some large industrial customers may be served from the subtransmission system. Capacitor banks and reactor banks are usually installed in the substations for maintaining the transmission line voltage.

1.3.3 DISTRIBUTION

The distribution system is that part which connects the distribution substations to the consumers' service-entrance equipment. The primary distribution lines are usually in the range of 4 to 34.5 kV and supply the load in a well-defined geographical area. Some small industrial customers are served directly by the primary feeders.

The secondary distribution network reduces the voltage for utilization by commercial and residential consumers. Lines and cables not exceeding a few hundred feet in length then deliver power to the individual consumers. The secondary distribution serves most of the customers at levels of 240/120 V, single-phase, three-wire; 208Y/120 V, three-phase, four-wire; or 480Y/277 V, three-phase, four-wire. The power for a typical home is derived from a transformer that reduces the primary feeder voltage to 240/120 V using a three-wire line.

Distribution systems are both *overhead* and *underground*. The growth of underground distribution has been extremely rapid and as much as 70 percent of new residential construction is served underground.

1.3.4 LOADS

Loads of power systems are divided into industrial, commercial, and residential. Very large industrial loads may be served from the transmission system. Large industrial loads are served directly from the subtransmission network, and small industrial loads are served from the primary distribution network. The industrial loads are composite loads, and induction motors form a high proportion of these load. These composite loads are functions of voltage and frequency and form a major part of the system load. Commercial and residential loads consist largely of lighting, heating, and cooling. These loads are independent of frequency and consume negligibly small reactive power.

The real power of loads are expressed in terms of kilowatts or megawatts. The magnitude of load varies throughout the day, and power must be available to consumers on demand.

The daily-load curve of a utility is a composite of demands made by various classes of users. The greatest value of load during a 24-hr period is called the *peak* or *maximum demand*. Smaller peaking generators may be commissioned to meet the peak load that occurs for only a few hours. In order to assess the usefulness of the generating plant the *load factor* is defined. The load factor is the ratio of average load over a designated period of time to the peak load occurring in that period. Load factors may be given for a day, a month, or a year. The yearly, or annual load factor is the most useful since a year represents a full cycle of time. The daily load factor is

1.6 COMPUTER ANALYSIS

For a power system to be practical it must be safe, reliable, and economical. Thus many analyses must be performed to design and operate an electrical system. However, before going into system analysis we have to model all components of electrical power systems. Therefore, in this text, after reviewing the concepts of power and three-phase circuits, we will calculate the parameters of a multi-circuit transmission line. Then, we will model the transmission line and look at the performance of the transmission line. Since transformers and generators are a part of the system, we will model these devices. Design of a power system, its operation and expansion requires much analysis. This text presents methods of power system analysis with the aid of a personal computer and the use of *MATLAB*. The *MATLAB* environment permits a nearly direct transition from mathematical expression to simulation. Some of the basic analysis covered in this text are:

- Evaluation of transmission line parameters
- Transmission line performance and compensation
- Power flow analysis
- Economic scheduling of generation
- Synchronous machine transient analysis
- Balanced fault
- Symmetrical components and unbalanced fault
- Stability studies
- Power system control

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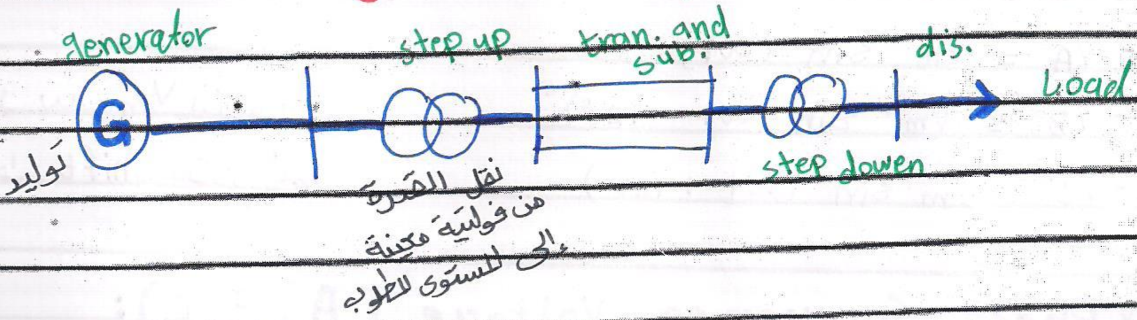
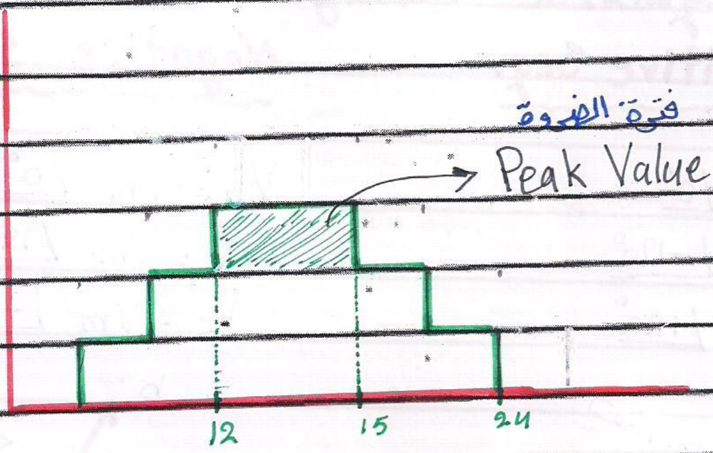
* Power System analysis:





$$P.F = \cos\phi = \frac{P}{S}$$

*Note:- $P.f \approx 1$ يكون أفضل كلما كان قريب إلى الواحد.

* Balanced 3-Phase System:-

- $V_A = V_m \sin(\omega t)$
- $V_B = V_m \sin(\omega t - 120°)$
- $V_C = V_m \sin(\omega t + 120°)$

* الـ ω و Vm نفسها
وفرقها shift بمقدار 120°

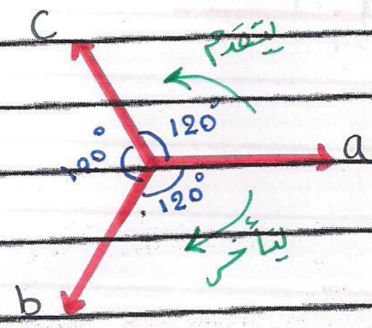
* Phase Sequence Voltage (A, B, C):

Positive Seq.

$V_A = V_m \angle 0°$

$V_B = V_m \angle -120°$

$V_C = V_m \angle 120°$

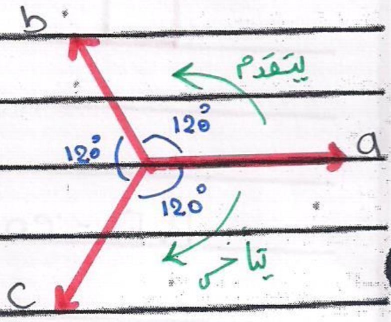


Negative Seq.

$V_A = V_m \angle 0°$

$V_B = V_m \angle 120°$

$V_C = V_m \angle -120°$



* Three Phase connection:-

Source ← → Load

- $\Delta \rightarrow \Delta$
- $\Delta \rightarrow Y$
- $Y \rightarrow Y$
- $Y \rightarrow \Delta$

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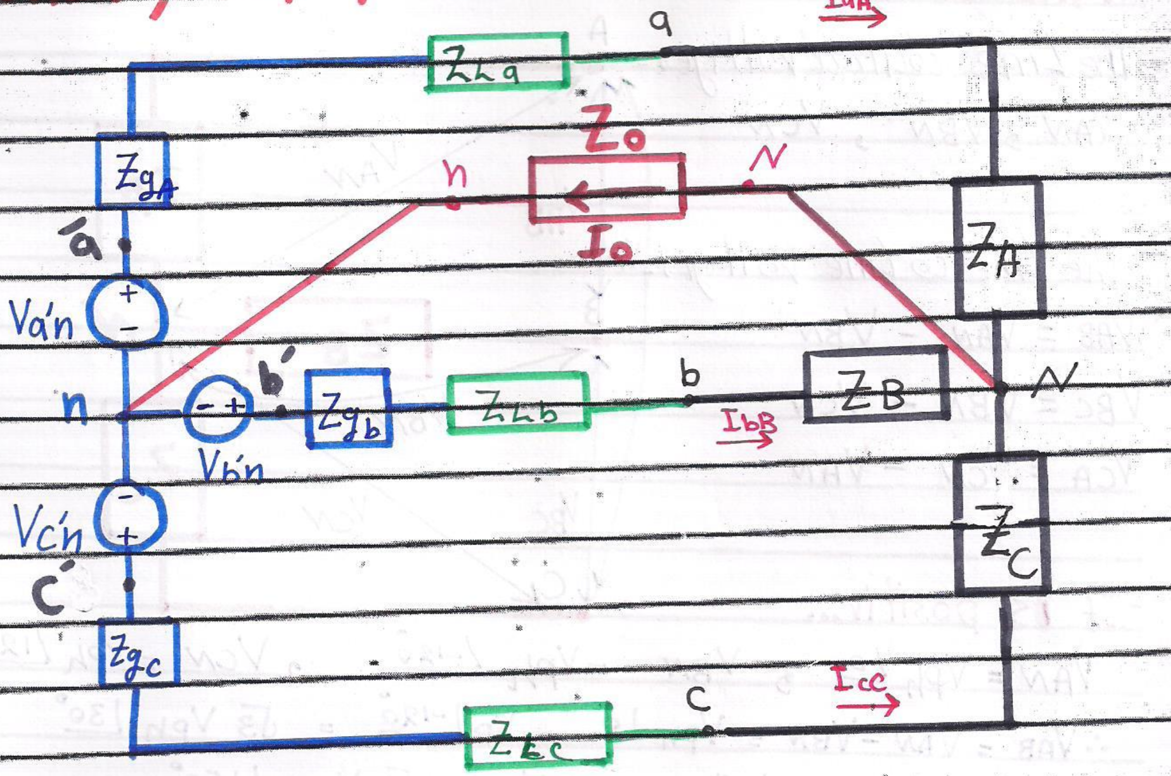
***Analysis Y-Y circuit :-**



***Note:**

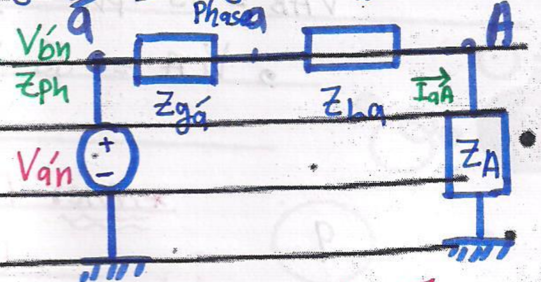
السلك الرابع الـ N يظهر في حالة النظام غير متزن وإذا كان متزن لا يظهر

* يمكن تحويلها إلى single phase ليسهل الحل:

① $Z_{Ph} = Z_{ga} + Z_{La} + Z_A$

② $I_{aA} = \dfrac{V_{a'n}}{Z_{Ph}}$, $I_{bB} = \dfrac{V_{b'n}}{Z_{Ph}}$

, $I_{cC} = \dfrac{V_{c'n}}{Z_{Ph}}$.



* يمكن نعمل shift بمقدار 120°

* مجموع التيارات في 3-Phase يساوي صفر.

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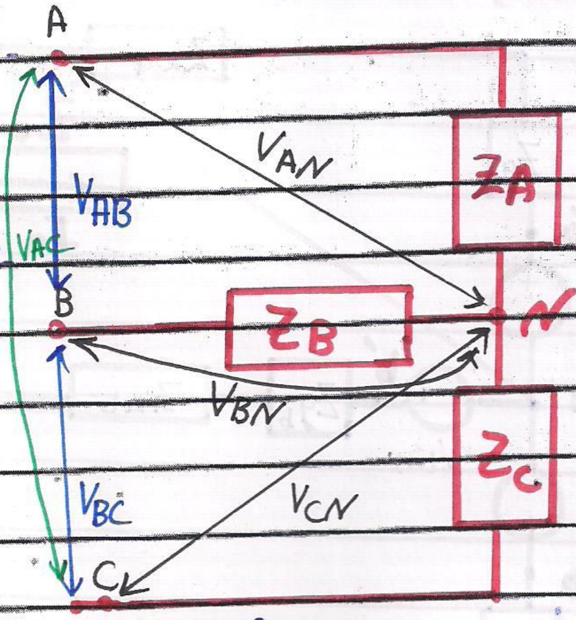
* Line to Line and Line to neutral Voltages:-

- The Line to neutral voltage:-

V_{AN} , V_{BN} , V_{CN}



- The Line to Line Voltage:-

$V_{AB} = V_{AN} - V_{BN}$

$V_{BC} = V_{BN} - V_{CN}$

$V_{CA} = V_{CN} - V_{AN}$

- If is positiv...

$V_{AN} = V_{ph}\angle 0$, $V_{BN} = V_{ph}\angle -120^\circ$, $V_{CN} = V_{ph}\angle 120^\circ$

$\therefore V_{AB} = V_{AN} - V_{BN} = V_{ph}\angle 0^\circ - V_p\angle -120^\circ = \sqrt{3}\, V_{ph}\angle 30^\circ$

$V_{BC} = \sqrt{3}\, V_{ph}\angle -90$, $V_{CA} = \sqrt{3}\, V_{ph}\angle 150^\circ$.

* Note :- V_{L-L} Lead V_{ph} by 30°.

- If Negative seq.

$V_{AB} = \sqrt{3}\, V_{ph}\angle 30$, $V_{BC} = \sqrt{3}\, V_{ph}\angle 150^\circ$

, $V_{CA} = \sqrt{3}\, V_{ph}\angle -90^\circ$

* Note: ABC → Positive.

ACB → Negative.

معلومة

* التحويل في نظام الفيز لبدل 2Phase ولا نغير الفيز الثالث.

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Example: 1

A balanced three-phase Y-connected generator with positive sequence has an impedance of $0.2 + j0.5\ \Omega/\Phi$ and the internal voltage of $120\ V/\Phi$. The generator feeds a balanced three-phase Y-connected load having an impedance of $39 + j28\ \Omega/\Phi$. The impedance of the line connecting the generator to the load is $0.8 + j1.5\ \Omega/\Phi$. The a-phase internal voltage of the generator is specified as the reference phasor.

a) Construct the a-phase equivalent circuit of the system.

b) Calculate the three line currents I_{aA}, I_{bB}, and I_{cC}.

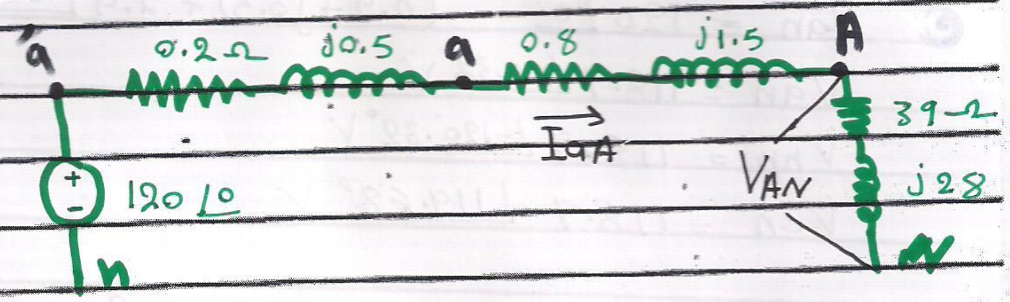
c) Calculate the three phase voltages at the load, V_{AN}, V_{BN}, and V_{CN}.

d) Calculate the line voltages V_{AB}, V_{BC}, and V_{CA} at the terminals of the load.

e) Calculate the phase voltages at the terminals of the generator, V_{an}, V_{bn}, and V_{cn}.

f) Calculate the line voltages V_{ab}, V_{bc}, and V_{ca} at the terminals of the generator.

Sol:-



a) هذه الرسمة هي المطلوب ⓐ حتى لو ما طلبها ارسمها وحل عليها بكون الحل أسهل ...

b) $$I_{aA} = \frac{120}{(0.2+0.8+39)+(0.5+1.5+28)j} = 2.4\angle -36.83\ A$$

$$I_{bB} = 2.4\angle -156.87^\circ\ A$$

$$I_{cC} = 2.4\angle 83.13^\circ\ A$$

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c) $V_{AN} = 2.4 \angle -36.87 * (39 + j28) = 115.22 \angle -1.19^\circ$ V

$V_{BN} = 115.22 \angle -121.19$ V

$V_{CN} = 115.22 \angle 118.81$ V

d) $V_{AB} = \sqrt{3}\, V_{AN} \angle 30^\circ = 199.58 \angle 28.81^\circ$ V

$V_{CB} = 199.58 \angle -91.19^\circ$ V

$V_{CA} = 199.58 \angle 148.81^\circ$ V

e) $V_{an} = 120 \angle 0 - (0.2 + j0.5) * 2.4 \angle -36.87^\circ$

$V_{an} = 118.9 \angle -0.32$ V

$V_{bn} = 118.9 \angle -120.32^\circ$ V

$V_{cn} = 118.9 \angle 119.68^\circ$ V

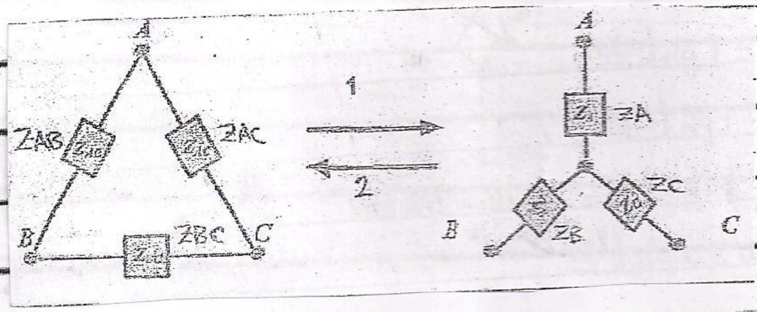
f) $V_{ab} = \sqrt{3}\, V_{an} \angle 30^\circ = 205.9 \angle 29.68^\circ$ V

$V_{bc} = 205.9 \angle -90.32$ V

$V_{CA} = 205.9 \angle 149.68^\circ$ V

H.W: Solve the same example but at **Negative seq.**

*Transformation from Δ to Y OR Y to Δ :-



Δ to Y	Y to Δ
$Z_A = \dfrac{Z_{AB}\, Z_{AC}}{Z_{AB}+Z_{BC}+Z_{AC}}$	$Z_{AB} = \dfrac{Z_A Z_B + Z_B Z_C + Z_C Z_A}{Z_C}$
$Z_B = \dfrac{Z_{AB}\, Z_{BC}}{Z_{AB}+Z_{BC}+Z_{CA}}$	$Z_{BC} = \dfrac{Z_A Z_B + Z_B Z_C + Z_C Z_A}{Z_B}$
$Z_C = \dfrac{Z_{AC}\, Z_{BC}}{Z_{AB}+Z_{BC}+Z_{AC}}$	$Z_{CA} = \dfrac{Z_A Z_B + Z_B Z_C + Z_C Z_A}{Z_A}$

- For Balanced Load :-

$$Z_Y = \frac{Z_\Delta}{3} \quad , \quad Z_\Delta = 3 Z_Y$$

هذه القوانين في حالة الحمل المتزن أما
إذا كان غير متزن نحل على القوانين السابقة

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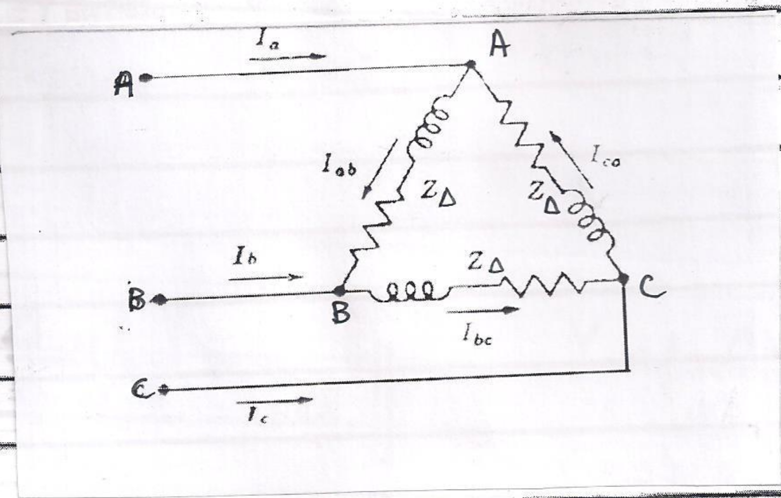
* The phase and line current for Δ circuit:-



- If is poistive seq. :-

$I_{AB} = I_{Ph} \angle 0$

$I_{BC} = I_{Ph} \angle -120^\circ$

$I_{CA} = I_{Ph} \angle 120^\circ$

- at load :-

$I_{aA} = I_{AB} - I_{CA} = I_{Ph} \angle 0^\circ - I_{Ph} \angle 120^\circ = \sqrt{3}\, I_{Ph} \angle 30^\circ$

$I_{bB} = I_{BC} - I_{AB} = \sqrt{3}\, I_{Ph} \angle -150^\circ$

$I_{cC} = I_{CA} - I_{BC} = \sqrt{3}\, I_{Ph} \angle 90^\circ$.

Example: 2

A balanced three-phase Y-connected generator with positive sequence has an impedance of $0.2 + j0.5\ \Omega/\Phi$ and the internal voltage of $120\ V/\Phi$. The Y-connected source feeds a Δ-connected load through a distribution line having an impedance of $0.3 + j0.9\ \Omega/\Phi$. The load impedance is $118.5 + j85.5\ \Omega/\Phi$. The a-phase internal voltage of the generator is specified as the reference phasor.

a) Construct a single-phase equivalent circuit of the three-phase system.

b) Calculate the line currents I_{aA}, I_{bB}, and I_{cC}.

c) Calculate the phase voltages at the load terminals.

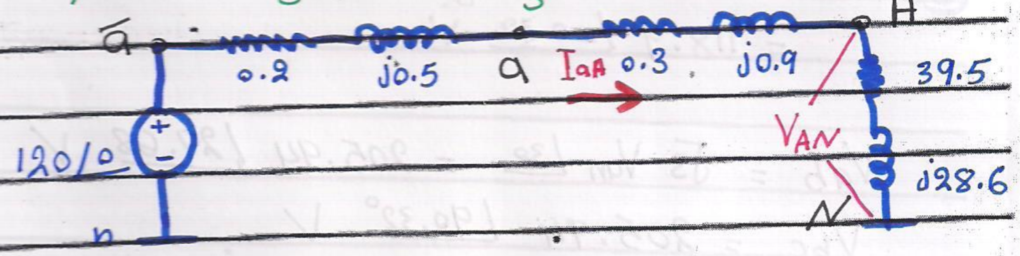
d) Calculate the phase currents of the load.

e) Calculate the line voltages at the source terminals.

نحول Δ إلى Y
ليسهل الحل

Solution:

(a) $Z_\Delta = 3Z_Y \Rightarrow Z_Y = \frac{Z_\Delta}{3} = \frac{118.5 + j85.8}{3} = 39.5 + j28.6\ \Omega/\Phi$



(b) $I_{aA} = \frac{120\angle 0}{(0.2+0.3+39.5) + j(0.5+0.9+28.6)} = 2.4\angle -36.87^\circ\ A$

$I_{bB} = 2.4\angle -156.87^\circ\ A$

$I_{cC} = 2.4\angle 83.13^\circ\ A$

(c) $V_{AN} = [2.4 \angle -36.87^\circ * (39.5 + j28.6)] = 117.04 \angle -0.96^\circ$ V

$V_{AB} = (\sqrt{3}\, V_{AN} \angle 30) = 202.72 \angle 29^\circ$ V

$V_{BC} = 202.72 \angle -91^\circ$ V

$V_{CA} = 202.72 \angle 149^\circ$ V.

(d) $I_{AB} = (\frac{1}{\sqrt{3}} \angle 30)\, I_{aA} = 2.4 \angle -36.87 * (\frac{1}{\sqrt{3}} \angle 30) = 1.39 \angle -6.87^\circ$ A

$I_{BC} = 1.39 \angle -126.87^\circ$ A

$I_{CA} = 1.39 \angle 113.13^\circ$ A

(e) $V_{an} = V'_{an} - I_{aA} * Z_g = 120 \angle 0^\circ - (2.4 \angle -36.87^\circ * (0.2 + j0.5))$

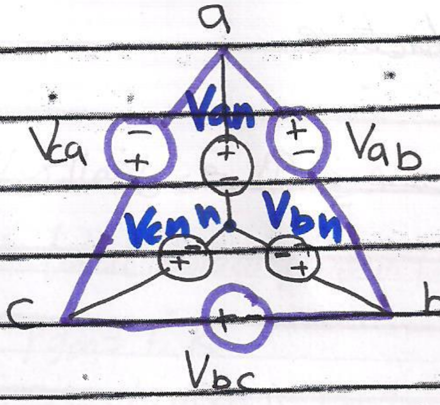
$= 118.9 \angle -0.32$ V

$V_{ab} = \sqrt{3}\, V_{an} \angle 30 = 205.94 \angle 29.68$ V

$V_{bc} = 205.94 \angle 90.32^\circ$ V

$V_{ca} = 205.94 \angle 149.68$ V

* Δ-Y connection :-



$$V_{an} = \frac{V_{ph}}{\sqrt{3}} \angle -30^\circ$$

$$V_{bn} = \frac{V_{ph}}{\sqrt{3}} \angle -150^\circ$$

$$V_{cn} = \frac{V_{ph}}{\sqrt{3}} \angle 90^\circ$$

* Power in three phase system:-

① Active power : [kW]

$$P_T = 3P_{ph} = 3V_{ph}I_{ph}\cos\phi = \sqrt{3}V_L I_L \cos\phi = S_T\cos\phi$$

② Reactive power :- [kVAR]

$$Q_T = 3Q_{ph} = 3V_{ph}I_{ph}\sin\phi = \sqrt{3}V_L I_L\sin\phi = S_T\sin\phi$$

③ Apparent power :- [kVA]

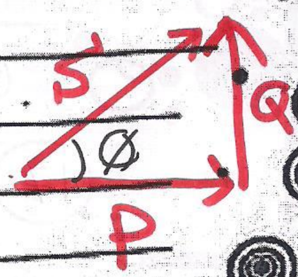
$$S = 3\,|V_{ph}|\,|I_{ph}| = \sqrt{3}\,|V_L|\,|I_L|$$

④ Complex power :-

$$S = \sqrt{3}\,V_L I_L^*$$

$$= 3\,V_{ph} I_{ph}^*$$

$$= P_T \pm jQ_T$$



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*Note: $-Q \rightarrow$ capacitive
$+Q \rightarrow$ Inductive

Example 3:- هذا المثال تابع المثال رقم (1) في صفحة (10)

a) Calculate the average power per phase delivered to the Y-connected load in example 11.1.
b) Calculate the total average power delivered to the load.
c) Calculate the total average power lost in the line.
d) Calculate the total average power lost in the generator.
e) Calculate the total number of magnetizing vars absorbed by the load.
f) Calculate the total complex power delivered by the source.

Solution:-

(a) $P_{Ph} = V_{Ph} I_{Ph} \cos\phi = 115.22 * 2.4 \cos(35.68) = 224.64$ watt

OR $P_{Ph} = I_{Ph}^2 * R_{Ph}$

(b) $P_T = 3 P_{Ph} = 3 * 224.64 = 673.92$ watt OR $P_T = \sqrt{3} V_L I_L \cos\phi$

(c) $P_L = 3 I_L^2 R_L = 3 * (2.4)^2 * (0.8) = 13.82$ watt

(d) $P_g = 3 I_g^2 * R_g = 3 * (2.4)^2 * (0.2) = 3.46$ watt

(e) $Q_T = 3 Q_{Ph} = 3 V_{Ph} I_{Ph} \sin\phi = \sqrt{3} V_L I_L \sin\phi$

$= \sqrt{3} * (199.58)(2.4) \sin(35.68) = 483.84$ VAR

(f) $S_T = \sqrt{3} V_L I_L^* = 3 S_{Ph}$

$= 3(120)(2.4 \angle 36.87)$

$= 691.20 + j518.4$ VA

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Ex: 4

A balanced 3-phase reqvires 480kw at a lagging P.F of 0.8 the load is fed from a line voltage an impedance of 0.005+j0.025 Ω/.the line voltage at the terminal of load is 600 V .

a) calculat a single eq. circuit of the system.

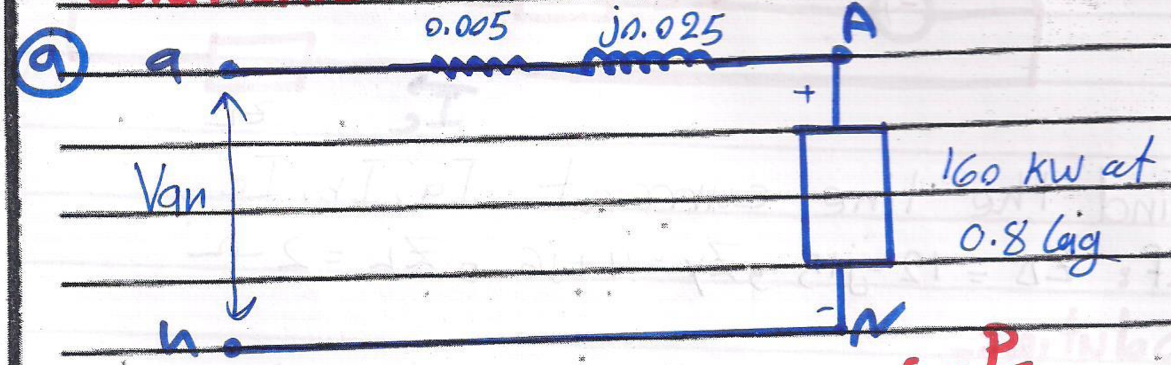
b) calculat the magintude of the line current.

c) calculat the magintude of the voltage of the sending end of the line .

d) calculat the power factor at the sending end of the line.

Solution:-

(a)



$S = \frac{P}{\cos\phi} = \frac{160}{0.8}$

(b) Line current: $P_L = 3 I_L^2 R_L$

$\Rightarrow \left(\frac{600}{\sqrt{3}}\right) I_{aA}^{*} = (160 + j120) \times 10^3$

$I_{aA}^{*} = 577.35 \angle 36.87 \Rightarrow I_{aA} = 577.35 \angle 36.87° A$

(c) $V_{an} = V_{AN} + I_{aA} * Z_L$

$= \left(\frac{600}{\sqrt{3}}\right) + \left((0.005 + j0.025)(557.35 \angle 36.87)\right)$

$= 357.54 \angle 1.57° \ V$

$V_L \equiv V_A = \sqrt{3} |V_{an}| = 619.23 V$

(d) V_{an} & I_{an}

$P.F = \cos(1.57 - (-36.87)) = 0.78$ lag

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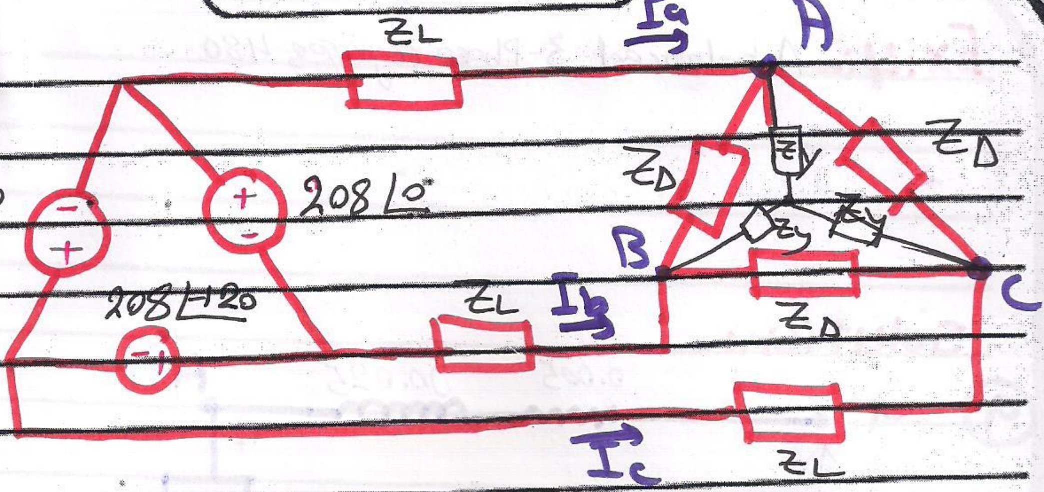
Ex5:



Find the line current Ia, Ib, Ic

If: $Z_\Delta = 12 - j15$, $Z_Y = 4 + j6$, $Z_L = 2\ \Omega$

Solution:-

$V_{an} = \frac{V_{ph}}{\sqrt{3}} \angle -30 = \frac{208}{\sqrt{3}} \angle -30 = 120 \angle -30\ V$

$Z = Z_Y // \frac{Z_\Delta}{3} = (4+j6) // (4-j5) = 5.723 - j0.2153$

$I_{aA} = \frac{120 \angle -30}{(5.723 - j0.2153) + 2} = 15.53 \angle -28.4\ A$

$I_{bB} = 15.53 \angle -148.4\ A$

$I_{cC} = 15.53 \angle 91.6\ A$

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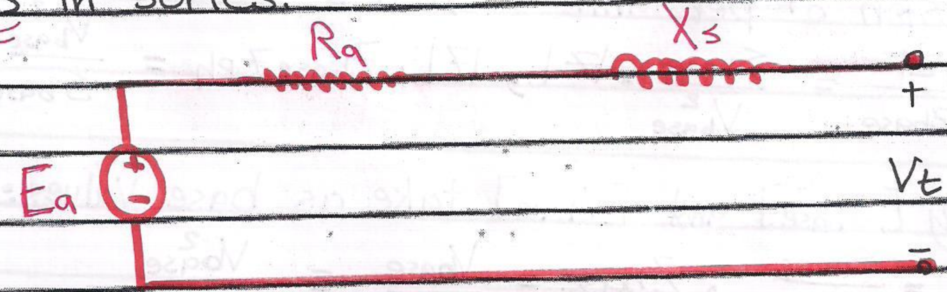
*Power System components:-

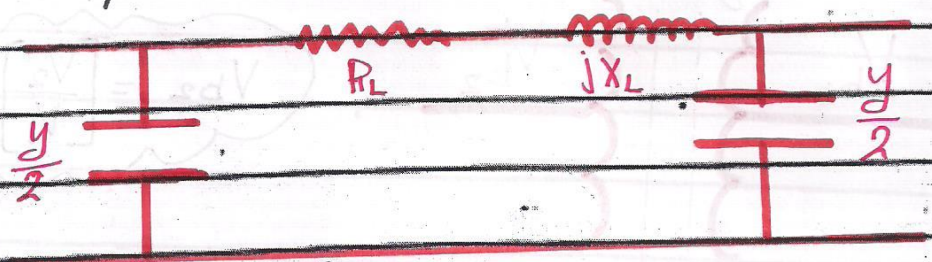
① synchounus generator:-

For steady-state operation synch. generator can be represnted by a circuit consists of per phase generator Voltage E_a and the per phase armature resistance R_a and synchaunus reactunce X_s in series.



② Transmission Line:-

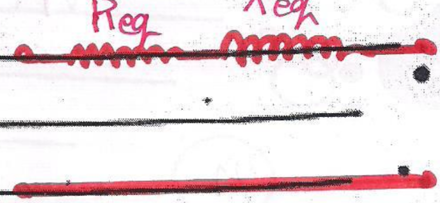
T.L. equ. circuit uses for anodeling is usually π circuit.



(T) $R_L \ll X_L$

③ Transformer:-

Transformer are usually represented their equvalent approximate circuit.



* Per Unit System :-

① Per unit Value $= \dfrac{\text{Acual Value}}{\text{base Value}}$

ⓐ $S_{ph} = \dfrac{|S|}{S_{base}}$ ⓑ $I_{ph} = \dfrac{|I|}{I_{base}}$ ⓒ $V_{ph} = \dfrac{|V|}{V_{base}}$ ⓓ $Z_{ph} = \dfrac{|Z|}{Z_{base}}$

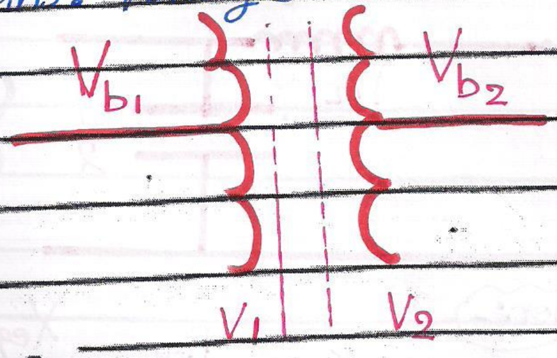
② Conversion of per unit values :-

$$Z_{ph} = \frac{|Z|}{Z_{base}} = \frac{S_{base}}{V_{base}^2} * |Z| \; , \; |Z| = Z_{base} Z_{ph} = \frac{V_{base}^2}{S_{base}} Z_{ph}$$

③ Usually [S_{base}] and [V_{base}] take as base Values :-

$$I_{base} = \frac{S_{base}}{V_{base}} \; ; \; Z_{base} = \frac{V_{base}}{I_{base}} = \frac{V_{base}^2}{S_{base}}$$

④ Trans. Voltage base :-



$$V_{b2} = \left[\frac{V_2}{V_1}\right] V_{b1}$$

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(5) Per unit in three system:-

$$S_b = \sqrt{3}\, V_b I_b \quad ; \quad I_b = \frac{S_b}{\sqrt{3}\, V_b}$$

$$V_b = \sqrt{3}\, I_b Z_b \quad ; \quad Z_b = \frac{V_b}{\sqrt{3}\, I_b} \text{ or } \frac{V_b^2}{S_b}$$

(6) Chang of base:-

$$Z_{p.u}^{old} = \frac{Z_{\Omega}}{Z_b^{old}} = \left[\frac{S_b^{old}}{(V_b^{old})^2}\right] Z_{\Omega}$$

$$Z_{p.u}^{New} = \frac{Z_{\Omega}}{Z_b^{New}} = \left[\frac{S_b^{New}}{(V_b^{New})^2}\right] Z_{\Omega}$$

$$\Rightarrow Z_{p.u}^{New} = Z_{p.u}^{old} * \left(\frac{S_b^{New}}{S_b^{old}}\right) \cdot \left(\frac{V_b^{old}}{V_b^{New}}\right)^2$$

طريقة الحل:-

(١) تقسيم الـ Trans. إلى Zones.

(٢) تحديد الـ Sb والـ Vb

(٣) نحسب قيم Z بالـ PerUnit

(٤) رسم الدائرة المكافئة.

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Ex; 6:-

The one line diagram of an unloaded power system is shown below . Reactance of the T.L is shown on the diagram the generator and transformers are rated follows :

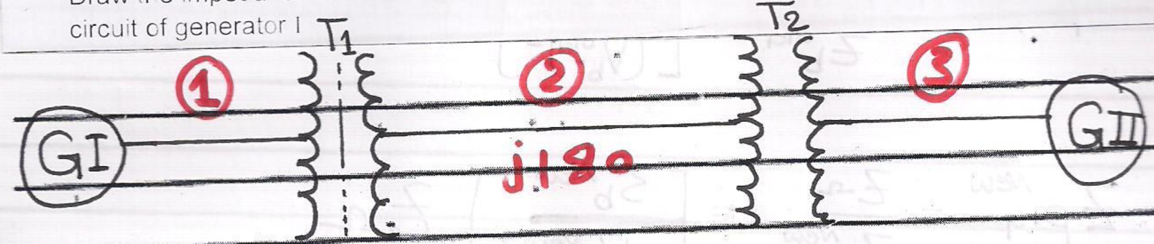
Generator I: 20 MVA , 13.8 KV , $X'' = 0.20$ per unit

Generator II: 30 MVA , 18 KV $X'' = 0.20$ per unit

Transformer I: 25 MVA , 220Y / 13.8 Δ KV , X = 10 %

Transformer II: 30 MVA , 220Y / 18 Δ KV , X = 10 %

Draw the impedance with all reactance chooses a base of 50 MVA , 13.8 KV in the circuit of generator I



Solution:

$$S_b = 50MVA = S_{b1}^{New} = S_{b2}^{New} = S_{b3}^{New}$$

$$V_{b1} = 13.8\ KV = V_{b1}^{new}$$

$$V_{b2}^{new} = \left(\frac{220}{13.8}\right) V_{b1}^{new} = \left(\frac{220}{13.8}\right)(13.8) = 220\ KV$$

$$V_{b3}^{New} = \left(\frac{18}{220}\right) * V_{b2}^{New} = \left(\frac{18}{220}\right) * 220 = 18\ KV$$

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- The corresponding base impedanc in each reg.:-

$$Z_{b1}^{New} = \frac{(V_{b_1}^{New})^2}{S_{b_1}^{New}} = \frac{(13.8)^2}{50} = 3.8088\ \Omega$$

$$Z_{b2}^{New} = \frac{(V_{b2}^{New})^2}{S_{b2}^{New}} = \frac{(220)^2}{50} = 968\ \Omega$$

$$Z_{b3}^{New} = \frac{(V_{b3}^{New})^2}{S_{b3}^{New}} = \frac{(18)^2}{50} = 6.48\ \Omega$$

$$Z_{p.u}^{New} = Z_{p.u}^{old}\left[\frac{S_b^{New}}{S_b^{old}}\right]\left[\frac{V_b^{old}}{V_b^{New}}\right]^2$$

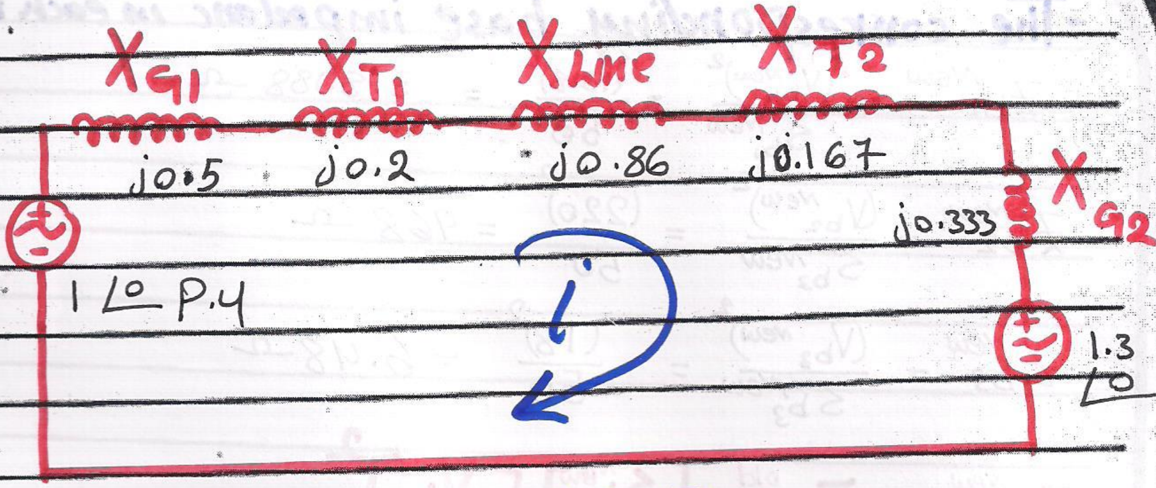
$$Z_{G1}^{New}\ p.u = (j0.2)\left[\frac{50}{20}\right]\left[\frac{13.8}{13.8}\right]^2 = j0.5\ p.u$$

$$Z_{T1}^{New}\ p.u = (j0.1)\left[\frac{50}{25}\right]\left[\frac{13.8}{13.8}\right]^2 = j0.2\ p.u$$

$$Z_{line}^{New}\ p.u = \frac{Z_{line}}{Z_{base}} = \frac{Z_{line}}{Z_{b2}^{New}} = \frac{j180}{968} = j0.186\ p.u$$

$$Z_{T2}^{New}\ p.u = (j0.1)\left[\frac{59}{30}\right]\left[\frac{220}{220}\right]^2 = j0.167\ p.u$$

$$Z_{G2}^{New}\ p.u = (j0.2)\left[\frac{50}{30}\right]\left[\frac{18}{18}\right]^2 = j0.333\ p.u$$

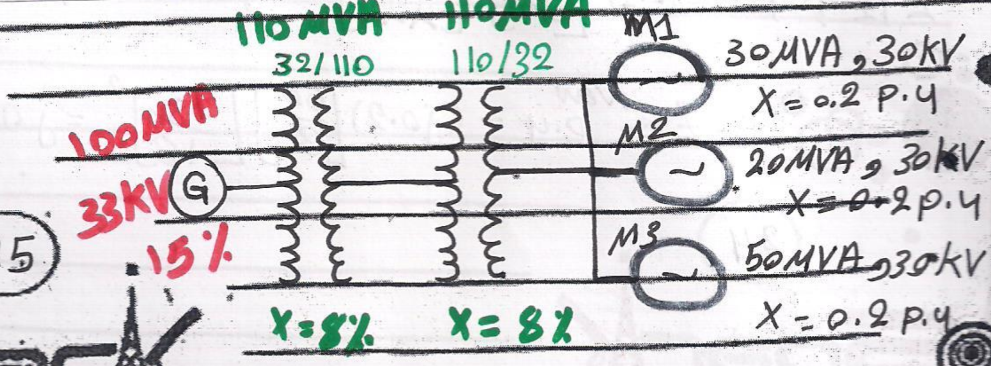


$18/13.8 = 1.3\angle 0$

$$I = \frac{1\angle 0 - 1.3\angle 0}{Z_T \text{ P.u}} =$$

EX: 7 :-

A 100 MVA ;33KV 3-Phase generator has sub transient reactance of 15% the generator is connected to the motors through a T.L and transformers.
Selecting the generator rating as the base quantities in the generator circuit. Determine the base in other parts of the system and evaluate the corresponding p.u value.



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***Solution:** $S_b = 100\,MVA$, $V_b = 33\,kV$

$S_{b_1}^{New} = S_{b_2}^{New} = S_{b_3}^{New} = 100\,MVA$

$V_{b_1}^{New} = 33\,KV$

$V_{b_2}^{New} = \left[\frac{32}{110}\right] V_{b_1}^{New} = \left[\frac{32}{110}\right] * 33 = 113.438\,kV$

$V_{b_3}^{New} = \left[\frac{32}{110}\right] V_{b_2}^{New} = \left[\frac{32}{110}\right] * 113.438 = 33\,kV$

$$Z_{b_1}^{New} = \frac{(V_{b_1}^{New})^2}{S_{b_1}^{New}} = \frac{(33)^2}{100} = 10.89\,\Omega$$

$$Z_{b_2}^{New} = \frac{(V_{b_2}^{New})^2}{S_{b_2}^{New}} = \frac{(113.438)^2}{100} = 128.68\,\Omega$$

$$Z_{b_3}^{New} = \frac{(V_{b_3}^{New})^2}{S_{b_3}^{New}} = \frac{(33)^2}{100} = 10.89\,\Omega$$

$$Z_{g_1\,p.u}^{New} = Z_{p.u}^{old}\left[\frac{S_{b_1}^{New}}{S_{b_1}^{old}}\right]\left[\frac{V_{b_1}^{old}}{V_{b_1}^{New}}\right]^2 = j0.15\left[\frac{100}{100}\right]\left[\frac{33}{33}\right]^2 = j0.15\,p.u$$

$$Z_{T_1\,p.u}^{New} = j0.08\left[\frac{100}{100}\right] * \left[\frac{32}{33}\right]^2 = j\,0.6838\,p.u.$$

$$Z_{L\,p.u}^{New} = \frac{Z_{line}}{Z_{b_2}} = \frac{j50}{128.68} = j\,0.3886\,p.u$$

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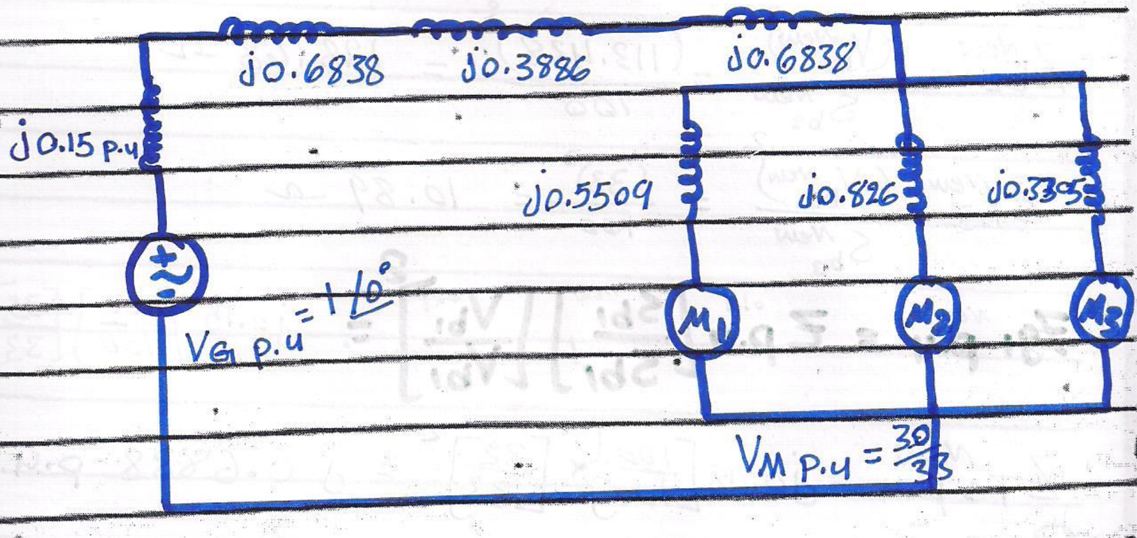
$$Z_{T2\ p.u}^{New} = j0.08\left[\frac{100}{100}\right]\left[\frac{110}{113.438}\right]^2 = j0.6838\ p.u.$$

$$Z_{M1\ p.u}^{New} = (j0.2)\left[\frac{100}{30}\right]\left[\frac{30}{33}\right]^2 = j0.5509\ p.u$$

$$Z_{M2\ p.u}^{New} = (j0.2)\left[\frac{100}{20}\right]\left[\frac{30}{33}\right]^2 = j0.826\ p.u$$

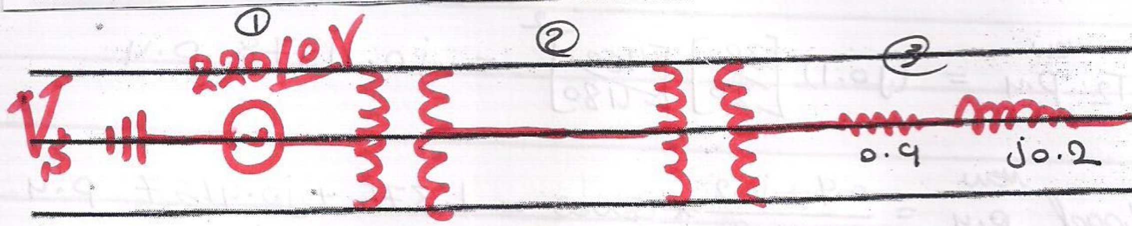
$$Z_{M3\ p.u}^{New} = (j0.2)\left[\frac{100}{50}\right]\left[\frac{30}{33}\right]^2 = j0.3305\ p.u$$



Note: you can find the current

Ex: 8:-

Using base values of 30 KVA and 240V in zone1;draw the per unit circuit and determine the per unit impedance and the per unit source .then calculate the load current both in per unit and amperes.



30 KVA, 240/480 V
X = 0.10 P.U

20 KVA, 460/115
X = 0.10 P.U

Solution:- $S_b = 30\ KVA = S_{b_1}^{New} = S_{b_2}^{New} = S_{b_3}^{New}$

$V_{b_1}^{New} = 240\ V$

$V_{b_2}^{New} = \left[\frac{480}{240}\right] * V_{b_1}^{New} = 480\ Volt$

$V_{b_3}^{New} = \left[\frac{115}{460}\right] * V_{b_2}^{New} = 120\ Volt$

$Z_{b_1}^{New} = \frac{(V_{b_1}^{New})^2}{S_{b_1}} = \frac{(240)^2}{30000} = 1.92\ \Omega$

$Z_{b_2}^{New} = \frac{(V_{b_2}^{New})^2}{S_{b_2}^{New}} = \frac{(480)^2}{30000} = 7.68\ \Omega$

$Z_{b_3}^{New} = \frac{(V_{b_3}^{New})^2}{S_{b_3}} = \frac{(120)^2}{30000} = 0.48\ \Omega$

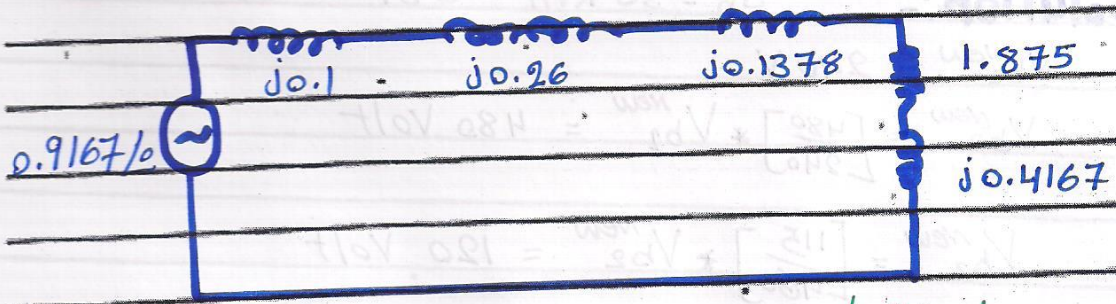
$$Z_{T_1\,p.u}^{New} = (j0.1)\left[\frac{3\times10^3}{3\times10^3}\right]\left[\frac{240}{240}\right]^2 = j0.1 \ p.u$$

$$Z_{line\,p.u}^{New} = \frac{j2}{(480)^2} * 30000 = j0.26 \ p.u$$

$$Z_{T_2\,p.u}^{New} = (j0.1)\left[\frac{30}{20}\right]\left[\frac{460}{480}\right]^2 = j0.11378 \ p.u$$

$$Z_{Load\,p.u}^{New} = \frac{0.9+j0.2}{(120)^2} * 30000 = 1.875 + j0.4167 \ p.u$$

$$V_{s\,p.u} = \frac{220}{240} = 0.9167 \angle 0^\circ \ p.u$$



$$I_{Load\,p.u} = \frac{0.9167}{2.086\angle 26.01} = 0.4395 \angle -26.01 \ p.u$$

$$I_{acutal} = (I_{Load\,p.u})(I_{base_3}) \Rightarrow I_{base_3} = \frac{S_{b3}}{V_{b3}} = 250$$

$$I_{acutal} = (0.439 \angle -26.01)(250)$$
$$= 109.9 \angle -26.01 \ A$$

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*Performance of Transmission Line:-

Short T.L	Medium T.L	Long T.L
(STL)	(MTL)	(LTL)
80km ≤ T.L	80km < M.T.L < 250km	L.T.L > 250km

*Important terms:-

-Voltage Regulation:

The difference in voltage at the relieving end of a transmission line (T.L) between conditions of no Load and full Load is called "Voltage Regulation"

$$\%\text{Age Voltage regulation} = \frac{V_S - V_R}{V_R} * 100\%$$

$$\left.\begin{aligned} V_S &= AV_r + BI_r \\ I_S &= CV_r + DI_r \end{aligned}\right] \rightarrow AD - BC = 1$$

*Transmisson efficiency:-

The ratio of recieving end power to the sending end power of T.L

$$\%\text{age T.L } \eta = \frac{\text{Res. end Power}}{\text{Sen. end power}} * 100\%$$

OR

$$\eta = \frac{V_r I_r \cos\phi_r}{V_s I_s \cos\phi_s} * 100\%$$

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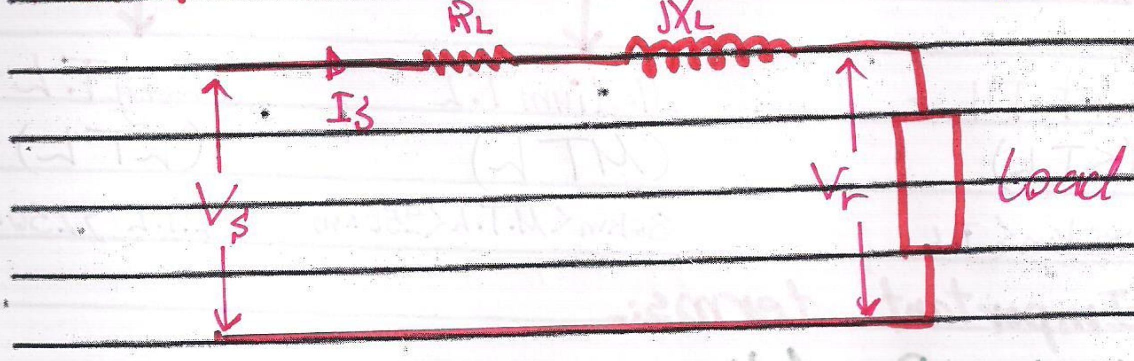
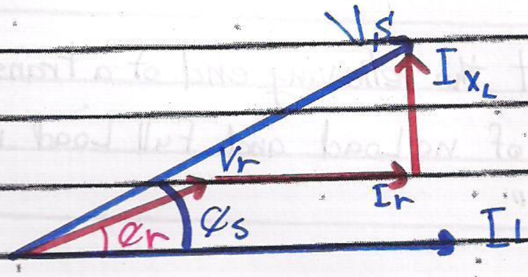
* Short Transmission Line :- (Single Phase)





$$V_s = V_r + I_r Z$$

$$I_s = I_r$$

$$\begin{bmatrix} V_r \\ I_r \end{bmatrix} \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} V_s \\ I_s \end{bmatrix} \quad ; Z\angle\theta = Z\cos\theta + jZ\sin\theta$$

* %age regulation $= \dfrac{V_s - V_r}{V_r} * 100\%$
* line losses $= I^2 R$
* Power sent out $= V_r I_r \cos\theta_r + I^2 R$
* % age T.L eff $= \dfrac{V_r I_r \cos\theta_r}{V_r I_r \cos\theta_r + I^2 R} * 100\%$

*effect of load P.F on regulation & efficiency

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P.f → lag → Vr < Vs → Voltage regulation positive **+ve**

P.f → Lead → Vr > Vs → Voltage regulation negative **-ve**

$$P.f = \cos\phi = \frac{P}{S} = \frac{R}{Z}$$

Ex: 9:-

Single phase over head transmission [OHT]divers 1100 KW at 33KV out of 0.8P.F lagging the total resistance and reactance of the line are 10Ω ,15Ω respectively .

a) Sending end voltage.

b) Sending P.F.

c) Transmission efficiency.

Solution:- $Z_L = 10 + j15$, $P.f = \cos\phi = 0.8 \Rightarrow \phi = 36.78$

* line current: $I = \dfrac{1100 * 10^3}{33 \times 10^3 * 0.8} = 41.67\ A$

$$\phi = \cos^{-1}(0.8) = 36.78^\circ$$

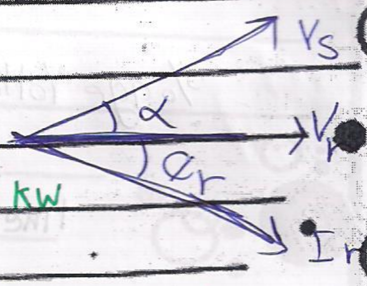
$$V_s = V_r + I Z_L$$

$$= 33 \times 10^3 \angle 0 + [(10+j15)(41.67 \angle -36.78)] = 33.709 \angle 0.42^\circ\ V$$

sending end P.f:-

$$\phi_s = \phi_r + \alpha = 36.87 + 0.42 \Rightarrow P.f = \cos(37.29^\circ)$$

$\therefore P.f = 0.7956$ lagging



*** line Losses:**

$$I^2 R = (41.67)^2 * (10) = 17.364\ kW$$

Power sent:

$$1100 + 17.364 = 1117.364\ kW$$

$$\eta = \frac{1100}{1117.364} * 100 = 98.44\%$$

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Ex:10:

A 3-Phase 50Hz ,16Km , long OHTL supplies 1000KW at 11KV ,P.F 0.8 lagging the line resistance is 0.03Ω per phase per km and line inductance is 0.7m.H per phase per km .Calculate the sending end voltage ,voltage regulation and efficiency of T.L

Solution:

$R_L = 0.03 * 16 = 0.48\ \Omega$

$X_L = j2\pi f L = j2\pi * 50 * 0.7\times10^{-3} = j0.22\ \Omega$

$X_L'' = X_L * 16 = j0.22 * 16 = j3.52\ \Omega$

$Z_L = 0.48 + j3.52$

$V_r = \dfrac{11\times10^3}{\sqrt{3}} = 6351\ V$

$I_r = \dfrac{1000\times10^3}{3 V_r \cos\phi} = \dfrac{1000\times10^3}{3*6351*0.8} = 65.6 A$

$V_s = V_r + I_r Z$

$= 6351 + [(65.6 \angle -36.87)(0.48 + j3.52)] = 6515 \angle 1.46$

$\%\text{age Voltage Reg.} = \dfrac{6515 - 6351}{6351} * 100 = 2.58\ \%$

$\text{line losses} = 3 I^2 R = 3(65.6)^2(0.48) = 6.2\ kw$

$\eta = \dfrac{1000}{1006.2} * 100\% = 99.38\ \%$

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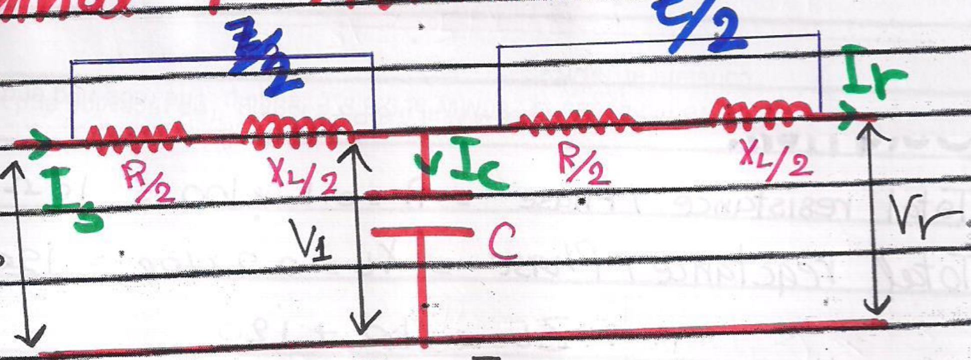
* Medium Transmission Line :-

* The effect of capacitance cann't be neglected.
* The line capacitance must be taken into consideration.
* The capacitance in unformly distributed over the entire length of the line.
* The must commonly used Methods:

① End condenser method
② Nominal "T" Method.
③ Nominal "π" Method.

* Nominal "T" Method :-



$$V_1 = V_r + I_r * \frac{Z}{2}$$

$$I_s = I_r + I_c \quad ; \quad I_c = j2\pi f C V_1$$

$$V_s = I_s * \frac{Z}{2} + V_1$$

$$X_c = \frac{-j}{wC} \quad ; \quad y = \frac{1}{-jX_c}$$

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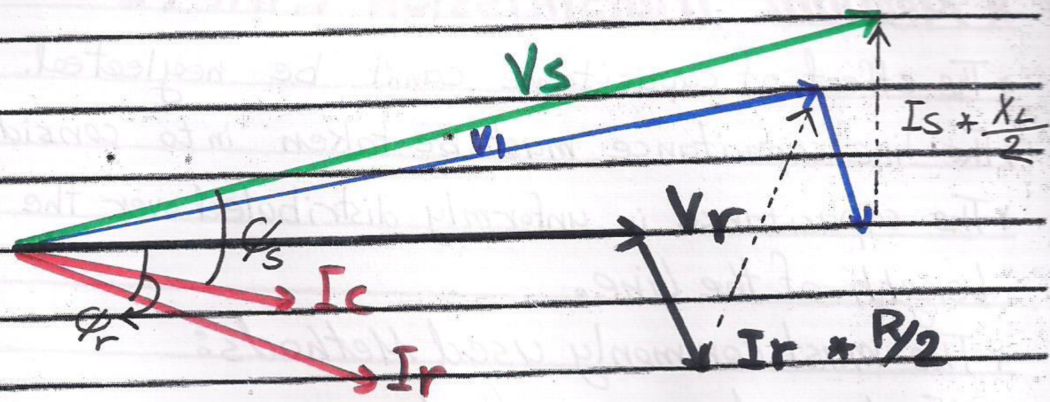

Ex: 11: -

A 3-Phase 50Hz, over head T.L 100km has following constants:

Resistance /km/phase = 0.1Ω

Inductive reactance /km/phase = 0.2Ω

Capacitive reactance /km/phase = $0.04*10^{-4}$ S

Find: a) Is b) Vs c) Sending end P.F d) Transmission eff.

When a use nominal T method when balanced of 10KW ; 66KV ; P.F=0.8lagging

Solution:

Total resistance / Phase = $R = 0.1 * 100 = 10\,\Omega$

Total reactance / Phase = $X_L = 0.2 \times 100 = j20\,\Omega$

$$Z_L = 10 + j20$$

Capacitive susceptance = $y = 0.04 \times 10^{-4} * 100 = 4 \times 10^{-4}$ S

$$V_r = \frac{6600}{\sqrt{3}} = 38105 \cdot V$$

$$I_r = \frac{10 \times 10^3}{\sqrt{3} * 66 * 10^3 * 0.8} = 109\,A$$

$$\phi = \cos^{-1}(0.8) = 36.87$$
$$= -36.87 \Rightarrow \text{Lagging}$$

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$V_1 = V_r + I_r \frac{Z}{2} = 38105 + (109 \angle -36.87)(5 + j10)$

$= 39195 + j545$

* Charging current : $I_c = jyV_1$

$I_c = j * 4\times10^{-4} * (39195 + j545) = -0.218 + j15.6$

$I_s = I_c + I_r \Rightarrow I_s = 100 \angle -29.47° \text{ A}$

$V_s = V_r + I_s \frac{Z}{2} = (39195 + j545) + (87 - j49.8)(5 + j10)$

$= 40145 \angle 11.4 \text{ V}$

line Value $= 40145 * \sqrt{3} = 69.533 \text{ kV}$

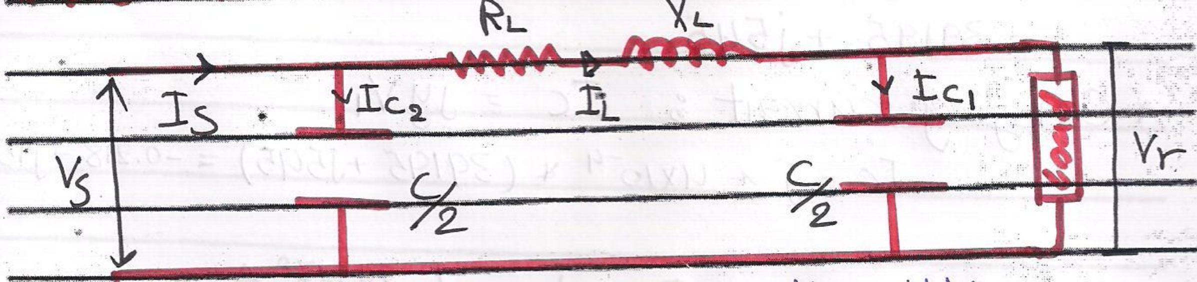
Sending end P.f $= \cos\phi_s = \cos(31.87) = 0.853$

ending end Power $= 3 V_s I_s \cos\phi_s$

$= 3(40.145)(100)(0.853) = 10333.323 \text{ kW}$

$\eta = \frac{10000}{10333.323} * 100\% = 96.77\%$

* Nominal 'π' Method:-



$I_L = I_r + I_{C1}$

$I_S = I_L + I_{C2}$

$I_{C1} = j\pi f C V_r$ $\quad \frac{1}{y}$

$I_{C2} = j\pi f C V_S$ $\quad \frac{1}{y}$

$I = \frac{V}{Z} = YV$

$y = \frac{1}{X_C} = \frac{1}{1/\omega C} = \omega C = 2\pi f C$

$\frac{y}{2} = \pi f C$

$$V_S = V_r + I_L Z$$

Ex: 12

A 3-Phase 50Hz , 150km line has resistance, inductive reactance and capacitive shunt admittance of 0.1Ω ;0.5Ω and 3*10 S per km per phase If the line delivers 50MW at 110KV and 0.8P.F lagging .Determine the sending end voltage and current .Assume a nominal circuit for the line .

Solution:-

$$V_r = \frac{110 \times 10^3}{\sqrt{3}} = 63.508\ V$$

$$I_r = \frac{50 \times 10^6}{\sqrt{3}\ 110 \times 10^3 * 0.8} = 328\ A$$

$$\theta = \cos^{-1}(0.8) = 36.87^\circ$$

$$\therefore I_r = 328 \angle -36.87^\circ\ A$$

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$R_L = 0.1 * 150 = 15\,\Omega$

$X_L = j0.5 * 150 = j75\,\Omega$

$y = j3\times10^{-6} * 150 = j45\times10^{-5}\,S$

$I_L = I_r + I_{C1}$; $I_{C1} = V_r * \frac{y}{2}$

$= 328 \angle -36.87 + j14.3$; $= 63.508 * \frac{j45\times10^{-5}}{2}$

$= 262.4 - j182.5\ A$; $I_{C1} = j14.3$

$V_s = V_r + I_L\, Z \rightarrow (15 + j75)$

$= 63.508 + (262.4 - j182.5)(15 + j75)$

$= 82.881 \angle 11.47\ kV$

line Voltage (V_s):-

$V_{s_L} = \frac{V_{s\,ph}}{\sqrt{3}} = 143.55\ kV$

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A 100km long 3-Phase , 50Hz T.L has following line constant :

Resistance /km/ phase = 0.1 Ω

Inductive reactance /km/phase = 0.5 Ω

Capacitive reactance /km/phase = 10*10 S

If the line supplies load of 20MW of 0.9 P.F lagging at 66 KV at the receiving end ,calculate by nominal π method :

a) sending P.F b) Transmission eff. c) regulation.

Solution:-

$R = 0.1 * 100 = 10\,\Omega$

$X_L = 0.5 \times 100 = 50\,\Omega$

$Z_L = 10 + j50$

$y = 10 \times 10^{-6} * 100 = 10 \times 10^{-4}\ S$

$V_r = \frac{66 * 10^3}{\sqrt{3}} = 38.105\ kV$; $\phi = \cos^{-1}(0.9) = 25.84$

$I_r = \frac{20 \times 10^6}{\sqrt{3} * 66 \times 10^3 \times 0.9} = 195 \angle -25.84\ A$

$I_{C1} = V_r * j\frac{y}{2} = 38.105 * j\,\frac{10 \times 10^{-4}}{2} = j19A$

$I_L = I_r + I_{C1} = 195 \angle -25.8 + 19 \angle 90$

$= 176 - j66A$

$V_s = V_r + I_L Z$

$= 38.105 + (176 - j66)(10 + j50)$

$= 43.925 \angle 10.65^\circ\ V$

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$I_S = I_{C2} + I_C$; $I_{C2} = V_s \, j \frac{y}{2}$

$= (43.925\angle 10.65)(j \frac{10\times10^{-9}}{2})$

$= -4 + j21.6$

$I_S = (-4 + j21.6) + (176 - j66)$

$= 177.6 \angle -14.5 \text{ A}$

* Sending end P.f $= \cos\phi$

$= \cos(25.15) = 0.905$ Lagging

* Voltage Reg. $= \frac{V_s - V_r}{V_r} \times 100\%$

$= \frac{43929 - 38105}{38105} \times 100 = 15.27\%$

* Sending end power: $3 V_s I_s \cos\phi$

$\Rightarrow 3(43925)(177.6)(0.9051)$

$\Rightarrow 21.18 \text{ MW}$

$\eta = \frac{20}{21.18} \times 100\% = 94\%$

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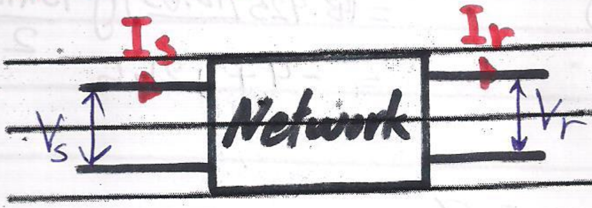
* Generalised circuit constants of T.L :-



$V_s = A V_r + B I_r$

$I_s = C V_r + D I_r$

* A, B, C and D → constant [complex number]
* B → ohm's.
* C → siemen.
* for a given T.L   A = D
* for a given T.L   AD − BC = 1

* Short T.L :-

$V_s = V_r + I_r Z$

$I_s = I_r$

$A = 1$, $B = Z$

$C = 0$, $D = 1$

→ $AD - BC = 1$

* Medium T.L ["T" Method]

$$V_s = \underbrace{\left[1 + \frac{YZ}{2}\right]}_{A} V_r + \underbrace{\left[Z + \frac{YZ}{4}\right]}_{B} I_r$$

$$I_s = \underbrace{Y}_{C} V_r + \underbrace{\left[1 + \frac{YZ}{2}\right]}_{D} I_r$$

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*Medium T.L [π Method]:-

$$V_s = \left[1 + \frac{YZ}{2}\right] V_r + I_r Z$$

A, B

$$I_s = V_r Y \left[1 + \frac{YZ}{4}\right] + I_r \left[1 + \frac{YZ}{2}\right]$$

C, D

Ex: 13.-

A balanced 3-Phase load of 30MW is supplied at 132KV ,50Hz and 0.85 P.F lagging by means of a T.L. The series impedance of single conductor is 20+j52 Ω and the total phase neutral admittance is $315*10^{-6}$ S.

Using Nominal "T" method determine:

A) The A,B,C and D constant of the line .

B) Sending end voltage.

C) Regulation of the line .

Solution:-

$Z_L = 20 + j52$, $Y = 315 \times 10^{-6}$

(A) $A = D = 1 + \frac{ZY}{2} = 1 + \frac{(20+j52)(315 \times 10^{-6})}{2}$

$A = D = 0.992 \angle 0.18$

$B = \left[Z + \frac{ZY}{4}\right] = (20+j52)\left[\frac{(20+j52)(315 \times 10^{-6})}{4}\right]$

$B = 55.5 \angle 169° \ \Omega$

$C = Y = 0.000315 \ S$

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$$V_r = \frac{132 \times 10^3}{\sqrt{3}} = 76210\ V$$

$$I_r = \frac{30 \times 10^6}{\sqrt{3} \times 132 \times 10^3 \times 0.85} = 154A$$

$$\phi = \cos^{-1}(0.85) = 31.7^\circ$$

$$\therefore I_r = 154 \angle -31.7^\circ\ A$$

(B) $V_s = AV_r + BI_r$

$$= (0.992 \angle 0.18)(76210) + [(55.5 \angle 69)(154 \angle -31.7)]$$

$$= 82.428 + j5413$$

$$V_s = \sqrt{(82.428)^2 + (5413)^2} = 82.6\ kV$$

(C) At No Load $(I_r = 0)$:

$$V_s = AV_r + \cancel{BI_r}^{0} \Rightarrow V_r = V_s/A$$

$$\%\ \text{Regulation} = \frac{\left(\frac{V_s}{A}\right) - V_r}{V_r} \times 100\%$$

$$= 9.25\%$$

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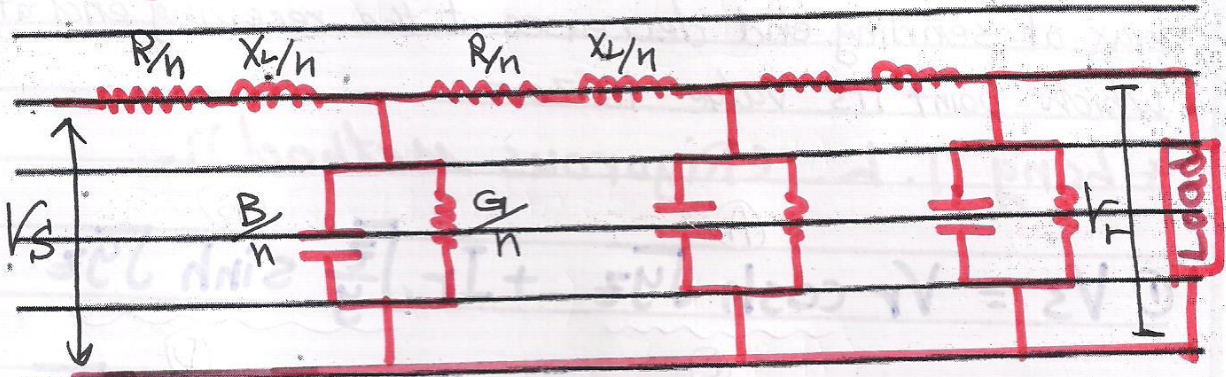
* Long Transmission Line:-



* The line constant of the T.L are uniformly distribnteel over the ontire Length of the line.

* The Leakage suseaptance (B) and Leakage conductane (G) are shunt elements.

* The Leakage susceptance is due to the fact that capcitance exists between line and neutral.

* The Leakage conductance takes in to account the energy losses occurring through Leakage over the in isolators.

* The leakage current through shunt admittance is max at sending end decreases at the receiving end at which point it's value is zero.

* Long T.L. (Rigorous method):-

① $V_s = V_r \underbrace{\cosh\sqrt{yz}}_{A} + I_r \underbrace{\sqrt{\frac{z}{y}}\sinh\sqrt{yz}}_{B}$

② $I_s = V_r \underbrace{\sqrt{\frac{y}{z}}\sinh\sqrt{yz}}_{C} + I_r \underbrace{\cosh\sqrt{yz}}_{D}$

- hyperbolic sine and cosine :-

① $\cosh\sqrt{yz} = \left[1 + \frac{zy}{2} + \frac{z^2y^2}{24} + \cdots\right]$

② $\sinh\sqrt{yz} = \left[\sqrt{yz} + \frac{(yz)^{\frac{3}{2}}}{6} + \cdots\right]$

③ $\gamma = \sqrt{yz}$ → Propagation constant

④ $Z_c = \sqrt{\frac{z}{y}}$ characteristic impedance.

$A = D = \cosh\sqrt{yz}$

$B = \sqrt{\frac{z}{y}}\sinh\sqrt{yz}$

$C = \sqrt{\frac{y}{z}}\sinh\sqrt{yz}$

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Ex:14:-

A 3-Phase T.L. 200km long has the following constants:
Resistance /km/phase = 0.16Ω
Reactance /km/phase = 0.25Ω
Shunt admittance/km/phase= 1.5×10^{-6} S.
Calculate by rigorous method the Sending end voltage and current when the line is delivering a load of 200MW at 0.8 P.F lagging. The receiving end voltage is kept constant at 110KV.

Solution:- $R = 0.16 * 200 = 32\ \Omega$

Total restance per phase $\Rightarrow X_L = 0.25 \times 200 = j50\ \Omega$

Total shunt admitance phase $\Rightarrow y = 1.5 \times 10^{-6} * 200 = 0.0003\angle 90$

$Z = R + jX_L = 32 + j50 = 59.4\angle 58°\ \Omega$

$$V_S = V_r \cosh\sqrt{yz} + I_r \sinh\sqrt{yz} * \sqrt{\frac{z}{y}}$$

$$\sqrt{yz} = \sqrt{\underbrace{(59.4\angle 58)}_{z} * \underbrace{0.0003\angle 90}_{y}} = 0.133\angle 74$$

* لاحظ هنا أولاً الزوايا في الضرب تجمع تصبح الزاوية **148**
ويوجد **√** وتحت زاوية إذاً الزاوية التي تكون تحت
الجذر تقسم على **2** تصبح الزاوية **74** .

$$zy = (0.0003\angle 90) * (59.4\angle 58)$$
$$= 0.0178\angle 148.$$

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$$Z^2 y^2 = (59.4 \angle 58)^2 * (0.003 \angle 90)^2$$

* انتبه .. دائماً التربيع هو عبارة عن ضرب الزاوية 2

$$Z^2 y^2 = (3528.36 \angle \overset{58*2}{116}) * (9\times10^{-8} \angle \overset{90*2}{180})$$

$$= 0.00032 \angle 296^\circ$$ ← الزوايا في الضرب تجمع *

$$\sqrt{\frac{Z}{y}} = \sqrt{\frac{59.4 \angle 58}{0.0003 \angle 90}} = 445 \angle -16^\circ$$

$$\sqrt{\frac{y}{Z}} = \sqrt{\frac{0.0003 \angle 90}{59.4 \angle 58}} = 0.00244 \angle 16^\circ$$

$$\cosh \sqrt{yz} = \left[1 + \frac{zy}{2} + \frac{z^2 y^2}{24}\right]$$

$$= 1 + \frac{0.0178 \angle 148}{2} + \frac{0.00032 \angle 296}{24} = 0.992 \angle 0.26$$

$$\sinh \sqrt{yz} = \sqrt{yz} + \frac{(\sqrt{yz})^3}{6} = 0.1325 \angle 74.6^\circ$$

$$V_r = \frac{110\times10^3}{\sqrt{3}} = 63508\,V$$

$$I_r = \frac{20\times10^6}{\sqrt{3} * 110\times10^3 * 0.8} = 131 \angle -36.87\,A$$

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$V_{s\,Phase} = 67366 \angle 5.5\ V$

$V_{s\,L\text{-}L} = \sqrt{3}\, V_{sph} = 116.7 \angle 5.5\ V$

$$I_s = V_r \sqrt{\frac{y}{z}} \sinh \sqrt{yz} + I_r \cosh \sqrt{yz}$$

$I_s = 131.1 \angle 8^\circ\ A$

* Symmetrical Fault [3-Phase short circuit]:-

- Fault studies → Bas Voltage.
  → Current during fault.

- Three phase fault information is useel to scleet and set phase relays. Fault studies are used for phaper chaice CB's.

- Drving fault, Loads current can be neglected because Voltage dip Very low so that current drawn by Loads can be neglected in comparison to fault currents.

- The magnitude of the fault current depends on the intimal impedance of the synchronous generator and the impedance of the intervening circuit.

- The purpose of fault studies generator behaviour can be divided in to three different period:

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① The subtransient period, lasting only for the first fewcycle.
② The trasient period, covering arelatively longer time.
③ Steady state period.

- Another important point: That the circuit breakers MVA capacity is based of three phase fault MVA CC/B munfactured in standared size, 250; 500; 750 MVA etc.

- For three phase fault calculation following assumptions are mode:
① The emf's of all generator are $1\angle 0$ p.u.
② Charging capacitances of the T.L are ignored.
③ Shunt elements in the transformer model are neglected.

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Example 8.1: *A synchronous generator and a synchronous motor each rated 20 MVA, 12.66 KV having 15% subtransient reactance are connected through transformers and a line as shown in Fig. 8.1. The transformers are rated 20 MVA, 12.66/66 KV and 66/12.66 KV with leakage reactance of 10% each. The line has a reactance of 8% on a base of 20 MVA, 66 KV. The motor is drawing 10 MW at 0.80 leading power factor and a terminal voltage 11 KV when a symmetrical three-phase fault occurs at the motor terminals. Determine the generator and motor currents. Also determine the fault current.*

Solution:

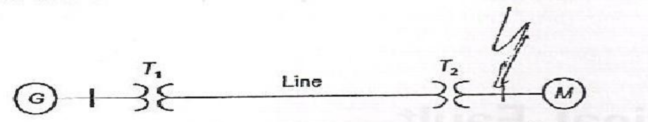

Fig. 8.1: Single line diagram.

All reactances are given on a base of 20 MVA and appropriate voltages.

Prefault voltage $$V_0 = \frac{11}{12.66}\angle 0^\circ = 0.8688\angle 0^\circ \text{ pu.}$$

MW

$$\text{Load} = 10\text{ MW, 0.80 power factor (leading)} = \frac{10}{20} = 0.50\text{ pu.}$$

Prefault current $$I_0 = \frac{0.50}{0.8688 \times 0.80}\angle 36.87^\circ$$

$$\therefore \quad I_0 = 0.7194\angle 36.87^\circ\text{pu}$$

Prefault equivalent circuit is shown in Fig. 8.2

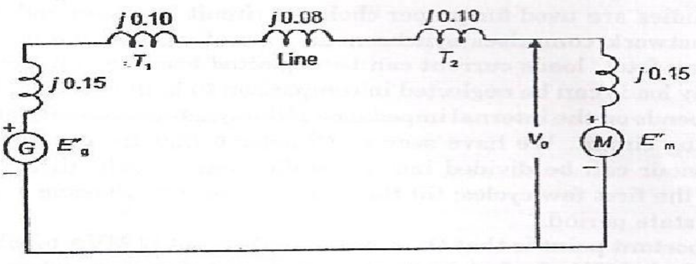

Fig. 8.2: Prefault equivalent circuit of Example 8.1.

Equivalent circuit during fault is shown in Fig. 8.3.

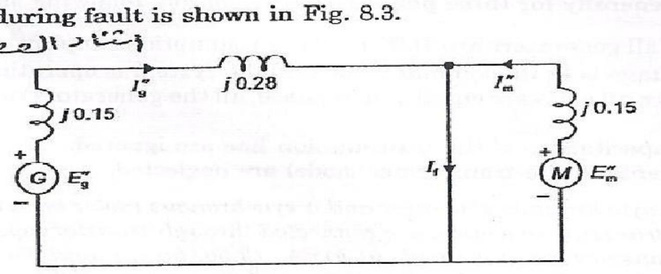

Fig. 8.3: Equivalent circuit during fault.

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From Fig. 8.2, voltage behind subtransient reactance (generator)

$$E_g'' = V_0 + j\,(0.15 + 0.10 + 0.08 + 0.10) \times I_0$$

$$E_g'' = 0.8688 \angle 0^\circ + j0.43 \times 0.7194 \angle 36.87^\circ$$

$$\therefore \quad E_g'' = 0.7266 \angle 19.9^\circ \text{ pu}$$

Similarly,

$$E_m'' = 0.8688 \angle 0^\circ - j\,0.15 \times 0.7194 \angle 36.87^\circ$$

$$\therefore \quad E_m'' = 0.9374 \angle -5.28^\circ \text{ pu}$$

From Fig. 8.3,

$$I_g'' = \frac{E_g''}{j(0.15 + 0.28)} = \frac{0.7266 \angle 19.9^\circ}{0.43 \angle 90^\circ}$$

$$\therefore I_g'' = 1.689 \angle -70.1^\circ \text{ pu}$$

$$\therefore I_g'' = (0.575 - j\,1.588) \text{ pu}$$

$$I_m'' = \frac{E_m''}{j0.15} = \frac{0.9374 \angle -5.28^\circ}{0.15 \angle 90^\circ}$$

$$\therefore I_m'' = 6.25 \angle -95.28^\circ \text{pu}$$

$$\therefore I_m'' = (-0.575 - j6.223) \text{ pu.}$$

Fault current

$$I_f = I_g'' + I_m'' = 0.575 - j1.588 - 0.575 - j\,6.223$$

$$\therefore \quad I_f = -j7.811 \text{ pu}$$

Base current (generator and motor)

$$I_B = \frac{20 \times 1000}{\sqrt{3} \times 12.66} = 912.085 \text{ Amp.}$$

$$\therefore \quad I_g'' = 912.085 \times 1.689 \angle -70.1^\circ = 1540.5 \angle -70.1^\circ \text{ Amp.}$$

$$\therefore \quad I_m'' = 912.085 \times 6.25 \angle -95.28^\circ = 5700.5 \angle -95.28^\circ \text{ Amp.}$$

$$\therefore \quad I_f = 912.085 \times (-j7{\cdot}811) = 7124.3 \angle -90^\circ \text{ Amp.}$$

حل نفس السؤال على نظرية

Thevenin's Therorem

Example 8.2: *Solve Ex-8.1 using Thevenin's Theorem.*

Solution: The detailed derivation for this is given in Chapter-4, Section-4.8.2.

Figure 8.4 shows the Thevenin's equivalent of the system feeding the fault impedance.

$$X'' = j\,(0.1 + 0.08 + 0.01) = j0.28$$

$$X_{dg}'' = j0.15,\; X_{dm}'' = j0.15$$

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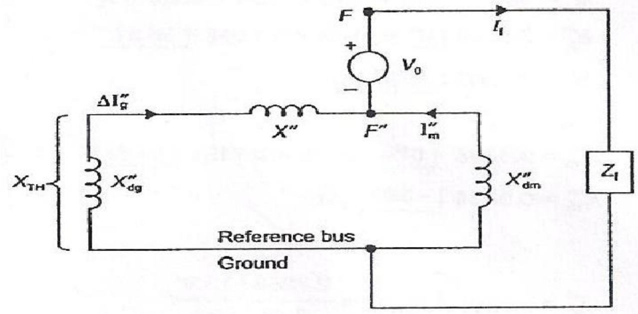

Fig. 8.4: Thevenin equivalent circuit of Example–8.1.

$$X''_{dg} + X'' = j\,(0.15 + 0.28) = j0.43$$

$$\therefore \quad X_{TH} = \frac{\left(X''_{dg} + X''\right)\left(X''_{dg}\right)}{\left(X''_{dg} + X'' + X''_{dm}\right)} = \frac{j0.43 \times j0.15}{j\left(0.43 + 0.15\right)}$$

$$X_{TH} = j0.1112 \ \text{ pu}$$

$$\therefore \quad I_f = \frac{V_0}{(Z_f + X_{TH})} = \frac{0.8688\lfloor 0^\circ}{j0.1112} \ \text{[since } z_j \ z_0]$$

$$\therefore \quad I_j = -j7.811 \text{ pu.}$$

Change in generator current

$$\Delta I''_g = I_f \times \frac{X''_{dm}}{(X''_{dg} + X'' + X''_{dm})}$$

$$\therefore \quad \Delta I''_g = -j7.811 \times \frac{j0.15}{j(0.15+0.28+0.15)}$$

$$\Delta I''_g = -j2.02 \text{ pu}$$

Similarly,

$$\Delta I''_m = -j7.811 \times \frac{j(0.15+0.28)}{j0.58}$$

$$\therefore \quad \Delta I''_m = -j5.79 \text{ pu}$$

Therefore,

$$I''_g = \Delta I''_g + I_0 = -j2.02 + 0.7194\,\lfloor 36.87^\circ$$

$$\therefore \quad I''_g = (0.575 - j1.589) \text{ pu}$$

$$I''_m = \Delta I_m - I_0 = -j5.79 - 0.7194\,\lfloor 36.87^\circ$$

$$\therefore \quad I''_m = (-0.575 - j6.221) \text{ pu.}$$

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8.2 RATED MVA INTERRUPTING CAPACITY OF A CIRCUIT BREAKER

The circuit breakers rating requires the computation of rated momentary current and rated symmetrical interrupting current computation of symmetrical short circuit current requires subtransient reactances for synchronous machines. RMS value of momentary current is then computed by multiplying the symmetrical momentary current by a factor of 1.60 to consider the presence of DC off-set current.

The interrupting current of a circuit breaker is inversely proportional to the operating voltage over a certain range, i.e., تيار الفصل تتناسب عكسيا مجال محدد

$$I_{ov} = I_r \times \frac{V_r}{V_{ov}} \qquad \text{...(8.1)}$$

Where

I_{ov} = current at operating voltage
I_r = current at rated voltage
V_r = rated voltage
V_{ov} = operating voltage

تتزيد او تتخطى — Note that operating voltage cannot exceed the maximum design value. Also rated interrupting current cannot exceed the rated maximum interrupting current.

Therefore, three phase rated interrupting MVA capacity of a circuit breaker is given as

$$(\text{MVA})_{\text{rated-}3\phi} = \sqrt{3}\,|V_{\text{line}}|_r \times |I_{\text{line}}|_{ric} \qquad \text{...(8.2)}$$

where

$|V_{\text{line}}|_r$ = rated line voltage (kV)

$|I_{\text{line}}|_{ric}$ = rated interrupting current (KA)

Thus, three phase short circuit MVA to be interrupted, where

$$\text{SC MVA } (3\phi) = \sqrt{3}\,|E_o|\,|I_{sc}| \times (\text{MVA})_{\text{Base}} \qquad \text{...(8.3)}$$

where

$|E_o|$ = prefault voltage (kV)
$|I_{SC}|$ = short circuit current (KA)

Note that $\text{MVA}_{\text{rated-}3\phi}$ is to be more than or equal to the SC MVA (3ϕ) required to be interrupted. A three phase fault which is very rare gives the highest short circuit MVA and a circuit breaker must be capable of interrupting it. نادرا يستطيع

Example 8.3: *Three 11.2 KV generators are interconnected as shown in Fig. 8.5 by a tie-bar through current limiting reactors. A three phase feeder is supplied from the bus bar of generator A at a line voltage 11.2 KV. Impedance of the feeder is (0.12 + j0.24) ohm per phase. Compute the maximum MVA that can be fed into a symmetrical short circuit at the far end of the feeder.*

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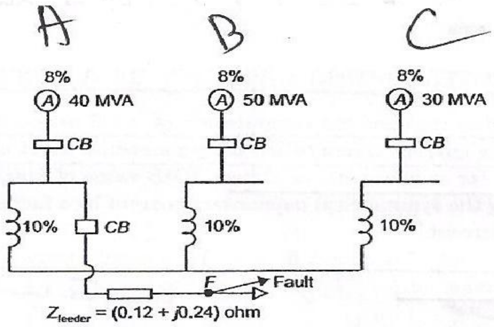

Fig. 8.5: Circuit diagram of Example 8.3.

Solution: Generator reactance

$$x_{Ag} = 8\% = 0.08 \text{ pu}, x_{Bg} = x_{Cg} = 0.08 \text{ pu}$$

Reactor reactance

$$x_A = x_B = x_C = 10\% = 0.10 \text{ pu}$$

Feeder impedance

$$Z_{feeder} = (0.12 + j0.24) \text{ ohm}.$$

choose a base 50 MVA, 11.2 KV

Base impedance $\quad Z_B = \dfrac{(11.2)^2}{50} \text{ ohm} = 2.5088 \text{ ohm}$

$$\therefore \quad Z_{feeder}\text{ (pu)} = \frac{Z_{feeder}\text{(ohm)}}{Z_B} = \frac{(0.12 + j0.24)}{2.5088}$$

$$\therefore \quad Z_{feeder}\text{ (pu)} = (0.0478 + j0.0956) \text{ pu}.$$

$$x_{Ag} = j0.08 \times \frac{50}{40} = j0.10 \text{ pu}$$

$$x_{Bg} = j0.08 \text{ pu}$$

$$x_{Cg} = j0.08 \times \frac{50}{30} = j0.133 \text{ pu}$$

$$x_A = j0.10 \times \frac{50}{40} = j0.125 \text{ pu}$$

$$x_B = j0.10 \text{ pu}$$

$$x_C = j0.10 \times \frac{50}{30} = j0.166 \text{ pu}$$

Assume a zero prefault current (i.e., no load prefault condition). Circuit model for the fault calculation is given in Fig. 8.5(*a*).

$$Z = 0.0478 + j0.0956 + j\frac{0.10 \times 0.2375}{0.3375}$$

$$\therefore \quad Z = 0.1727 \angle 73.94° \text{ pu}.$$

Short circuit $\quad \text{MVA} = |V_0|\ |I_f| \times (\text{MVA})_{\text{Base}}$

$$= |V_0| \frac{|V_0|}{Z} * (MVA)_{base}$$

$$= \frac{(1)^2}{0.1727} * 50 = 289.5 \text{ MVA}$$

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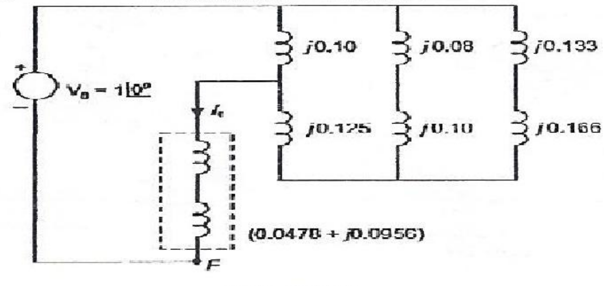


Fig. 8.5(*a*)

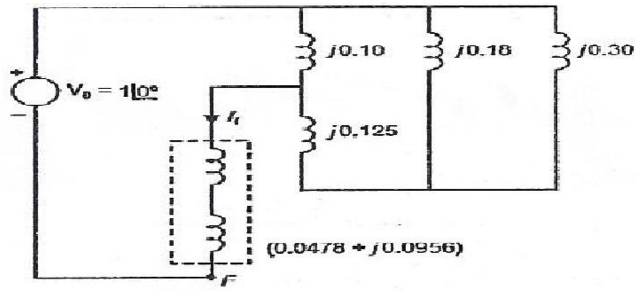


Fig. 8.5(*b*)

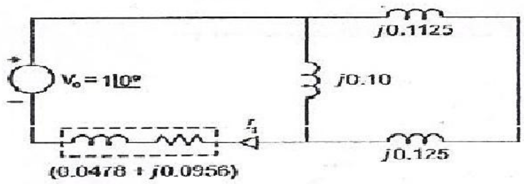


Fig. 8.5(*c*)

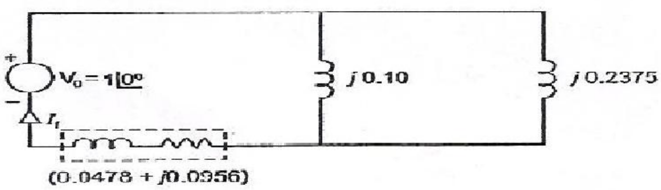
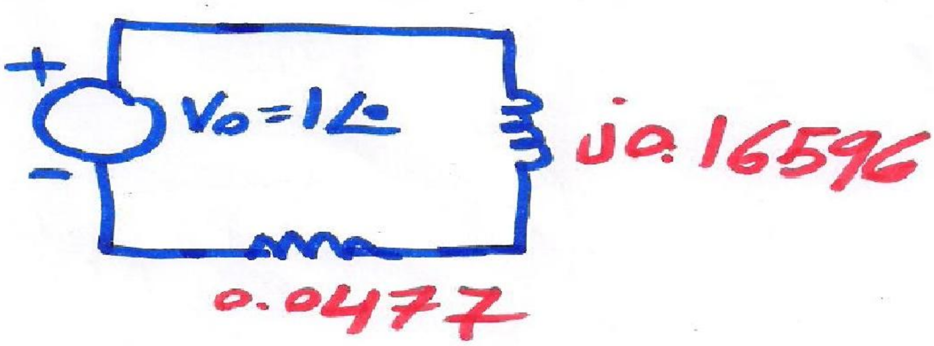


Fig. 8.5(*d*)



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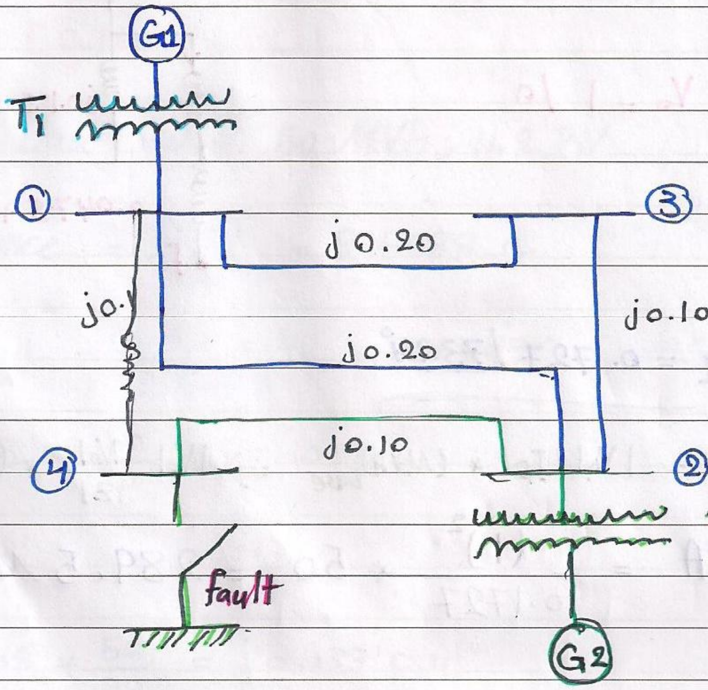
Example: A 4 bus sample power system. Perform the short circuit analysis for a three phase solid fault on bus 4.
Data are given below:

$G1$: 11.2 KV ; 100 MVA ; $X'_{g_1} = 0.08$ P.u
$G2$: 11.2 KV ; 100 MVA ; $X'_{g_2} = 0.08$ P.u
T_1 ; 11/110 kV ; 100 MVA ; $X'_{T_1} = 0.06$ P.u
T_2: 11/110 KV ; 100 MVA ; $X'_{T_2} = 0.06$ P.u

Assume perfault Voltage 1.0 P.u and prefault current to be zero.



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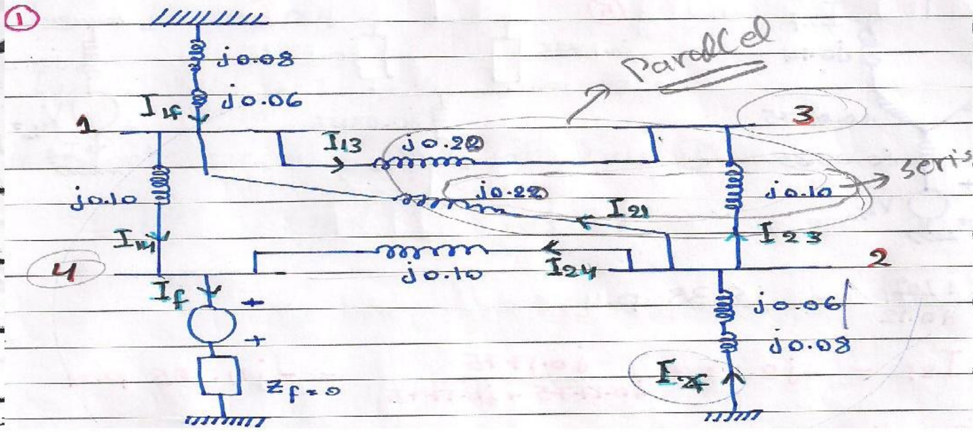

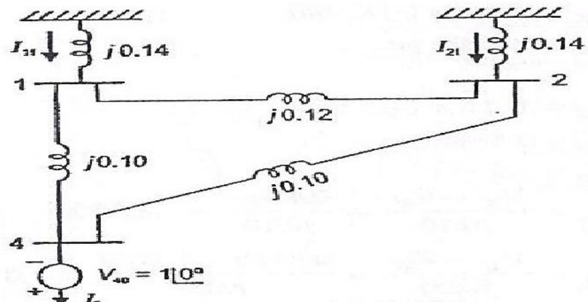

Fig. 8.6(b)

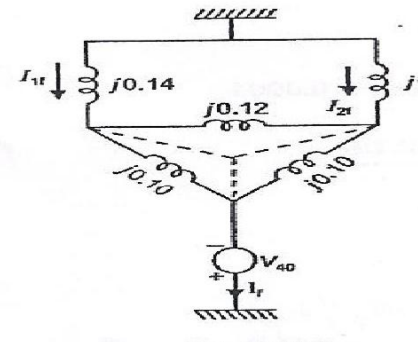

Fig. 8.6(c)

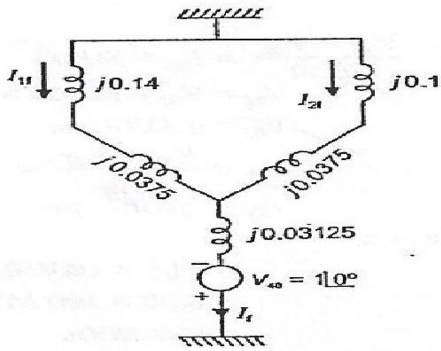

Fig. 8.6(d)

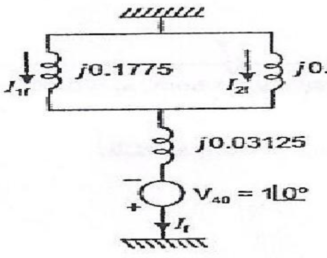

Fig. 8.6(e)

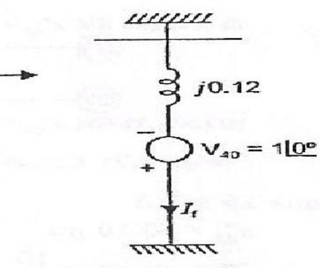

Fig. 8.6(f)

$$\therefore \quad 1 - V_{1f} = j0.14 \times (-j4.165)$$

$$\therefore \quad V_{1f} = 0.4169 \text{ pu.}$$

Similarly

$$1 - V_{2f} = j0.14 \times (-j4.165)$$

$$\therefore \quad V_{2f} = 0.4169 \text{ pu.}$$

$$V_{4f} = 0.0$$

$$I_{24} = \frac{V_{2f} - V_{4f}}{j0.10} = \frac{0.4169}{j0.10} = -j4.169$$

$$I_{21} = \frac{V_{2f} - V_{1f}}{j0.20} = \frac{0.4169 - 0.4169}{j0.20} = 0.0$$

$$I_{2f} = I_{24} + I_{21} + I_{23} = -j4.169 + 0.0 + I_{23}$$

$$\therefore \quad -j4.165 = -j4.169 + I_{23}$$

$$\therefore \quad I_{23} = j0.004 \text{ pu.}$$

Now

$$\frac{V_{2f} - V_{3f}}{j0.10} = I_{23} = j0.004$$

$$\therefore \quad V_{3f} = V_{2f} - j0.004 \times j0.10 = 0.4169 + 0.0004$$

$$\therefore \quad V_{3f} = 0.4173 \text{ pu.}$$

$$I_{13} = \frac{V_{1f} - V_{3f}}{Z_{12}} = \frac{(0.4169 - 0.4173)}{j0.20}$$

$$\therefore \quad I_{13} = -j0.002 \text{ pu}$$

SC MVA at bus 4

$$= |I_f| \times (\text{MVA})_{\text{Base}}$$
$$= 8.33 \times 100 \text{ MVA}$$
$$= 833 \text{ MVA}$$

Example 8.5: *Two generators G1 and G2 are rated 15 MVA, 11 KV and 10 MVA, 11 KV respectively. The generators are connected to a transformer as shown in Fig. 8.7. Calculate the subtransient current in each generator when a three phase fault occurs on the high voltage side of the transformer.*

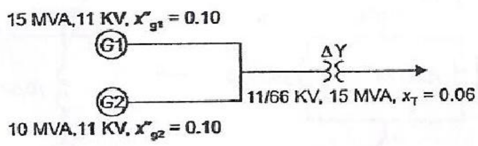

Fig. 8.7: Circuit diagram of Example 8.5.

Solution: Choose a base 15 MVA

$$x''_{g1} = j0.10 \text{ pu}$$

$$x''_{g2} = j0.10 \times \frac{15}{10} = j0.15 \text{ pu}$$

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$$x_T = j0.06 \text{ pu}$$

$$I_f = \frac{V_o}{j0.12} = \frac{1}{j0.12} = -j8.33 \text{ pu}$$

$$I''_{g1} = \frac{j0.15}{j(0.1+0.15)} \times (-j8.33)$$

$$= -j5.0 \text{ pu}$$

$$I''_{g2} = \frac{j0.10}{j(0.1+0.15)} \times (-j8.33) = -j3.33 \text{ pu}$$

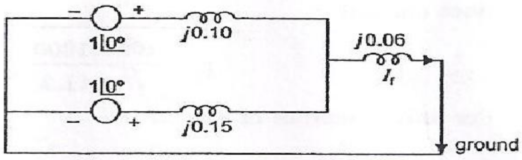

Fig. 8.7(*a*)

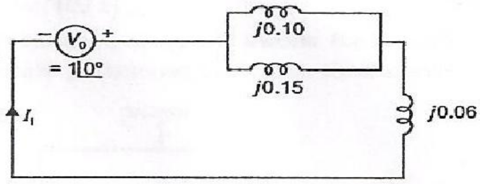

Fig. 8.7(*b*)

Base current

$$I_B = \frac{15 \times 1000}{\sqrt{3} \times 11} = 787.3 \text{ Amp.}$$

$$\therefore \quad I''_{g1} = -j5 \times 787.3 = -j3.936 \text{ KA.}$$

$$I''_{g2} = -j3.33 \times 787.3 = -j2.621 \text{ KA.}$$

$$I_f = -j8.33 \times 787.3 = -j6.557 \text{ KA.}$$

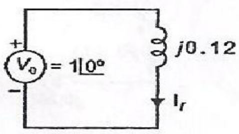

Fig. 8.7(*c*)

8.3 CURRENT LIMITING REACTORS

The short circuit current is large enough to do considerable damage mechanically and thermally. The interrupting capacities of circuit breakers to handle such current would be very large. To reduce this high fault current, artificial reactances are sometimes connected between bus sections. These current limiting reactors are usually consist of insulated copper strip embeded in concrete formers. This is necessary to withstand the high mechanical forces produced by the current in the neighbouring conductors.

Example 8.6: *The estimated short circuit MVA at the bus bars of a generating station-1 is 900 MVA and at another generating station-2 of 600 MVA. Generator voltage at each station is 11.2 KV. The two stations are interconnected by a reactor of reactance 1 ohm per phase. Compute the fault MVA at each station.*

Solution:

SC MVA of generating station-1 = 900 MVA
SC MVA of generating station-2 = 600 MVA
Assume base MVA = 100

$$\therefore \quad x_1 = \frac{\text{Base MVA}}{\text{SC MVA}} = \frac{100}{900} = 0.111 \text{ pu}$$

$$\therefore \quad x_2 = \frac{100}{600} = 0.166 \text{ pu}$$

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Base current

$$I_B = \frac{100 \times 1000}{\sqrt{3} \times 11.2} = 5154.9 \text{ Amp.}$$

Per unit reactance of reactor

$$x_R = \frac{1 \times 100}{(11.2)^2} = 0.797 \text{ pu}$$

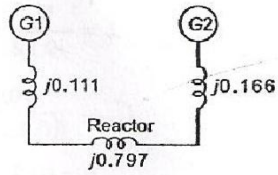

Fig. 8.8: circuit diagram.

Figure 8.8 shows the pu impedance diagram.

When fault occurs at generating station-1, pu impedance diagram is shown in Fig. 8.8(a)

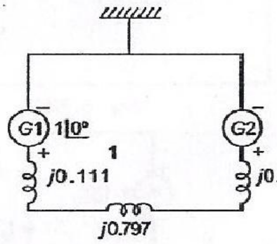

Fig. 8.8(a)

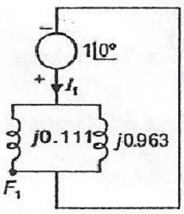

Fig. 8.8(b)

$$x_{eq1} = j\frac{0.111 \times 0.963}{1.074} = j0.0995 \text{ pu}$$

$$I_{f1} = \frac{1}{j0.0995} = -j10.047 \text{ pu}$$

SC MVA = 10.047 × 100 = 1004.7 MVA

When fault occurs at generating station-2

$$x_{eq2} = j\frac{0.166 \times 0.908}{1.074} = j0.1403 \text{ pu}$$

$$I_{f2} = \frac{1}{j0.1403} = -j7.125 \text{ pu}$$

SC MVA = 7.125 × 100 = 712.5 MVA.

2 **Example 8.7:** *A 50 MVA generator with a reactance of 0.10 pu is connected to a bus-bar. A 25 MVA transformer with a reactance of 0.05 pu is also connected through a bus-bar reactor of 0.10 pu to the same bus-bar. Both these reactances are based on 25 MVA rating. If a feeder taken out from the bus-bar through a circuit breaker develops a line to ground fault, what should be the rating of circuit breaker?*

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Solution: Circuit connection is shown in Fig. 8.9.

Set base MVA = 50

$$x_g = j0.10 \text{ pu}$$

$$x_R = j0.10 \times \frac{50}{25} = j0.20 \text{ pu}$$

$$x_T = j0.05 \times \frac{50}{25} = j0.10 \text{ pu}$$

$$\therefore \quad x_{eq} = \frac{x_g(x_T + x_R)}{(x_g + x_T + x_R)} = j\frac{0.10 \times (0.10 + 0.20)}{(0.10 + 0.20 + 0.10)}$$

$$\therefore \quad x_{eq} = j0.075 \text{ pu}$$

Therefore $\quad \text{SC MVA} = \dfrac{\text{Base MVA}}{x_{eq}} = \dfrac{50}{0.075}$

$$= 667 \text{ MVA. Ans.}$$

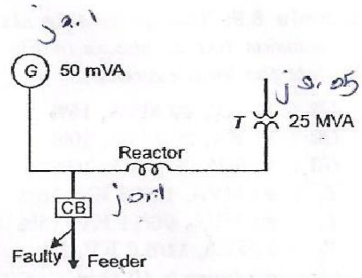

Fig. 8.9: Circuit diagram of Example–8.7.

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Example 8.8: *Determine the ohmic value of the current limiting reactor per phase external to a 30 MVA, 11 KV, 50 Hz, three phase synchronous generator which can limit the current on short circuit to 6 times the full load current. The reactance of the synchronous generator is 0.06 pu.*

Solution: Given that

$$\frac{\text{Full load current}}{\text{Short circuit current}} = \frac{1}{6}$$

$$x_g = j0.06 \text{ pu}$$

External reactance required per phase

$$= j\left(\frac{1}{6} - 0.06\right) = j0.1066 \text{ pu.}$$

Full load current,

$$I_{fl} = \frac{30 \times 1000}{\sqrt{3} \times 11} = 1574.6 \text{ Amp.}$$

$$\text{Per unit reactance} = \frac{Ix_R}{V}$$

$$\therefore \quad 0.1066 = \frac{I_{fl} \times X_R}{\frac{11 \times 1000}{\sqrt{3}}}$$

$$\therefore \quad x_R = 0.43 \text{ ohm. Ans.}$$

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Example 8.9: *Two generating stations are connected together through transformers and a transmission line as shown in Fig. 8.10. If a three phase fault occurs as shown in Fig. 8.10, calculate the fault current.*

$G1$: 11 KV, 40 MVA, 15%
$G2$: 11 KV, 20 MVA, 10%
$G3$: 11 KV, 20 MVA, 10%
T_1 : 40 MVA, 11/66 KV, 15%
T_2 : 40 MVA, 66/11 KV, 15%
T_3 : 5 MVA, 11/6.6 KV, 8%
Line reactance = 40 ohm.

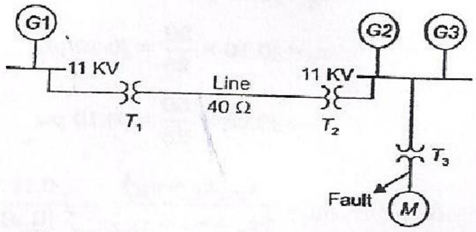

Fig. 8.10: Circuit diagram of Example 8.9.

Solution:

Set Base MVA = 40, Base Voltage = 11 KV

$\therefore$

$$x_{g1} = j0.15 \text{ pu},$$

$$x_{g2} = j\frac{40}{20} \times 0.10 = j0.20 \text{ pu}$$

$$x_{g3} = j0.10 \times \frac{40}{20} = j0.20 \text{ pu}$$

$$x_{T1} = j0.15 \text{ pu}$$

$$x_{T2} = j0.15 \text{ pu}$$

$$x_{T3} = j0.08 \times \frac{40}{5} = j0.64 \text{ pu}$$

$$x_{\text{line}} = j40 \times \frac{40}{(66)^2} = j0.367 \text{ pu.}$$

Circuit model for fault calculation is shown in Fig. 8.10 (*a*).

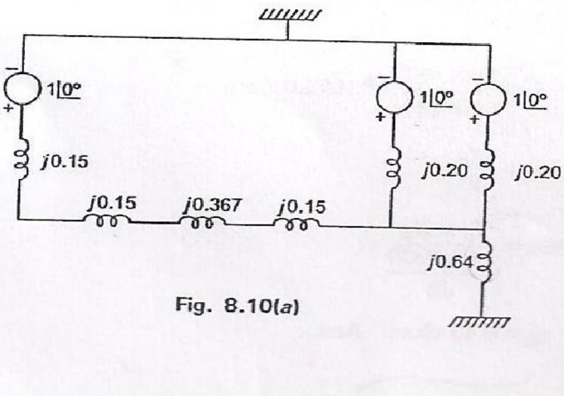

Fig. 8.10(*a*)

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$$\therefore \qquad I_f = \frac{1\angle 0^\circ}{j0.729} = -j1.37 \text{ pu}$$

$$\text{Base current } I_B = \frac{40 \times 1000}{\sqrt{3} \times 11}$$

$$= 2099.45 \text{ Amp}$$

$$\therefore \qquad |I_f| = 1.37 \times 2099.45$$

$$= 2.876 \text{ KA. Ans.}$$

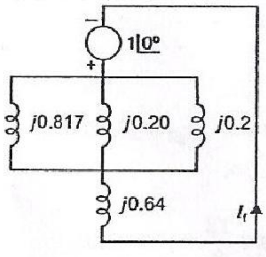

Fig. 8.10(b)

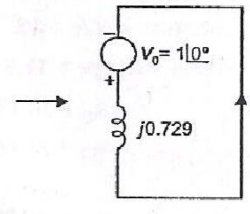

Fig. 8.10(c)

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Example 8.10: *A generating station consists of two 100 MVA generators with 6% reactance each and one 150 MVA generator with 8% reactance as shown in Fig. 8.11. These generators are connected to a common bus bar from which loads are taken through a number of 50 MVA, step up transformers each having 5% reactance. Compute the rating of circuit breaker on (i) low voltage side and (ii) on high voltage side.*

Solution:

Set base power = 150 MVA.

$$x_{g1} = x_{g2} = j0.06 \times \frac{150}{100} = j0.09 \text{ pu}$$

$$x_{g3} = j0.08 \text{ pu}, \; x_T = j0.05 \times \frac{150}{100} = j0.15 \text{ pu.}$$

(*i*) If the fault occurs on low voltage side current will be restricted by the reactance of three generators in parallel.

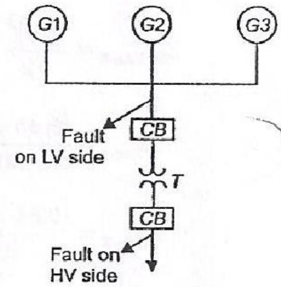

Fig. 8.11: Circuit diagram of Example 8.10.

$$\therefore \qquad \frac{1}{x_{eq}} = \frac{1}{j0.09} + \frac{1}{j0.09} + \frac{1}{j0.08}$$

$$\therefore \qquad x_{eq} = j0.0288 \text{ pu.}$$

$$\text{SC MVA on low voltage side} = \frac{150}{0.0288} = 5208 \text{ MVA.}$$

(*ii*) On the high voltage side,

$$x_{eq} = j(0.0288 + 0.15) = j0.1788 \text{ pu}$$

$$\text{SC MVA} = \frac{150}{0.1788} = 840 \text{ MVA.}$$

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Example 8.11: *A radial power system network is shown in Fig. 8.12, a three phase balanced fault occurs at F. Determine the fault current and the line voltage at 11.8 KV bus under fault condition.*

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Solution:

Let Base MVA = 12

Base Voltage = 11.8 KV.

$$x_{g1} = j0.12 \text{ pu}, \quad x_{g2} = j0.15 \text{ pu}$$

$$x_{T1} = j0.12 \text{ pu},$$

$$x_{T2} = j0.08 \times \frac{12}{3} = j0.32 \text{ pu}$$

Base voltage for line-1 is 33 KV.

Base voltage for line-2 is 6.6 KV.

$$Z_{B,\text{ line-1}} = \frac{(33)^2}{12} = 90.75 \text{ ohm.}$$

$$Z_{B,\text{ line-2}} = \frac{(6.6)^2}{12} = 3.63 \text{ ohm.}$$

$$\therefore \quad Z_{\text{line-1}} = \frac{(9.45 + j12.6)}{90.75} = (0.104 + j0.139) \text{ pu}$$

$$Z_{\text{line-2}} = \frac{(0.54 + j0.40)}{3.63} = (0.148 + j0.11) \text{ pu}$$

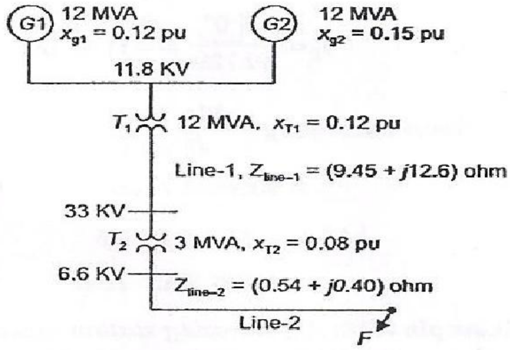

Fig. 8.12: Radial power system network.

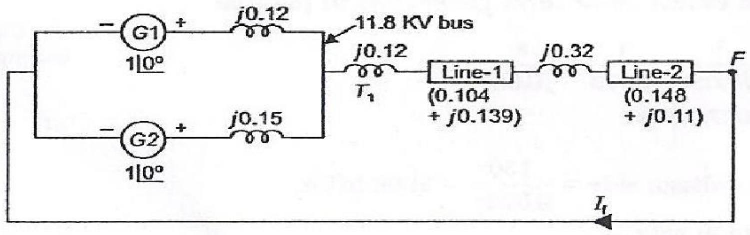

Fig. 8.12(*a*)

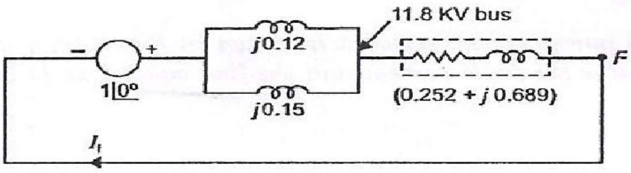

Fig. 8.12(*b*)

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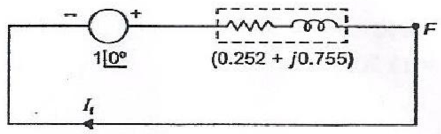

Fig. 8.12(c)

Base current $$I_B = \frac{12 \times 1000}{\sqrt{3} \times 6.6} = 1049.7 \text{ Amp.}$$

Now $$I_f = \frac{1\angle 0°}{(0.252 + j0.755)} = 1.256\angle -71.5° \text{ pu}$$

$\therefore$ $$I_f = 1.256\angle -71.5° \times 1049.7$$

$\therefore$ $$I_f = 1318.4\angle -71.5° \text{ Amp.}$$

Total impedance between F and 11.8 KV bus

$$= (0.252 + j0.689) \text{ pu}$$

Voltage at 11.8 KV bus

$$= 1.256\angle -71.5° \times (0.252 + j0.689)$$

$$= 0.921\angle -1.6° \text{ pu}$$

$$= 0.921\angle -1.6° \times 11.8 \text{ KV}$$

$$= 10.86\angle -1.6° \text{ KV.} \quad \text{Ans.}$$

Example 8.12: *A 100 MVA, 11 KV generator with $x''_g = 0.20$pu is connected through a transformer, and line to a bus bar that supplies three identical motor as shown in Fig. 8.13 and each motor has $x''_m = 0.20$ pu and $x'_m = 0.25$ pu on a base of 20 MVA, 33 KV. The bus voltage at the motors is 33 KV when a three phase balanced fault occurs at the point F. Calculate*

(a) Subtransient current in the fault.
(b) Subtransient current in the circuit breaker B.
(c) Momentary current in the circuit breaker B.
(d) The current to be interrupted by circuit breaker B in (i) 2 cycles (ii) 3 cycles (iii) 5 cycles (iv) 8 cycles

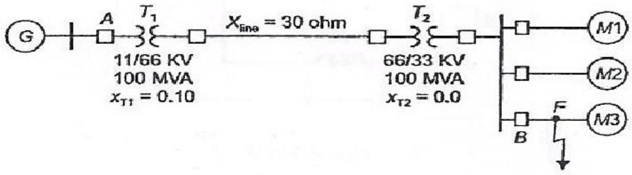

Fig. 8.13: Circuit diagram of Example 8.12.

Solution:

Let Base MVA = 100

Base Voltage = 11 KV.

$x''_g = j0.20$ pu.

$$x''_m = x''_{m1} = x''_{m2} = x''_{m3} = j0.2 \times \frac{100}{20} = j1.0 \text{ pu.}$$

$$x'_m = x'_{m1} = x'_{m2} = x'_{m3} = j0.25 \times \frac{100}{20} = j1.25 \text{ pu.}$$

$x_{T1} = x_{T2} = j0.10$ pu

$$x_{line} = 30 \times \frac{100}{(66)^2} = j0.688 \text{ pu.}$$

(*a*) The circuit model of the system for fault calculation is given in Fig. 8.13(*a*).

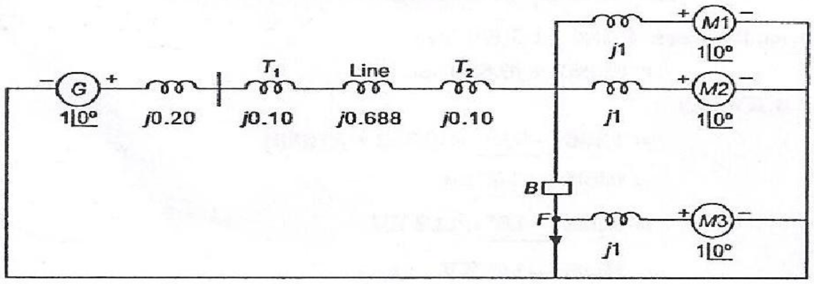

Fig. 8.13(*a*)

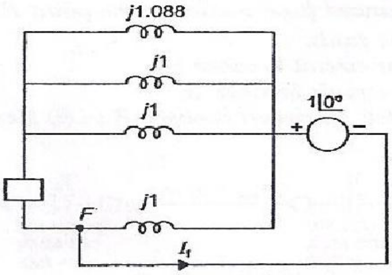

Fig. 8.13(*b*)

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$$\therefore \quad x_{eq} = \frac{j}{3.919} = j0.255$$

$$\therefore \quad I_f = \frac{1\angle 0^\circ}{j0.255} = -j3.919 \text{ pu.}$$

Base current for 33 KV circuit

$$I_B = \frac{100 \times 1000}{\sqrt{3} \times 33} = 1.75 \text{ KA.}$$

$$\therefore \quad |I_f| = 3.919 \times 1.75 = 6.85 \text{ KA.}$$

(*b*) Current through circuit breaker B is,

$$I_{fB} = \frac{2}{j1} + \frac{1}{j1.088} = -j2.919 \text{ pu}$$

$$\therefore \quad |I_{fB}| = 2.919 \times 1.75 = 5.108 \text{ KA.}$$

(*c*) Momentary current can be calculated by multiplying the symmetrical momentary current by a factor of 1.6 to account for the presence of DC off-set current.

$\therefore$ Momentary current through breaker B

$$= 1.6 \times 5.108 \text{ KA} = 8.17 \text{ KA.}$$

(*d*) For computing the current to be interrupted by the breaker, motor $x''_m \left(x''_m = j1.0\right)$ is now replaced by $x'_m \left(x'_m = j1.25 \text{ pu}\right)$. The equivalent circuit is shown in Fig. 8.13(c).

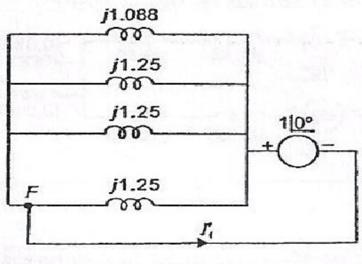

Fig. 8.13(*c*)

$$x_{eq} = j0.3012$$

Current to be interrupted by the breaker

$$I'_f = \frac{1}{j0.3012} = -j3.32 \text{ pu}$$

Allowance is made for the DC off-set value by multiplying with a factor of (*i*) 1.4 for 2 cycles (*ii*) 1.2 for 3 cycles (*iii*) 1.1 for 5 cycles (iv) 1.0 for 8 cycles.

Therefore, current to be interrupted as:

(*i*) $1.4 \times 3.32 \times 1.75 = 8.134$ KA

(*ii*) $1.2 \times 3.32 \times 1.75 = 6.972$ KA

(*iii*) $1.1 \times 3.32 \times 1.75 = 6.391$ KA

(*iv*) $1.0 \times 3.32 \times 1.75 = 5.81$ KA.

Example 8.13: *Fig. 8.14 shows a generating station feeding a 220 KV system. Determine the total fault current, fault level and fault current supplied by each generator for a three phase fault at the receiving end of the line.*

$G1$: 11 KV, 100 MVA, $x'_{g1} = j0.15$

$G2$: 11 KV, 75 MVA, $x'_{g2} = j0.125$

$T1$: 100 MVA, $x_{T1} = j0.10$, 11/220 KV

$T2$: 75 MVA, $x_{T2} = j0.08$, 11/220 KV

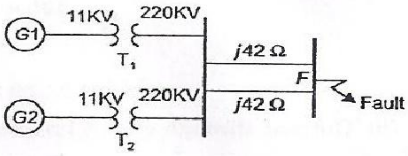

Fig. 8.14: Sample network of Example 8.13.

Solution:

Let base MVA = 100, Base voltage = 11 KV.

$$x'_{g1} = j0.15, \quad x_{T1} = j0.10$$

$$x'_{g2} = j0.125 \times \frac{100}{75} = j0.166$$

$$x_{T2} = j0.08 \times \frac{100}{75} = j0.106$$

Per unit reactance of each line

$$= j42 \times \frac{100}{(220)^2} = j0.0867 \text{ pu.}$$

Single line reactance diagram is shown in Fig. 8.14(*a*)

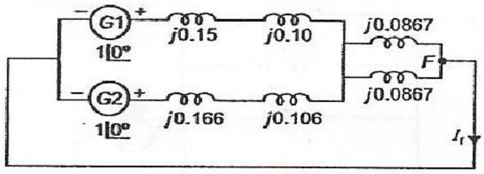

Fig. 8.14(*a*)

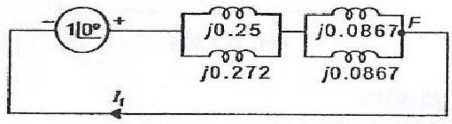

Fig. 8.14(*b*)

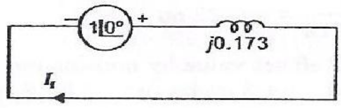

Fig. 8.14(*c*)

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$\therefore \quad I_f = \dfrac{1}{j0.173} = -j5.78$ pu

Base current for 220 KV side

$$I_B = \frac{100 \times 1000}{\sqrt{3} \times 220} = 262.43 \text{ Amp.}$$

$\therefore \quad |I_f| = 5.78 \times 262.43 = 1.516$ KA.

Fault level = 5.78 pu = 5.78 × 100 = 578 MVA.

Base current on 11 KV side

$$= I_B \times \left(\frac{220}{11}\right) = 262.43 \times \left(\frac{220}{11}\right)$$

$$= 5248.6 \text{ Amp.}$$

Fault current supplied by the two generators

$$= 5248.6 \times (-j5.78) = 30.34\angle -90^\circ \text{ KA}$$

$\therefore \quad I_{fg1} = \dfrac{0.272}{0.522} \times 30.34\angle -90^\circ$ KA

$\therefore \quad I_{fg1} = 15.8\angle -90^\circ$ KA

$$I_{fg2} = \frac{0.25}{0.522} \times 30.34\angle -90^\circ \text{ KA}$$

$\therefore \quad I_{fg2} = 14.53\angle -90^\circ$ KA

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Example 8.14: *Fig. 8.15 shows a system having four synchronous generators each rated 11.2 KV, 60 MVA and each having a subtransient reactance of 16%. Find (a) fault level for a fault on one of the feeders (near the bus with x = 0). (b) the reactance of the current limiting reactor x_R to limit the fault level to 860 MVA for a fault on one of the feeders near the bus.*

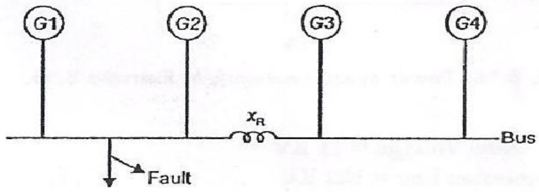

Fig. 8.15: Sample power system of Example 8.14.

Solution:

Set Base MVA = 60, Base voltage = 11.2 KV.

$$x''_{g1} = x''_{g2} = x''_{g3} = x''_{g4} = 16\% = 0.16 \text{ pu}$$

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Circuit model under fault condition is shown in Fig. 8.15(a)

$$x_{eq} = j\frac{0.16}{4} = j0.04$$

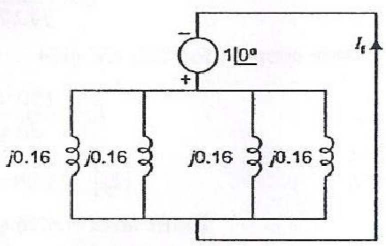

Fig. 8.15(a)

(a) fault level$= \frac{1}{0.04} = 25.0$ pu $= 25 \times 60$ MVA

$= 1500$ MVA. Ans.

(b) The generators $G1$ and $G2$ will supply $\frac{1}{2} \times 1500 =$ 750 MVA, directly to the fault. Therefore, the fault MVA from $G3$ and $G4$ must be limited to $(860 - 750) = 110$ MVA. The reactance of $G3$ and $G4$ together is $\frac{0.16}{2} = 0.08$ pu.

Thus,

$$\frac{1}{x_R + 0.08} = \frac{110}{60}$$

$\therefore \qquad x_R = 0.465$ pu

$$\text{Base impedance} = \frac{(11.2)^2}{60} = 2.09 \text{ ohm}$$

$\therefore \qquad x_R = 0.465 \times 2.09 = 0.97$ ohm.

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Example 8.15: *Fig. 8.16 shows a power system network. Each of the alternators G1 and G2 is rated at 125 MVA, 11 KV and has a subtransient reactance of 0.21 pu. Each of the transformers is rated at 125 MVA, 11/132 KV and has a leakage reactance of 0.06 pu. Find (a) fault MVA and (b) fault current for a fault at bus 5.*

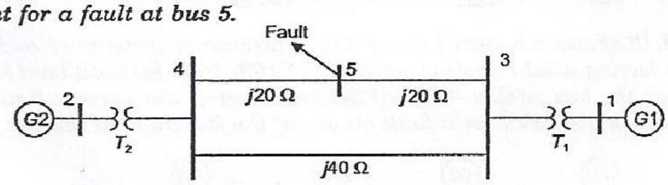

Fig. 8.16: Power system network of Example 8.15.

Solution:

Set Base MVA =125, Base Voltage = 11 KV

Base voltage for transmission line = 132 KV

Base impedance for the transmission line $= \frac{(132)^2}{125}$ ohm.

$= 139.392$ ohm.

$$\therefore \qquad x_{34} = j\frac{40}{139.392} = j0.286 \text{ pu},$$

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$$x_{45} = x_{35} = j0.143 \text{ pu.}$$

$$x''_{g1} = x''_{g2} = j0.21 \text{ pu.}, x_{T1} = x_{T2} = j0.06 \text{ pu.}$$

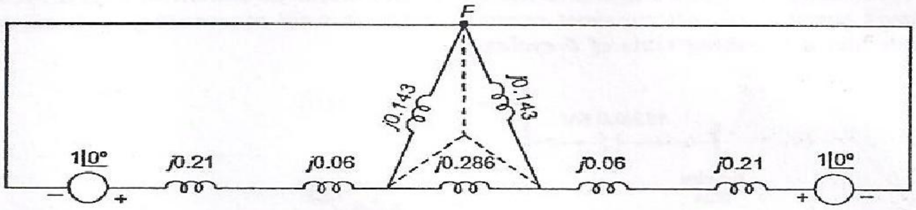

Fig. 8.16(*a*)

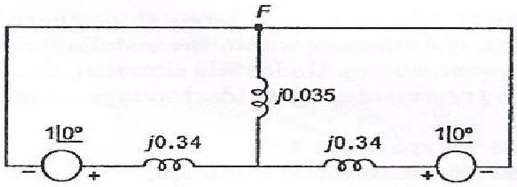

Fig.8.16(*b*)

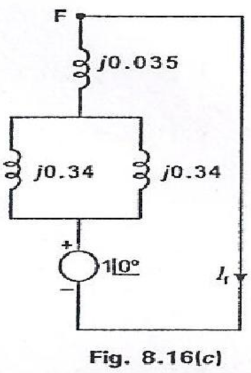

Fig. 8.16(*c*)

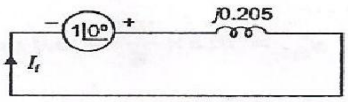

Fig. 8.16(*d*)

(*a*) $\text{Fault level} = \dfrac{1}{0.205} \times 125 = 610 \text{ MVA.}$ Ans.

(*b*) $I_f = \dfrac{1\lfloor 0^\circ}{j0.205} = \dfrac{-j}{0.205} \text{ pu.}$

$\therefore \quad I_f = \dfrac{-j}{0.205} \times \dfrac{125 \times 1000}{\sqrt{3} \times 132}$

$\therefore \quad I_f = -j2.66 \text{ KA.}$ Ans.

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Example 8.16: *A 12 MVA, 132/6.6 KV, transformer having a reactance of 0.15 pu is fed from an infinite bus. The transformer feeds two motor each 6 MVA, 6.6 KV. Each motors has a transient reactance of 0.14 pu and a subtransient reactance of 0.30 pu based on its own rating. A three phase balanced fault occurs at the terminals of one motor as shown in Fig. 8.17. Find (a) subtransient fault corrent (b) subtransient current in breaker (c) momentary current rating of breaker D which has a breaking time of 5 cycles.*

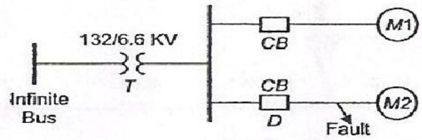


Fig. 8.17: Power system network of Example 8.16.

Solution: If the external power system is very large as compared to the system under consideration of any installation, disturbances within the installation do not affect the voltage and frequency of the external power system. Under this situation, the external power source is known as infinite bus and can be represented by an ideal voltage source, i.e., a constant voltage with zero impedance.

Let base MVA = 100, base voltage = 132 KV.

Therefore, on the motor bus bar, base voltae is 6.6 KV.

∴ Base current,

$$I_B = \frac{100 \times 1000}{\sqrt{3} \times 6.6} = 8747.7 \text{ Amp.}$$

$$x_T = j0.15 \times \frac{100}{12} = j1.25 \text{ pu.}$$

$$x''_{m1} = j0.3 \times \frac{100}{6} = j5.0 \text{ pu}$$

$$x''_{m2} = j5 \text{ pu}$$

$$x'_{m1} = j0.4 \times \frac{100}{6} = j6.67 \text{ pu}$$

$$x'_{m2} = j6.67 \text{ pu.}$$

(*a*) Circuit model under fault condition (Subtransient condition) is shown in Fig. 8.17(*a*).

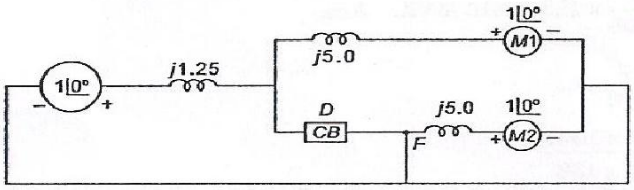


Fig. 8.17(*a*): Circuit model under subtransient condition.

Subtransient fault current,

$$I_f = \left(\frac{j\angle 0^\circ}{j0.833}\right) \times 8747.7$$

$$= 10.5\angle -90^\circ \text{ KA.}$$

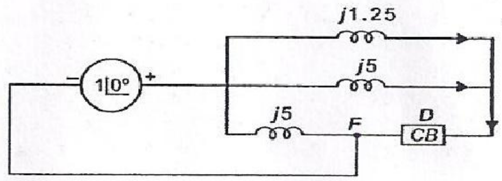


Fig. 8.17(*b*)

(*b*) Subtransient current through breaker *D* is the current from infinite bus and motor M_1.

Fault current from infinite bus

$$= \frac{1\angle 0^\circ}{j1.25} = -j0.8 \text{ pu}$$

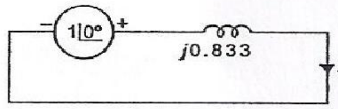


Fig. 8.17(*c*)

Fault current from motor M_1

$$= \frac{1\angle 0^\circ}{j5.0} = -j0.20 \text{ pu}$$

Fault current through circuit breaker *D*

$$= -j0.8 - j0.2 = -j1.0 \text{ pu}$$

$$= -j1.0 \times 8747.7 = 8.74\angle -90^\circ \text{ KA.}$$

(*c*) To find the momentary current through the breaker, it is necessary to calculate the dc-off set current. However, emperical method for momentary current = 1.6 times symmetrical fault current.

$\therefore$ momentary current $= 1.6 \times 10.5\angle -90^\circ$ KA.

$$= 16.8\angle -90^\circ \text{ KA. Amp.}$$

(*d*) Fig. 8.17(*d*) shows the circuit model under transient condition.

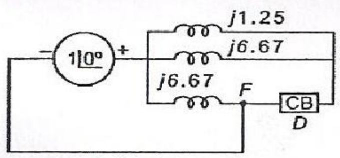


Fig. 8.17(*d*): Circuit model under transient condition.

Current interrupted by breaker *D*

$$= \frac{1}{j1.25} + \frac{1}{j6.67} = -j0.95 \text{ pu}$$

$$= -j0.95 \times 8747.7 = 8.31\angle -90^\circ \text{ KA.}$$

However, effect of dc off-set can be included by using a multiplying factor of 1.1. Therefore current to be interrupted by breaker

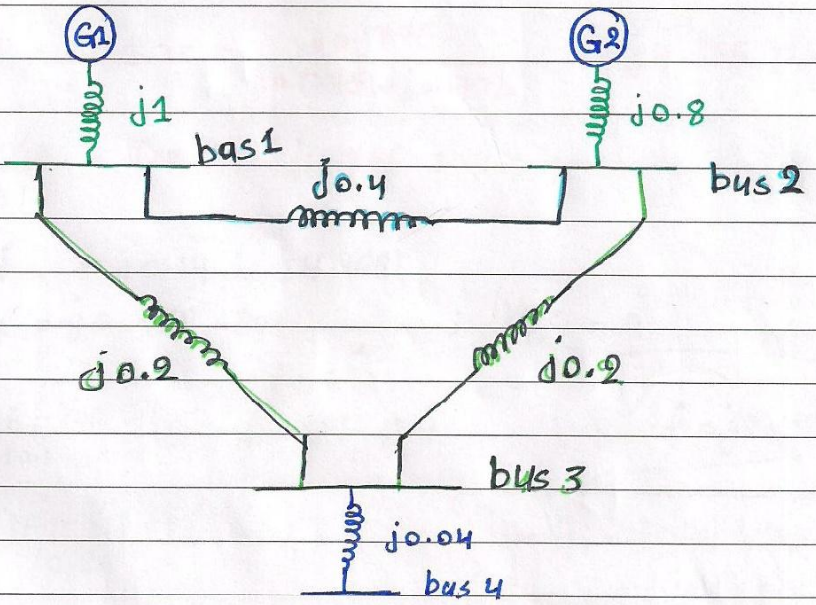
$$= 1.1 \times 8.31\angle -90^\circ = 9.14\angle -90^\circ \text{ KA.}$$

* Power Flow Analysis [P.F.L]:-

_ The power flow is the backbone of the power system operation, analysis and design, it n necessary for planning, operation, economic scheeduling and exchange power between utilities.

$$[I] = [y][V]$$

* bus Admittonce Matrix or y_{bus} :-



- Fonmulate the bus admittunce for the network shunt admittunce are ignored.

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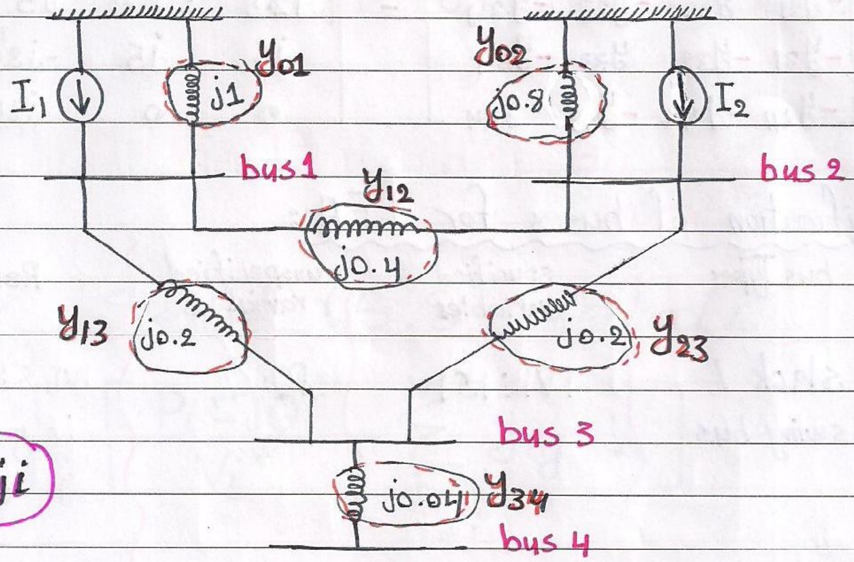
* تحويل مصدر الفولتية إلى مصدر تيار...



$$y_{ij} = y_{ji}$$

$$y_{11} = y_{01} + y_{12} + y_{13}$$

$$y_{22} = y_{02} + y_{21} + y_{23}$$

$$y_{33} = y_{31} + y_{32} + y_{34}$$

$$y_{44} = y_{43}$$

$$y_{01} = \frac{1}{j1} = -j1$$

$$y_{23} = y_{32} = \frac{1}{j0.2} = -j5$$

$$y_{02} = \frac{1}{j0.8} = -j1.25$$

$$y_{34} = y_{43} = \frac{1}{j0.04} = -j25$$

$$y_{12} = y_{21} = \frac{1}{j0.4} = -j2.5$$

$$y_{13} = y_{31} = \frac{1}{j0.2} = -j5$$

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$$Y_{bus} = \begin{bmatrix} y_{11} & -y_{12} & -y_{13} & -y_{14} \\ -y_{21} & y_{22} & -y_{23} & -y_{24} \\ -y_{31} & -y_{32} & y_{33} & -y_{34} \\ -y_{41} & -y_{42} & -y_{43} & y_{44} \end{bmatrix} = \begin{bmatrix} -j8.5 & j2.5 & j5 & 0 \\ j2.5 & -j8.75 & j5 & 0 \\ j5 & j5 & -j35 & j25 \\ 0 & 0 & j25 & -j25 \end{bmatrix}$$

Table 1. Classification of buses for LFA

Sl. No.	Bus Types	Specified Variables	Unspecified variables	Remarks
1	Slack/ Swing Bus	$\|V\|$, δ	P_G, Q_G	$\|V\|$, δ: are assumed if not specified as 1.0 and 0^0
2	Generator/ Machine/ PV-Bus	P_G, $\|V\|$	Q_G, δ	A generator is present at the machine bus
3	Load/ PQ Bus	P_G, Q_G	$\|V\|$, δ	About 80% buses are of PQ type
4	Voltage Controlled Bus	P_G,Q_G, $\|V\|$	δ, a	'a' is the % tap change in tap-changing transformer

$$P_i = \sum_{j=1}^{n} |V_i||V_j|\left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) \quad (9)$$

$$Q_i = \sum_{j=1}^{n} |V_i||V_j|\left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) \quad (10)$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{j=1 \\ j\neq i}}^{n} Y_{ij}V_j\right] \quad \forall\, i = 2, 3, \ldots\ldots\ldots n \quad (17)$$

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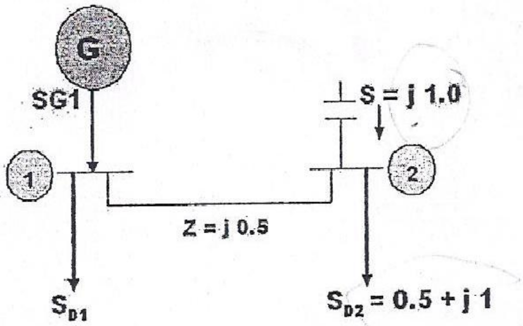
Examples on GS load flow analysis:

Example-1: *Obtain the voltage at bus 2 for the simple system shown in Fig 2, using the Gauss–Seidel method, if $V_1 = 1\angle 0^0$ pu.*



P, Q

Fig : System of Example 1

Solution:

Here the capacitor at bus 2, injects a reactive power of 1.0 pu. The complex power injection at bus 2 is

$$S_2 = j1.0 - (0.5 + j\,1.0) = -0.5 \text{ pu.}$$

$$y = \frac{1}{j0{,}5} = -j2$$

$$V_1 = 1\angle 0^0$$

$$Y_{BUS} = \begin{bmatrix} -j2 & j2 \\ j2 & -j2 \end{bmatrix}$$

$$V_2^{(k+1)} = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{\left(V_2^{(k)}\right)^*} - Y_{21}V_1\right]$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{j=1 \\ j\neq i}}^{n} Y_{ij}V_j\right] \quad i = 2,3 \ldots n$$

Since V_1 is specified it is a constant through all the iterations. Let the initial voltage at bus 2, $V_2^0 = 1 + j\,0.0 = 1\angle 0^0$ pu.

$$V_2^1 = \frac{1}{-j2}\left[\frac{-0.5}{1\angle 0^0} - (j2 \times 1\angle 0^0)\right]$$

$$= 1.0 - j0.25 = 1.030776 \ \angle -14.036^0$$

$$V_2^2 = \frac{1}{-j2}\left[\frac{-0.5}{1.030776\angle 14.036^0} - (j2 \times 1\angle 0^0)\right]$$

$$= 0.94118 - j\ 0.23529 \ = 0.970145 \ \angle -14.036^0$$

$$V_2^3 = \frac{1}{-j2}\left[\frac{-0.5}{0.970145\angle 14.036^0} - (j2 \times 1\angle 0^0)\right]$$

$$= 0.9375 - j\ 0.249999 \ = 0.970261 \ \angle -14.931^0$$

$$V_2^4 = \frac{1}{-j2}\left[\frac{-0.5}{0.970261\angle 14.931^0} - (j2 \times 1\angle 0^0)\right]$$

$$= 0.933612 - j\ 0.248963 = 0.966237 \ \angle -14.931^0$$

$$V_2^5 = \frac{1}{-j2}\left[\frac{-0.5}{0.966237\angle 14.931^0} - (j2 \times 1\angle 0^0)\right]$$

$$= 0.933335 - j\ 0.25 \ = 0.966237 \ \angle -14.995^0$$

Since the difference in the voltage magnitudes is less than 10^{-6} pu, the iterations can be stopped. To compute line flow

$$I_{12} = \frac{V_1 - V_2}{Z_{12}} = \frac{1\angle 0^0 \ - 0.966237\angle -14.995^0}{j0.5}$$

$$= 0.517472 \ \angle -14.931^0$$

$$S_{12} = V_1 I_{12}^* = 1\angle 0^0 \times 0.517472 \ \angle \ 14.931^0$$

$$= 0.5 + j\ 0.133329 \text{ pu}$$

$$I_{21} = \frac{V_2 - V_1}{Z_{12}} = \frac{0.966237\angle -14.995^0 - 1\angle 0^0}{j0.5}$$

$$= 0.517472 \ \angle -194.93^0$$

$$S_{21} = V_2 I_{21}^* = -0.5 + j\ 0.0 \text{ pu}$$

The total loss in the line is given by

$$S_{12} + S_{21} = j\ 0.133329 \text{ pu}$$

Obviously, it is observed that there is no real power loss, since the line has no resistance.

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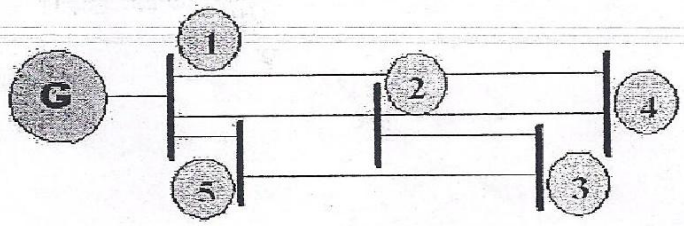
Example-2:

For the power system shown in fig. below, with the data as given in tables below, obtain the bus voltages at the end of first iteration, by applying GS method.



Power System of Example 2

Line data of example 2

SB	EB	R (pu)	X (pu)	$\frac{B_c}{2}$
1	2	0.10	0.40	-
1	4	0.15	0.60	-
1	5	0.05	0.20	-
2	3	0.05	0.20	-
2	4	0.10	0.40	-
3	5	0.05	0.20	-

Bus data of example 2

Bus No.	P_G (pu)	Q_G (pu)	P_D (pu)	Q_D (pu)	$\lvert V_{SP}\rvert$ (pu)	δ	
1	-	-	-	-	1.02	0°	→ slack bus
2	-	-	0.60	0.30	-	-	→ P Q
3	1.0	-	-	-	1.04	-	→ P V
4	-	-	0.40	0.10	-	-	→ P Q
5	-	-	0.60	0.20	-	-	→ P Q

Solution: In this example, we have,

- Bus 1 is slack bus, Bus 2, 4, 5 are PQ buses, and Bus 3 is PV bus
- The lines do not have half line charging admittances

$P_2 + jQ_2 = P_{G2} + jQ_{G2} - (P_{D2} + jQ_{D2}) = -0.6 - j0.3$

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for ex

Y_{bus} [ ]

$Y_{12} =$ 5 + j10

G B

$P_3 + jQ_3 = P_{G3} + jQ_{G3} - (P_{D3} + jQ_{D3}) = 1.0 + jQ_{G3}$

Similarly $P_4 + jQ_4 = -0.4 - j0.1$, $\quad P_5 + jQ_5 = -0.6 - j0.2$

The Y_{bus} formed by the rule of inspection is given by:

$Y_{bus} =$

2.15685 -j8.62744	-0.58823 +j2.35294	0.0+j0.0	-0.39215 +j1.56862	-1.17647 +j4.70588
-0.58823 +j2.35294	2.35293 -j9.41176	-1.17647 +j4.70588	-0.58823 +j2.35294	0.0+j0.0
0.0+j0.0	-1.17647 +j4.70588	2.35294 -j9.41176	0.0+j0.0	-1.17647 +j4.70588
-0.39215 +j1.56862	-0.58823 +j2.35294	0.0+j0.0	0.98038 -j3.92156	0.0+j0.0
-1.17647 +j4.70588	0.0+j0.0	-1.17647 +j4.70588	0.0+j0.0	2.35294 -j9.41176

The voltages at all PQ buses are assumed to be equal to 1+j0.0 pu. The slack bus voltage is taken to be $V_1^0 = 1.02 + j0.0$ in all iterations.

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^{o*}} - Y_{21}V_1^o - Y_{23}V_3^0 - Y_{24}V_4^0 - Y_{25}V_5^0\right]$$

$$= \frac{1}{Y_{22}}\left[\frac{-0.6 + j0.3}{1.0 - j0.0} - \{(-0.58823 + j2.35294) \times 1.02\angle 0^o\}\right.$$

$$\left. - \{(-1.17647 + j4.70588) \times 1.04\angle 0^o\} - \{(-0.58823 + j2.35294) \times 1.0\angle 0^0\}\right]$$

$$= 0.98140\angle -3.0665^o = 0.97999 - j0.0525$$

Bus 3 is a PV bus. Hence, we must first calculate Q_3. This can be done as under:

$$Q_3 = |V_3||V_1|(G_{31}\sin\delta_{31} - B_{31}\cos\delta_{31}) + |V_3||V_2|(G_{32}\sin\delta_{32} - B_{32}\cos\delta_{32})$$

$$+ |V_3|^2 (G_{33}\sin\delta_{33} - B_{33}\cos\delta_{33}) + |V_3||V_4|(G_{34}\sin\delta_{34} - B_{34}\cos\delta_{34})$$

$$+ |V_3||V_5|(G_{35}\sin\delta_{35} - B_{35}\cos\delta_{35})$$

We note that $\delta_1 = 0^o$; $\delta_2 = -3.0665^o$; $\delta_3 = 0^o$; $\delta_4 = 0^o$ and $\delta_5 = 0^o$

$\therefore\ \delta_{31} = \delta_{33} = \delta_{34} = \delta_{35} = 0^o\ (\delta_{ik} = \delta_i - \delta_k)$; $\quad \delta_{32} = 3.0665^o$

$Q_3 = 1.04\,[1.02\,(0.0 + j0.0) + 0.9814\,\{-1.17647 \times \sin(3.0665^o) - 4.70588 \times \cos(3.0665^o)\} + 1.04\{-9.41176 \times \cos(0^o)\} + 1.0\,\{0.0 + j0.0\} + 1.0\{-4.70588 \times \cos(0^0)\}]$

$= 1.04\,[-4.6735 + 9.78823 - 4.70588] = 0.425204$ pu.

$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{V_3^{o*}} - Y_{31}V_1^o - Y_{32}V_2^1 - Y_{34}V_4^0 - Y_{35}V_5^0\right]$$

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$$= \frac{1}{Y_{33}}\left[\frac{1.0 - j0.425204}{1.04 - j0.0} - \{(-1.7647 + j4.70588) \times (0.98140\angle -3.0665^o)\}\right.$$

$$\left. - \{(-1.17647 + j4.70588) \times (1\angle 0^o)\}\right]$$

$$= 1.05569\angle 3.077^o = 1.0541 + j0.05666 \text{ pu.}$$

Since it is a PV bus, the voltage magnitude is adjusted to specified value and V_3^1 is computed as: $V_3^1 = 1.04\angle 3.077^o$ pu

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{V_4^{o*}} - Y_{41}V_1^o - Y_{42}V_2^1 - Y_{43}V_3^1 - Y_{45}V_5^0\right]$$

$$= \frac{1}{Y_{44}}\left[\frac{-0.4 + j0.1}{1.0 - j0.0} - \{(-0.39215 + j1.56862) \times 1.02\angle 0^o\}\right.$$

$$\left. - \{(-0.58823 + j2.35294) \times (0.98140\angle -3.0665^o)\}\right]$$

$$= \frac{0.45293 - j3.8366}{0.98038 - j3.92156} = 0.955715\angle -7.303^o \text{ pu} = 0.94796 - j0.12149$$

$$V_5^1 = \frac{1}{Y_{55}}\left[\frac{P_5 - jQ_5}{V_5^{o*}} - Y_{51}V_1^o - Y_{52}V_2^1 - Y_{53}V_3^1 - Y_{54}V_4^1\right]$$

$$= \frac{1}{Y_{55}}\left[\frac{-0.6 + j0.2}{1.0 - j0.0} - \{(-1.17647 + j4.70588) \times 1.02\angle 0^o\}\right.$$

$$\left. - \{(-1.17647 + j4.70588) \times 1.04\angle 3.077^o\}\right]$$

$$= 0.994618\angle -1.56^o = 0.994249 - j0.027$$

Thus at end of 1st iteration, we have,

$V_1 = 1.02\angle 0^0$ pu $\quad V_2 = 0.98140\angle -3.066^0$ pu

$V_3 = 1.04\angle 3.077^0$ pu $\quad V_4 = 0.955715\angle -7.303^0$ pu

and $\quad V_5 = 0.994618\angle -1.56^0$ pu

Example-3:

Obtain the load flow solution at the end of first iteration of the system with data as given below. The solution is to be obtained for the following cases

(i) All buses except bus 1 are PQ Buses

(ii) Bus 2 is a PV bus whose voltage magnitude is specified as 1.04 pu

(iii) Bus 2 is PV bus, with voltage magnitude specified as 1.04 and $0.25 \le Q_2 \le 1.0$ pu.

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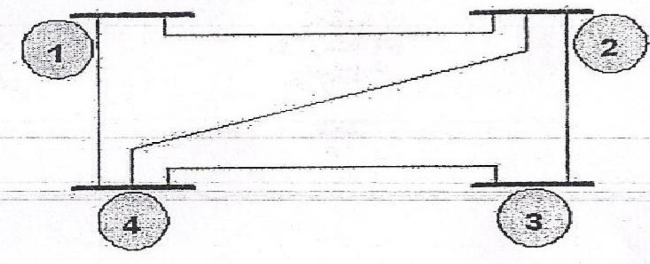

Fig. System for Example 3

Table: Line data of example 3

SB	EB	R (pu)	X (pu)
1	2	0.05	0.15
1	3	0.10	0.30
2	3	0.15	0.45
2	4	0.10	0.30
3	4	0.05	0.15

Table: Bus data of example 3

Bus No.	P_i (pu)	Q_i (pu)	V_i
1	–	–	$1.04\angle 0^0$
2	0.5	– 0.2	–
3	– 1.0	0.5	–
4	+0.3	– 0.1	–

case II

2 | 0.5 | — | 1.04∠

Solution: Note that the data is directly in terms of injected powers at the buses. The bus admittance matrix is formed by inspection as under:

$$Y_{BUS} = \begin{bmatrix} 3.0 - j9.0 & -2.0 + j6.0 & -1.0 + j3.0 & 0 \\ -2.0 + j6.0 & 3.666 - j11.0 & -0.666 + j2.0 & -1.0 + j3.0 \\ -1.0 + j3.0 & -0.666 + j2.0 & 3.666 - j11.0 & -2.0 + j6.0 \\ 0 & -1.0 + j3.0 & -2.0 + j6.0 & 3.0 - j9.0 \end{bmatrix}$$

Case(i): All buses except bus 1 are PQ Buses

Assume all initial voltages to be $1.0\angle 0^0$ pu.

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^{o*}} - Y_{21}V_1^o - Y_{23}V_3^0 - Y_{24}V_4^0\right]$$

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$$= \frac{1}{Y_{22}}\left[\frac{0.5 + j0.2}{1.0 - j0.0} - \{(-2.0 + j6.0)\times(1.04\angle 0^o)\}\right.$$
$$\left. - \{(-0.666 + j2.0)\times(1.0\angle 0^o)\} - \{(-1.0 + j3.0)\times(1.0\angle 0^o)\}\right]$$
$$= 1.02014\angle 2.605^o$$

$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{P_3 - jQ_3}{V_3^{o*}} - Y_{31}V_1^o - Y_{32}V_2^1 - Y_{34}V_4^0\right]$$

$$= \frac{1}{Y_{33}}\left[\frac{-1.0 - j0.5}{1.0 - j0.0} - \{(-1.0 + j3.0)\times(1.04\angle 0.0^o)\}\right.$$
$$\left. - \{(-0.666 + j2.0)\times(1.02014\angle 2.605^o)\} - \{(-2.0 + j6.0)\times(1.0\angle 0^o)\}\right]$$
$$= 1.03108\angle -4.831^o$$

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{P_4 - jQ_4}{V_4^{o*}} - Y_{41}V_1^o - Y_{42}V_2^1 - Y_{43}V_3^1\right]$$

$$= \frac{1}{Y_{44}}\left[\frac{0.3 + j0.1}{1.0 - j0.0} - \{(-1.0 + j3.0)\times(1.02014\angle 2.605^o)\}\right.$$
$$\left. - \{(-2.0 + j6.0)\times(1.03108\angle -4.831^o)\}\right]$$
$$= 1.02467\angle -0.51^o$$

Hence

$V_1^1 = 1.04\ \angle 0^0\,\text{pu}$ $\qquad V_2^1 = 1.02014\ \angle 2.605^0\,\text{pu}$

$V_3^1 = 1.03108\ \angle -4.831^0\,\text{pu}$ $\qquad V_4^1 = 1.02467\angle -0.51^0\,\text{pu}$

Case(ii): Bus 2 is a PV bus whose voltage magnitude is specified as 1.04 pu

We first compute Q_2.

$$Q_2 = |V_2|\left[|V_1|\left(G_{21}\sin\delta_{21} - B_{21}\cos\delta_{21}\right) + |V_2|\left(G_{22}\sin\delta_{22} - B_{22}\cos\delta_{22}\right)\right.$$
$$\left. + |V_3|\left(G_{23}\sin\delta_{23} - B_{23}\cos\delta_{23}\right) + |V_4|\left(G_{24}\sin\delta_{24} - B_{24}\cos\delta_{24}\right)\right]$$

$$= 1.04\,[1.04\,\{-6.0\} + 1.04\,\{11.0\} + 1.0\{-2.0\} + 1.0\,\{-3.0\} = 0.208\text{ pu.}$$

$$V_2^1 = \frac{1}{Y_{22}}\left[\frac{0.5 - j0.208}{1.04\angle 0^0} - \{(-2.0 + j6.0)\times(1.04\angle 0^o)\}\right.$$
$$\left. - \{(-0.666 + j2.0)\times(1.0\angle 0^o)\} - \{(-1.0 + j3.0)\times(1.0\angle 0^0)\}\right]$$
$$= 1.051288 + j0.033883$$

The voltage magnitude is adjusted to 1.04. Hence $V_2^1 = 1.04\angle 1.846^0$

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$$V_3^1 = \frac{1}{Y_{33}}\left[\frac{-1.0 - j0.5}{1.0\angle 0^{0}} - \{(-1.0 + j3.0)\times(1.04\angle 0.0^{o})\}\right.$$
$$\left. - \{(-0.666 + j2.0)\times(1.04\angle 1.846^{o})\} - \{(-2.0 + j6.0)\times(1.0\angle 0^{o})\}\right]$$
$$= 1.035587\angle -4.951^{o} \text{ pu.}$$

$$V_4^1 = \frac{1}{Y_{44}}\left[\frac{0.3 + j0.1}{1.0 - j0.0} - \{(-1.0 + j3.0)\times(1.04\angle 1.846^{o})\}\right.$$
$$\left. - \{(-2.0 + j6.0)\times(1.035587\angle -4.951^{o})\}\right]$$
$$= 0.9985\angle -0.178^{o}$$

Hence at end of 1st iteration we have:

$V_1^1 = 1.04\ \angle 0^{0}$ pu $\quad V_2^1 = 1.04\ \angle 1.846^{0}$ pu

$V_3^1 = 1.035587\ \angle -4.951^{0}$ pu $\quad V_4^1 = 0.9985\angle -0.178^{0}$ pu

<u>Case (iii):</u>Bus 2 is PV bus, with voltage magnitude specified as 1.04 & $0.25 \le Q_2 \le 1$ pu. If $0.25 \le Q_2 \le 1.0$ pu then the computed value of $Q_2 = 0.208$ is less than the lower limit. Hence, Q_2 is set equal to 0.25 pu. Iterations are carried out with this value of Q_2. The voltage magnitude at bus 2 can no longer be maintained at 1.04. Hence, there is no necessity to adjust for the voltage magnitude. Proceeding as before we obtain at the end of first iteration,

$V_1^1 = 1.04\ \angle 0^{0}$ pu $\quad V_2^1 = 1.05645\ \angle 1.849^{0}$ pu

$V_3^1 = 1.038546\ \angle -4.933^{0}$ pu $\quad V_4^1 = 1.081446\angle 4.896^{0}$ pu

<u>Limitations of GS load flow analysis:</u>

GS method is very useful for very small systems. It is easily adoptable, it can be generalized and it is very efficient for systems having less number of buses. However, GS LFA fails to converge in systems with one or more of the features as under:

- Systems having large number of radial lines
- Systems with short and long lines terminating on the same bus
- Systems having negative values of transfer admittances
- Systems with heavily loaded lines, etc.

GS method successfully converges in the absence of the above problems. However, convergence also depends on various other set of factors such as: selection of slack bus, initial solution, acceleration factor, tolerance limit, level of accuracy of results needed, type and quality of computer/ software used, etc.

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