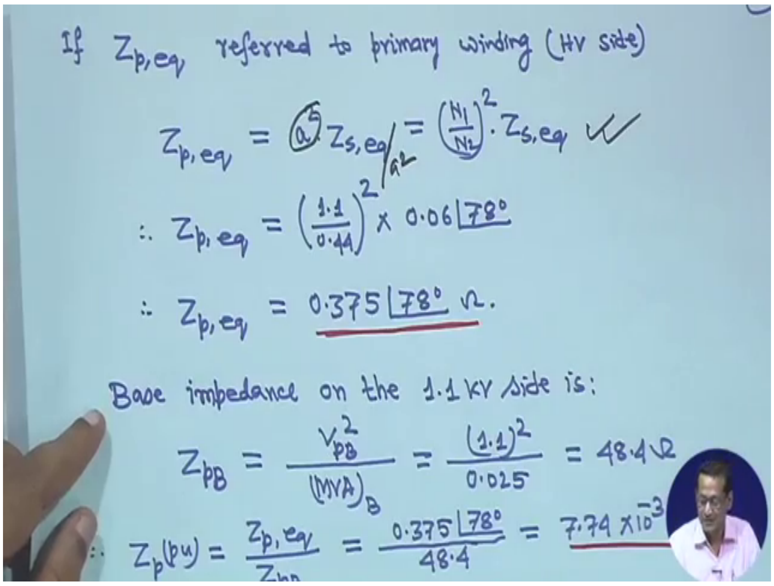
Power System Analysis
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

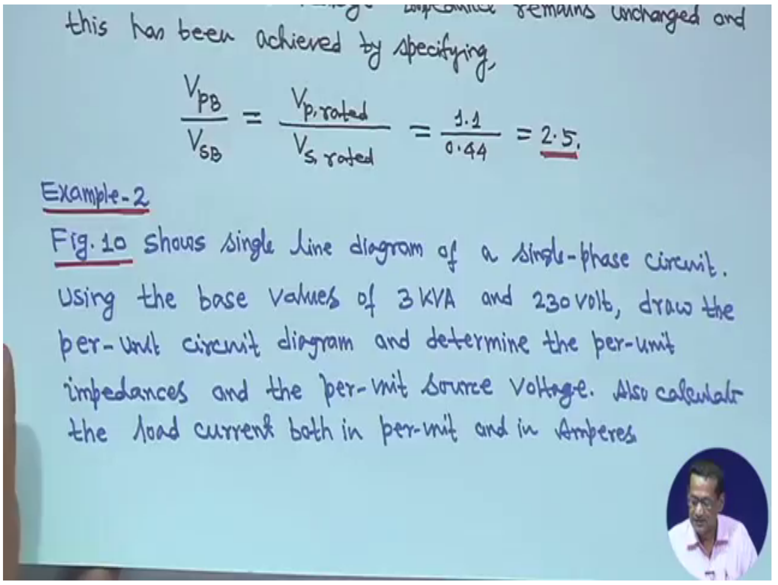
Lecture - 18
Power System Components and Per – unit System (Contd.)

(Refer Slide Time: 00:28)



So, this is the first example you took right and one small correction you make actually this one actually this one actually it will be divided by a square right, when I was going through it by mistake I multiplied a square, it should be divided a square then this is correct right, rest is ok.

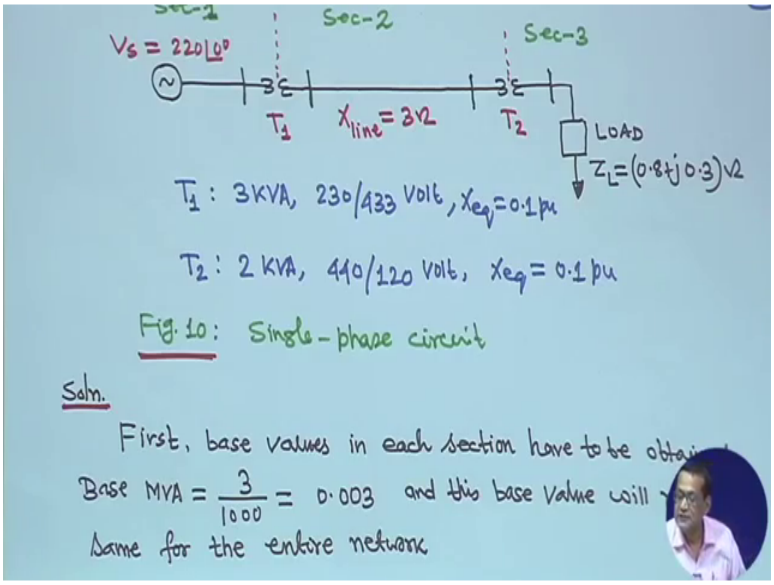
(Refer Slide Time: 00:48)



Next is that example then come to the second examples. This is actually now little bit slowly I am slowly we will go to the different type of problem. Now figure 10 I will show you it, so single line diagram of a single phase circuit right using the base values of 3 KVA and 230 volt right.

So, you have to draw the per unit circuit diagram and determine the per unit impedances and the per unit source voltage. Also calculate the load current both in per unit and in amperes right, I mean you have to calculate per unit values as well as in terms of your current values.

(Refer Slide Time: 01:34)

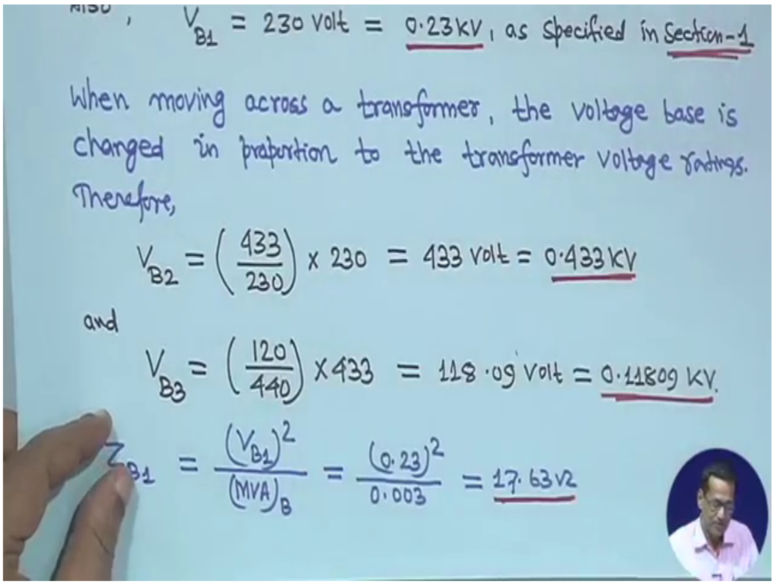


Now, ampere values now this is the diagram this is sending an voltage 220 angle 0, this is actually KV right, 220 just the KV or volt just let me see this right. 230 volt actually small system, 230 volt. So, this is your, what you call base values 3 KVA 230 volt right. So, this is actually 220 angle the angle 0 volt this is the section 1 is figure 10 these are transformer T 1 this is line resistances line reactance is given 3 ohm right and this is transformer T 2, and this is the load, load impedance is given 0.8 plus j 0.3 ohm. So, this whole thing has been divided into 3 section this is section 1, this is section 2 and this is section 3.

Now, for transform T 1 it is given 3 KVA 230 upon 433 volt this is the rating of the transformer and equivalent reactance is given 0.1 per unit right. Similarly for transformer T 2 this one is 2 KVA this transform is 440 upon 120 volt right and x e q again 0.1 per unit these are the data given right. Now first what you have to do is you have to choose base values right and in this problem, in this problem that is given that you have to take this value 3 KVA and 230 volt and based on that you have to determine everything right.

So, when base MVA it is base KVA is given 3. So, it convert it to MVA. So, it is 3 by 1000, so 0.003 that is your base MVA right and it is this base value will remain same for the entire network; that means, this base value we will not be change it will remain same as it is right and base voltage it is given that is your 230 volt. But if you look into that mean this transformer that 3 KVA and 230 volt basically it is given as a base for you therefore, this section 1, you write that voltage base 1 that is for the section 1 is 230 volt that is 0.23 kilovolt right as specified in section 1 because this because this transformer T 1 actually 3 KVA 230 volt the this side is this is section 1 right this side.

(Refer Slide Time: 03:45)

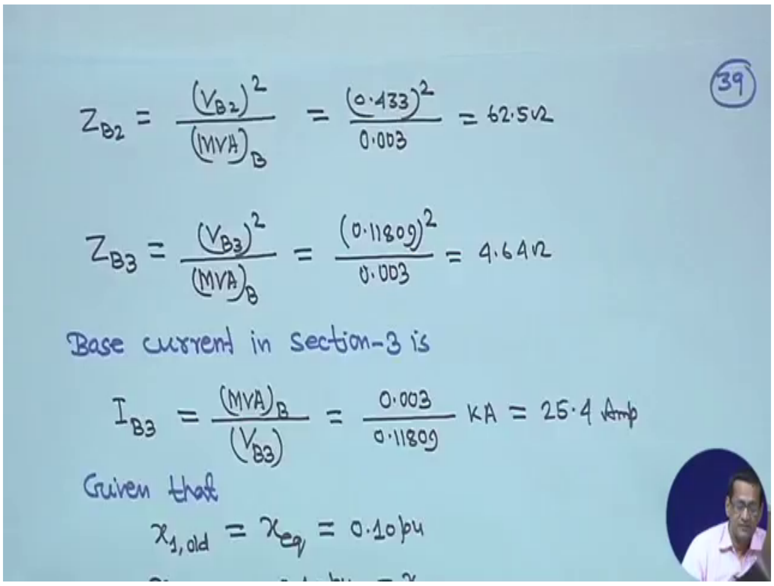


Now, based on that we have to transformer the base voltage to the line as well as to the other side therefore, when moving across a transformer the voltage base is changed in proportion to the transformer voltage rating therefore, that is for section 2 base voltage will be 433 by 230 into 230 is 430 volt. It is if you see there that this side is to base it has been ask that your base voltage is 230 volt them in this side. So, you the transformer is 433 volt rating. So, automatically this side will be base voltage will be 433 volt that is why, but you have to transforms. So, it is 430 by 230 into 230 that is 433; your 433 volt. So, this is actually 0.433 kilovolt right.

Similarly for the base voltage your for section 3; that means, this side basically transformer actually 440 upon 120, but this lines volt base voltage is 433. So, accordingly you have to see what is the base voltage for the section c that is there, that is your this side right, that is your this portion right. That means, your V B 3 will be 120 upon 440 into 433 because you are going to the lower voltage side although it is; although transformer is 440 by 120, but you are transforming whole network into it this one a common base right.

Therefore this b, section 3 base voltage you will 118.09 volt that is 0.11809 KV. So, hope you have understood this right that how to transform. Similarly now for the section 1 Z B 1 is the base impedance which is equal to V B 1 square upon MVA base that is your 0.23 square upon 0.003 that is 17.63 ohm this is the base impedance for the section 1 of the diagram right.

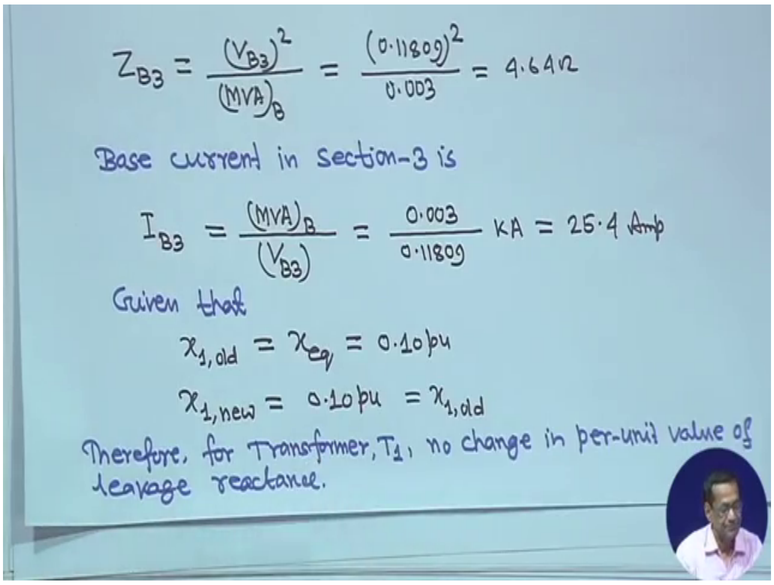
(Refer Slide Time: 06:08)



Similarly, are Z B 2 is equal to V B 2 square upon MVA base right. So, that is equal to your 0.433 square divided by 0.003 is equal to 62.5 ohm right.

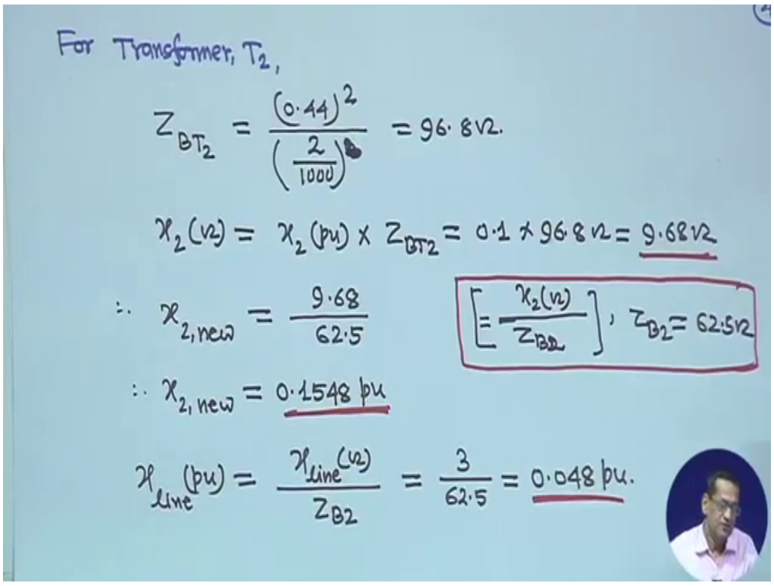
So, similarly Z B 3 is equal to V B 3 square upon MVA base is equal to 0.1 way 118.09 square upon 0.003, so for 4.64 ohm. So, all the 3 sections base impedance are computed right. Now base current in section 3 is the for the section 3 base MVA base remains and throughout therefore, base current in section 3 I B 3 is equal to MVA base upon V B 3 that is 0.003 upon 0.11809 kilo ampere and that is equal to 25.4 ampere right.

(Refer Slide Time: 07:06)



Now, it is given, given x e q is equal to 0.10 per unit this is actually old value. So, you are writing because we have to convert into the other base. So, x 1 old is equal to x 1 q 0.10, but x 1 new also 0.10 per unit is equal to x 1 old because this is for transformer, transformer you are rating 3 KV that is 0.003 MVA and 230 volt is the base. So, for transformer T 1 this will not change it will remain as it is because transformer rating itself has been taken as a base that voltage as well as your volt ampere therefore, for transformer T 1 no change in per unit values leakage reactance.

(Refer Slide Time: 07:55)

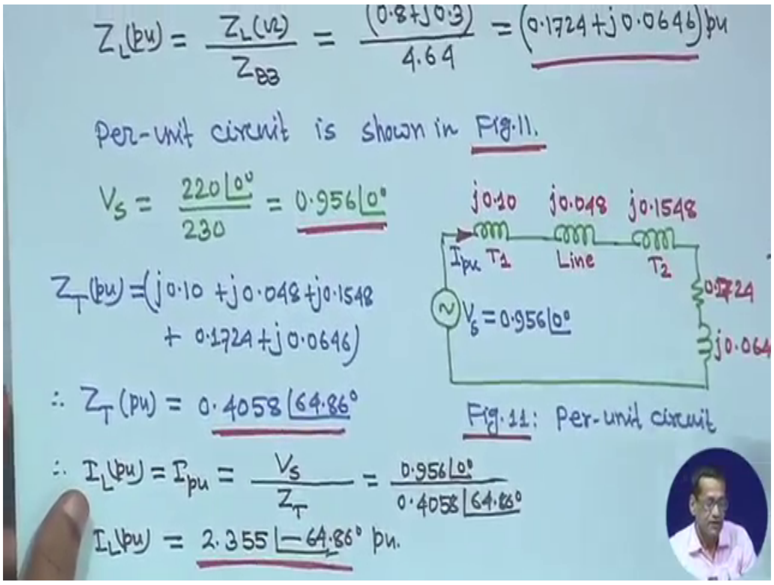


For transformer T 2 for transformer T 2 Z B T 2 is equal to again that that 0.44 square divided by your 2 by 1000. The reason is like this the transformer T 2 actually it is 2 KVA right and 440 volt by 120 therefore, base impedance for transformer T 2 right first you find out therefore, transformer this your primary side it is 440 volt. So, 0.44 KV square because 0.44 KV divided by it is 2 KVA because rating is for transformer T 2 is 2 KVA 2 by 1000 that is 2 by 1000 MVA. So, MVA your KVA square upon MVA that we will get 96.8 ohm this is transformer own base right, based on its rating.

Now, transformer 2 is reactance is given 0.1 per unit now find out what is ohmic value. So, x 2 ohm is equal to x 2 per unit into Z B 2 b T 2 that is 0.1 into 96.8 that is 9.68 ohm right; that means, x 2 new now is equal to because new base impedance that is for your what you call that Z B 2, Z B 2 you have got this value that 62 for the section 2 Z B 2 we have got 62.5 ohm right. Therefore, a new value of that reactance of the transformer 2 x 2 new 9.68 upon your 62.5 I have written here Z B 2 is equal to 62.5 ohm right. That means x 2 new is equal to 0.1548 per unit, similarly for the line x line per unit is equal to x line ohm upon Z B 2 that is 3 upon 62 because line reactance is 3 ohm divided by base impedance of the section 2 that is 3 upon 62.5 that is 0.048 per unit right.

Next load is given, load per u Z l per unit is equal to Z l ohmic value this is given 0.8 plus j point this impedance is given, this impedance is given divided by the base impedance of your line section 3 right.

(Refer Slide Time: 10:12)



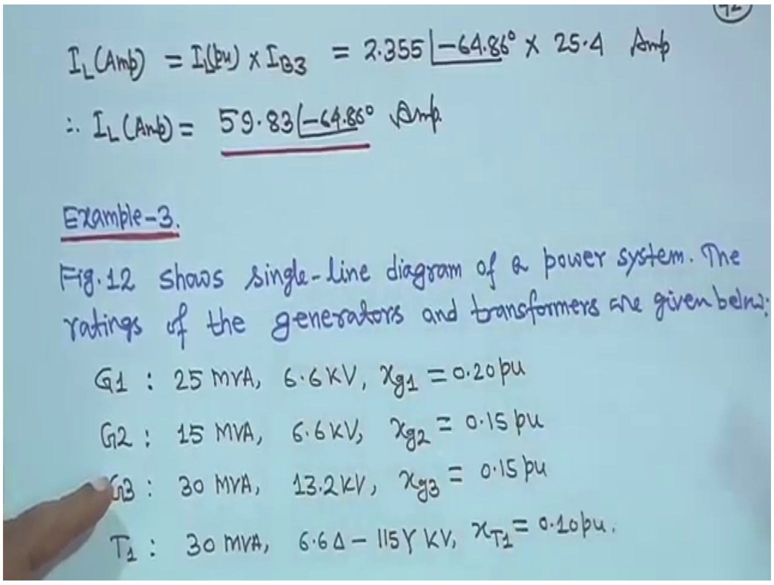
That means section 3 base impedance you have obtain Z B 3 is equal to 4.64 ohm this one, this one right; that means, your per units your Z l is equal to your Z l ohm upon Z B 3.8 plus j 0.3 upon this is 4.64 that is 0.1724 plus j 0 0.0646 per unit right.

So, per unit circuit is shown in figure 11. So, you have in the circuit you have a shows voltage V S the V S actually it is given your it is given 220 angle 0, but base voltage is 230 in the pro this base voltage is 230 is given. So, 220 upon 230 that we will become actually 0.956 angle 0 this is 220 upon 230 right. For transformer T 1 that is j 0.10 as it is for the line it is j 0.048 per unit and for transformer T 2 j 0.1548 and for the load it is 0.1724 plus j 0.0646 per unit right. Here it is forgiven 0.1724 this is resistive path because load is inductive and it is j 0.0646 this is the load right and this is the pi unit diagram.

So, V S also it 220 angle 0 upon 230 is the base. So, 0.956 angle 0 that is I have told you right therefore, total per unit impedance Z T p u the Z total you sum up all you sum it up all it will right it will become 0.4058 angle 64.86 degree like this is a resistive part right this is resistive part right. So, therefore, I L per unit is equal to that is I pu because same current is going to the load this is load. So, I L per unit is equal to series circuit I pu is equal to V S upon Z T right.

So, is equal to 0.965 angle 0 degree divided by this is Z T the total is equal to you will get 2.355 angle minus 64.86 degree per unit, this is your what you call this is the per unit value of the current.

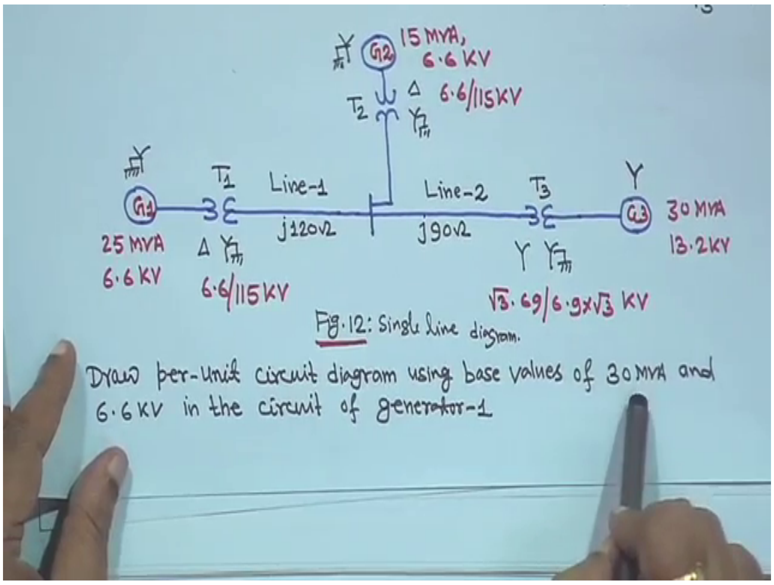
(Refer Slide Time: 12:56)



Then that you have to find out ampere know, we have see we have to find out I L pu into I B 3, we have seen the base current for that side is 25.4 ampere b 4. So, this per unit values multiplied is 25.4. So, this will be 59.83 angle minus 64.86 degree ampere. So, this is the load current and current is lagging because load is inductive right. So, this numerical you have understood right.

Now, we will go to little bit further tougher problem right slowly and slowly such that all type of things we will be clear that were then you will know what is the advantage of this per unit conversation, conversion such thing. So, figure 12, 12 I will show you 12 I will show it is big diagram. So, single line diagram of a power system the ratings of the generators and transformers are given below right.

(Refer Slide Time: 13:57)



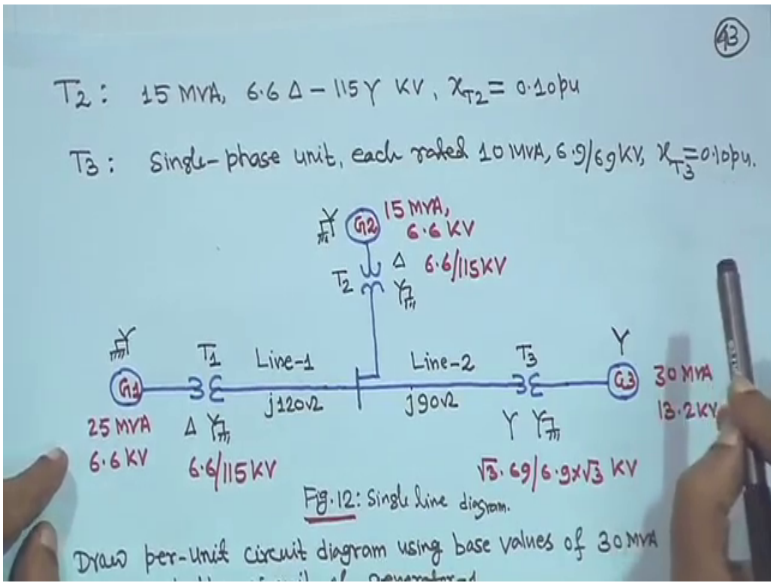
So, this is actually your before giving the data this is actually your figure 12, figure 12 there are 3 generators - generator 1, generator 2 and generator 3 right. Now this generator 1 this stars are connected it is grounded, generator 3 is not grounded, generator 2 is grounded.

So, generator 1 it has 25 MVA rating and 6.6 KV terminal voltage. These transformer is a delta star, star is grounded is the delta star transformer 6.6 and 115 KV right similarly and this line it is a line 1 it is only reactance we have considering. So, j 120 ohm and this is generator 2 it is star connected but grounded, it is 15 MVA 6.6 KV these transformer actually delta star delta side is 6.6 and star side is 115 KV right and this is your line 2 this is j 90 ohm this is the your what you call this is the line reactance right. And this is transformer 3, these are, these 2 transformers are 3 phase transformer, this one and this one 3 phase transformer, but this transformer actually this 3 phase transformer actually 3 single phase transformer connected.

So, that is why that each single facilitating was 69 upon 6.9 KV, but as it is may made 3 phase it is star of star secondary side is grounded that is why root 3 into 69 slash 6.9 into root 3 KV because single phase it was given 69 by 6.9 high voltage to low voltage. But when you are making it your star connection using 3 single per transformer and all these thing we have to represent it will no line to line voltage that is why multiplied by root 3 and you have secondary side also multiplied by root 3. And this generator is star right connected G 3 is 30 MVA and 13.2 KV. This is the single line diagram, you have to make per; that means, this one you have to make single line diagram of this one right generator given below.

So, we have to you; what you have to do is that you have to find out it is per unit you are reactance diagram. So, G 1 is 25 MVA I told 6.6 KV the generator rating is sorry, generator reactance is given 0.2 below j will be there, but not (Refer Time: 16:27) they only in this final circuit we will put the j that complex operator right. So, G 2 is equal to G 2 rating is 15 generator 2 rating is 15 MVA 6.6 KV and reactance is 0.15 per unit. Similarly generator 3 it is 30 MVA right and 13.2 KV and it is a generator reactance is 0.15 per unit transformer T 1 is 30 MVA it is 6.6 delta side KV and 115 is star side KV right and transformer reactance is 0.10 per unit right.

(Refer Slide Time: 17:10)

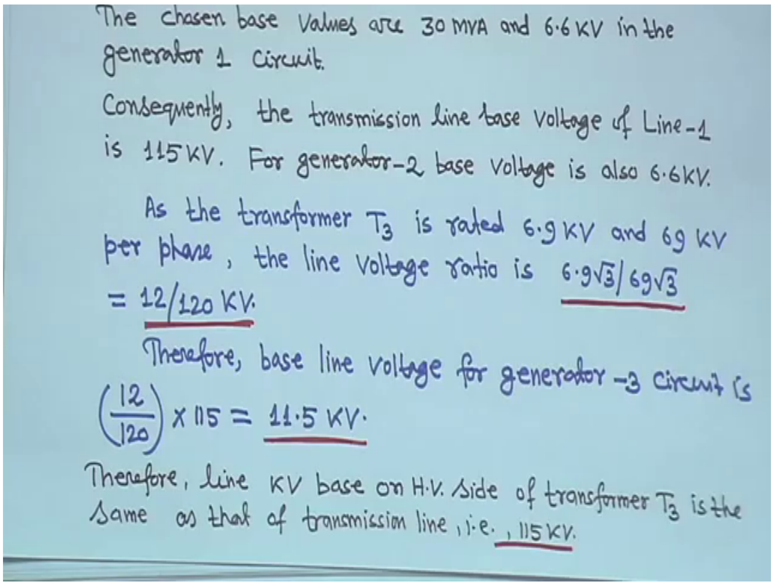


Similarly, for transformer T 2 it is 15 MVA, it is 15 MVA 6.6 KV delta side and 115 KV star side I am writing KV here, but understandable right and reactance is for transformer T 2 is 0.10 per unit and transformer T 3 actually single phase unit each rating; each rated ten MVA right and 6.9 upon 69 KV and x T 3 is given 0.10 per unit right. So, as it is a single phase transformer that is why line to line were 3 single phase transformer connected to 3 phase transformer the 3 single phase transformer is 3 phase transformer that is why I line to line voltage or to multiply this one by root 3 on this one by root 3

KV right. So, we have to draw the per unit circuit diagram is base values of 30 MVA and 6.6 KV in the circuit diagram of sub circuit of generator 1 right.

Its base value is given that you have to take 30 MVA base, MVA base should be 30 and this voltage should be 6.6 KV based on that you have to make this diagram single per unit your reactance diagram right. So, how you will do this?

(Refer Slide Time: 18:22)



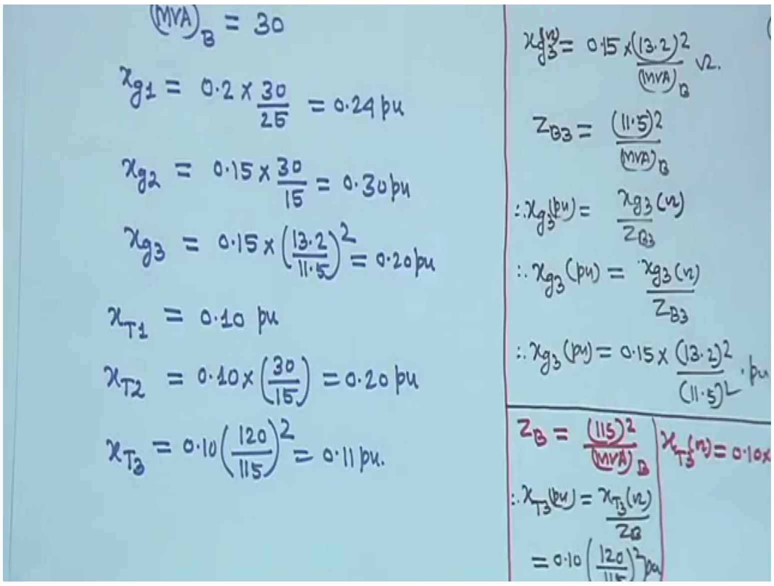
So, the chosen base values are given 30 MVA and 6.6 KV in the generator 1 circuit that mean this side you have to take their 6.6 KV, but this side base is 30 we have all the generate rating is 25 MVA 15 MVA and this side is 13 MVA right. Therefore, the transmission line base voltage of line 1 is 115 KV because the generator side voltage generator terminal voltage is 6.6 KV, this transformer also 6.6 KV, so automatically this line this side base voltage we will be 115 KV because this is your secondary side transformer voltage right.

So, that is why and for generator 2 base voltage is also 6.6 KV I mean for this generator also terminal voltage 6.6 KV. So, base voltage also 6.6 KV; that means, here you actually directly connected no line is here. So, no impedances reactance’s is shown or impedance is shown mean it is directly connected right. So, this side base voltage is 115 KV and automatically base voltage 6.6 KV is taken. So, generator terminal voltage is also 6.6 KV. So, other side base voltage will be 115 KV, so absolutely no problem.

Now, next is the as the transformer T 3 is rated 6.9 KV and 69 KV per phase because 3 single phase transformer we have used therefore, line voltage ratio will be 6.9 root 3 slash 69 root 3 right that is if you multiply by root 3, root 3 it will basically 12 on the low voltage side 12 KV and high voltage side will be 120 KV line to line right. Therefore, baseline voltage for generator 3 circuit is that it is for this generator because this transformer actually 12 your 12 KV by 120 KV so, but line base voltage this side also it is line based voltage is a 115 volt right, but this side should be then 12 by 120 into 115 that is this side will be 11.5 KV this generator this side right .

So; that means, that base line voltage for generator 3 circuit will be the 12 because transformer is now 12 by 2, this is 12 by 120 right, but your base voltage the this voltage is 115 KV that line side therefore, this side voltage will be 12 by 120 into 115. So, 11.5 KV right, so that is your this side base voltage. So, this way you have to transform and you have to make things correctly. I hope you have understood this right.

(Refer Slide Time: 21:18)



Once this is done then as MVA base is given as MVA base is given 30 throughout this generally base voltage generally do a sorry base MVA generally do not change, so MVA base 30, but first generator right, but first generator that its rating is 25 MVA, but on this base voltage is 6.6 KV; that means, in proportion to the ratio of this base MVA this reactance will change.

So, x g 1 is equal to 0.2 into 30 because 0.2 is given, so into 30 of 0.2 is 1 its own base right on its own dating so, but 0.2 into 30 upon 25 there is 0.24 per unit because you have to convert everything on a common base common MVA base and common voltage base right. Similarly x g 2 will be 0.15 into 30 by 15 where generatorize 15 MVA, but base MVA is 30. So, it will be 0.15 into 30 upon 15 that is 0.30 per unit.

Now, in the case of generator 3 base MVA is 30 and this is also 30. So, there ratio 30 by 30 will be cancel, but it will become 0.15 into 13.2 upon 11.5 whole square is equal to 0.2 per unit the idea is I mean if you have any confusion it will be something like this right. I have made something come calculation for your for generator this thing. Generator impedance actually given 0.15 per unit for generator 3, for these generator it is given data it is given. So, its rating is 13.2 KV one its own dating, one is own dating or own base 13.2 KV and 30 MVA. So, 0.15 it will 13.2 square upon MVA base.

So, MVA base is this generalized 30 MVA and MVA base is also 30 m v a. So, Z B 3 is equal to that your and your base impedance on is any con convert this base impedance MVA base both the cases same 30 30, but will base for this side that is that generalized 3 side we obtain base voltage 11.5 KV right; that means, this Z B 3 11.5 whole square by MVA base right. This is actually ohm we convert it to its own rating and this is the base value we got we got 11.5 right therefore, x g 3 per unit will be x g 3 upon Z B 3 this is the x g 3 means this ohmic values, this ohmic values.

So, if you bring if you put it here the MVA base MVA base will be cancelled. So, finally, it will become your x g 3 per unit 0.515 into 13.2 whole square upon 11.5 square and that is per unit right; that means, your x g 3 will become 0.20 per unit right. So, this way you have to transform. For transformer 1 x T 1 0.10 per unit right because transformer your where this is rating I will show you the data, for transformer similarly for transformer also base MVA 30 transformer rating is also 30.

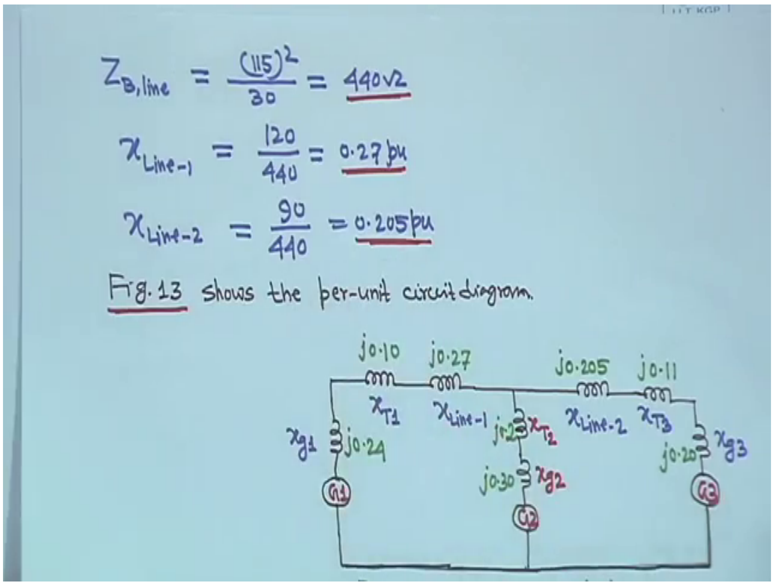
So, base MVA we will not affect, but voltage will level we have to see. So, for transformer x T 3 will be 0.10 120 upon 115 square because this transformer T 1 actually a 115 your what you call sorry; this is this transformer T 1 and lines other side is 115. So, transformer T 1 will remain same because base voltage are 30 MVA 6.6 KV, primary side. So, secondary side is 115. So, that is why there is no change for transformer T 1 right it will remain as it is.

Now, for transformer T 2, transformer T 2 it is its say a rating is just for just 1 minute let me find out the data T 2. Transformer T 2 it is 15 MVA, but again 6.6 delta side 115. So, voltage we will not effect because 6.6 KV is the base voltage. So, other side will be 115 automatically, but rating MVA rating is different 15 MVA, but base MVA is, base MVA is 30, base MVA is 30 right; that means, x T 2 will be 0.1 into 30 upon 15 same as those generator we have doing. So, it is 0.20 per unit.

Similarly, x T 3 for transformer T 3 right it is 3 single phase transformer as you made, but is rating is per unit it is 0.10. So, if it is 3 listen one thing that for single phase or 3 phase does not matter even it is given per unit means you have to take 0.10 as it is 3 phase, please do not multiply by 3 or root c it is power unit given wherever things will be wrong whatever is there you will take right. So, x T 3 will be 0.10 and base impedance is 30 and transformer rating is also 30 MVA. So, only that 0.1 into 120 upon 150 square it will be if you that is equation 16 again or same as before that whatever I have made it similar way you will get this 0.11 per unit right. So, all these impedances you have got.

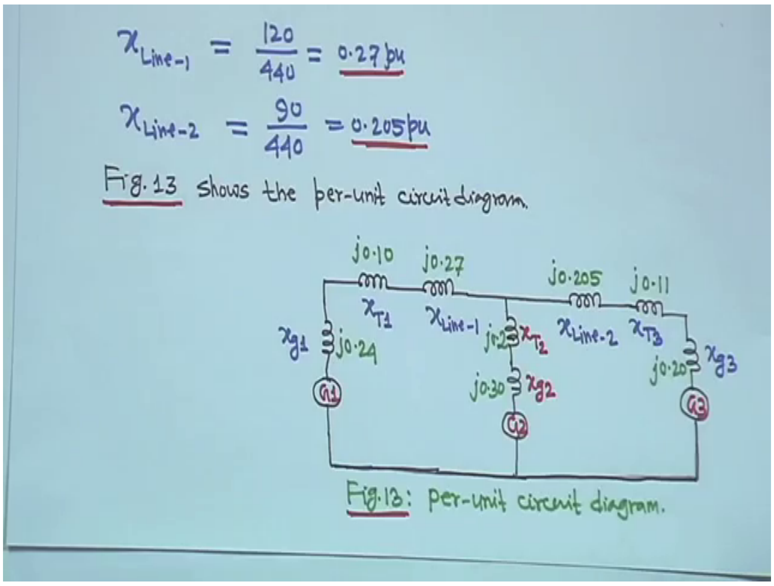
So, here also for this calculation I have made it here also for we can go through this one also.

(Refer Slide Time: 26:58)



And now for line it 115 KV is the line base voltage. So, Z B line is 115 square upon 30 that is 440 ohm. So, x line 1 120 by 440 is equal to point your what you call 27 per unit because line reactance such given 120 ohm, so it is 0.27 pu. Similarly for x line x line 2 is equal to 90 upon 440 that is 0.205 per unit. Now look at this diagram, now you see this equivalent that per unit diagram right.

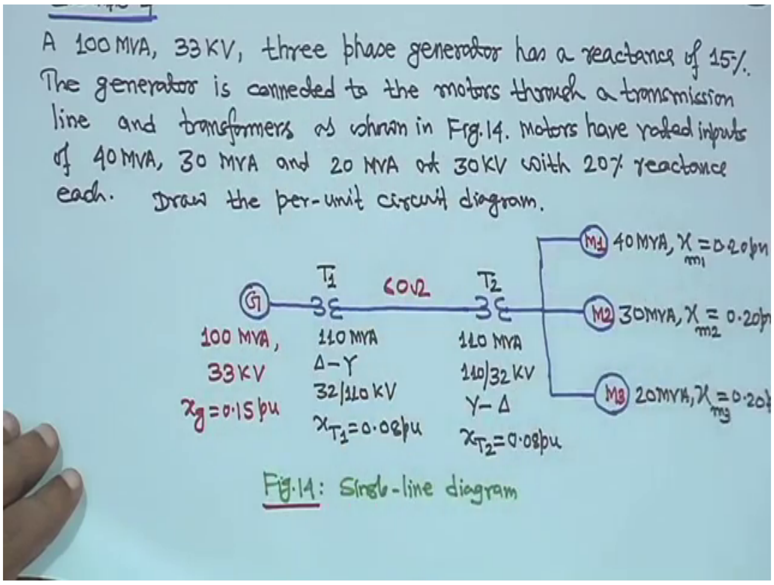
(Refer Slide Time: 27:33)



So, this is generated 1 and this is your generator 1 right. So, its 0.224 x g 1, x T 1 is point your 1 0. So, this is transformer T 1 then line is coming then this x this is x line j 0.27 we have got right. Now this is generate 2 is connected it between this 2. So, it is generate 2 it will be in parallel right this G 2 and G 3 will be in parallel right, these two are in parallel therefore, this is your x T 2 this is x T 2 T 2 that is your j 0.2 here right and x g 2 we computed that is j 0 point generate 2 per, then this line is coming x line 2 then this is x line 2 j 0.205 then x T 3 is coming that mean this one is coming now x T 3.

So, it is j 0.11 then this generator x g 3 is coming here j 0.20 and compute the circuit. So, this is the per unit circuit diagram right. So, this is G 1 and G 2 G 3 are in parallel that is why it is in parallel right. So, this is per unit diagram. I hope this one you have understood right this is a, this is I mean slightly difficult one, but just you have to see with difficult in this is that you have to see that you have transform every quantities in appropriate base per unit values by converting that to the appropriate base right base is more important right. So, next is another one this is another type right.

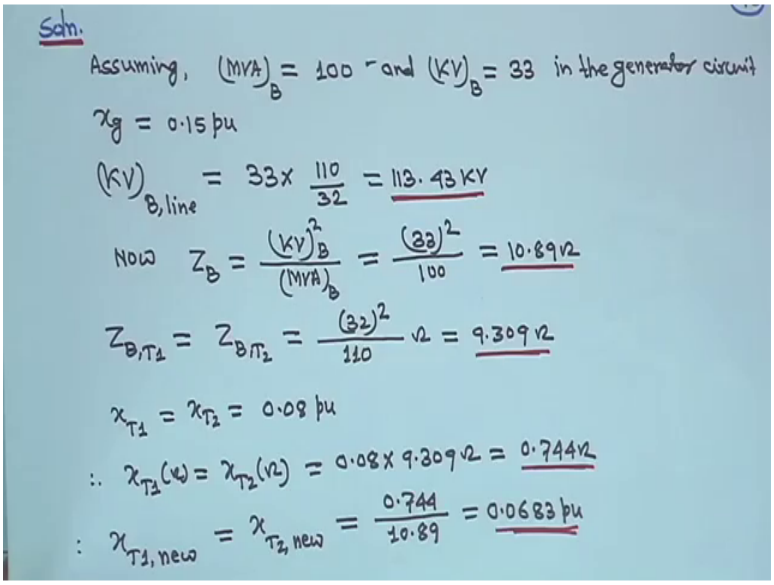
(Refer Slide Time: 29:26)



So, in this case a 100 MVA 33 KV 3 phase generator has a reactance of 15 percentage that is 0.15 per unit. The generator is connected to the motors right through a transmission line and transformer as shown in figure this is figure 14 I will come to that motors have rated inputs of 40 MVA 30 MVA and 20 MVA at 33 30 KV with 20 percent reactance each draw the per unit circuit diagram; that means, you have a generator it is hundred MVA 33 KV right and x g is equal to 0.15 per unit is given this is your transformer T 1 is there it is 110 MVA transformer rating is not mention here. But here it is mention 110 MVA it is delta transformer delta side is 30 2 KV and star side is 110 KV all are line to line and x T 1 reactance of this transformer is 0.08 per unit and then line is call then this is the transmission line this is a 60 ohm this is 60 ohm and this is transformer T 2.

Here also 110 MVA transformer T 2 also 110 MVA voltage also 110 by 30 2 k slash 30 2 KV that is high voltage side is 100, I told you earlier the star side generally k for high voltage side and delta side is for the low voltage side right. So, 110 by 32 KV is the star this side is star, this side is delta right and x T 2 also 0.08 per unit. Now here 3 motors are connected in parallel right, one rating is 40 MVA and x m 1 is equal to 0.20 per unit this is motor 1 reactance similarly 30 MVA another one motor 2 is 0.20 per unit and 20 MVA another one and motor reactance is point with j j j not so and every not so in everywhere, but in the final per unit diagram we will put the j right.

(Refer Slide Time: 31:33)



So, assuming you have to here, nothing has been mentioned. So, you have to assume that MVA base is you assume it is 100 right and KV base you have assume 33 in the generator circuit right. So, MVA base; that means, from generator side we have taken generator rating is given 100 MVA 33 KV base, 33 KV. So, this 33 KV base voltage and hundred MVA this thing we are choosing as a base such that x g you will never change right therefore, x g will remain as it is 0.15 per unit right therefore, KV B line that that is your line base, base voltage will be 33 into 110 by 32 because this transformer actually 32 by 110 line side is 110 KV right, but we have to converted to the common base. So, that is why it is, but this voltage you have taken 33. So, line side will be 33 into 110 by 32 that will become 113.43 KV.

So, now Z B is equal to your KV square base upon MVA base that is actually 33 square upon 100 that is 10.89 ohm this is that common base it is Z B because base m is 100 and this thing. So, Z B T 1 is equal to Z B T 2 is equal to 32 square upon 110 ohm is equal to 9.309 ohm because transformer T 1 and transformer T 2 they have the same voltage rating right and that is why on the; your base voltage you are taking 33 KV. So, low voltage side is 32 KV for those transformer. So, KV square MVA is 110 for the transformer it is given. So, that will become 9.309 ohm right therefore, x T 1 and x T 2 will be it is given 0.08 per unit; that means, x T 1 ohm x T 1 is equal to x T 2 ohm, but both the transformer same per unit you converted ohmic values 0.08 into 9.933 upon 9.309 ohm that is 0.744 ohm.

So, this is the ohmic value for the transformer reactant; that means, on its own rating you find out what its base impedance and then you convert it to the ohmic values right. But base impedance is 10.89 therefore, x T 1 new is equal to x T 2 new 0.744 upon 10.89 0.0683 per unit this is the new values. Of course, this same thing you can use equation 16 that in terms of new and old values of the base quantities and the per unit quantities. We will come again.

Thank you.