Power System Analysis

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Lecture - 17
Power System Components and Per-unit System (Contd.)

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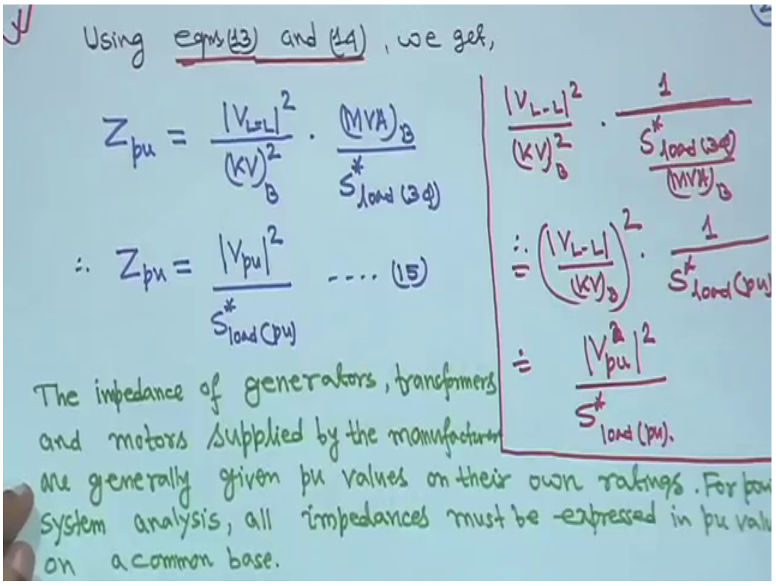

So, we have just seen this one that Z per unit is equal to magnitude of V per unit square upon s conjugate load that per unit right this is equation 15. So, the impedance of generators transformer and motors supplied by the manufacturer are generally give him per unit values on their own rating; that means, when you are buying a generator or transformers right or motor, you will see that on the name plate that MVA rating is available and per unit reactance also it is available right in general per unit impedance right. So, for power system all this must be expressed in per unit values just because of your easy calculation that only thing is that that you have to transform everything on a common base right.

So, when quantities when base quantities are change from MVA old to MVA base new, and from K V b old to k b v new, the new per unit pet unit impedance can be given as it is something like this, that suppose this formula I have written just now it show you.

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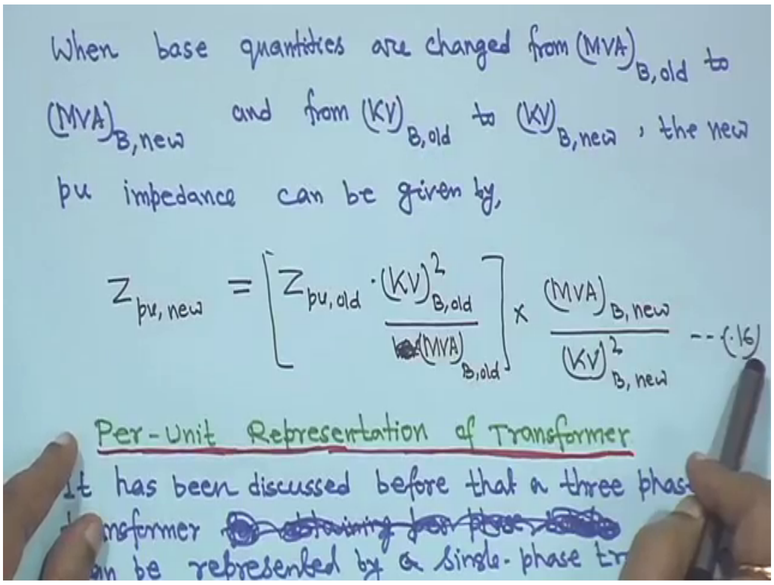

That this is frequent this will be this this is equation 16, and this will be frequently use that Z per unit new is equal to Z per unit old into K V square base that is old right divided by MVA base old into MVA base new divided by K V base new square this is equation 16; that means, for example, suppose you have per unit impedance or reactance or resistance whatsoever suppose you have this is your Z per unit old right this is the old value and this value on its base we are writing that is K V base old and MVA base your new right.

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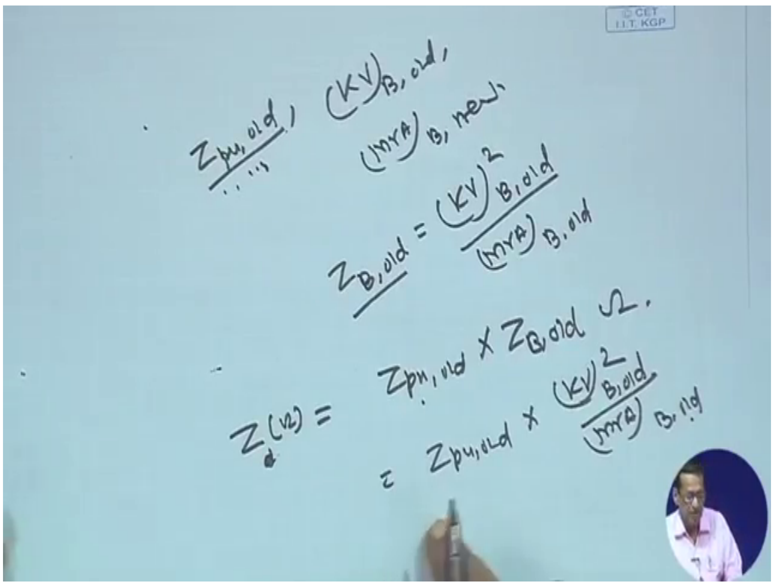

Therefore this Z base old is equal to your K V base square right old divided by MVA base old right. So, this is the base impedance for the old base therefore, you convert this Z per unit old into ohmic values; that means, your Z ohmic values right I can put this one is equal to Z per unit old, this is per unit values into Z base old right. So, this is actually ohm right because this is your Z base old. So, multiply; that means, it is multiplied by Z p u old into K V square right just hold on, K V square base old divided by MVA base old right. So, this is the ohmic value.

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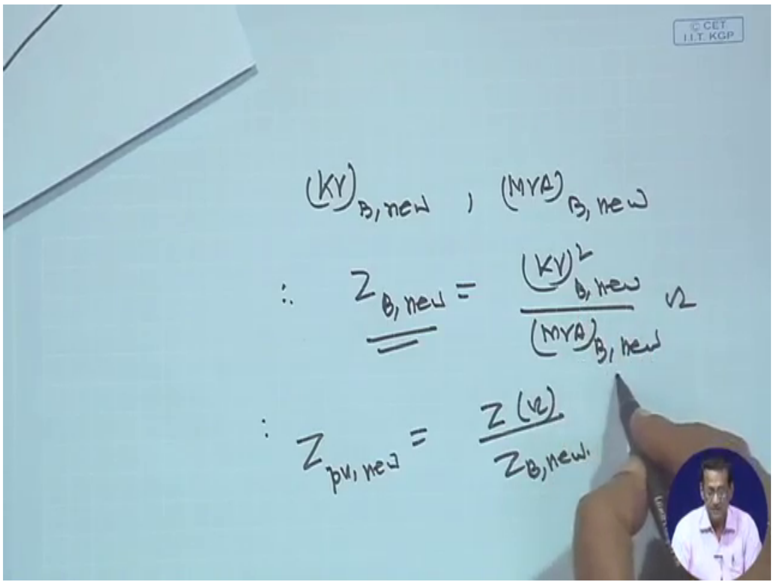

Now, suppose the new base value is given, say that is your suppose this is given you have to transform with for this one suppose this is your K V base new, and say MVA base new right therefore, Z base impedance that new value is equal to K V square B new divided by MVA base new right; that means, this is the new value this is this is actually ohm this is the new value therefore, j. Now, therefore, your Z new right I can write that Z per unit values new is equal to your Z that ohmic value whatever you have got here this ohmic value, this ohm divided by Z B new right.

Now, this Z ohmic value is this one, you substitute here you substitute here and this j and this Z B new is here K V square base new available MVA is where you substitute here, then you will get this expression that Z p u new is equal to Z p u old K V square base old upon MVA base old into MVA base new upon K V square b new right. This is equation 16. Actually no need to remember anything no need to put it in your memory just old impedance you convert and that corresponding base is given for that. So, for which you can compute this part right and divided by you are the new base impedance right. Now next is that this is equation sixteen for numericals these has to be wholes frequently right. So, per unit representation of transformer. So, we have seen that a three phase transformer can be represented by is a c or single phase transformer, because it is balance system. So, it can be represented for obtaining per phase solution of the system now just hold on.

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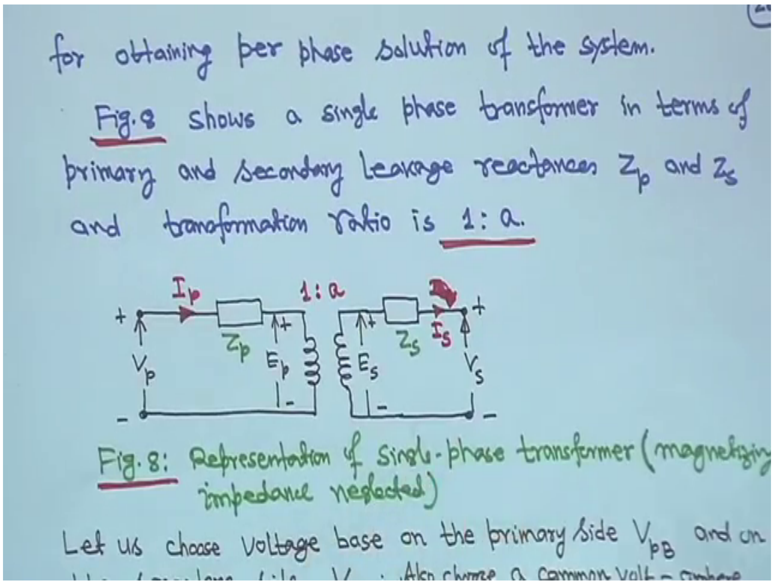

So, now this is the single phase diagram right representation of a your these thing, magnetizing impedance is neglected for this one for the timing no magnetizing impendence is consider right. So, this side we refer to as a pri primary this is figure 8 right. It says a single phase transformer in terms of primary and secondary leakage reactances, Z p this is Z p primary side and this is Z s right and this is your terminal voltage V p and this is your secondary side is V s right and voltage E p is across the winding and the E s pi where winding, and E s is across the secondary winding right and trans ratio it is taken it given as 1 is to a right. 1 is to a means just I will tell you very simple thing we know it right one is to a means

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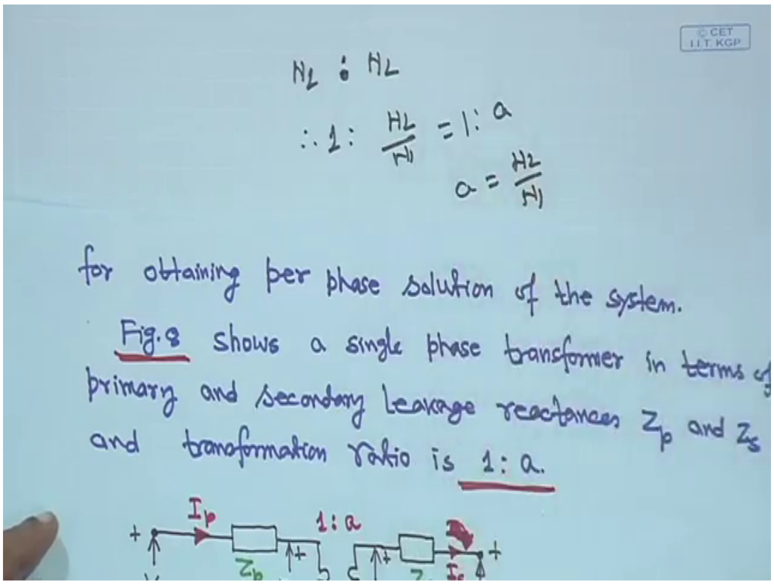

that is suppose primary side trans ratio is N 1 and secondary side trans ratio is N 2. So, N 1 is to N 2; that means, it can be written as 1 is to N 2 by N 1 is equal to 1 is to a right and a is equal to N 2 upon N 1.

So, N 1 is the primary side trans number of trans, N 2 is the secondary side number of trans. So, a is equal to N 2 upon N 1 right. So, that is why trans ratio transformation ratio is given one is to if this way we will do right. Now this whole this thing you have to you have to write down the your equivalent your voltage equations refer to primary or secondary we will see that both are same in per unit right. So, let us choose a voltage base on the primary side. Primary side voltage base we are choosing V p B, p stands for primary and b stands for base in right and on the secondary side your making it V s B is stands for secondary and V base.

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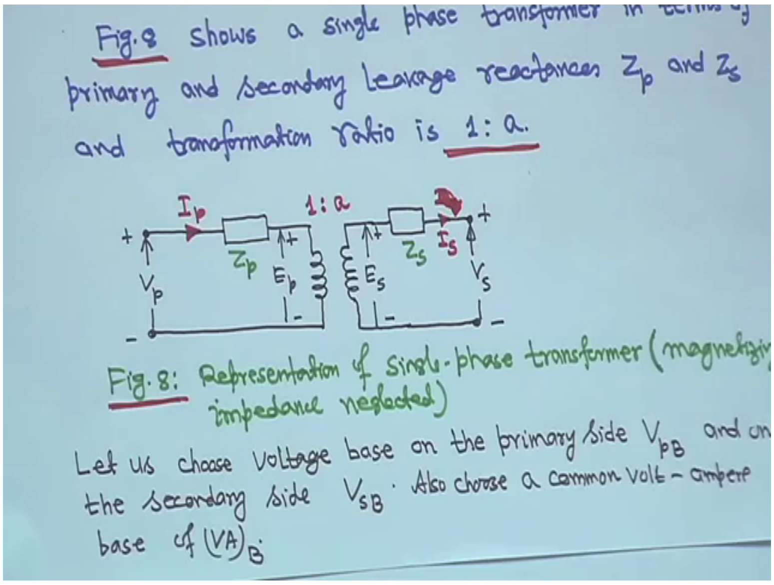

So, V s B also you have to choose a common volt ampere base. So, that is your V a V a base right it is volt ampere base for this transformer right.

Now, and this is the your what you call this.

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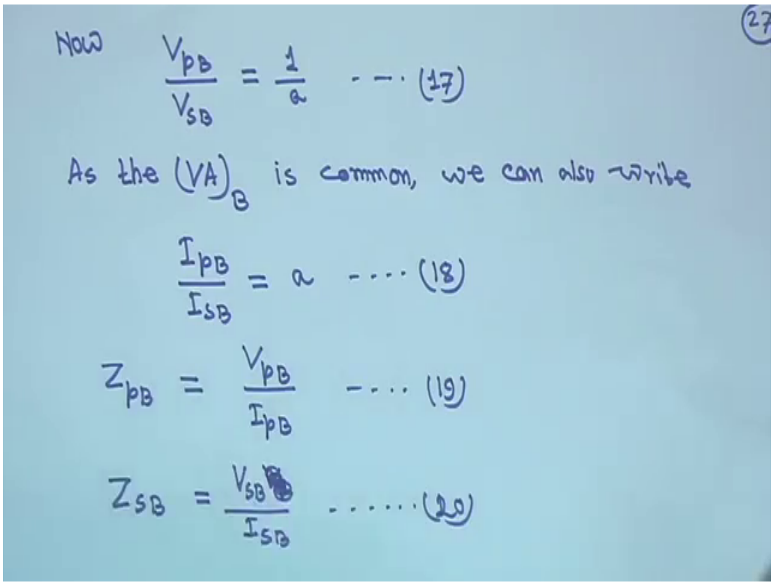

This one; that means, B primary base upon V s B base it can be written as 1 upon a, the it is it is as you know that you know if it is primary side voltage is V p secondary side voltage is V s right.

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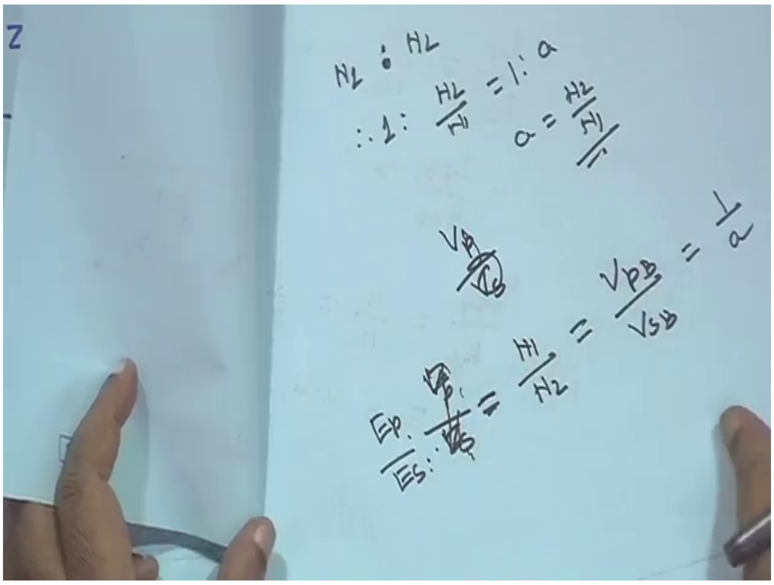

Then your I making it here if primary side voltage is V p secondary side voltage is V s. So, V p upon V s right. So, is equal to you can write that primary side winding is a number of your trans N 1 and this you know the secondary trans N 2 right this one also can be written as V p B base upon V s B base right that is why we are writing.

So, that and your a is equal to a is equal to you have seen that a is equal to N t N 2 upon N 1 that is why this one actually 1 upon a right because it is N 1 upon N 2, but a is equal to N 2 upon N 1 so; that means, V p B upon V s B is equal to 1 upon a right therefore, as the volt ampere base is common, we can also write I p B by I s B is equal to a; you know if the primaries hold on.

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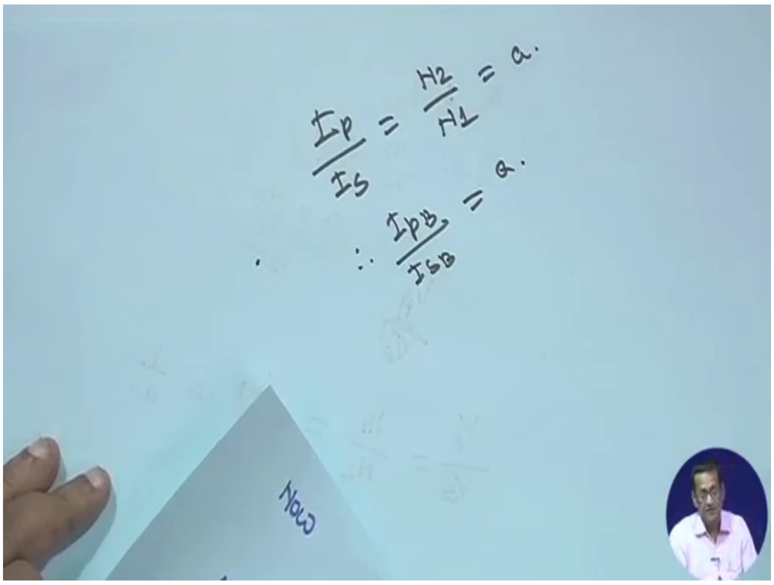

if the primary side current is I p and secondary side current is I s, that you know it is N 2 upon N 1 right and N 2 upon N 1 just we have seen that is equal to actually a therefore, this one also can be written as primary side base current by secondary side base current is equal to a right.

So; that means, we are writing same thing that primary side base current by secondary side base current is equal to a this is actually equation 18. Therefore, primary side base impedance Z p B is equal to primary side base voltage by primary side base current this is your 19. Similarly for the secondary side the base impedance V s B upon I s B that is secondary side base voltage upon secondary side current, base current that is equal to equation is equal this you can be said 20 right. Therefore, from figure 8 right your secondary side voltage from figure 8 you can write you apply your cause of second law in this loop right.

So, it will be I s into Z s plus V s minus E s is equal to 0 right; that means, this from that means.

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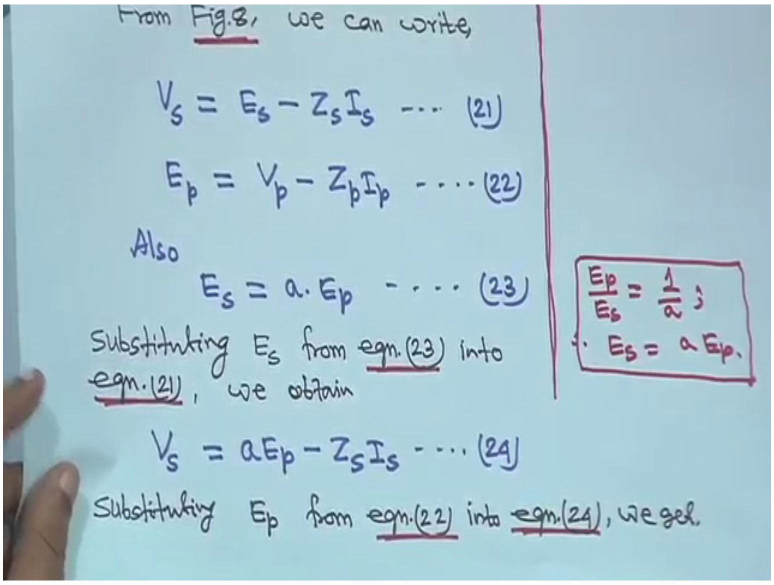

V s is equal to actually E s minus Z s into I s this is equation 10 21 right. This equation we are writing from this figure 8 and on the second that is we are apply K V here right therefore, and similarly E p is equal to similarly here E p is equal to I p into Z p plus E p minus V p is equal to 0 therefore, E p is equal to V p minus Z p into I p this is equation 22. So, secondary side and primary side these two voltage equations are retained right. So, once it this is actually your you one thing you should see that here we writing the terminal voltage right and this is second time primary said we are writing this find voltage (Refer Time: 11:48) E p you are writing right.

Also this E s upon E p is equal to a; that means, it is something like this that this voltage is E p this voltage is E s right. So, what we can do is that your these thing that E p is the primary voltage.

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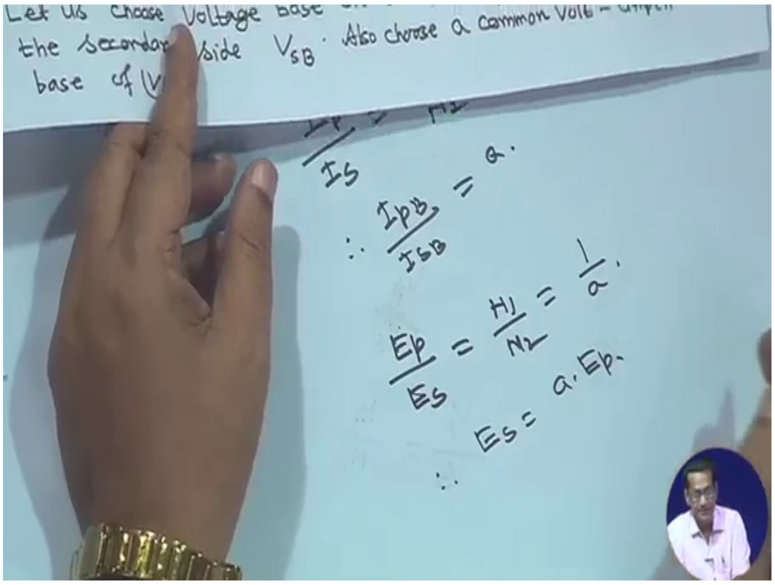

And E s the secondary voltage that is equal to N 1 upon N 2 that primary number number of tons N 1 secondary number of tons N 2 right; that means, this one actually is equal to one upon a; that means, your E s is equal to a into E p right. So, this way you can this thing what you call this these equation E s is equal to a into E p we are writing, here I just now I showed that E s is equal to a into E p right.

So, just one thing here actually it should have been E p upon E s right this correction right actually I did not look at the figure it is e upon E s right. So, that is equal to V p B upon V s it is not V p upon V s it should be E p upon E s right because I did not look at the figure at the time right. So, it is a just E p upon E s instead of V p upon V s right . So, this one your therefore, this E s is equal to E p you substitute E s from equation 23 I mean this one into equation 21 here you substitute right. If you do so, you will get V s is equal to a into E p minus Z s into I s right that is equation 24.

So, now substituting E p from equation 22; that means, from these equation 22, this E p you substitute here you substitute here right in that is into equation 24 then.

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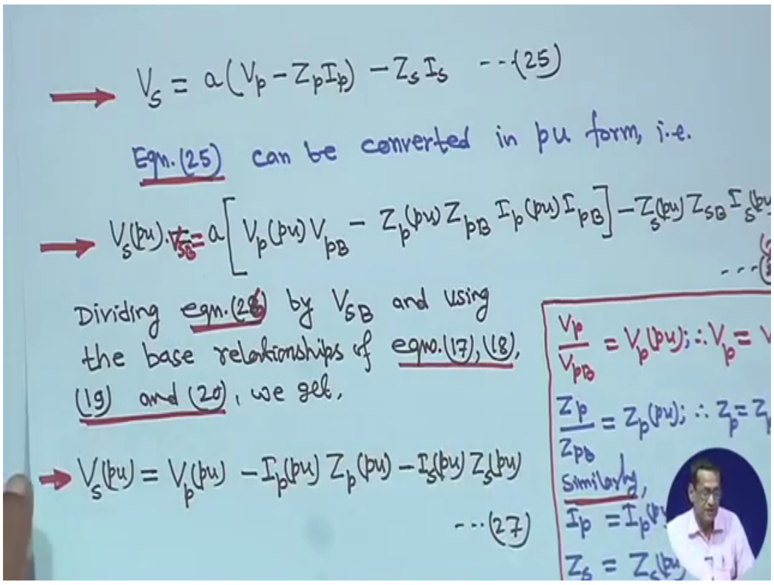

What you will get this one that V s is equal to a into V p minus Z p I p minus Z s I s this is equation 25. Now this equation we have to converted to per unit form right. So, what you what one can do is that when you are trying to converted to per unit form, then simple thing is that V s is equal to a real voltage is equal to say V s B V s per unit voltage of the secondary side into V s B this is actually.

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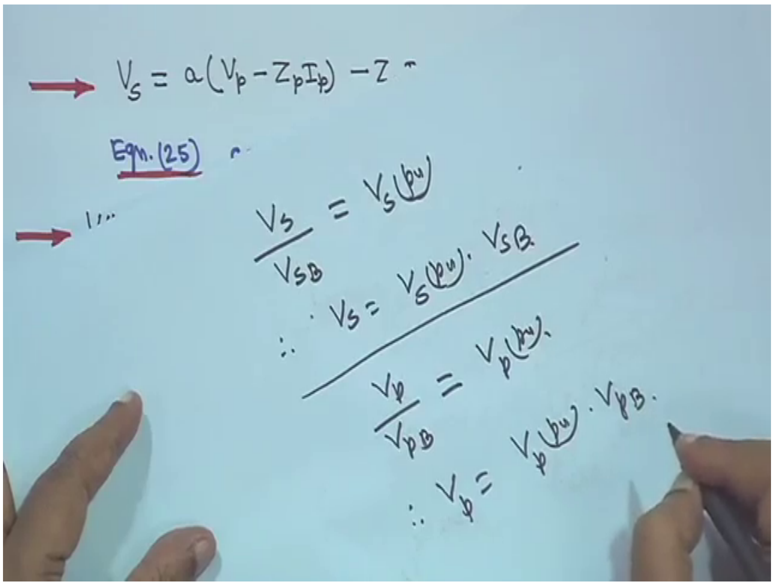

This is actually into this V s is equal to look this V s upon V s B is equal to V s this is per unit voltage; that means, V s is equal to you can write V s per unit into V s B right. That is why instead of V s instead of instead of V s we are relating a V s p into V s B is equal to a.

Similar way that V p it is V p we are writing, on the primary side base voltage is V p b. So, V p upon V p B is equal is equal to your V p per unit right; that means, V p is equal to V p per unit into V p B right. That is why here we are writing V p is equal to V p B V p per unit into V p per unit means this is a per unit values into primary side base voltage right.

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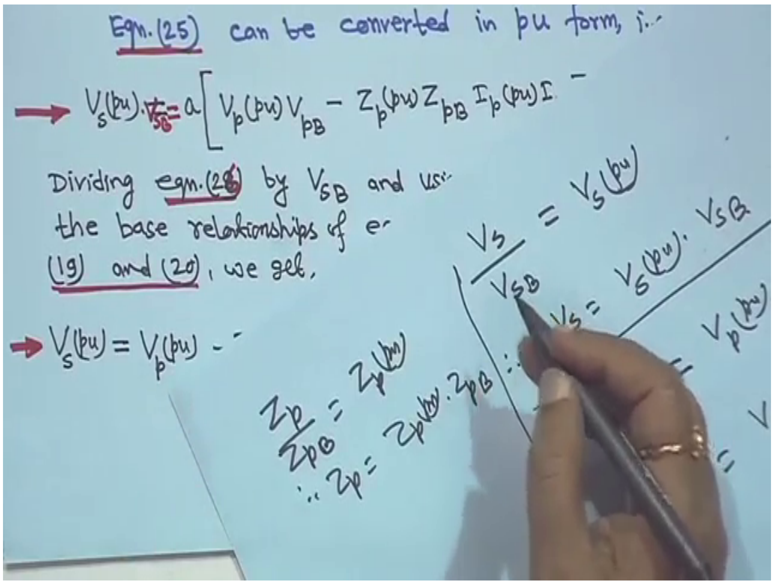

Similarly Z p that same thing that Z p upon Z p B is equal to Z p per unit right; that means, Z p is equal to Z p per unit into Z p B. So, this Z, this Z p actually replace by Z p u and Z p B right this is the per unit impedance.

Similarly, I p case also now everything is understandable. So, I p case also we are putting I p per unit into I p B right. So, bracket close now similarly per secondary side it is minus Z s I s term this is actually this minus Z s I s term. So, Z s is equal to also Z s per unit into Z is b there secondary side base impedance right and this I s is equal to also I s per unit into I s B the secondary side base current, this is equation 26 right. So, all this thing int I mean can be put in the your per unit form, but all the time, but have the same time their base values all are multiplied right. Now divide dividing equation this 26 by divide equation by V s B. So, the left hand these V s B term is there. So, all this equation you divide by V s B and using the base relationship eq of equation 17, 18, 19 and 20.

So, whatever equations we have shown for base quantities that is 17, this 17 18 19 and 20 you use that and substitute that.

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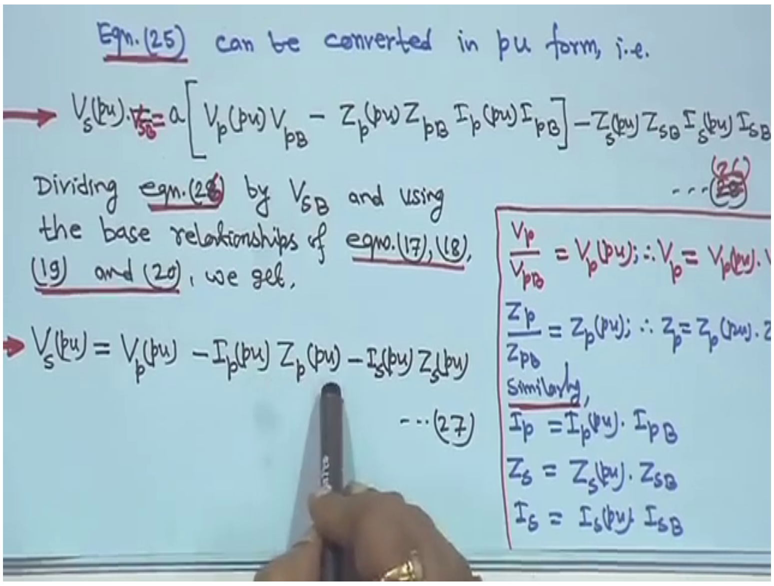

if you do so, you will get the V s per unit this part I think understandable you can do it right. So, V s per unit is equal to V per unit in minus I p per unit into Z p per unit, minus I s per unit into Z s per unit. In bracket we are writing all per unit to indicate that these are all per unit values of voltage and current and impedance right this is equation your 27.

So, to replace all this things. So, whatever I showed it is I put on the left hand side for your this thing for example, I p is I p p u into I p B, Z s is equal to Z s p u and Z s B and so on. So, left hand side this has been worked out right. So, this is actually your per unit impedance I mean this is that your ah secondary voltage, primary volt all in your per unit that is why bracket per unit is written right.

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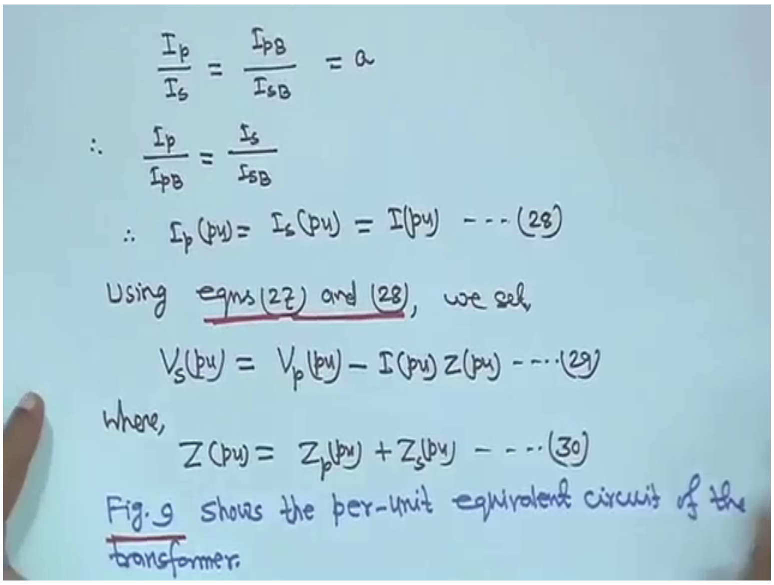

Next is now we can write that I p upon I s is equal to I p B upon I s B. This also earlier we have told that primary ratio of primary to secondary current in is equal to ratio of primary side base current by secondary side base current is equal to a. This we have discussed earlier therefore, I p upon I p B is equal to I s upon I s B. I p primary side I p upon I p B is I p per unit is equal to secondary side also I s per unit, is equal to we assume I per unit.

That means in per unit primary side and secondary side both the currents are same for transformer, is equal to we assume is single value that is instead of p or s we will simply write that is I per unit that is a per unit current. Because per unit current primary and secondary side both are same. Now using equation your 27 and 28; that means, the previous equation, in this equation you put I instead of I p, instead of I p and I s because I p p u is equal to I s p u is equal to I p u. So, this I p p u is equal to I and similarly I s p is equal to I both are in per unit substitute. If you do then you will get V s per unit is equal to V p per unit minus I per unit into Z per unit right this is equation 29.

Where Z per unit is equal to Z per unit secondary side plus Z s that is sorry Z p Z p per unit primary side per units values, plus Z s per unit secondary values this is equation 30 right so; that means, this is the your what you call per unit all this equation secondary and primary side this related to per unit right.

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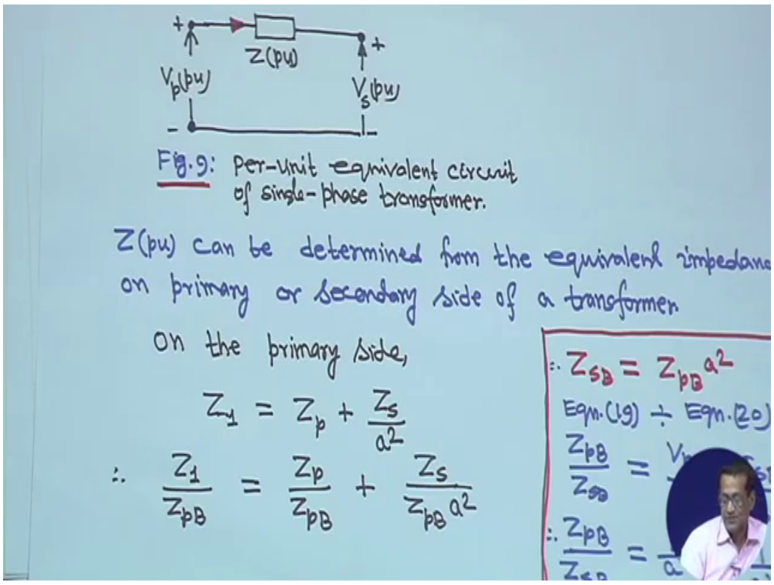

So, if you your what you call if you draw now the simple circuit diagram right for the transformer. So, it will be like this, this is the per unit equivalent circuit of single phase transformer. This side is primary side this is per unit voltage secondary side per unit voltage and this is the Z p u right.

So, that is that j your Z s p u plus Z p p u right. Now Z per unity values can be determined from the equivalent impedance on primary or secondary side of a transformer for example, on the primary side right when you primary side impedance in Z p and when you go for transforming bring that transformation no equivalent impedance. So, secondary side impedance Z s, but it is refer to primary we will make. So, it will be Z s upon s square that you know right; that means, your what you call that mean both side you divide by pri because it is refer to primary Z 1 is refer to the Z 1 is a primary side your impedance we want to find out. So, Z 1 you divided by primary side base impedance Z p B, is equal to Z p upon Z p B plus Z s upon Z p B into s square right.

Now, this Z s this thing your what you call this is Z p B into s square. Now this is actually Z s B because if you equation 19and 20 you have made it right just hold on just just hold on equation 19 and 20. So, this is equation 19.

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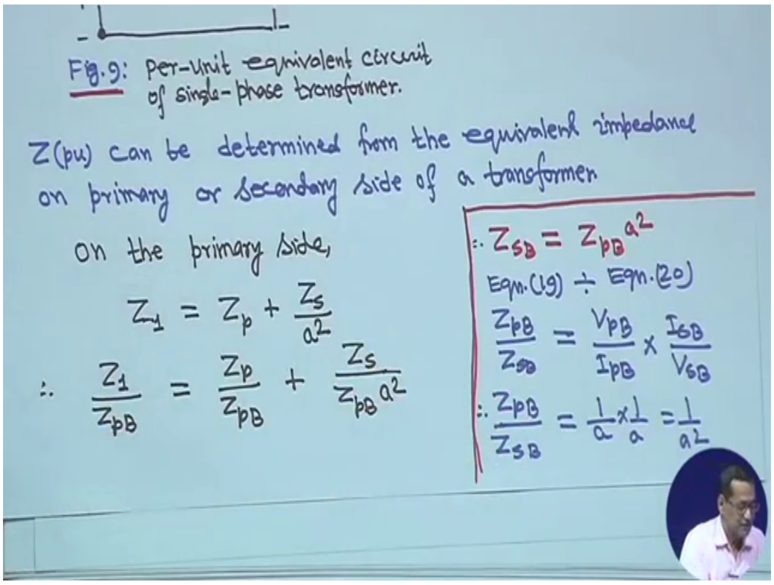

And Z p B is equal V p B upon I p B, and this is equation 20 Z s b is equal to V s B upon I s b. So, eq you divide equation 169 by equation 20 right. That that little bit exercise I have done on the right hand side here. So, therefore, if you do so, it will be Z p B upon Z s B is equal to V p B upon I p B into I s B upon V s B right; that means, Z p B upon Z s b we will become one upon a square; that means, Z s B will be s square Z p B.

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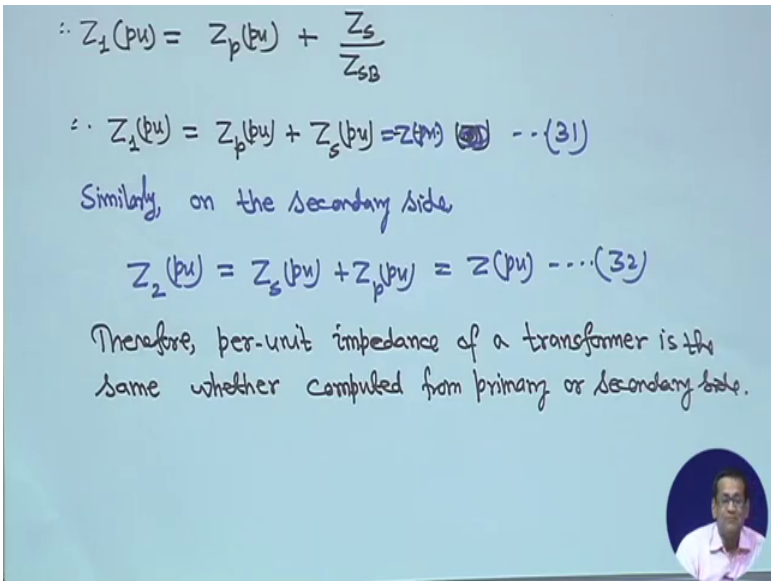

So, basically a square Z p B is actually Z s right that is going to the next slide; that means, Z 1 per unit this per unit value of impedance is equal to Z p u plus Z s upon Z s B right. So, this is Z s b also because Z s upon Z s B therefore, Z 1 p u is equal to Z p p u plus Z s p u is equal to here making it as a Z per unit right this is equation 31. Similarly if you do on the secondary side you will get the same thing then Z 2 p u is equal to Z s p u plus Z p p u is equal to Z p u; that means, that in per unit that refer to primary side or refer to secondary side that impedance per unit value of impedance remain same therefore, per unit impedance of a transformer is the same whether computed from primary or secondary side.

That means this is the major advantage of transforming all the parameter seen per unit values right. So, after this we will take few good examples and then we will come to the method of voltage control right different thing we will come.

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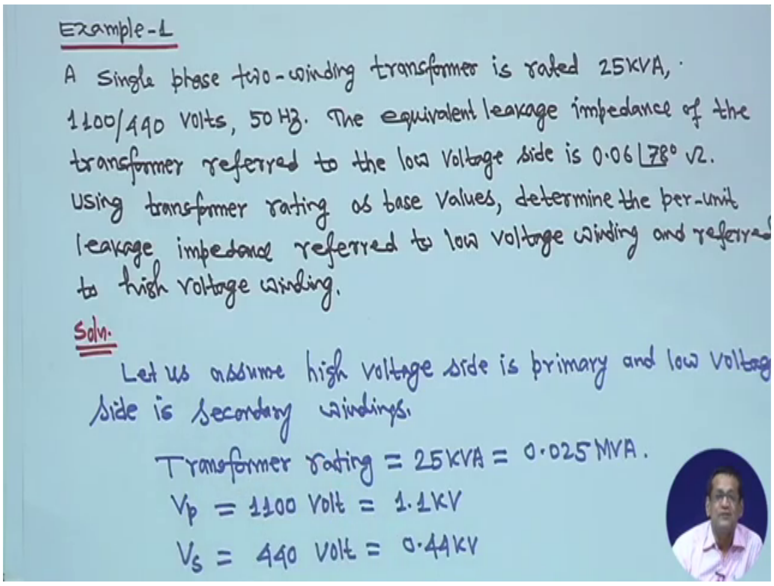

So, first generally this your what you call this per unit transformation and this numerical many things you have to understand. Whatever little bit theories we have seen that is fine now all this theories we have to apply for this your what you call considering numerical. This per unit system actually transformation not only for this small numerical at the same time it is require for our pass system analysis right.

For all sort of things whenever you study everything that voltage, current, power, impedance we consider everything is in per unit values, this makes our calculus and simple right by choosing proper based values first. Next we will take one example first example we will take few example such that things will be or different type of example such that all the ideas will be clear right. So, first one is a single phase two winding transformer is rated 25 K VA. That mean say it a your 25 K V A means it is distribution transformer right and 1100 by 440 volts 50 hertz the equivalent leakage impedance of the transformer referred to the low voltage side; that means, if we will take 1100 is primary then 440 volts secondary.

So, referred to the low voltage side is 0.06 angle 78 degree ohm this is the actually secondary side leakage impedance right referred to secondary side. So, using; that means, low voltage side if I take if we take 1100 volt in the primary side. Now using transformer rating of as base values; that means, the this is 25 K V A base K V A and this is your primary side we will be 1100 and secondary side we will be 440 right base value determine the per unit leakage impedance, referred to low voltage winding and referred to high voltage winding right.

So, first let us assume high voltage side is primary and low voltage side is your secondary windings; that means, transformer rating is given 25 K V A, it is given transformer 25 K V A is given therefore, this 25 K V A make it divided by 1000 you make it 0.025 MVA. Actually when we solved numericals rather than keeping base in K V A V A or volt, my suggestion is everything you per base voltage case you transform it to you cons a you converted to kilovolt and whatever may be the base volt ampere all that I have converted to MVA there is I think actually in my opinion then things will be easier for you to calculate right.

Therefore transformer rating is 25 K V A here we have converted to 0.025 MVA and primary side voltage is 1100 volt that we have converted to 1.1 K V. Secondary side 440 volt that is 0.44 K V right next MVA base that for transform rate is own rating.

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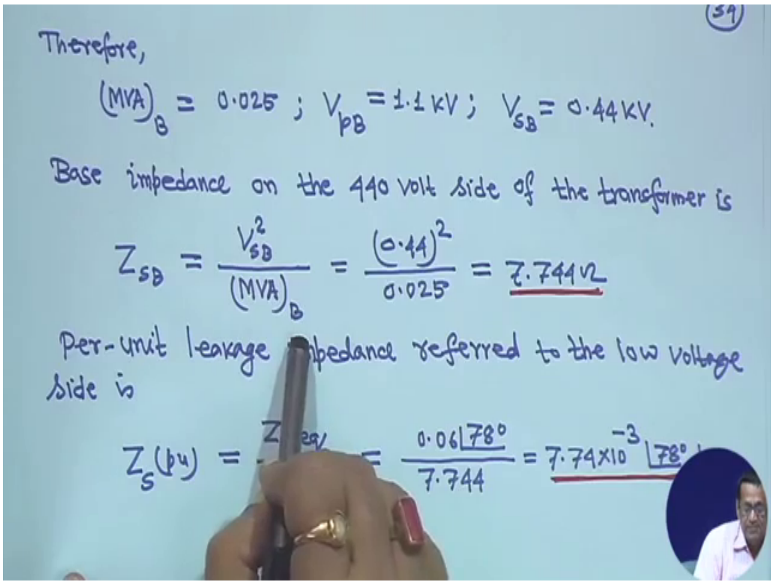

You have to find out therefore, MVA base is equal 0.05 V p B there primary side base voltage you can write 1.1 K V, and secondary side base voltage is 0.44 K V right. Now you have to find out base impedance on the 440 volt side of the transformer right.

Therefore the secondary side we are writing Z s B is equal to V square V s B square divided by MVA base. So, V s B equal 0.44 K V square divided by 0.025 is equal to 7.744 ohm right therefore, per unit leakage imp leakage impedance refer to the low voltage side that is Z s per unit Z s e q is given if this is given point by Z s B.

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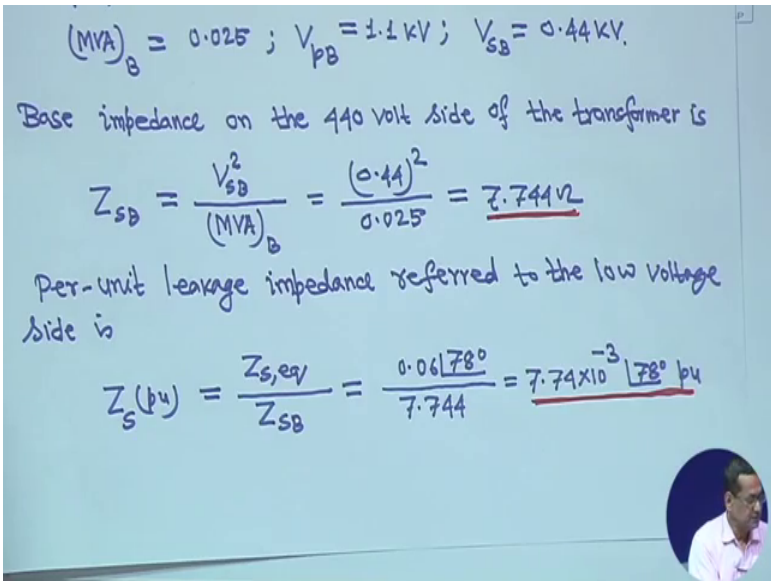

This Z s secondary side leakage impedance is given. So, it is po 0.06 angel 780 degree ohm, divided by base impedance on the secondary side that is 7.744 is equal to 7.74 into 10 to the power minus 3 angles 778 degree per unit values right this angle is also given right.

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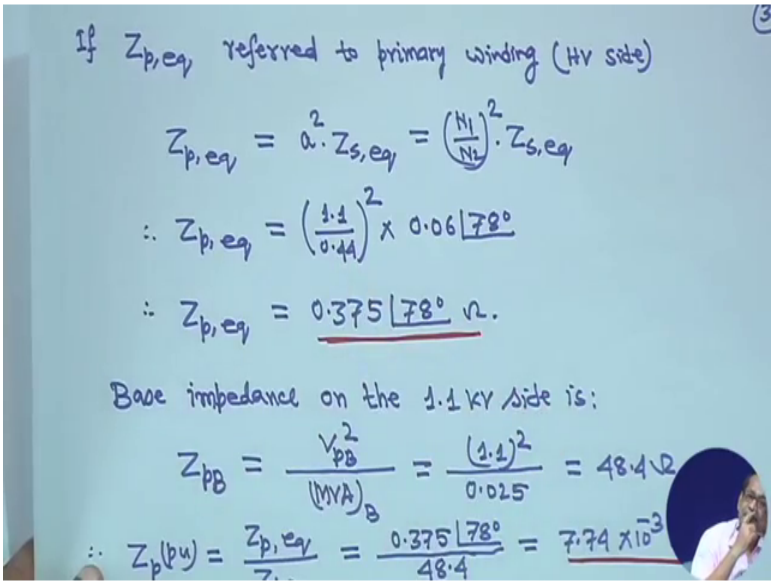

This is on the Z per unit value of the secondary side, but you have to see that primary or secondary per unit values will remain same. Similarly Z p e q refer to primary side that is winding that is high voltage side that is 1.1 K V that is 1100 volt that Z p e q will be a square Z s e q we have seen just now for transformer equivalent circuit per unit equivalent circuit your derivation, that Z p is equal to actually a square Z s square I writing Z p e q is equal to a square into Z s e q right. So, that is actually N 1 upon N 2 whole square into Z s e q right this way we are writing one is to a, a is equal to N 2 upon N 1 right N 1 upon N 2 whole square a square into Z s e q into this one.

So, Z p e q is equal to Z p e q is equal to 1.1 divided by your 0.44 whole square into zero point is 06 angle 780 degree. So, this Z p equivalent is equal to 0.3 c 575 angles 780 degree ohm right. So, once your what you call this primary and this thing you are what you call this Z p q; that means, base impedance on the 1.1 K V side is that you can make it that your Z p B is equal to V p B square upon MVA base is equal to 1.1 whole square upon 0.05 is equal to 48.4 ohm right therefore, Z p per unit is equal to Z p q upon Z p B is equal to 0.375 angle 78 degree by 48.4 is equal to 7.74 into 10 to the power minus 3, 7 angle 78 degree right.

That means this refer to secondary sides this value and refer to primary side also you will get the same value right and this one therefore, per unit leakage impedance remain unchanged and this has been achieved by specifying V p B base upon V s B rate this thing is equal to V p re rated value on the primary side 1.1 K V, by V s rated that is 1.1 upon 0.44 is equal to 2.5 right so; that means, this small example you to you just to show that whether you take refer to primary side or secondary side on per unit values this this your what you call the (Refer Time:31:06) impedance per unit impedance we will remain same.

Thank you