Power System Analysis
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Lecture – 20
Power System Components and Per-unit System (Contd.)

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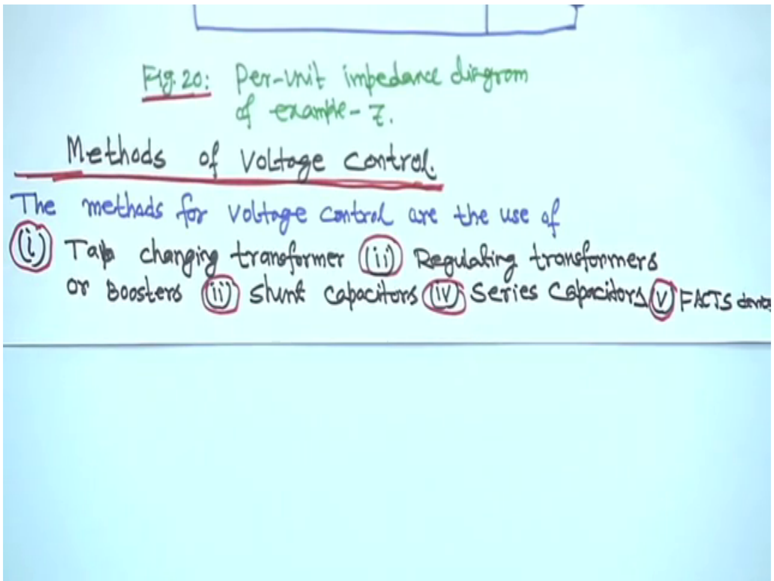

So, in the previous thing we have seen that per unit compo per unit system now we will come for that method of voltage control right. So, the methods for voltage control are the use of one is the tap changing transformer then regulating transformer or booster transformer, shunt capacitor, series capacitor and the facts devices right.

So, in this course we will not discuss about facts devices right because it is a very big topic. So, we will not discuss, but we will discuss on tap changing transformer regulators or boosters shunt capacitors and series capacitors just tell some ideas you will get right.

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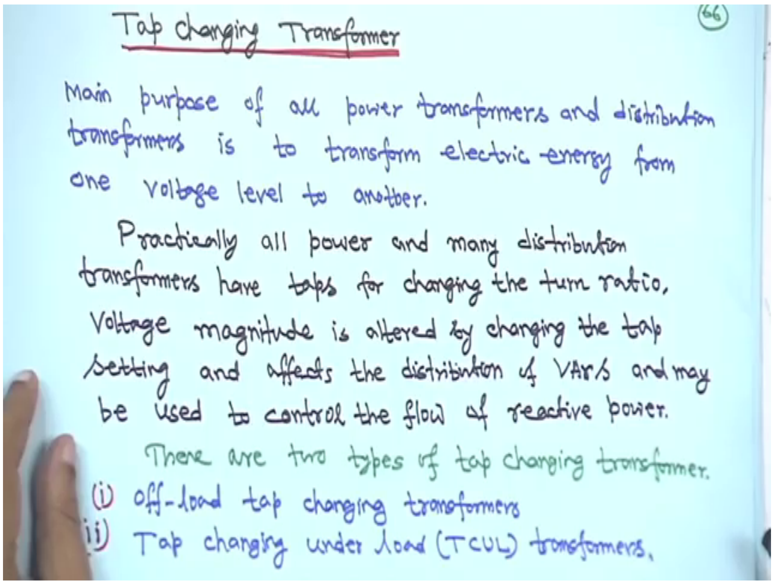

Now, tap changing transformers right that main purpose of all power or distribution transformer basically the transform electrical energy from 1 voltage level to another voltage level right. So, practically all power and many distribution transformer they have the you know they you have the taps for changing the turns ratio. So, voltage magnitude is altered by changing the your tap setting and affects the distribution of VArs that is the volt amperes and may be used to control the flow of reactive power right that is for the tap changing transformer.

So, basically there are 2 types of tap changing transformer - one is that off load tap changing transformers, another is that tap changing under load TCUL transformers right. So, 2 types of your tap changing transformer off load means you have to disconnect the load from the transformer then you have to change the tap another is tap changing under load transformer; that means, all line you can change the tap right.

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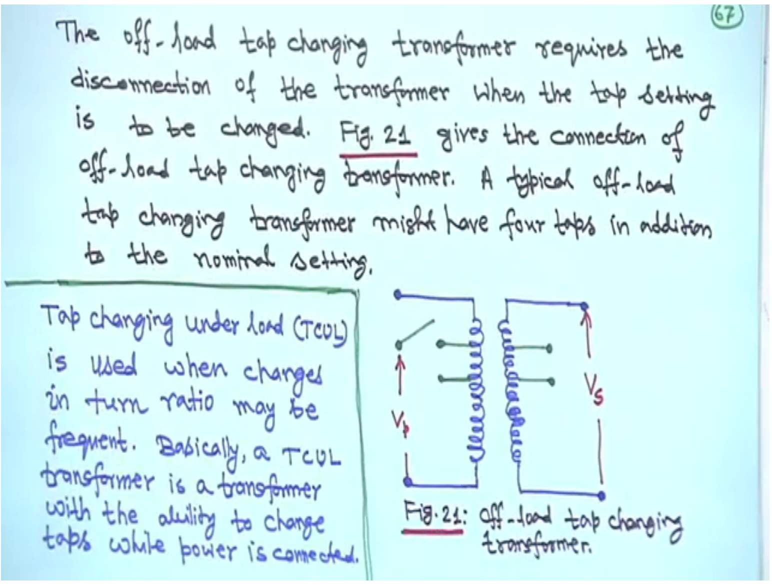

So, some schematic diagram right some schematic diagram the off load tap changing transformer requires the disconnection of the transformer from the supply or when the tap setting is to be changed right you have to disconnect the transformer from the supply right. So, figure this is figure 21, this is actually figure 21 it give the connection off load tap changing transformer right. So, in this case there are four - taps this side 2 taps this side 2 taps and a switching mechanism is there if your these thing that if you want to change the tap from this side to that side that there are four taps are there right that is why switch is owned.

So, in the other way basically you are reducing the number of trans right. So, this is primary side and this is your secondary side, if you fix your switch position is here that is full voltage is applied to that otherwise the voltage thing you are what you call if it is coming here means that voltage we will reduce to this side right similar arrangement is shown here also right. So, this is your off load tap changing transformer; that means, you have to make it off line.

Now next is the TCUL right that is tap changing under load right it is used when changes in turn ration may be frequent; that means, when you want to change the tap ratio very frequently this is not very frequently because every time you have to switch on or switch off right. So, it is not very frequently, but tap changing underload when it is necessary that you have to change the; you have to change the tap very frequently that side is at the time you have to do it on line right. So, it can change while that the power is connected to the transformer.

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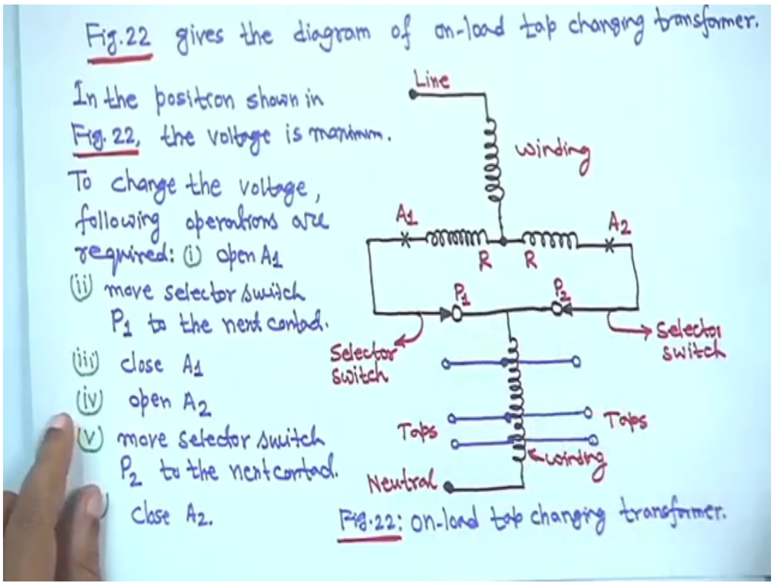

Now, the this is actually a typical your TCUL connection right that is that tap changing on load tap changing transformers, this is the connection shown when it is your what you call in the voltage is maximum this is figure 22, this is voltage is maximum this is the line and this is the neutral. These are all connections have been made shall that tap can be changed. So, several taps may be there generally in a transformer power transformer you will find that tap changing we will start from 5 or your point 6 to 5 percent to your point your what you call that plus minus ten percent right. So, 1 side if it is point 6 to 5 pa your percent if you take then I lowering or higher side totals taps will be may be 32 right I mean voltage can vary from 0.9 to your what you call that one 0.1 right, but it depends on the design.

So, in this case this diagram this is your line to neutral now this is for the maximum voltage now if you want to you have to make it online it will basically it is online in that case what will happen that this is 1 selector switch this P 1 this is another selector switch right and what we will happen here also 1 connection is there and A 1 and another thing is there what one can do is this I am not showing it again this things just listen this one you this one you can open this one you can open right once you open it bring the selector switch to the next position. That means, here right and after that you connect it to a 1;

that means, it position is change right it position is change that is why to change the value of the following operation are required 1.

Open A 1 you open this one right move selector switch P 1 to the next control; that means, from here to here from here to here right and then again you close A 1. Similarly from this side also you are what you do open A 2 similar its operation open A 2 right once is A 2 then bring move selector switch to the next switch and you bring it here right and again you close A 2 this way your voltage level we will change right. So, alignment I am not showing you again redrawing all these. So, everything all steps that is why I have written that you have to first open this one right and then move this P 1 to your what you call this position then again you close A 1. Similarly this one you open it move it here and then again you close it this way your trans ratio can be changed. So, these are the tap settings and this is the winding this is the winding right and this is selector switch this is selector switch. So, this is actually on load on load tap changing transformers schematic diagram right. Only for this course, is only this understanding that how actually it operates right.

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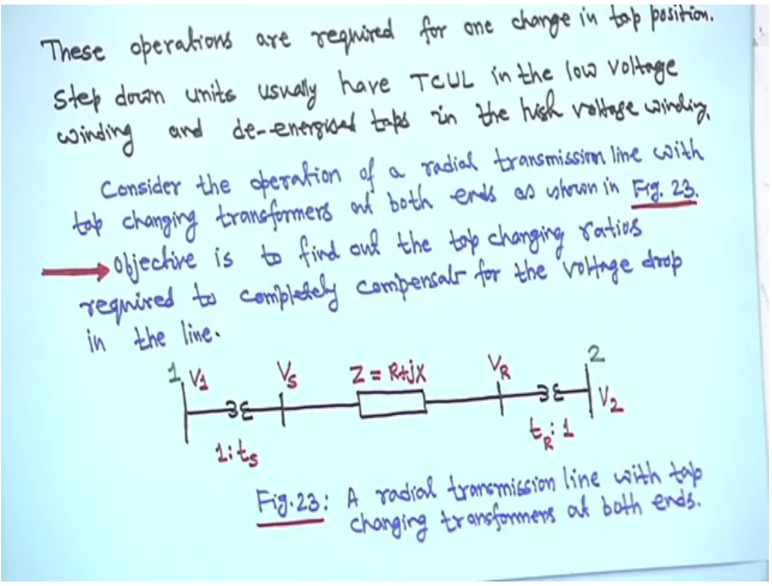

Next is this operations are required to required for one change in tap position rise. So, step down units usually I have TCUL in the low voltage winding, low voltage side for actually step down units usually I have TCUL that is on the low voltage side and the de energized taps in the high voltage side. So, now, to little bit your for further understanding you consider this thing this operation of a radial transmission line just for the purpose of understanding we have taken it your radial transmission line right with the tap changing transformer on both side this side and this side this is sending inside and this side receiving inside and this is one node is mark this is bus (Refer Time: 08:12) marked or node whatever you say 1 and this side it is 2 right this is sending end and this is the receiving end right.

So, actually its objective is to find out the tap changing ratios required to completely compensate for the voltage drop in the line right. So, you have to find out t S t R both though this is 1 is to t S and the when we will look this transformer you should look from this side. So, it is 1 is to t R, but this side it is retain from I will if I assume this is primary this is secondary - secondary to primary. So, t R is to 1 basically 1 is 2 t R this side also 1 is to t R and this is the line impedance Z is equal to R plus j x and this is the sending in voltage and this is the receiving and voltage this is the radial transmission line.

Next as you know later we will see after all this voltage control methods later we will see for transmission system.

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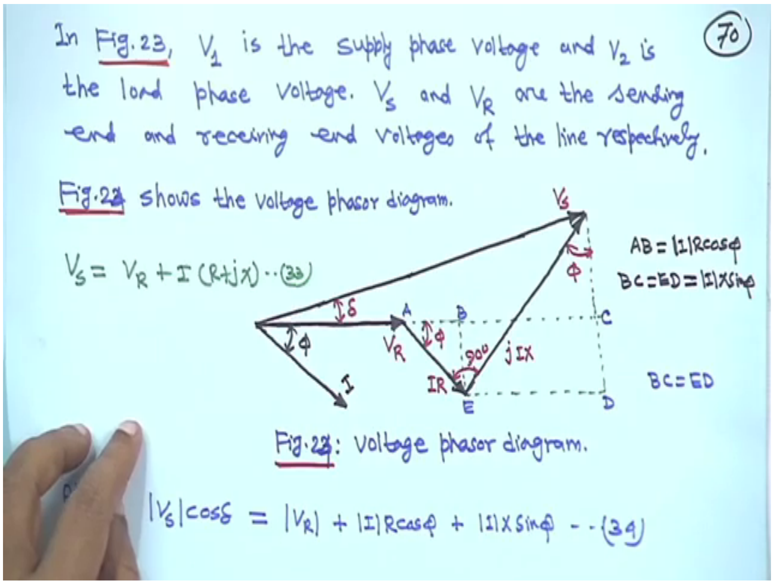

Now, this is your this is your that take receiving in voltage at phasor diagram that is a voltage phasor diagram you take this is your reference voltage right and take currents through this is lagging suppose this is the current currents to this is lagging current 5 right and then this your this voltage is your I R, I R draw right and 90 degree with this

this is j into I x and you complete the phasor diagram this is sending in voltage. And angle between sending in voltage a receiving in voltage is delta and current I is lagging from receiving in voltage that by an angle 5 right.

So, this now that, this is 5 this is angle 5. So, this angle is 90 degree. So, this angle is also 5 right therefore, this portion A B portion is equal to magnitude I R cos 5. So, I R cos 5. Actually it is better if I put that your what you call this I R if I put it magnitude then things will be better. So, if I put magnitude I R right and this side actually your j IX. So, if I put your I magnitude I into that your j x right. So, that why your this is your what you call this A B is equal to magnitude I R cos 5 right and similarly this bc is equal to is equal to E D is equal to your this is your IX. So, I X sin 5 right therefore, sending in voltage you make the projection on it you know is. So, magnitude V S cos sign delta is equal to V R this the receiving end plus A B that is your I R cos 5 I is the magnitude of the current plus bc that is magnitude IX sin phi. So, this is say equation 34 right.

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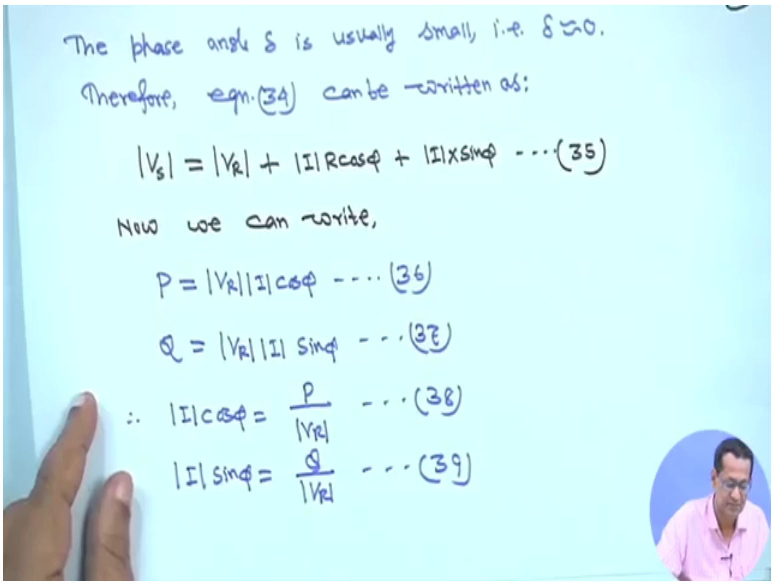

But this phase angle delta between your sending and end receiving end with very your negligible very small right, usually delta we can take it say as approximately as 0 right; that means, that means that equation 34; that means, this equation 34 can be written as if delta here it is delta is equal to 0 you put, so it is cos 0 1 right. So, magnitude of V S is equal to magnitude of V R plus magnitude I R cos 5 plus magnitude IX sin 5 this is equation 35 right.

Now we can write P is equal to magnitude V R I cos 5 this is power equation 36 and Q is equal to magnitude V R, magnitude I sin 5 that is 37 right. Now from equation 36 from this equation this equation you can write magnitude I cos 5 is equal to P upon magnitude V R and from this equation that magnitude I sin phi is equal to Q upon V R this is equation 39. Now this is magnitude I cos 5 and magnitude I sign phi you substitute in equation 34 you substitute right.

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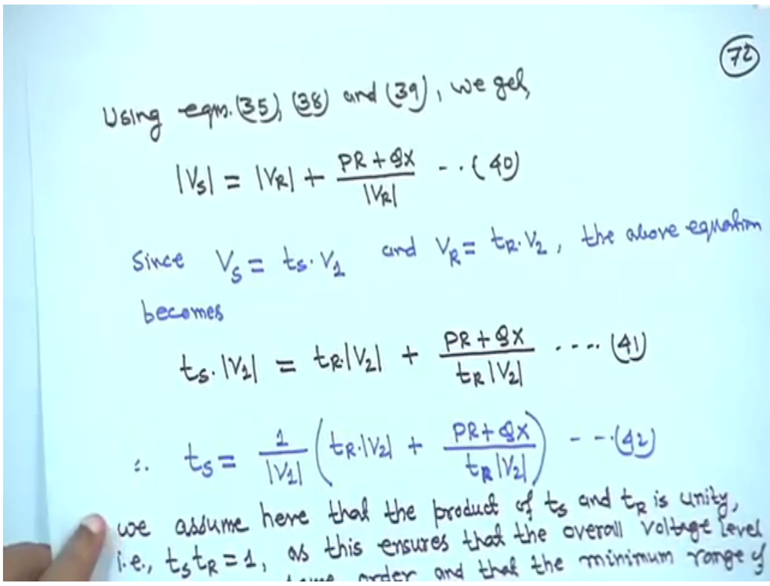

If you substitute then what we will get you will get magnitude of that is I have written equi using equation 35 and 38 and 39 you will get magnitude of V S equal to magnitude of V R plus P R plus Q x upon magnitude of V R right. Now if you come to this diagram right, come to this diagram.

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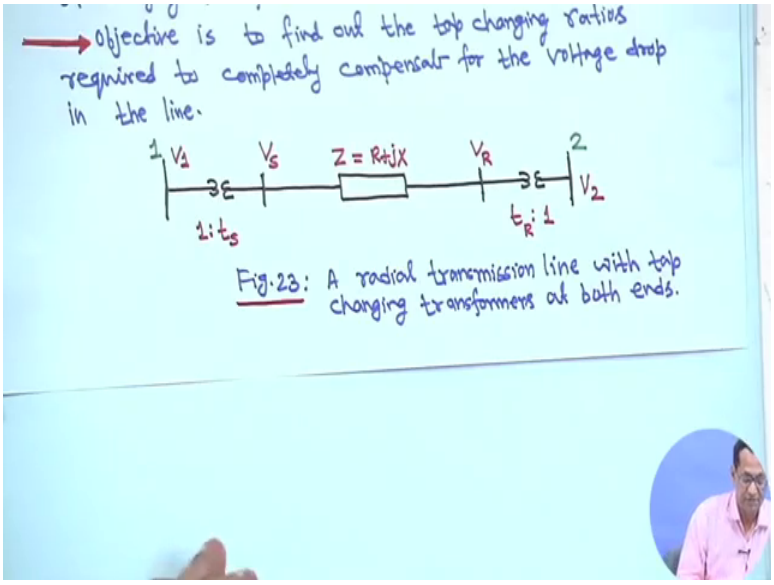

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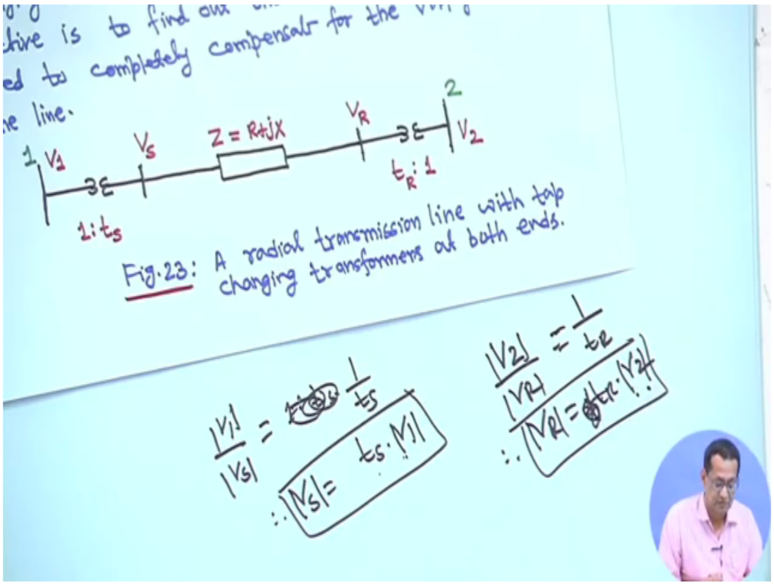

Now, this diagram this diagram your V 1 this one this diagram that is figure 23 V 1 upon V S the ratio is 1 is to t S. So, 1 is to t S sorry it is; that means, 1 by t S say rather than this thing 1 by t S; that means, V S is equal to t S into V 1 this side. Similarly if you come to the receiving end side this side it will be V 2 by V R is equal to 1 by t R; that means, V R is equal to your t R into V 2 right. So, that is one is V R is equal to t R into V 2 anoth another is your V 2 another is V S is equal to t S into V 1.

That is if you actually it is magnitude vise if you take. So, this is magnitude. So, you take all magnitude that is better right because you use all the magnitude. So, the this one is equal to your this things. So, magnitude V S is equal to t S into V 1 and magnitude V R is equal to t R your into t R into magnitude V 2 right. So, this V S and V R magnitude you substitute in this equation, this equation you have substituting that magnitude V S is equal to t S into V 1 is equal to t R into magnitude V 2 plus this P R plus QX divided by V R is equal to magnitude of V 2 into t R - this is equation 41.

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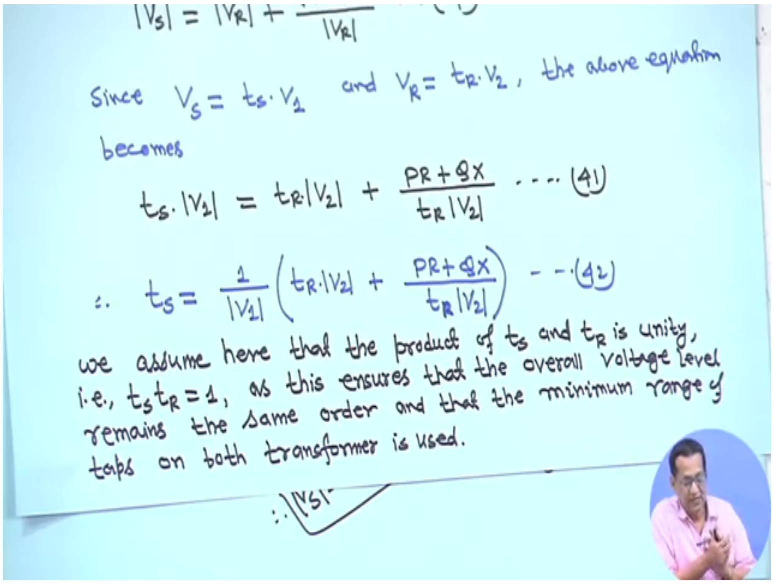

Now, from this equation you can right t S is equal to 1 upon magnitude V 1, magnitude of V 1 in bracket t R magnitude V 2 plus this term right. Now we will assume one thing we assume here that the product of t S and t R is unity right this we will assume that is t S into t R is equal to 1 right. So, as this ensures that the overall voltage level remains the same order and that the minimum range of taps on both transformer is used. So, this is the condition we will put right, t S t R is equal to 1.

Therefore what we will do we will substitute t R is equal to 1 upon t S in this equation because that you want to find out that what will be the expression for t S right.

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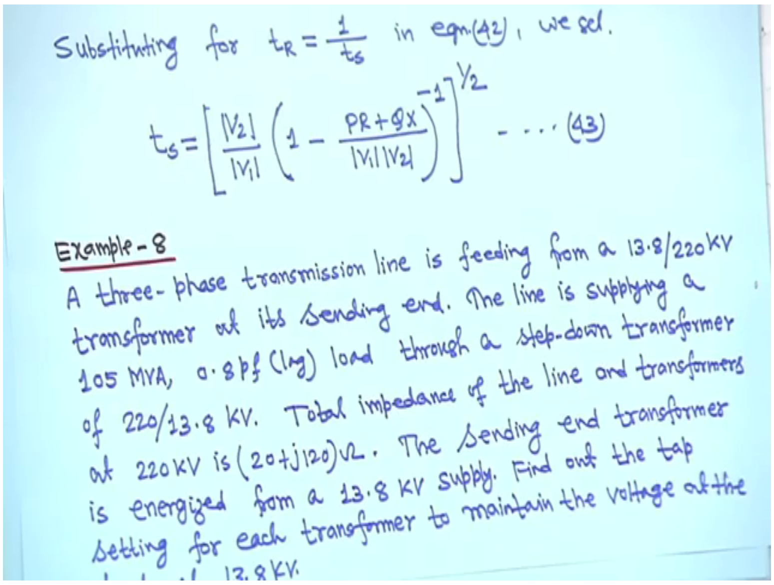

That means if we you substitute in this equation that is in this equation you substitute that t R is equal to 1 upon t S you substitute. Here if you do so, that is we are writing here for t R is equal to 1 upon t S in equation 42 and you solve it you will get t S is equal to magnitude V 2 upon V 1 brack into 1 minus P R plus Q x upon magnitude V 1 V 2 to the power minus 1; that means, this is 1 upon that actually right to differ minus 1 bracket close the to the power half right this is equation 43. So, this is that if you know t S when you can find out t R also because t R is equal to 1 upon t S because we have assume that t S t R is equal to 1 right such that both side taps are used.

Now, we will take an example right. So, the example is a 3 phase transmission line. So, before give the example that little bit we have some ideas regarding tap changing transformer and this expression of to find out the tap ratio 1 side either t S or t R any side you find it out. So, from the t R into t S 1 from that you can get the tap ratios. Now take one example.

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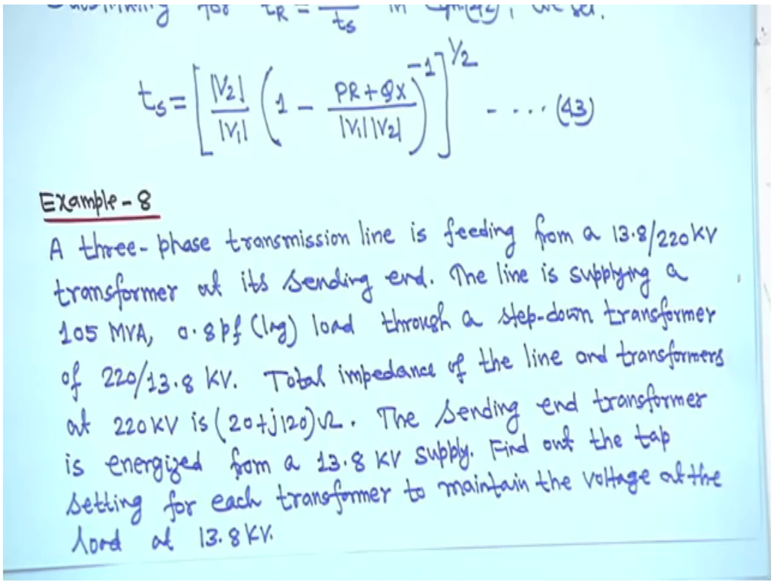

So, in this case a 3 phase transmission line is feeding from a 13.8 slash 220 KV transformer at its secondary end right sending end rather sorry sending end. The line is supplying 105 MVA 0.8 power factor lagging load through a step down transformer of 220 by 13.8 KV. Total impedance of the line and transformer at 220 KV is 20 plus j 120 ohm the sending end transformer is energized from a 13.8 KV supply. Find out the tap setting for each transformer to maintain the voltage at the load at 13.8 KV right.

Now, this is simple problem this is simple problem. Now it is the line is supplying your 105 MVA at 0.8 power factor lag. So, it is a 3 phase. So, P is equal to 1 upon 3 into 105 and multiplied by power factor 0.8. So, it is 28 megawatt right.

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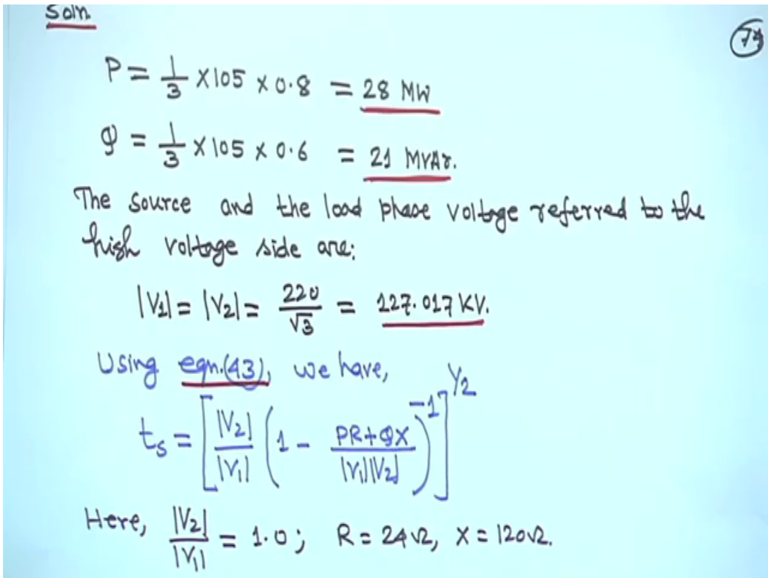

Similarly actually when you when you draw the phasor diagram or those equation or P Q V S V R that V S V R all are per phase quantity. So, it is not a line to line quantity V S and V R actually it is a per phase voltage right line to neutral right and at the time P and Q also you have to find out that per phase that is why it is divided by 3 divided by 3 right and V S V R magnitude also per phase basis. So, that is 28 megawatt and Q is equal to cos 5.8. So, sign phi is 0.6, so 21 mega var.

The source and the load phase voltage referred to the high voltage side are V 1 magnitude is equal to magnitude V 2 220 upon root 3. So, all line to line you convert it to per phase voltage that is 127.017 kilo volt right. Now if we using equation 43 right. So, same equation you use this formula you know R and X you know that V 1 magnitude V 1 is equal to magnitude V 2 here. So, magnitude V 2 upon V 1 ratio is 1 because these 2 are equal right R is given 24 ohm, X is given 120 ohm P and Q all are known. So, you substitute you substitute in this expression all these right.

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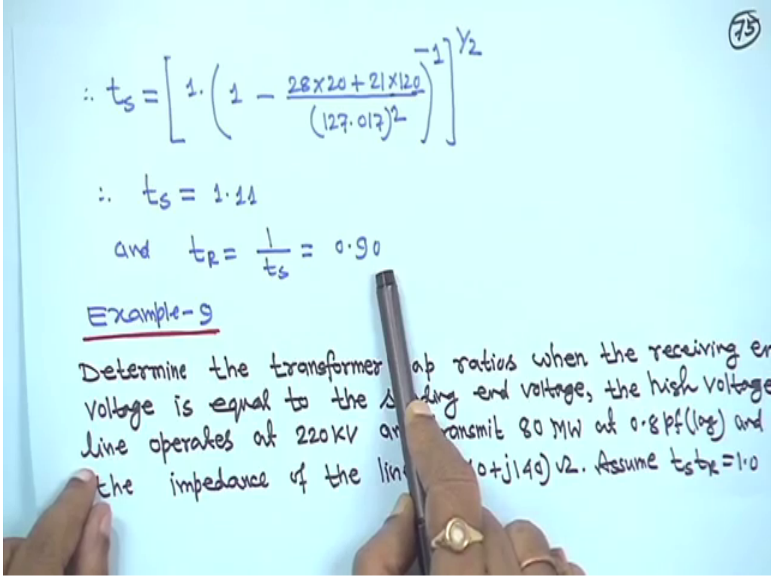

So, in this case t S it is ratio 1 into whatever it is 1 minus all this things to the power minus 1 and to the power half. So, t S comes actually 1.11 therefore, t R 1 upon t S is equal to it will come 0.90 right. So, this 2 are tap settings.

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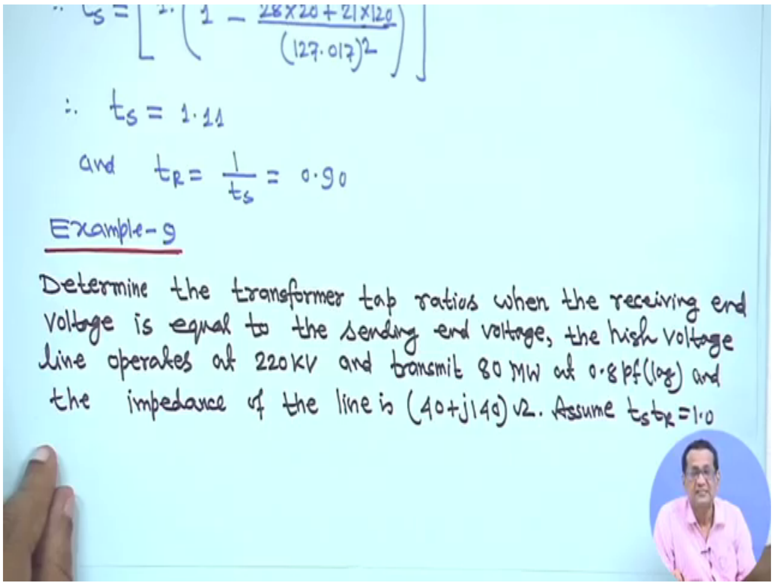

Now, one more example. So, another one is, this is understandable this things are very simple. So, directly you can apply right. Similarly example take another example, example 9 determine the transformer tap ratios. So, in the receiving end voltage is equal to the sending end voltage. The high voltage line operates at 220 KV and transmit 80 megawatt at 0.8 power factor lag and the impedance of the line is 40 plus j 140 ohm assume t S t R is equal to 1 even it is not mentioned that you have to assume that t S into t R is equal to 1. So, here just taken almost similar type of example.

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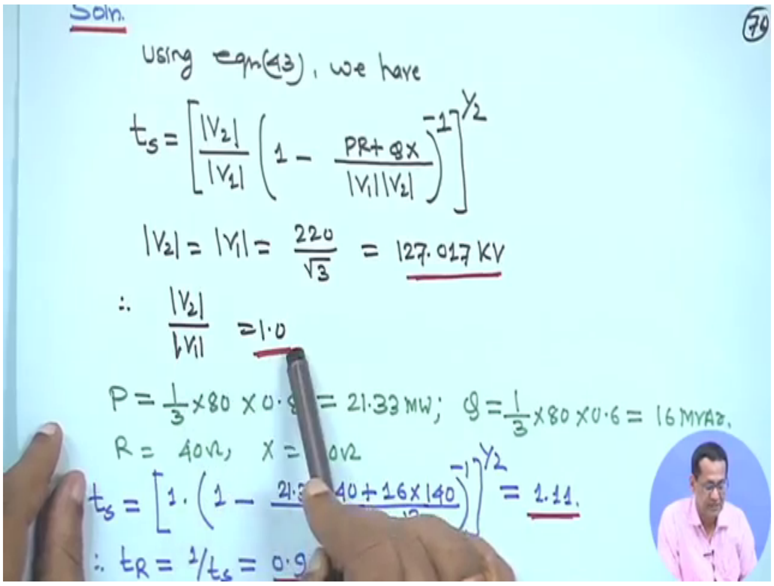

So, that is equation 43 this is the formula V 2 is equal to magnitude of course, V 1 220 upon root 3 127.017 KV and magnitude V 2 upon V 1 is 1.

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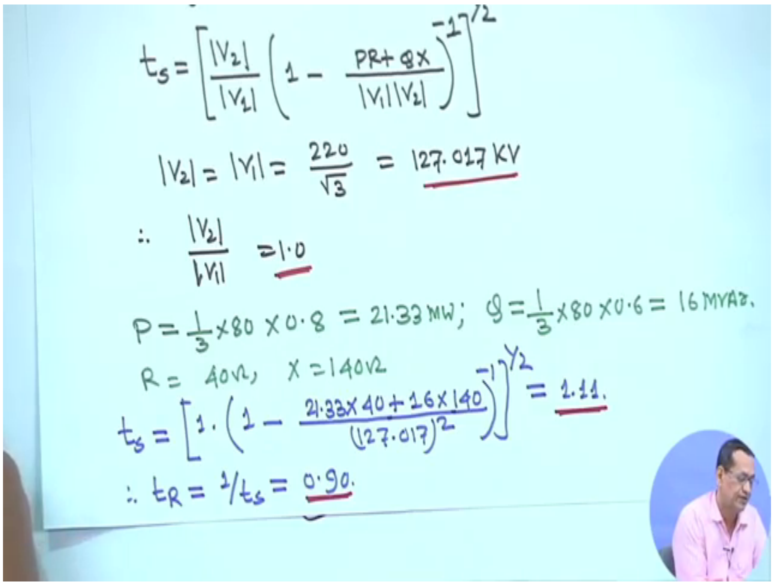

P is equal to one-third again per phase basis. So, 21.33 megawatt cos 5.8, Q is equal to one-third 80 into sign phi 0.6 so 16 mega var, R 40 ohm, X 140 ohm. So, put all these things you will get again t S is equal to 1.11 and t R is equal to 1 upon t S that is 0.90 this is the tap ratio this 2 simple example we have taken right. So, this is for the tap changing transformer right.

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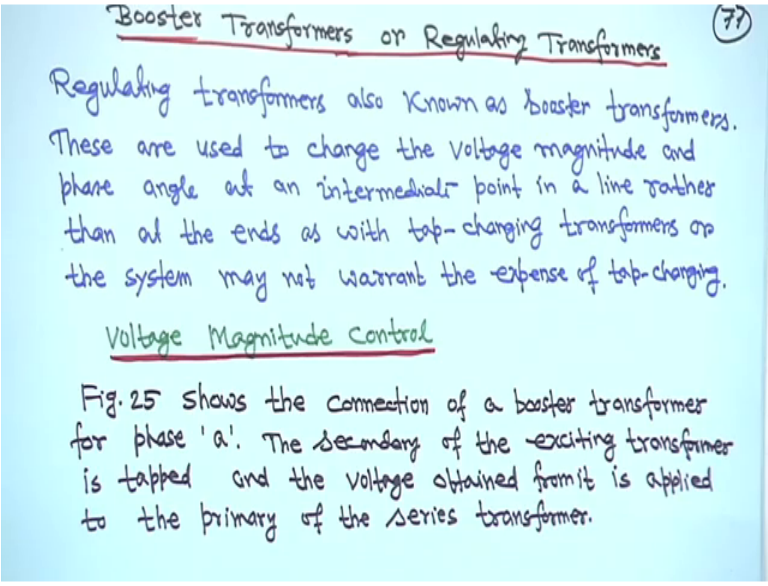

Now, next is that booster transformer or regulating transformer. In this case this booster transformer or regulating transformer these are this thing what you call it is same thing sometimes we call regulating transformer sometimes we call booster transformer. These are actually used to change the voltage magnitude and phase angle, at an intermediate point in a line rather than at the ends right. So, as we the tap changing transform, tap changing transform what you do? We make it either this sending inside or receiving inside right or the system in our warrant the expense of tap changing, but in this case we can we can put it in this somewhere intermediate position of the line. So, one is voltage magnitude can be control phase angle also can be controlled.

So, figure 25 I will come to that shows the connection of a booster transformer for phase a right.

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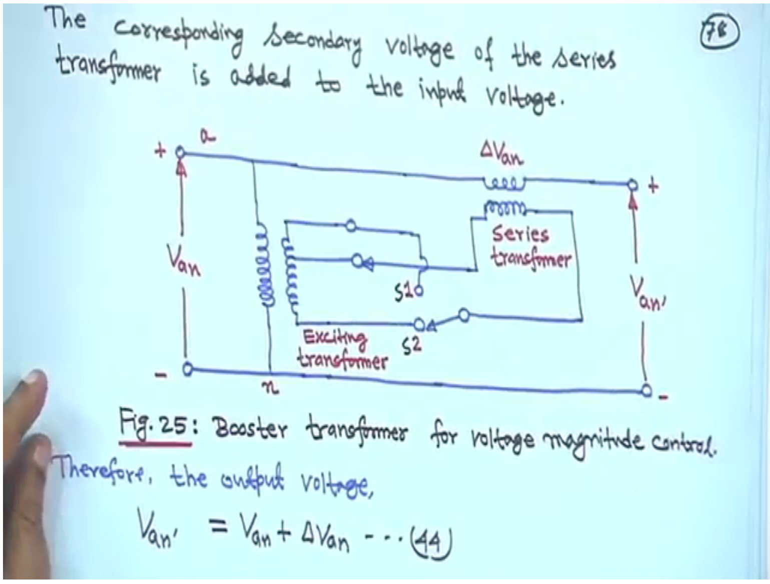

So, this is your booster transformer connection right, this is boost this is say only phase a we are considering we are taking line to neut also this voltage is V an right and this is the exciting transformers. So, suppose 2 switch position is there this is actually, this is you make a S 1 say and this is say S 2 right and this is exciting transformer.

Now if you come here right the secondary of the exciting transformer is tapped and the voltage obtained from it is applied to the primary of the series transformer; that means, this is actually tapping tap position this is tap position this is 1 connection is given right for example, the another transformer is there called series transformer is other winding is in series with the phase a line right. So, this is series transformer and this is exciting transformer with this thing here also some voltage is influence (Refer Time: 23:23) here and automatically voltage will be influenced here right therefore, this V an that is this side voltage this side voltage will be V an plus delta V an right this is equation 44 I have marked. So, this is the output voltage, this is the output voltage right. So, if you if connection is like this then this voltage we will be added right.

Now, if you interchange this is position of S 1 and S 2 right then what we will happen this will be a subtraction right, if you make the position a R and this one you will if you make it here right I mean if you interchange the position then what we will happen that S 1 S 2 interchange that what we will happen - that it will be the, it will minus at that time this voltage will be less than this one right. So, this way you can go for controlling the your what you call this is call in phase booster right because the voltage are in phase in this case right. So, this is that your connection, this is that V an this is exciting transformer you have the tap connections are shown and this is that this output of this is connected to the 1 series transformer this side other winding is in series with that phase a such that voltage can be added or can be subtracted right they are in phase right. So, voltage magnitude can be added.

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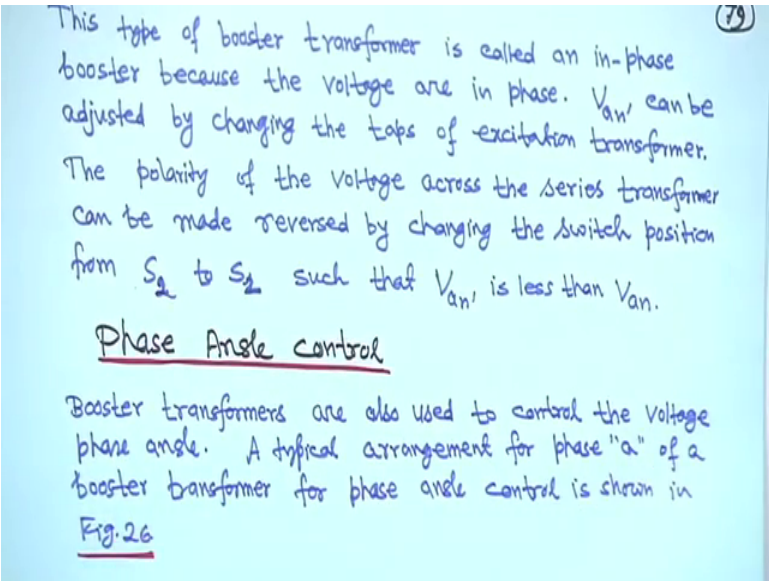

So, this type of booster transformer is called an in phase booster because the voltage are in phase. So, V an does can be adjusted by I told you by changing the taps of excitation transformer the polarity of the voltage across the series transformer can be made reverse by changing the switch position I told you from S 2 to S 1 such that V an dash is less than your, less than your V an right. So, this delta V an it can be made negative, it can be made negative also if you interchange the position right. So, this is actually your what you call that your booster or regulating transformer.

Now, another thing is that your phase angle control right. So, booster transformer are also used to control the voltage phase angle. So, a typical arrangement for phase we have a booster transformer is shown right.

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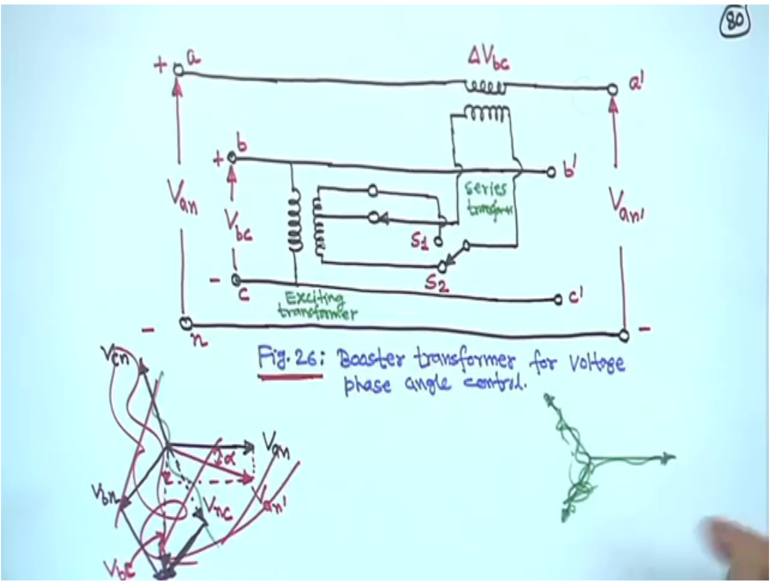

I mean this is a booster transformer, now in this case for phase a we are taking line to neutral V an right this is a dash n dash V an dash the output now here this is exciting transformer this is series transformer, but this is bc voltage is bc that way your phase bc V bc right plus minus now here also tap settings are there here also there switch S 1 S 2 is there this series transformer is there.

So, this side that in the phase a that delta V bc that voltage we will be added right, in that case. So, what we will happen the equation will be V an dash is equal to your V an plus your what you call delta V bc right; that means, I mean I just see once again the this is phase a we are taking considering phase a into neutral voltage we take in other 2 phases V bc and one exciting transformer is there from that these are the tap setting and it is this is shown only 2 taps for you know is a easy showing here right and this and output of this is here it is series trans transformer one side of the this winding that voltage impressed other winding in series with the phase a such that V an dash is equal to V an plus delta V bc, but delta V bc is anyway not in phase with your with phase a voltage that is V an right.

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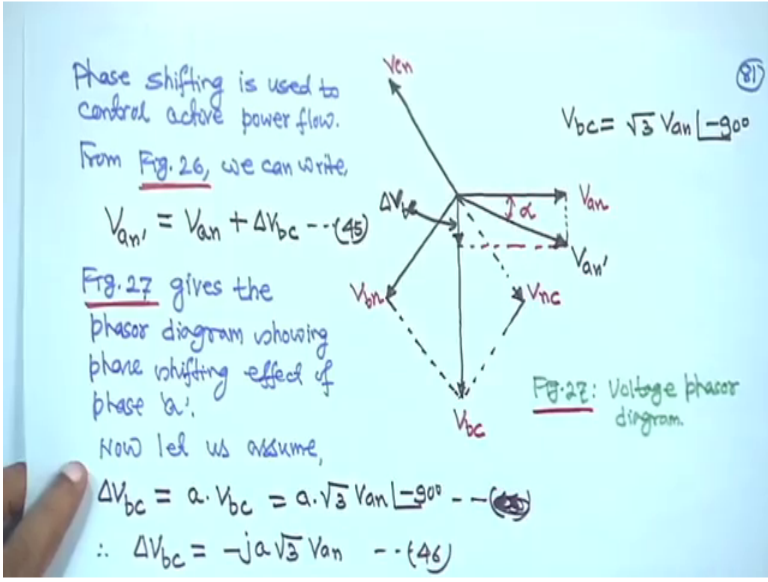

So, in that case what we will happen that you go for little bit the phasor diagram right. So, before selling anything you consider V an is your reference phasor that is this one V an is your reference phasor this right, then if this is V an this is V b n and this is your bc n 120 degree phase it right. So, this is V cn; that means, this is V nc this is V bn resultant is V bc. So, V bc actually is lagging 90 degree from V an right.

Now figure 27 this one right now this is your a n now figure 27 that is this one give the phasor voltage phasor diagram. Now, let us assume that delta V bc; that means, this delta V bc means this one this influence voltage which is in series with a in this a phase this winding is in series with this is delta V bc. So, this delta V bc we assume it is equal to a into your V bc right; delta V bc is equal to a into V bc total is V b c, but this is delta V bc this is actually from here to here this is delta V bc right this is delta V bc. So, this is a into your V bc a is fraction right. So, is equal to V bc actually V bc lagging from Van by is this thing 90 degree and V bc is line to line voltage right V ab bc a line to line voltage they are route 3 time the your what you call phase voltage it is balance system. So, we can write V bc is equal to here root 3 into V an angle minus 90 degree, from this phase diagram.

So, this V bc you substitute here if you do. So, it will be a into root 3 V an angle minus 90 degree this is; that means, delta V bc is equal to it is angle minus 90 degree; that means, we can write minus j a root 3 V an. So, delta V bc is equal to minus j a root 3 V an this delta V bc expression you substitute here in equation 45 you substitute here right.

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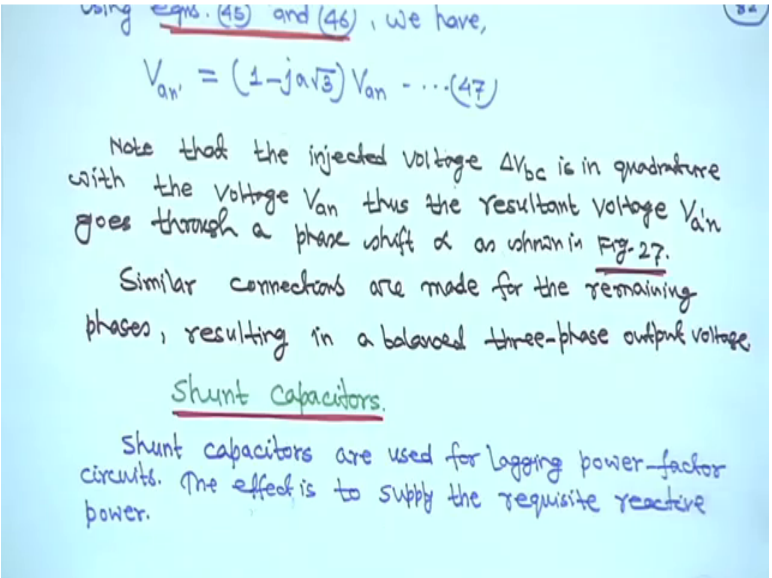

If you do so, if you do so you will get that V an dash is equal to 1 minus j a root 3 into V an this is equation 47. That means, this V an dash this V an dash actually it is it is minus j root 3 a may be some fractional value right, but then you that you V an dash is lagging from V an by an phase shifting angle alpha. So, V an and V an dash there not in phase, but V an dash is lagging from V an by angle alpha right therefore, note that this injected voltage delta V bc is in quadrature with the voltage V an and thus the resultant voltage V a dash n goes through a phase shift alpha as shown in figure 27 this one right. Therefore, similar connections for your or made for the remaining phases also because 3 phase balance, you have to make the same connection for the other 2 phases like b and c right resulting in a balance 3 phase output voltage.

Thank you.