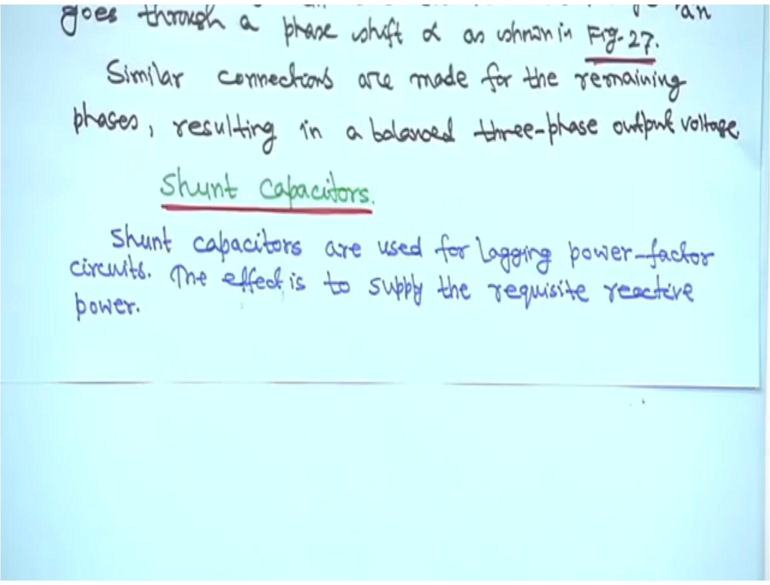
Power System Analysis
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 21
Characteristic and Performance of Transmission Lines

So, next is we will come to another two thing that is that shunt capacitors and series capacitors right.

(Refer Slide Time: 00:25)



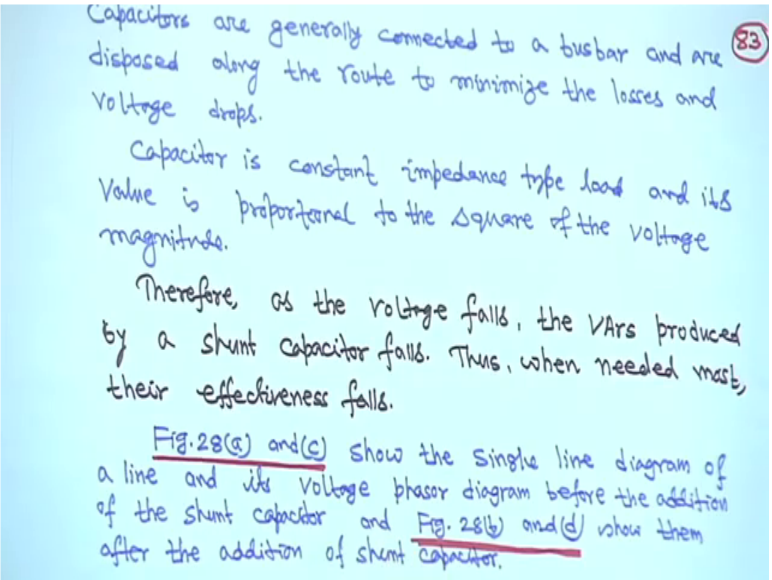
goes through a phase shift α as shown in Fig-27.
Similar connections are made for the remaining phases, resulting in a balanced three-phase output voltage.

Shunt Capacitors.

Shunt capacitors are used for lagging power-factor circuits. The effect is to supply the requisite reactive power.

So, shunt capacitors basically used for a lagging power factor circuit, when you have solved that circuit theory problem is a circuit theory problem, you might have solved the problem when capacitor is connected across the load to improve the power factor right. So, so the (Refer Time: 00:48) is to supply the your requisite reactive power. So, shunt capacitor basically it injects reactive power.

(Refer Slide Time: 00:58)



Capacitors are generally connected to a busbar and are disposed along the route to minimize the losses and voltage drops.

Capacitor is constant impedance type load and its value is proportional to the square of the voltage magnitude.

Therefore, as the voltage falls, the VArs produced by a shunt capacitor falls. Thus, when needed most, their effectiveness falls.

Fig.28(a) and (c) show the single line diagram of a line and its voltage phasor diagram before the addition of the shunt capacitor and Fig. 28(b) and (d) show them after the addition of shunt capacitor.

Now capacitors basically you will find shunt capacitors is generally connected to a bus bar. If you go to any substitution they are you will see the shunt capacitors are there if you go to any substitution 33 KV or above then you can see it right.

And dispose along the route to minimize the losses and voltage, the basically shunt capacitors actually right I mean first telling one or two line when it is connected in the transmission or distribution system. The primary objective of the shunt capacitor is to reduce the power loss right and though not much it improves the voltage magnitude also and in the case of series capacitor just reverse series capacitors primary objective is to improve the voltage magnitude and though not much it reduce the power losses; because power loss is inversely proportional to the square of the voltage magnitude. So, as the series capacitor improves the voltage magnitude. So, to some extent it deduce the power losses, but it basically primary objective of series capacitor is that it is actually improves the voltage magnitude.

Whereas the shunt capacitor the main objective is which are primary objective is to reduce the power loss, and though not much it improves the voltage magnitude this two should be in your mind right. So, capacitor is basically is a constant impedance type load, later we will see I will try to show you where that impedance constant impedance type load right and that value the reactive power which it injects actually, it is proportional to the square of the voltage magnitude at you know where it is connected right therefore, when voltage is suppose capacitor is connected at a 33 KV bus bar right. So, whenever you are buying capacitor from the manufacturer suppose it is rating is say 5 megawatt for example, that is actually specified at that say 33 KV voltage level right; that means,. So, in voltage level is 33 KV it will inject 5 mega var. Generally you will find that at 33 KV bus bar voltage may not be 33 KV, it may be 32 31 or 30 KV right.

But capacitor, that reactive power injection actually is proportional to the square of the voltage magnitude. If 5 magavar it give a 33 KV, then suppose voltage instead of 33 30 k v; that means, reactive power injection we will be 30 upon 33 whole square into 5 megawatt; that means, it will not inject 5 megavar as are it will inject less megavar into the netvar right. So, that is why as the voltage falls the VArs produced by a shunt capacitor falls, thus when needed most their effectiveness actually falls right anyway. So, that is that your what you call shunt capacitor. Now take a simple circuit right with and without shunt capacitor.

(Refer Slide Time: 04:09)

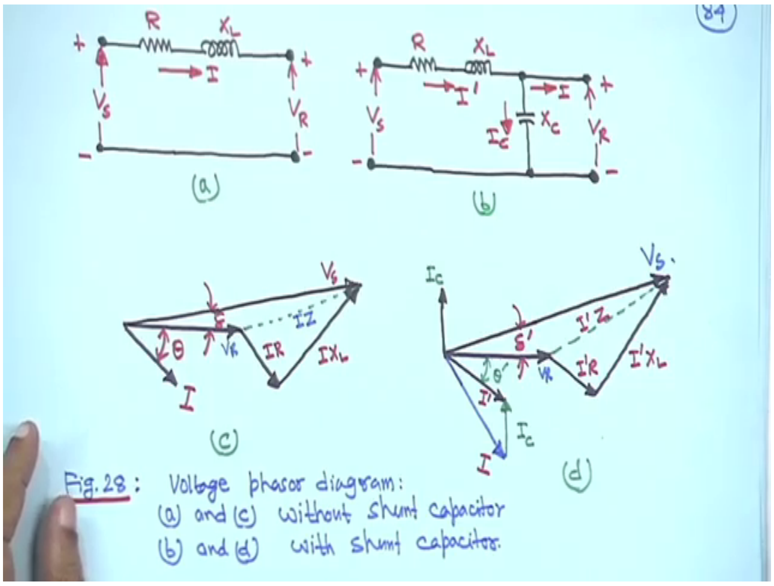


Fig. 28: Voltage phasor diagram:
(a) and (c) without shunt capacitor
(b) and (d) with shunt capacitor.

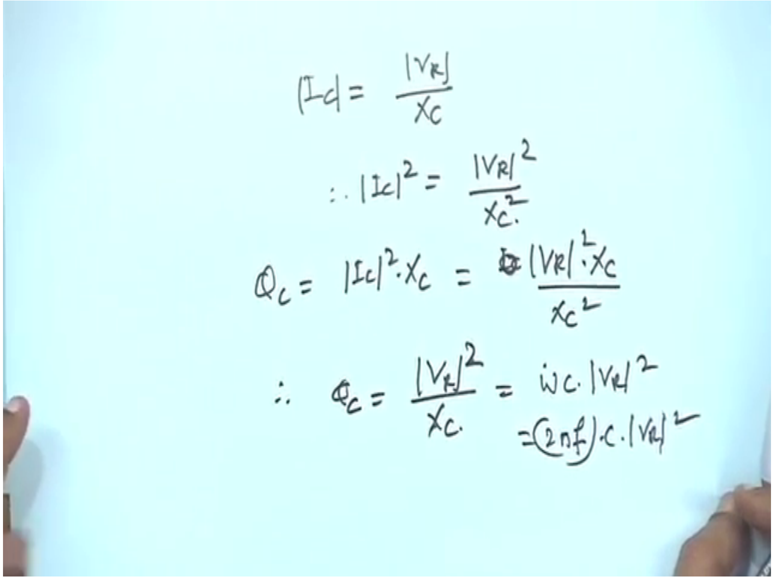
So, this is the circuit, this is that simple series circuit say right and r and x value this is sending and voltage receiving one thing I could like to tell you whenever we take V S V R all these things you it is all per phase voltage V S V R all per phase voltage line to neutral voltages right. So, this is R n R resistance and your reactance of the line inductive reactance of the line and if you draw the phasor diagram same as before these voltage is your V R this is V R right and this your I R magnitude understand level, it is everywhere it is magnitude I am not saying here this is the I R drop this is the I Z, l drop and this is I this dash green line is I Z and this is V S this is the your without capacitor and figure a and figure C actually this is the phasor diagram without shunt capacitor.

Now, in figure b a shunt capacitor is connected right at the receiving end. So, in this case because of that that I C is the leading current, this is your this voltage is V R this voltage is V R. So, leading current I C leads actually V R by 90 degree. So, this is the leading current, now this current initially this without capacitor this current was I. So, here it is I, but this leading current is there right so; that means, this I C is made it upwards and then this is the resultant current I dash right; that means, this is the I dash.

So, initially it was I now due to capacitor the current is I dash, that mean current actually is decreasing because of this right. So, this angle is theta dash here is theta here is theta dash here is delta it is delta dash and; that means, this current is I dash now with capacitor. So, this is I dash R, right this is I dash X L right and this is I dash Z this green line and this voltage your what you call that your V S right. So, that is your that means, what that capacitor actually that as soon as you put it that capacitor actually it is your reduces the current because it here it was I now it is I dash.

So, magnitude did you and changing the angle also. The in this case if you I mean if you see that delta and theta here it is delta dash theta dash. So, later we will see because of this changing delta dash or theta dash from delta and theta, it improves the power factor of the load also right. Now as I told you that capacitor actually it injects your what you call reactive power, if you look into this this diagram I will just show you this way, for example, this diagram right now this is that X C is the magnitude that reactance right over upon omega c right. So, as capacitor is constant impedance type of load because X C is equal to 1 upon omega C, we assume that omega is equal to this thing we have omega is not changing because a if we assume 50 or 60 are system generally a prevance more or less constant. So, reactance remain constant.

(Refer Slide Time: 07:36)



$$|I_C| = \frac{|V_R|}{X_C}$$

$$\therefore |I_C|^2 = \frac{|V_R|^2}{X_C^2}$$

$$Q_C = |I_C|^2 \cdot X_C = \frac{|V_R|^2 \cdot X_C}{X_C^2}$$

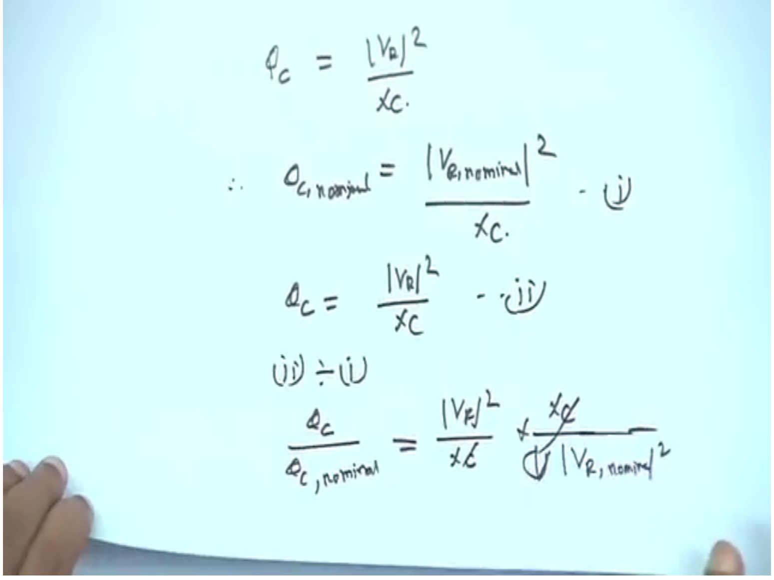
$$\therefore Q_C = \frac{|V_R|^2}{X_C} = \omega C \cdot |V_R|^2$$

$$= (2\pi f) \cdot C \cdot |V_R|^2$$

Now, question is that take this simple circuit right. Now I will take only the magnitude. So, this current magnitude I C actually it is V R upon X C right this is the current magnitude therefore, my here also I C magnitude right; that means, I C square is equal to X C, X C square right now a reactive power Q C is equal to actually I C square into X C, that is actually your this I C square actually V R square into X C by X C square; that means, Q C that reactive power comes from this is equal to V R square X C right; that means, that this is that V R square upon X C, that is a reactive power supplied from the shunt capacitor.

Now, if we assume that V R is constant for example, right then an X C also frequency we will remain more or less constant right omega X C is equal to 1 upon 2 omega c right. So, that is your it is omega C into V R square and that is equal to 2 pi a right into c then V R square, this same frequency remains more or less constant right and if for a nominal voltage if we assume V R is constant. So, naturally capacitor is constant impedance type of load because frequency is not changing right second thing is as I said capacitor that Q C injector is proportional to the voltage square, just now we saw this thing say Q C is equal to your V R square upon X C.

(Refer Slide Time: 09:21)



$$Q_C = \frac{|V_R|^2}{X_C}$$

$$\therefore Q_{C,nominal} = \frac{|V_{R,nominal}|^2}{X_C} \quad \text{- (i)}$$

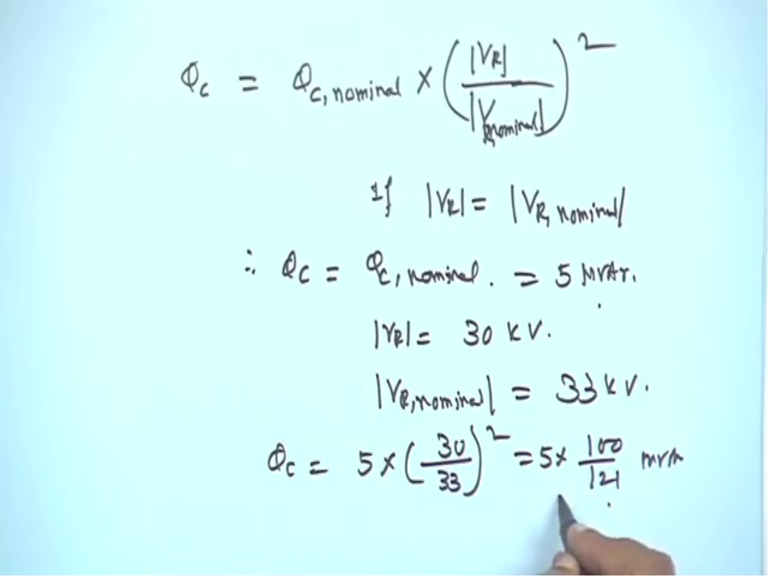
$$Q_C = \frac{|V_R|^2}{X_C} \quad \text{- (ii)}$$

(ii) ÷ (i)

$$\frac{Q_C}{Q_{C,nominal}} = \frac{|V_R|^2}{\cancel{X_C}} \times \frac{\cancel{X_C}}{|V_{R,nominal}|^2}$$

Generally what happen in the case of when you by for manufacturer it is actually nominal thing is that Q C nominal value right is equal to V R nominal means rated right. So, V R that is nominal right square upon X C. This is that your what you call this, but if it is not then this is say equation one right and if it is Q C is injected as any voltage, V R square say upon X C this is equation 2 right. So, this is actually Q C nominal and this is actually Q C or getting at any voltage V R right; that means, if you divide that is equation 2 divided by equation 1, then you will get Q C by Q C nominal is equal to you will get V R square upon X C into X C divided by just hold on, divided by your V R right then nominal square X C X C will be cancelled.

(Refer Slide Time: 10:58)



$$Q_c = Q_{c,\text{nominal}} \times \left(\frac{|V_R|}{|V_{R,\text{nominal}}|}\right)^2$$

if $|V_R| = |V_{R,\text{nominal}}|$

$$\therefore Q_C = Q_{C,\text{nominal}} = 5 \text{ MVAr.}$$

$|V_R| = 30 \text{ kV.}$

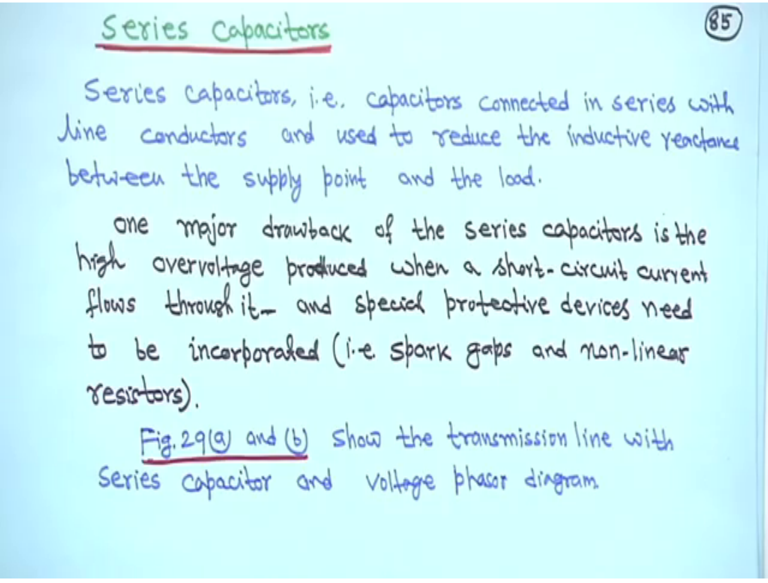
$|V_{R,\text{nominal}}| = 33 \text{ kV.}$

$$Q_C = 5 \times \left(\frac{30}{33}\right)^2 = 5 \times \frac{100}{121} \text{ MVAr}$$

That means here I have writing you know you know this thing as a phrase that means, Q C is equal to Q C nominal right into your magnitude of your V R divided by magnitude of V R nominal right whole square; that means, that if magnitude of V R is equal to magnitude of V R nominal, then Q C is equal to Q C nominal right. But if V R is less than this thing for example, suppose Q C is equal to Q C nominal say 5 mega var, say magnitude of V R is equal 33 KV say right and magnitude of V R nominal is equal to 33 KV say; that means, Q C is equal to 5 into your 30 by 33 whole square right; that means, 5 into your 100 by 121 megavar right.

So; that means what that only at rated voltage this 5 megavar will be injected into the network. If it is less that that then your voltage this Q C will be 5 into 100 by 121 right. So, roughly it will be your nearly 80 percent say I do not have calculator to calculate. So that means, slightly more than perhaps 4 megavar will be injected right; that means, whenever it is needed actually at the time because the voltage is low at the time it injects less your what you call less megavar right. So, that is the thing; that means Q C that capacitor thing it is proportional to the your what you call voltage magnitude square, and second thing is capacitor actually is a constant impedance load right. So, this is your hope these things are understandable to you right.

(Refer Slide Time: 13:44)



Series Capacitors

Series capacitors, i.e. capacitors connected in series with line conductors and used to reduce the inductive reactance between the supply point and the load.

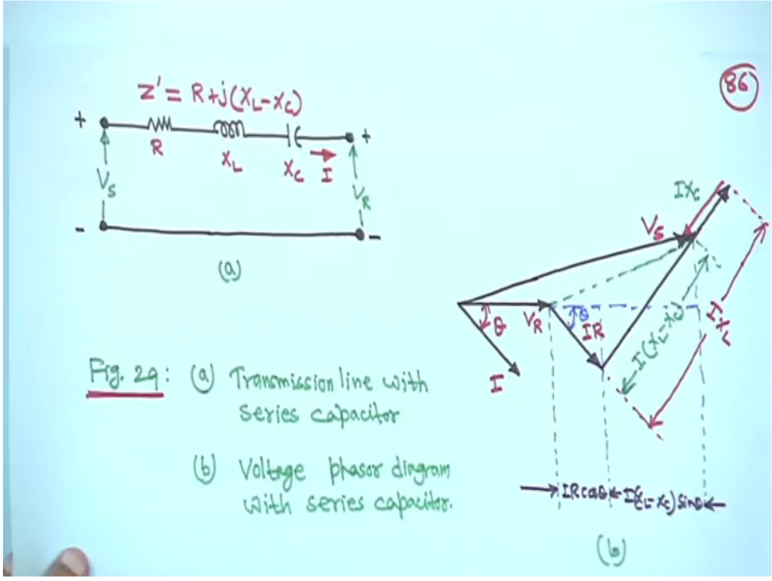
one major drawback of the series capacitors is the high overvoltage produced when a short-circuit current flows through it – and special protective devices need to be incorporated (i.e. spark gaps and non-linear resistors).

Fig. 29(a) and (b) show the transmission line with series capacitor and voltage phasor diagram.

Later we will see when you will take the transmission line also, at the time we will take some problem at time things will be. But one thing I am telling this V S V R whenever you will solve everything should be on per phase basis right and this power factor improvement. Next is that series capacitor. Series capacitor is actually it is connected in series with the transmission line such that that inductive reactance will be compensated by your capacitive reactance, but those things are not discussable in this course, but let us on the see the another problem for series capacitor, but we will not discuss on that right.

So, one major drawback of the series capacitor of course, is the high over voltage produced right when a short circuit current flows through it right and special protective devices need to be incorporated such that spark gaps and non-linear resistors, this two also will not discuss here. If time permits at the aim then something new I will try to tell, but right now we will not go through that right. So, series capacitors you need whenever connecting series capacitor in a line, you need lot of your what you call protection right we have to very careful of right. So, figure we will take a simple your what you call simple circuit diagram for that series capacitors.

(Refer Slide Time: 14:44)

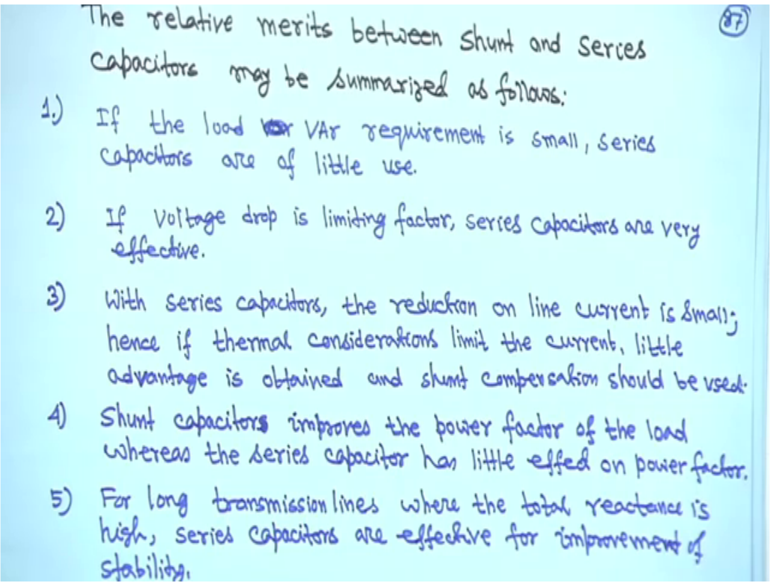


Suppose you have a transmission line this sending end voltage this is receiving end voltage, this R and X L is the transmission line, a series capacitor is connected in series right. So, just I give you one I will tell you one thing, you find out what is the reason. Generally series capacitor they give it is analogues to voltage regulator right. So, why that you find it out right.

So, series capacitor this thing is in series with that your what you call in the line so; that means, impedance Z as actually when capacitor was not there Z is equal to R plus j right. It will be R plus j X L minus X C and this is the thing. So, what will happen that because of this X C this X L minus X C component we will reduce naturally voltage drop we will reduce. So, hence the receiving voltage we will be a better it will be improved voltage right. Now if you draw the diagram instead of separate diagram like shunt capacitor we had 4 diagrams, two phasor diagram two circuit diagrams here only one we have made it. So, this is the current flowing through this this I. So, this is the current I is angle theta say and this is the receiving and voltage V R, and again and again I am not putting I R that I magnitude, but understandable right.

So, this part this is theta, this is theta, this part is I R right because it is I is here. So, this I R drop 90 degree with this this black one it is actually I X L right I am not putting magnitude again, but understandable I X L. Now this now this x is also there because it will be minus I X C. So, that is why this red one arrow is down words because subtraction right. So, it is I into X C. So, resultant actually I into X L minus X C that is this part I into X L minus X C and this is that your what you call that Z as into your I right this dash line not written here, but this dash line is this thing. So, this is the sending end voltage and this is V R I R. So, this is the resultant phasor diagram. So, this part is I R cos 5 and this side is I into X L minus x sin 5 automatically, you can find out what are the relationship V S V R on this thing, but this phasor together this phasor diagram is shown right. So, series now, this is understand level this is simple thing right very simple thing. So, only thing is that you have to see that is I X L, this I X C because it is if you multiply by I then this is I X C. So, naturally this much will be reduce. So, this is the resultant right.

(Refer Slide Time: 17:43)



The relative merits between shunt and series capacitors may be summarized as follows:

1.) If the load ~~var~~ VAr requirement is small, series capacitors are of little use.

2) If voltage drop is limiting factor, series capacitors are very effective.

3) With series capacitors, the reduction on line current is small; hence if thermal considerations limit the current, little advantage is obtained and shunt compensation should be used.

4) Shunt capacitors improves the power factor of the load whereas the series capacitor has little effect on power factor.

5) For long transmission lines where the total reactance is high, series capacitors are effective for improvement of stability.

If the series capacitor is not there then V S t we will go to the top here only here only not shown, but here only right. So, next this merits and demerits of using series and shunt capacitor right. So, the relative merits between shunt and series capacitors may be summarized as follows right. So, I have written few points, but I will tell you something also. So, if the load var requirement is small series capacitors are of little use right because no need actually. If load var requirement is very small now if voltage drop is a limiting factor series capacitors are very effective because it is actually reduce the voltage drop X L minus X C.

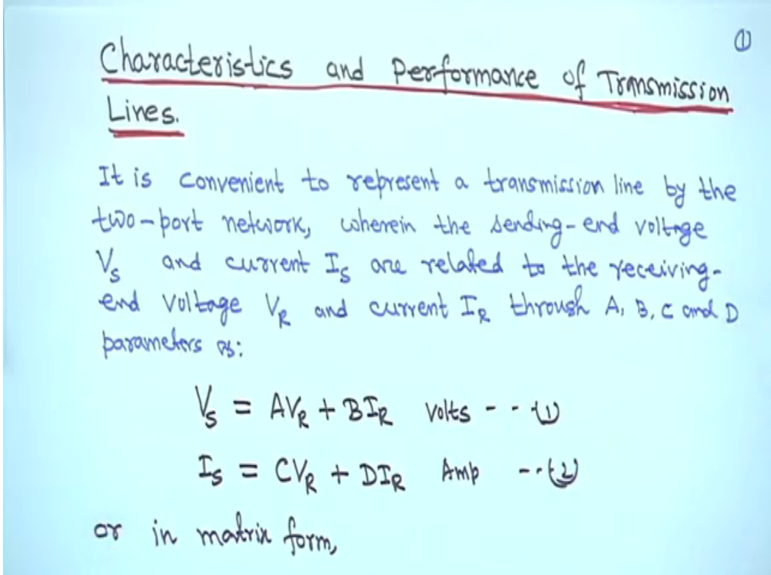
So, series capacitor actually it improves the voltage right with series capacitor the reduction on line current is small right, the hence when you collect the series capacitor it is X L minus X C, but ultimately it is R plus j X L minus X C. Just you have to when you connect series capacitor you have to consider many other design problems I mean design parameters just like that resonance is one right. So, that X L minus X C component we cannot make it 0 right. So, X L minus X C component right that will be reduced, but in that case, but R is there R plus j X L minus x series number right.

So, reduction in line current is small although current will be reduced is small, hence if the thermal considerations limit current little advantage is obtained and shunt compensation should be we used right. Thermal consideration means that every transmission conductors has the maximum your what you call maximum current carrying capability right. So, different conductor side different rating they call thermal limit. Now shunt capacitors improves the power factor of the load it is true whereas, series capacitor has little effect on power factor. I told you there primary objective of shunt capacitor is to reduce the loss and improve the voltage magnitude right whereas, the series capacitor has little effect on the power factor right. For the transmission line where the total reactance is high series capacitors are effective for improvement of the stability. For a transmission system if the if a long transmission line series capacitor we will be very effective right for and it improves the stability detail studies are there for the higher level course right.

But for this course those this is general idea you have that between the series and shunt capacitors. So, if you have any questions or anything when you will study this you can send as a mail right so, but many other things are there on series and shunt capacitors, but that is that will take long, that will take I mean long time and this is beyond that scope for this course right. So, up to this that per unit co your what you call power system component per unit system, and booster transformer, regulating transformers and series capacitors shunt capacitors we have discussed right? Next we will go to the characteristic or of the transmission line that performance of the transmission line for short line, medium line and long line right. After that we will see voltage (Refer Time: 21:00) other things right. So, let us start with after this that short line thing right just one minute 1 the second just wait right.

So, for this; for the characteristics and transmission line right. So, this is another new topic for you right. So, whatever phasor diagram we have made in the previous cases here also we will come and those equations we will come right.

(Refer Slide Time: 21:24)



①

Characteristics and Performance of Transmission Lines.

It is convenient to represent a transmission line by the two-port network, wherein the sending-end voltage V_s and current I_s are related to the receiving-end voltage V_R and current I_R through A, B, C and D parameters as:

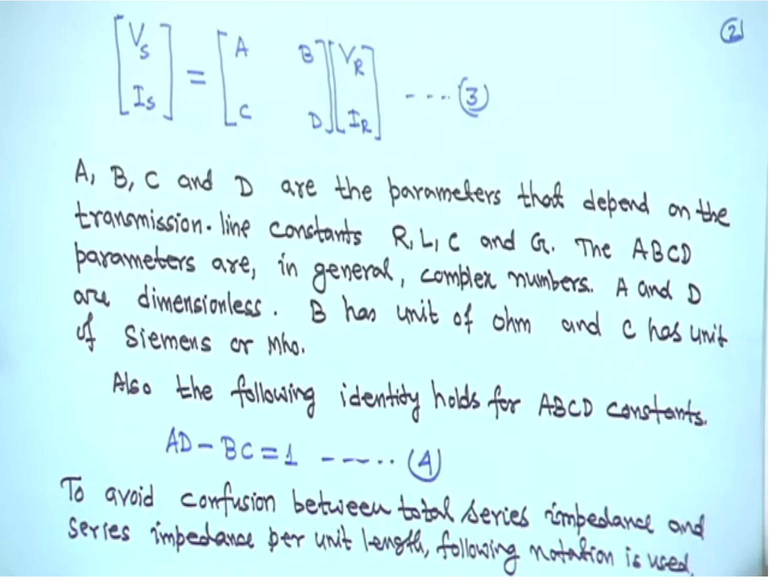
$$V_s = AV_R + BI_R \quad \text{Volts} \; \text{--} (1)$$

$$I_s = CV_R + DI_R \quad \text{Amp} \; \text{--} (2)$$

or in matrix form,

So, generally for the transmission line that it is convenient to the represent a transmission line by the two port network, you know right. Where in study sending end and the sending end voltage v s and the current I s can be related to the receiving end voltage V R and the current I R right through a b c d parameters right. So, generally this is generally you know that this V s we can right a V R plus B I R basically it is units should be volts. So, I am writing here volts and I s is equal to C V R plus D I R is ampere. So, this is a new topic started. So, this equation is 1 and this equation is 2 right.

(Refer Slide Time: 22:22)



②

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad \text{- - - -} (3)$$

A, B, C and D are the parameters that depend on the transmission-line constants R, L, C and G. The ABCD parameters are, in general, complex numbers. A and D are dimensionless. B has unit of ohm and C has unit of Siemens or Mho.

Also the following identity holds for ABCD constants.

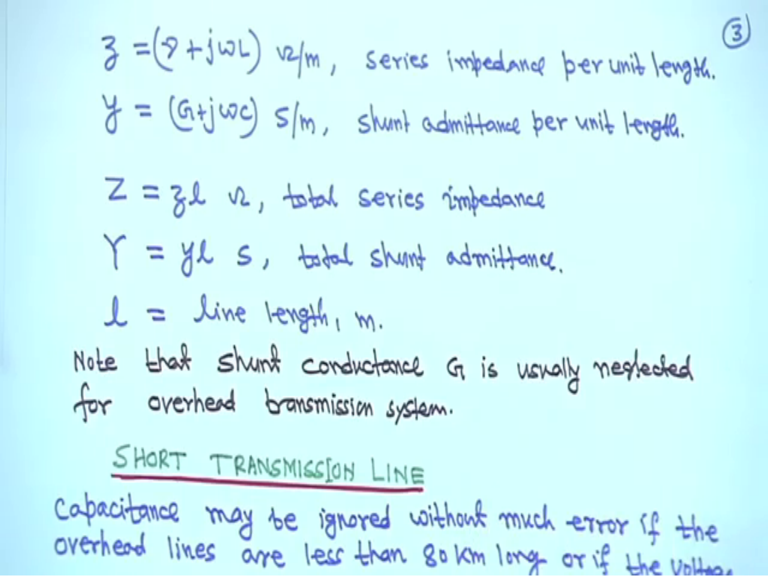
$$AD - BC = 1 \quad \text{- - - - -} (4)$$

To avoid confusion between total series impedance and series impedance per unit length, following notation is used.

So, or in matrix form or in matrix form we can write V s I s this side is equal to A B C D V R I R this is equation 3 right. So, A B C D parameters are that depend on that transmission line constant, write your R then your L C and G of course, conductance will be neglected for our study right. So, basically A B C D parameters they are all complex number right and the from this equation you can make out the unit right unit of all this parameters for example, A and D are dimensionless right B is ohm and C is Siemens or Mho right I l will use for numerical another thing move right.

So, an another identity holds for this kind of systems that A D minus B C is equal to one this holds right. So, to avoid the confusion between total series impedance and series impedance per unit length, we will follow certain notation right. So, notation means that who will follow this kind of notations such that right from the beginning I should clear everything, there should not be any confusion when you will derive this.

(Refer Slide Time: 23:31)



$z = (r + j\omega L)\ \Omega/\text{m}$, series impedance per unit length.

$y = (G + j\omega C)\ \text{S/m}$, shunt admittance per unit length.

$Z = zl\ \Omega$, total series impedance

$Y = yl\ \text{S}$, total shunt admittance.

l = line length, m.

Note that shunt conductance G is usually neglected for overhead transmission system.

SHORT TRANSMISSION LINE

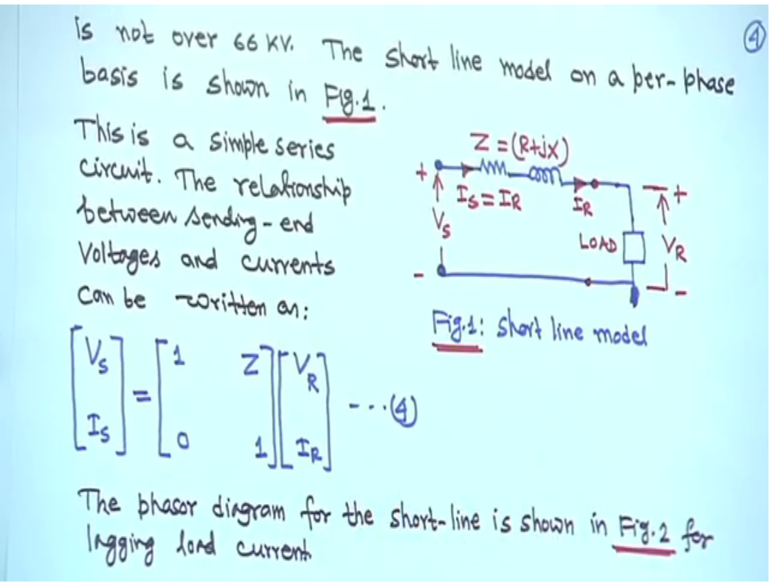
Capacitance may be ignored without much error if the overhead lines are less than 80 km long or if the

For example small z is equal to gamma plus your j omega L ohm per meter right. So, it is actually series impedance per unit length, we are writing gamma plus j omega L then similarly shunt admittance we will write is equal to G plus j o omega j omega see it is Siemens per meter I will use mho per meter right. It is shunt admittance per unit length there when small z small y it is basically that parameters actually per unit length right per meter say and capital Z is equal to small z into l that is ohm total series impedance. Similarly Y is that total shunt admittance, small y into l Siemens I will use more some book they are using Siemens that is I think yes or mho m h o right. So, total shunt admittance and l is the line length in meter right. So, this notation will be used throughout this. So, should not be any short of confusion right. So, g will neglect it as we have discussed earlier also right. So, we will not talk about this thing.

Next we will come first short transmission line. So, what we will say that capacitance that is that your shunt capacitance may be ignored without much error if the overhead lines are less than 80 kilo meter longs. So, this 80 kilo meter long or 60 kilo meter long these are some your terminology right we use 60 80, actually it depends also on the your what you call that voltage level right. So, or if the voltage is not over your in our country it is 66 KV level is also is there 33, 66, 132, 220 and above right. So, in that case we can ignore shunt capacitance, but for underground Kevil you cannot ignore right underground Kevil you have you cannot ignore that they would things you have to consider the your charging capacitance or shunt admittance right.

So, we will assume that line is less than 80 kilometer long or if the voltage is not our 66; ultimately it is not 80 or 60 you have to see that up to which length that charging admittance is not effecting that your performance evolution of the transmission line that is the major thing right. So, that is why I have written it is not over 66 KV is a short line model on a power phase basis that is why I have written here.

(Refer Slide Time: 26:04)



④

is not over 66 KV. The short line model on a per-phase basis is shown in Fig.1.

This is a simple series circuit. The relationship between sending-end voltages and currents can be written as:

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad \cdots ④$$

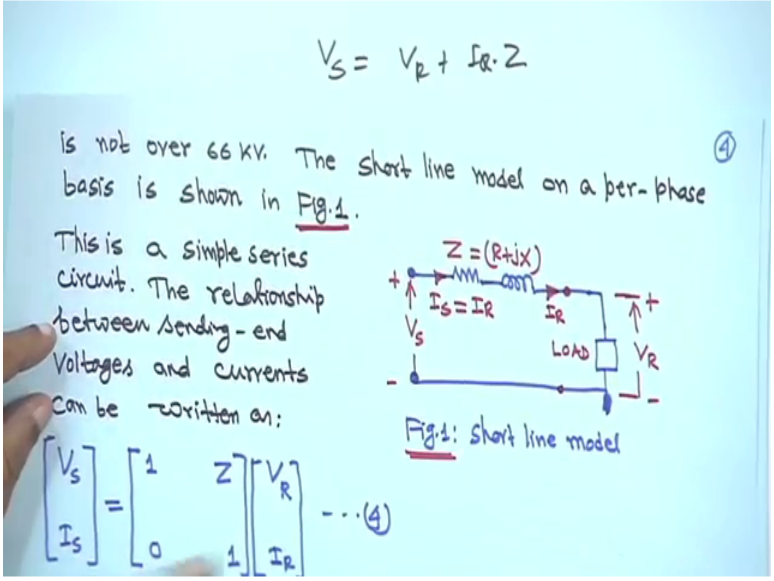
Fig.1: Short line model

The phasor diagram for the short-line is shown in Fig.2 for lagging load current.

Everything we will do on power phase basis right is show in figure one. This diagram we have shown earlier also, but at the time load was not shown. So, this is a short transmission line. So, sending in it is a nothing is there no shunt connection parallel connection nothing is there. So, I s is equal to I R. So, sending in current is equal to receiving current line impedance is R plus j X a write reactant impedance and this is the receiving end load is connected and voltage across the load is receiving and voltage is V R.

So, this is a short line model now if you write down this equation. So, V s is equal to V R plus Z I R and I s is equal to I R this is I mean I mean if you we apply KV l here if you apply KV l here. So, we will get know this equation V s is equal to your what you call this v e V R plus your I R into Z.

(Refer Slide Time: 27:04)



$V_S = V_R + I_R \cdot Z$

④

is not over 66 kV. The short line model on a per-phase basis is shown in Fig.1.

This is a simple series circuit. The relationship between sending-end voltages and currents can be written as:

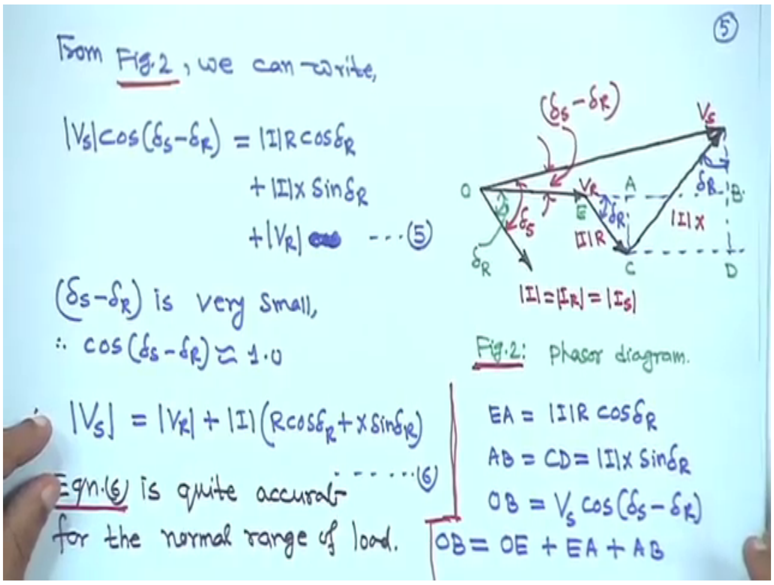
$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \quad \ldots (4)$$

Fig.1: Short line model

So, this equation we will get. So, this is V s I s is equal to V R plus Z. Although I R is and I s now both are same here this thing right another thing is I s is equal to I R. So, this equation is I s is equal I R, 0 into V R plus 1 into I R right. So, this sending end and receiving end this this is a b c d parameter this is a is equal to 1 in this case v is equal to of course, here a is a real quantity for this one right z of course, is complex c is 0 and d is 1. So, a d minus b z is one because one into and minus 0 into z. So, that identity holds and this is equation 4 right.

The phasor diagram for the short line I will show you in this figure right. So, you have also seen this one. So, this is actually voltage V R, V R is taken as a reference right.

(Refer Slide Time: 28:04)



⑤

From Fig.2, we can write,

$$|V_S|\cos(\delta_S-\delta_R) = |I|R\cos\delta_R + |I|X\sin\delta_R + |V_R| \quad \cdots (5)$$

$(\delta_S-\delta_R)$ is very small,

$\therefore \cos(\delta_S-\delta_R) \simeq 1.0$

$$|V_S| = |V_R| + |I|(R\cos\delta_R + X\sin\delta_R) \quad \cdots\cdots (6)$$

Eqn.(6) is quite accurate for the normal range of load.

$|I| = |I_R| = |I_S|$

Fig.2: Phasor diagram.

$EA = |I|R\cos\delta_R$

$AB = CD = |I|X\sin\delta_R$

$OB = V_S\cos(\delta_S-\delta_R)$

$OB = OE + EA + AB$

What I will do I will give you a another thing, that instead of taking V R as a reference it is your job you will do it you take I as a reference and draw this whole phasor diagram this is your exercise right, now come to this. So, this is V R as a reference. So, this is I R, I have taken magnitude here this is I X and this is the voltage V s right. So, angel your that angel that b two in this I and the V R is delta R, this green color this is delta R angle between your I and V R right and angel between V s and I is delta S right.

So, this is rate color delta S and angle between V R and V s it is delta S minus delta R. So, this is delta S minus delta R this is the angle between this V s and V R right and now here E A is equal to I R cos delta R, because this is delta R this is also delta R right and a b is equal to c d is equal to I X sin delta R this is c d is equal to I X sin delta R, and your E A is equal to I R cos delta this we have seen earlier also just now just in that previous thing we have show right. So, this is the phasor diagram and magnitude I is equal to magnitude (Refer Time: 29:40) current is equal to magnitude sending in current.

Now, from this only we can write magnitude V s cosine delta S minus delta R the projection on this is equal to your I R these are magnitude understandable. So, every time I am not calling as magnitude, magnitude, I will call I R understandable right. So, I R cos delta R plus I X I in delta R plus V R this is equation 5 right. Now delta S minus delta is very small the angle between V s and V R actually very small we can take cosine delta S minus they are approximately 1 that is delta S minus delta R approximately is 0, cosine of this 1 delta S minus delta R approximately 1. So, here you put one then we will get magnitude V s is equal to magnitude V R. plus I R cosine delta R plus x sin delta R right.

So, equation this is equation 6. Equation 6 is quite accurate for the normal range of load right that means, because this is an approximation delta S minus delta is an approximation right. So, if difference is more then we can automatic this approximation right, but for nominal load this is equation is more or less quite accurate right. So, one thing I am telling another exercise you try, the take I as reference and draw the redraw the whole phasor diagram fall this thing right and see how it will looks like you will find perhaps rather than this one that one may be easier to you, but I have not made it for you, you should do it.

Thank you.