Power System Generation, Transmission and Distribution
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Module No .# 01
Lecture No. # 12
Characteristics and performance of Transmission Lines

Good morning, ladies and gentlemen. Today, we start chapter, the lecture 12, characteristics and performance of transmission lines, continued. We have seen yesterday how the change of excitation controls the power factors and the current.

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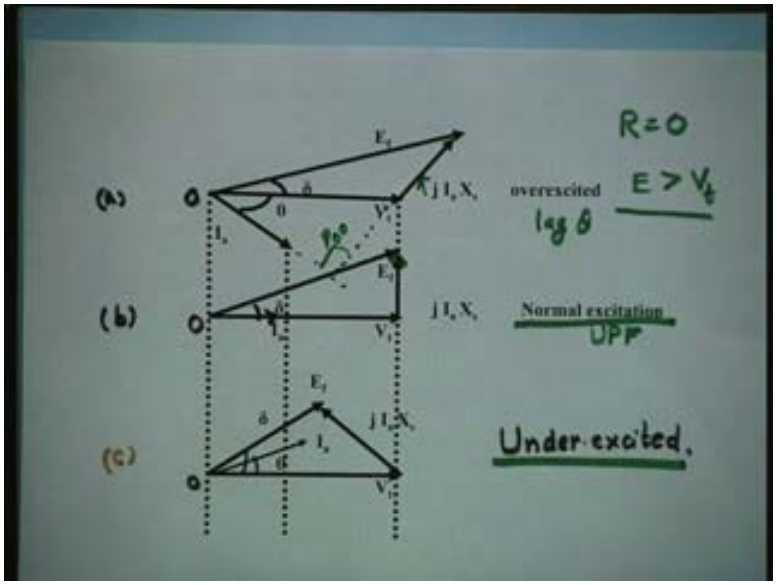

Now, as you can see in this diagram, three diagrams are drawn, as you can see very clearly, the voltage terminal voltage remains constant, this is the phases o V t, o V t, o V t remains constant in all the three. The current in figure a is lagging angle theta, current in figure b is in phase with the voltage, and current in figure c is leading. right Now, as you know the rules of the game, that is drawing the phasor diagram, you have to add to the V the reactance drawn, resistance is neglected, and this is to be 90 degrees to this current.

So, naturally this is the if you proceed for this is 90 degree and this j I a X a. So, we get E f and the angle between V and E is called torque angle, load angle which is always shown by delta, this is called over excited case, E is much much higher than V t, it is

over excited case. Normal excitation is when the current and voltage are in phase, it is a unity path, this was lagging unity and you to just add 90 degree, and this E f which is definitely lower than case b, case a is normal excitation, it is called normal excitation and the case c, which is under excited case, the current is leading by angle theta the voltage v, you add a draw and E f is very very small, in fact smaller than the V.

So, you have seen how beautifully we have controlled the power factor from lagging to unity to leading, just by changing the excitation. And there are various methods of excitation control available in the literature and that is the beauty of synchronized machine that it can be operated from, this you must have done in your practical in under graduate V-curves synchronous machines. So, you can operate the machine from lagging to unity power factors to d d which is not possible in induction machine or any other machine. So, that is why it is versatile machine and it can supply negative volts, positive volts or anything.

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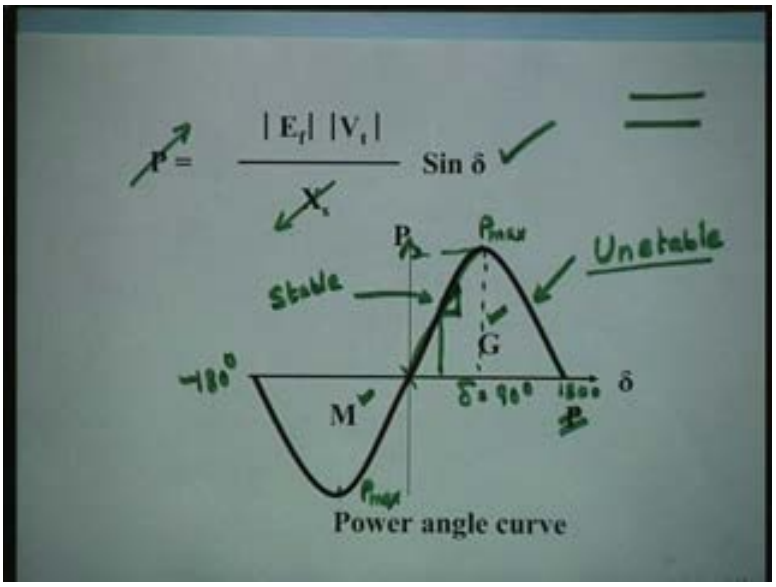

This is the well known power angle curve P versus delta, this is Y axis the real power, X axis is delta, this is for generator operation, and this is for motor operation. And in fact, this is P max, here also it is P max which is delta equal to 90 degree, and this is well known equation for dual power electric power generator E f V t X s into sign delta, if we reduce X s, P goes up and that is why we are using bundle conductor where X s is reduced. That is why we are using parallel lines, because if there are parallel lines, the X

will be less than the individual lines, parallel lines incidentally also gives you reliability, because both the lines failing like both the kidneys failure is very rare and very unfortunate, somebody has both the kidneys. If you increase the voltage again the power transmission is increased, that is why we go for 400 k v, 800 k v, and 765 k v.

So, this picture gives you the clear picture how power is controlled and the controlling factor are reactance, the power angle and of course, the voltage. You can see why this is called stable, if it operates from here to here, this is stable region and this is unstable, why? Can anybody reply to this question: why 0 to 90 degree is stable and 90 to 180 degree is is unstable? Because, here the delta goes up, that speed goes up and power also goes up.

So, this is a positive, tangent is positive where as reverse happens from 90 degree to 180 degree, the speed goes up, power goes down which is not like expensive go up, the salary or your income should go up, if not it is unsustainable situation, you will have other go take loan or you cut short your other expenses; that means, you face with the problem, if your expenses go up and correspondently, the income does not follow up. And then same thing happen in electric machine, if delta goes up and power comes down it is unstable. Of course, stability is a separate chapter all together, which we will be doing next semester, E X 860 power system analysis.

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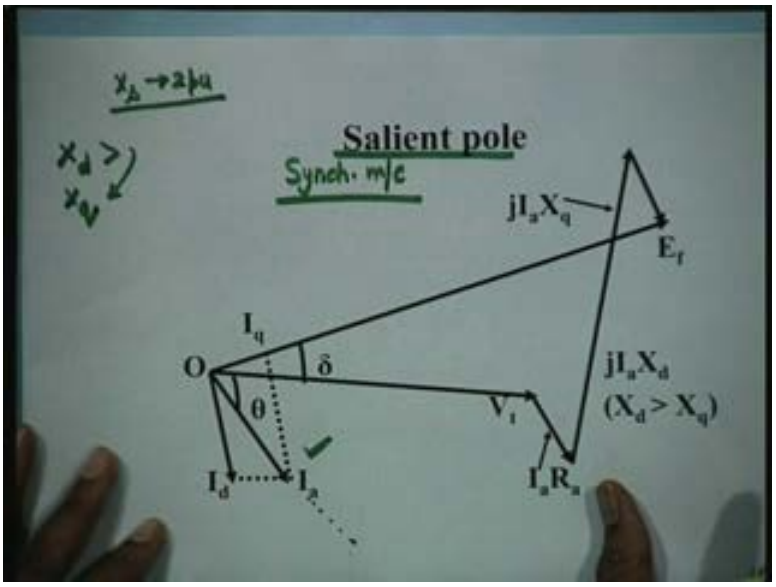

Now, this is a Salient pole synchronous machine (No Audio from 9:13 to 9:23), the air gap is not in form, I had drawn the picture yesterday. So, what happens, there are two reactances, direct axis and quadrature axis, and X d is more than X q. Do you know the normal value of X s now, which is now going up to 2 per unit, it is on increase and air gap is almost reduced to irreducible value, we cannot further reduce air gap, because the rotor has to move, it is no air gap which cannot be 0, the trend is that SCR ratios is incoming down, the SCR is inverse of X s, short circuit ratio, SCR not silicon control rectifier, SCR has so many other meaning also right, so short circuit ratio is inversely proportional to X s.

We will come to that, I am only telling you the fundamentals of it, the values of X s gone up 2 per unit, it is going up and up because we want to reduce SCR, that is the norm because the I j s are coming, you know down and down, machines are very compact, the air gap is reduced, air gap is reduced naturally X will go up. Now, X d is more than X q, if it is point 8 per unit, it is point 6 per unit something like that. Now, we come to the phasor diagram, this V t is horizontal, it may not look so in figure, it is a reference phasor, this is a current, the resistance has to be added, the resistance drop in parallel to the current which has to be done, then this should be 90 degree to this; obviously, the diagram has not been properly drawn.

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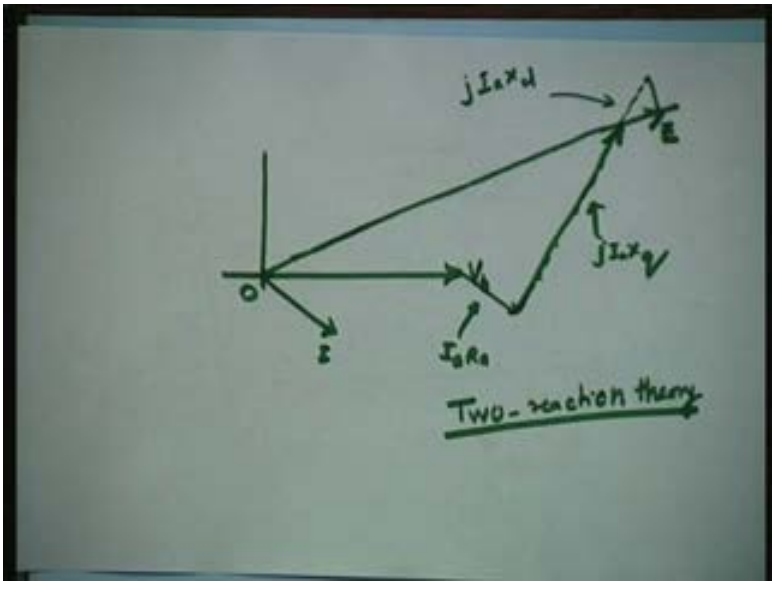

I think we can draw it properly, of course it is not to the scale, draw this, this is very simple way of drawing diagram, draw parallel to this perpendicular and this is E, and this is your whole thing is I a X d, is it or not? Is it not the same thing? And this part is ok, this is not 90 degree to this, this is going somewhere outside the paper. So, I think this this diagram is ok and this is the easiest method to draw a, this is two reaction theory. Where do you use this salient pole, any idea? Hydro power plant, because their speeds are low. So, we need this salient pole machine in hydro power plants and we need cylindrical rotor machine in thermal power plant, so their speed is 3000 rpm and so.

So, we were talking about the two reaction theory, which is in fact required whenever there is a salient pole synchronized machine, why? Because, the air gap is not uniform and once the air is not uniform, the machine presents two types of reactances; one which is along with direct access is called direct access reactance, another which is quadrature to that, quadrature is 90 degree is called quadrature access reactance. X cube, X d is always more than X cube and is equal; that means, machine is reduced to cylindrical rotor synchronized machine. Now, we have seen here the phasor diagram for as salient pole machine and that I have already explained you. Let us now go for the power angle curve for the salient pole machine.

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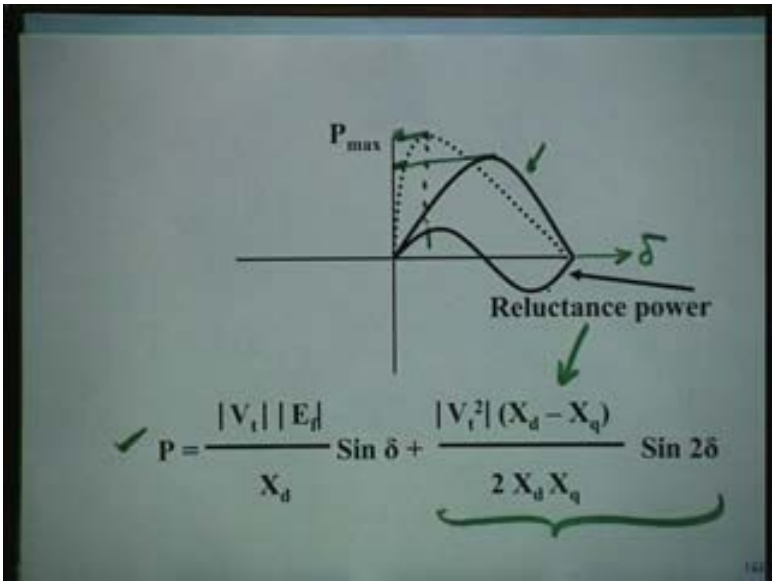

As you can see, this part was known to us for cylindrical rotor and this part is called Reluctance power which is the second order term; that means there has to be more power

in salient pole machine and so, the maximum also shifts slightly less than 90 degrees. Alright So, we add superimpose the term with this second order term and you get doted curve as a P maximum which is higher than the P maximum of cylindrical machine, so we get extra power. In fact, there has been machine design based on this principle called Reluctance motor which relies on only Reluctance power, which we might have read in machine course. Otherwise, you can see our machine book or any book, someone asked last time what is representation of loads.

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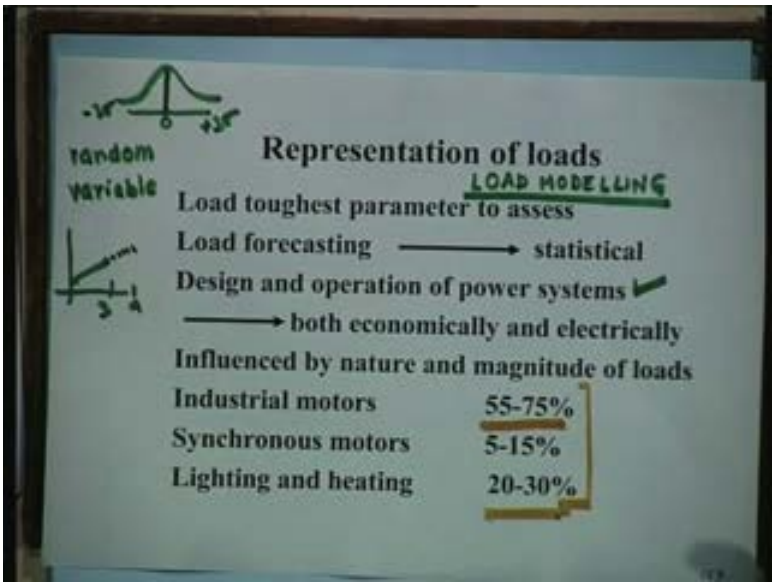

Now, the time is come to talk about load model and this is also called load modeling and I just said, it is a very important topic you can do in the p h d, there are books on load modelling, load toughest parameter to assess because it is a random variable. When it is going to rain, nobody knows, people do forecast but it may go wrong. In fact, you you are aware of normal distribution or Gaussian distribution which is like this, minus 3 sigma to plus 3 sigma sigma is standard deviation, this is expected value. I do not know whether you have read it in the probabilistic theory somewhere, this is called normal distribution or Gaussian distribution.

So, variation is around the expected value or mean value, and that is why loading anything which is random variable. When will you get phone call nobody knows, you only have phone in front of you, and any time it can ring, when the customer will come in the shop nobody knows, he never announces, he never gives a notice. When the death

comes nobody knows, it is also a random variable, even the birth is a random variable, the exact time of arrival that is why it is called expected time of arrival E T D, but it always go you know, 15 days this way.

So, load is random variable, hence it is very tough to access load forecasting is there, statistical methods are there, you have the you know the extrapolation technique for example, I have shown you up to 2003, whatever is the earlier curve we can always put 4, would likely to the this one, but things may go wrong, it will not happen the monsoon may fail, the the summer may be severe. So, you need more AC load, and which you have counted on some basis and that basis is no more there.

So, that is why it is called random variable, the whole design and operation of power system depends on load. Both economically and electrically, it is influenced by nature and magnitude of loads. If load is there, then only we generate, if there is no load why should we generate? We are not generating power in Satpura's jungle or somewhere there is no body, there is no industry, there is is no living being. Roughly, the percentage of various loads are given here, industrial motors vary from 55 to 75, if it is a region of Vidharba, under developed Jharkhand, Bihar, no industries then industries motors used a 55 percent, but if it is Bombay, Pune, Bangalore, Hyderabad it may as the Delhi, it may be as 75 percentage, so is synchronous motors.

It varies from 5 to 15 percent, the electric clocks use synchronous motors, and the paper paper industry uses synchronous motors, why? You need the constant speed motor and synchronous motor is only motor which if it runs, runs on synchronous speed, otherwise it does not run 0, news paper cannot be first page will be in different width, and second page and third page, you will feel awkward, in a book all pages are supposed to be uniform, the copy where are taking notes each page must be same size, same thickness, same height, otherwise the copies will look very odd, lighting and heating is remaining 20 to 30 percent, heat in our country is not so much, because we have a winter, winter is confined to few hilly areas, north areas; Himachal Pradesh, Jammu Kashmir, even in temperature this time 30 degree, it is also global warming, but lighting five star hotel for example, forty percent of electricity bill is because of lighting studios, you can see the amount of elimination level is very high, shops, for monuments you need good lighting, tennis court, the day and night match, so lighting level is very very high.

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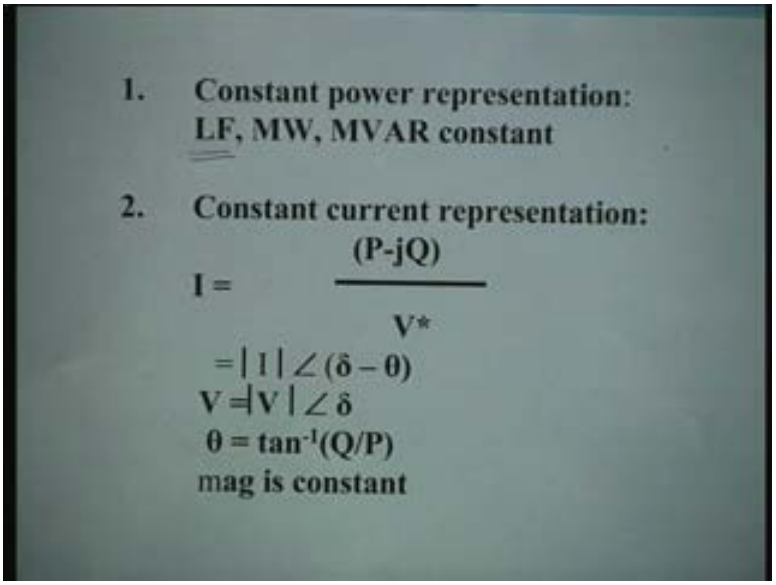

As I told you, there are three ways to represent the load, constant power representation right for example, in load flow you have megawatt and MVAR constant, constant current Representation, which is required in production P minus j Q by V star, i magnitude delta minus theta, V is equal to V delta, theta is tan inverse Q by P, magnitude is constant.

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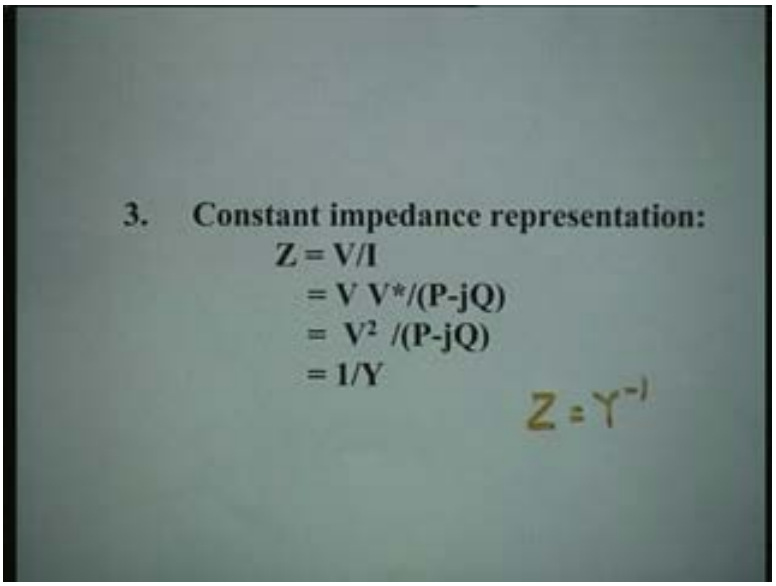

And the third is constant impedance Representation or there are inverse of each other Z is equal to one over y or if it is matrix or Z is equal to y inverse v by I we have just found out value of I V square by P minus j Q one over Y, so this is constant the load of 5

Ohms right. So, these are the three ways in which you can listen load: constant megawatt, constant current and constant impedance all and it is. Now, we are starting chapter five: performance and characteristic of transmission line, why do you want to study this? This is proper transmission lines we are going to study, because we need to worry about flow of p and q on lines, how much real power is flowing? How much reactive power is flowing?

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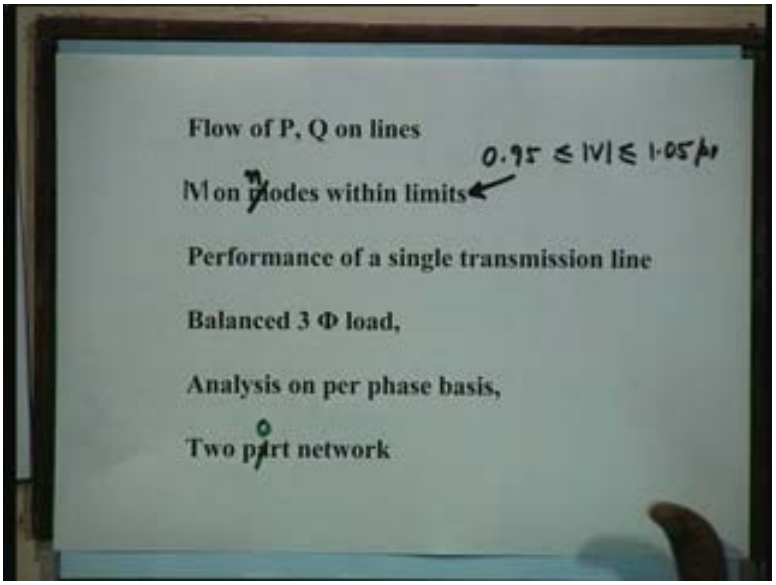

What are the various values of voltages on nodes within limits, it has to be within limits, what are the limits? 0.9 5 per unit 1.05 per unit, this this is the limit, you cannot go beyond this, lower than point 0.95 and higher than 1.05 percent, voltage is supposed to be constant. Performance of a single transmission line we will study, because it is easy because the principle are same whether is single whether it is single, whether it is double or anything. We will consider balanced three phase load, most of the time the loads are balanced, that is why we will see domestic supplied they give, they use all the three pages such that the loads are balanced, analysis is always done on per phase basis even in industry and two port network, it is you must have done the circuit theory, there you must have read two port network, which are solve by X parameters y parameters Z parameters and so on. This is being done in your circuit theory.

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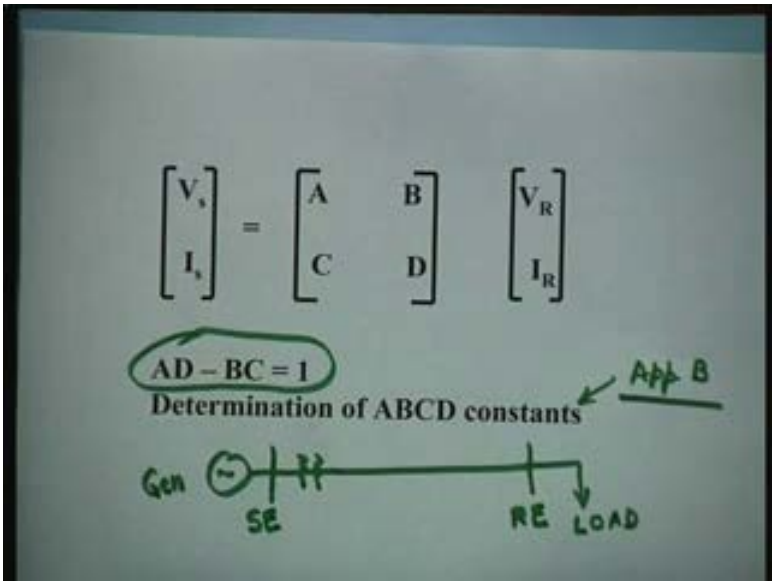

This equation is very important; this is the trucks of the matrix. What does this equation show? It shows how the sending end is connected to receiving end, the subscript S denotes sending end, subscript R denotes receiving end. Receiving end is normally load end; sending end is normally generator end, at least for an isolated system. If it is the interconnected power system as I have been repeatedly telling you earlier, from any end you can send power from any end you can receive. In fact, from the end you are sending power, you can also receive power. India gets aid from various developed counties we also give aid to Nepal, Bhutan, Bangladesh, the counties which are poorer than us.

So, we definitely have give and take, this identity is very important AD minus BC is equal to 1, why it is very important? If you know three constant you can find out fourth one without actually conducting an experiment. A, B, C, D these are the four generalized circuit constant further also known as A, B, C, D constants. Please read appendix B of the book to determine this constant, how to find out, how to determine in lab. So, that is given in detail and sure you must have done here also, but if you haven't, then kindly go and read the appendix B, am right is it appendix B? ya. So, please any book whether it is red book or brown book or green book or blue book and now black book is coming, coming Monday in third edition. So, you can find this appendix in all the variations from here it should be clear to you how do you find out A?

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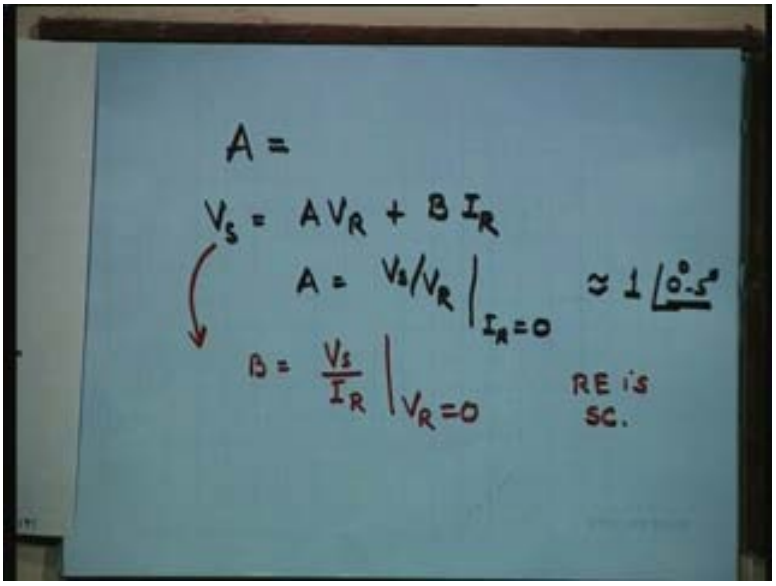

A can be find out, which is as simple as that, that is write the whole equation V s is equal to A V R plus B I R. So, A will be equal to V s upon V R with I R is equal to 0, where you say I R is equal to 0 is what? hm. Open circuit. Open circuit, absolutely, Very good, the receiving end is open circuit.

Now, I have to tell you repeatedly the voltage as most of the nodes remain same or nearly same, because as it is they are allowed to vary between very narrow range, 0.95 per unit to 1.05 per unit, that gives you immediately a clue, the value of A has got to be around 1, because V S and V R same. So, the value of A is nearly 1 and the angle will be very small because A is a phasor quantity. So, the angle will be is around 0 degree when 5 degrees. So, when you do a numerical and if you happened to get the value of A as 958, immediately there should ring in your years that there is something has gone wrong drastically, and if you do not have time in any exam to correct such situation where you are sure that you gone wrong please write in note your examiner, sir I know the value of A should be around one; however, I got it, I have gone somewhere wrong, he will give some credit at at least he know you are aware that A should not have been a 958 or 18 or whatever, you should have been nearly 1, how could B? The B from here can be written as V S upon I R where V R is 0, that is receiving end is short circuit. Can you tell me the units of B? ohms, it is an impedance where A was dimension less there was units to E A, if I ask this question in UPSC or any where NTPC, what is the unit of A? Generalized circuit constants, we should not say ohms or something, it is unit no unit, it is

dimensionless, B is nothing, but impedance the transmission line impedance and its unit are ohms.

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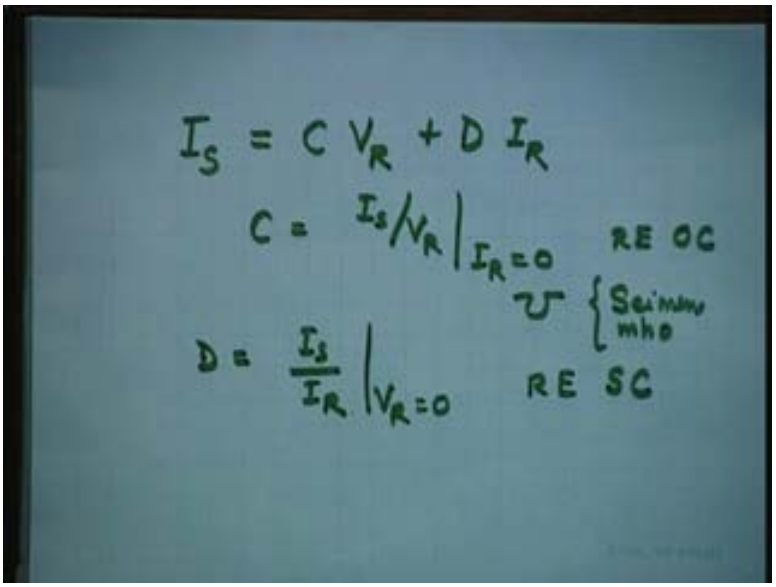

Now, we come to C and D, I S is equal to C times V R plus D times I R, and if you want to calculate C, I S over V R; that means, receiving end is open circuit. And please remember, the dimension of C or units of C will be now days is called Seimen or if you want to you can write mho and finally, the value of D receiving end short circuit. Please understand the value of D is again dimension less, current upon current. And in fact, these currents are very nearly equal, if you consider the Short Line model is no parameter series circuit, so whatever is I S is equal to I R.

So, D becomes 1, A also becomes 1, if it is exactly same the voltages are 1 per unit and that is called flat voltage start when all the voltages are one per unit in a system. The system has a flat voltage start same one per unit volts, angle will be different, otherwise no power transfer if the angles are also same, the also same, then where did you think power go? Nowhere, it cannot flow, now all the four constants as I told earlier, not be computed because there is an identity which links all the four constants that identity is AD minus BC is equal to 1. So, having computed three, even computed four, for special networks A=D which are bilateral, otherwise A will be in different angle.

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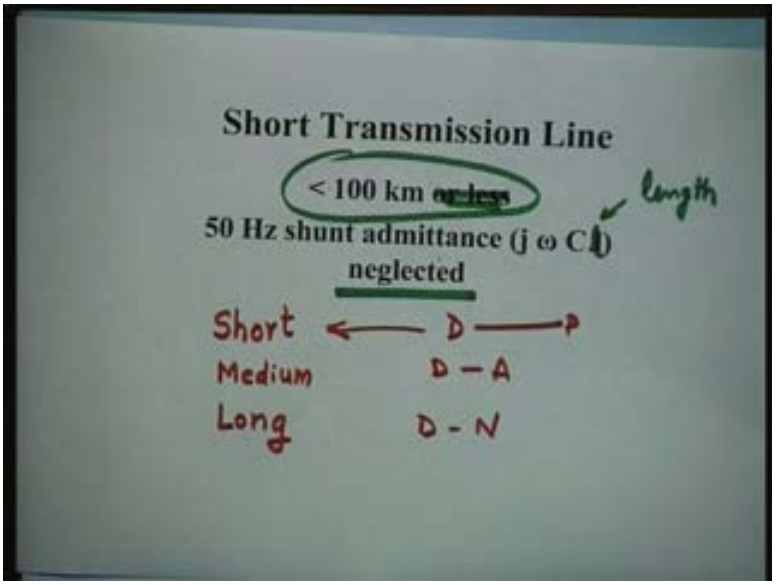

What is the short transmission lines, there are three types of transmission lines. What are those three transmission lines? Short, very good medium and long. From Delhi to Panipet, around less than 100 kilometers or around 100 kilometers, it is a short transmission line, from here to Ambala, it is a medium transmission lines and from Delhi to Nagpur long transmission, why you want to divide transmission line into short, medium and long? Their characteristics change, their performance change, even a layman will know that when you want to carry a large amount of you take a Draft, but if you are going for careless for drinking cup of tea, you wont pay your bank card or atm card or cheque book, 2 rupees you take cash.

So, short line, medium line, long line; all the three lines models are different, characteristics are different, performance are different, and that is why we have divided the line performance into three parts: short, medium, long. We start with short as I just explained you it is less than hundred kilo meter, less than hundred kilo meter 50 hertz shunt admittance j omega C l, l is the length of the line is neglected is hardly any and so, the model is short line model is simple series circuit shown in the next slide, this figure is the simplest type of figure for a transmission line.

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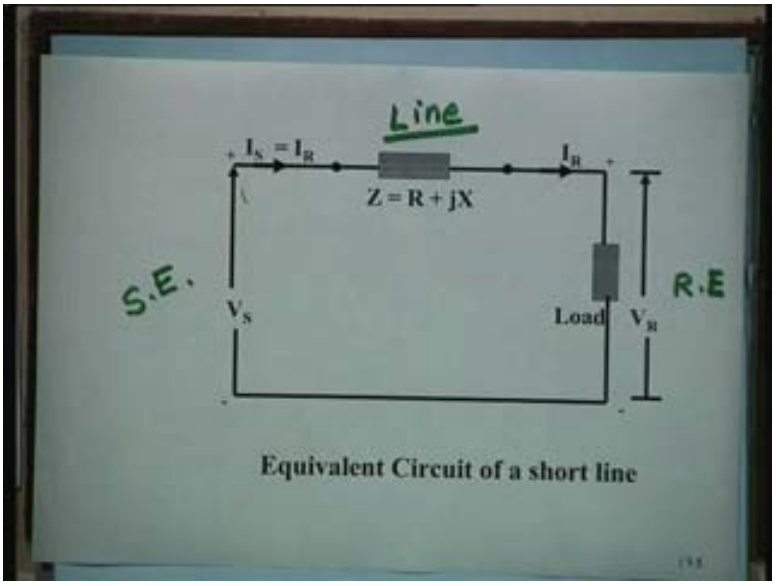

We cannot at be a simpler there is a sending end there is a receiving end and this is the Line this is sending end voltage this is sending end current which is same as receiving end current this is receiving end current this is Load this is Load voltage or receiving end voltage this the Line is modeled by just series impedance R plus j X. So, what will be the ABCD constant for such a Line? It will be, a will be 1, D will be one and C will be 0 and B will be why C I s 0 because I S is equal to I R why a will be one because V s is only a drop plus V R

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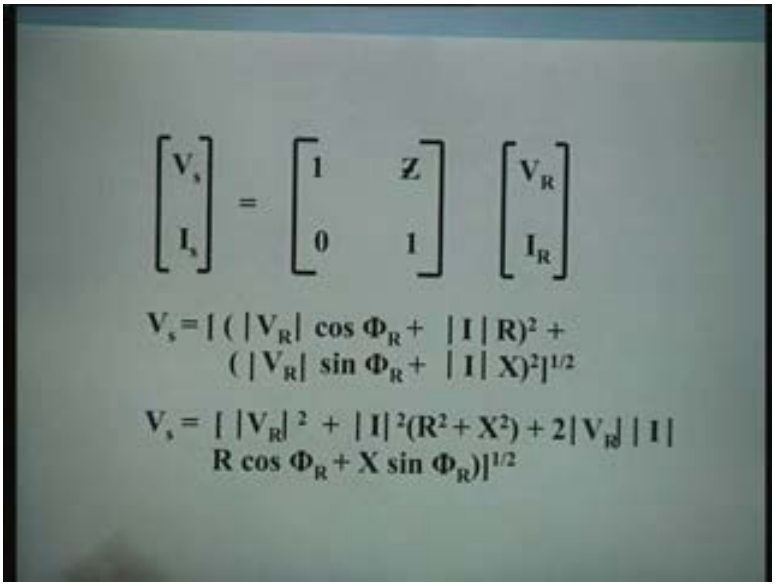

Let us write the equation these are the equations V s I S 1 0 1 V R I R, I can write V s in this particular form V R cosine phi R plus I R whole square plus V R sin phi R plus I X whole square, you may ask me from where you got this equation.

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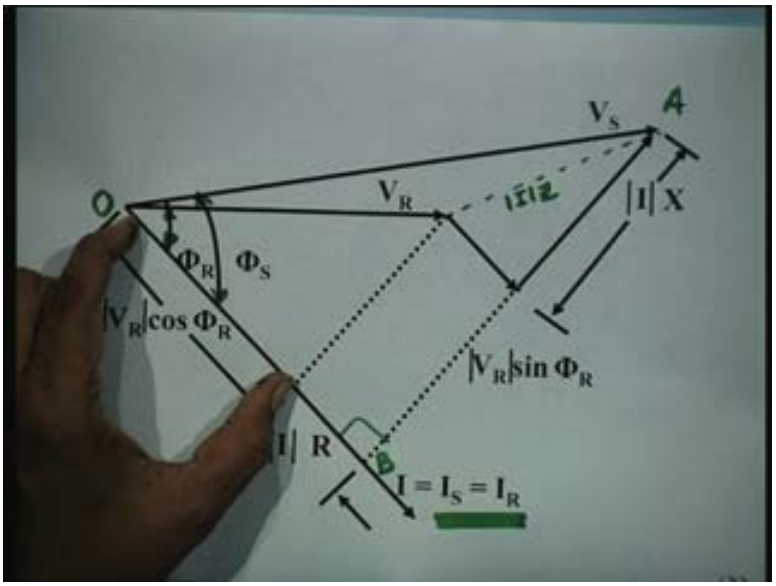

This equation is coming from this diagram this is origin this is V R, this is the current which is same as I S equal to I R, this is receiving end, power factor this is sending end, power factor. You add this V R the drop and reactance drop and this is nothing but I Z, and this is V s, now how do you get the value of V s in terms of V R? Consider this triangle you have must done in ninth class, Pythagoras theorem it with theorem 29 in my days 1958, I learned that Pythagoras theorem what was Pythagoras theorem, the square of two sides when added gives the square of the hypo hypotenuse, a square plus b square is equal to C square C, I s a and b are two other side of a right angle triangle, this is a right angle triangle, this is 90 degrees. So, O A B, I am thus getting O A. So, OA is V s. So, o square is equal to this square plus this square, what is this V R, cosine phi R are this part and this I R is as it is, I R and what is this part I X? And what is this part V R sin phi R. Now, I hope you will have no objection in accepting this equation as V R cosine phi R I R whole square plus V R sin phi R I X whole square and the root, otherwise V s square and this is nothing but Pythagoras theorem. You do not know when you use what what you learn in nursery you continue to use in whole life, 3 plus 2 is equal to 5, when you take sabji, when you take something, you add in it, you will surprise even that do I calculate. They are not able to add 13 plus 8 is 21 is 13, 8 plus 21, 21 dollars please

something like that whereas, our mathematics used to be very strong in our days, we have used the even the table of factors of you know you know we could (( )). So, it is to be 1725 you may take. So, much time to find out 7 into 25 anyway rearranging the terns who knows tomorrow also write book and some of you.

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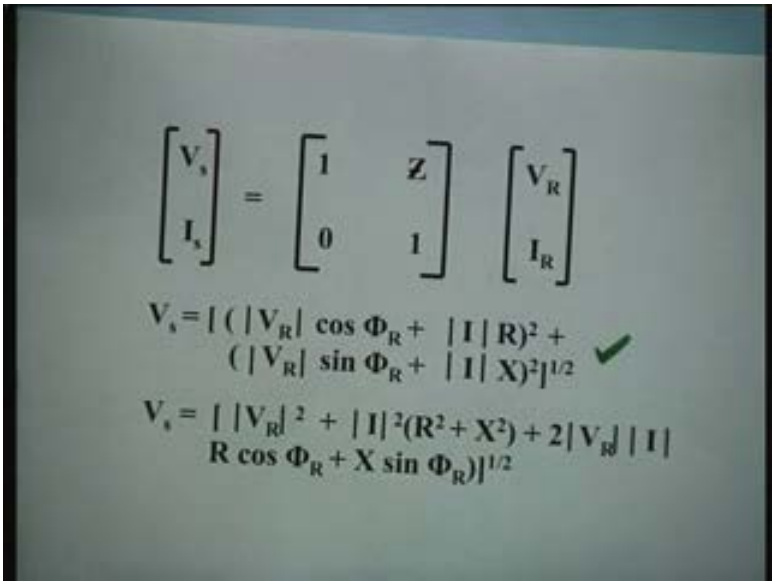

So, it to write that term here here the language is not there because economized on the also time also. So, V R Is square from here because cosine square phi R plus sin square phi R Is one trigonometry I do not know which class you are read I Read eleventh class. So, trigonometry right books are famous for last hundred years is still is great great loyalty. So, v cosine square phi R plus sin square phi R Is one. So, this V R square plus I Square r square plus X square twice V R I I R cosine phi R plus X sin phi R under root this is the equation for V s of course, you can check it from 'hm book or anywhere further simplifying.

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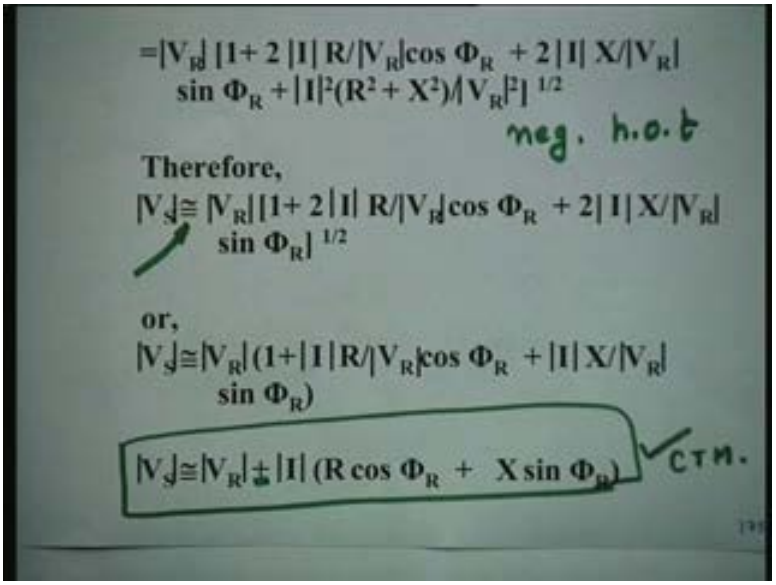

I do not think you can copy it may you can take it from the book as it is given in the book. So, do not do not take copy just understand what I am talking, now I am simplifying what are the simplifying I am ignoring higher order terms neglecting higher order terms. Now, I am putting the sign of approximation or V R 1 plus I R V R cosine phi R I X V R sin phi R. Finally, this is you to remember whether it is machine or is power system this is called C t M W hat is C t m commit to memory problem solve using this formula that V s is equal to V R plus I R cosine phi R plus X sin phi R this is the drop across the Line this is receiving end voltage this is sending end voltage.

So, you can derive it using a parser diagram using mathematics Pythagoras theorem series expansion in we are used an ignoring higher order terms finally, we have got this equation. So, this equation is very important diagram have a shown you is a phases diagram just now shown for a Short Line for current if it is leading current diagram will change still same Pythagoras theorem same mathematics what will be the change instead of plus you will get minus not here sorry here instead of plus will get plus minus here that will be the only change.

So, when I ask to derive the equation for leading power factor for said do not derive lag in and the changes sign you got 0 you are derive for leading only only the answer is this that does not mean you derive an lag in for leading it will be minus 0 what is voltage regulation I think we do voltage regulation tomorrow. So, any questions you have what

done today what we have done we have done the control how to change the power factor angle how to change the value of current keeping the active power still the same. So, the constant I V cosine theta remains the same.

So, we have seen case you are seen an normal case you are seen circuit then you have seen synchronization machine the reaction two reaction theorem salient pole power angle diagram how the p max is more than the p max for this cylindrical, thanks to the reactance power. We also seen the reactance power can be used for a new variety of machine called machine then your seen the most important parameter in the whole electric engineering for we what for which there Load, Load there are books, there are papers and Load modeling. The best papers is by are Load management. I told earlier also then there is a constant megawatt for will be a constant impedance constant admittance and constant current depending an the particular study you are going to use the Load modeling corresponding Load modeling use the still sophisticated slide with voltage variation Load also varies like when you to go walk for long you walk to go mile you can take a cycle two miles two kilometers to the scooter if you go to 30 miles, 40 miles or kilometer you have car you take car.

So, depending on the requirement you change your mode of transport when no money you go for bus you still those are even the bus money is not with you then you take lift, but taking a lift is very dangerous now a day's all of you know that. So, depending on requirement the modeling changes what is your objective function from any other question. In fact, you are not ask any question I if not in please read for the tomorrow we talk on the medium Line.