Power System Generation, Transmission and Distribution

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Lecture No. #15

Methods of Voltage Control

So, good morning ladies and gentlemen. Today, we are starting lecture 15 and that is on methods of voltage control. Why do you need to control voltage? That is a very important question because, this supposed to be constant; obviously, it does not remain constant, which we wanted to and therefore, we had to control it in such a way that, it remains constant. You may ask me another question, why it should remain constant? We already answered in past because, most of the devices, apparatus and machines, they are all supposed to work at a given voltage, the rated value, which is a designed value and if it deviates from that, naturally it p performance would not be there, which it is desired to have it. You have say, anything A C or your computer or fridge, whatever, if the voltage varies its p performance detoriates.

And hence, we need to study certain techniques, certain methods, even a system wide basis, that is, we are talking about load or about consumer's interest. But, even in system at various points, voltage should be fairly constant as already explained several times. I was talking about 7 observations. After deriving those 2 very very approximate equations, what were those approximate equations, 1 was p is equal to E V by X sine delta and other was delta V not delta V the this Q is equal to V R by X into delta V Right, where there is no delta at all and that gives you a famous p principle of d coupling. right What is d coupling; p is friendly to delta and Q is friendly to V if V varies only Q gets p predominantly affected, if delta varies, it is p which gets p primarily affected. So, if delta varies, Q remains by and large unaffected, if V varies, P remains by and large unaffected; this is called p principle of d coupling.

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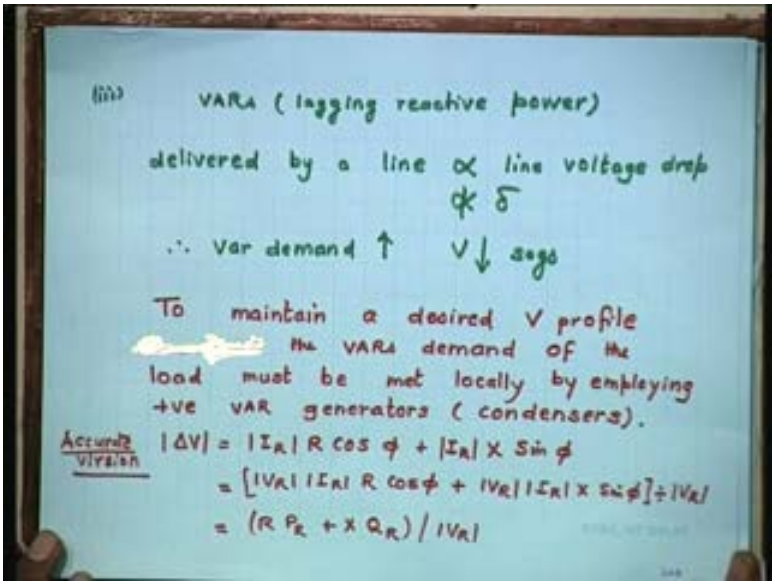

Now, what is lagging reactive? p owner Most of the time, it is lagging delivered by a line is p proportional to line E Voltage drop and is not p proportional to delta. This is what I was talking, the p principle of d coupling; if delta varies, it hardly makes any difference on vars. So, if vary demand goes up, which can happen anytime, because of your machines excitation changes and so on. So, voltage sags and this is bad sagging of voltage is bad, you can as low you can go, as low as p point 7 p point per unit p point eight per unit, whereas, V is supposed to remain between p point 9 5 per unit 2 1 p point o 5 per unit 2. So, to in order to maintain a desired voltage profile and desired voltage profile is what flat flat voltage, which is around 1 per unit, the E V airs demand of the load must be met and has to be met locally, because, it is low point in transmitting vats along with watts on several hundred kilometers of length. Because this will also cause a drop, it will also cause I squared X heating losses, which is all undesirable. There is not a single desirable thing which can happen, if you transmit watts. Also, whatever watts are coming automatically is welcome, because, you cannot stop it, you cannot block it.

But undesired watt was, why should become, because, we can as well supply them locally. Suppose you have the bank balance or bank account in Bombay, why should you carry money from New Delhi? Because, on the way we may get pick pocketed, you may loose it, you may drop it. So, better to have go there, you have debit card and you have an ATM card, withdraw money there and use it. In case you do not have that facility, then this is a different issue. Now, what are these local arrangements? We have E V are

generators, now which machine can generate E Vary synchronous machine, induction machine takes vats it is a sink and not a source or you can have a bank of capacitors or bank of inductors, which will give you different type of vats. If you want positive E V airs, then capacitors if you want negative E Vats, which also you may need sometime, most of the time you need positive E V airs because, E Voltage sags in India, and therefore, you need a bank of capacitors. But sometimes, like when is a light load condition or say 0 load conditions, no load conditions, well, in that case, you need a bank of inductance. Now, this equation is a accurate E version of voltage deviation, delta V this you must have proved in transformer chapter in So, many line chapter

Also, this is an exact expression for delta V I R cosine p hi plus I R X sine p hi. Now, if you want to divide by V R even multiply by V R same quantity, if you divide and multiply or you multiply both denominator and numerator, the E Value remains same. So, what have done, that I multiplied by D R and I divided by V R, what happens? I can replace this big quantity by P R real p owner received at the load end, that is P R, so, R P R. Similarly, I can replace this by Q R. So, X Q R divided by V R. This is an example which I wanted to solve tomorrow in the classroom. It is a very good example, it gives you all the fundamentals of load flow, how line flows takes place, how load flows, how p owner flows or a line. What is an example, we are considering an interconnected cable links.

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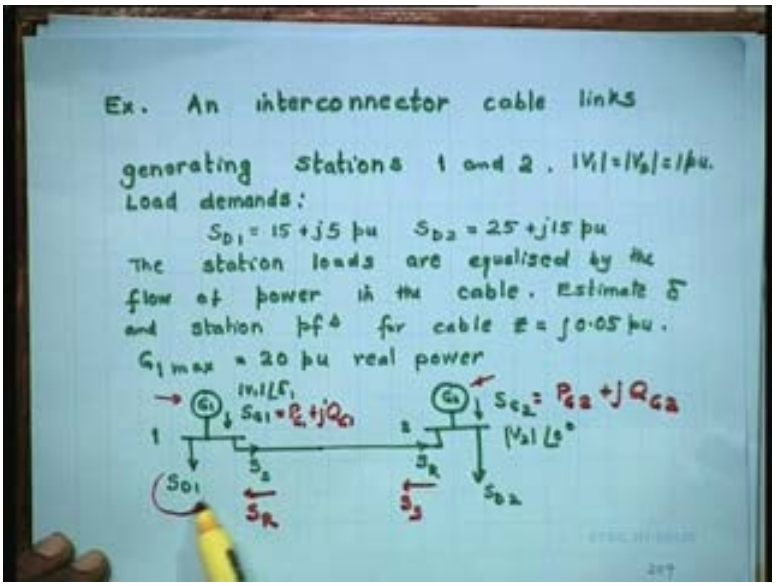

So, this is a generator 1, this is generator 2; naturally this is voltage E V 1 delta 1. This is V 2 0, because, the reference generator without loss of generating, you could have considered 0 here delta, here it hardly matters as g 1 is a complex power generated by generated number 1 which is in fact, equal to p g 1 plus j Q G 1. Similarly, s g 2 is power complex power generated at generator number 2, which is equal to p g 2 plus j Q G 2. Now, this is the sending end complex power, this is a receiving end complex power. It could have been, also this could have been sending end complex power. This could have been receiving end complex, every end is sending end, every end is receiving end; just for simplicity, we have considered, because, this is 1.

So, sending to receiving, this is a complex load which is equal to P D 1 plus j Q D 1. Similarly, this is a complex load, which is equal to p d 2 plus j Q D 2. So, what is required, what do you want to solve? We have generating stations 1 and 2. Having flat voltage, flat voltage means both are 1 per unit as it should be. Load demands are given to you, the numerical values fifteen plus j 5 per unit second station, the load demand is twenty 5 plus j 15 per unit. Means. there is a bigger load, is a bigger industry, thanks to generator too and that is why, it is a receiving end. See, there is a justification. Why did we consider is not, there is a method in magnums. Also, why you are considering generator 2, as a I mean the bus 2, as a receiving end, because, it is a bigger load.

So, naturally, generator 1 alone or 2 alone may not be able to satisfy at load and hence, we need a help. Commercial load, you are p eying for it, you need power from some far off generator or nearby, depends on the length of the line. The station loads are equalized by the flow of power in the cable, estimate delta and station power factors for cable impedance. I am assuming r to be 0 r of line and X point 0 5 per unit g 1 max is given to you, generator 1 can maximum power generation possible and this is twenty per unit real power; that is a maximum value that you can, you cannot go beyond that. So, this is a P problem I will like you to attempt it tonight at your respective rooms and if you cannot solve this, please do bring your calculators tomorrow. Do not, I mean, ask each other to share because, that will be a loose time and please inform others who would like to attend tomorrow not to come here, but come in my office and someone should take responsibility of informing somebody like you should inform your 2 other girl friends even if they are not your friends, he may be your just classmates.

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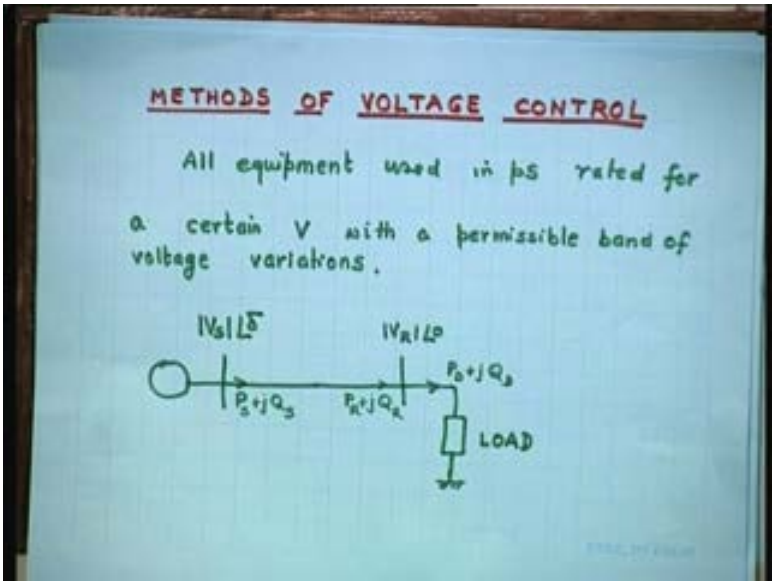

Now, we come to the P proper voltage control, all equipment used in power systems are rated for a certain voltage that I ha have been repeating again and again, with permissible band of voltage is no that it has got to be 1 per unit, no point 9 5 2 1 point 2 5. This is a narrow band within which, it can vary. This is again a 2 bus system, which we have just talked about. Only difference is, here generator is only at the bus number 1, there is no generator at.

So, there is no doubt about receiving end and sending end, the obviously, generator end is their sending end and load end is a receiving end, it could not have been reversed. In this case, naturally the E Voltage at the load end is reference 0, this is p d plus j Q D is of this load and this is the receiving power, this is the sending power. Obviously, the difference of the 2 is loss this is generator, I am repeating those 2 equations which is.

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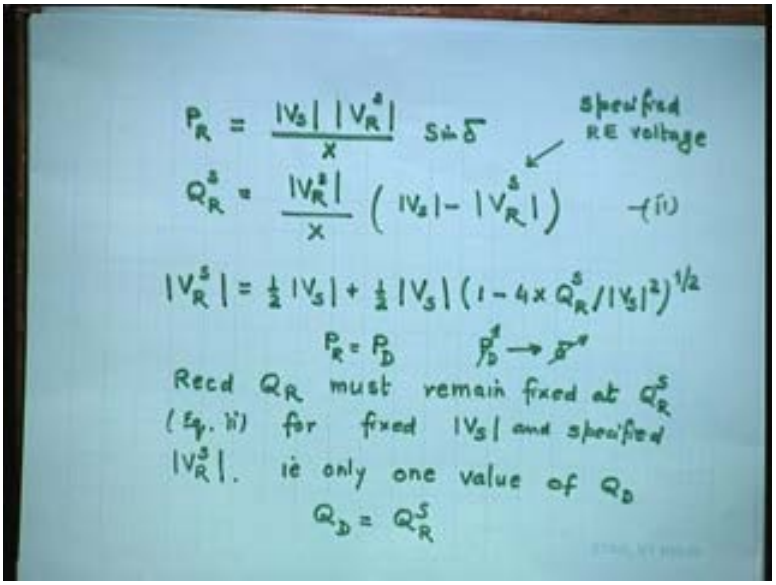

So, now, friendly to us P R, the receiving end, real power is V s V R s. What is this superscript s? The superscript s is nothing but specified, this is what I want at the receiving end, V R s, this is not voluntary retirement scheme V R s, but this is specified receiving end voltage. Similarly, this Q R s, that is the receiving end reactive power specified, why it is specified? Once you specify a voltage, Q gets automatically specified, you have no choice. So, this is equal to specified receiving end voltage upon X V s minus V R s. Here, we were using delta V earlier, but now we cannot use delta V because, we have this specific values of sending end and receiving end voltages. Now, V R s specified is equal to half V s plus half V s 1 minus four X Q R s divided by V s squared this, alright, derivation we will see in the book, how we got this equation, but we can find out the E Value of V R s from these 2 equations. P R is always supposed to be P D the whole p owner system is there for this particular equation. Otherwise, there is no need to study power system. Whatever is a demand, I want real power received equal to I do not know, more you pay only 2 rupees when you take a cup of tea, you do not paying 2 point 2 5, that is extra, you cannot pay also 1 point 7 5 because, even have a give a dirty look, if you do that again and again, so, you to pay 2 rupees. So, whatever is the demand, why should I get less power? If it is less power, the customers will shout at me, they will be you know, inconvenienced by some load sharing or their business will be affected, my revenue will be affected because I am not giving you power which you want. So, naturally you are not paying me for power which I have not supplied.

So, it is, we say, loss loss situation and not a win win situation. So, I must ensure as a power engineer, as an electric energy system engineer, that P D has got to be satisfied at any cost. So, my receiving end power has to be equal to P D f p d goes up is naturally load is not in your hand. Suddenly you feel hot, you re request person you please rise the air conditioning, air conditioning rise is not free, it will need money, it will need power, means money. So, the moment load goes up, what is what is choice? Power system engineers have got load frequency control, automatic generation control. you If it is a thermal power plant or you rise the gate opening if it is a hydro power plant, nuclear power plant you have done already in this course. The type of control is very little and that is why, it is used as a base power plant. I ask this question, also minor 1 because, since the power of is fixed, it is normally use as a best load part, but hydro and thermal, you can always varying the power output delta variation is sine delta variation.

So, p is equal to, it is written there E V s V R s by X is fixed once transmission line is fixed, unless, until you go for compensation, then, X Can vary. So, this is know only follow, you can vary 2 vary p r, that is what I am doing here, received Q R must fixed as Q R s if you want to V R s fixed. This is equation 2 Q R s, is given by equation 2 for fixed V s. I am assuming that sending end voltage remains fixed. Circular is not much of a variation. It is in jungle, no industries there, no grade number of people are living there, only those station are personal, they live there, sometimes they also come from 5 kilometers 10 kilometers, they are also not living there, but few minimum percentage are living there.

So, V R s, this is a reasonable assumption to assume that V s remain fixed. If at all some silly can ask me question, no no sir, it is also varying, how do you know it is not varying? There is a excitation P R obi, even people living there can vary the load, well, there is a transformer sending end also and you can have and you can put it V s as fixed and specified V R s. V R s we do not want to change, anyway, that somewhere the whole object is function a power system that we do not want to change the E Voltages, that is only 1 value of Q D can be supplied, then if P D changes you have mechanism change delta, put it equal and not able to do that import power. You have always at the Haryana chief minister has just said Haryana will be able to supply power to other state by 2005.

So, there are states in India, very few though, who are power sufficient state. In fact, there is an excess power they used to be Kerala which is to have excess power once upon

a time, no more. But, maybe Haryana will be next state where there will be an excess power. So, unfortunately if you want to keep Q R s fixed at a particular value, which remain fixed as long as V R s is fixed. So, you can only supply 1 value of Q D, but do not thing p d only changes Q D is equally keeps all changing. How can you stop it from changing? After all, what is Q? Q is also will be load power factor varies Q is sine delta sine p hi it is not cosine p hi, so, sine phi. So, Q D you cannot ask, you to keep quite and remain fixed, you know it also changes and if it changes, Q R s also I want to change, but I do not want to change Q R s for the reason that I do not want to change E V R s.

So, there is a need to supply extra reactive power locally, now I am proving it. I am stabilizing it, why real power is a global P R bole real power control whereas, as a reactive power control is a local P R bole? This is asked in interview, this is asked in examination several times, show why reactive power control is a local P R bole and why real power control is a global P R bole, think global act local, this is what people says nowadays for P R tactical loads. We are not talking about theoretical loads, most of them are lagging in nature.

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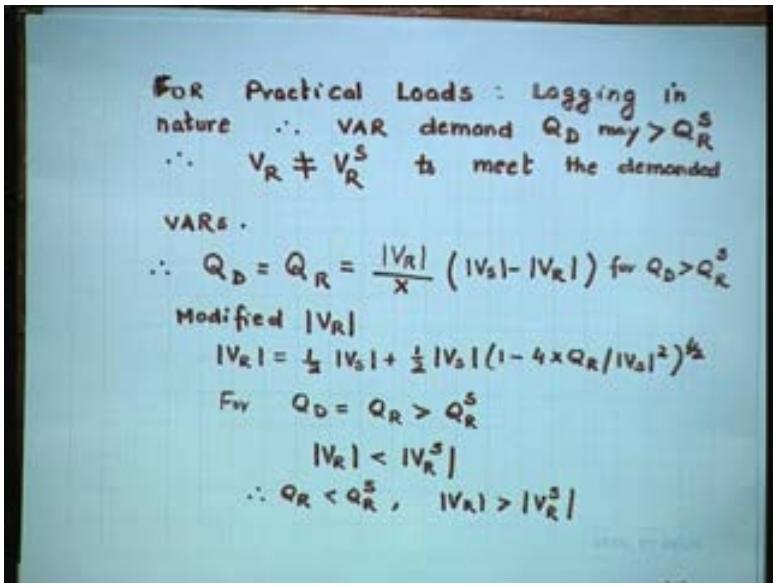

In fact, all the induction motors that you use in the world from fractional kilowatt to many many megawatts, what is the maximum size of motor? We have seen something like that, it is a hundreds of megawatt. What is a maximum size of a direct current motor, anybody and anyway find it out and please tell me in next class. So, what demand Q D

will definitely exceed Q R s most of the time and hence E V R will not remain V R s specified, because, that is a only way you can supply Q by sagging of the E Voltage to meet the demanded vars.

So, Q D is equal to Q R is equal to V R by X V s minus V R for Q D more than Q R s. I had to remove this s from here because, E V R will go down. So, this a modified V R and modified V R is given by same equation half V s half V s 1 minus four X times Q R V s squared half for Q D for Q D more than for Q D equal to Q R which is more than Q R s. Naturally, this V R will be less than V R s sagging and just P R loving. Mathematically, why there is a sag in voltages? The new V R will be less than specified V R in in order to meet that demand. So, Q R will be again less than Q R s.

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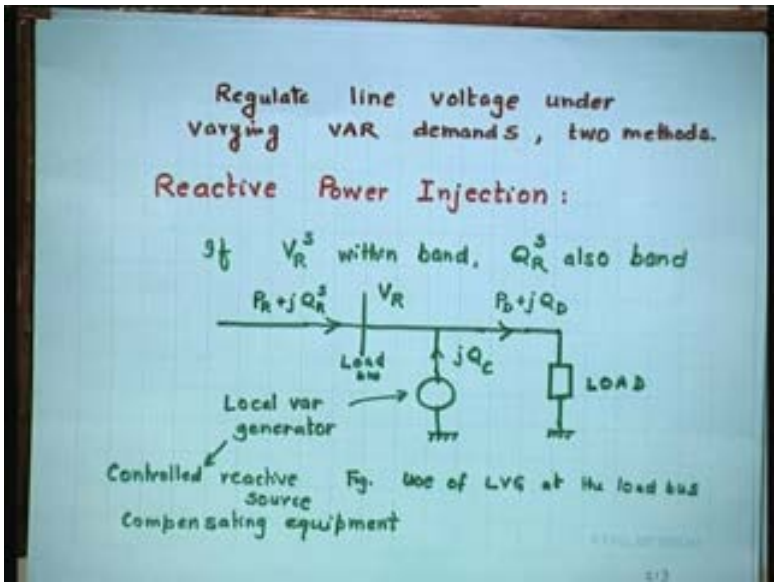

So, V R will be more than V R sulfate the line E Voltage under varying, vary demands that is what is our objective functions, that is what we want to do, we do not want line E Voltage to vary any time from V R s. You want to keep it as close to V R s as possible. So, there are only 2 methods for doing this. Now, you understand why we should do that, because, load is changing all the time.

So, Q D is changing, Q D is changing Q R s remains constants, but then, if voltage changes, that is also changes. So, you have to supply extra vars. So, first method is reactive power injection. if V R s is within band Q R s, will also remain within band. As you know, V R s cannot be 1 value, it is a band point 9 5 to 1 point 4 5. Similarly, Q R s

is also not 1 value, because, it is a corresponding band. But we do not wanted to cross that band. So, when you are in class, you can sit back seats, but you are going outside, you are not in the class, you cannot say that I will remain outside the class and get I am in the class, that you are not attending the class. So, you will not be given attendance. This is a figure which is very important, this is coming from generator and this is a receiving end power P R plus j Q R s, this is V R the bus voltage, this is a load bus, this is the load, this is p d plus j Q D is a load and since Q R s will not remain Q R s. So, as and when Q D changes, I too follow Kirchhoff current law. What is Kirchhoff current law? At this node, Q R plus Q C must be equal to Q D, this is the Kirchhoff current law. At this node, the power I am receiving from the line reactive, the reactive power, I need the short fall; if it is extra I will absorb it so that, voltage again, that does not change. So, here, whether I have to absorb or I have to supply negative watt or positive watt and this fellow is called local vary generator. Why local, it is close to load. What is local 1, who lives in Delhi is local 1, who leaves in Chandigarh cannot be a local. So, if their condition is, has to stay in Delhi, so, then only we consider our local. Similarly, local vary generator is close to the load. This is a controlled reactive source, because, it can varying, it is not just 1 point or 1 value, but it can be controlled. So, this is the use of local vary generator at the load bus, this figure. In fact, it is also called compensating equipment or compensating equipment what it could be; well, local vary generator can either be synchronous motor running at no load, which is called synchronous capacitor or dynamic compensator or it can be static compensator, either the bank of capacitors or the bank of inductors. This is a var balance equation, which is kirchoff current law. I just showed you and what are E Variables, here, if demand varies Q C varies Q R is remain fixed, so, V R s will also remain fixed.

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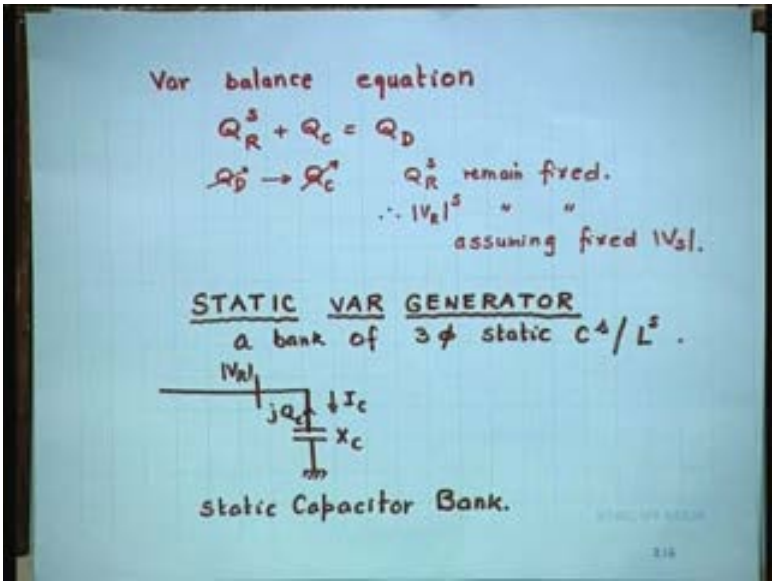

So, we ensured for a fixed V s, V R s remains fixed by using a compensate, by using a local vary generator, we have ensured that, we have seen to it that, my V R s remains fixed by keeping Q R s fixed, static vary generator. What do you understand by s V C S V s, there are 2 names, static vary compensator, static vary system, bank of three phase static capacitors or inductors. You can either have this or you can have X l I l Q L Static capacitor bank. Most of the time, you will need in India, static capacitor band. Why India, throughout the world, sagging is more, so, any PR bole. So far, this is the current taken by the capacitor, this is the E V airs supplied by the capacitors. Assume that V R is in line K V. So, what will the E Value of I C V R upon x. So, j V R upon root three X C, why root three, because, E V R in line and why kilo amp, because, E V R in K V.

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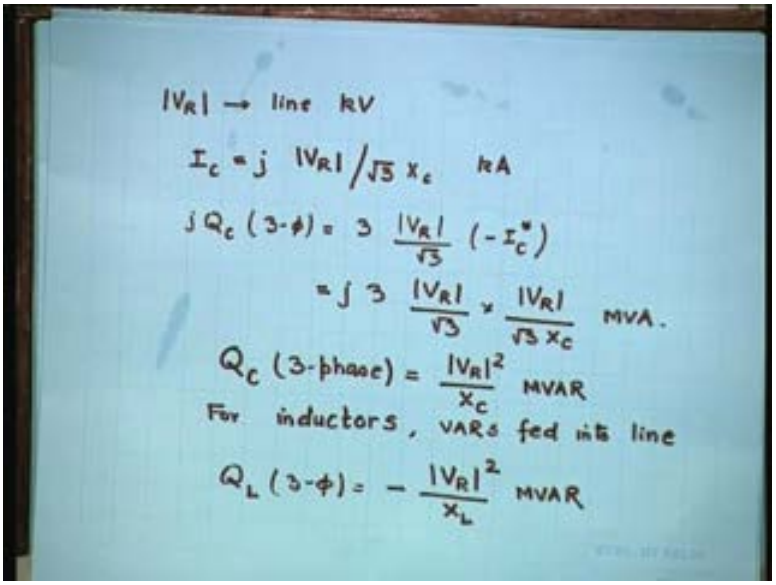

So, you to very careful about units, if you go wrong in units, the teacher is entirely to cut as half marks, because, a engineers without units, can you give, suppose, somebody wants 10 rupees, can you give 10 paisa, no, because, unit is important, it has to be rupees and not paisa.

So, what will be Q C three times V R by root three into minus of I C star, why, minus the direction of I C is in other way. Why conjugate, because, the power is always V I. Conjugate now V R by root three, as it is, this value of I C, if you substitute conjugate. So, what you will get? So, j times three times V R by root three into V R by root three X C and because, there is a, what is this, if there any P R bole here? I think this should be minus here ya. So, it is. So, there is no mistake, this I C conjugate, as its rightly saying, will be minus j, but this minus sign sitting already here. So, that minus minus will plus. So, you get j times three root three, this root three is coming from here, which will naturally get cancelled with this three. So, finally, we get Q C is equal to, because, now I do not need j, this j gets cancelled here. So, Q C will b E V R square by X C m V A R mega volt ampere reactive. Similarly, for inductors, you will get vary feds into the line Q l, only sign will change. Again, if I ask you to derive for Q l, do not derive for Q C and then say they are for Q l will be this.

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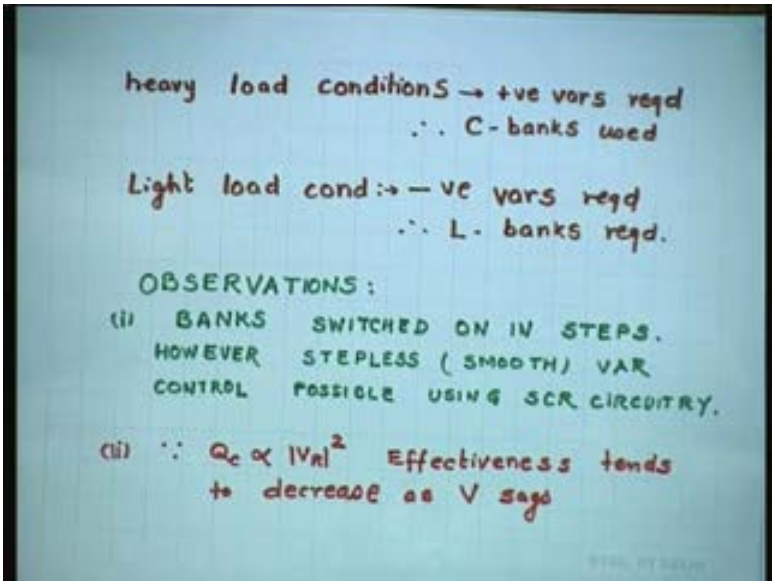

Never do that is it all of you, heavy load conditions, you need positive E V airs. I think this you have been repeating again and again and hence, capacitor bands are fused light load conditions. We need, we get vats and hence inductor banks required, this is a random band. Let us have certain observations. Whenever we solving any engineering P R boles, we have to talk on conclusions, observations, etcetera. Observation is, the banks are switched on in steps, you cannot have a smooth variation of capacitors and inductions. You go on adding capacitors, which will be in certain steps, like your modular p V. You have to go on adding your panel, you know modules; however, now steeples or smooth vary control is possible using s c r circuitry. What is s c r? Silicon control rectifier solid state control. This chapter is given in our machine book on solid state control or you might have read separately also on power electronics drives. This observation without the help of solid state control, your bands will be switched on only in steps. So, steeples control is not possible without the help of solid state control or s c r circuitry, s c r means any family of s c r, it does not have to be a whatever. Second important observation is, because Q C is P R operational to V R square, look at here, this is very important observation, Q C is P R operational to V R square if V R goes down Q C will not be more that extent. So, effect becomes less.

So, when you really need help, the help coming is less. So, Q s is Q R is P R operational to V R square effectiveness 10 do to decrease, as voltage sags. Suppose, you become immune to certain medicines, when you actually need it, medicine may not work, that is

why people die most of the time. that After the several years of uses of same medicine, the body becomes certain type of immune and if it does not help you, then you go on increasing potency, but how long? The time will come when there will be multiple P R boles the kidney failure, the lung failure, the heart failure, and so on and and the guy goes 1 day. Similarly, here when there is a real P R bole like first January 2002, what what was that 18 hours of power failure in north India, 2001 or 2002, a very recently there was a power failure in US, there was a power failure in Canada, there was a power failure. So, it is throughout the world.

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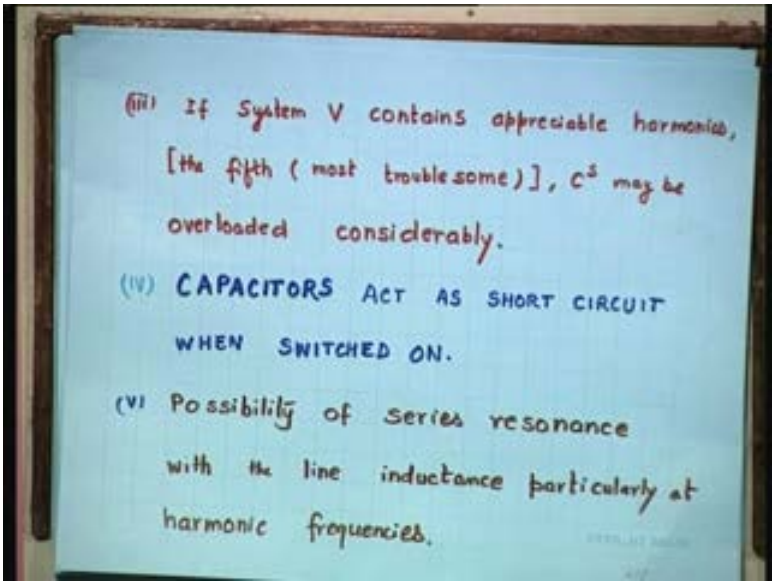

If system voltage contains appreciable harmonics harmonics and power electronics is responsible or are responsible for the new area in power systems called power quality. Everybody is now working in power quality, there are books available on power quality, the first book in power quality appeared in 1990 1 and so, by university then, New Zealand cxcg. Both are my friends as well as he has brought out book on power system harmonics and power quality, the harmonics have really player now and so, you have to calculate T H D. What is T H D? There is 1 more meaning of T H D. You know that any idea, no that is, this is a tall handsome in dull, this like modern youth use this. Anyway, here we are concern with T H D that is total harmonic and should not be more than 5 percent; if it is more than 5 percent, it is not a quality power yes.

It has really made the thrust area and you are as good as any computer engineer or as bad as any computer engineer. Now, especially the fifth 1 is the most, not even it is a most troublesome, because, third 1, you can eliminate. There are certain wastes and capacitance may be overloaded considerably, if there is a appreciable amount of fifth harmonics P R sent. Besides,, you must have in circuit theory in your second year or third year, capacitors act as a short circuit when switched on, that also creates P R boles.

So, these are all various important observations on local vary generators. Next important observation is, which is also true in use series capacitors or compensation possibility of series with the line inductance particularly at harmonic frequencies. So, all these P R boles, you have to tackle like, when you fly you have a P R bole of bird height, you have a P R bole of somebody can take it away to or anything or crash. Ultimately, another important thing is rotating vary generators second methods.

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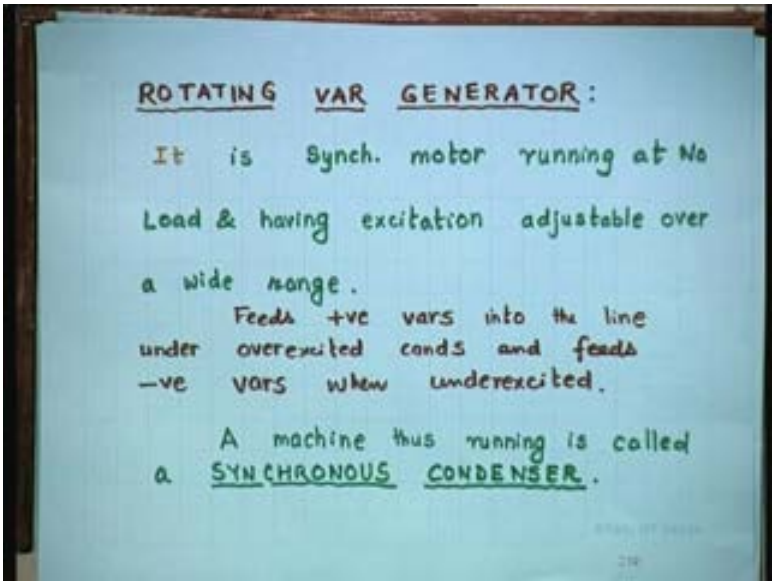

There are 2 methods. I told you, one was bank of capacitors or inductors. The second method is rotating var generator; it is synchronous method running at and having excitation adjustable over a wide range. That is a beauty of synchronous machine, though it run with constant speed, the only speed it runs is synchronous speed, otherwise it does not run 1 0 binary. But, the power factor can vary, excitation can vary the E V curves or o curves. It feeds positive E V airs into the line under overexcited conditions, positive EV airs under overexcited conditions and feeds negative E V airs when under excited

conditions. We have in fact, drawn the pharos diagram in chapter four, showing how the power factor varies with excitation, normal excitation, under excited case, overexcited case. A machine thus running is called a synchronous condenser or dynamic compensator like.

Another name is, this is being used for last fifty years near the states and there is a book by miller john 1982, who has given in this book; now that book you should read, the whole book is on reactive power management. In case you want to do a P R object mini or major or minor, whatever on reactive power management, then this is the book and there is a full chapter on dynamic compensator, what it can do, what it cannot do, where it is situated, installed in states, all those thing; incidentally in India which is not installed anywhere. But in world it has been used, still being used, I mean continue to be used because of these several advantages which we want to study as we go ahead. I think today we will stop with this and we will continue Friday on rotating vary generator. Then we will go for compensation and then next week, we will start some other topic which I have not yet finalized, which topics to start. We are now something like that or may be 15, we have we have to go to up to November what 24 27. So, twenty fourth 24 November is the last working day, any question? So, for whatever we have done today, we have done P R imparity today, methods of voltage control, why why voltage has got be controlled, how it is to be controlled, why it is the need for its control, what happens if it is not controlled. 2 methods, we have static vary compensator, we have rotating vary compensator, their plus and minus merits and demerits of course we have not fully studied, may be on Friday we will continue. Then, we can come to conclusion when to use what, there is no you cannot say particular thing is the bes; depends on the particular situation, sometimes operations you do, sometimes medicines, sometimes homeopathy, sometimes ayurvedic, it depends on situation. Yes you want to ask some question.

A nuclear power plant can we use only as a base load, base load power plant. So, we have earlier power plant that sir by controlling the depth of the growth inside the nuclear reactor, we can change the rate of the reaction and thus increase the power, increase the power generator. No point by how much is it, can you go to the wide range? It is a limited, the limits, there is more on you to also understand whether it is desirable. For example, from here to IIT gate, you can call taxi and go, but see how much cost it is. Taxi will come all the way from outside, then where you to go only main gate, is it desire

you can go. I am saying, you cannot hire a taxi for going to the main gate for all is, if you have enough money you can do that, but is it desirable? The most desirable thing is start walking towards main gate, not even auto, not even lift which you normally so happily asked at all the way. Everywhere, students are standing and asking for a lift even in this lift, first also people have, I mean that ridicules. Any other question please.