Power System Generation, Transmission and Distribution

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Lecture No. # 31
Control of Voltage Profile

Today's topic control of voltage profile; before I talk about it, we must understand the power system is broadly divided into three areas sub areas rather, in fact 4; generation, transmission, distribution, and utilization that is the load, because of which there has to be a generation. Now generation is always done at a lower voltage, at best you can go 11 kv or even 25 kv. Why? Why cannot we generate at 400 kv? Because that is the transmission line voltage, then there is no need of transformer if you can generate 400 you can transmit at 400 without having the use of transformer; however, when you generate, you have to see what sort of synchronous generator you have, so only generator which is used for bulk power generation.

Induction generator is used only for renewable energy sources like wind, like micro hydel, mini hydel, and small hydel. It is never used for generation of big power for variety of reasons, first of all its speed is not constant; it varies with slip that much electrical engineering all of you know. So, synchronous generation is always possible at twice synchronous generator at a constant speed , it runs at synchronous speed or it does not run it is 01, if it is a 4 pole it is a 1500 rpm, if it is a 6 pole it is a 1000 rpm.

So, the if you increase the voltage the problem of cooling and insulation comes that insulation will not withstand 400 kv voltage and that is why you go for lower voltage the then cooling the heating you know, produced has to be cooled the cooling and heating cycle, which you might have learnt in your undergraduate utilization of electric energy by Tailor or Star or H Prathap or whatever book you might have Wadwa whatever book you might have read, I think that is the answer to that question and that is why we go and then naturally we need a transformer because we need to transmit at a higher voltage because the transmission line losses gets reduced if the voltage is high the current is low. So, I squared R losses that will get lowered down.

Then the conductor size will be lower the moment the current carrying is smaller. Otherwise you will have to spend huge money in purchasing those big conductors. Now we come to the topic control of voltage profile, I think we have already talked about it last time and I told you how the two problems are delinked and that is why we had a method called FDLF Fast Decrypted Load Flow method. Now, voltage can also be controlled using generators, how by controlling the excitation by adjusting the generator excitation.

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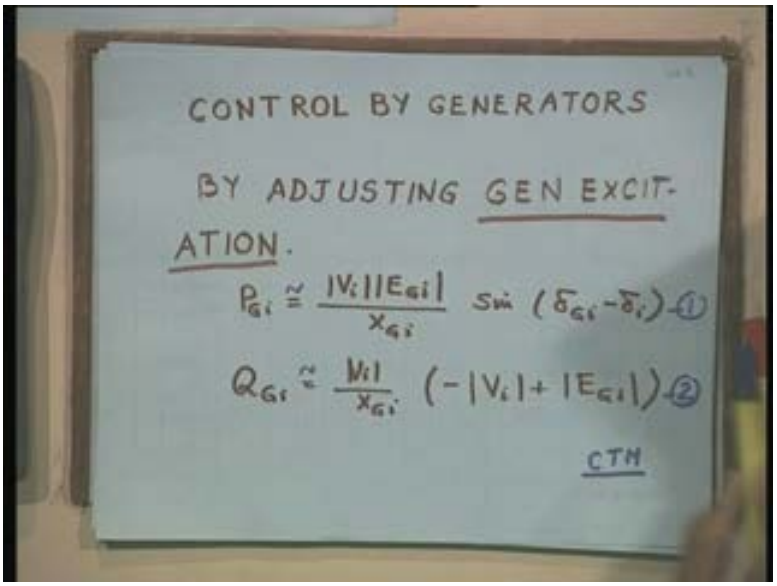

Now, the control of excitation itself is a big topic it is given in Kimbark's book. If you have heard of Kimbark there are various types of excitation systems IEEE excitation systems, they are given in literature also, and in books also these two equations are very important. In fact, there should be CTM. What is CTM? Commitive Memory it should be on your finger tips.

Real power generation and then transmission from i th bus is V i E Gi X G i sine delta G i minus delta i. Excitation voltage the terminal voltage the reactance these are the two angles, since these are constants two voltages since reactance is known. So, it is directly proportional to delta there is no V involved in it likewise in Q Gi you can see there is no delta of course, these are approximate equations even this is approximate in the sense resistance has been ignored neglected. So, you can see that Q is totally independent of delta and that is why we could make those half diagonal turns 0. So, if you want to

control voltage you have to control reactive power that is what I told you last time that is VAR control SVS.

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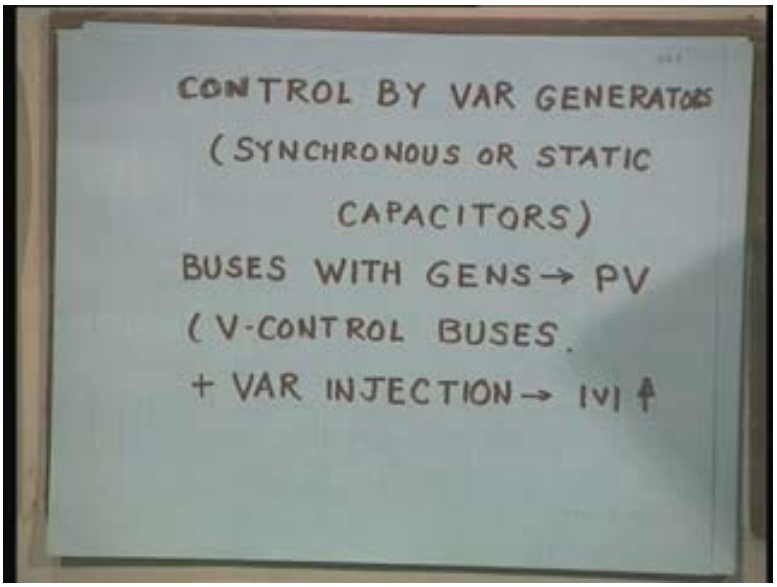

We have done it last time we have introduced at least last lecture control of VAR generators synchronous or static capacitors. What is synchronous capacitor? That is also called dynamic compensator it is nothing, but a synchronous motor running at no load and it does provide you VAR and you must have seen in United States of America this is being used for last 50 years and still being used. There is a book by Tailor: Reactive power control and management 1982 John Wiley the total book is exclusively on VAR control that is voltage control. So, in case somebody wants to project wants to know more about it, they can read that book; the reference is given in our book what is wrong with that? It is a motor. So it runs, it is not a static device it is a dynamic device, it needs maintenance it needs care due to handle it care, but suppose the buses are not necessarily all buses are in city, areas metro areas, they may be in jungles transmission lines are all over; now, who is going to go there and see whether operating satisfactorily or not whether there is an insulation failure in synchronous machine, whether there is an excitation problem or whether there is a cooling problem.

So, these are the problems yet it has not been written of still being used in India of course, we do not have it, but overseas outside we definitely use it still it is comparison is given in chapter 5 you can see the dynamic compensator versus static compensator what

are the comparisons. So, normally we use static capacitors or bank of inductors as I told you last time; here being a static device there is nothing to worry about maintenance, nothing to worry about excitation ,cooling any failure the failure of the static device that is the reason why transformer efficiency is 98-99 percent this question is always asked in any UPSC interview or any interview and the normally student says with a great hesitation sir 96 percent, still more he says 97 percent he is bit hesitant in saying 99-98 because he thought, he thinks that this much efficiency is not possible but transformer does have a very high efficiency because it is a static device there is no moving part, no friction, no wear and tear of that extent you will have in it in rotating device that is why many machines titles are rotating machines and transformer though transformer is also a machine in a way but they clearly differentiate between the two just because it is a static device.

Now, most of the buses are PQ buses I told you in my load flow lecture 85 percent PQ and 50 percent PV and 1 (( )), but whichever those 15 percent buses are there they are normally having generators attached to it though let me has not it to add it is not necessary to have a generator attached to a PV bus, PV bus merely says that it P and V are known to you it can have a bank of capacitor attached to it. So, that it keeps the voltage constant or a bank of inductors attached to it, because we have to keep the voltage constant at a given value that is all is the condition of PV bus it never says that you have necessarily have to have a generator bus to qualify it is a PV bus.

Loosely these bus has several names like slag bus reference bus slag bus similarly, PV bus has three names PV bus generator bus and voltage control bus. In fact, in some bus the fourth bus category is given for example, in this book I have categorized 4 bus whereas, in other bus we have only three buses expert or up to a author to talk about it, but we can buy and large group them into one that is the PV bus. So, we have to have a VAR injection if we want to raise the voltage you know sync, you know and source if you want to reduce the voltage the voltage has to be absorbed that I have already talked last time.

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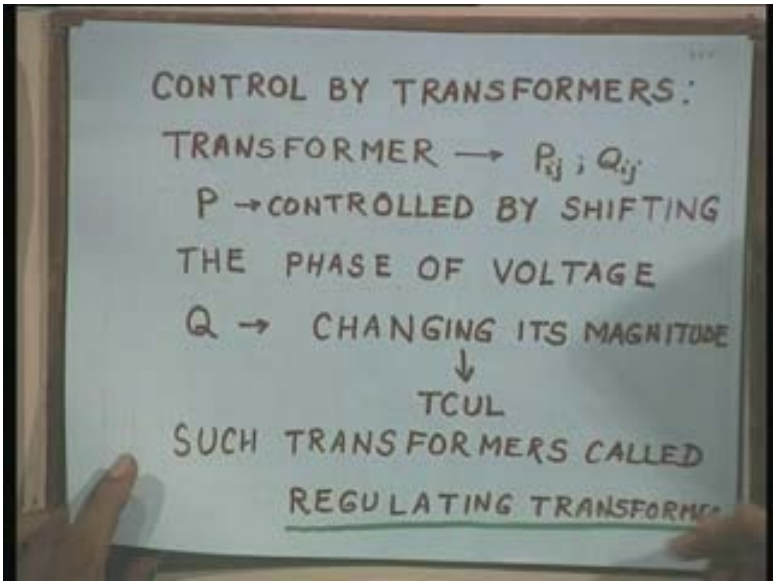

What I did not talked the same thing could have been achieved by transformers. So, transformer is a magical thing. The whole of electronic need transformers, no electronic circuit can be complete without the presence of transformers your TV it has the transformer circuit, because that 11 kv and so on; it has to be stepped down, stepped up and so on. Transformer is required in instrumentation, they are called instrumentation transformer CTs, PTs current transformer, potential transformer CVTs and so on. They are required in IDDC centers as well they are required in biomedical centers, because the doctors and patients, what they handle is a very low voltage; they cannot be subjected to 11 kv sort of thing.

So, here transformers also plays a role of voltage control, how the real power can be controlled by shifting the phase of the voltage changing angle, because real power depends on angle that I have been telling you again and again. P has a friendship with delta and Q has a friendship with V and if you want to change the Q, by changing Q you can control the magnitude of voltage. How do you do that? Q can be controlled by changing the magnitude, how do we change the magnitude? By TCUL what is this TCUL? Transformer Tap Control Under load T is tap all of you must have taught in machine codes that there are taps in transformers. Where do you keep taps? On a high voltage side, HV winding. Why? The control is easy. And Secondly, HV winding is always outside LV winding is the along the core and then HV winding. So, anything

which is outside is easy to control anything which is inside we have to do lot of jugglery lot of effort to reach there then if you control it becomes very difficult.

If you put a fan regulator where the fan is you have to bring some stair case or (( )) or something go there, it is running you have to stop it then control, if you remember the olden days you when TV use to have a voltage stabilizer. So, when you are watching it go there again get up with great difficulty, because you are settled nicely in sofa then go tuck you know you used to change it manually I do not know whether you recall whether you are born with the automatic voltage stabilizer. So, now everybody wants to do everything by remote control no physical activity if anything by like if I can lunch here why should I go to the hostel, all the way one kilometer long distance stand and ask for lifts somebody give somebody does not give in one hour you have to go come back and so on, you want to have to have your house open by remote control, the garage open by remote control all these things have been done in our modern society everything by remote control governments have been run in remote control etcetera.

So, such transformers are called regulating transformers, this is the name gentlemen given like instrumentation transformers like they are called regulation transformers, in bracket in short RT.

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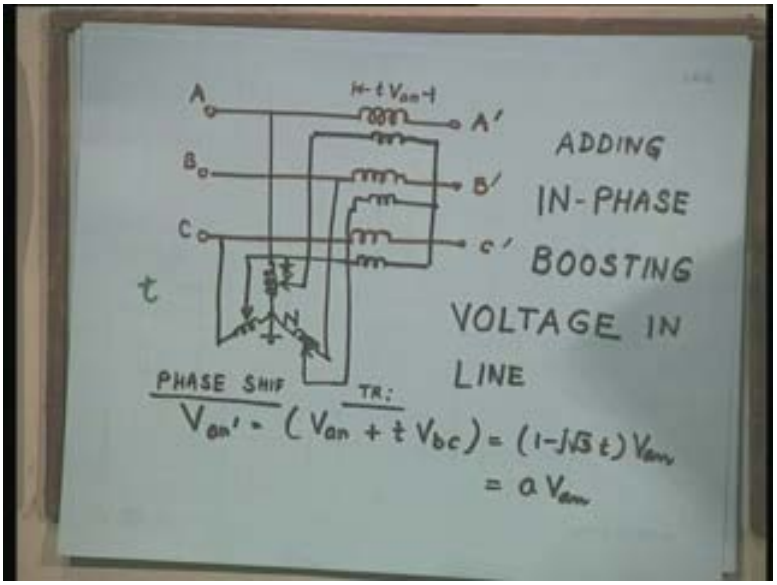

Look at this is the figure I have drawn how adding in phase boosting voltages is line improves the raises the voltage. And, so Q control if you raise the voltage Q will also can

control Q depends on V. So, this is the star combination of a transformer this is another winding of transformer star delta. I think this is star, star and then depending on this t this is t here tap, but mostly we are interested in controlling t because the general public does not know what is Q control, but everybody knows about megawatt, everybody knows about watts, everybody knows about energy kilowatt hour, because you pay for it, every house gets these two bills definitely whether they get another third bill or not, one is telephone bill another is electricity bill of course, you may have to pay house rent you may have to pay so many other things.

But now of course, telephone bill got shifted to from landline to cellular phone if it is postpaid if it is not postpaid you have to at least go and buy the card, prepaid card. So, if you want to control P then you have to use phase shifting transformer which changes the phase without changing the magnitude of it, I do not want to change the magnitude the moment I change magnitude Q will change unless until your objective function is to change both, but normally we go in steps. See if we have two diseases doctor will first try to attack the one which is more serious, you see then he will tackle the other one less series, otherwise if you try to tackle both sometimes it works sometimes it does not work. That is why whenever there is confusion between sequential or simultaneous normally we opt for sequential like FDLD like I told you it is easier to tackle one problem at a time.

So, you cannot work for all the 4 subjects your taking simultaneously, what you do? 8 to 9 this subject 9 to 10 this subject 10 to 11 you cannot start all the 4 book simultaneously, read 1 line from here 1 line from here it will be chaotic it will be disaster. Right! So, V an dash for this equation you have to see this figure first.

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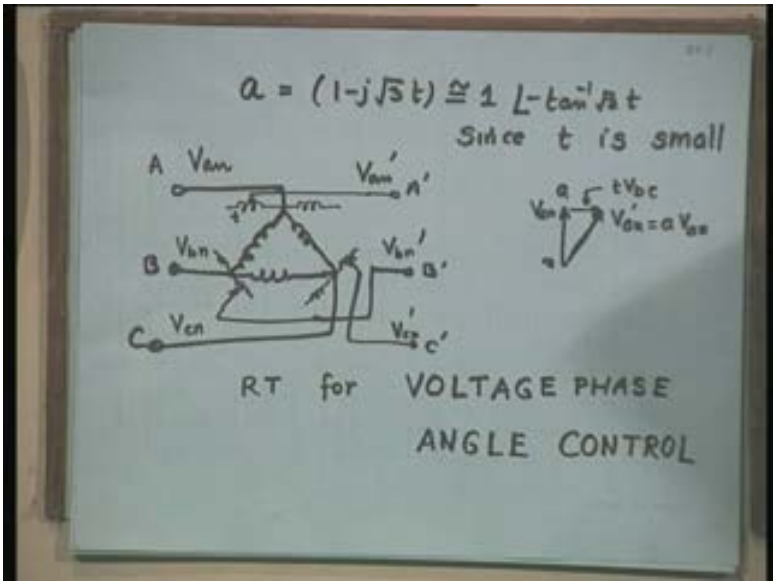

This is the RT Regulating transformer for voltage phase angle control. So, this is V an and this is output is V an dash and V an dash is changed voltage this is V an plus t times V bc, t is again tap and the one minus j root t, t is very small; V an is equal to aV an this is called a. This quantity is replaced by a, a is variable depending on t, t is the only variable 1 and root 3 is the numerals cannot change them, t is the tap. So, the small figure I have drawn here which will tell you this tV bc is added. So, it becomes V an dash a times V an and this is how the angle is shifted once angle is shifted P is shifted, either P is reduced or P is increased, sine delta means more the angle more the power 90 degree is 1; 0 degree is 0; sine 0 is 0; sine 90 is 1; So, if you increase the angle slightly you get more power of course, by this you cannot make 400 megawatt as 500 megawatt otherwise nobody will install power houses they will only put phase shifting transformers and do magic and somehow they will increase by know this is only minor change the fine tuning few mega watts after all transformer is not a generator it cannot generate power by doing this technical or technological jugglery you are able to improve slightly that is all. So, do not be under impression the transformer suddenly become power generator it only improves slightly similarly their voltage control transformer the limit is very small if you want large variation no choice you have to go for SVS flexible transmission that is fax and so on.

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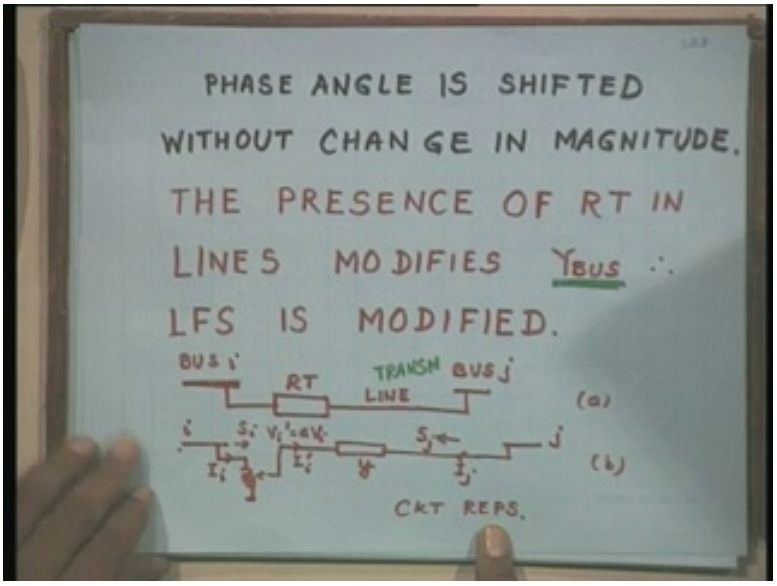

Phase angle is shifted without change in magnitude, but there is a psi defect, you take any medicine there will be a psi defect, but you cannot be just be afraid of psi defect otherwise you cannot be cured you got to take medicines certain medicines you get allergies certain medicine you get stomach ache then doctor gives another medicine to take care of that stomach ache. So, here what is the impact of putting transformer in the line the presence of RT lines modifies Y BUS, Y BUS gets modified and since Y BUS gets modified and Y BUS is a load flow model. So, load flow solution is gets modified once Y BUS is modified the natural corollary is your load flow solution is no longer same which you obtained. So, this is the price you have to pay you have to rerun the load flow solution, why how does it get modified locate these two small figures. ith bus; jth bus this is the line means, transmission line, RT regulating transformer draw the circuit model of this is the one line diagram this is the circuit diagram all of you are aware of one line diagram whatever book you might have studied you must have studied one line diagram.

Now, what is the circuit diagram this is the transformer this is the tap this is S i all of you remember the machine again which ever book you must have studied Fitzgerald, M.G Say our book or Bhimra's book every book told you that input power and output power remains same; that means, transformer operation is power in variant like your symmetrical components.

So, again a power invariant, so, S i will remain S i even after the transformer S i is complex input power coming from i th bus to the network this is current I i currents change I i dash that is a well known in a transformer you get voltage and currents change in a ratio of trans ratio some directly some inversely all these things you know I have no intention to teach all over machines which all of you have earlier mastered. Then this is a line, and I am using here a short line model, because my point is here not to explain you transmission models, the short line; middle line; long line; middle line can be used by T model; pi model the long line can be can be exact model modified T modified pi and so on. All these things you have already studied if you want to brush up your memory revise your memory you can see the chapter 5 of this book or any book chapter number may change the material remains the same 2 plus 2 will remain 4, which ever writes that this is BUS j. So, S j is a power injected from Jth bus I j is a current coming from jth bus this is a circuit representation this is a 1 line diagram this is a circuit representation of the same circuit diagram.

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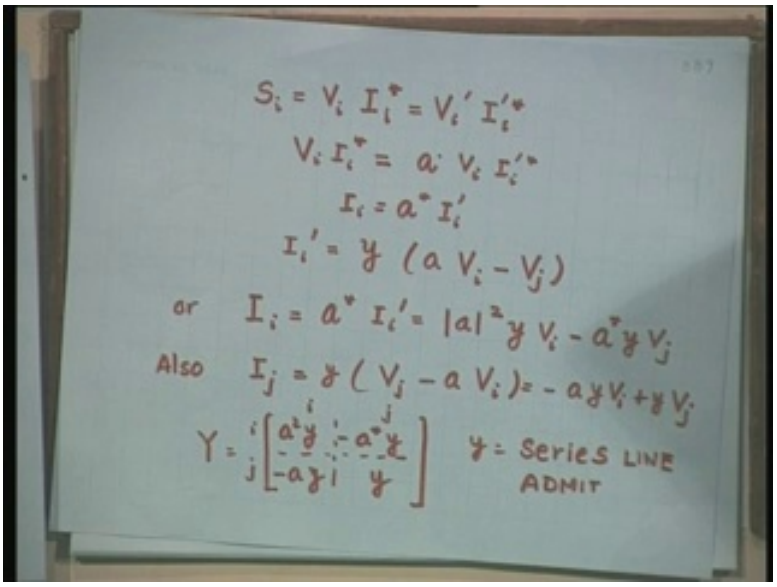

These are questions I have written keeping that circuit in mind in case you have not drawn that circuit I have to keep it once more here I am looking at this circuit and drawing those, writing those equations, S i input complex power is equal to V I, I i star everybody knows about it, which is also equal to V i dash I i dash star as I said transformer is a power in variant operation now if I convert this V i dash is equal to a V i like transformer operation is a trans ratio. So, I i equal to a star I i dash a conjugate star

means, conjugate I am sure all of you know what complex variable. So, I i dash is nothing, but a y times aV i minus V j that is your ohms law current is equal to y into V or V is equal to Z into I since we people do not use Z as a model for load flow studies we are using y here, or I i becomes a star I i dash substitute I i dash from here a dash into a becomes a magnitude whole square y V i minus a conjugate y V j similarly I can find out I j.

You can write it down if you want, again I am emphasizing here reiterating here repeating here y is nothing, but the series line admittance, that is the short line model if it is a point model nothing to worry there will be equations will be slightly modified. Now this is y BUS what is y BUS? Is equals to y into V. So, collect the terms you get a Y BUS what you are seeing it for the first time Y BUS is not symmetrical this question I have been asking you may be I have asked you in the first terminal exam or first minor whatever you call it that is Y BUS symmetrical. The answer is normally yes except when you use phase shifting transform there you can have a look at these two of diagonal terms they are not quite same both are minus no problem, both are y no problem, but here it is a here it is a star, once it becomes a normal voltage control problem or Q control problem then it becomes symmetric, but once you want to control P then it is a phase shifting transform and then it is not symmetrical.

So, this is the answer to that question which I have just told you earlier on Y BUS is symmetric subject to there is no presence of phase shifting transformer; however, if there is phase shifting transformer then it is unsymmetrical this is the answer you should give because this question is normally asked.

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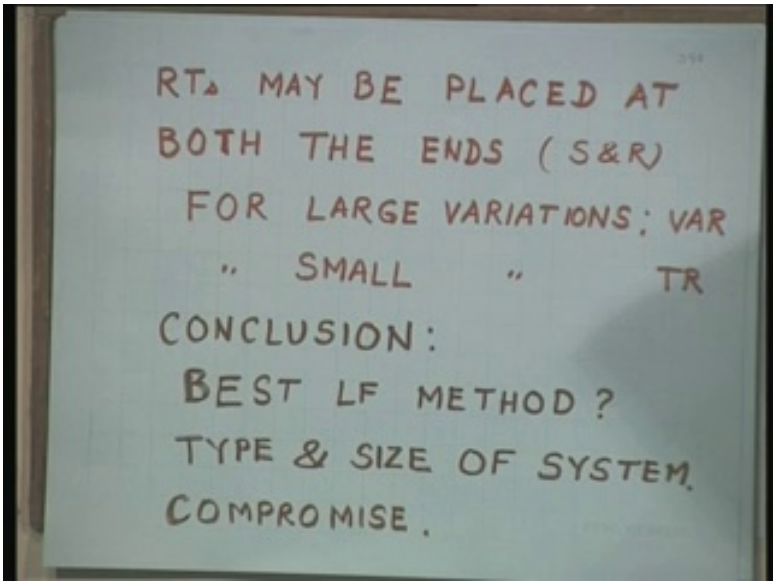

Today we are going this finish chapter 6 we will start chapter 7, RT may be placed both the ends I have just showed you one end, but if you are more fussy more careful you want to improve slightly more than you can have one RT near sending end one RT near receiving end. As if you are taken some money from home then you go for shopping you also have a credit card with you in case that money in sufficient or you have a ATM card you can withdraw money from anywhere. So, that is additional help. So, you are not only improving the voltage at the sending end you are also improving at the receiving end of course, the analysis becomes slightly more complicated it is given in the book in case you want you can go through it, because it is exactly similar.

For large variations we need VAR control for small variations transformer is adequate I have already told you about this, up to 20 percent of variation can be achieved by transformer, but if you want to go beyond as is a normal case in India when the voltage goes as low as 220 form 220 to 170 or 220 to 270 then you have no choice, but to have the VAR control. In India we have only one place where there is SVS installed Do you know where is that place anybody? Very good it is in Kanpur near Kanpur Panki, that it is the only SVS station in India. So, far because it involves lot of money and when you happen to be in Kanpur do go and visit this SVD station static VAR control static VAR system you can have a trip or whatever depends on you. Normally, question is asked whatever subject you may be doing whatever topic you may be studying which is the best low flow method and it is always controversial whether it is a Arjuna award or

whether it is a Padma award some people who do not get it they always say that there is something wrong with the system see whether it is a selection committee somebody who does not become a professor he is a selection committee must biased, somebody who does not get in admission he also says oh-huh that fellow was sitting he must have done something similarly, here when you answer this question which load flow method is the best you have studied COS, COS Idle, Newton Maxon decouple fast decouple in side there is a second order load flow method also which have not covered and that is slight improvement, but it is not worth trouble instead of Jacobean you will get Hasian matrix that is teller series is truncated after second order term here in Newton Apson method we have truncated teller series just after the first order term there you will take it to the second order term and that much accuracy will ill slight more accurate results in load flow, but it has not found much favor and so it is only studied in classes or by scholars and you really use in practice.

Actually it depends on type and size of system it is like saying which medicine will help you in solving problem heard will universal no doctor will find a job will just make a manual cold action 500, if it is pain D Cold or Amrutanjan or Zandu balm they will help only the transformers first 20 percent if something goes wrong beyond that you have to visit a doctor and doctors normally ask you your history because each case has to medical science is not that perfect science yet whereas, it will never be why one operation is success why another is not, same problem same bypass surgery same whatever and one fellow comes back from operation theater and one fellow does not. So, that is the problem. So, here also that it depends on type of a system size of a system is it a normal system is it an ill condition system and so on. What type of numbering you have done that is optimal ordering what types of controls are there and so on.

Merrily it is compromise, Newton Apson is very accurate it is a convergence is the best quality convergence, but it is complicated writing the program now it is program writing is not a big deal there are ready made programs available and you can purchase or get even free. So, that used to be in our days when you use to say programming now a day's programming is not really required programs are already there, but still there are so many other compromises do you want speed, do you want accuracy do want to memory your problem like you go for purchase of a car not everybody purchase a Mercedes it may be the very best car in the world. You see your requirement see you see your family size

you see the money you have in your pocket you see the need and. so on. So, you cannot say which is the best car, somebody goes for Accent somebody goes for Zen somebody goes for indicia, a taxi driver needs an Indicia is a grand success as far as private taxis are concern; so, that is a compromise. So, you can never answer this question for definitely yes here after this is the best method.

So, does not study the other methods and you know which is the best method under all circumstances why study other methods at all, but know like optimization techniques I do not know whether you have studied optimization technique or not and there is a linear programming there is a quadratic programming there is a dynamic programming and there is maximum principle there is a you know what you call so, many other methods if you study this operation research this optimization techniques it depends on the problems, it depends on why you want to apply it depends on what is objective function you cannot say for sure as this is the best optimization techniques on all time to come or all problems to solve same answer you can give it here. I think with this we finish chapter 6 and now you can solve problems there are additional problems there are solved problems there are unsolved problems, but answers are given there at the end of the book hopefully all of them are correct if there are something wrong you can always point it out to me.

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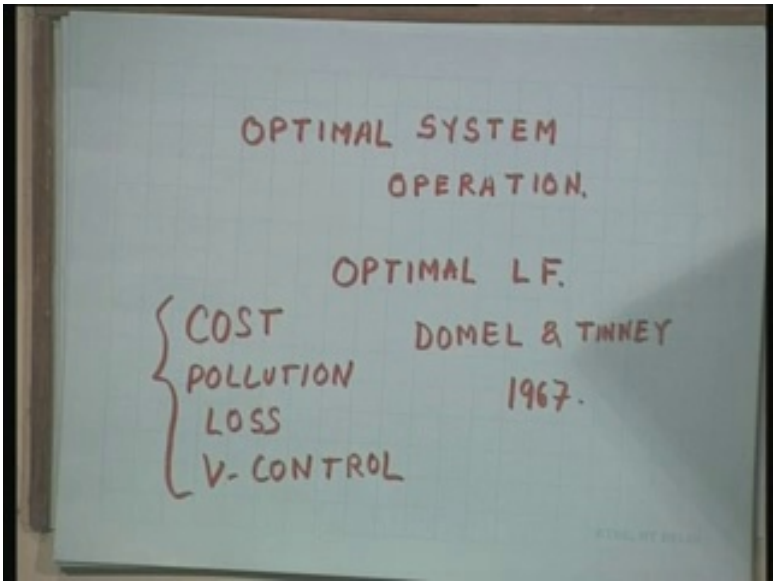

Now, we start chapter 7 and that is on optimal system operation. As you see in yourself in load flow you change those specified variables you get a different load flow solution, it is a function of values which you selected by experience by whatever means you can get 1000 of solutions load flow solutions by permutation combination there are 100 per systems 1000 per system whole India if you solve there are is a 1000 bus NREB northern region you solve some 350 buses are there. So, you could have innumerable alternative solutions, but a customer is not interested in those 1000 solutions he wants the best solutions. Now we are come back to the same question what is the best? Each student studies different subjects for different times, because each students objective function is different somebody s objective function is to get gold medal 10 pointers. Now, the IIT Delhi has started an award for 10 pointer 1 girl students got this convocation physics department CGPA 10.

Now a day's getting c g p a ten is a tough job because of this a minus a, b minus b, c minus c earlier days when there were no a minus no b minus people use to get a. Now if there is a doubt the teacher gives a minus a minus means 9 that is all 9 to your 10 CGPA is gone moment you get one a minus in the whole program you cannot be 10 pointer. So, what is best for another person need not be best for everybody, somebody's objective function is to remain in the system there is some CGPA called that you know beyond which if you go below that you are out of the main gate, because nowadays only cars can come from main gate can go also from main gate similarly, those lower CGPA can also go from out or there are whatever rules are there.

Somebody's objective function is to get eight CGPA is good I also work in dramatist I am a player I am an all rounder. So, I have to divide my time in various activities that is what I want some are poor persons like in US etcetera they do jobs, small little jobs babysitting, garage or they give watering to the lawns and get dollars, naturally there are 24 hours in a day you cannot do everything you have to decide like teachers can decide should he write books should he guide PhD thesis, Mtech thesis, write papers do consultancies do sponsor project go and give lectures outside of course, minimum thing you have to do that is teaching in the institute.

Now, should we become warden or not that is not compulsory it is up to your wish should I be in rendezvous in-charge like Viraj Dutta is bar president or whatever choice is yours there are so many things to do what you want to do there is no prospection. So,

everybody decides his or her course of action in life some of you want to go for IAS some want to go for engineering services some want to go abroad and so on. So, these out of these 1000 loads flow solution I want one which is called optimal load flow. The first paper in this topic came by Domel and Tinny these are the two persons who wrote this paper in 1967 I have given the reference in my book those of you want to read this paper you are most welcome of course, I will be covering here in the class.

That gives you one particular load flow which is best load flow, again best decided on what which is the best way to reach New Delhi station, there is a taxi, cab if you are more sophisticated public school student you call it a cab, if you are a rural taxi, but it takes 200 rupees, but then your suit will remain way it is you are not worried about the rains you are not worried about the heat outside, if it is the air conditioned cab cool cab as they call it in Bombay here also all Indicia's are air conditioned. So, you are immune to the atmospheric conditions whether it is 5 degree centigrade or 45 degree centigrade you are not bothered there is a heating inside the car there is a cooling inside the car, but you have to pay 200 rupees, but look fresh at the New Delhi station Ajmeer gate or parliament whichever side you are going.

If you are not having 200 rupees your ticket may be to your place may be 55 rupees why pay 200 for going you may go for auto, but auto, but if there is a rains heavy rains raining cats and dogs you get drenched your bag will get drenched, but then you go straight you will not take anybody else you are the exclusive owner of that vehicle, but you pay around 70 rupees 60 rupees depending on your bargaining power, or your knowledge of the person who always stands in front of the hostel gate, but you do not want to spend even 55 rupees or 70 rupees if there is 6.20 or 6.15 you go there stand 10 rupees you are in railway station if you are lucky you get a seat, if you are not lucky you will get seat after some time or you will never get, but you are still go all the same, but if you are a really most unlucky you are a pocket in pocket it may happen.

So, but still you reach the railway station you even do not want to give the 10 rupees go and stand near the red light where are you going can I come. So, two three installments you reach railway station if you start one and a half hour early. So, there are several ways what is best it is left to the perception of an individual for somebody that cab is based, for somebody that auto is based, because bus will stop at several place merely. So, you also have to stop at that time. So, you need not have to see the watch at that time because

you have to start sufficiently early this is optimization it depends upon your perception what is the best. So, what do you want what for this load flow is it for planning purposes it is for operational purposes, is your objective function cost is your objective function pollution, is your objective function loss minimization, and is your objective function voltage control or anything else? So, you are guided by these objective functions and then you decide upon a method. Now ladies, no ladies here only gentlemen, we will continue next time this story of optimal system operation.