Power System Generation, Transmission and Distribution

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Lecture No. # 16

Compensation of transmission lines

Good morning ladies and gentlemen. Today, is our lecture number 16 and the topic is compensation of transmission lines. Now, before we come to compensation, let us see what is the meaning of rotating var generator?

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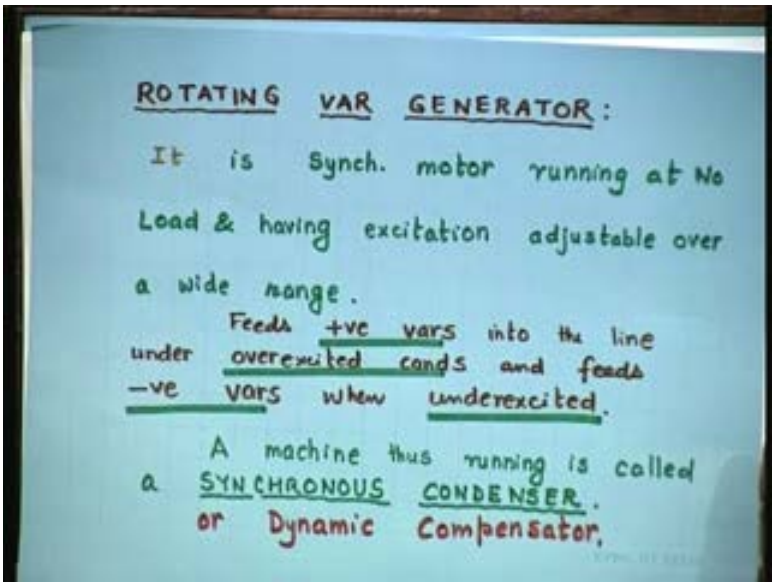

We already talked about static var generator S V S or S V C, by as the name indicates rotating, it is dynamic, and anything that is in rotation is dynamism. So, it is also called dynamic compensator as is given here. Now, it is the synchronize motor, I am sure all of you have done machine course in your under graduate, running at no load and having excitation adjustable over a wide range. This is a beauty of synchronized machine, though it runs on a constant speed, the control is tremendous because of excitation field control and you can have under excited motor, over excited motor, normally excited motor or generator. It feeds whatever watts are required, if you will want positive watts,

well, it is the line is under over excited conditions and feeds in the negative watts, when it is under excited depending on the need requirement.

A machine thus running is called synchronize condenser, synchronize compensator, dynamic compensator. There are several names given in the literature. That Miller's book I was referring last time please do read it in 82 that is, John Wilier deactive power control and management.

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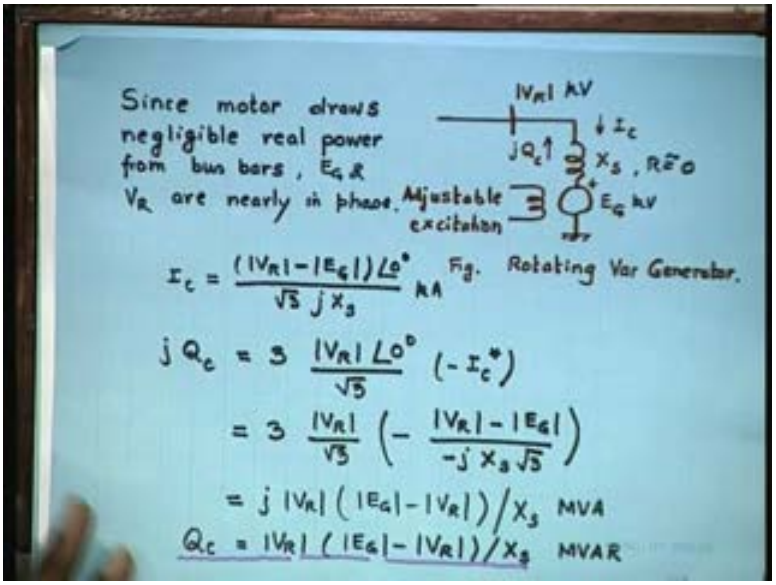

Now, here is the circuit diagram given on the next slide, this is rotating var generator, this is synchronize motor, this is the real control here, adjustable excitation, and this is access is your old synchronize reactance. Assuming R 0, in most of the time the electrical engineering we assume resistance to be 0, which is the fairly good approximation or assumption. The current I c is be fed in the motor and hence j Qc goes into the system, into the line. VR kV is the voltage here which is supposed to be control and kept within very strict narrow range the band, which are repeated some 100 times minute, 0.95 per unit to 1.05 per unit. This is the motor draws negligible real power from bus bars. The real power drawn is almost 0, EG and VR are nearly in phase, is EG as well as VR are nearly in phase and hence I can write any question for Ic, VR minus E G, 0 degree as a phase angle root 3 times j, why root 3, this voltages are line voltages. x is so much kilo amp why kilo amp, because the voltages are in KV.

We are to respect units like anything, otherwise the whole thing in wrong, if your units are wrong. There where the 50 percent of mistakes in electrical engineering are caused because of wrong units, remaining 50 percent are caused by root 3. Root 3 is very dangerous thing, if you forget it and finished, your whole electric engineering is gone.

So, jQc, once you know Ic, you know the formula, VI conjugate. So, since I c is a different direction we change minus and conjugate VR root 3 phase, that is why 3 times, 3 times phase, substitute the value of Ic here from here and hence we get this. A conjugate means the j becomes minus j, there is no angle there. So, only thing what can happen is j becomes minus j. There is angle becomes minus 90 degree becomes minus 90 degree, j is an operator, which rotates the phaser by 90 degrees. Another operator you must been recalling the symmetrical components alpha which rotates an angle by 120 degrees. That is symmetrical component. And here, when you simplify root 3, root 3 will cancel this 3, this minus, minus will become plus and j has gone upstairs, there is minus sign again the loop change. So, this becomes EG minus VR by Xs MVA and if you remove j, it becomes MVAR. And this is very important equation.

And notice the change from this equation to the static watts system equation. There are it was second order, the voltage was second order, and here it is first order. Can you tell me one more reason why dynamic compensator is better than static compensator? Because if you recall there when the voltage sags you need the help more and at that time help is less, because it is squared second order. Here what happens VR sags, this goes down, but this goes up. So, there is a counter balance, something goes down something goes up, so Q c remains fairly good value. It will not reduce drastically which happens in a static voltage. So, definitely this is much better mechanism for compensation, especially when there is a too much of his side which normally happens in our country. Because our U P lines continuously operate at point 8 per unit, we call it normal operation, because that is we call normal operation.

Similarly, our generating units are de rated, what do you mean by de rated? That is, the 100 megawatt as never given 100 megawatt, it gives you 80 megawatt. So, we have almost forgotten that this machine is 100 megawatt, for as it is 80 megawatt, like a government employee comes at 11, goes at 3, for his working hours have become from 9 to 5 30 instead of that 11 to 3. And we are used to this. Same thing is happening in our country everywhere. So, we are happy that pointed per unit (()) is normal operation,

though as we know it should 0.95. So, we need compensation much more than any other country, because the loads are high, generations are low, system are badly maintained.

From this it is clear whatever I said so for is now written in words, that the machine feeds positive watts into line when EG is more than VR, than that equation is positive. When E G is more than V R, q c will be positive?

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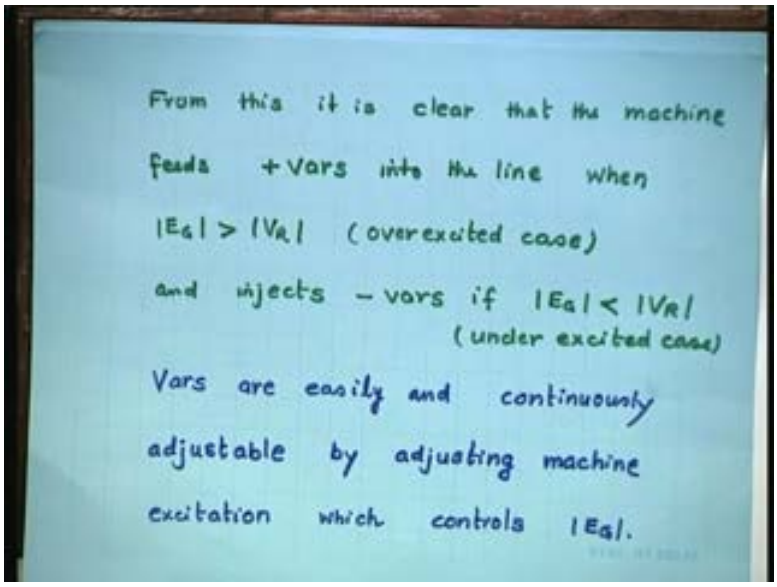

Anyone can appreciate this point without any intelligence. The rest are all positive quantities and EG is more than VR, q c is positive. And that is overexcited case, but if you want negative watts, when do you want a negative watts? Low load conditions, no load conditions, light load conditions, than EG should be less than VR. That is the only way you can make that equation negative; that means it has to be under excited case. Vars are easily and continuously adjustable by adjusting machine excitation which controls EG.

And excitation control is a well known topic you might have read it in your under graduate or some papers. There are several IEEE norms excitation system type 1, type 2, type 3. I do not know how many of you read. Otherwise you can see the IEEE website and go for excitation, you will find. Similarly IEEE text systems are there. 14 bus,30 bus, 57 bus, 101 bus, 1000 bus. This you will need if at all you do the project in electrical engineering. So, need the test system to try your algorithm, to try your method for testing. So, there are 14 bus, 30 bus and so on.

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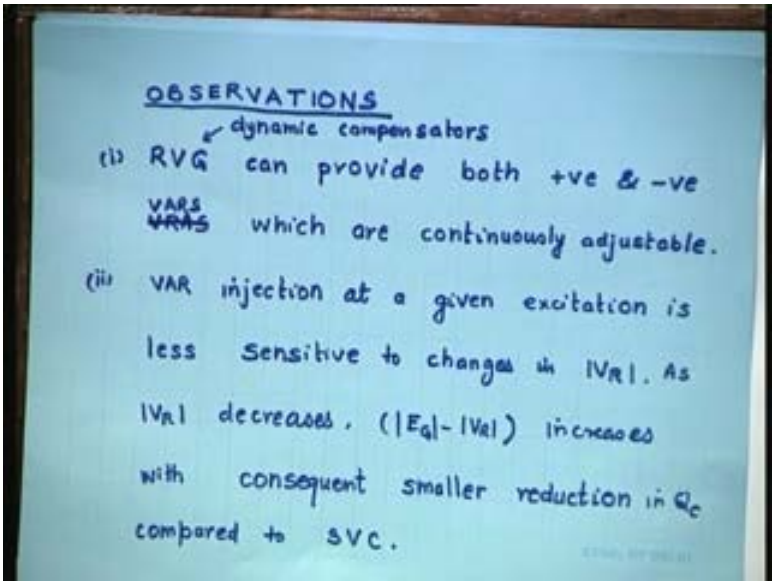

So, no problem so far? Let us understands some of the implications or observations of dynamic compensator or synchronous compensator, whatever the name is. RVG, this is rotating var generator, several names given by different people give to different names. Can provide both positive and negative vars, which is not possible in static vars system. See I can ask 2 marks, I will talk about how you should prepare (()).

Now, this positive and negative vars from the same compensator, this facilities only there in dynamic compensator. There you have to switch from bank of inductors to bank of capacitors, back to bank of inductors. I think you should go to the only place in India, where static var system is in place and working is Punki, that is near Kanpur about 20 kilometers or so. As and when you go to Kanpur do visit that place. I am sure you would not be will make visit officially, will where within them where the position of going to Kanpur. That is the only place we have static var system in India, because it is very costly.

Var injection at a given excitation is less sensitive to changes in VR. This point I have explained to you. Because there is a double effect, as VR decreases EG minus VR increases. So, this increase will partially compensate the decrease in VR, which consequent smaller reduction in Q c compared to static var controller or static var system or static var compensator. So, SVC can be many anything.

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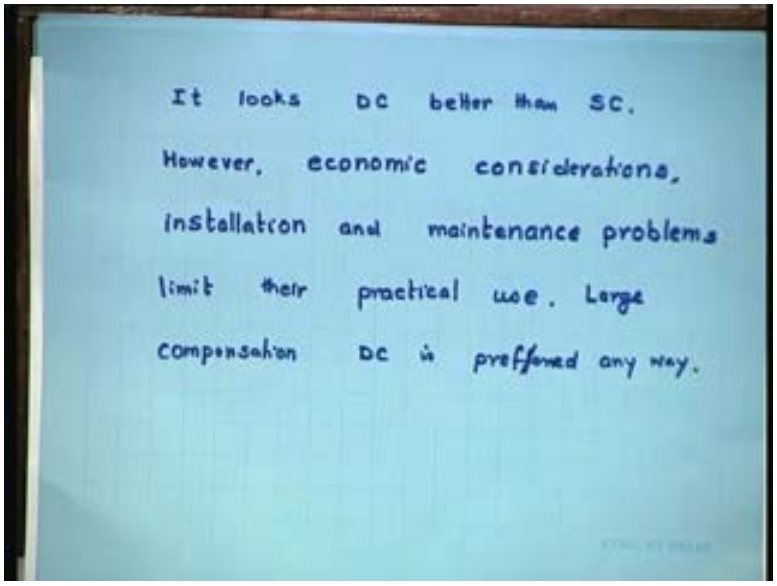

So, this is better. This is what is the next line which we have just spoken. It looks DC is better than SC. DC is dynamic compensator, SC means static compensator. DC does not mean direct current. SC does not mean short circuits. However, there are other considerations. This is one consideration and other consideration are always in life is money. You are also doing M Techs, that do get better job, better brand, IIT degree. So, you have more salary. So, here also anybody will ask me question, sir it is ok, it is work well and thus the whole compensation, how what money which will cost be less as the state electricity boards are all red because nobody pays and there can be free electricity etc. Any way we are not going to power reforms here in this class.

Installation and maintenance problems are other important issues. If something is static, where is the question of maintenance? Why transformer has 99 percent efficiency? Because it is a static device. That standard answer, to this question which matter will put several teachers in viva or selection committees. So, there is no friction loss, there is no rotational losses and so on. So, this is a dynamic compensative means, rotational is involved. So, maintenance cost will be more as compared to static. Similarly installation cost will be more in case of synchronous machine. In compensator bank of inductors what is the installation cost.

Further we do not know where we need this compensation, where are the loads, the industry can be anywhere, the load can be anywhere, then whose is going to go? And

even in Delhi if you ring 10 times, then somebody comes for maintenance, within then when they know that IT is a big customer and yet they do not care. And AMC is already contract is signed AMC is Annual Maintenance Contract, money is already paid and that is why they do not come, that if you tell there is no AMC, they will come because then money is there. For each case separate money, but once you do in this country, AMC means it is NMC, no maintenance contract, like your TQM is what, you know TQM. Anybody knows TQM?

Total Quality Management

You should knows this terms, but in India NQM, no quality, not low, no quality, low quality is still better than no quality.

Similarly, in India there is a maintenance problem and these dynamic compensators can be anywhere, who is going to maintain them. If something goes wrong, that means, compensation is not available. So, that limits their practical use, large compensation DC is preferred any where, if you want to big MBA adds, I do not think you can gone putting bank capacitor and inductors. So, there is a limit to which you can go for static var compensator. So, if you want real large compensation, then DC is the only choice.

Now, that was a left over from the last class, now we start today's topic. Control by transformers, the compensation still continuous. Now, transformers are there any way whether you like it or not.

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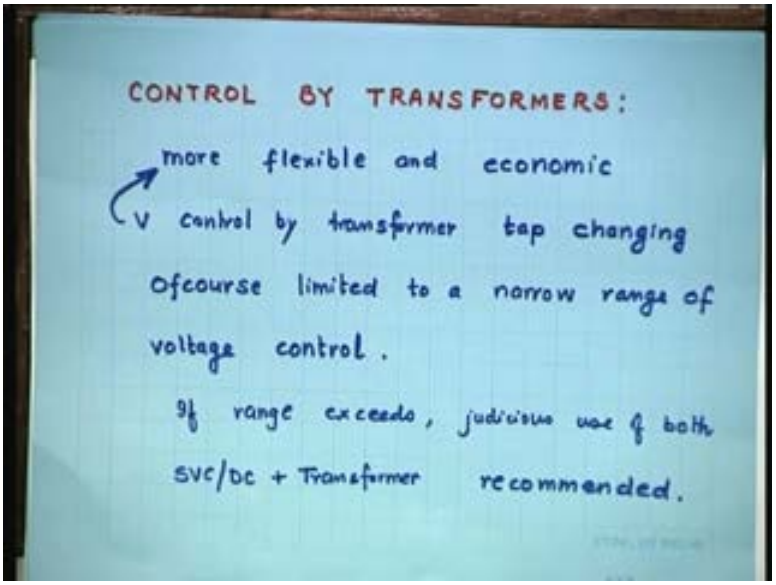

In any power system even electronics, even computer the voltage stabilizer is what, transformer. So, transformer is there in everything, even that the shaver or your lady's hair dryer, because your voltage has to be reduced to certain smaller value. Then how did you reduce, transformer is the only way only mechanism. So, transformer can also control the voltage to some extent. How that providing taps, if you do not provide taps, there is no control, whatever number of there N1 by N2, then all your quantity will get transferred from primary to secondary, from side one to side two, because primary and secondary again keep on changing? it depends from which side giving input. So, let us one low voltage side to high voltage side, because low voltage and high voltage side will not keep on shifting, even will be definitely low voltage side and other will be definitely high voltage side, unless and until to change the transformer.

So, from LV to HV, that ratio is fixed N1 by N2, but if you put taps, then that ratio can be marginally changed. You cannot make it double. Then one transformer you make and keep on changing it is ratio that providing taps. Taps are just there for marginal adjustments. So, if you call some people for dinner and for four persons, if fifth also comes, it is you can perhaps manage, but four more come then the house lady will have a real problem. So, may have cook all over again. So, that is exactly the same thing is here. If there is a smaller adjustment, it can be done by this transformer. Otherwise you have to again resolve to static var compensator or dynamic var compensator.

So, this is more flexible, more economic. Why economic? Transformer dynamic all be there. Can you tell me where do you put taps? That is well known because that is outer side.(()) Of course, that is what I have been talking for last five minutes it is limited to the narrow range of voltage control. You cannot just keep on changing the voltage when tap changing. If range exceeds, judicious use of both SVC oblique DC plus transformer recommended. In fact, judicious use of all the three not both, both means I combine these here. That is why I written both. Otherwise you would have read all the three.

What percentage of this purpose of that depends on particular problem, particular location, particular requirement? You cannot give a general prescription, you to work out each problem separately. Otherwise you never need any CA or any MBA if there is general prescription for all the problems, all financial problems. No audit is required even medical. So, there is one book, take one thing know, that may be ok for initial, to reach hospital.

VR can be raised by simultaneously changing the taps of sending end and receiving end. This is double engine because taps are there on both the transformers. This is your system, this is 2 bus system.

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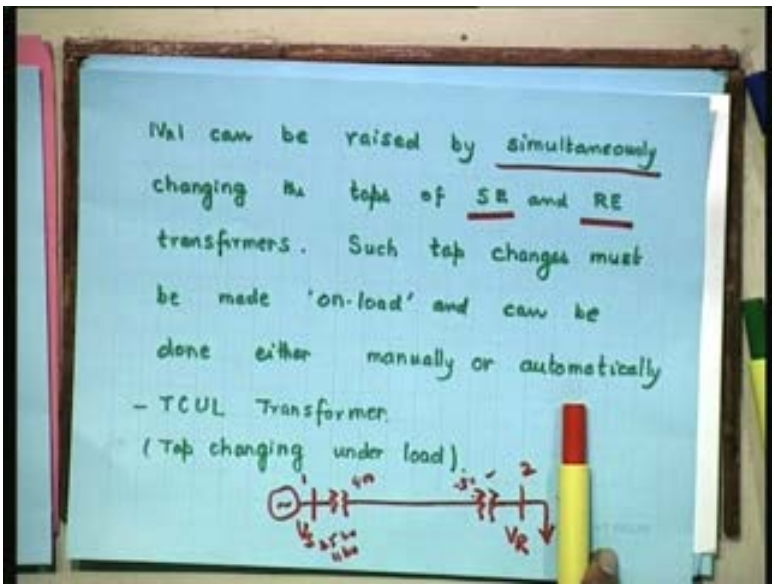

Now this is VS and this is VR, this VS gets converted to 400 unit, this may be 25 kv or 11 kv. Generation is always at a low kv, because of these installation problems, cooling problems, economic problems and so on. So, when this 25 kv becomes 400 kv, you can

make it 410 by taps here on sending one. So, that is 410 once gets reduced, it will becomes 400 unit and then 400 can be lower to 11 kv, which is load is there. But suppose is 400 becomes 350 here, so this again there taps here. So, this 350 or 380 can be made 400 back and you get 11 kv. So, that is how these taps, taps are on high voltage side in any way. So, taps will help you both ends that is what is written here. Simultaneously changing the taps of SE and RE, if you change offline or you can change online. That is called TCUL, Transformer Tap Changing Under Load. Such tap changes must be made on load and can be done either manually or automatically.

If you recall in olden days when you used to see TV, so one has to go and walk and adjust that knob of voltage stabilizer. Now, you do not want to move at all, for every damn thing you have, what is that?

(())

Not automatically invertors, remotes, you do not want anything to do yourself. Whereas tomorrow you may have remote box, sit here you will get some water here. No movement, any body does not want to move at all. Just put a button on remote, garage will open, where as next button will bring car out, the third button will put you in the car. And in UK, there are cars you do not have to even drive, the computer drives it and there is screen in which it comes, which road you should take, which is optimum.

What is GPS?

Global Processing System

Very good, you know it. So, this will tell you which way there is no traffic jam, which way there are less red lights, which is free way, which is high way, everything. You do not do anything, you need not think, computer will think for you. For us you do not need brain. In west, if you take a 30 cent something, they do not know, how much they should give back, is you pay them one dollar, seventy cents, 70 cents you cannot calculate, any way. Now, I can do it either manually or automatically.

Now this is the circuit diagram or symmetric diagram for transformation control, which has explained you there in brief way, now it is a big diagram here. This is VS IS, this is that sending end transformer which is step up because the generator KV is lower and the

transmission line is higher. So, it is 1: TS plus n1, n1 is the original number of tones, TS is taps, sending n taps, then ZR plus jx, assuming that it is a short line.

(())

Where is multiply? This is plus

(())

It should be multiply, for TS n1, similarly it will be TR n2 multiply 1, this is receiving end this is I, this is VR IR this is load. TR is less than 1, TS is more than 1. Transmission line with tap changing transformer at each end let TS and TR is the fractions of the nominal transformation ratios that is, the tap ratio oblique nominal ratios. A transformer with nominal ratio of 3.3 kv to 11 kv, when tapped to give 12 kv with 3.3 kv input as TS is equal to 1.09. This much value of TS is required, in case you need 12 kv instead of 11 kv. 11 kv will get any way, because of the original TS ratio, but suppose you want higher, other said I want 410, so I can always calculate TS 410 upon whatever 11, 33, 25 kv depending on the value. So, I will get the value of TS.

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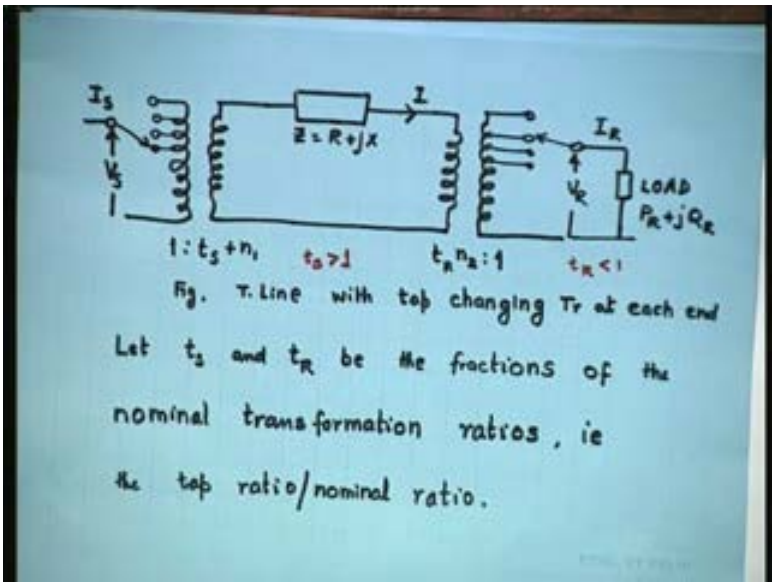

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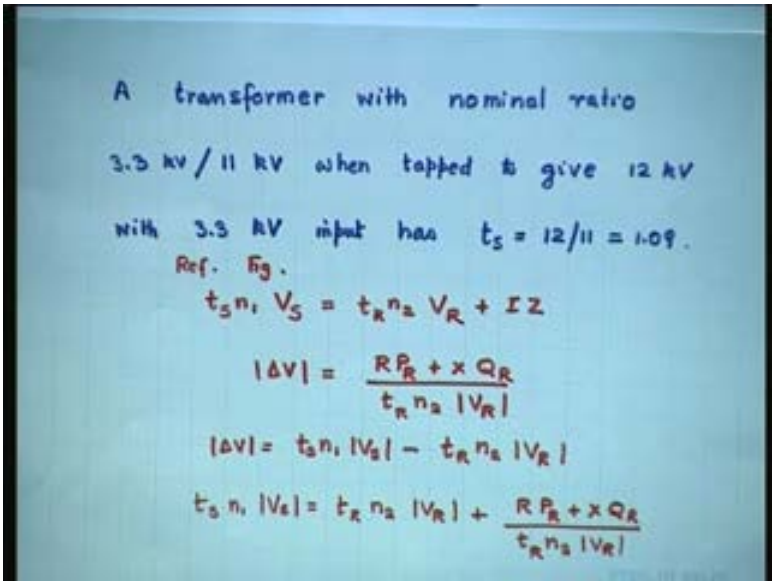

So, I must adjust my TS taps to value of 1.09. Again you refer the figure. This is what your (()) voltage law. The voltage at the sending end is tsn1 Vs which will be equal to the Tr n2 VR plus IZ, which is the series impedance. This equation we already proved it sometime back, RPr plus XQr upon VR, it was originally. Now it is Tr n2 VR. So, what is delta V? The drop tsn1 Vs minus trn2 VR, clear. Taking this on left hand side or keep it there take this two left hand side and change these sides. Then delta v, I am substituting from here and we get this equation. Is this equation is ok for all of you, ts n1 Vs is equal to tr n2 VR plus this delta V. R is resistance, Pr is the receiving end real power plus x the reactance. Qr is the receiving end reactive power, tr multiply VR.

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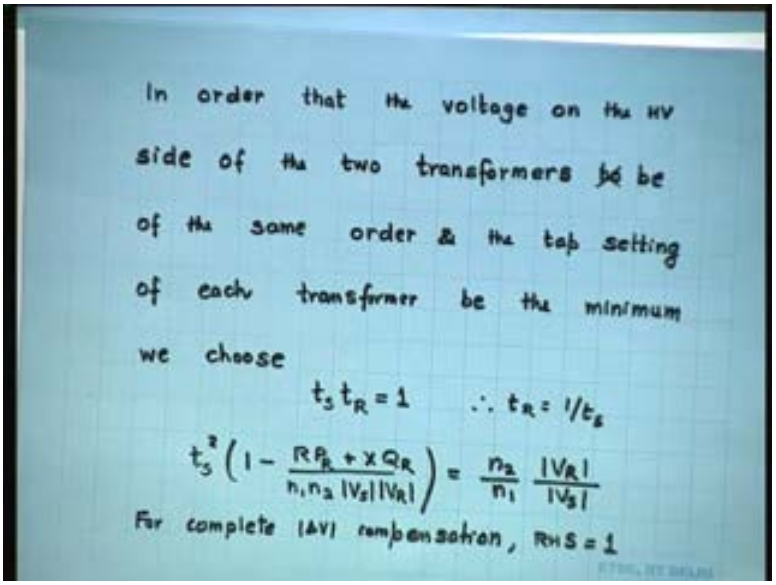

In order that the voltage on the HV side of the two transformers, be of the same order. If they are of the same order means no step up transformer and step down transformer, two ends. If the HV side of this and HV side of this are same; that means, 400 kv has travel and still remain 400 kv, it practically means delta V is 0. Tap setting of each transformer be the minimum, we choose ts tr is 1 and hence tr is 1 upon ts, naturally 1 is more than 1 other has to be less than 1, that is proof from here. And now we substitute here and we get this answer. Because I can substitute tr is equal to 1 upon ts in the formula, which was there in the last sheet, so I get this formula.

For complete delta v compensation right hand side should be 1, if this is 1, it means there is no problem of compensation, is fully compensated. N2 times VR is equal to n1 times Vs means same voltage, is it worth or not that is a separate issue. It means it involves money, it involves planning, it involves control. So, in practice normally we allow some job. It is very difficult to have 0 job and in fact, now with the power reforms in place, let me tell you what is happening now, the generators, private PPP the call is, Private Power Producers, P not that what is public what was that peoples were not there not that p, this is private power produces now there is a competition.

Even in the Delhi, BSNL and Tata that is the separate issue you are given TATA one side. So, there is no competition, it is the only whole Delhi is divided into two private companies, but suppose they can give power to anybody like you are free to purchase a

Airtel, Aircel, BPL, Hutch or Reliance, whatever you are free. Nobody can force you. Similar there are suppose four power producers. Now what is happening? They are giving you raw power without any quality, quality you decide depending on your need.

So, the quality has become a responsibility of the consumer. So, he will install whatever voltage stabilizer you wants, whatever UPS you wants, whatever harmonics you wants to control or eliminate, it is his headache. They will only use the open access, the transmission line will be already made and then you can use it. Like if you run a parallel train or like parallel planes, parallel train is not there yet except he conqueror railway or there couple of more smaller portions, but planes are very much in reality. So, jet planes and these sahara planes also use the same air terminal, same air traffic controllers and they share the same space. Only thing there is a coordination done by air traffic controllers when particular plane will take off, he will give you the green signal, till then you will be there.

Similarly, if you are landing you will be known around Delhi airport till air traffic, you will say, the pilot will announce, look we were seventh in the queue. He may do some biasing in lines first that is the separate issue, but once Indian line also becomes private, even that will go. Then you will say Indian condition is more money to him and so on.

So, here we get a raw power and then you are a suppose seven different consumers, depend on your need, your coca cola company, your soap factory, what sort of power you need, you will bring up to that quality. So, this voltage drops, if it is permitted for you, you will use that. Why should we spend money compensated? So, that is what is to be understood now, power quality is no more requirement from generator point of view. It is a consumer requirement and that is why the power quality has become a very important field. There are books on power quality, there are subjects on power quality, if possible you can take it next semester under your open slot or whatever, examine properly what courses you can take outside circle and taking electric department such courses, power quality HV DC or facts you know or optimization power system, optimization and so on.

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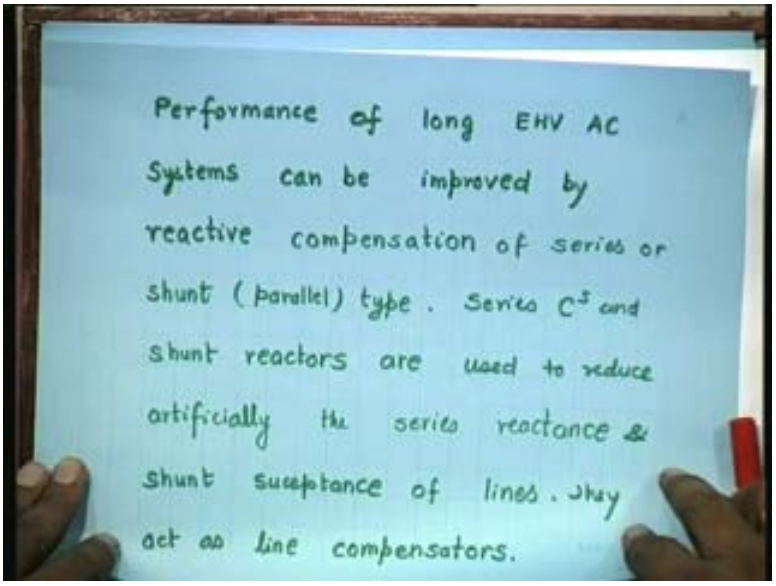

Performance of long EHV AC systems can be improved by reactive compensation of series or shunt. Now we started compensation of lines. So far it was compensation at the receiving end. Now we have come to the transmission line. Aim is same, Aim is only four, we have four objective function. It is a multiple objective problem, like what is your problem? That M Tech degree, try to maximize your CGPA, try to minimize your efforts to achieve that CGPA, as if you can someone find out how to do it, then try to get a good job, try to go abroad and try to become ISO engineering service somewhere. So, it is a multiple objective function.

How you do it? How you do it depends on your intelligence and your strategy adopted by. Similarly here what are my four objectives, I want no voltages drop, voltage profile should be flat, I want good power factors that my load, I want higher transmission line efficiency, please remember, example 5.1, where we achieved all and I want the maximum power transmission. Transmission capability should go up, EV by X sin delta. So, these are all objective function as a power system engineer or electric energy system engineer. Now, which one is more important depends on you. You cannot tell all maximized, there has to be waiting factors w1 w2 w3 w4. And this waiting factor sigma should be one. This is starting optimization course and you can use goal programming, you can use any mix integer programming, linear programming, non-linear programming, five three approaches, evolutionary programming, genetical algorithm, A N systems there are so many good techniques.

Now you can have 2 compensations, 2 compensators are possible, series or shunt, there is no third. If you want to go from near to Madras, there only 3 ways you can go, by air by rail or by surface transport, car, bus, there is no bus any way from Delhi to Madras to going steps. Similarly, for compensation, you have only two mechanisms, one is series compensation another is shunt and third is of course is combination, you read in control system lead lad lead lad, same thing, there also compensation here, that is the different variety. Similarly filters you have, filters in circuit theory, you have filters in controls, your filters in drives and so on, active filters passive filters.

Series capacitor in shunt reactors are used to reduce artificially the series reactance, they are not actually reduce, actual transmission lines takes the way it is, what find to do your artificially time to reduce the reactance. So, that the power transmission capability go up. So, that the voltage drop is reduced. So, that voltage profile becomes fine and so on. All these four objectives and you also want to reduce the shunts acceptance of lines. They act as line compensates. Both of them, shunt as well as series.

You can read this chapter book also, you can read this chapter in book, you can read this chapter in our black book also. And there is very good paper by Kimbark on compensation in 89 or 88 somewhere. I think I have given the reference of that paper in the new book some late 80s that is his last paper, where footnote is written that he is no more. You must have read his book on stability, has three volumes.

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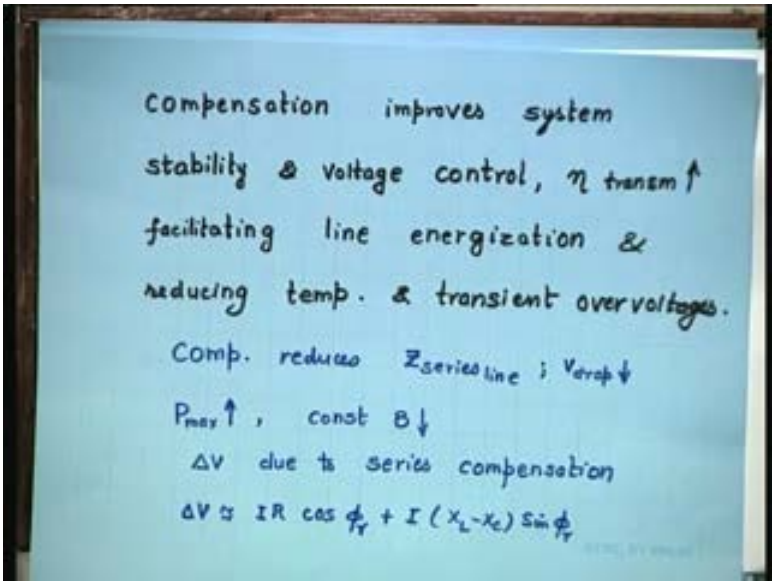

Compensation improves system stability as well. Do not think that compensation, this is another dimension, it is not only voltage control, it will make system more stable. Why? Voltage will remain high. Even transmission line efficiency improves with compensation, facilitating line energization and reducing temporary and transient over voltages. You must have done the chapter on over voltages, switching over voltages, transient over voltages, temporary over voltages. Compensation reduces series line, the series impedance of transmission line. This is how you should write in brief, but do not write it in your papers, and the teachers may not understand what you write. So, this three things can read how much series impedance of transmission lines, z series line, and voltage drop also reduces, this is used in chemistry, if you read chemistry, if you remember, I assured said then precipitation and then gases, h 2, it show the upper arrow, then precipitation is downs, the same arrow, you can use the voltage drop reduced, P max up and constant B down.

What is constant B? a b c d. Those generalized circuit constants, a b c d constants, B gets reduced, why B gets reduced? B is practically z most of the times, even if it is a long line, it is a z times shine comma L upon L. Delta v due to series compensation will be this now, this is a famous equation Which we have proved by phase diagram figure 5.1.

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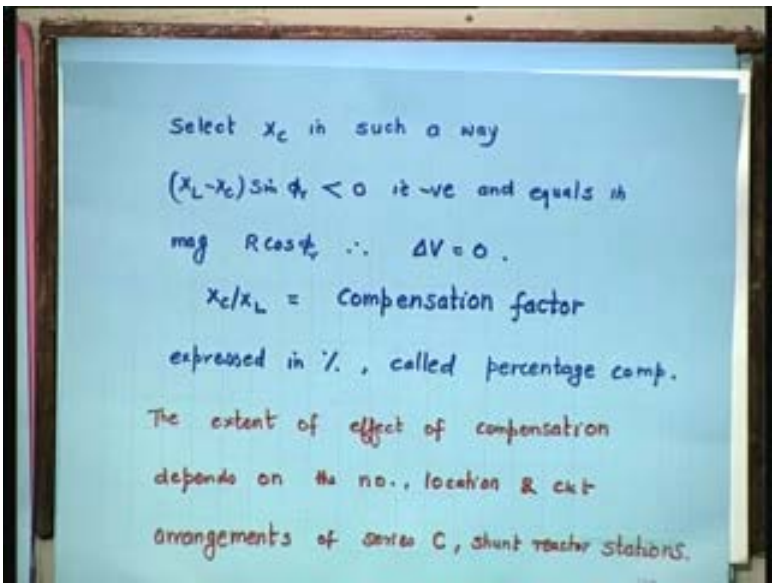

This Ir cosine pi r plus Ix sin pi r now becomes XL minus XC. This XC has come because of compensation. So, naturally when this is reduced here, in delta v also gets

reduced. How much reduction you want depends on how much money you want? That much how much compensation you are willing to provide. (()) Select XC in such a way, that this is negative, XL minus XC sin pi r is negative and equals, you should not stop here, and equals in magnitude r cosine pi r. Let us bring back that equation on the screen once again. If this quantity is negative, how much negative you wants, so that it equals this, then what happens, 0, that is a ideal condition, provided your willing to spend that much money to bring it make it negative and equal to this quantity. If you can do that, fair enough you get constant voltage for pi. So, delta V will be 0 and this ratio XC divided XL is called compensation factor.

One mark question, define compensation factor. Do not write stories. Just write XC by XL is called compensation. Always answer to the point and this quality is very useful for lawyers in the court, judge will get annoyed if you waste time, unless and until one you already met him once earlier before coming to the court, then there is no problem, but if you have not met, he will get annoyed if you waste his time, you should be very even with the boss talk minimum. So, talking more is always harmful.

So, compensation factor is defined as XC by XL. Expressed in percentage, then you called percentage compensation later regulation. Percentage regulations is multiplied by 100 to get percentage value. So, if you are asked in examination in numerical find out percentage regulation, you have no business to give answer is 0.48, it is a 48 percent or p0.05 it write 5 percent. Do not do same thing, do not cut my marks, no marks will be cut you have been asked in percentage and you are not giving percentage. So, should not give any opportunity to examiner to cut single mark.

The extent of effect of compensation depends on what? Three lines are very important. It depends on number of compensators, it is number and location where you are putting it, security, this is security problem, is called placement problem. What is field placement is so important? Why captain is so important person it is here who ask you to stand at a particular place? Field placements, so that catches. So, the ball will not cross the boundary. This is in every game. Do not think it is only in cricket. In volley ball, in foot ball, in hockey everywhere.

So same is the game in power system, where do you want have compensation? It is a one third of the transmission line, middle of transmission line, 80 percent of the transmission

line, this is again optimization problem, even final answer, the suitably formulating objective function and using a optimization technique. Or experience, if you have no time, or a like where do you place guards, you must have seen guards in campus throughout. Somebody must be planning, they are not just going in standing anywhere, where they like the everyday, they have been ask to go and stand somewhere and circuit arrangements of series capacitors. How you put the series capacitor or shunt reactor stations? Is there are very huge if you go and see and then life any substation, do not think it is just one foot some box, there huge substations.

I think it is a next class, are any difficulty will stop here. Any difficulty so far? So, we are done today we continue with static vars over last time. Today we start dynamic compensative, then we came to transformer tap changing and now we are started line compensation.