Power System Generation, Transmission and Distribution

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Lecture N0. # 21

HVDC

So, welcome to this lecture number twenty one HVDC. Now, what is HVDC, it is a high voltage DC transmission. Now, you may ask me when everything is being shifted to AC, why we are talking about anything direct current, let me tell you this HVDC was or even direct current was gone forever, but in 50s to be precise in 1954, it staged a spectacular comeback.

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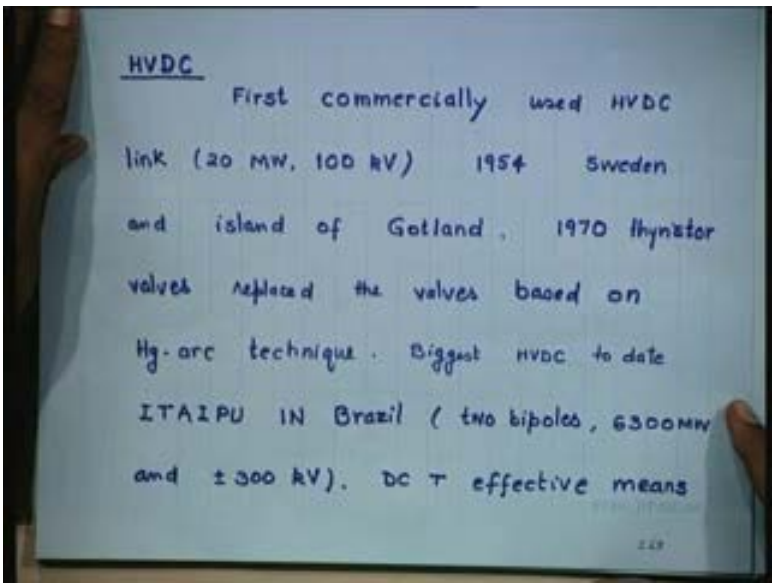

So, first commercially used HVDC link, which was of 20 megawatt and 100 kV was established installed in 1954 from Sweden mainland to island of Gotland. 1970 as the power electronics progressed or electronics progressed. Shockley effect 1960 and the advent of transistors; so, valves slowly, but surely got replaced by thyristor valves. So, 1970, thyristor valves replaced the valves based on mercury arc technique, and you must read mercury arc rectify in your under graduate.

Biggest HVDC to date that is 2003 is in Brazil. And the system is called I T A I P U, itaipu popularly called itaipu. Brazil is known for it is a contribution to energy, early I told earlier on in this course that the biggest hydro power plant is also in Brazil on the river Amazon. It is 12000 megawatt; imagine we have only 1200 megawatt our biggest hydro power plant that is Bhakra. It is started in 56, in even in 2006 is after three year, and it continues to the biggest. The Brazil system is two by poles 6300 megawatt and plus minus 300 kV.

Now, what is DC transmission, obviously generation has to be AC because the DC generation is hardly there, then why we are going for DC, and what we are wrong in AC transmission, which is anyway predominately most of the transmission is AC even today, and will continue be so. In future, yet we are going for HVDC in selective way to get certain advantages is certain situations, which have you explain you what are those situations.

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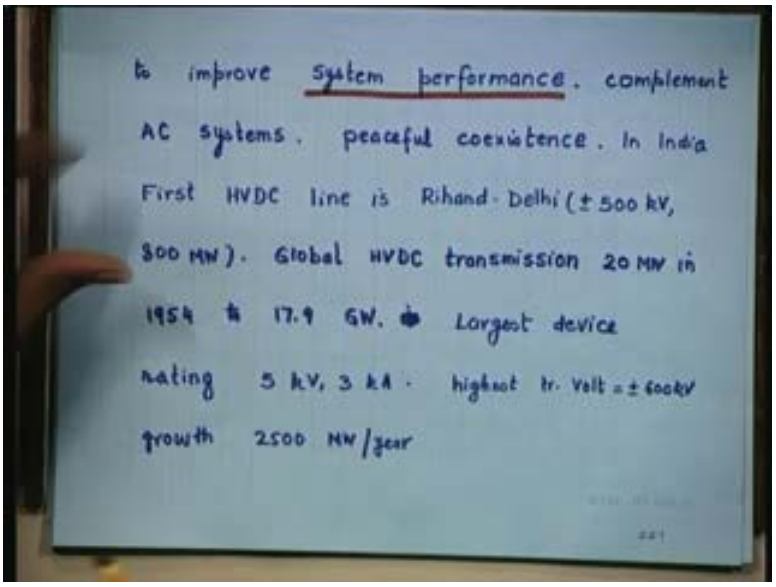

So, DC transmission effective it is a effective way of or means, improving system performance. It is complement to AC systems. We never want to replace AC by DC system. In facts we want peaceful coexistence of both simultaneously exactly the same way, as we have non conventional resources, and conventional resources. Non conventional energy resources are not competitor to conventional resources we primarily mainly use renewal energy resources are non conventional resources were is not possible

to use conventional resources even today where do use bullet card, where there is no deadline, where there is no road, where you can run the bus.

So, interior or if it is a water ways; we go by streamers; were go by boats even, and recently we now proposing ferry to Bombay to Karachi, which use to run before 65. The first are second Pakistan; indo Pakistan war, if you consider 40 80 as a first war Kashmir. why we are go going by ferry, because there is no railway link there is in between sea. So, in India first HVDC line, world was 54, that was Sweden to Gotland. But in India the first HVDC line k from Bihar to delhi and this was plus minus 500 kV 800 megawatt about 15 years back, roughly 1990. Since, then we have that several HVDC applications are; there is one at Chandrapur; big HVDC station, one is Satpura. And, I hope if you can we taken in to one HVDC station to see it actually I do not know whether it will metalize or not, whether even it will be able to go to the load dispatch center, which is across a road. But my job is tell you were you should go.

So, this Rihan to Delhi line is continues to your biggest HDVC line. Now, they want to connect still bigger, north east to south; 2000 kilometer plus minus 600 kV and 2000 megawatt, why because north east has potential, it can generate power, but they are no takers. It is not required there unfortunately or fortunately the way you look at it. But it is required is south. So, that line will go all the way from Assam to down south to Karnataka. Global HVDC transmission is started with a modest 20 megawatt in 1954, is today 17 point 9 gigawatt. So, it is 1000 times, suppose we assume this is also 20 this also 20. So from megawatt to gigawatt, largest device rating so far is 5 kV, 3 kilo amps. So, device is this there are simultaneous progress in power electronics also has help in becoming; in making; HVDC more and more attractive, more and more cheaper. Why we are going for this power electronic devices, because there are availability; availability in bigger sizes, easier of control, yes and cheaper. Highest transmission nine voltage is plus minus 600 kV in the world, not in India alone, and growth is 2500 megawatt per year every year you have another 2500 megawatt available through HVDC, throughout the world; it is not in India throughout the world.

That is one device.

But there may be some problems while using for HVDC that you can use for any other; you know applications for HVDC it is not yet used, there are certain problems with the

inverter and converter stations. So, is application is main important thing, for example of some patients can be given kichidi, some even cannot be given kichidi, only liquid diet because of the requirement. So, because of that perhaps it is limited to only that.

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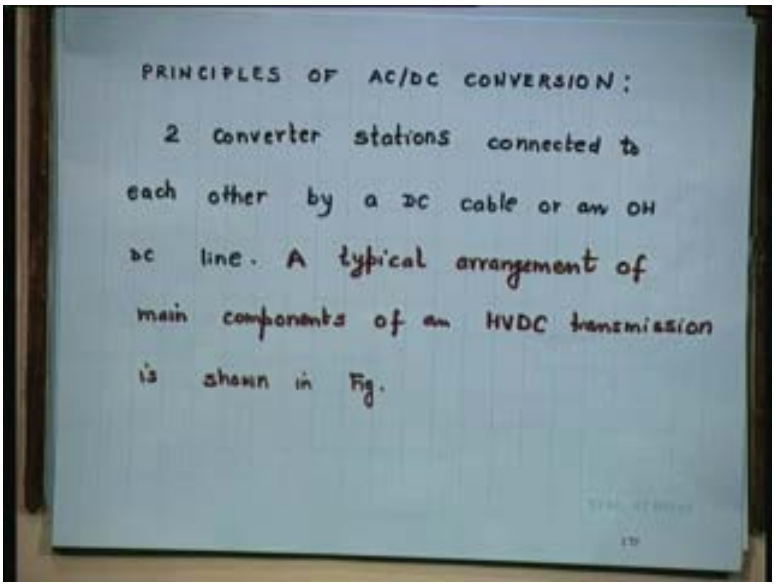

How do you convert AC to DC, because generation continues to be AC. So, what are the principles of converging the AC supply to DC supply; converting, two converter stations connected to each other by a DC cable or a DC over head transmission line. Now are not all places you can use the overhead transmission line. So, that point we are already discussed a lot, while talk that that is why I edit cable also the one lecture, a part of a lecture. So, we need to use cables; DC cables, also do not think there only AC cables. A typical arrangement of main components of an HVDC transmission line is shown in the figure which is coming next.

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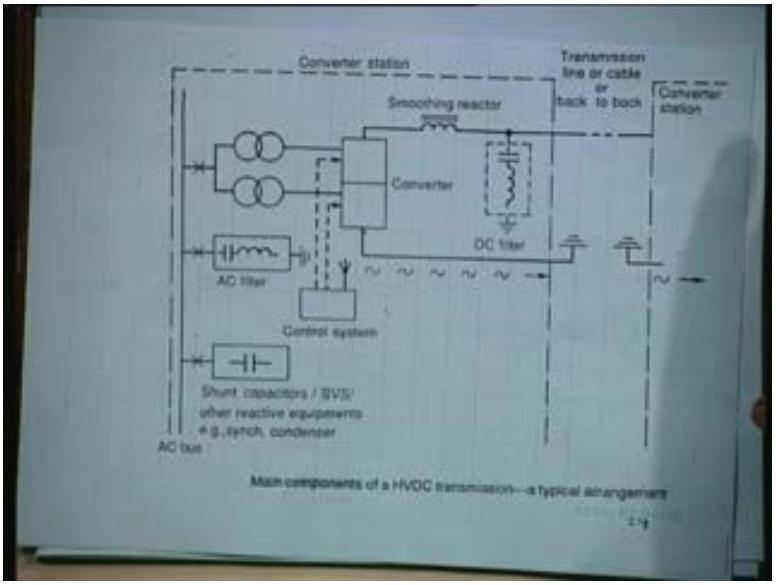

Now, these are main components of HVDC transmission a typical arrangement, does not meant it has to be exactly like this. So, this is just typical arrangement. It depends on particular local needs. This is the AC bus, after generation you transformer bring it to a particular voltage and from here it comes to convert converter stations and converter station is so big, this is the control system, this is the converter, this is the filter, this is AC filter, this shunt capacitors, as we as any other reactor equipment such as synchronous condenser, reactor power management are already done.

What is the one negative drawbacks of HVDC, before we talk of positive think, the negative drawback is; are drawback is it cannot transmit any reactive power unlike its counterpart or it is elder brother HVAC, were you can very easily transport, transmit or reactive power, which is naturally available to you, because when you connect synchronous generator to transmission line whether, you like it are not along with ps qs also there that is you known that I actually [FL] there are always together like your shadow.

Now, this case you cannot transmit anything forget about part. So, you do not you do not only you have to prepare for any short fall, but the whole total requirement you to supply additionally whether you supply locally, globally; you known by theft, by borrowing, by bugging, that separate issues, but it has to be not through transmission line, that is a main point, this is one of the main drawbacks of HVDC lines; however, since we have another

resources. So, it is not that bigger drawback, that will deter you that will force you not to adopt HVDC option.

Sir installation cost is also

Well, overall cost is you have to compare, you have to see, and it depends on requirements also. There so many other factors; is just one factor, I am going to be talk about 20 factors as the time progresses as we go.

I do not known what is happens finally. But in converters are there is big devices, whether it's should be zero frequency conversions or infinity frequency conversions.

That we do not go into the debates thus left to power electronic classes.

What has been to finally

No no that I would not talk on that because this debate will, because we have six lecture left, and we have miles to go we have to cover a g c, otherwise you will be left because but used to cover a half the classes in a g c only and you are I have not done a g c at all suddenly you realize in a g c. So, then this the transmission line are cable back to back that means length is almost zero and then there is a converter station. Where do you use these back to back; where ever there are two systems, which have different frequencies.

Frequency

Which are not in talking terms, you known we need a mediator like Pakistan always says, a need mediators to talk to India. So, since there is a France sixth years, England fifth years, and if you want to inter connect this France and England the best thing is HVDC links, which is called asynchronous link. So, this back to back connection is nothing, but making two non-talking partners talk, and then converting station and back to AC, whatever you know frequency you want, and if the frequency is same then off course there is no problem, and still can you have it, and there are certain advantages of not getting synchronization excreta, excreta.

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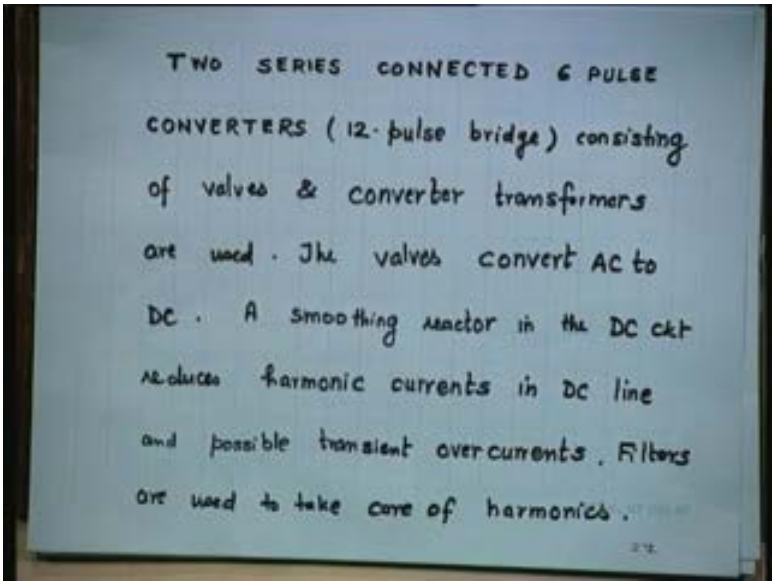

Now what do we need, we need two series connected 6 pulse converters which is 12 pulse bridge consisting of valves and converter transformers. The valves convert AC to DC. What you need is smoothing reactor is, show the figure there is a smoothing reactor shown here. This smoothing reactor is required in DC circuit to reduce harmonic currents in DC line. In facts there is a separate book on power system harmonics, and you should read it is by Navel Watson, he is a very good friend of mines I visited him for a month in university of Christ church, Newzealand. He has several books and always books are now available in India in cheaper edition on dynamics, on harmonics, in power system, analysis, and so on, Harilaka; Harilaka has a HVDC book, also even Hindurani has a HVDC book, Kimbark has a HVDC books and our own Indian book Padiyar, that is an HVDC, exclusively on HVDC, and chapter is given my many books.

Now, valves convert AC to DC. A smoothing reactors in DC circuit reduces harmonic currents in DC line, and possible transient over currents. So, smoothing reactor has name itself indicates, smoothen south several things, it makes yours life easy. Filters are use to take care of harmonics, why this power electronics have created, why power quality is immersed as major player, major topic for PhD, M.tech, B.tech, because of this power electronics, the problems, otherwise thirty year back there was no harmonics.

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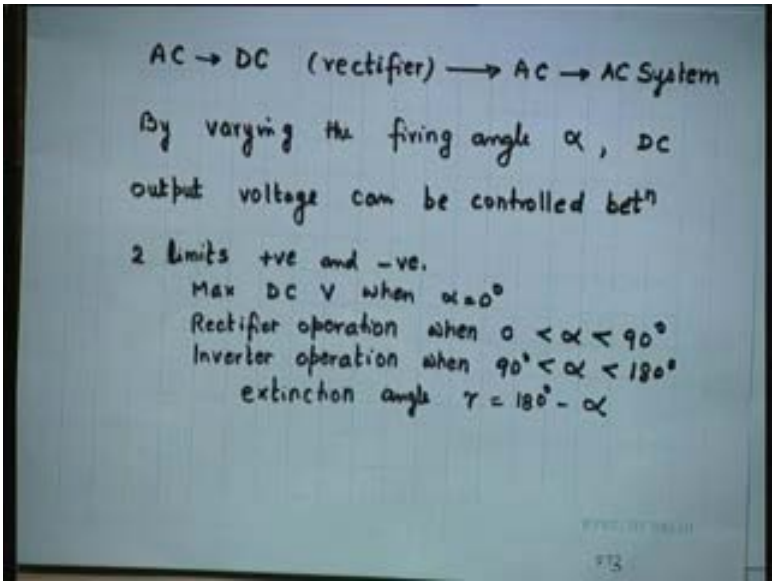

AC to DC converter station is called the rectifier. Again back to AC will be a DC to AC inverter. How do you convert and control this things by varying the firing angle all thirstier operation control can be done by and you have be big control circuits, mutual control the firing angles, microprocessor based, computer based, intelligent control, whatever, what you have all those sorts are things there are big; big controllers are sliding mode control variable structure control.

Drivers

Thus whole lot of host of controllers, DC output voltage can be controlled between two limits; positive, and negative. That is why we always specify a plus minus 500 kV, plus minus 600 kV and so on. Maximum DC voltage will be available when alpha is equal to 0 degree. For rectifier operation, alpha is varies from 0 to 90. For inverter operation it varies from 90 to 180 degrees. An extinction angle is nothing but 180 minus complement of alpha. That you all these things you know, because you know better power electronics. I never study power electronics.

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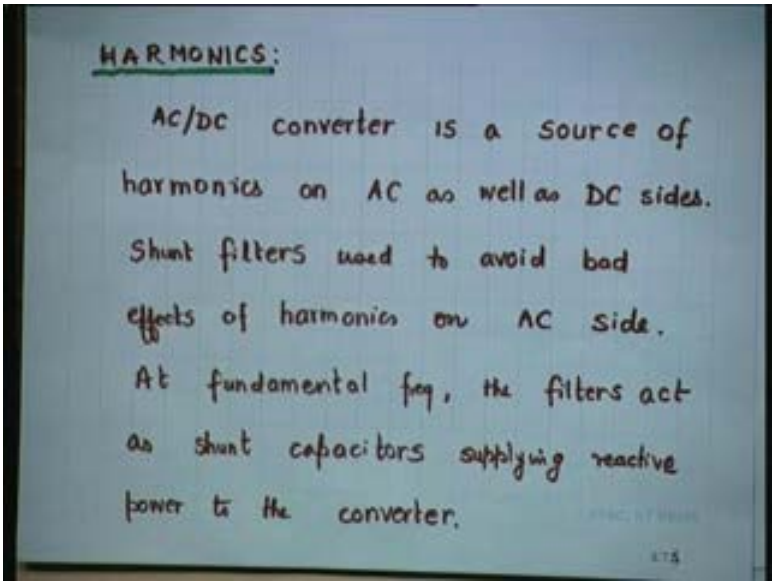

Harmonics, AC; any AC DC converter see the ADC; AC to DC, DC to AC converter as become an important ingredient of so many circuits in electrical engineering. The source of harmonics; do not think only on AC side, AC DC both. So, it is spoils uniformly, there is a specialism there. It does not spare any particular variety of circuit. Shunt filters used to avoid bad effects of harmonics on AC side. At fundamental frequency, the filters act as shunt capacitors that is why the any capacitors can act as a filter in s v s matter studying, that while studying static war control supplying reactive power to the converter. So, you can supply use this capacitors, as I told you we need to supply reactive power in HVDC circuits.

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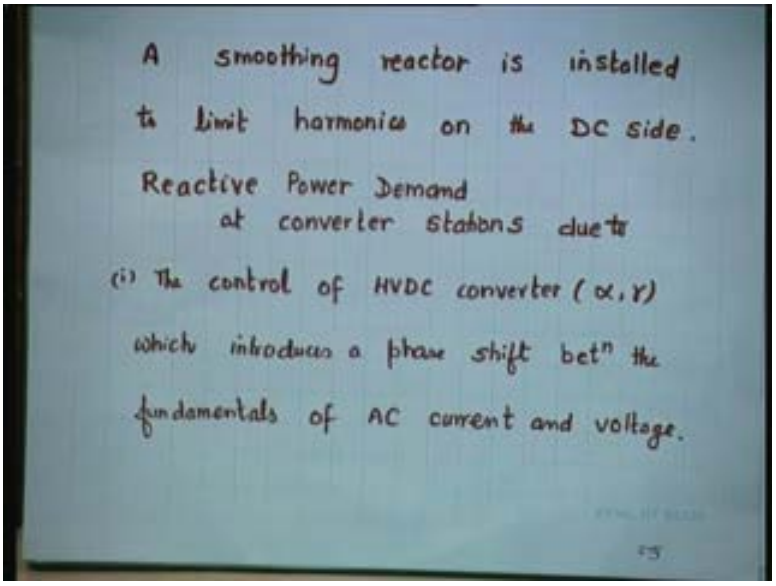

A smoothing reactor is installed to limit harmonics on the DC side. This we are already restated here, reiterated here. So, that you do not forget. Now, let us as find out what is the various reactive power demand, which are additional here, the sides AC requirements. So, will not only HVDC line cannot carry any reactive power; there is an additional load burden in HVDC circuit of reactive power requirement. At, converter stations due to the control of HVDC converter alpha, and gamma, which introduces as a phrase, shift between a fundamental of AC current, and voltage.

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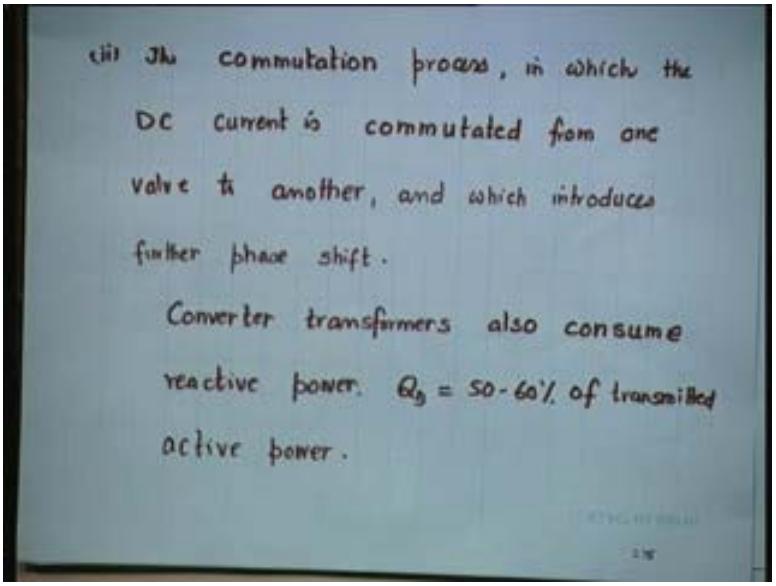

You must have read lot about commutation, linear commutation, and commutation less motors and so on. Commutation is big issues in power electronics. The commutations process in which the DC current is commutated from one valve to another and which introduces further phase shifts.

That is why thyristors are very bad.

That is right. In fact, we are shifting to transistors.

Algebity

And, algebity, masfads because of;

But most of the word the charge problem

So, there is always plus and minus in life. I have been telling you, you would not get anything perfect in this world, even gods were not perfects I told you several times. So, there are problems you have to see which particular thing gets best fitted in a given situation. Even if you want to cure your health you are take some medicines, if you also have short side effects. But you have to take a medicine. A converter transformer also consumes reactor power. So, queue demand is roughly 50 to 60 percent of total transmitter real power. This is the brief story about reactive power requirement in HVDC line.

Now, naturally when you have a requirement you have to worry about it is apply, if you need thousands rupees you will have several options; asks a friend, if a scholarship is due, or look towards your parents. So, you have to get thousand rupees there are several ways or do extra labor, which in India no student does. In abroad every student earns his own money while studying. Earning while learning; it is slogan in India, but is reality in abroad.

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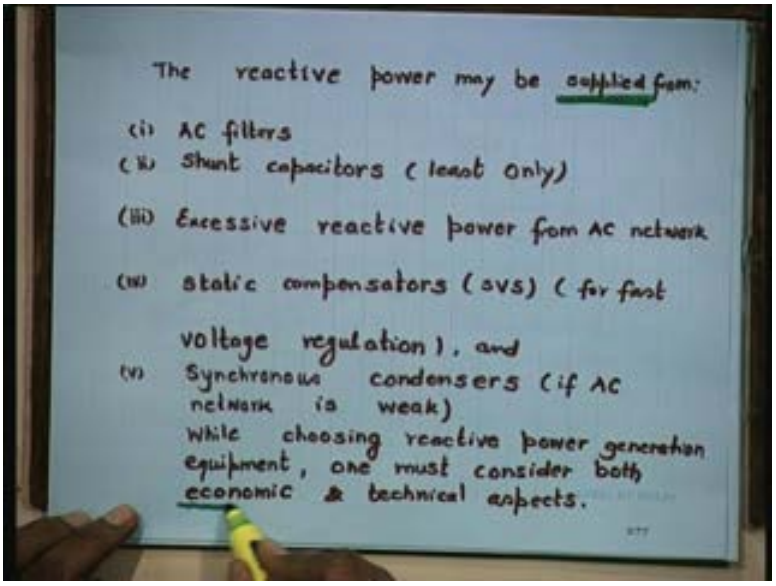

So, as I said the automatic next topic should be, how do we get those fifty to sixty percent of reactive power of total reactive power; first AC filters, second shunt compensators or capacitors, then excessive reactive power from AC network, static compensators this for fast voltage regulation s v s you are all familiar with s v s or s v c static volt controller or static volt system, and synchronous condensers.

We also done this topic in chapter 5 if we recall and we compare static compensators versus dynamic compensator, there plus and minus points and so on. Synchronous condensers are recommended especially if AC's network is weak that means that is do not have that do not supply much of reactive power. While choosing reactive power generation equipment one must consists consider, in facts this sentence is valid for anything in life you have to consider economic as well as technical aspects, suppose you have to take a treatment, which doctor we will go, not cheapest, it also see a own make you die also. So, you should have some reputation, you should have some history of curing some people otherwise why should you go just because is free or this available is freely, if not free.

So, economic, and technical aspects both in what proportion again, it depends on this is a continuous optimization problem, you are solving in life all the time, that is how much economic is important, and how much requirement technical. In my mind technical

requirement should get preference over economical requirement. At times, if you do not have money what can you do.

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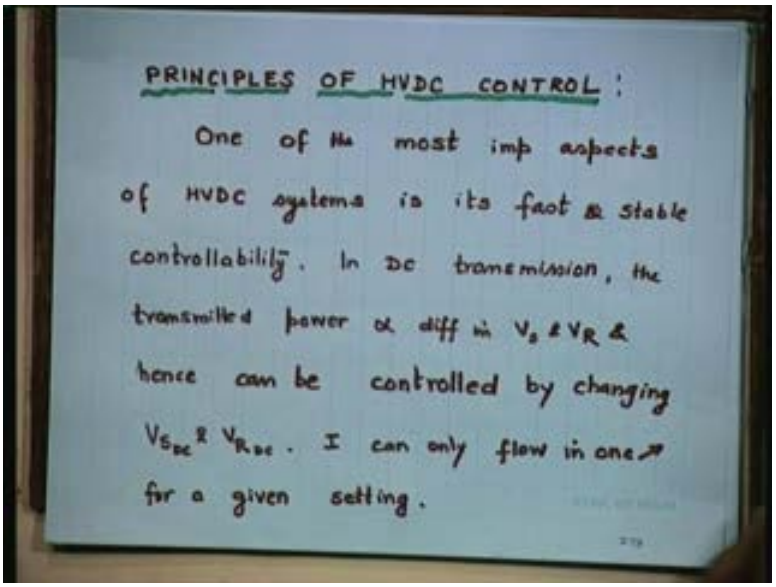

Principles of HVDC control here let me tell you one more thing, because of HVDC whole power system dynamic is change, whole power control is change, whole power system analysis course is change. How can you explain me why it is happen just one topic has change all this text books we are force them to because modeling has change what should we that bus were HVDC is connected how do you model that and the best books which talks about this is Harilaga, he is a Spanish champ and settled in Newzealand.

Even height of the HVDC wires

Height of the HVDC wires

What happen to that

Yes, everything is taken into the accounts.

Why does it get low

No, that I told you that is the different mechanical considerations, the the chapter we did, why do you think done all those chapters briefly, because they affect design. So, how much should be the clearness what is the field will produced by d DC how did

different from AC how what area is affected how far should be the nearest building if you see if you go to that Shivally gorvindrajal behind, now we are building boys hostel eight hundred, have you seen that do you go evening walk, morning walk or no walk for you.

The other gates sir, that side gate

Which other gate, this gate was behind vindhyajal there is no gate. I am talking about mini campus. So, if we go there; there is certain minimum clearance between existing houses and boy's hostel. You do not want, you to just see what happening in these quarters, you should not be shown dangerously close. So, there has to be minimum clearness or your windows should not open towards their windows, you know these are the gainer consideration may not be technical, but these are practical considerations. Any way let us come to the why it has made people write different edition of the books when HVDC come back. The load flow is change the AC DC load flow is entirely different topic. What should be the bus, what should be specified, what should not be specified, anyway we will see it when we arrived at the bridges, will cross the bridge, when will arrive it at as the same in English. One of the most important aspects of HVDC systems is it is fast, and stable control ability, which is, which property is not available in AC. the control or fast, and easy. Unstable, there is no point in having a unstable control. In DC transmission, the transmitter power is proportional to?.

Different of voltages

Difference in voltages at the two ends, if you wants to call its sending end, and receiving end; you can call it. And hence can be control by these two voltages which are DC voltages. Current can only flow this not I can only flow this is current. Current can only flow. So, that there is no misunderstanding in one direction say I mean have habit of writing you know, shorthand. In one direction for a given setting you cannot have a current flow in a different directions if you want to have then, again you want to change the voltages.

Yes, any control which is easier in AC to change that direction.

In alpha, just by changing alpha we can change

Due to change the alpha

It is very easy to change their alpha.

Easy, but otherwise if you do not change it can flow in only wonder

Yes sir.

Not alpha is used, only pw is used

Passwords more are less.

Yes sir.

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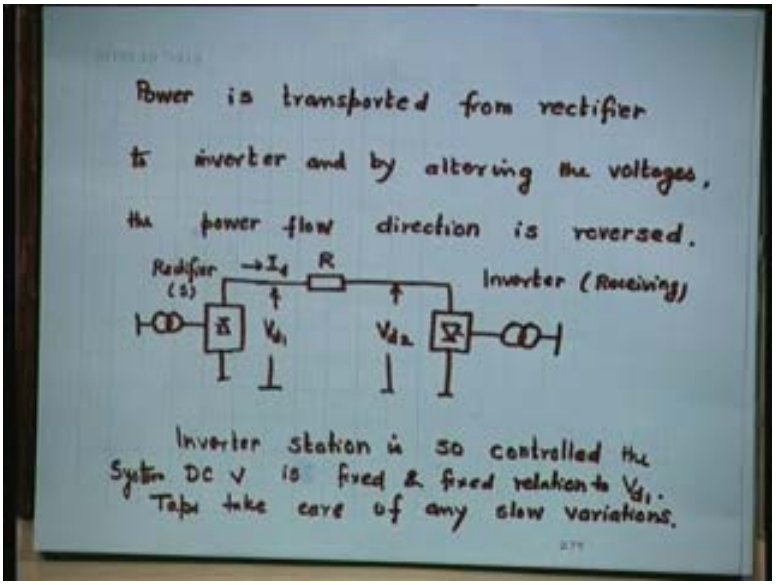

Power is transported from rectifier or transmitter from rectifier to inverter, and by altering the voltages

In the power flow direction is reversed.

In the power flow direction can be reversed, why touch alpha, and gamma. So, we just change.

The alpha control

the voltages. This figure tells you whatever I have been talking in last two minutes, here is the rectifier station, and here is the inverter. Rectifier converts AC to DC, and inverter converts DC back to AC. Because in reality the generation continues to be AC and distribution circuits continues to be AC. There are hardly any DC loads; there are hardly any DC to distribution system in the world. So, only it is transmission sector which is gone primarily DC mode not distribution, not generation. Now, these are the your converting stations; this I d is a DC current, R is the total resistances. I included lumped all the resistances is here. Now, there is no short line, no middle is only long line here 2000 kilometers or will be zero length line for back to back. So, there are only two applications. So, nobody will built for short line DC, because it is very costly V d 1 and V d 2 are the DC voltages at station one, and station two receiving end, and sending end also can be used as a . Inverter station is so control; the system DC voltage is fixed and fixed relation to V d 1 you can always use transformer tapes table to take care of any small variations slow variations the transformer are still there.

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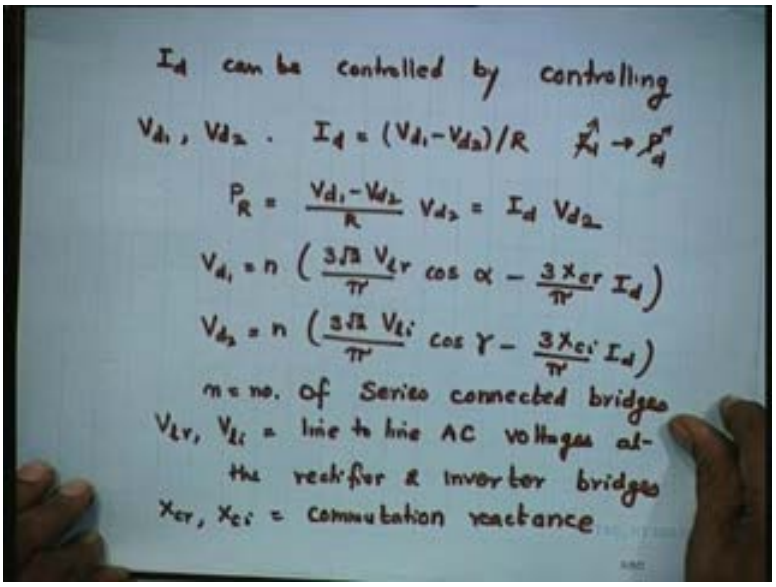

Converter transformers, I d can be control by controlling V d 1 and V d 2 again retrace of the same statement, which we are done. I d is equal to V d 1 minus V d 2 by arc is simplest, there is no cosine, and no sin, no phrase shift, nothing is there, if you increase I d; obviously, power will also increase as simple as that is again in very short cut notation I explain if you increase I d results in increase in p d. Forgot say, do not use a notation in any other subjects which teachers would not follow. So, you can only use it for those

people follow it, and to understand it, otherwise I am not understood it, what you are written this I he will says you canceled it, and send it somewhere else what is P R receiving end V d 1 minus V d 2 upon R into V d 2 current into voltage at that point; this is current in a voltage at that point. V d 1 and V d 2 are also given in the terms of alphas and gammas, which you have been talking so for 3 root 2 V l r, V l i alpha, gamma, I d, x c r, and x c i what is the n here, n is the number of series connected bridges.

Six pulse will be there.

Whatever it is, you know power electronics as I told you I am going to; go into the power electronics I will only explain you is the power system part of it V l r and V l i are line to line AC voltages at the rectifier, and inverter bridges. R stands for rectifier, and I stands for inverter, l stands for line, and V stands for voltage, the x c r and x c i these are commutation reactance's at rectifier, and inverter and respectively.

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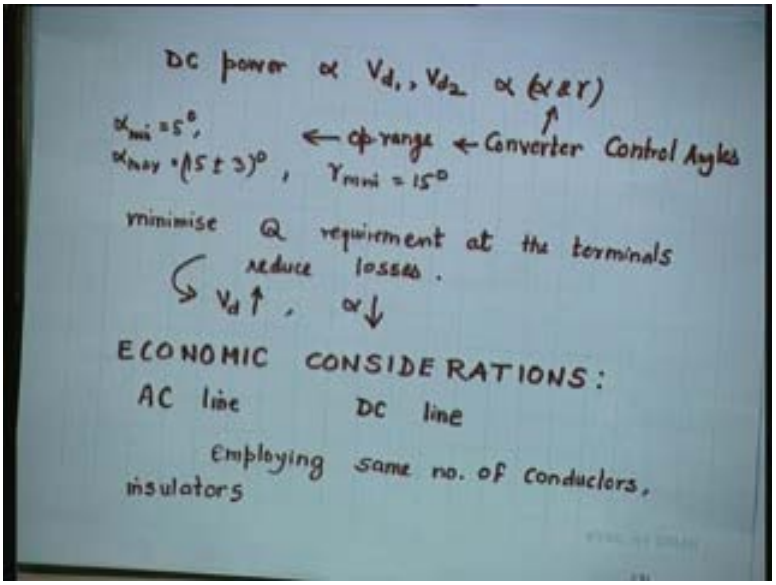

DC power is proportional to again I am retreating two voltages V d 1 and V d 2, which intern are proportional to alpha and gamma just now you said few minutes back. These are converter control angles and there operating range is given by alpha mini five degree, alpha max is fifteen plus minus three degrees, and gamma mini is around fifteen degree this is for experience. In fact, you can solve optimization problem, and get this value depending on, what is your objective function; the objective function changes the values will change, the constraint change the values will change.

So, the values; the final optimal values always are depended on what you want if you want to save money the optimum way is text 620 10 rupee you reach station, but if have a lot of money, then auto still lot of money taxi, if no money left. Minimize reactive power requirement at the terminals reduces loses.

No sir, if V d increases; then queue will decreases

No sorry, you want to minimize the queue require again I repeat you want to minimize queue requirement anybody will like to have minimize any requirement, except the money you want to have more and more money, more and more comfort. That anything is expense site you would not to minimize. Now, how do you achieve this minimization; So, it is very complicated way it is written, you have to increase V d or reduce alpha this will reduce losses if loses are reduced naturally few requirement is also, because loses are also to be provided they would not be provided by god, and that is why load flow, slack bus is not to be specified till the end because if that is job of slack bus is to provide loses and loses are not know till the end. So, that why in slack bus you do not specify P s and Q s you only specify V and delta. Now, we come to economic considerations, which are very important let us compare AC line with DC line, these are the only two comparison to have the valid comparison, all other condition remain same, this is line view always use, what are the conditions, here employing same number of conductors, and insulators.

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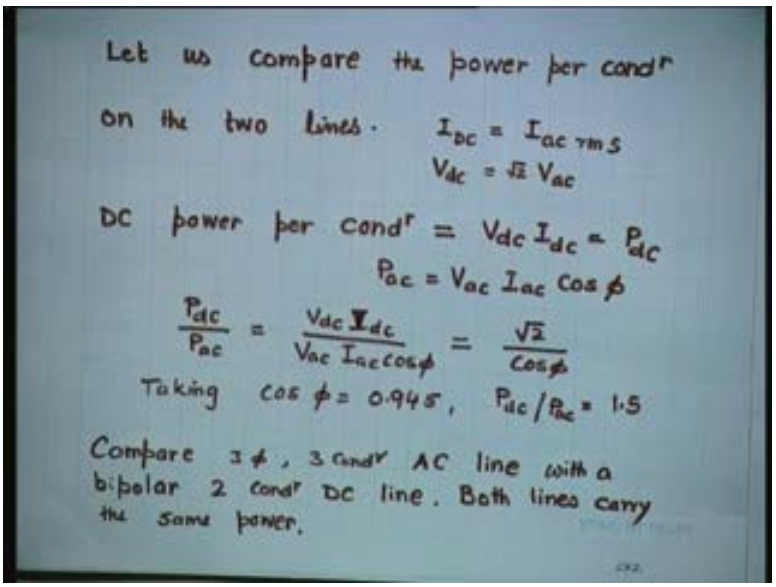

Let us compare the power per conductor on the two lines, let us assume we have current DC is equal to AC r m s, and V d c of course is equal to root two times to V a c. V a c is r m s. If you want peak value you have to multiple by root two and peak value can be your DC value. So, DC power per conductor is how much; very easy, just multiply voltage and current V d c into I d c which is equals to P d c. P a c is all of view know since your childhood V a c into I a c into cosine phi the first manthra which is given in first semester by Sadaija, V a c into I a c into cosine phi take a anything we want to compare is easiest thing is take a ratio of them. So, P a d c upon the P a c substitute the values, we have just obtain them V d c into I d c upon V a c I a c cosine phi, we are left with root two upon cosine phi. So, root two is always more than one because it is 1.41,whereas cosine phi is always less than one, at the most worst case or best case it will be one. So, this ratio is bound to be always more than

1.4

It can be more than 1.4

Always more than 1.41

As you are saying, that alright always more than root two, because worst case it will be divided by one, and rest of time it will be less than one. Let us so phi would not be zero. So, otherwise it will be infinity, cosine phi will never be zero, that means the angle should be ninety degrees.

Only pure inductor transmission

There are nothing like pure induction, some resistance is always attach to it. That is only in theory; pure inductor. Taking cosine phi as 0.945 which is in normal value in western countries not in Indian context; but anyway this is just example, we get to get a nice figure, actually I work backwards, see a I told you, there is a secrete of writing books. So, this figure should come neat 1.5 is it is register the students minds wow, [FT] you know 50 percent more power. So, it 1.61, so, what is this figure 1.61. So, I have chosen backwards and got the value of cosine phi as 0.945. Compare three phase, and three conductor, this is the assignment for you similarly as have gone for this you compare three phase this is take home assignment, in USA it is called take home assignment.

Here, it is no meaning because everybody will join together and solve it that will not for any purpose.

In fact, they give marks also on take home assignment, which in India we can do because just consult each other and solve. So, three phase three conductor AC line with bipolar two conductor DC line, the answer I am giving you both line carry the same power so, they are exactly equivalent. So, this is a home assignment to you and do it and see whether, you get this answer are not. Today I have to go early, because meeting. So, still two more slides. DC line is however simple anybody say, that will cheaper, why; two conductors, instead of three.

In HVDC because that two invertors

But the neutral conductor is always cheaper

Than the line conductors, in any case this statement is true. The DC is cheaper as compare to AC as per as conductor cost is concern, further overhead line requires only two third as many insulators towers are simpler, cheaper, narrower, and it is results in a narrower right of way, which is very big issues, now a days in many countries.

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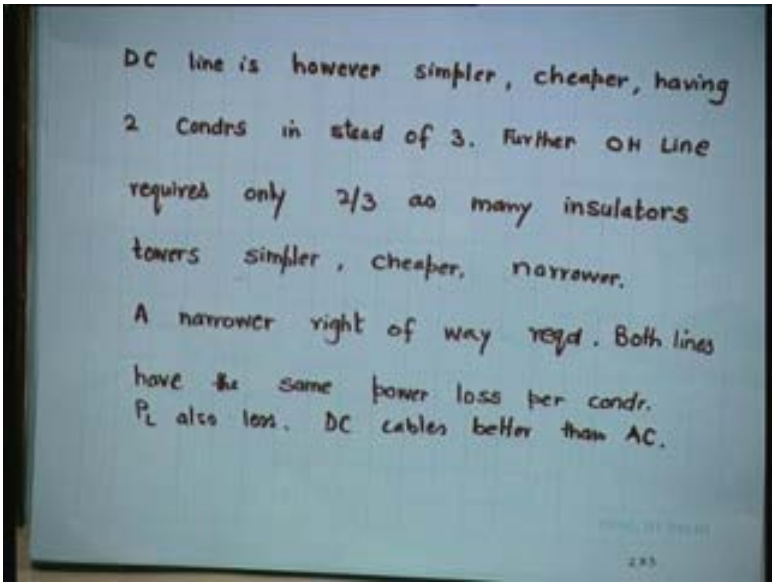

Both lines have same power loss per conductor. So, P l is also less; that is total loss; real power loss DC cables are always better than AC.

Yes, but costly at the same time. So, this is the brief comparison.

BDV of DC is less than BDV of Ac

What is BDV?

Break down voltage

Break down voltage. That is the separate category.

Reliability also more sir

There so, many other, I told you I will talk, this is not a end of HDVC, will have one more lecture and remaining points will talk on Tuesday.

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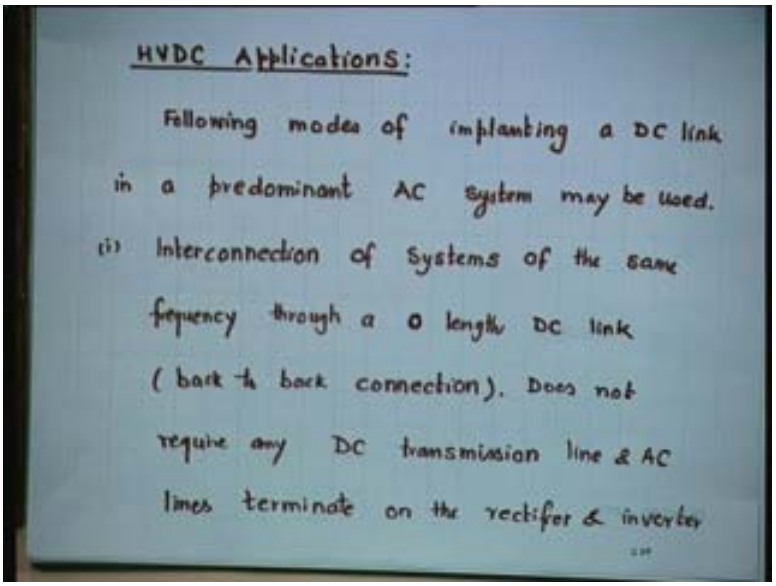

What are HVDC application, one application I have told you so far will retreated here following modes of implementing in DC link in predominant AC system may be used, as I told you most of the system continue to be in the world not in India, AC, and will continue to be so in near future are forcible future, why near unless until some breaks through some where happens, which we did not know. Interconnection of the system of same frequency through a zero length this next is zero. DC link, we already talk about the back to back connection, this does not require any DC transmission line. In fact both the converting stations are housed in the same building, if you go to Chandrapur HVDC station if you told you happen to go some time you will see that there all the both

converting or Chandrapur while going to Madras after Nagpur around three hours, after three hours

You can go to Dhadri also, Dhadri is very close to Delhi, does not require any DC transmission line, in AC line terminate on rectify in inverter stations housed in the same building. Second important HVDC application is transmission of bulk power as I told u north east to south that is going to be biggest HVDC line perhaps in the world 2000 kilometers mini countries will not our length of two thousand kilometers baring Australia, US, and Canada, if you go east west not north south, north south only India or china or US are will have two thousand kilometers, US perhaps will have, Australia will have off course Australia is twice the size of India two India makes a one India area wise population wise one delhi is more than Australia, any difficulty, so far in case, there is no difficulty.

In same frequency than we do back to back

We can do for different frequency as where as I said France and England.

Sir, then why for same frequency

Same frequency also we do for avoiding any synchronization problems. So, there is no synchronization required

So just for synchronization

And too isolate if you want is not just one think that is why certain thing we should also think yourself, you are masters graduates students you come up, in fact anyone of you could have been teacher anywhere.