Power System Generation, Transmission and Distribution

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Lecture No. #18

Underground Cables

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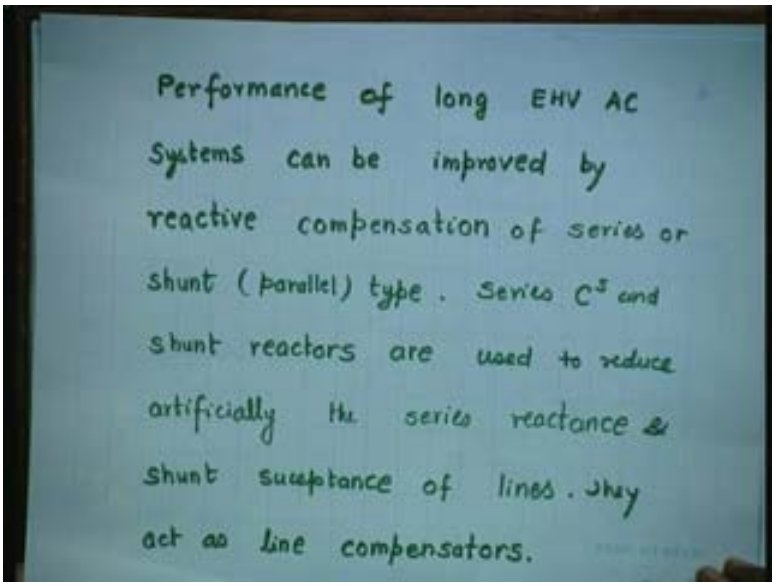

So, welcome to this lecture number 18, which is on underground cables, but before we do that, we have left something from the last lecture. Performance of long EHV AC systems can be improved by reactive compensation of series or shunt, that is parallel type, this we already talked. Series capacitors and shunt reactors are used to reduce artificially the series reactance and shunt susceptance of the lines and they act as line compensators. The compensation improves system stability, voltage control and transmission efficiency, also goes up facilitating the line energization and reducing temperature and transient over voltages.

Compensation reduces Z series line voltage drops also reduced, power transmission capability increases and constant B goes down which is equal to Z. Most of the time constant B is equal to Z, delta V due to series compensation is modified, this expression of delta V is modified here. This is as shown by the arrow this X c comes in. So, X l

minus X c is reduced. So, the drop is reduced automatically there is no change in this term, but there is a change in this term. Select X c in such a way, that this second term becomes 0, less than 0 rather that is negative and if you can equate it to the first term, that is beautiful, that is wonderful, you cannot ask for more. What happens? The total deviation is reduced to 0.

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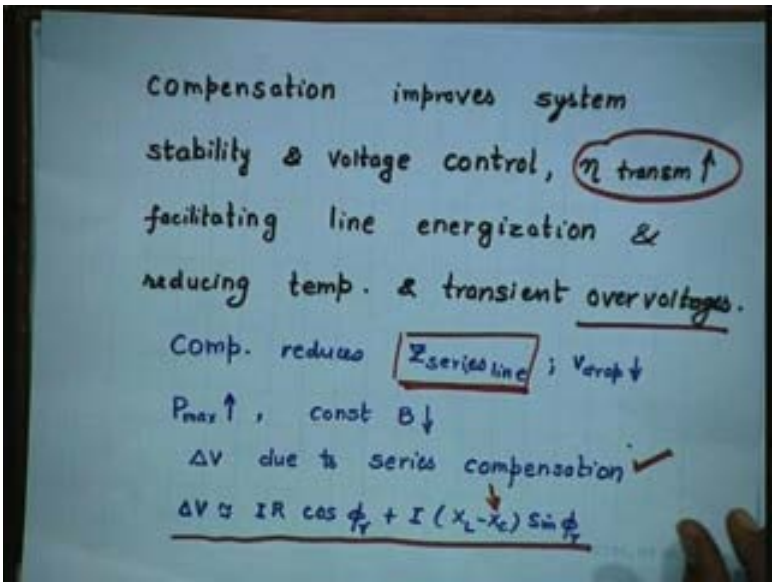

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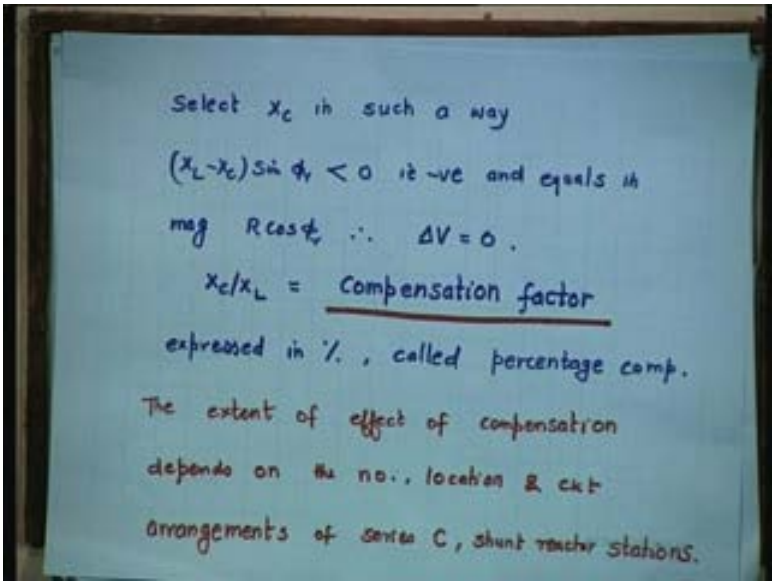

So, that means, you are having a flat voltage in the system, flat voltage profile, which is a very ideal thing of course, it is at a cost and the cost is you have to equate the two terms.

So, that it becomes 0. So, the compensation factor is defined as X c by X l, expressed in percentage, then it is called percentage compensation, like you regulation, there is absolute regulation, there is a percentage regulation, you have to multiply by 100. The extent of effect of compensation depends on the number, what number of capacitors and inductors you are using, location where are you using, and circuit, in what circuitry you are using it, what combination we are using it, circuit arrangements of series capacitance shunt reactors stations.

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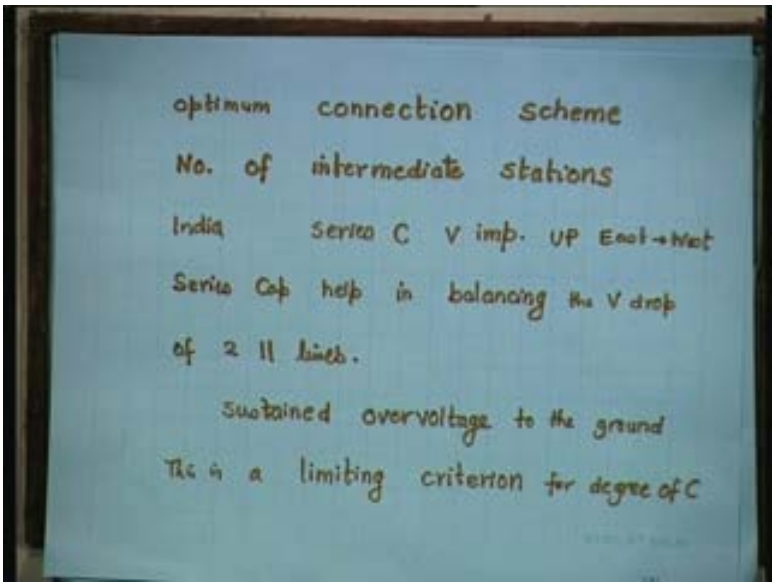

So, there as I told you, if you visit Panki and see that SVS, it is as big as any substations, that big it is I hope you will go one day to Kanpur and Kanpur to Panki, that is the only station in India on SVS. Optimum connection scheme, people have done masters projects PhD project on compensation to come at a conclusion of an ideal scheme, number of intermediate stations of course, cost is always a factor in life, whatever we do, even in US, they do worry, they do bother about the cost and that is why they have started now, outsourcing and number of people going there are reduced from 2,00,000 H1V visas to 65,000.

It is about one third now, as they have understood rather calling a person is better to giving a job outside. So, this cost minimization continues to remain a very important optimization problem. Series capacitor is very important in India. Why? Any long line transmission needs series compensation, because in India we have, as I told you

repeatedly, generation is always confined to eastern part of the country and most of the loads are in the western part. You can see the industrialized states, highly industrialized states are on western side, Karnataka, Maharashtra, Gujarat and the whole coal belt is eastern belt, that is Bihar, UP, MP, Orissa and so on.

Now, the series capacitance help in balancing the voltage drop of two parallel lines sustain over voltage to the ground, this is a limiting criterion for degree of capacitance compensation. How much compensation you can do? Even resonance, sub synchronization is specially as a SSR, which is again a PhD topic, many PhD's have been produced in SSR, is again a very important phenomena which can be produced because of series capacitors.

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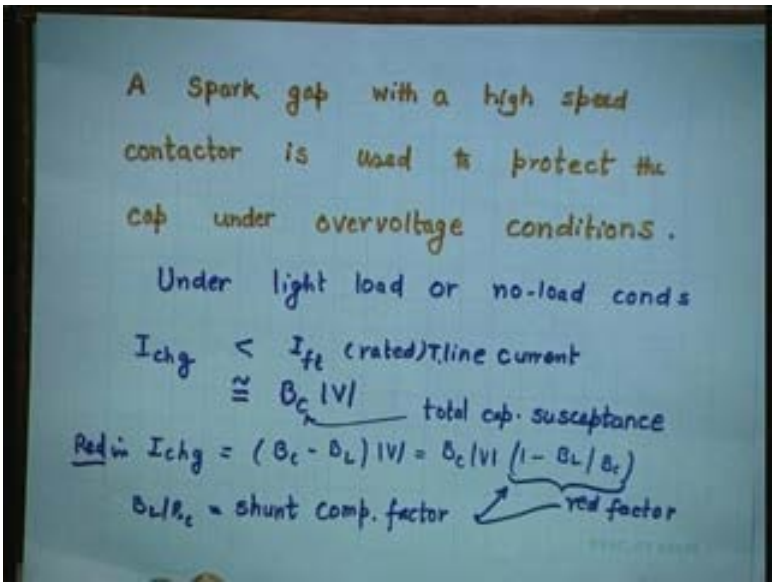

So, series capacitance is a good medicine, but there are side effects and one of the most side effects is SSR. A spark gap with high speed contactor is used to protect the cap under overvoltage conditions. These are protective devices, which you might have learnt in your undergraduate. Under light load or no load conditions, I charging is less than I full load rated transmission line current, which is equal to B c into v, total capacitance, capacitive susceptance and reduction in I charging is because of B c minus B l into v or you can play with the mathematics, B c, v l minus B l by B c and this B c v is reduced by this factor. This has to be less than 1, as long as B l and B c both are positive. And B l by B c is called shunt compensation factors.

You can read this from anywhere, you can there is a Vadva also gives one full chapter, our third edition also gives full chapter or there are papers by Kimbak, you should learn to read from several sources. I do not know the Pie's book gives compensation, but in (( )) I also do not know, whether it gives compensation, if it gives you are welcome to read from any book because 2 plus 2 will remain 4. Now, if the load is withdrawn or gone, then reactors are in to avoid Ferranti effect. So, there were you need reactors, do not think that you do not need reactors, you need only capacitors.

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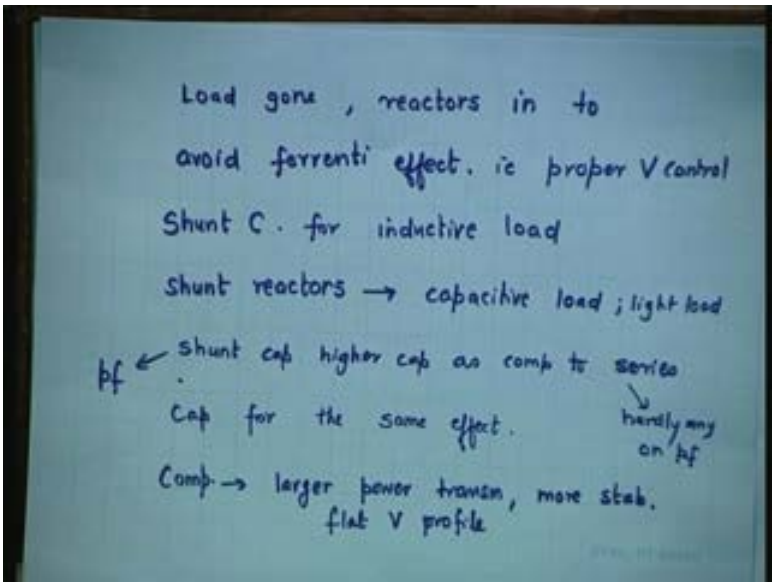

So, sometimes load is thrown off by accident, it is a fault, anyway it is a fault. You must have studied in a stability chapter in your undergraduate, what happens when suddenly load is off? Because, the generation is still there so, and you take time to reduce generation, it is not a joke, it is not just switching on and off.

You have to reduce the steam, amount of steam, the wall has to be closed or water gate opening the gate has to be closed, otherwise the power will continue to be generated, even if it is not required and that will create acceleration p m minus p e p input minus p output p a and m d square delta or d t square is equal to p a this is Swing equation. So, delta versus t curve, it will start going upper oscillations. So, shunt reactors also play a very important role in compensation. Do not think that they are not required.

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Yes, no load or light load.

Of course, shunt compensations is required for an inductive load and most of the load is inductive in life, in real life. If we have a capacitive load, obviously, you will you use reactors, shunt capacitance of course, it is more costlier. It is costlier, 3 times costlier than series compensation. If it is asked in interview or anywhere, you can say it is very costlier, but it does 3 jobs. So, it somehow compensates. What are the 3 jobs? That gives you example 5.1, the solved one it improves power factor, it improves transmission line efficiency, it also improves the voltage profile.

Series capacitance or compensation hardly has an effect on power factor whereas, shunt, it improves the power factors and you are seen in that example how from 0.7 not 7 to 2.94 or something like that it gets improved. Compensation is very much needed for larger power transmission, even a transmission capability increases, which we need all the time, because at times we have generation, but no transmission facility as I told you. It says not even generation problem at times, but it is a transmission problem, like there is a coal in the coal mines, but there is no wagon to carry it, there is a wagon shortage.

The train is not coming, but it is going somewhere else. So, there is a problem on power generations in thermal power stations. If they are not picked stations like Badarpur, like Indraprastha, where coal has to travel all the way from eastern zone to north. Stability is also increased because of compensation, naturally voltage profile is better, the stability will be better, v squared by x, x goes down, v goes up. So, it is a win, win situation.

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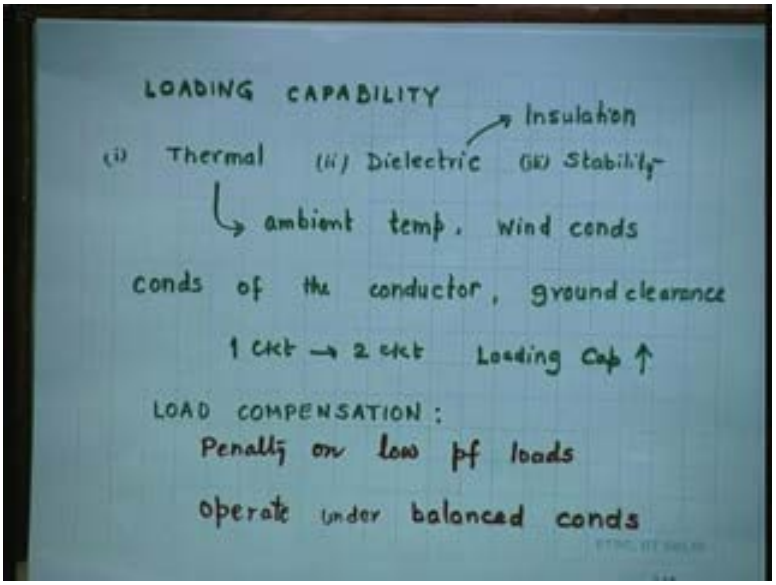

The transmission line capability improves loading capability, thermal dielectric and stability. These are the 3 important factors. Thermal is ambient temperature, wind conditions the transmission line behave in different way in north different way in central India and much different way in south India because their wind conditions vary the ambient temperature varies. Dielectric is insulation and stability is of course is very important thing, there are 2 types of stability now, angle stability and voltage stability. Angle stability is of 3 types, that is a steady state, dynamic and transient.

What are conductors? What are their conditions? Are they solid conductors? Are they hollow conductors? Are they SCSR conductors? Are they bundle conductors? Very few people have shown the diagram in bundle conductor, except one, see the beauty is you must show the diagram. So, that the examiner immediately understands without reading that you know bundle conductor. Just show two diagrams, one with a bigger conductor 3 phase and another 2 small sub contactors forming one phase, too small. This speaks volumes.

If you write pages after pages, which will not have same effect, if you just draw these 2 diagrams, one with single per phase slightly bigger diameter, another 2 smaller ones call it phase a, and then say d s is reduced, if self g m d is reduced, then naturally the x gets reduced, if x gets reduced it will naturally improves the transmission line capability and. So, the critical corona whole thing will goes up the corona will occur at higher voltage,

you do not prevent corona, it only prevents the occurrence of corona up to some extent. These are the only two lines. I do not know what you are writing unnecessarily. So, you should learn the art of writing, how will you write books? How will you write papers? How will you write your major project report? So, writing is an art, I think they are arranging an workshop on 2nd November, not matlab on how to write paper, how to write thesis, you are not aware.

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So, you should know all this things. There are some 6 speakers they are selected who all going to talk on this. Now, ground clearance is very important. Single circuit, double circuit, multiple circuit, loading capability goes up, if you just moves up from single to double. Reliability also goes up, because both the circuits cannot fail simultaneously. The probability is very low, q square, q is a probability of failure, p is a probability of success. Load compensation, this is different than line compensation.

Load compensation is penalty on low power factor loads, they are certain institution, electricity boards, electric companies which will penalize you; if your power factor is lower than 0.85. So, you are forced to use compensation equipment in your premises whether you like it or not, because nobody wants to spend money in life, if they can do without spending they will not, but there are certain losses which force you to spend money.

So, you to maintain the power factor above 0.85 and how do you maintain that by installing compensation equipment in your house. How do you save your fridge, how do you save your a c, how do you save your p c by installing stabilizer or how do you want to work when lights are not there? UPS system, big UPS systems are also there, uninterrupted power supply and see that you operate under balanced conditions, unbalanced is a bigger fault. Unbalancing is no good.

Just if you eat just once in a day, whatever you have to eat for whole day that is unbalancing. There you still taking the same amount, what you otherwise taking breakfast, lunch, dinner or supper or even a tea. Suppose you add all the 4 and try to consume in the morning itself the same amount, it will be horrible. You are definitely going to fall sick. Though you are consuming the same amount, you are not consuming more, but it is unbalanced operation, this is why we go for balanced operation.

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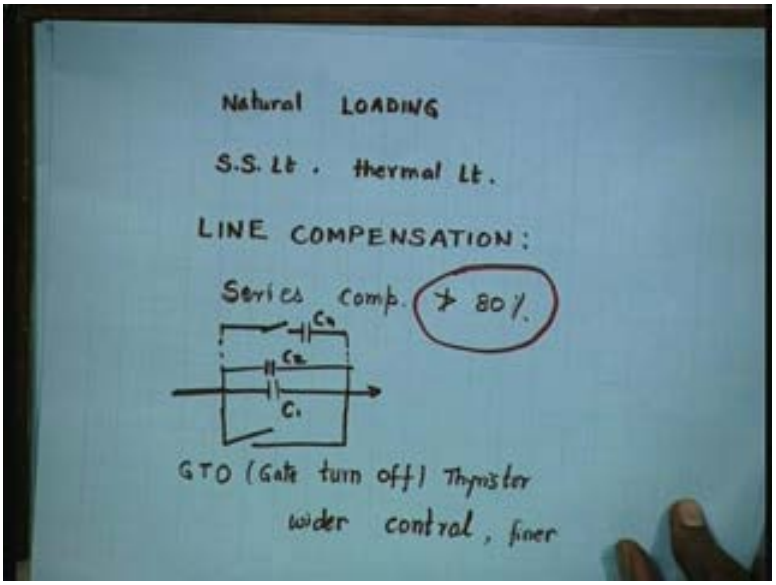

Natural loading, steady state limit, thermal limit. So, surge impedance loading etcetera line compensation, series compensation cannot be 100 percent. You cannot operate line as a resistive line. So, it cannot be more than 80 percent, this is the rough formula. First of all it costs money, it is not free and there is a limit on anything good. Some juice is good, can you go on taking the 50 mousambi juice? Even if somebody's health is pain. So, any good thing (()) no good thing can be taken in axis.

So, compensation cannot be more than 80 percent. Here the circuit, very simple circuit, where it is shown, how a switch if you open it, capacitors compensation is in, if you close it there is not compensation or even if you are go on closing this varies switches, different combinations of capacitance is in place. This is a very simple, I mean you do not need any brain to device this you can have better control, g t o gate turn off thrusters, wider control, solid state control, reactor control.

There are so, many controls smart control anything finer tuning sky is the limit. I think this slide have already shown you, that is a facts, margin and all those things, self regulating to some extent. Right of way is a big problem nowadays. There was no space and that is why we have to go to our next topic, cables. Why you should have cables and there is no electricity storage possible, it is very insignificant amount, a battery.

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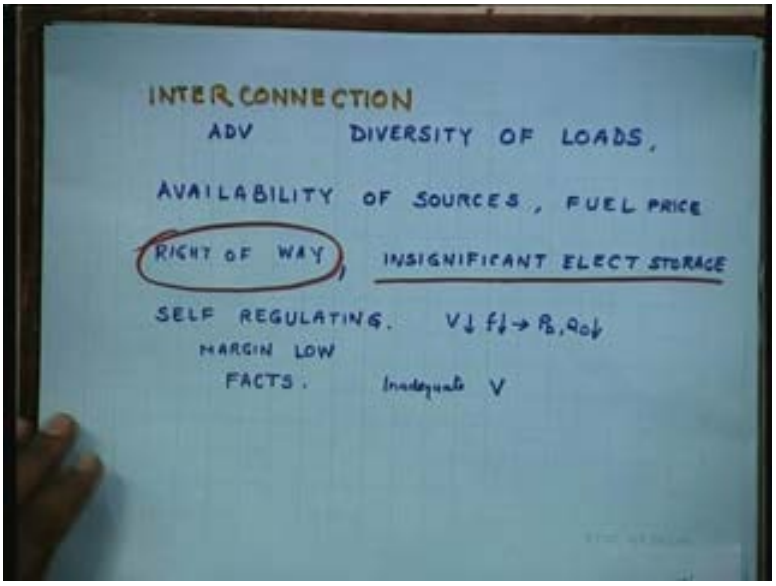

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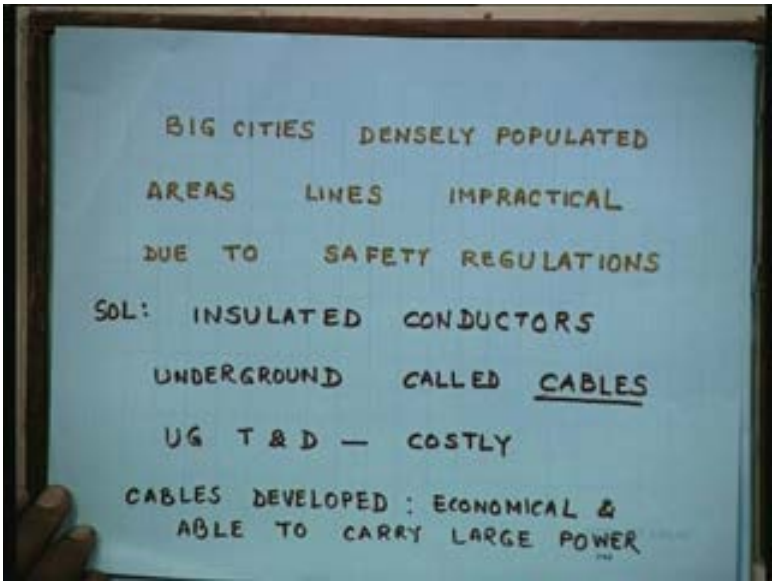

So, now we come to next topic that is cables, which I showed in the beginning of this lecture. Why we go for cables, if there is a possibility we need not go for a cables, because it is costly, but because the right of wastes not there, because big cities are densely populated, Delhi not single space is available, where you can do some construction, New York I told you is one city or metro, where there is no space even to stand. So, where is the question of having more and more transmission lines? So, the whole, the biggest cable network in the world is in New York and there where you need this reactive reactors for controlling because capacitance is too much.

And safety regulations also force you not to have a transmission, there should be 3 feet away from your house, you cannot there the children will touch the live wires. So, there are certain safety regulations, how far they should be from railway track, how far they should be from living house or any other construction or structure whatever. All these things you can read in rules, electricity rules. What is a solution?

You have just many times, we post problem without giving solution. Solution is insulated conductors, which are underground and they are called cables. Naturally, underground transmission and distribution is very costly. Let me tell you, there are very few books available in the world on cables, exclusively on cables. One such beautiful book is by Weedy, I do not know whether you have read Weedy power system book. Now, the latest edition has come with Cory, Cory and Weedy. So, fourth edition that book is of course, good, but a pure Weedy's cables book you should read.

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You should at least know. What is l p? All books are now available in low price, thanks to this globalization. Any foreign book is available in 200 rupees now. It is no more required you to read Indian books just because foreign books are costly. All foreign books are now available in cheaper edition around 200, 250 rupees 300 rupees. So, do not have to read any Indian books just because foreign books are costly. So, this is real competitive market, if any foreign book is good you can follow it and read it.

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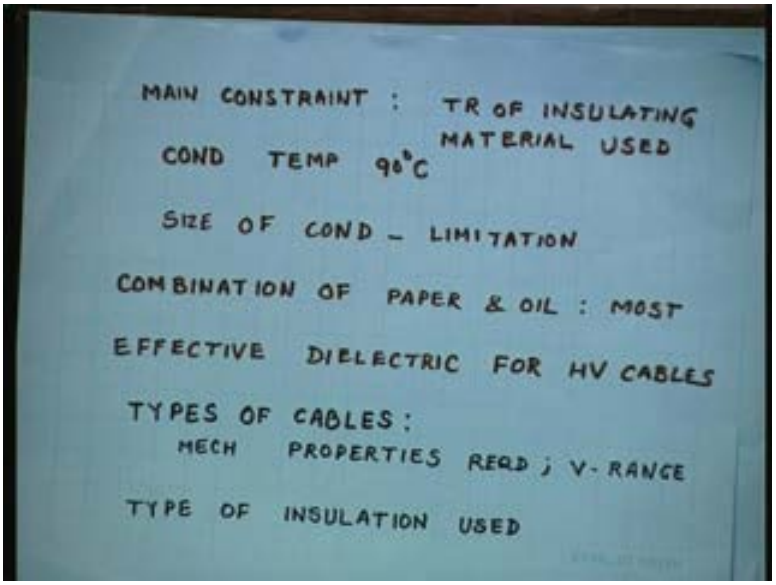

Cables developed economical, you have to see that they are economic, as it is they are costly and able to carry large power because you have to transmit large power. Main constraint is the temperature rise of insulating material used they are in the underground. How do you find out whether temperature you know the M A T R? What is this M A T R? Anybody? Maximum Allowable Temperature Rise. This word you should know, many of you are done heating and cooling cycles, those theta maximum, those curves, time constant for heating cycles, time constant for utilization of electric power in that course, if at all you are done that course, load balancing, fly wheel, illumination attraction.

So, there you must have drawn those curves exponential, heating and then cooling, there the heating should not cross maximum allowable temperature rise, but here the problem is, how do you find out, whether the temperature rise is cross the limit and if so, whether the insulation has failed. The next impact of the temperature rise will be on insulation. See anything will attack your weakest part, any disease will attack you if you do not have capacity to fight it.

So, the weakest link is always attacked, even in war, the enemy country, you have to attack or enter through the weakest least protected area. So, the conductor temperature allowed is up to 90 degree centigrade. Size of conductor is again a limitation. Combination of paper and oil, most effective dielectric for actual cables, types of cables, mechanical property is required, voltage range these are various factors, type of insulation used of course, nowadays the material science has made lot of progress.

You must have read material science, one subject in your undergraduate. There is one material centre also here, polymer centre, where you can do any course of your choice, if you have time. The insulating material used, good insulation resistance and high dielectric strength, non hygroscopic, it should not. Water should not affected, should not react with acids and alkalies, where acids and alkalies inside the earth, and if you start reacting with them, then there will be problem. They will get deteriorated, some chemical reaction will start, fault may develop, short circuiting may be there and so on.

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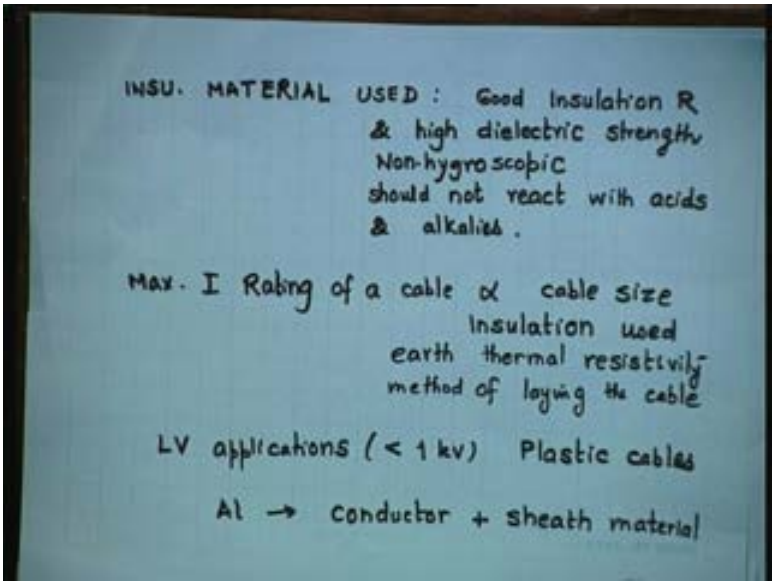

Maximum current rating of a cable is proportional to or it depends upon cable size, insulation used or thermal resistivity method of laying cable, this itself is an art, how do you lay a cable? Low voltage applications less than 1 kV, that is a domestic, we use plastic cables. Most of the campuses, good campuses, they use underground cables, you won't see those transmission lines, I think in our campus also, though have heavy used in many places. Aluminium is getting more and more popular as you know for variety of reasons one thing is it is cheaper, which is lighter, and we produced aluminum more than copper in India. (()) Not very less, it is less than copper.

1.1 is copper and 1.2 is Aluminum that is all enough, the point is if you do not have copper, what you do? Say you need coffee, but the shop fellow will say I have only tea, but you got up in the morning, you have to something hot. Suppose, if current density is low, automatically the resistance will also be high? See over all it is an optimum. So, you have to see 3 things. Availability, economics, cost and other properties.

Naturally on technical grounds, copper is a better conductor. Who says no? But gold we do not have in minimum gold we had in 91, when Chandrasekar government came, the whole gold was kept out. It was a mortgage, we did not have money. The total foreign reserve was almost rock bottom, today it is the highest, Forex, the foreign reserves, the dollars, anyway that is not the topic here, it is not a management class.

Then you compromise on efficiency for cost? It is not compromise, it is not a question of compromise, it is a question of overall optimum, let me use that word. This is not a compromise, many countries in the world have shifted to Aluminium, even those who have copper. So, that is why this is not a compromise. Aluminium has proved to be a better conductor overall because the users want aluminium. So, even USA has copper it cannot use copper, because the users do not want copper.

There are compensating factors that is I am saying as he rightly saying, we can compensate. So, that the effect is not felt for example, if you are that is what student do, per page typing in olden days now, everybody types himself or herself, the rates were 8 Anas per page, but typist use to take 12 Anas, those days Anas no Paisas. So, people used to increase the number of pages.

So, that the money given is same, it is not cheating or any corruption because you are not earning money out of it. Nowadays what happen, even if you not got type bill is produced for typing. This is corruption, those days that was adjustment because the government approved rules were 8 Anas, that typist use to take 12 Anas because the prices have gone up, but the rates are not part of in it. So, number of pages used to be increase that is what he is saying.

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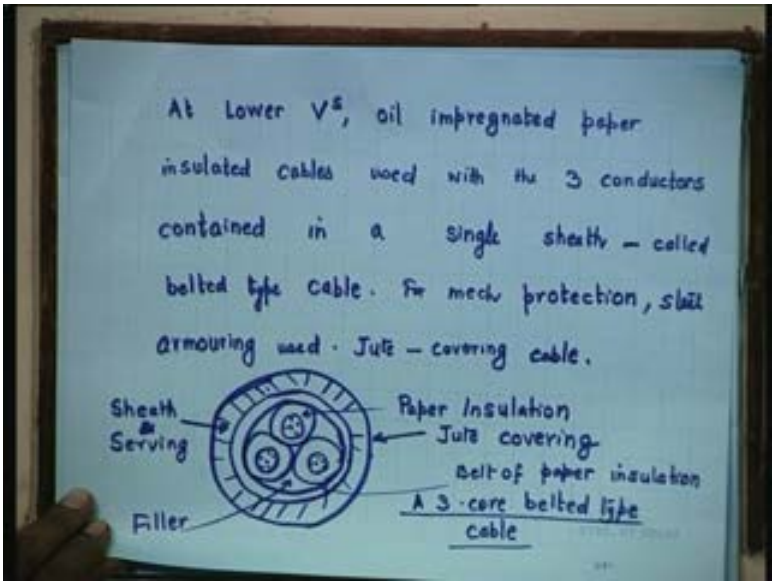

So, you can compensate that drawback of aluminum anyway, sheet material also aluminum is used at lower voltages oil impregnated paper insulated cables used with the

three contactors contained in a single sheath called belted type cable and here is a picture for a 3 core belted type cable. Now, there is a paper insulation is shown here, then there is a jute covering, this is a filler, this is a sheath and serving, this is a belt of paper insulation. You can see a better figure in a book, any book for mechanical protection, we have steal armoring is used.

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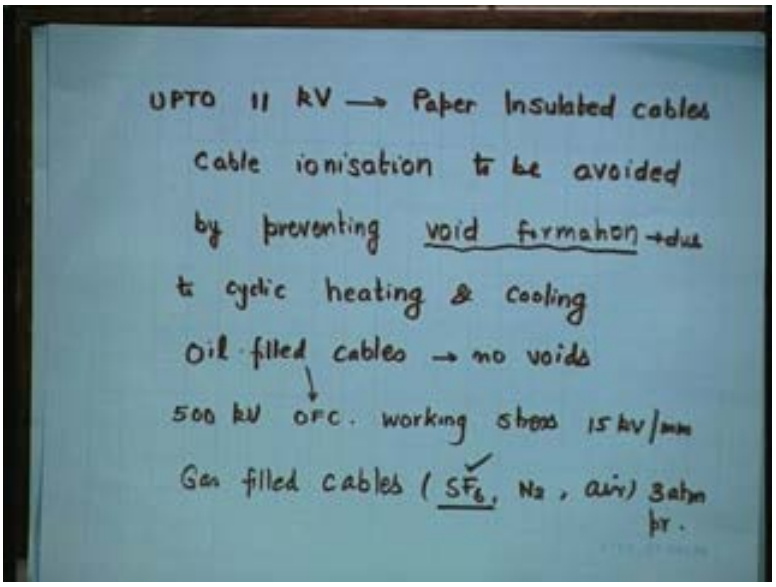

So, you need protection and jute is final covering up to 11 kV paper insulated cables are used, cable ionization to be avoided, this you must have read in your undergraduate, void formation. This question was very popular, how voids are not form or allowed to form or if they are formed how do you get rid out that? This question is to be very important. Why there are voids? Due to cyclic heating and cooling, this is a main reason and there is a cyclic heating and cooling that you know. So, that is why you prefer oil filled cables, because that there are no voids.

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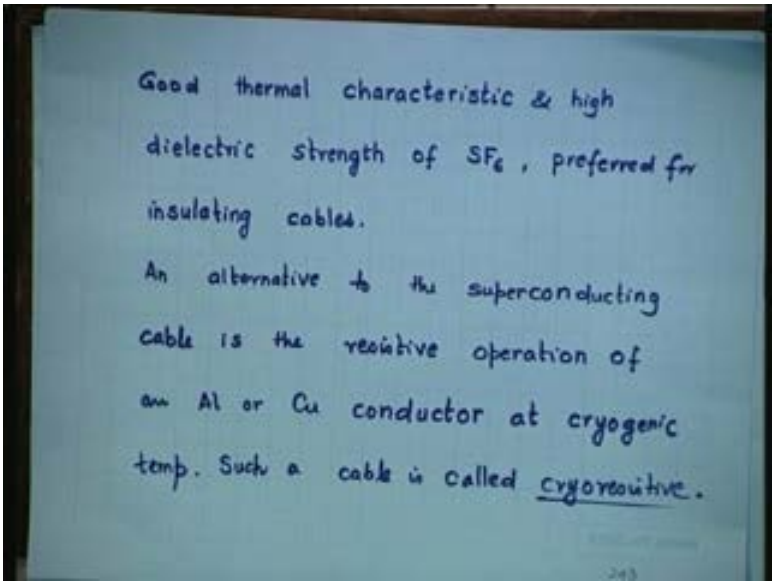

So, 500 kV oil filled cable are used, working stress is just 15 kV per millimeter and gas filled cables are again very popular, especially SF6 nitrogen air 3 atmospheric pressure. SF6 circuit breakers are also very important. Similarly, vacuum circuit breakers. We will talk about them also as we go ahead. Final slide for today is, good thermal characteristic and dielectric strength of SF6 preferred for insulating cables, an alternate to the superconducting cable is the resistive operation of an oil aluminium or copper conductor at cryogenic temperature. And there is a center of cryogenic in IIT Karagpur, IISC Bangalore also such a cable is called Cryoresistive cable. Well with this we finish a today lecture and we will continue on Friday. Any doubt so far?