**Power System Engineering**
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**Lecture – 06**
**Cables (Contd.)**

Next, is the paper insulated cables.

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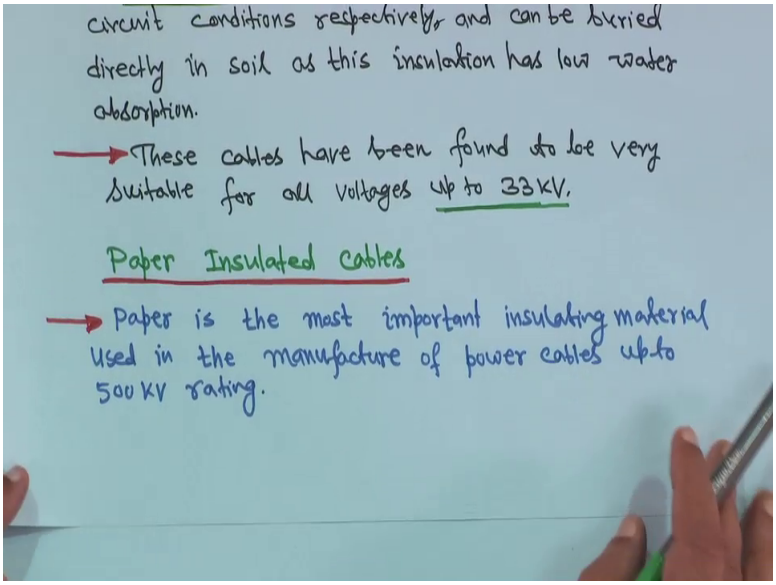


So, diagram and other thing cables I will come to that I will show you from the book only, but later. So, paper is most important insulating material used in the manufacture of power cables up to 500 KV rating. So, this paper insulated cables are very common.

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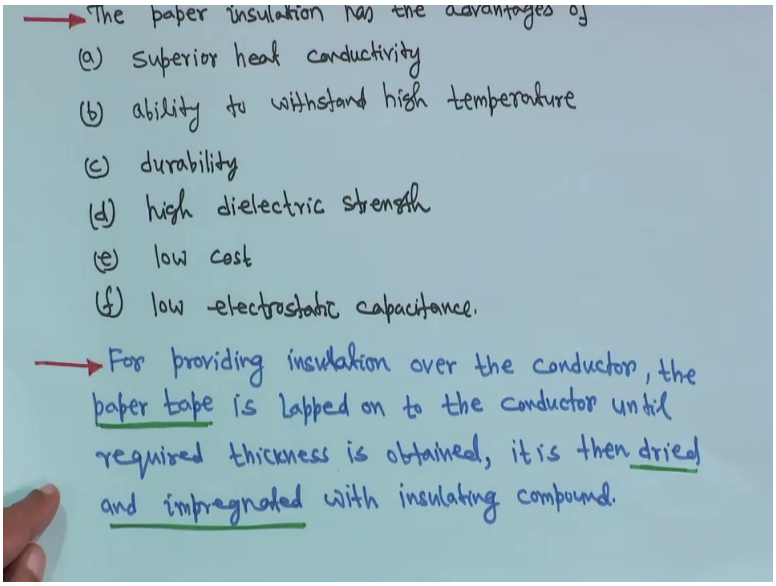


So, the paper insulation has the advantages of superior heat conductivity, then ability to withstand high temperature, then durability, then high dielectric strength, low cost and low electrostatic capacitance. So, these are the your advantages for paper insulation and for providing insulation over the conductor the paper tape is lapped on to the conductor until required thickness is obtained. So, it is then dried and impregnated with insulating compound.

So, when manufacturing process is not easy for cable that is why cable is very expensive. So, that is paper insulation. So, repeat again that superior heat conductivity, then ability to withstand high temperature, durability, high dielectric strength, low cost and low electrostatic capacitance.

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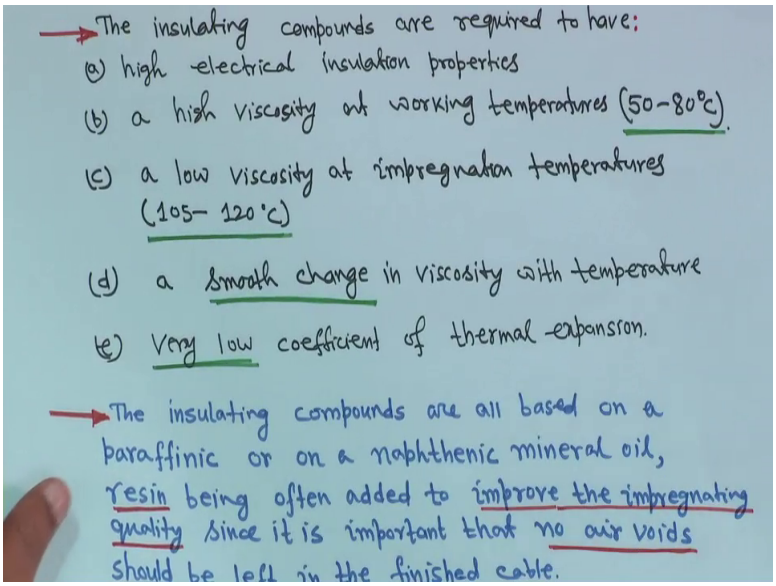


The insulating compounds are required to have; high elect insulation properties, then high viscosity at working temperatures see 50 to 80 degree Celsius normal, in low viscosity at impregnation temperatures that is 105 to 120 degree Celsius, a smooth change in viscosity with temperature and very low coefficient of thermal expansion. So, these are the insulating compounds are required to have particularly the very low coefficient of thermal expansion.

The insulating compounds are all based on a paraffinic or on a naphthenic mineral oil, resin being often added to improve the impregnating quality since it is important that no air voids should be left in the finished cable; that mean when cable is I mean manufactured there should not be any void, then it will create problem. So, there should not be anything.

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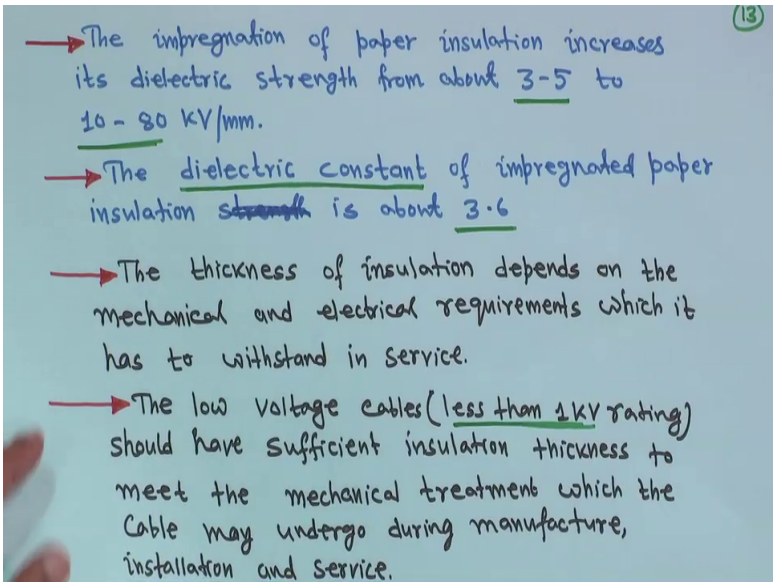


So, the impregnation of your paper insulation increases is dielectric stain from about 3 to 5 to 10 to 80 kilovolt per millimeter; that means, that is the advantage I think, that is, from 3 to 5 instead of the about 3 to 5 to 10 to 80 kilovolt per millimeter. The dielectric constant of imp impregnated paper insulation is about 3.6 roughly. Another thing is the thickness of insulation depends on the mechanical and electrical requirements which it has to withstand in service; it depends on the voltage level, thick depends on the mechanical and electrical requirements. So, to which has to withstand in service it depends on the voltage level how your do a single core or three-core.

So, the low voltage cables, that is, less than 1KV rating should have sufficient insulation thickness to meet the mechanical treatment which the cable may undergo during manufacturer installation and service. So, these are certain things. At high voltages, the insulation thickness is determined by electrical requirements particular the voltage level.

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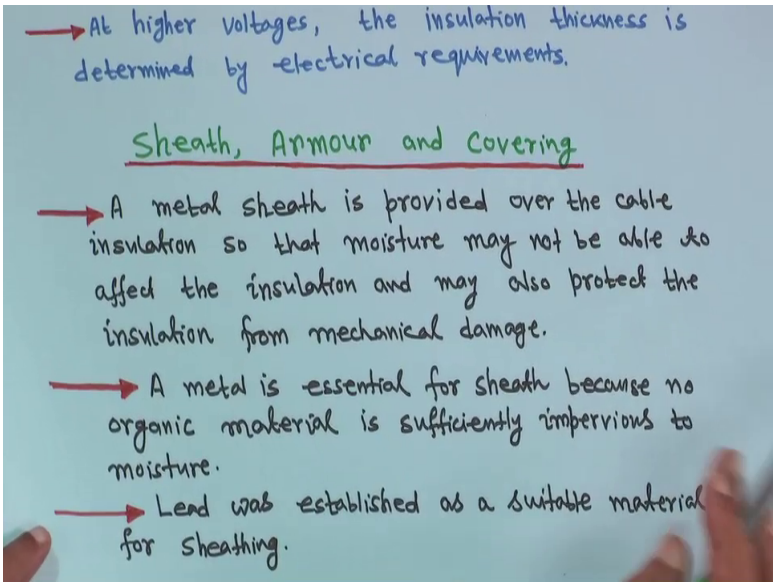


Next, one is diagram I will come later. Next, is sheath armour and covering. So, generally a metal sheath is provided over the cable insulation so that moisture may not be able to affect the insulation and may also protect the insulation for mechanical damage; that is why a metal sheath is provided over the cable insulation.

First conductor, insulation and then metal sheath is provided, what metal sheath is we will see later, also protect the insulation for mechanical damage. Metal is essential for sheath because no organic material is sufficiently impervious to moisture. Lead was established as a suitable material for sheathing, but later we will see that lead has very high specific gravity as compared to your aluminum.

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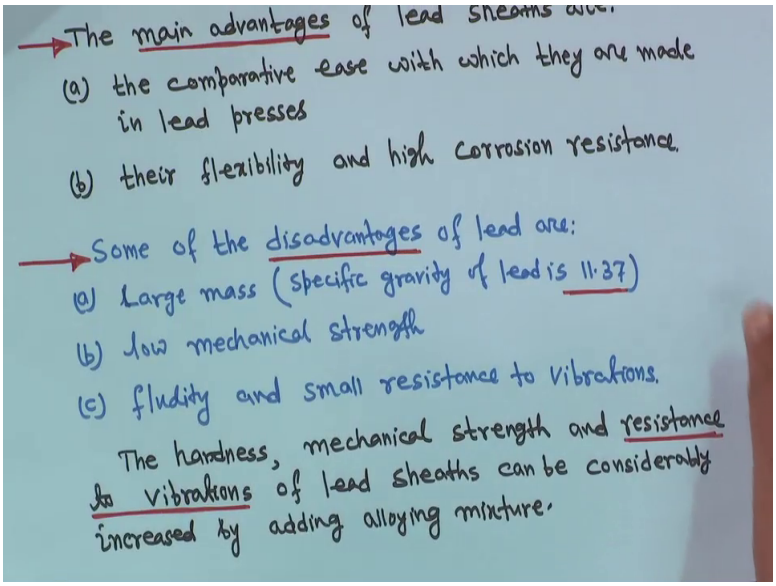


So, the main advantage of lead sheath, the comparative ease with which they are made in lead presses; second, their flexibility and high corrosion resistance. These are the advantages. The disadvantages; large mass because specific gravity of lead is 11.37, low mechanical strength and fluidity and small resistance to vibration; these are the disadvantages of lead.

The hardness, mechanical strength and resistance to vibration of lead sheath can be considerably increased by adding alloying mixture; wherein some kind of you have to mix copper, tin or bismuth, then this mechanical strength and resistance to vibration of lead it can be your constantly increased.

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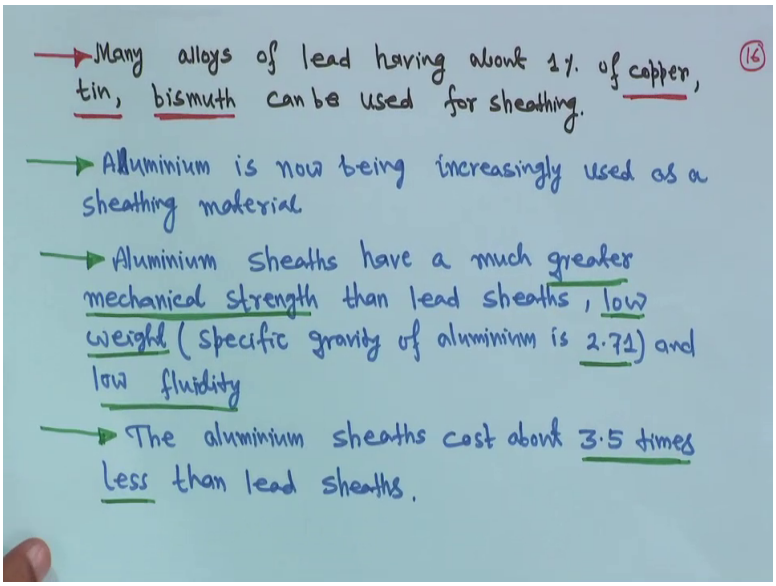


That means, many alloys of lead having about 1 percent of copper or tin or bismuth can be used for sheathing. But, aluminum is now being increasingly using as a sheathing material. Aluminum sheaths have a much greater mechanical strength than lead sheaths; low weight specific gravity is only 2.71, so, roughly your one fifth of the your lead and low fluidity. The aluminum sheaths cost about 3.5 times less than lead sheaths. Cost is also lower for aluminum. So, I mean for cable several components are there one after another. Diagram, I will show you how thing are.

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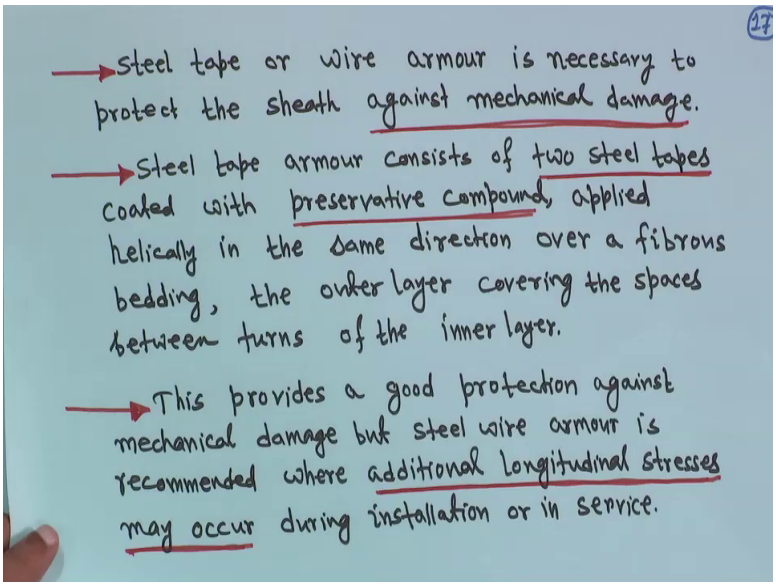

So, steel tape or wire armour is necessary to protect the sheath against mechanical damage look. We are protecting insulation for the sheath now steel tape or wire armour is necessary to protect the sheath against mechanical damage; that means, another round you have to use for steel tape or wire one after another. So steel tape it is like your onion know, one after another.

So, steel tape armour consists of 2 steel tape coated with your preservative compound, applied helically in the same direction over a fibrous bedding the outer layer covering the spaces between turns of the inner layer. This provides a good protection against mechanical damage, but steel wire armour is recommended where additional longitudinal stresses may occur during installation or in service.

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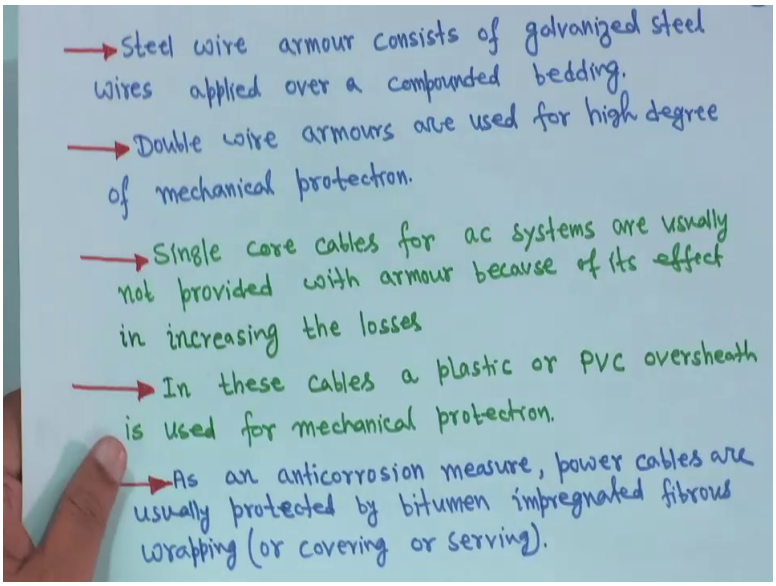


So, initially if I show you the figure then it is not possible to tell all this things. So, steel wire armour consists of a galvanized steel wires applied over a compounded bedding. Now, double wire armors are used for high degree of mechanical protection, but cost will increase. Single core cable for ac systems are usually not provided with armour because of its effect in increasing the losses; because, loss will be more, later will come to all this thing. In this cables a plastic or PVC over sheath is used for mechanical protection. So, as an anticorrosion measure, power cables are usually protected by bitumen impregnated fibrous wrapping or covering or serving. So, these are these are certain things.

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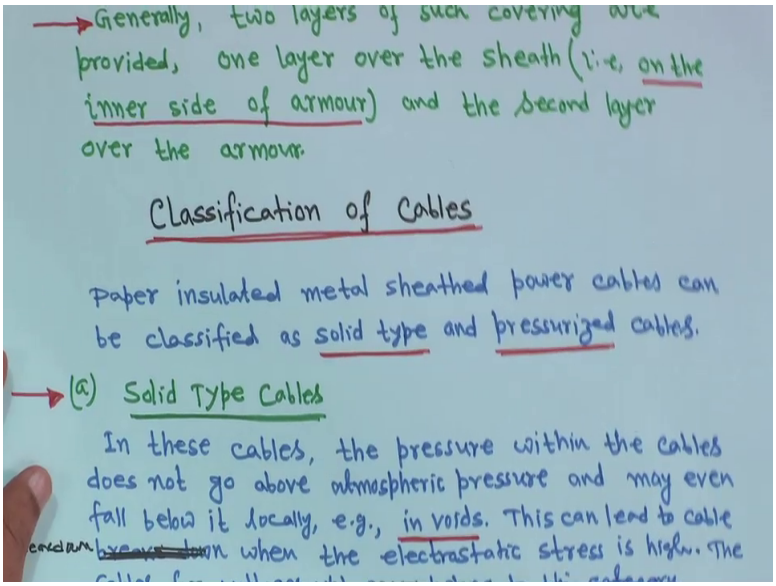


But, next is the generally, 2 layers of such coverings are provided, one layer over the sheath and there on the inner side of armour and the second layer over the armour. Now, before classification to your these thing cable, first I will show you one diagram and then this thing.

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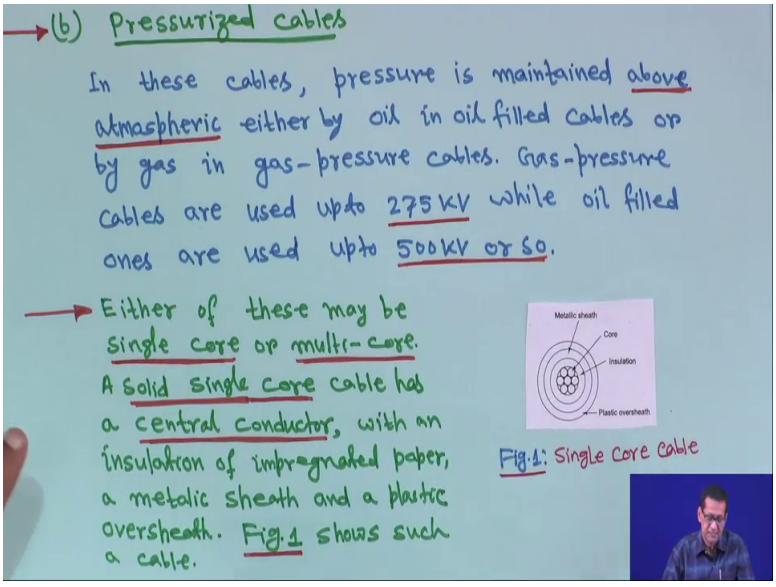


Generally do not see anything. So, these are here is a standard conductors, these are I hope it will be readable for you these are called the core a conductor and after this insulation is there,

then next is metallic sheath is there because you have to cover the insulation by metallic sheath and then after this the plastic over sheath is also there.

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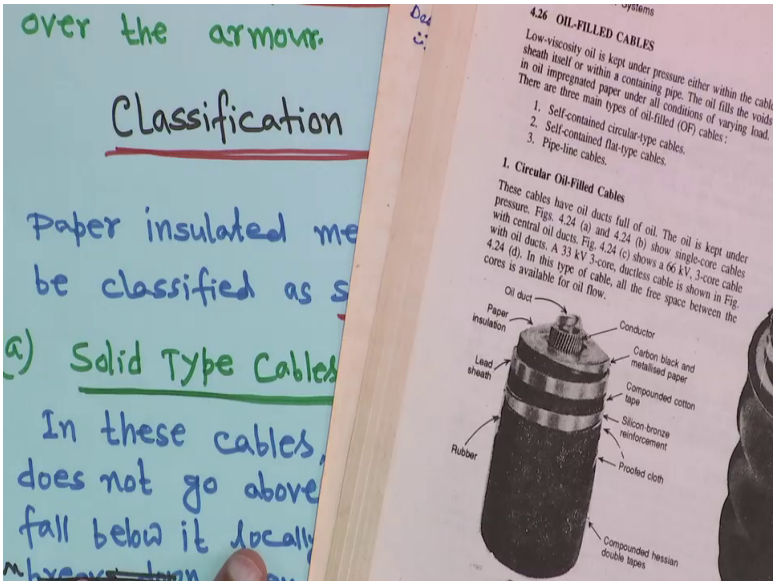


So, if you look at this diagram particularly, of course, this is your oil duct cable that does not matter forget about that look after this the paper insulation is there, over insulation lead sheath is there and after that a rubber is also there here and this is conductor, a carbon black and metalized paper is also here then compounded cotton tape is there in silicon bronze reinforcement and finally, it is proofed cloth and compounded hessian double tapes looked. So, many materials are there for that cable this is later we will come to that your oil duct or your oil field or gas filled cables, but this is actually. So, many coatings are there different for your what you call that different type of cables. So, sometimes your (Refer Time: 10:17) sometimes all the things all the three-cores that they will be binded together also by different material that will come later.

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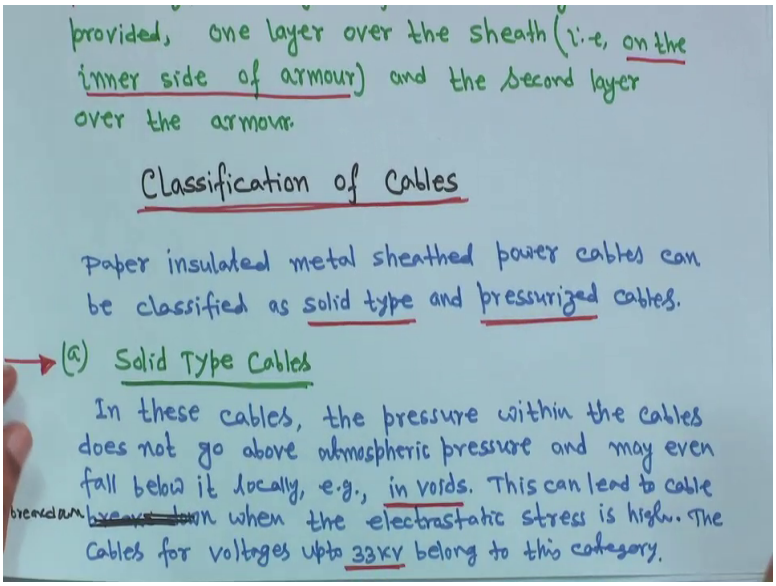


So, classification of cables; so, paper insulated metal sheathed power cables can be classified as solid and pressurized cable. First is, solid type cables in these cables the pressure within the cables does not go above atmospheric pressure and may even fall below it locally, example; in voids. If void formation is there then it will be less than that atmospheric pressure this can lead to cable break down here I have written here. It will lead to cable break down when the electrostatic stress is high. The cables for voltages up to 33 KV belong to this category. So, solid type cable is used for up to 33 KV.

Next, one is that pressurized cables. In these cable, pressure is maintained above the atmospheric either by oil or oil in oil filled cables or by gas in gas pressure cables. I will just show you one diagram that oil filled one. The gas-pressure cables are used up to 275 KV while oil filled ones are used up to 500 KV or so.

So, now, this one either of these maybe single core or multi core, either single core cable or multi core cable. So, a solid single core cable has a center conductor with an insulation of impregnated paper, a metallic sheath and a plastic over sheath, that is, figure one shows. This is your core that conductor is there then you are you have the insulation, over insulation metallic sheath is there and then your plastic over sheath is also there. This is single core cable. So, this diagram I have taken from a book.

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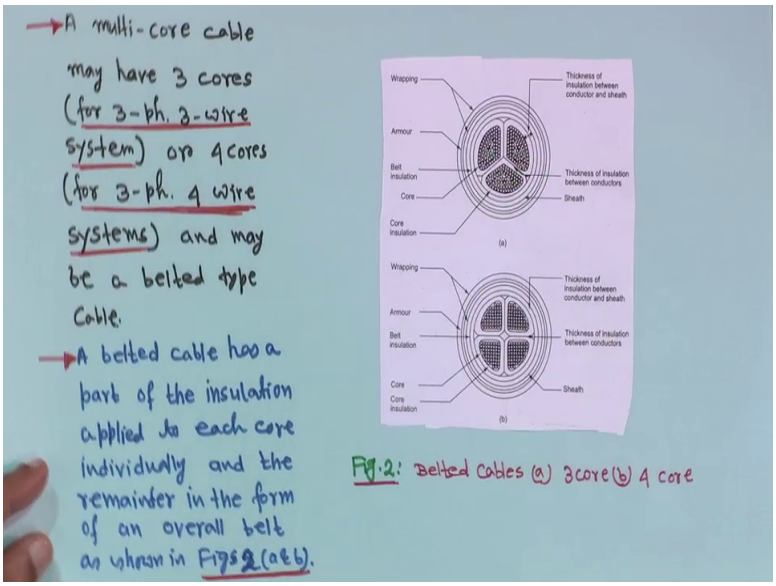


Next is that in this is belted cables three-core and 4 core I will come to that. So, the multi core cable may have three-cores that is for 3-phase 3 wire system or 4 core that is 3-phase 4 wire systems and may be a belted type cable. So, a belted cable has a part of the insulation applied to each core individually and the remainder in the form of an overall belt as shown in figure-2, a and b.

Here, this is so, many things are there. This is actually if you look into this one you are what you call this is the core that conductor inside that insulation is there and then belt insulation is also there around all this thing. That individual insulation between the core then around that all this cores you have the insulation. Then you have the thickness of insulation which will conductor and sheath. This is the thickness of insulation between conductor and sheath. Next is thickness of insulation between conductors. So, this is the conductor this is the conductors in between the thickness of insulation between conductor the insulation is there.

Then if you look into this one, core insulation here you look around the core insulation is there then belt insulation I told you around this that armour is there armour ring is there and they wrapping here is one another is one. So, wrapping is there this is actually 3 wire your for 3 phase 3 wire system. This is three-core cables. Here it is conductors actually the way it is shown next is 3 wire three-core this is 4 core. So, there are 4 cores and philosophy remain same all the things whatever I said same thing is here. So, just see so many things are wrapped on the conductor insulation. Then you are what you call armour, then core insulation

is required then you have to call insulation between conductor and sheath is required. So, everything is required to manufacture the cable. So, it is your what you call this is 4 core cables. So, these are belted cable because all are together in the same thing.

So, this is actually belted cable has a part of the insulation applied to each core individually and the remainder in the form of an overall belt as shown in your figure 2 a and b together. This part initially little bit of theory and after that all these things will come mathematics part.

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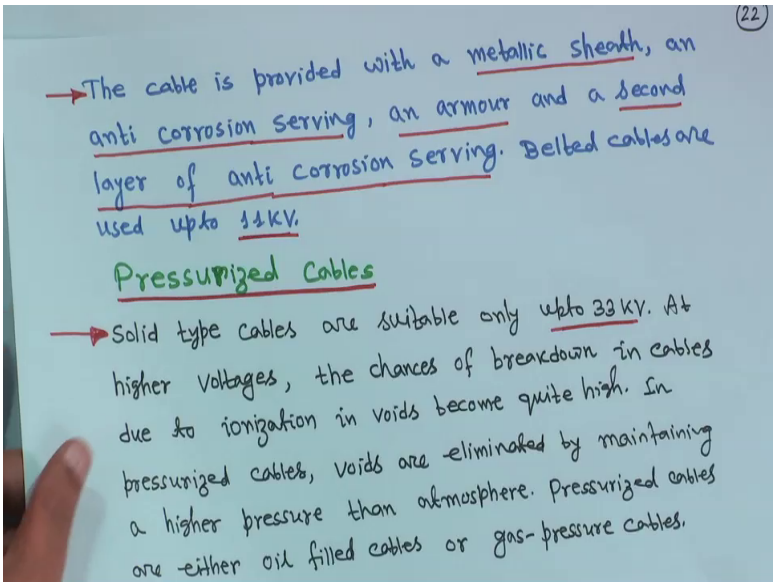


So, the cable is provided with metallic sheath, an anti corrosion serving, an armour and a second layer of anti corrosion serving. Belted cables are used up to 11KV.

Next, is pressurized cables; solid type cables are suitable only up to 33KV. At higher voltages the chances of breakdown in cables due to ionization in voids become quite high. There is a possibility of breakdown due to that ionization in void. In pressurized cables, voids are eliminated by maintaining a higher pressure than atmosphere. So, pressurize cables are either oil filled cables or gas pressure cables, particularly for high voltages, but advantages and disadvantages are also there.

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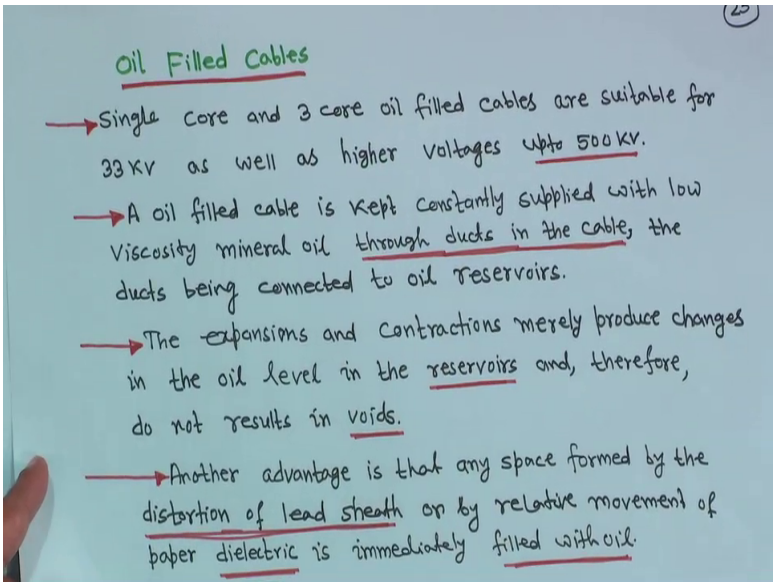


For example; that oil filled cables. Single core and three-core this is actually oil filled cable, this diagram it is oil filled cable, this is oil duct and if you look conductor in it. So, it is actually oil duct. So, single core and three-core oil filled cables are suitable for 33KV as well as higher voltages up to 500KV. A oil filled cable is kept constantly supplied with low viscosity mineral oil through ducts in the cable. This is the duct and through this duct this oil way your oil flow have to be maintained; that means, you have to have a reservoir for oils. So, constantly supplied with low viscosity mineral oil through duct in the cable, the ducts being connected to oil reservoir, there must be oil reservoir also.

The expansions and contraction merely produce changes in the oil level. So, there will be no change in the oil level in the reservoir for extension your expansion or contraction and therefore, do not results in voids. So, there will be no void formation. Another advantage is that any space formed by the distortion of lead sheath or by relative movement of the paper dielectric is immediately filled with oil.

So, if it is for example, lead sheath or your this thing your paper dilating this is actually lead sheath is here also there. Then compounded cotton tape is there, then carbon black and metalized your paper is also there. It is visible, everything it is there and paper insulation is there. So, another advantage is that any space formed by the distortion of lead sheath or by relative movement of paper dielectric is immediately filled with oil. So, there is no chance of void formation.

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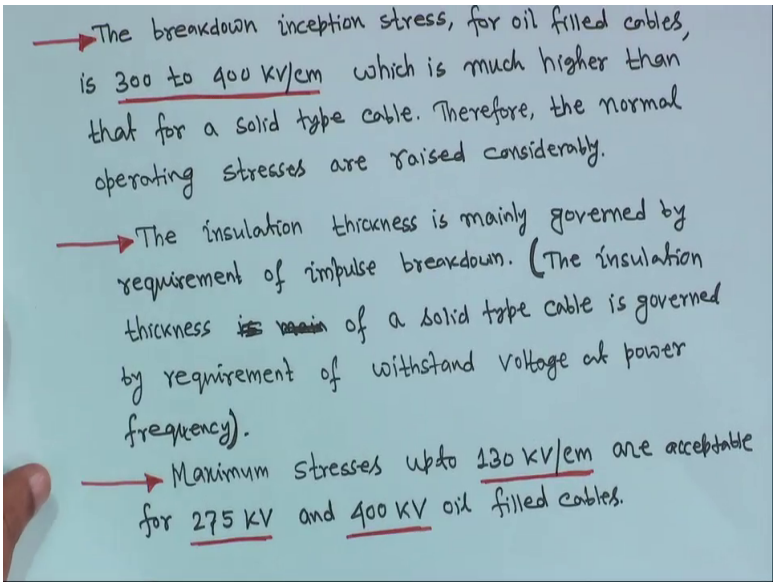


Now, the breakdown inception stress for oil filled cables is 300 to 400 KV per centimeter, the quiet high, which is much higher than that of a solid type cable. So, it is advantageous. Therefore, the normal operating stresses are raised considerably. The insulation thickness is mainly governed by the requirement of impulse breakdown. The insulation thickness of a solid type cable is governed by requirement of withstand voltage at power frequency; but, here the insulation thickness is mainly governed by requirement of impulse breakdown. So, maximum stresses up to 130 KV per centimeter are acceptable for 275 KV and 400 KV oil filled cables.

So, maximum stresses up to 130 KV per centimeter are acceptable for 275 and 400 KV. So, here it is 300 to 400. So, quiet acceptable that your maximum stresses particularly oil filled cables.

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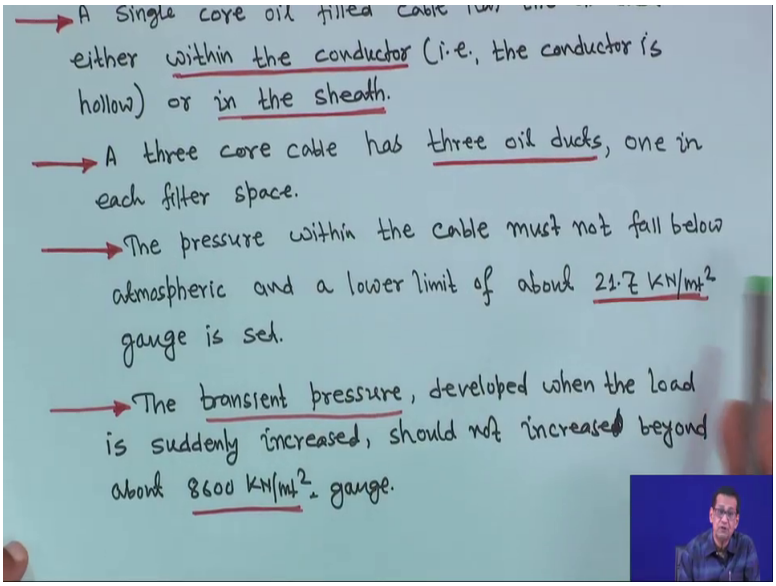


So, next one is a single core oil filled cable has the oil duct either within the conductor that is the conductor is hollow or in the sheath. I will show you the diagram. A three-core cable has 3 oil ducts. If there is a three-core, 3 oil ducts will be there, one in each filter space. The pressure within the cable must not fall below atmospheric and a lower limit of about 21.7 kilo Newton per meter square gauge is set. So, must not fall the below atmospheric pressure in the lower limit about this much is set this much gauge.

The transient pressure developed when the load is suddenly increased. So, natural transient pressure will be there should not increased beyond about 8600 kilo Newton per meter square gauge. So, these are your what you call that you have to maintain this part oil filled cable.

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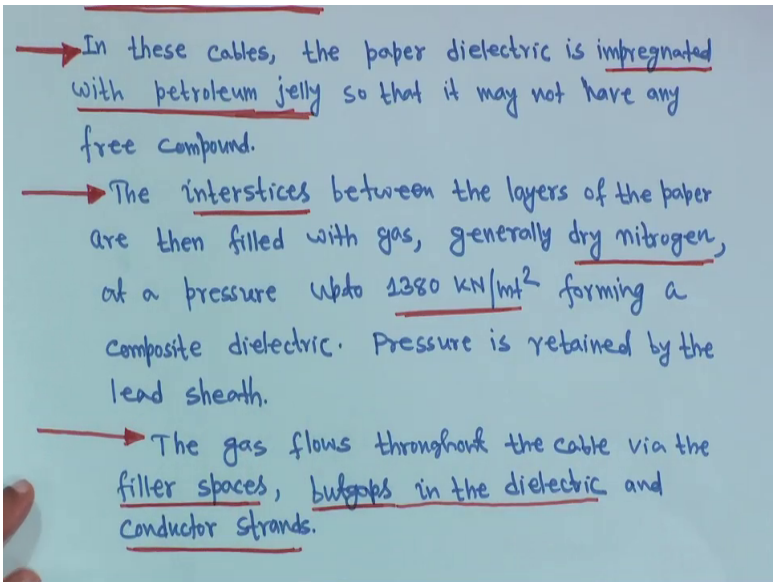


Next, one is that your what you call that gas filled cables. So, in this cable the paper dielectric is impregnated with petroleum jelly so that it may not have any free compound. The interstices between the layers at the paper are then filled with gas, generally dry nitrogen at a pressure up to 1380 kilo Newton per meter square forming a composite dielectric. Pressure is retained by the lead sheath. So, this is for gas filled cables.

Some advantage is there for gas filled cable. The gas flows throughout the cable via the filler spaces, where the filler spaces and I do not have the diagram here for that gas fill one, but the gas flows throughout the cable via the filler spaces, but gaps in the dielectric and conductors stand. But, one advantage is there here no reservoir is required.

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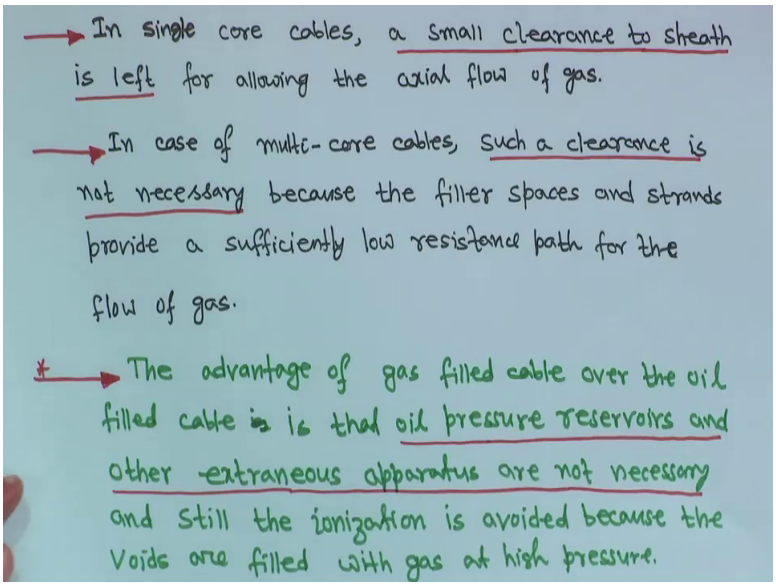


And, if void formation is just hold on, there in single core cable is a small clearance to sheath is left for allowing the axial flow of gas. So, there should be a small clearance to sheath is left for allowing the axial flow of the gas. In case of multi core cables, such clearance is not necessary because the filler spaces and strand provide a sufficiently low resistance path for the flow of gas.

The advantage of gas filled cable over the oil filled cable is that oil pressure reservoirs and other extraneous operators are not necessary and still the ionization is avoided because the voids are filled with gas at high pressure. So, it means if there is any void formation is there that void will be filled by the gas at the high pressure.

So, this is the advantage and no oil reservoir is required for your what you call that gas pressure cables.

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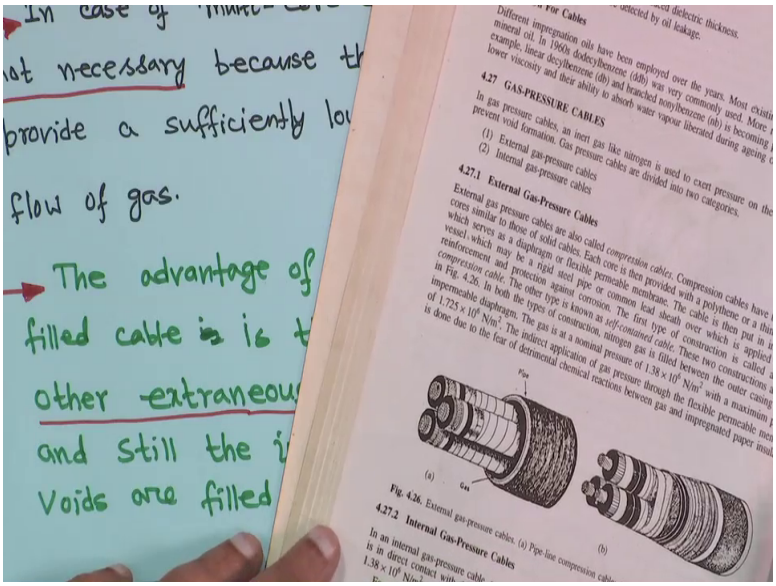


I have the diagram is here for this thing external gas pressure cable see here it is there. So, these are the your here from the diagram you cannot make out, but some your clearance will be there for that your gas and in any void formation any wire is there these gas will take the place of the void at high pressure. So, there is no chance of breakdown this is gas pressure cables that is external gas pressure cables. So, different types of I mean all the things not may not be available in front of you, but certain things we have to rely on the books because unless and until you go to some power plant or substation if those cables are available you can have a look on this kind of cables.

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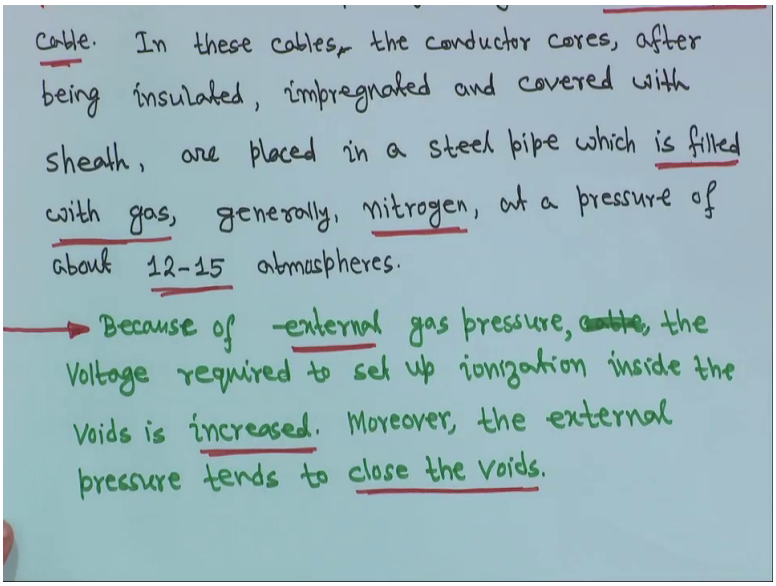


And, next is another cable used for high voltage is external pressure cable. In this cables, the conductor cores, after being insulated, impregnated and covered with sheath are placed in a steel pipe which is filled with gas, generally, nitrogen at a pressure of about 12 to 15 atmospheric pressure. So, that means, external gas pressure cables this is that diagram for external gas pressure cable. So, this is also used, but pressure, 12 to 15 atmospheric you have to maintain.

Because, of external gas pressure the voltage required to set up ionization inside the voids is increased. Moreover, the external pressure tends to close the voids. So, there will be no question of your breakdown if void formations are there, but design manufacture of such cables is very complicated one.

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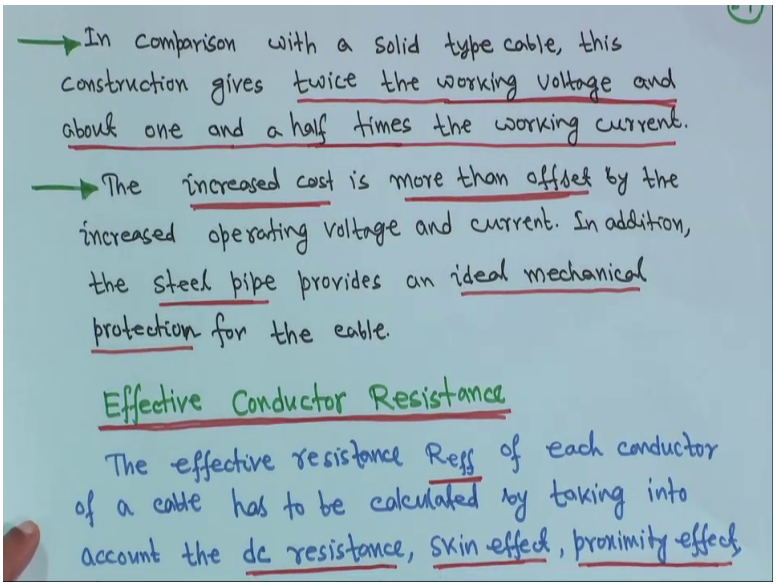


But, these are your some ideas about the theories. In comparison with a solid type cable, this construction gives twice the working voltage and about 1 and a half times the working current. If you compare with a solid type of cable, but the increase cost is more than offset by the increase operating voltage and current. Then, but cost of this cables are very high that therefore, whatever technical advantage your getting that will be completely offset. In addition, the steel pipe provides an ideal mechanical protection for the cable.

So, this is your steel pipe, that means, additional cost you have to incur for. So, this is actually what you call whatever little bit of cable theories are there something. Some diagram will see later, but somehow I have to condense everything because this I found cable is a very long chapter. So, we have many other topics has to be covered. So, that is why, but little bit ideas you have and some altogether 5 reference books will be given to you and those books you please follow for at most of that thing you will get it.

I will give you 5 reference books for reading text book.

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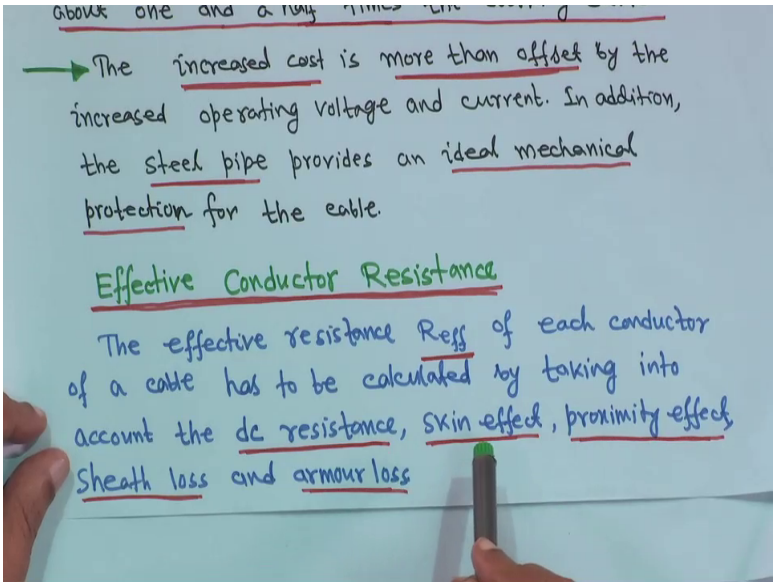


Next, is the effective conductor resistance of the cable. Here it is the effective resistance say it is might R effective. This is R effective of each conductor of a cable, has to be calculated by taking into account the d c resistance. This is actually d c resistance, skin effect, then proximity effect, sheath loss and armour loss. This skin effect and proximity effect you have studied in your inductance calculation chapters. So, all these things you have to consider for calculating the effective conductor resistance of cables.

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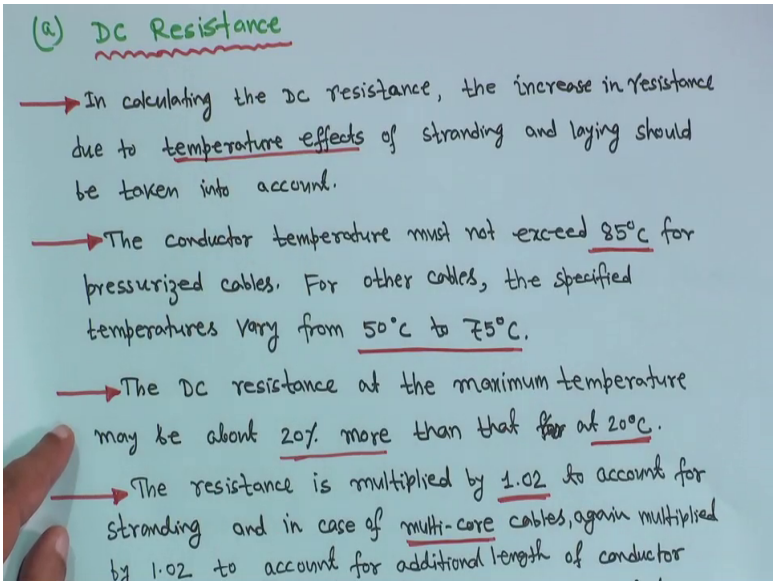

First one is that d c resistance. To come to dc resistance; so, in calculating the dc resistance the increase in resistance due to temperature effect of stranding and laying should be taken into account. You have to consider this first one. The conductor temperature must not exceed 85 degree Celsius for pressurized cables. For other cables the specified temperatures vary from 50 to 75 degree Celsius. The dc resistance at the maximum temperature may be about 20 percent more than that of at 20 degree Celsius.

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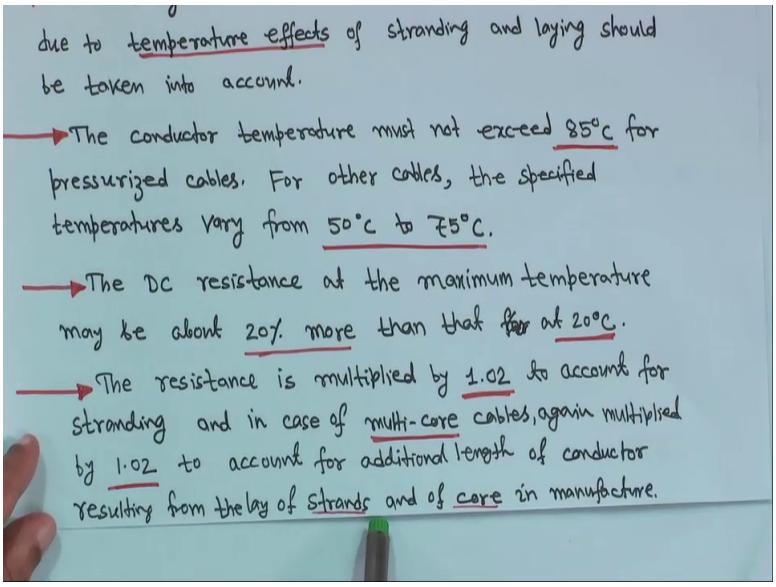


The resistance is multiplied by 1.02, that means 2 percent increase, to account for stranding and in case of multi core cable again multiplied by 1.02, that mean 2 percent increase, to account for additional length of conductor resulting from the lay of strands and of core in manufacture. So, these 2 percent your things you have to multiply, so that more or less you will get that your what you called that more or less accurate values.

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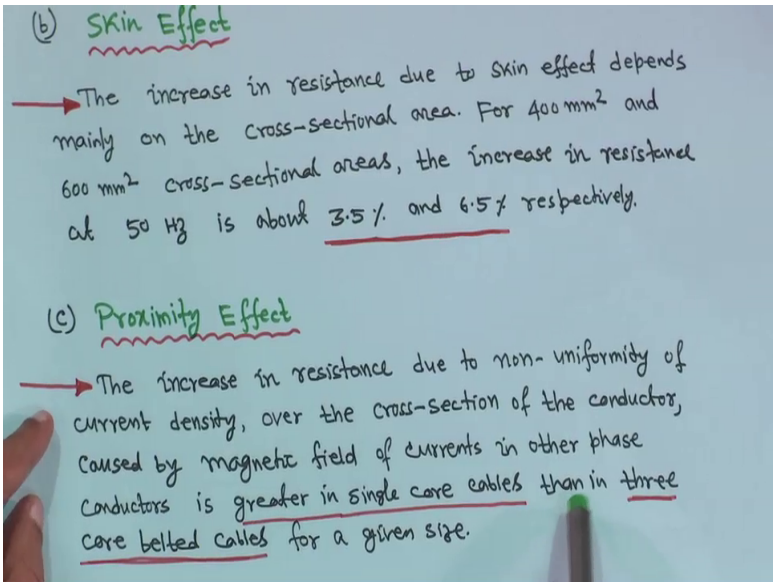


So, next is skin effect; skin effect you have studied. So, it will not be covered here, just it effect on cable it will be given. The increase in resistance due to skin effect depends mainly on the cross sectional area, that you know. For example, for 400 millimeter square and 600 millimeter square cross sectional areas the increase in resistance at 50 hertz is about 3.5 percent and 6.5 percent respectively.

So, this is for skin effect; roughly, using this cross sectional conductor you can try to compute it also, but in your inductance chapter you have studied skin effect. Proximity effect also. So, the increase in resistance due to non uniformity of current density over the cross section of this of the conductor caused by magnetic field of currents in other phase conductors is greater in single core cables than in three-core belted cables for a given size. So, proximity effect also you have to consider.

Proximity effect also you have studied it in your inductance chapter, in your power system analysis course in your college. So, those things will be not covered here only for cable for calculation purpose it has been shown.

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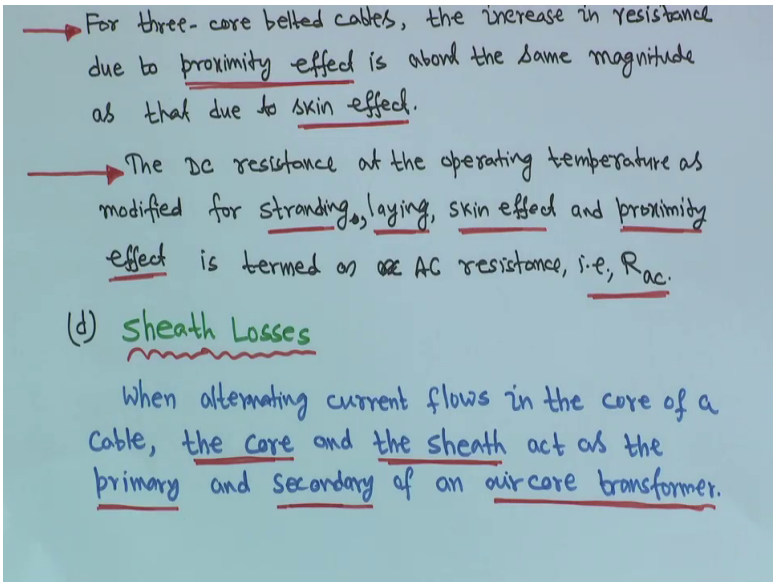


Now for three-core belted cables, the increase resistance due to proximity effect is about the same magnitude as that due to skin effect. I mean, both increase will be affected same for proximity and your skin effect. The DC resistance at the operating temperature as modified for stranding, laying, then skin effect and proximity effect is termed as AC resistance, that is, R ac. We refer as a R ac.

Thank you, again welcome.