Power System Dynamics, Control and Monitoring
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Lecture – 02
Power System stability (Contd.)

We are back again, right. So, next is so, this phasor diagram is a very simple one, very simple one for the system right, for the system.

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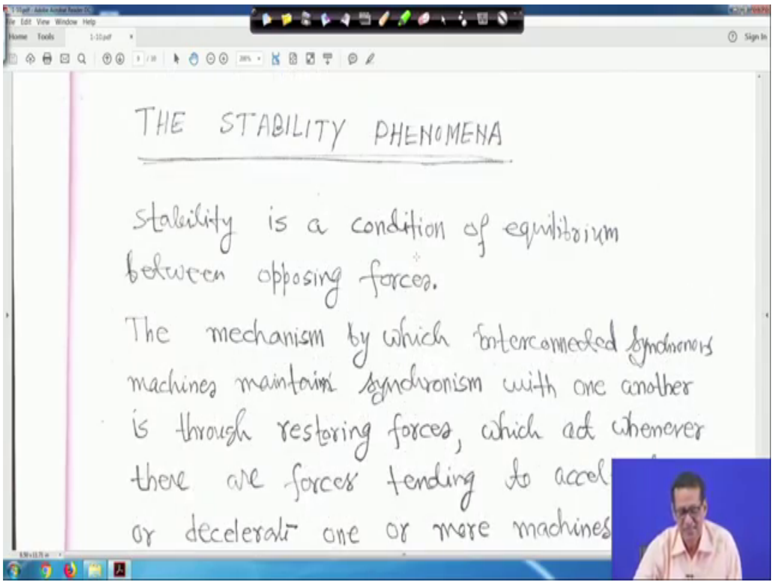

So, next is your the stability phenomena. So, stability is a condition of equilibrium between your opposing forces, right. So, the mechanism by which your interconnected synchronous machines maintained your synchronism, just hold on.

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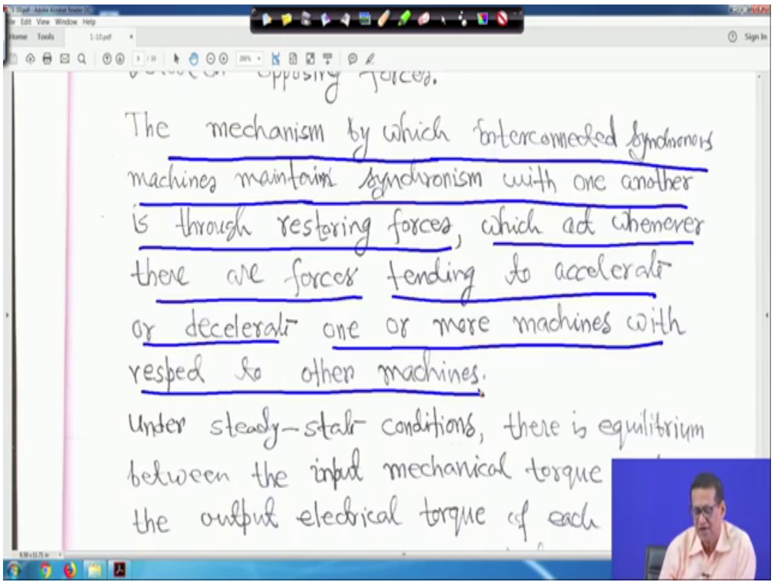

So, the mechanism by which interconnected synchronous machines maintain synchronism with one another is through restoring forces right which act whenever there are forces tending to accelerate or decelerate one or more machines with respect to other machines because all machines are swing swing any machine, right.

Therefore the mechanism by which interconnected synchronous machines maintains synchronism with one another is through restoring forces which act whenever there are your forces tending to accelerate or decelerate one or more machines with respect to other machines, right. So, let me clear it.

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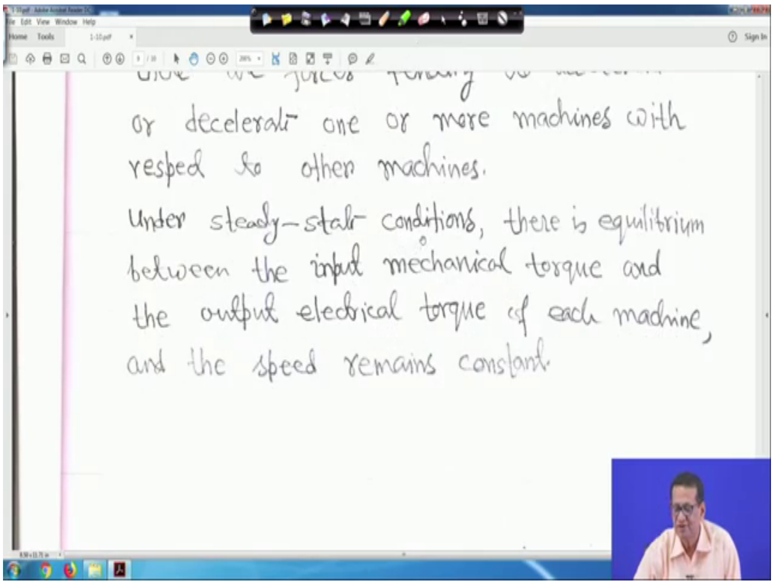

Under steady state condition, there is equilibrium between the input mechanical torque and the output electrical torque of each machines and the speed remains constant, right.

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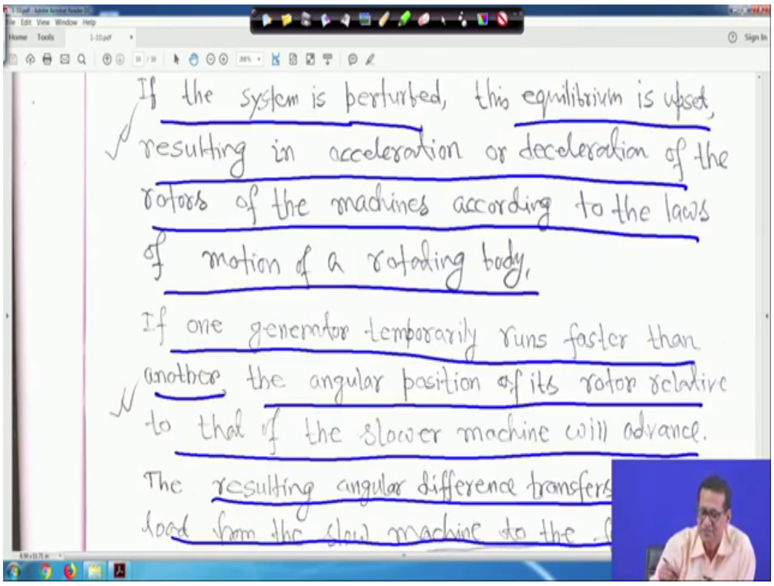

Now, if the now if the system is perturb, right; now if the system is perturb that means, some disturbance is there, this equilibrium is upset right. This is very common phenomena resulting in acceleration or deceleration of the rotors of the machines according to the laws of motion of your rotating body, right.

Now, if one generator temporarily runs faster than another right, the angular position of it is rotor relative to that of the slower machine will advance, right; that means, due to some disturbances something if it happens, that if one generator temporarily runs faster than another right, the angular position of it is rotor right is your up to that of the slower machine will be advance, right. So, the resulting angular difference transfers part of the load from the slower machine to the faster fast machine, right. Just hold on, let me clear it.

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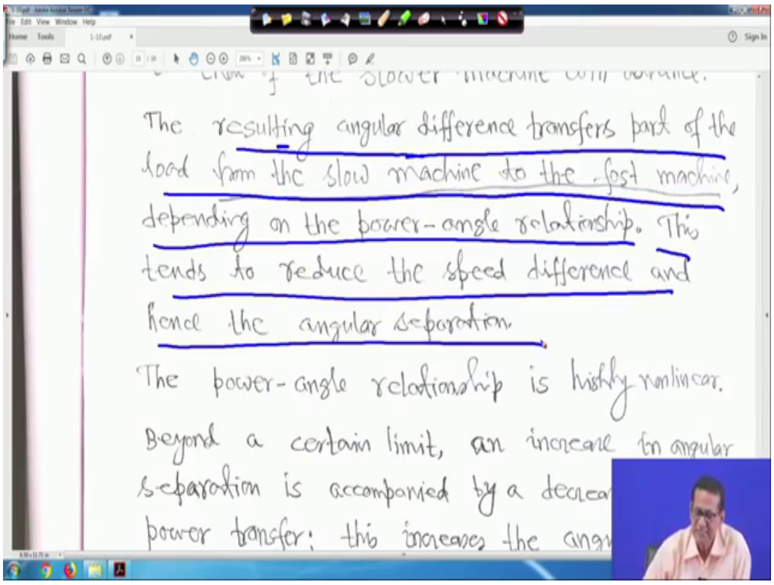

So, what happen actually, that your the resulting angular your the resulting angular difference right, your transfer part of the load from the slow machine to the fast machine this you should keep it in your mind for general knowledge right. And depending on the power angle relationship, this tends to reduce the speed difference and hence the angular separation right because they have to balance each other as well as they are not loosing synchronism right. It has to be balance, right.

So, let me clear it.

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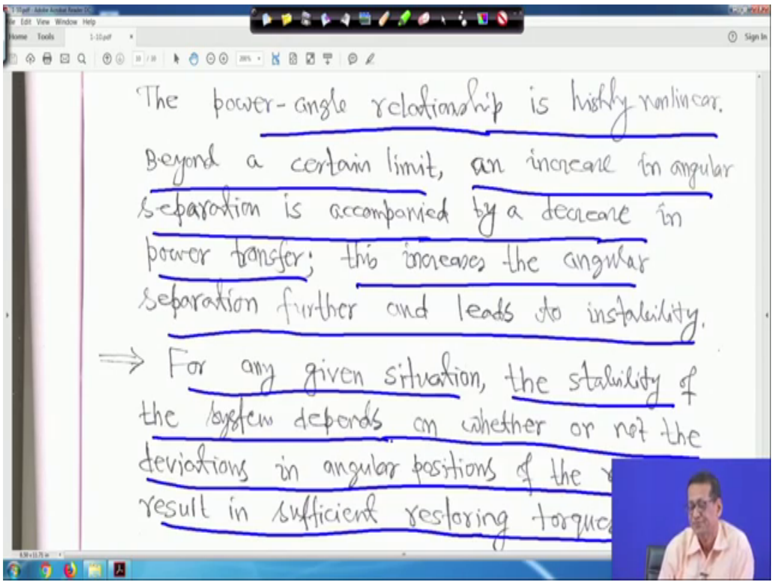

So, the power angle relationship highly is highly your, what you call is non-linear. This power just hold on, this is the power angle relationship is highly non-linear. So, beyond a certain limit an increase in angular separation is accompanied by a decrease in the power transfer. This actually increases the angular separation further and leads to instability, right.

So, power angle relationship is highly non-linear you know that is a sin function right or for a last system many other non-linearities are involve, so, beyond a certain limit and increase in angular separation is accompanied by decrease in power transfer. This increases the angular separation further and leads to instability, right. So, for any given situation, the stability of the system depends on whether or not the deviations in angular position of the rotors result in sufficient restoring torques, right. Otherwise, otherwise system will lose synchronism, right.

So, you have to see that stability depends on depends or not whether or your; what you call the stability of the system depends on whether or not the deviations in angular positions of the rotor result in sufficient restoring torque, right. So, just hold on, I am coming back to the next one, you just hold on.

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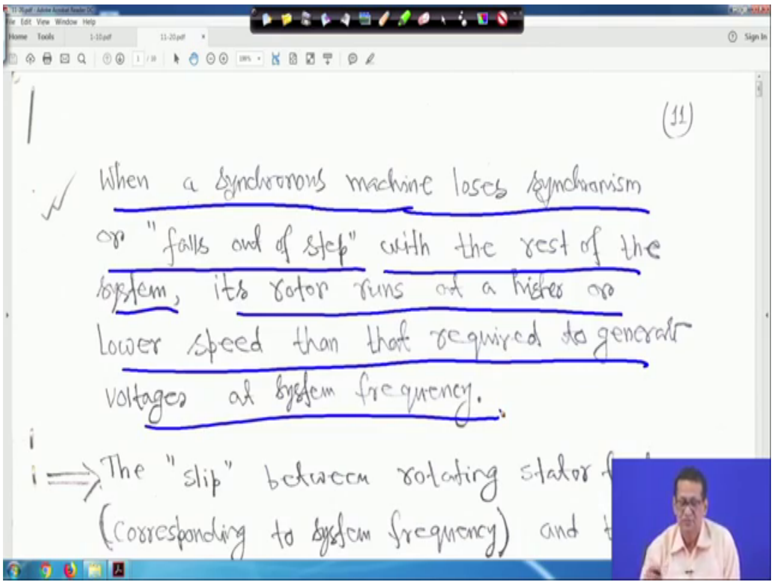

So, when a synchronous machine loses your synchronism or falls out of step with the rest of the system, the rotor runs at a higher or lower speed than the your what than that required to generate voltage at system frequency, right.

So, I mean when a system synchronous machine a loses synchronism or falls out of step with the rest of the system, it is rotor runs at either higher or lower speed than the required to generate voltage at system frequency, right.

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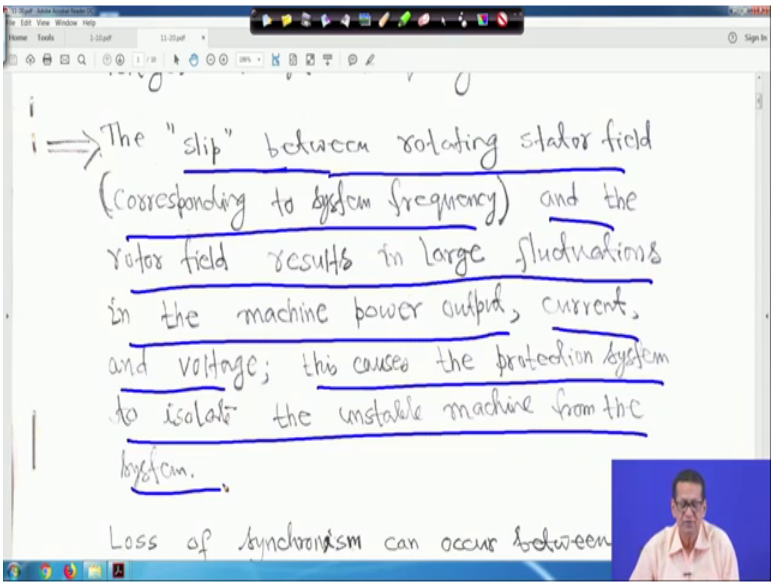

So, just hold on; the therefore, the slip between rotating your just hold on, just hold on. The slip between your rotating stator field that is corresponding to system frequency and the rotor field results in large fluctuation in the machine power output right, then current right and voltage this causes the protection system to isolate the unstable machine from the system.

That means, this slip between the your what you call rotating stator field and the rotor field result in large fluctuation in the machine power output current and voltage. This causes the protection system to isolate the unstable machine from the rest of the system right; otherwise whole system will become unstable.

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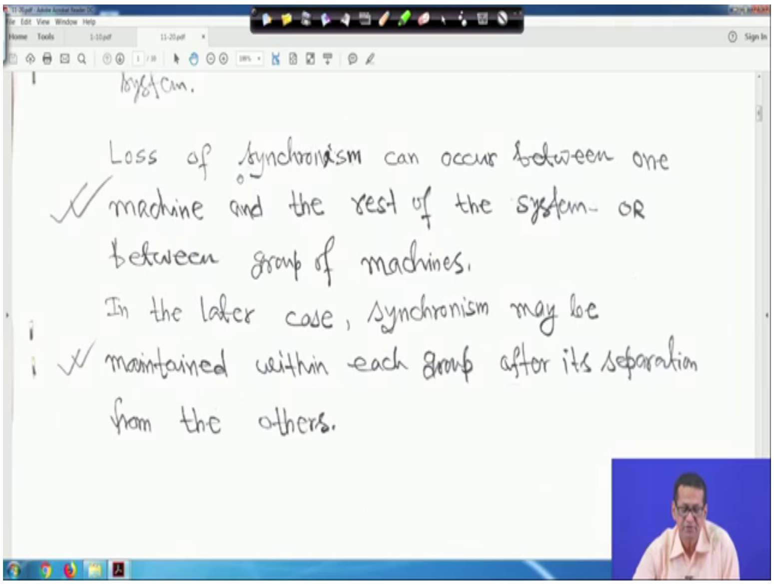

So, that lose of synchronism can occur between one machine and the rest of the system or between group of machines, anything can happen right. So, in the later case, synchronism may be maintain within each group after it is separation from the others, right. Suppose, one suppose your one group of machine is somewhere; another group of machine is somewhere right, if synchronism is lost between these two group, then it can be isolated but machines feature in one group they may not be lose synchronism. That is the meaning.

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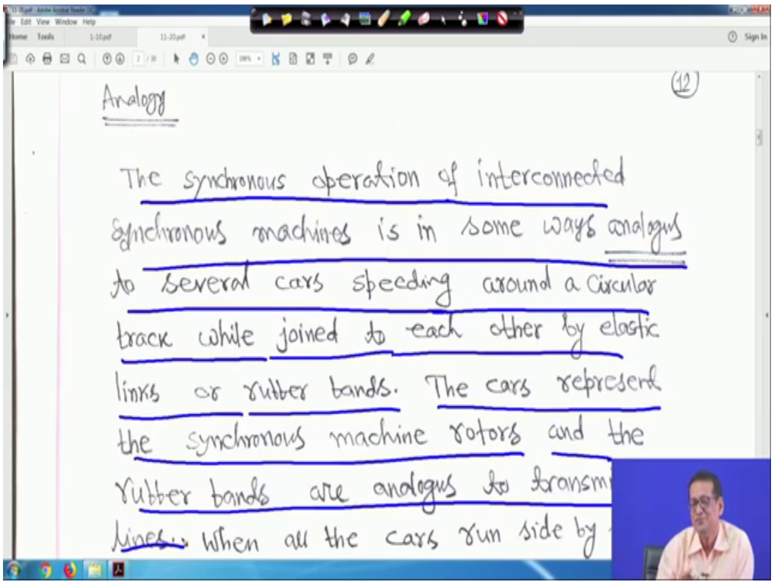

Now, this analogy right; so, the analogy is how that regarding the falls out of step; therefore, the synchronous machine operation in operation of your what you call interconnected synchronous machine is in some ways analogues to it is something like this that the synchronous operation in interconnected synchronous machine is in some ways analogues to several cars speeding around a circular track, while joined to each other by elastic links or rubber bands, right.

Suppose in a circular path, all the suppose so many cars are moving and they are tied with your, what you call elastic band or rubbers, right. So, that actually what happened; the cars represent the synchronous machine rotor say and the rubber bands are analogues to your transmission line, right. So, cars actually represents the synchronous rotor and you assume rubber band basically say analogues to transmission line.

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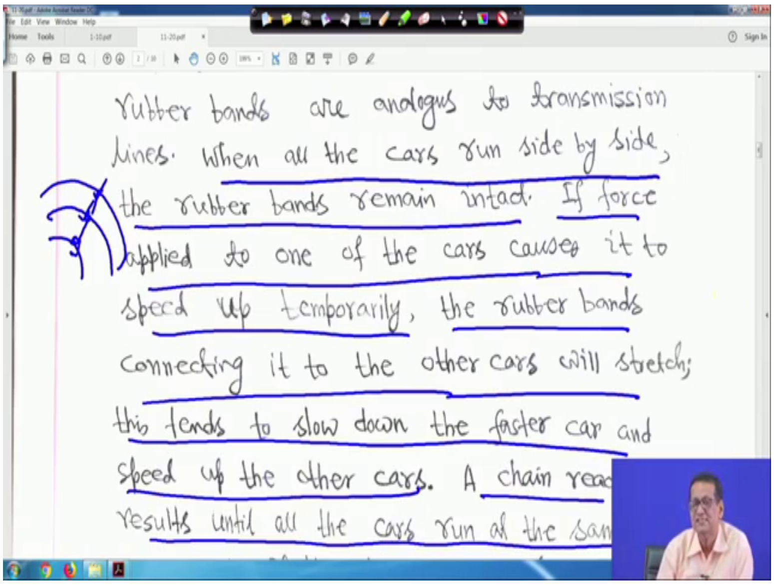

Then, so, when all the cars runs side by side right, when all the cars run side by side, the rubber bands remain intact right because all are actually it is moving like this, moving like this, this all are suppose this is car this is another car, this is another car, all are moving and this is your tied by rubber bands. I mean, so many are there say and this is one car this is another, this is another as well as they are moving there is ok, it is stable right.

So, now question is that if force applied to one of the cars causes it to speed up temporarily, suppose in one car if you suppose this one you speed up like temporarily, then what will happen the rubber bands connecting it to the other cars we will what you call we will stretch because if it moves little bit ahead, this rubber, rubber band or elastic band will be will stretch right. This tends to slow down the faster car right because as it tends, these are moving your, this is movingly little faster. So, it will be your, what you call it slow down the faster car and speed up the other cars and similarly other cars will be speed up, right.

Therefore, a chain reaction result until all the cars runs at the same speed. So, actually this is an analogous your to this right, so the synchronism right.

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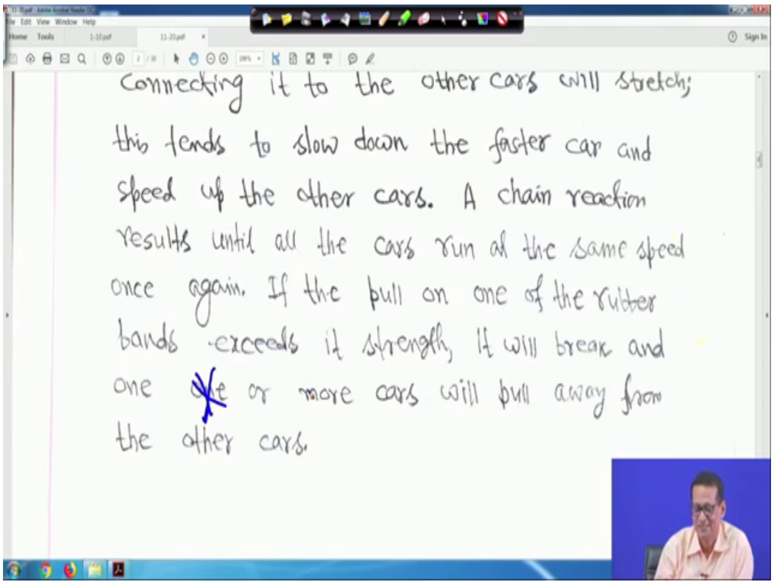

So, a chain reaction result until all the cars run at the same speed, right. Once again, if the pull on one of the rubber bands exceed right, then what will happen is pull actually pull on one of the rubber band, your bands exceeds it strength it will break because rubber band or rubber it has some maximum strength and if it is more than that, it will break and one they are also one repeated twice right. So, so, one or more cars will pull away from the other cars.

So, this is something like your analogous to a machine synchronous machine fall out of step and when all cars moving in a circular path tied by a rubber band or elastic band and moving and a one cars speed up how things are right and if little bit speed is increase of one car; so, naturally the rubber band or I this is an analogy or elastic band will stretch up.

So, faster car will slow down the speed and slower car will pick up the your little bit more speed, but finally, they will come to the your what you call, but which will less than the faster car and finally, they will come to the balance. But, if the strength of the and this is rubber band actually equivalent to transmission line and the analogues to and if the strength of the rubber band suddenly exceeds, then it will break so; that means, in that that car will be out of all other all other your cars from this rotation when they were rotating together. This is the analogy.

So, that machine is falling out of step right, this is an analogous to that this is I have taken from a book, right.

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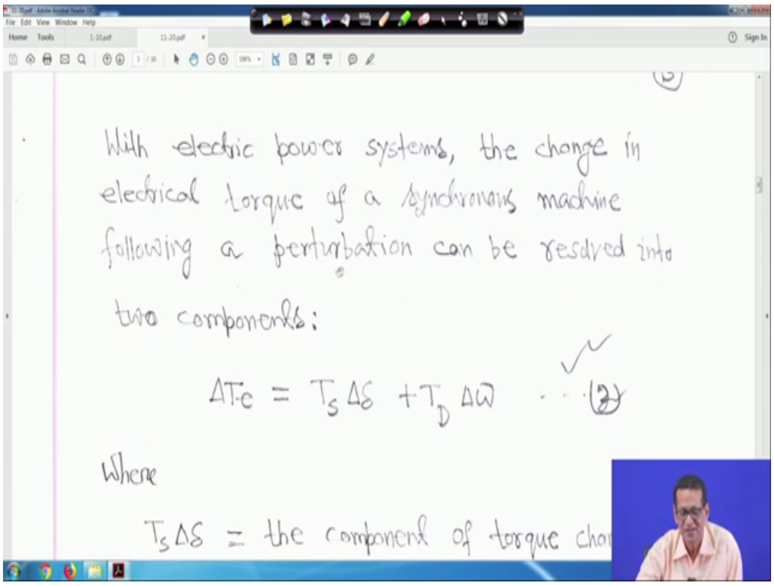

With, with electric power systems, the change in electrical torque of a synchronous machine following a perturbation can be reserved into two components, right.

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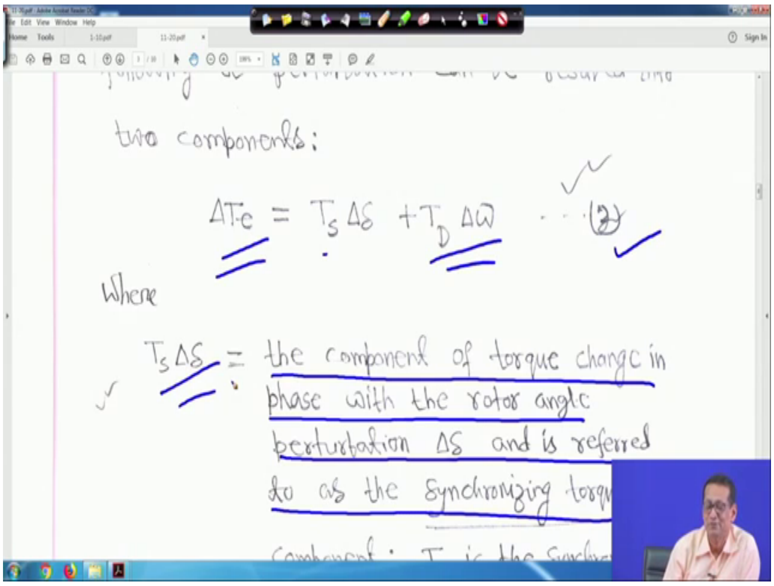

These two components we will learn much later not now. Right now I have written here the data T is equal to T s delta, delta plus T d delta omega; this is equation 2, but this one we will learn at much later right. All this things we will derive right; synchronizing component, damping component right and all these things we will derive at that your I mean after when the at the end of this synchronous machine part. So, this we derive, but here I have just written because for the sake of continuity of this topic, right.

So, where T s delta delta actually this is, this is the component of torque change in phase with rotor angle. What is change in phase with rotor angle perturb a this is right. So, that we will see later ah; perturbation delta and is your delta delta and is referred to as the synchronizing torque component. So, component of torque change in phase with the rotor angle perturbation delta delta and is referred to as the synchronizing torque. This how it is in phase and this and we will see later, we will derive that one, right.

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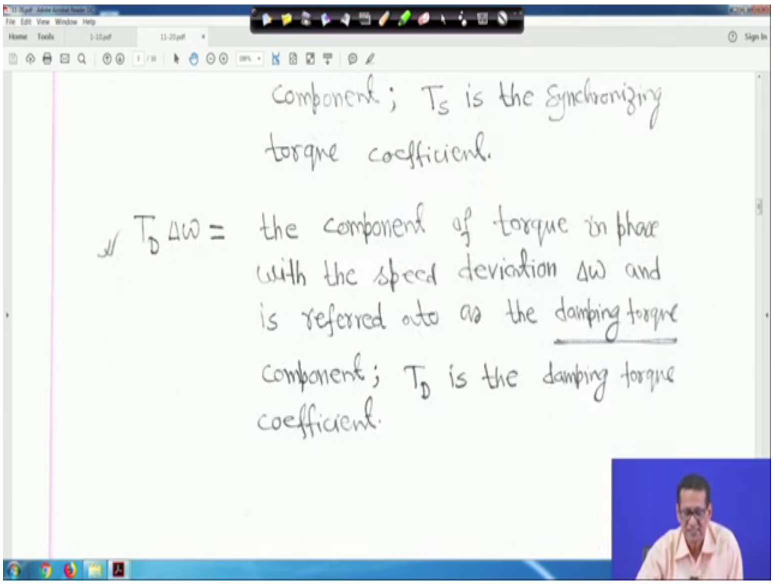

Similarly, that T D, T D delta your what an the component T s is the synchronizing torque coefficient, we will derive later. Then, T d delta omega the component of torque in phase with speed deviation, once we are known that torque is in phase with delta and this one is torque in phase with speed, what is that we will see later right. Delta omega and is referred to as the damping torque component T D is the damping torque coefficient, right

So, this equations later we will see detailed derivation of this one at the end of this when it will synchronization model will be develop fast, after that we will see that.

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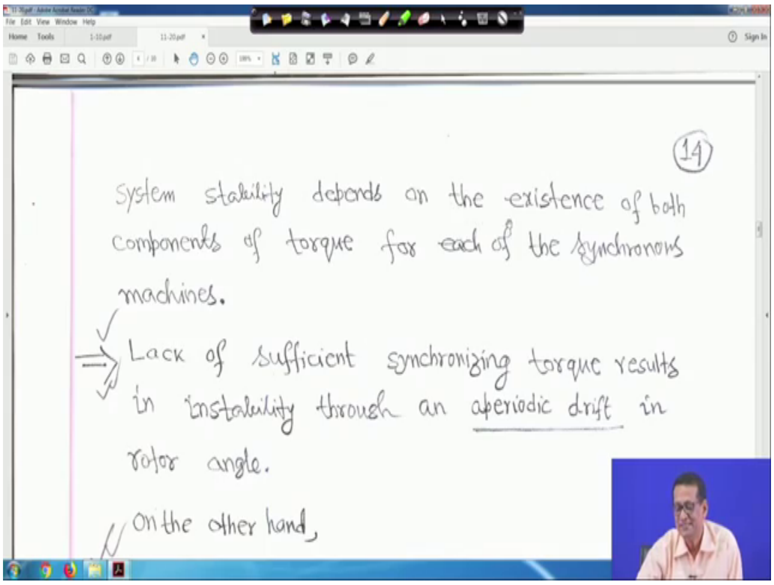

So, system stability depends on the existence of both components of torque right for each of the synchronous machine, right. So, lack of sufficient synchronizing torque result in instability through an aperiodic drift in rotor angle. This we will later we will taken it is numericals I hope and at the time, we will see.

So, lack of sufficient synchronizing torque result in instability through an aperiodic drift in rotor angle, right.

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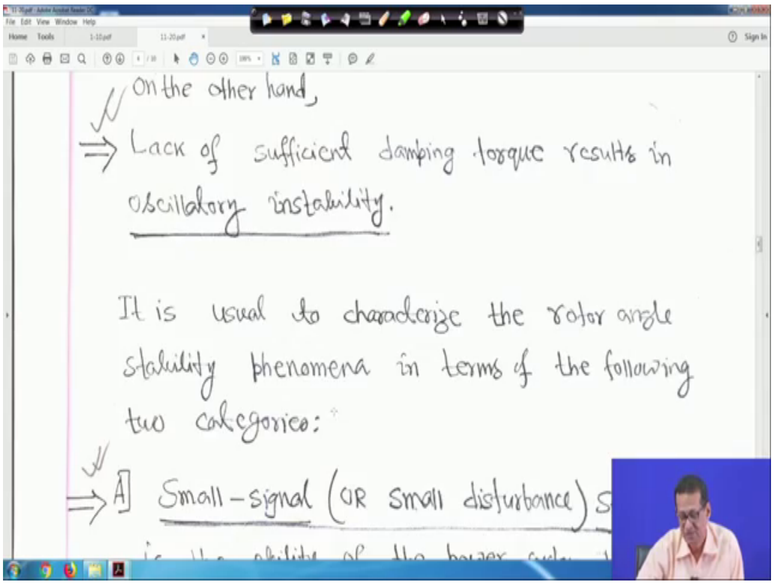

On the other hand, lack of sufficient damping torque results in oscillatory instability right. So, it is used to your, it is used where to characterize the rotor angle stability phenomena in terms of the following two categories; one is small signal or small disturbance stability, this is a right.

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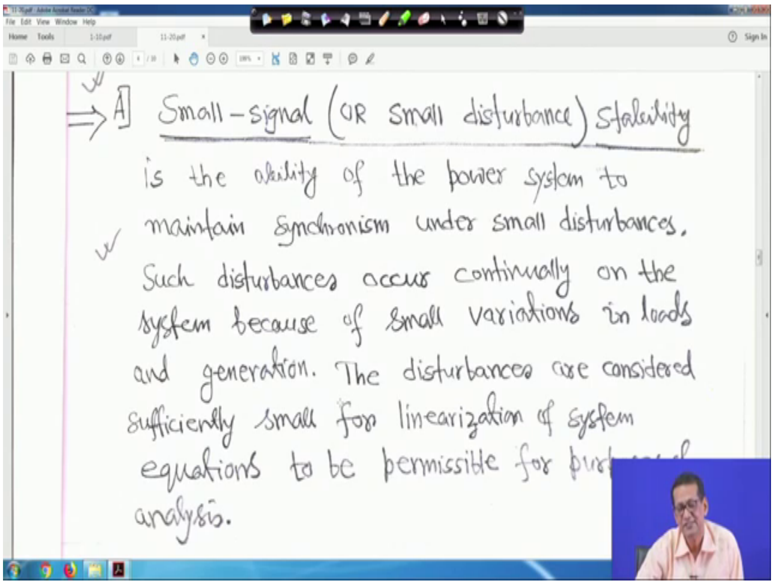

So, a actually small signal stability is the ability of the power system to maintain synchronism under small disturbances. Such disturbances occur continuously on the system because of small variation in loads and generation because loads are switch on switch off. Because of that, generation also continuously increase or decrease right.

The disturbances are considered sufficiently small for linearization of system equation to be permissible for purpose of analysis. We will for this small signal stability we will assume the disturbance is very small such that all this equation whatever mathematical things will be derived, it can be linearized, right.

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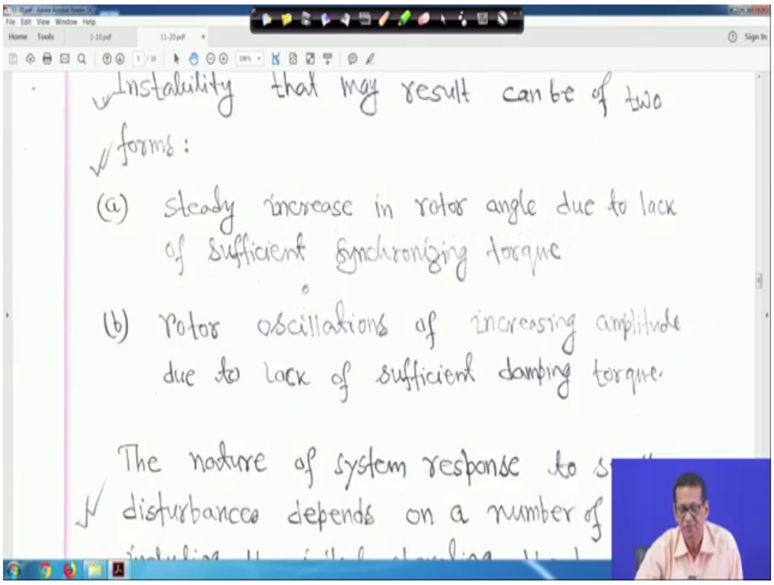

And instability that may result can be of two form; one is steady increase in rotor angle due to lack of sufficient synchronizing torque right. Another is rotor oscillations of increasing amplitude due to lack of sufficient damping torque, right.

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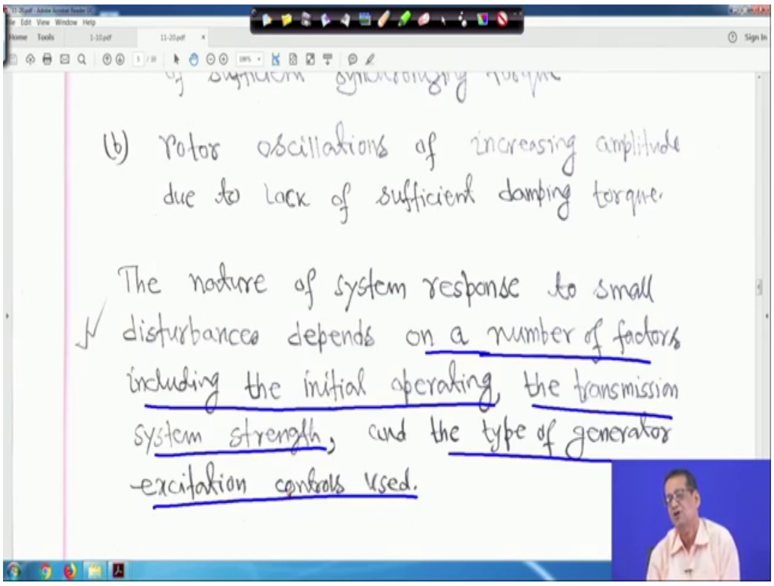

So, the nature of system response to small disturbances depends on a number of factors including the initial operating condition, the transmission system strength and the type of generator excitation controls, are used. So, this is on a number of factors actually right to a small disturbance thing that is initial operating condition, the transmission system strength and the type of generator excitation control used. Question is that, this excitation controls of the synchronize machine; if time permits, something I will talk about the your excitation system, right.

So, just hold on.

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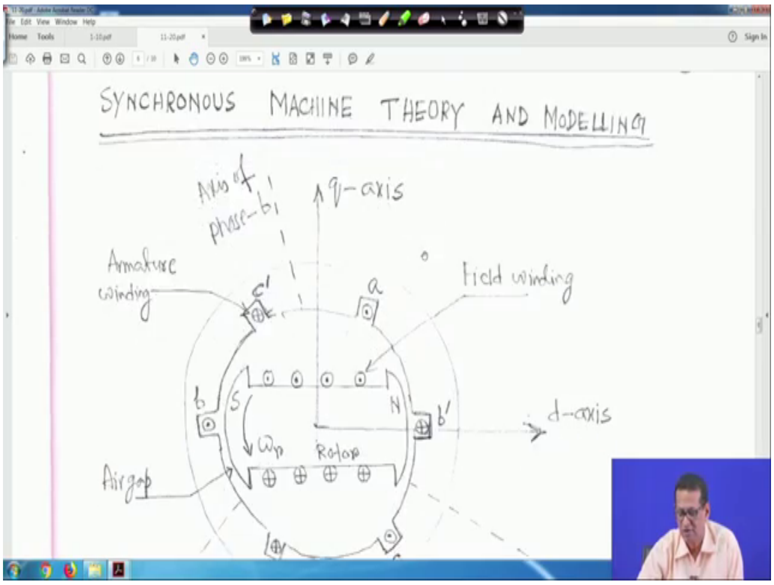

Next is synchronous machine theory and modeling, right.

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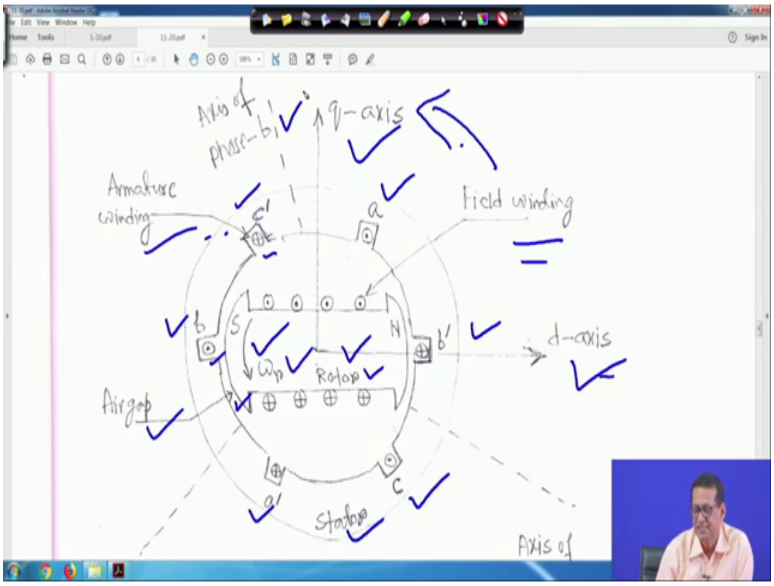

So, in this case, your what you call that your just schematic diagram is drawn schematic diagram is drawn for synchronous machine right plus and dot convention you will be knowing that one is current entering into the plain, another thing is it leaving the plain, right. So, this is just hold on. So, this is your N S pole is there, this rotor and these are all your, what you call this is field winding, this is D C that is because for synchronous generator field is DC. So, this is D C, this is the rotor and suppose it is rotating in anti clock wise direction this is overall the angular speed right and this is your stator, this is F, this is A this is A dash. If this is your B, then this is B dash and if this is C, this is C dash, right.

So, one is I told you plus or dot that current entering the plain or leaving the plain right. And, and second thing is and this is your along this, we have this is d axis and direct axis and this is your quadrature axis. So, quadrature axis leaving d axis by 90 degree right and machine rotation of the rotor direction is anticlockwise, that is here given here right. And, here these are all these are all armature winding right, armature winding.

It is marked between stator and rotor the air gap is there, it is uniform. So, this is air gap is there this is your stator part right and this is I told you this is the rotor part right. This is the schematic and this is your different axis are there axis of phase A, phase B and your what you call the phase C right. This is axis of phase B right; similarly axis of phase A and axis of phase C.

So, just hold on, right. So, all the and all this your what you call A, B, C that is you know that 120 degree apart right, mechanical 120 degree apart.

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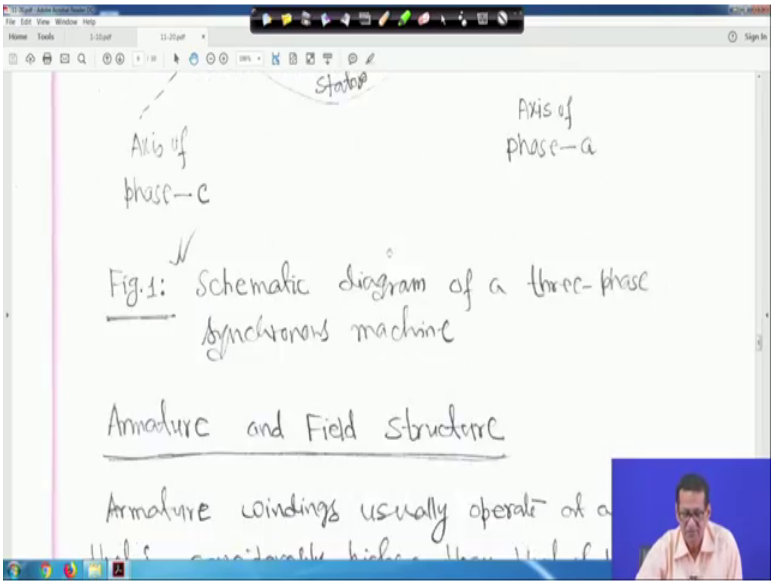

So, this is a schematic diagram of three- phase synchronous machine. So, armature and field structure.

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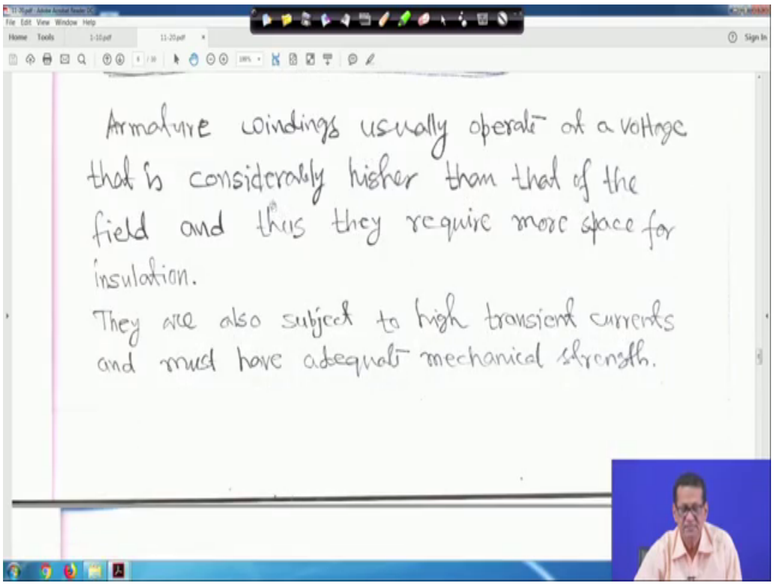

Whatever schematic diagram it is shown right, but that is armature and armature winding usually operate at a voltage, that is considerably higher than that of the field and thus they require more space for insulation right. They are also subject to high transient currents and must have adequate mechanical strength.

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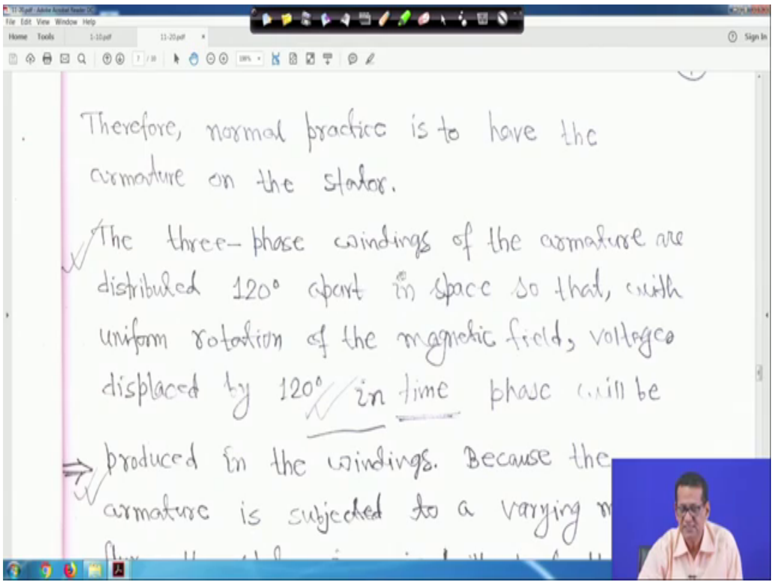

Now, therefore, the normal practice is to have the armature on the stator. That is why armature is on the stator the three phase windings of the armature are distributed 120 degree apart in space, right, so that with uniform rotation of the magnetic field voltages also displaced by 120 degree right in time till time phase and will be produced in the windings because the armature is subjected to a varying magnetic flux, the stator iron is built up of thin lamination to reduce eddy current losses.

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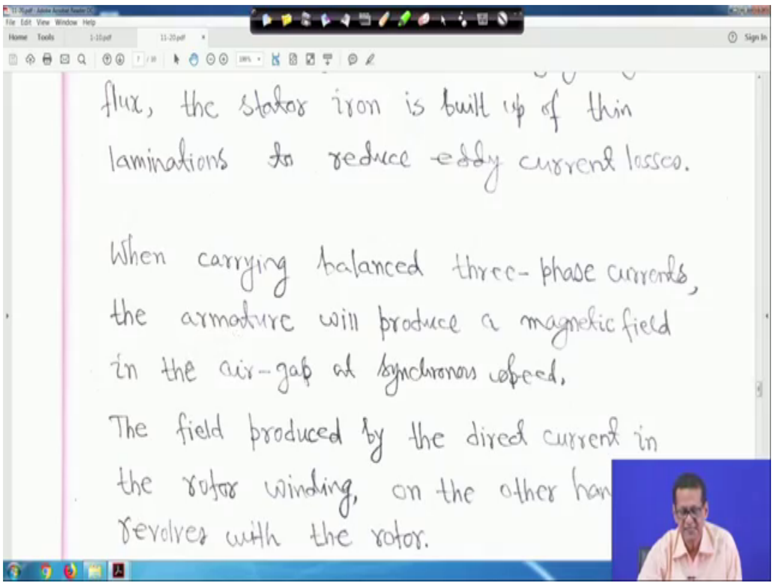

When carrying balanced three phase current, the armature will produce a magnetic field in the air gap of synchronous speed that is your, this is the air gap, this is the air gap here here here, right.

So, that is your, at the synchronous speed, the speed produced by the direct current in the rotor winding on the other hand revolves with the rotor right. Actually, actually it is actually how they do it this field actually is on the rotor and you need D C supply right and the rotor is rotating suppose if it is a 2 pole machine and 50 hertz; that means, this synchronous generator is rotating at a 3000 rpm right and this and this your what you call the DC supply actually it comes from somewhere.

So, this is a question to you that this DC actually field is on the rotor. So, how actually from where this dc supply come, how they do design, how they how they how do they design this, right because field is on the rotor; that means, some something must be there for supplying DC which is also rotating with the rotor, right. So, this is a question to you and you just find out how actually it is done. Otherwise, we will answer you in the forum right because DC is on the rotor and rotor is rotating at a speed of 3000 rpm for 50 hertz system right; that means, whole mechanism is rotating it the such a high speed.

So, what is the mechanism, then provide this DC supply come this is a question to you, right. So, field produced by the DC current in the rotor winding on the other hand revolves with the rotor, right.

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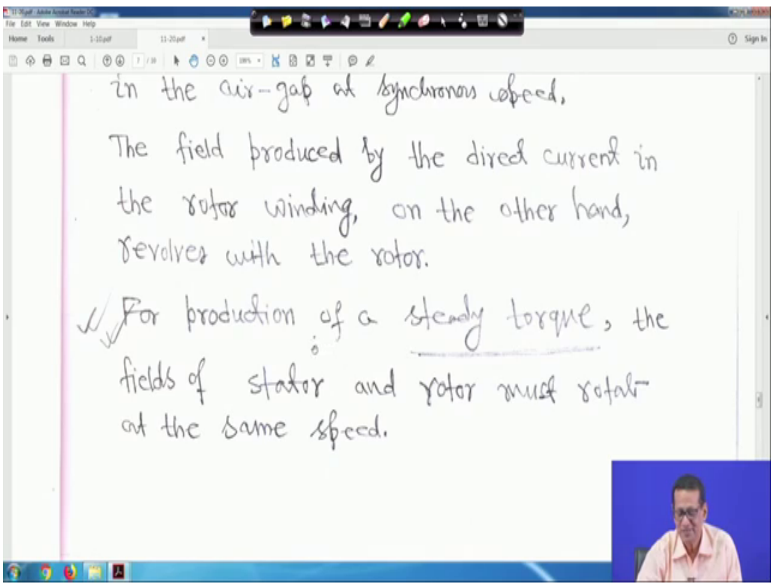

So, for production of a steady torque, the fields of stator and rotor must rotate at the same speed right.

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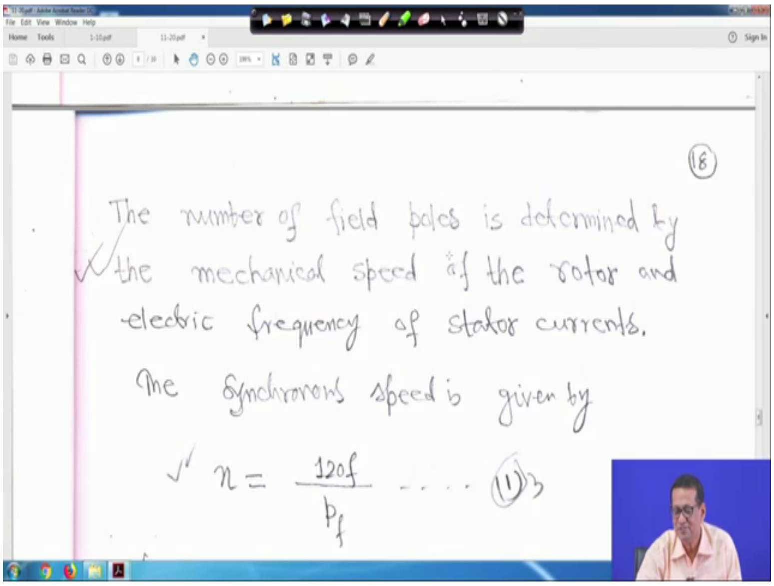

So, the number of field poles is determined by the mechanical speed of the rotor and electric your and electric frequency of the your what you call the stator currents right. So, the synchronous speed is given by this you know, the synchronous speed we sometimes use n s also is equal to hundred 20 f by p f, that you know right.

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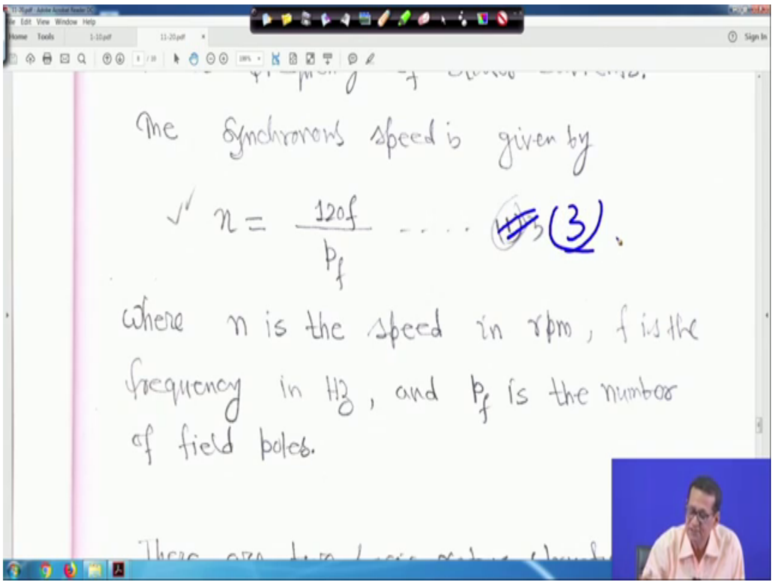

When n is the speed in rpm and f is the frequency in hertz and p f is the number of field poles, right. So, if f is 50 hertz right and p f is 2. So, it will be 3 thousand rpm right. This is actually equation 3, not 1 right. I corrected here, I corrected here. This is equation 3 because previously equation 1 and 2 are there, right.

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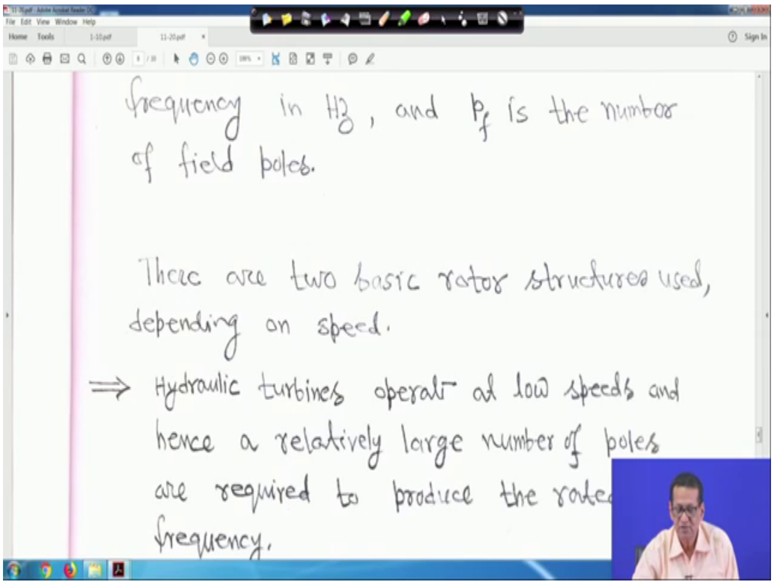

So, there are two basic rotors. Your rotor structures used depending on the speed hydraulic turbine particular for hydro hydro turbine, hydro generator right operate at low speed because they have many number of poles and hence a relatively large number of poles are required to produce the your rated frequency. So, for hydro generator number of poles are high because those generator rotate at a lower speed right ah; may be 3 may be 750 rpm or 370 rpm like this, right.

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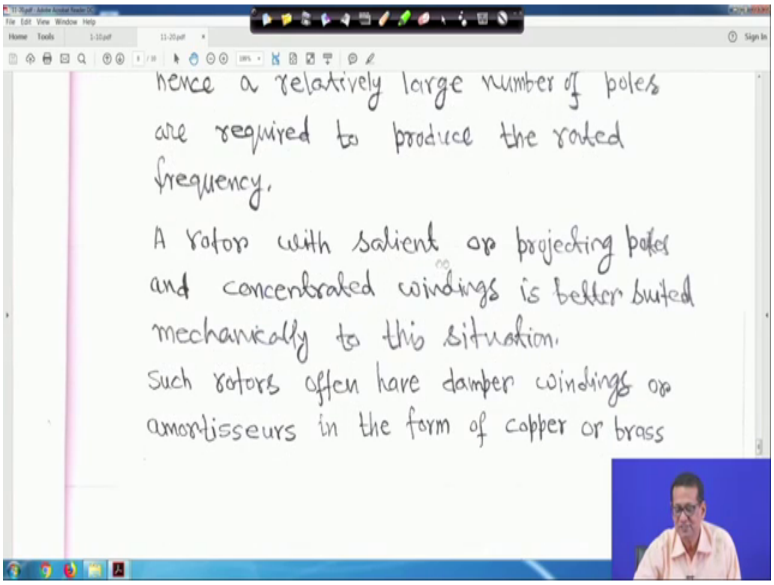

And a rotor with salient or projecting poles and concentrated windings is your what you call better suited mechanically to this situations. Such rotors often have damper winding or amortisseurs in the form of copper or brass. This I believe you have studied for synchronous machine.

So, we will not go into detail of that our object will be the different the dynamics and stability, right.

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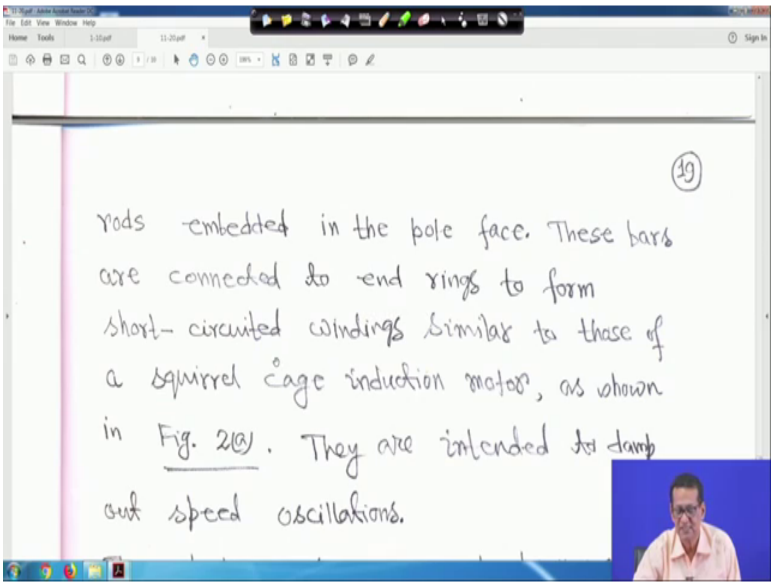

So, so, copper or your brass rods embedded in the pole face. These bars are connected to end rings to form short circuited windings similar to those of a squirrel cage induction motor right. So, in this case, a rotor with salient or projecting poles and concentrated windings is better suited mechanically to this situation. Such rotors often have damper windings or amortisseur in the form of copper or brass rods embedded in the pole face. These bars are connected to end rings to form short circuited windings similar to these of a squirrel cage induction motor as shown in figure 2 a.

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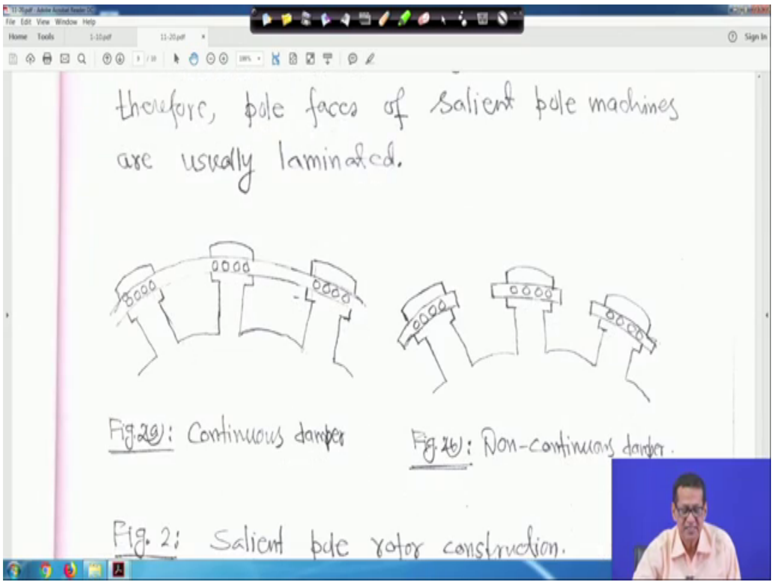

That means, either here it is placed and they are all either they all are joined together or it is open also. This is your continues damper and here this is non continuous damper because it is cut it is not there, right.

So, they are you know intended to damp out speed your what you call speed oscillation, right.

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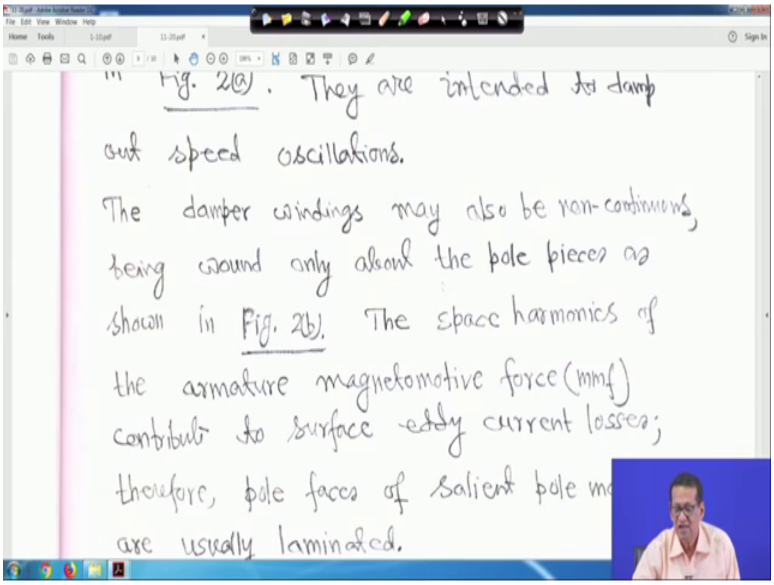

The damper windings may also be non continuous being wound only about the pole pieces as shown in figure 2 b. Only here it is there, but here no, no question of continuity, only here it is there. If you have studied missing design, I believe you have studied this right. The space harmonics of the armature MMF right that is magnetomotive force contribute to surface eddy current losses. Therefore, your pole faces of salient pole machines are usually laminated. This is all pole faces we will find for salient pole face machine it is your laminated, right. So, this is a continues damper and this is non continues damper, right.

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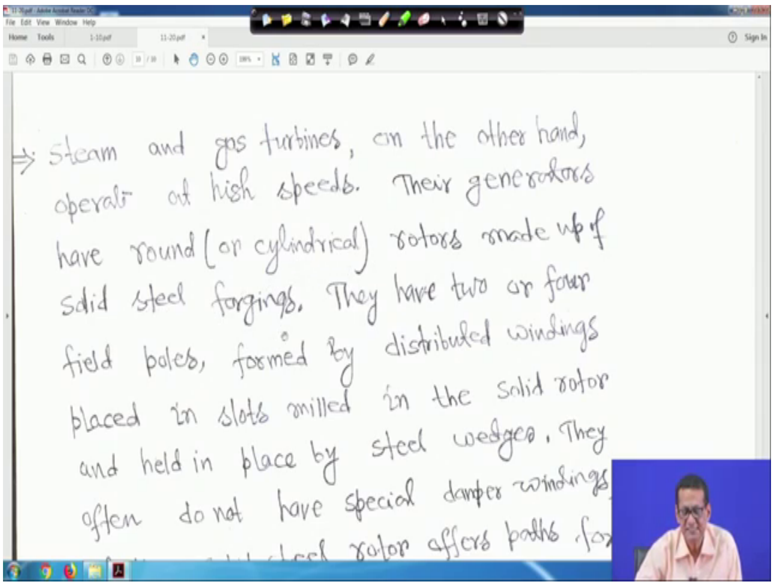

Now, steam and gas turbines on the other hand, they operate at high speed and their generators your what you call have round rotor that is cylindrical type of rotors right made up of solid steel forgings. They have two or four field poles; generally two poles in power system we see right formed by distributed windings placed in slots milled in the solid rotor and held in place by steel wedges, right.

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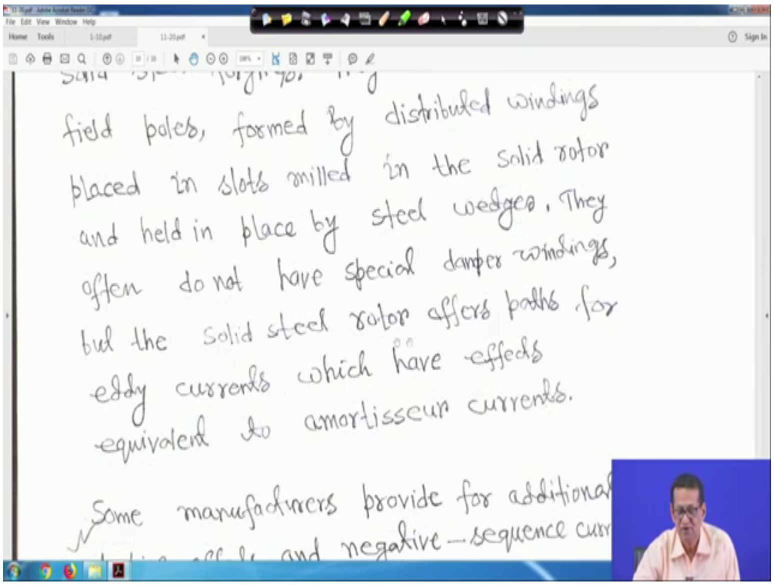

They often do not have special damper windings, but the solid steel rotor actually offers paths for the eddy currents which have effect equivalent to Amortisseur current, right.

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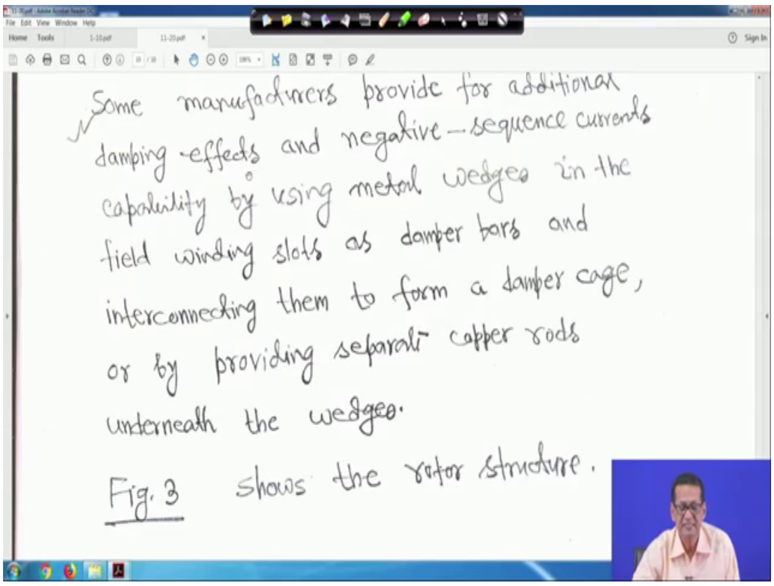

Some manufacturers, they provide for additional damping effects and negative sequence currents capability by using metal wedges in the field winding slots as damper bars and interconnecting them to form a damper cage right or by providing separate copper rods, underneath the wedges right. So, figure 3 shows the rotor structure, that we will see later.

So, for salient pole salient pole machines that generally your use for this your hydro generators right. Whereas, the cylindrical type of rotor that is basically your basically what you call the your thermal power plant right or your what you call that your steam turbine or gas turbines, but gas turbines are different operating principle than the steam turbines and for salient pole, it is basically used for hydro turbines right.

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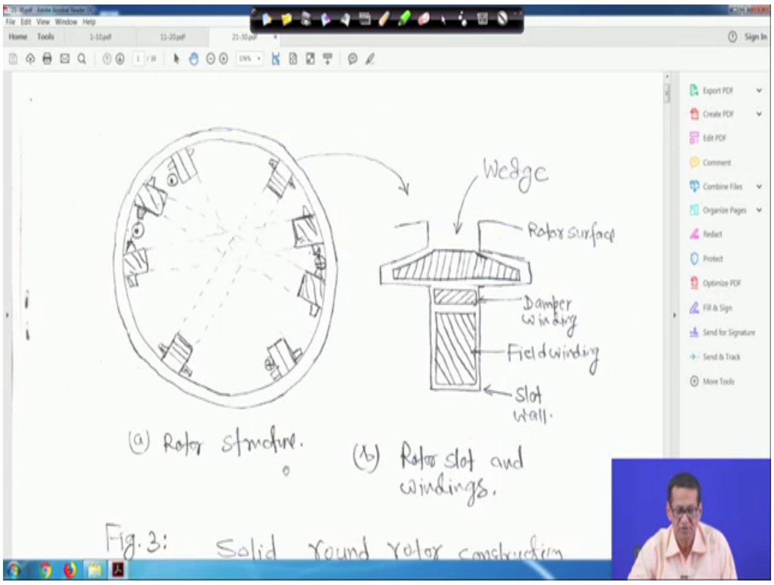

So, next we will so now, rotor your rotor structures are given right. So, this is your schematic; schematic your diagram and this is rotor slot and windings. So, everything is given here right, but drawing is not uniform; by the way I drawn it by hand. So, this, but nowhere here nothing is marked here, but here there is one thing I have marked it here, this is actually o s right this is actually o s this is the rotor surface right, this is the, this is your rotor surface, this is your damper winding, this is your damper winding, this is your field winding and this is the slot wall right this is the rotor slot and winding. It is a full schematic one and from here, this is shown this way rotor surface damper winding field winding and slot right.

So, this is solid round rotor construction, that is for your for thermal power plant or gas turbine or cylindrical rotor, right.

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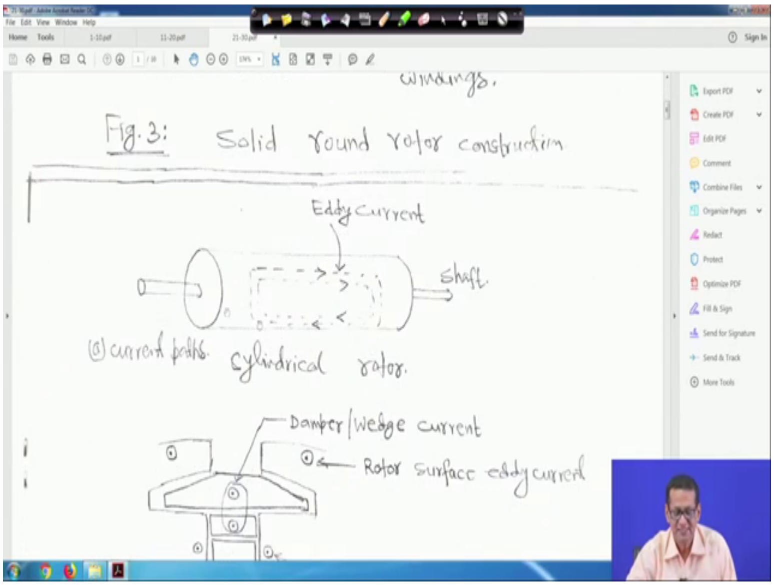

Now, eddy current actually this is a shaft. So, eddy current this is the direction flowing of the eddy currents in the your what you call this is the current path for cylindrical rotor, this for eddy current right.

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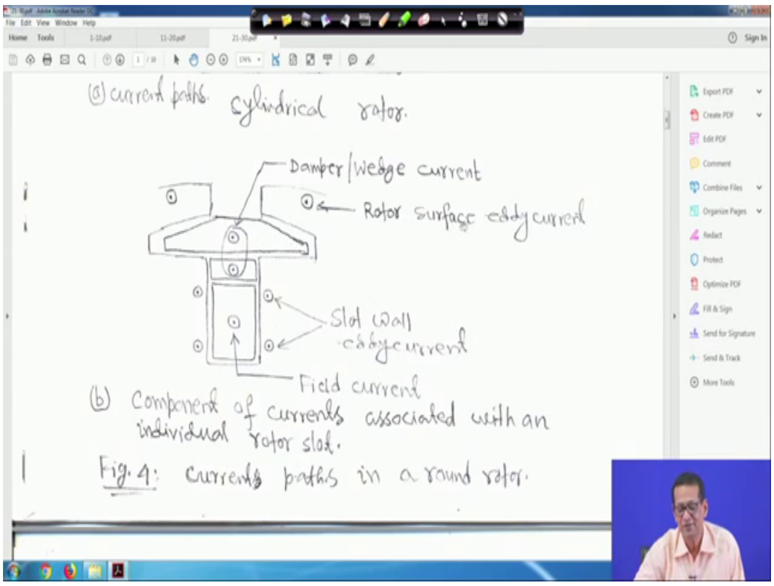

And for if you say damper or wedge current damper or wedge current, this is your damper or shown by these thing, then rotor surface eddy current is shown here, then slot wall eddy currents are shows there and this is the field current.

So, ultimately all this eddy currents you have to design the machine in a such a fashion such that things will be minimized. Those we have studied for electrical your, what you call electrical machine courses right, but our objective is something different. This is the just preliminary basic thing whatever thing little bit we are giving right.

So, this is the current path in a round rotor your, what you call in a round rotor for your synchronous generator which give cylindrical rotor type which is used for thermal power plant or there is steam power plant or gas turbine. So, this is different your what you call your eddy current the your what you call how actually eddy current flows which places, these are all marked right. But field current of course, you have to be there otherwise machine will never run you need the field current right and field is D C.

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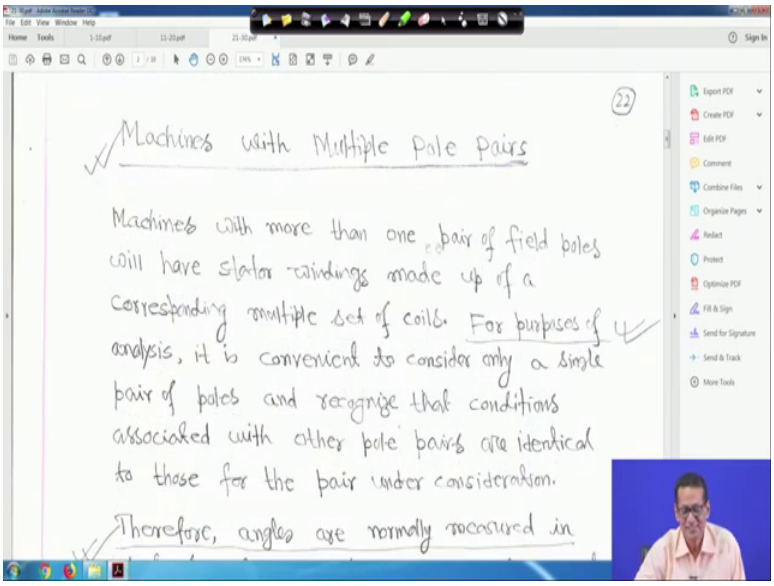

So, machines with multiple pole pairs. So, machine with more than one pole, one pair of field poles one pair means two pole machine. If it is 4 pole machine that I want to mean pair right will have stator winding made up of a corresponding multiple set of coils. For purposes of analysis, it is convenient to consider only a single pair of poles and recognize that condition associated with other pole pairs are identical to those for the pair under consideration.

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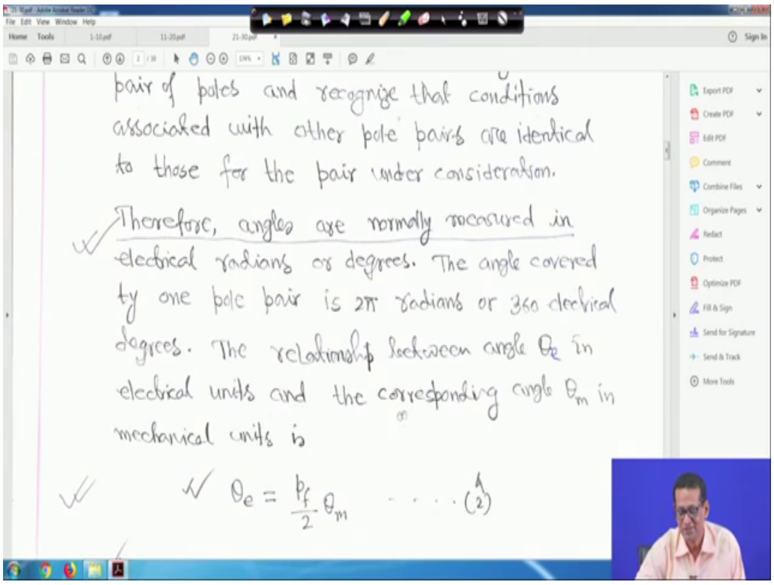

Therefore, in our study in our course will only consider the two pole machine that is one pole pair right. Therefore, angles are normally measured in electrical radians or degrees the angle covered by one pole pair is 2 pi radian or 360 electrical degrees, right. The relationship between angle theta in electrical units and the corresponding angle theta and mechanical unit, we know that theta electrical is equal to p by 2 theta m.

So, p f by 2 theta m, this we know right. If you have any doubt about this thing, another course I have recorded that is fundamentals of electrical engineering. Therefore, single phase s e circuit the just beginning of that this thing I have also I think I have talked about this right. So, theta electrical is p f by 2 theta m right. So, that means, your mechanically if mechanically if you suppose it is a two pole machine if you have right.

So, if it is p f is equal to 2, then theta e is equal to theta m then mechanically, it is theta m and if one rotation complete rotation is 360 degree, but your four pole NS, NS like this also mechanically, it will rotate your what you call about 360 degree but in that case electrically, it will be just double because at the time p f will be third pole.

So, 2 theta m, if theta m is 360, then it will doubled 2 theta m right 2 into 360.

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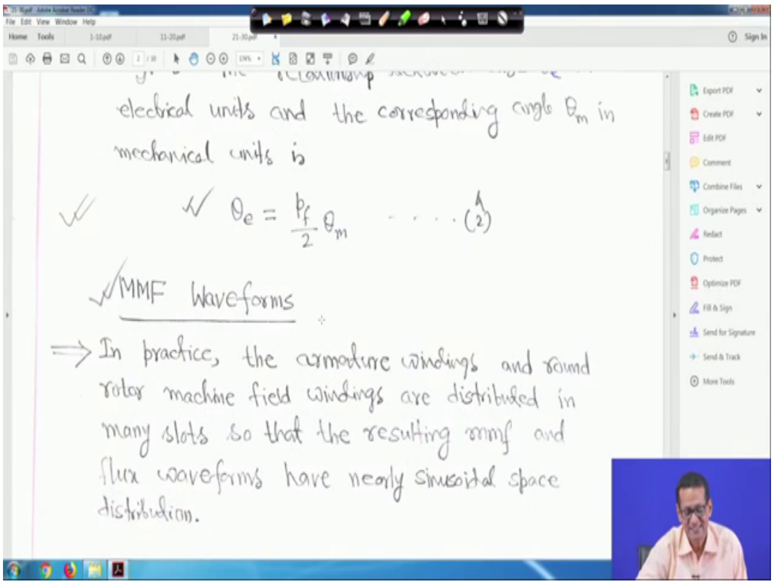

So, next is your MMF waveforms. So, this already also you have studied, but I have to you know start this thing. So, that is why little bit we have taken. In practice, the armature windings and round rotor machine field winding are distributed in many slots so that the resulting MMF and the flux waveforms have nearly sinusoidal space distribution, right.

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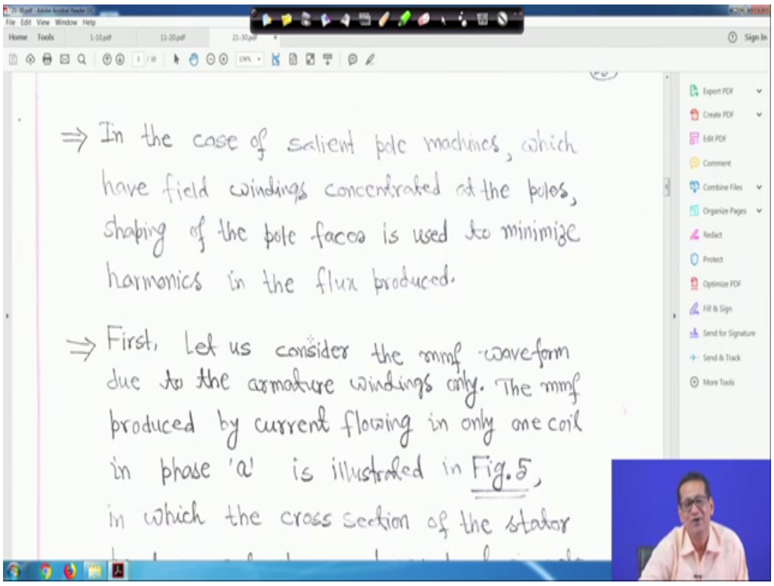

So, in the case of a salient pole machine which have field windings concentrated at the poles, shaping of the pole faces is used to minimize harmonics in the flux produced but in this course, we will not study the harmonics right.

I assume that you have studied all these thing. Our objective is dynamics and control which will come later.

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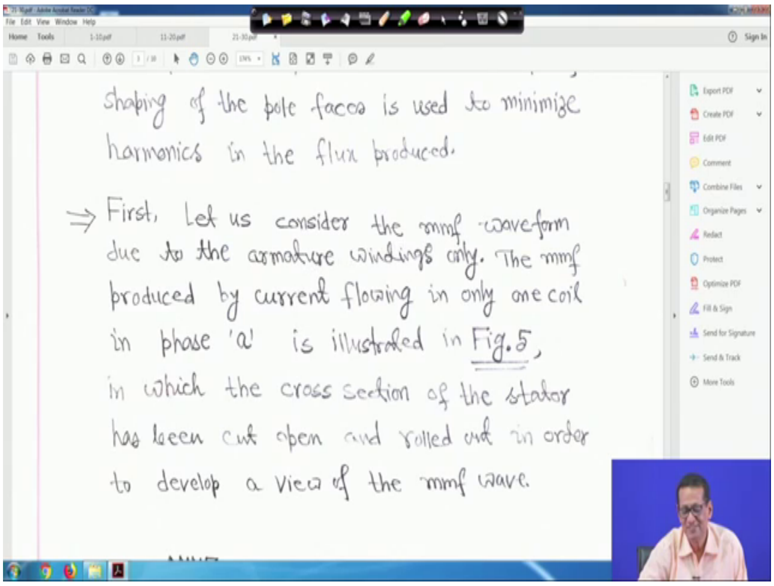

So, first let us consider the MMF waveform due to the armature windings only. The MMF produced by current flowing in only one coil in phase a is illustrated in figure 5. I will show that in which the cross section of the stator has been cut open and rolled out in order to develop a view of the MMF wave right.

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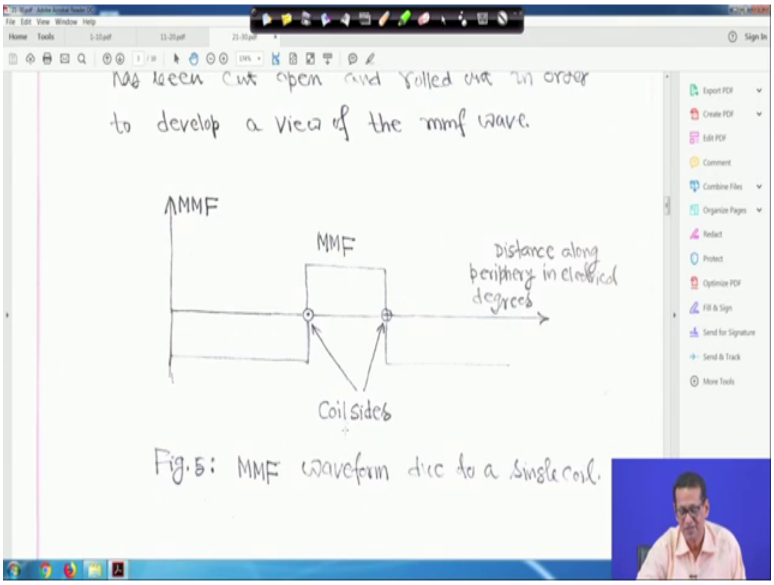

So, this is your what you call, this coil sides and this is distance along periphery in electrical degrees and this is my MMF right and this is a MMF waveform due to a single coil. I mean it is something like this that. If it is just showing in phase a right, in which the cross section of the your stator has been cut open and rolled out in order to develop a view of the MMF wave.

So, this is only a, only just for one coil, just is shown that this is MMF wave see. If you add one later, we will see if you add one after another, one after another, so it will be like a staircase. Finally, you have so many, so shapes to look like a sinusoidal waveform, right. So, this is MMF waveform due to a your single coil, right with this.

Thank you very much, we will be back again.