Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 16
STATCOM - II

Welcome to our second lectures on the STATCOM or facts devices, we shall continue with the that the point we have left in a previous section. So, we shall continue with the operation of the STATCOM.

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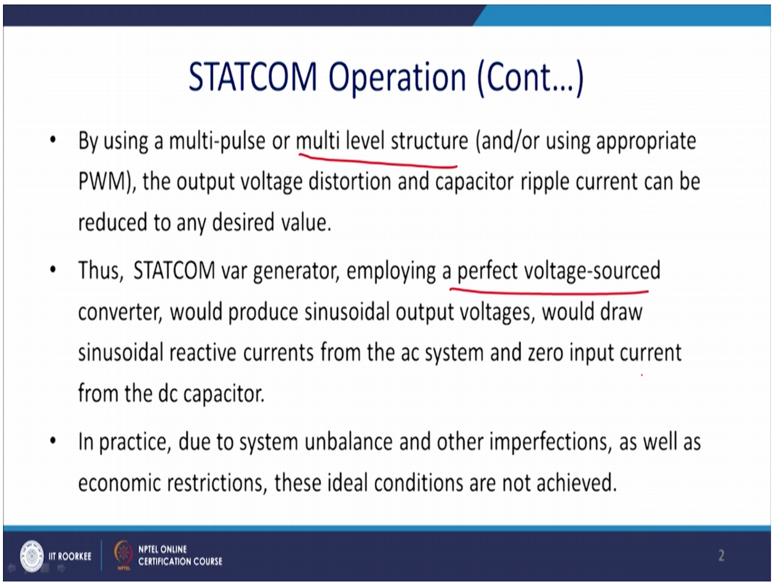

So, by using the multiple pulse or the multi-level structures and the output voltage distortion and the capacitor current can be reduced to a desired level as prescribed by the different standards like IEEE 519514 this kind of standard and it depends on the which voltage is connected. So, there is a different voltage level depending on the different regulatory conditional with there, and that is also the actually eh case of the investigation of the researcher.

So, what kind of multi level PWM structure will more suitable in economic for the particular requirement of the STATCOM as well as the what kind of PWM technique will also be suitable. Thus STATCOM var generator employing a perfect voltage sourced converter and that produce the sinusoidal output voltage. And would draw the sinusoidal reactive current from the ac system and zero input current from the dc capacitor theoretically, but it will take ripple current and the losses. So, there will be exchange of the power between the converter. In practice that is what I was saying; due to the unbalanced and the imperfection may be the value of the inductor is little different.

So, there will be a for this system there might be imbalance and even there might be a source unbalanced, we actually tolerate some amount of the source unbalanced as well as the economic restriction, this ideal condition is not achieved. So, there is a real power exchange between this STATCOM and the power system.

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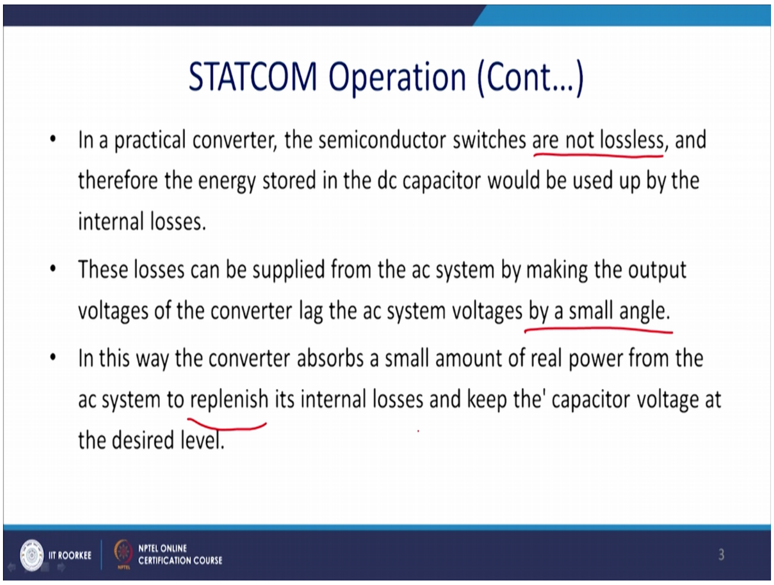

In practical converter the semiconductor switches are also not lossless and therefore, the energy stored in a dc stored must be used to feed those losses. So, the losses incurred switching losses incurred by this actually the STATCOM has to be fed from the dc source. This losses can be supplied from the ac system by making the output voltage is a converter lacks the ac system voltage by a small angle.

In this way what will happen the converter will absorb a small amount of the dl power from the system and will generate or replenish its internal losses and keep the capacitor voltage at the desired level. So, this is the way of actually achieving and the feed the losses and STATCOM also possible to equip the converter with the dc source.

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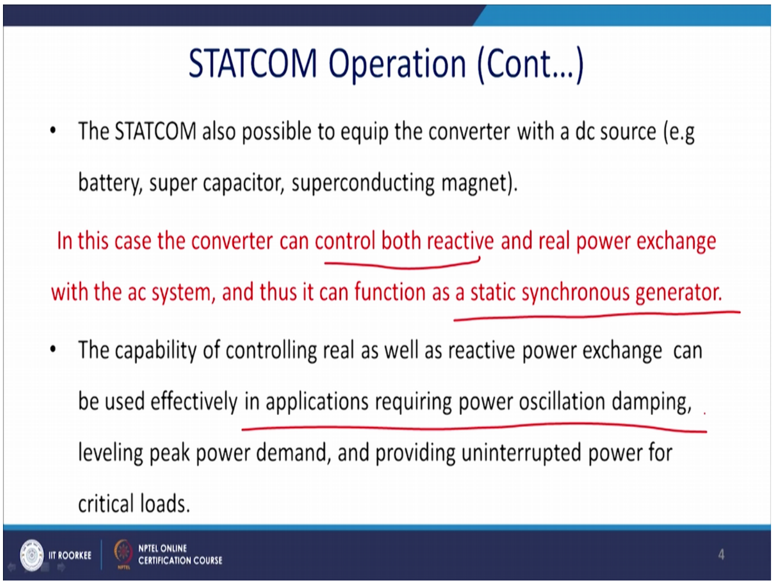

Now, a days it is possible with the battery super capacitor and super conducting magnet and all those things so, that can feed this losses. In this case converter can control both active as well as the reactive power of the system, and thus it can function as the static synchronous generator.

So, nowadays actually it is the one of the point investigation of this kind of topology, because super big as you know we have a solar panel, that can be feed into the STATCOM and thus it can inject also the real power. Capability of the controlling the real power as well as the reactive power exchange can be used effectively in application requiring the power oscillation damping.

So, we have discussed that how actually power oscillation damping can be achieved by (Refer Time: 04:30) same thing can be done with the STATCOM and in this more effectively. A damping a leveling peak power demand and providing uninterrupted powers to the critical load, these are the advantage of it. Now see that the this is actually the schematics of the STATCOM.

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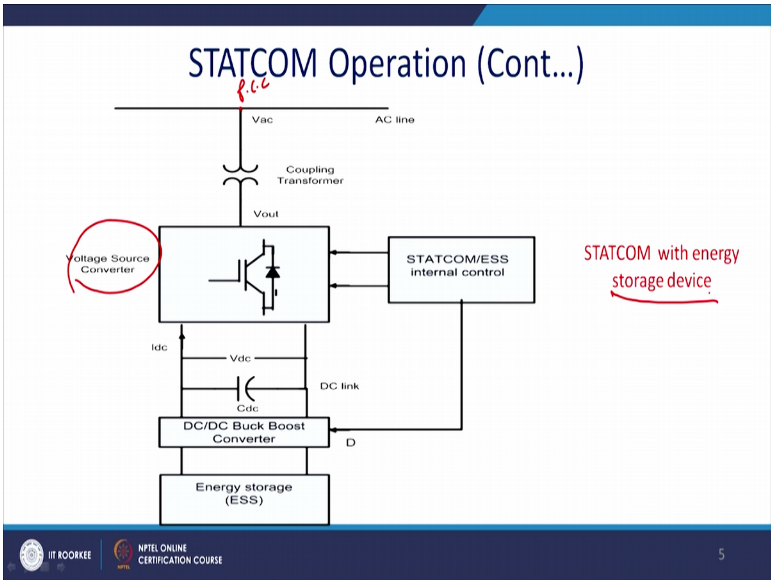

So, generally we require this couple inductor this inductor and the transformer has been coupled to the coupling transformer and it is connected to the point of common coupling it is called P C C and this transformer is required because the device rating may not match the system rating.

So, for this system we require to reach the voltage level and this is basically a current control voltage source converter, and what happen you know we require to have a DC link voltage. And DC link voltage may be feed to the energy system or the solar system. So, that will basically acts as a synchronous generator STATCOM with the storage energy devices. So, nowadays this is actually in is put in to practice.

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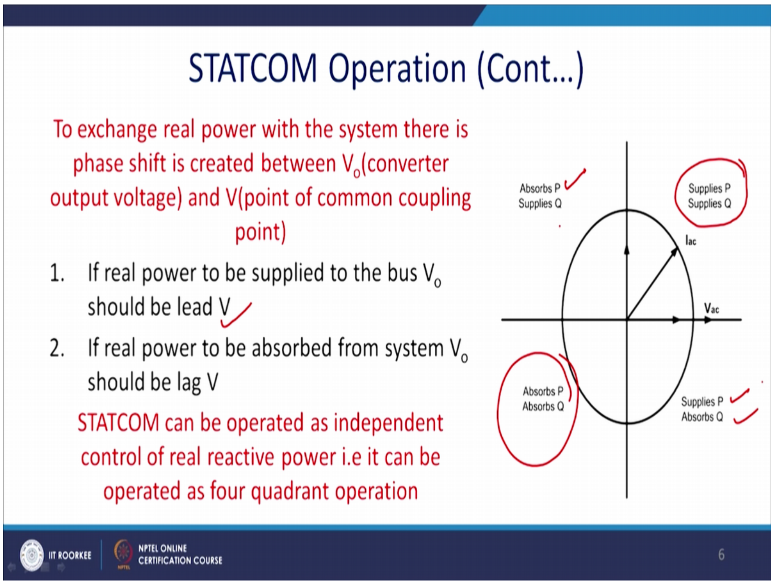

Now, let us again discuss and see revisit. So, what is a local sub operation of the STATCOM? To exchange the real power with the system, there is a phase shift created by the converter output voltage and the point of common coupling.

So, for this reason what happen? If the real power to be absorbed to the V 0 and it should lead it should be actually lead V. And if real power to be absorbed from the system then it should lag V. So, for this reason this is the location. So, this is V ac this is Iac and in this zone you can see that in a first quadrant it supplies. So, you know actually it supplies p it supplies q.

In second coordinate what happen? This is basically I and V and thus in this coordinate you know voltage is negative. So, for this reason in it absorbs P, but it supplies Q and same way here in third coordinate it absorbs both P and Q, but in this case it supplies P absorbs Q.

So, total 360 degree operation is possible and accordingly you can choose the operating condition of your system. Thus STATCOM can be operated as independent control of the reactive power that mean it can be operated in four quadrant operation. This is the flexibility when you put it with the with the storage element it capability enhances.

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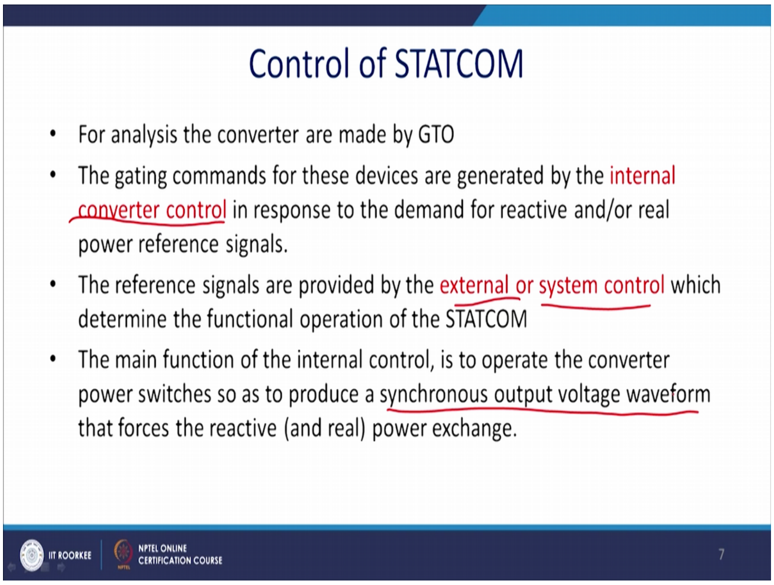

So, let us see that how STATCOM can be controlled. For analysis of the controller we consider that this devices are made of GTO because you require a full control devices and in may be for the lower rating we can use IGBT. The gating commands of this devices are generated by the internal converter control in response to the demand of the reactive or the real power generations.

The reference signals are provided by the external or the system control which is determined by the functional operation of the STATCOM. The main function of the internal control is to operate the converter power switches. So, as to produce the synchronous output voltage waveform, that forces the reactive and the real power exchange.

So, this is the actually the way of controlling the STATCOM.

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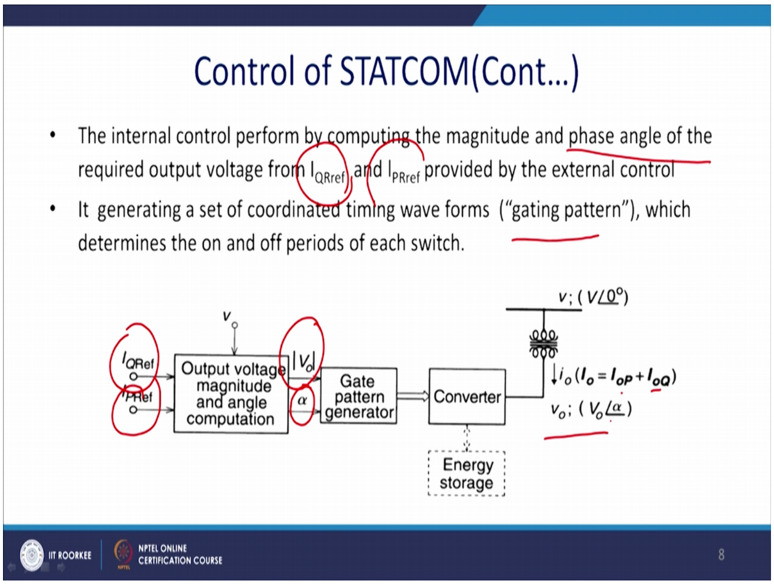

So, let us go to this actually the block diagram to understand it better. The internal control perform by computing the magnitude of the phase angle as required by the I Q Rref and I PRef this is actually the I PRef and I QRef that has to be computed by a processor dynamically. By generating the set of the coordinating timing and a getting pattern, which determines the on off period of the switches let us see that then actually you have a voltage and thus you will actually go to the stationary fame.

So, thus you generate this actually the output voltage and alpha. From there actually you calculate the switching sequence of this devices and you give it to the converter and in storage devices and thus you know actually your I 0 will be I P plus I Q, you see that how much real power and the reactive power generate and how much also the voltage you require to be generated.

Because you know that you require a different level of the voltages to compensate reactive power and the real power. Now how you do the internal control? Internal control can be achieved by the following way, indirectly while controlling the DC capacitor voltage.

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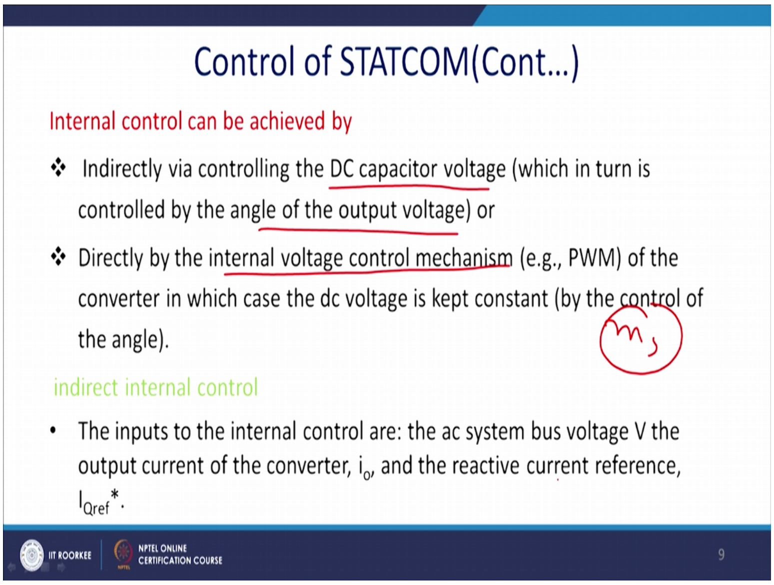

You can change the DC capacitor voltage, but generally DC capacitor voltage cannot be changed fast because of its inertia and thus internaties controlled by the angle of the output voltage or the second option, directly by internal voltage control mechanism that been the modulating index that you can change the PWM. This PWM value you can control from there you can change the terminal voltage, which in case of the DC cases kept constant and generally we prefer the second one, because it is the faster in operation.

The input of the internal control are the ac system bus voltage V and the output current of the converter ico and the reactive reference current I Q ref these are the feeding information accordingly you will calculate the PWM mostly this technique is used. So, let us see. So, voltage V operate at the phase locked loop that provides the basic synchronous angle theta which we have to have a pll.

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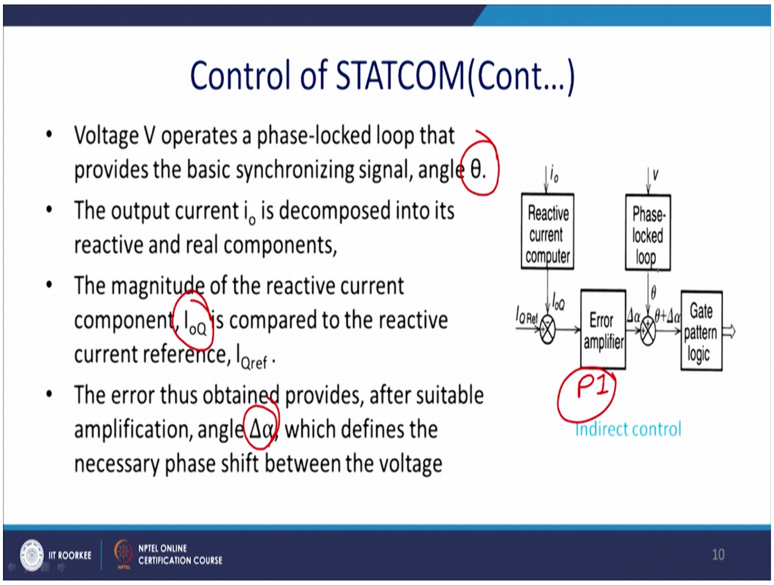

So, pll will generate gives you the information about the theta. The output current is decomposed into the two component real and the reactive power real and reactive component. The magnitude of the reactive component is I 0 Q is compared with the reactive component of the iQ reference.

The error is thus obtained provides the suitable amplification of this angle generally it is nothing, but a P 1 controller. So, P 1 controller will generate this del alpha, which defines a necessary phase shift between the voltage and the current. This is the principle of the operation and it will be del alpha will be added with the theta and thus net angle will be theta plus alpha del alpha and that will be given to the gate firing logics.

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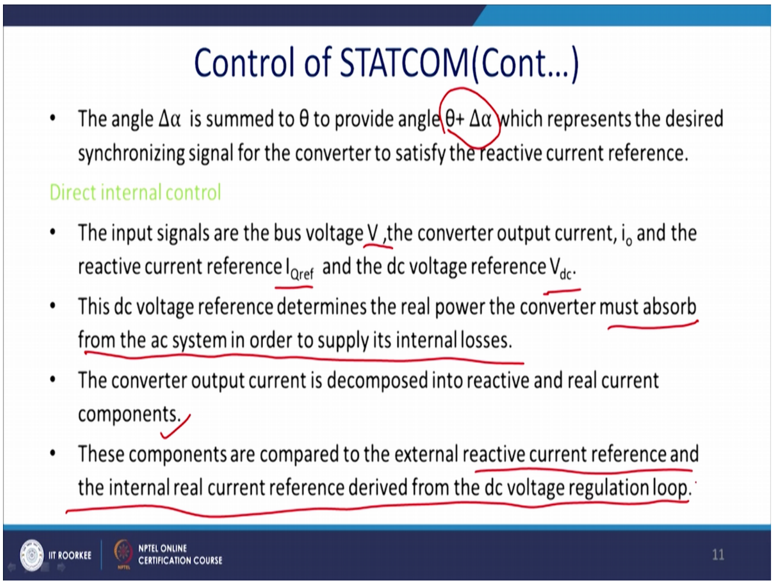

The angle del alpha is sum up to provide theta plus del alpha will represents the desired synchronizing signal to the converter to satisfy the reactive current reference. The input signals are the bus voltage V and the converter output current i 0 and the reactive current reference I Qref and the DC reference voltage V dc.

This dc voltage reference determines the real power of the converter and must absorb from the sys from the ac system in order to supply its internal losses. The converter output current is decomposed into the reactive at the real component of the currents. These components are compared to the external reactive current reference and the internal real current reference derived from the dc voltage of the regulation. So, this is the way you will actually control the STATCOM now see that.

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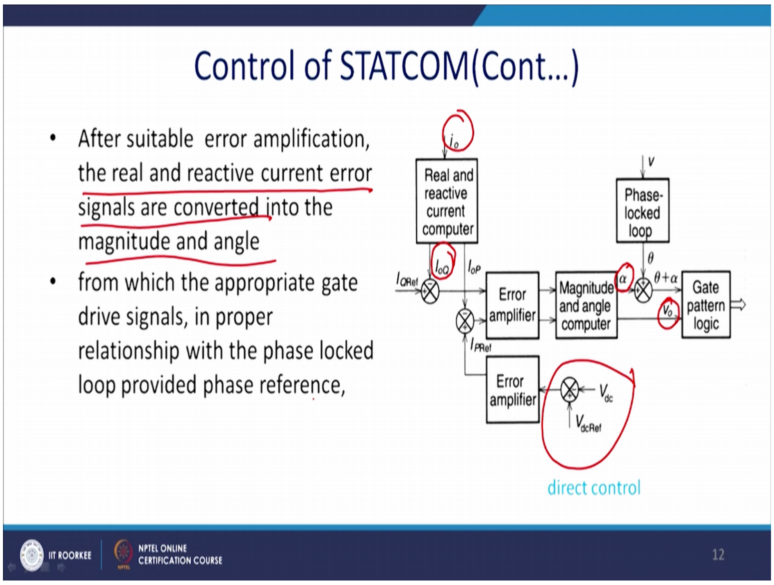

So, this is the reference i 0. So, i 0 will be spitted into the real and the reactive power and thus you have a IoQ and ip. So, IOQ you will compute that what amount of the reactive current required to fit thus you will be actually compare this IOQ with IQ reference and you will fit it to the error amplified and it essentially pi controller pi pi controller and output of the pi controller essentially compute the alpha or del alpha.

But what happen you also require to maintain the receivers voltage, because you have to fit the voltage also. For this reason you have a V dc minus V dc Ref from there actually there were errors signal, that error signal will be compared with the real component of the ip and it will also fit to the error amplifier. Generally it is a differ amplifier and this output of this two fed to this actually magnitude and the angle computing block of this processor; from there actually it will generate alpha and it will generate V 0 and alpha will be added up with the actually the pll.

So, effectively this angle will be the theta plus alpha and that will be actually fed to the gate signal logic to fire up the GTO or IGBT. So, after suitable error amplification the real and the reactive power current error signals are converted into the magnitude of the angle, you may have also look up table. And from which the appropriate gate signals and in proper relationship with the phase locked loop is provided as the reference to triggering the circuit.

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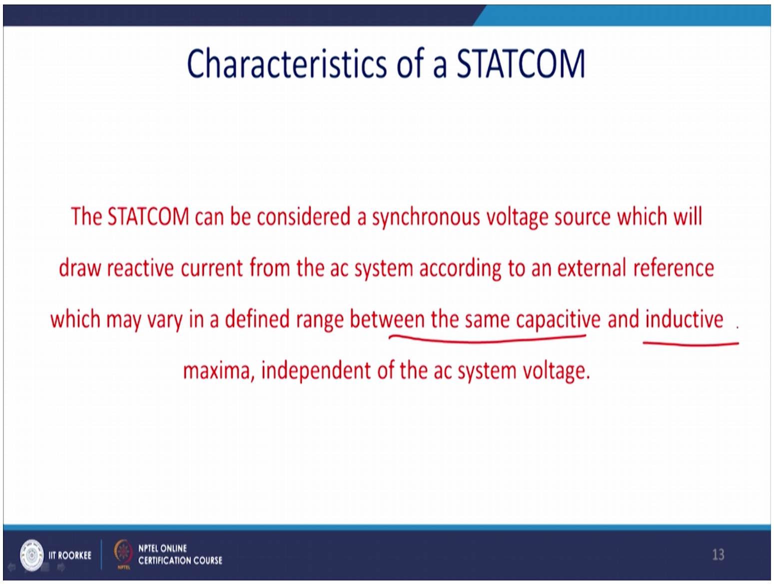

So, what is the characteristics of the STATCOM? STATCOM can be considered as a synchronous voltage source, which will draw reactive current from the ac system according to the external reference which may vary in a defined time range between the same capacity when the inductive maximum and independent of the system voltage. So, it is a very effective tool when you have a sag occur all those things.

We shall see our next class that you know the power this reactive power compensating capability decreases in case of the eh in case of the SVC for intransient and other condition, but it can handle it can compensate the reactive power very well even in a disrupt system. So, what we can conclude what is a characteristics of the system? Losses in the STATCOM are neglected if we neglect definitely ,and STATCOM is assumed to be a purely reactive.

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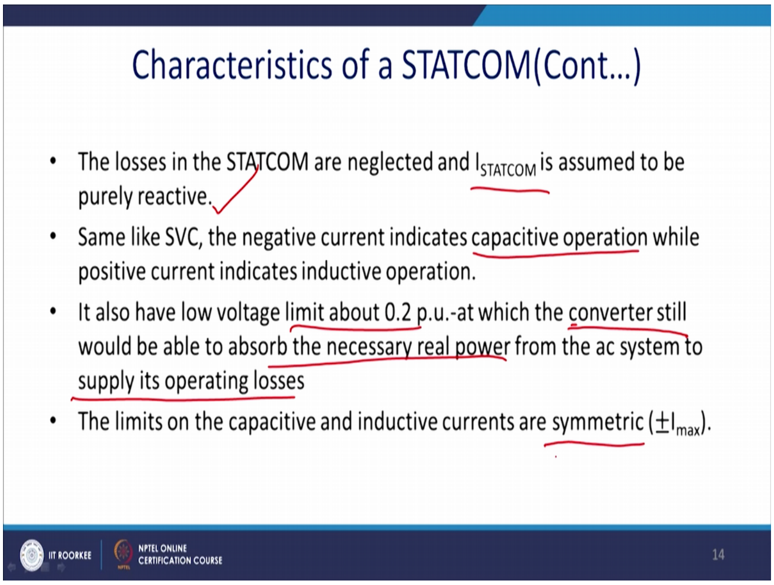

Same like SVC the negative current indicates capacitive operation, while the positive current indicate the inductive operation this is the same convention. We will follow it will also have a low voltage limit of 0.2, that is quite important features of the STATCOM.

At which the converter will still will be converter still would be able to absorb necessary real power from the system and supply the losses and thus can compensate the reactive power. The limit of the capacity with the inductive limit are symmetric and that is plus minus I max that is provide the limit by the switches mind it.

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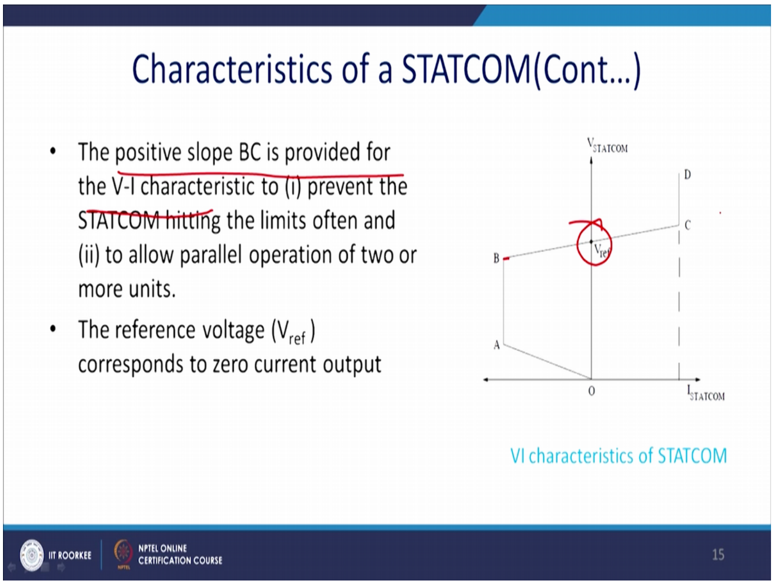

So, thus this is the characteristics of the STATECOM; As we have discussed in case of the SVC the positive slope BC provides for the V I characteristics to, prevent the STATCOM hitting the limit often and allow the parallel operation of the more than two units.

So, you can put more than the two unit if the power rating of the STATCOM cannot meet the that particular area. So, we can put into the casket bar. The reference of voltage V ref corresponds to the zero current output. So, this is basically the zero current output and till now it can actually go to the operating. So, it can go to B to C and in this zone, it can compensate and thus you can increase its limit by parallely putting the more STATCOM.

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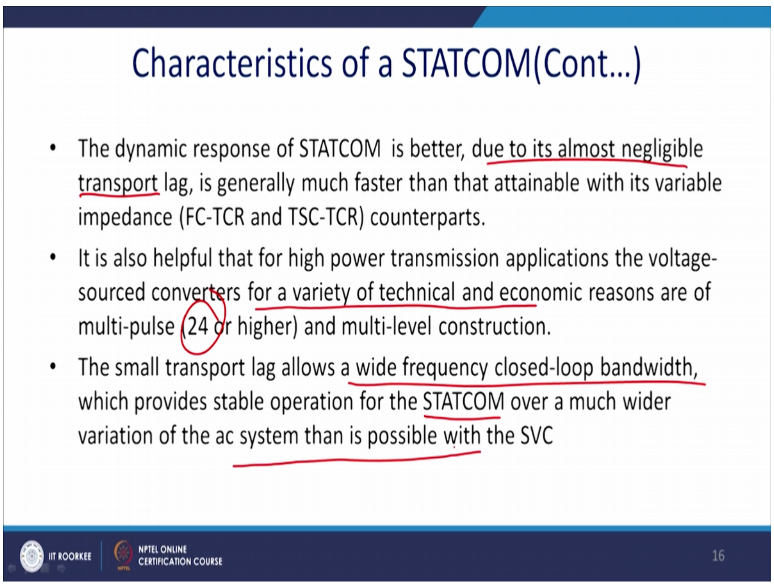

Now, the dynamic response is of the STATCOM is better compared to SVC why due to almost negligible transport loss or transport lag. Generally it is most faster than the then that of attainable with the variable impedance because capacitor will have its own inertia and we do not we also know that, we want to have a transient feed operation that we discussed.

So, we have a specific time of switching here you can change this dynamics by changing the modulation index of the PWM and thus it is quite faster. It is also helpful that the higher power transmission application the voltage source converter, for the variety of the technical and the economic reasons are multi pulse. Why because you know you can reduce the TST, we know that actually we have a 6 plus converter.

So, it is actually 6 and plus minus 1 you will have harmonic content and thus you make it 24 pulse. So, you definitely eliminate the higher lower actually higher strength or harmonics. So, it is multi for this we prefer for the harmonic consideration, we prefer the multi pulse converter. The small transport lags a wider frequency closed to bandwidth which provides the stable operation of the stats STATCOM over wide range of variation of the ac system, possible than the SVC. So, it is quite superior than SVC.

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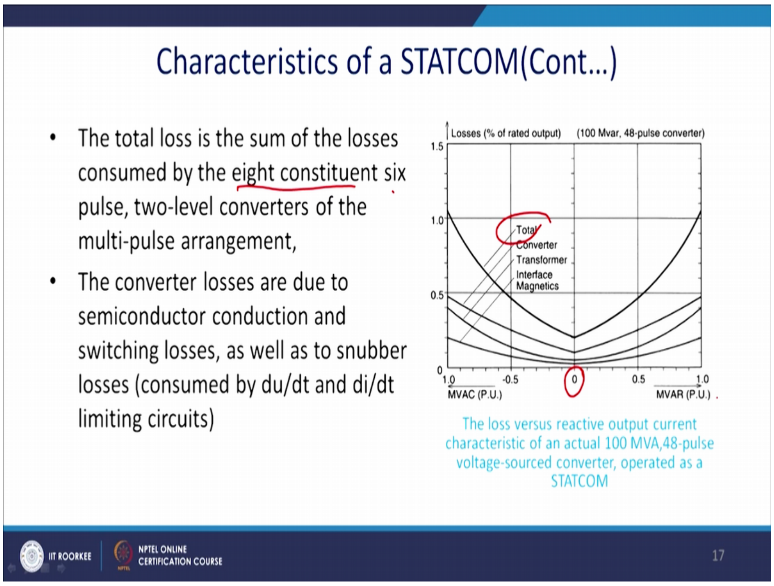

To see that characteristics of that STATECOM, this is the percentage loss and we have considered this differences taken from the Hingorani and yogis books this is a 100 MVA and 48 pulse converter. You see that this is the total losses this is the converter loss this is int this is the basically the magnetic loss. Say total loss essentially the sum of eight constituent eight constituent six pulse, two level converter of the multi arrangement.

So, see that you know this is the power rating so, how this losses actually changing. So, this is basically the zero voltage operation, this is zero current operation here and here it is actually plus MVAR and here it is a minus MVAR. So, it can compensate both actually inductive and as well as less capacitive converter; losses are due to the semiconductor conductions switching losses as well as the snubber losses and du dt and di dt losses.

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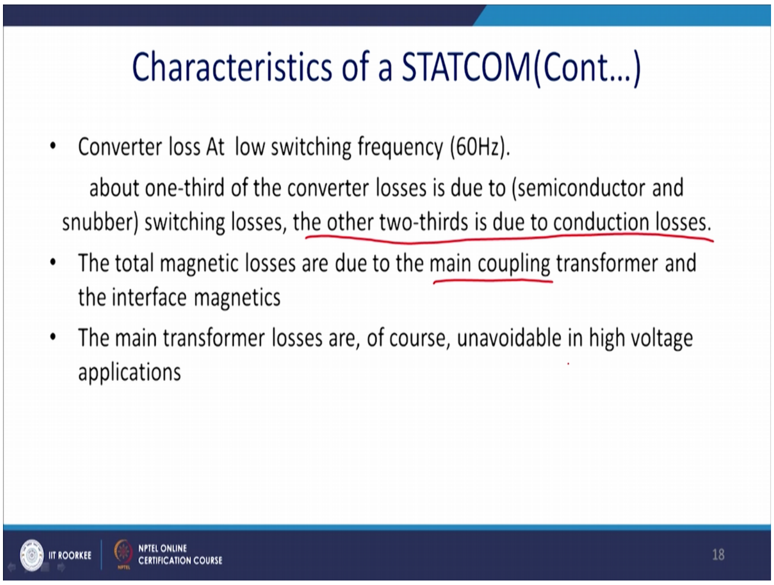

So, converter loss at converter loss at low switching frequency will be less, about one third of the converter loss due to the semiconductor switching losses, the other two third due to the conduction loss please mind it. The total magnetic losses are due to the main coupling transformer and the interference magnetics these are hysteresis and eddy current losses. And main transformer losses of course, are non avoidable in high voltage applications.

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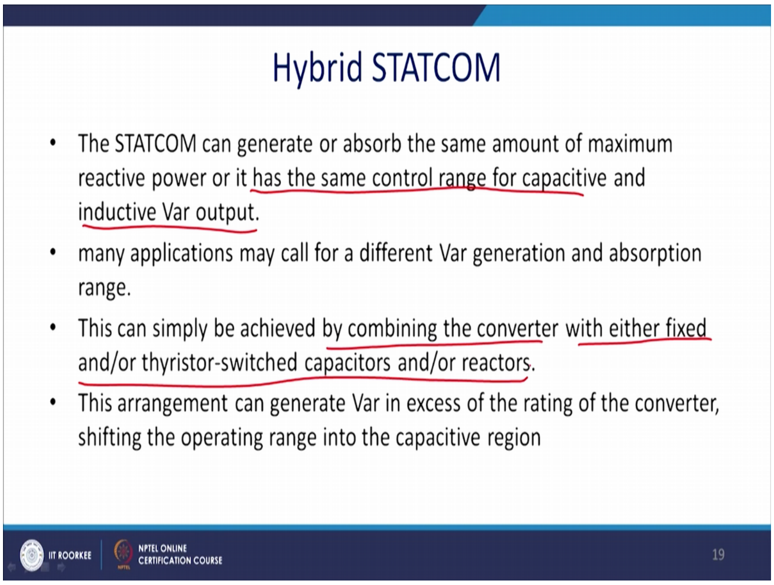

So, let us now come in to the important point, this is called hybrid STATCOM. A hybrid STATCOM can generate or absorb same amount of maximum reactive power or it has same control range of capacitive and the inductive output. So, it can work in either directions to the same power rating. Many application may call for a different var generation and absorption range, that is one of the practical consideration we have to keep in mind while designing the STATCOM. So, it can simply achieve by combining the converter with either fixed or the thyristor switched capacitor on the reactors.

So, it is a combination of the STATCOM and the SVC for this is called the hybrid STATCOM this arrangement can generate excess in var of the rating of the converter am shifting the operating point in to the capacitive region. So, essentially we most of the cases energy fed in to the drives thus it is inductive in nature. So, we require to feed the capacitive bar and thus this kind of arrangement is getting the attention as well as the popularity. So, for this reason what happen, you see that this is the STATCOM part.

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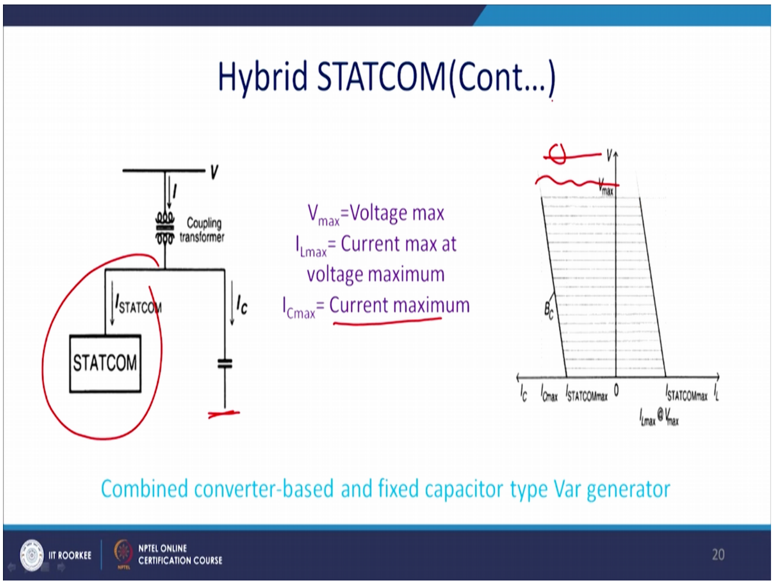

And paralelly you actually connect a capacitor mechanically couple capacitor may be or the fixed capacitor or different kind of SVC. And thus what happen this region will shift you can compensate more that inductive current by feeding more capacitive reactive power and less inductive power. So, V max is maximum voltage that given by the rating, I max is the rating transform the devices and C max is the maximum current.

So, that will be an add on of the STATCOM, thus you can compensate and the slope basically will be more cheaper and thus you can compensate more reactive power. So, similarly it is possible to move the operating point of the STATCOM further into the absorption region by combining and converter and the shunt reactor. So, you have connected a series.

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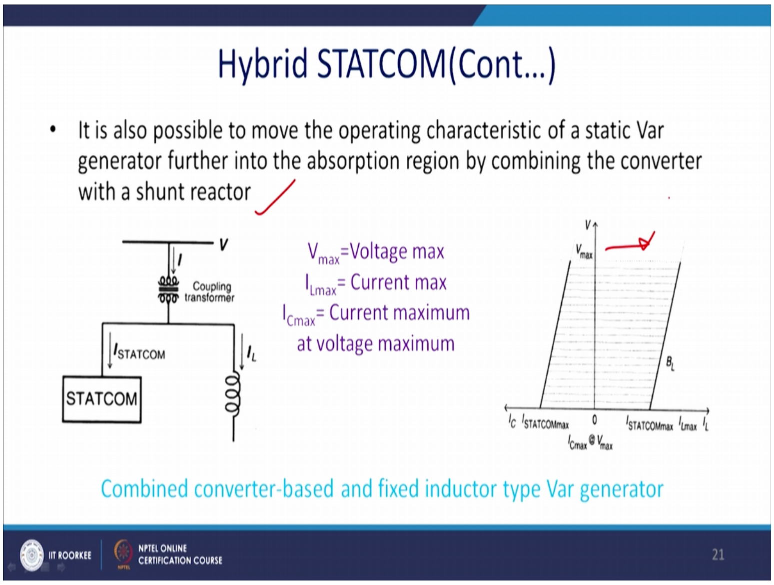

So, it will be coming this side and you have connected an inductor. So, it will be coming this side. So, not much difference just whether you are connecting an reactor or the capacitor that matters. So, other things are same.

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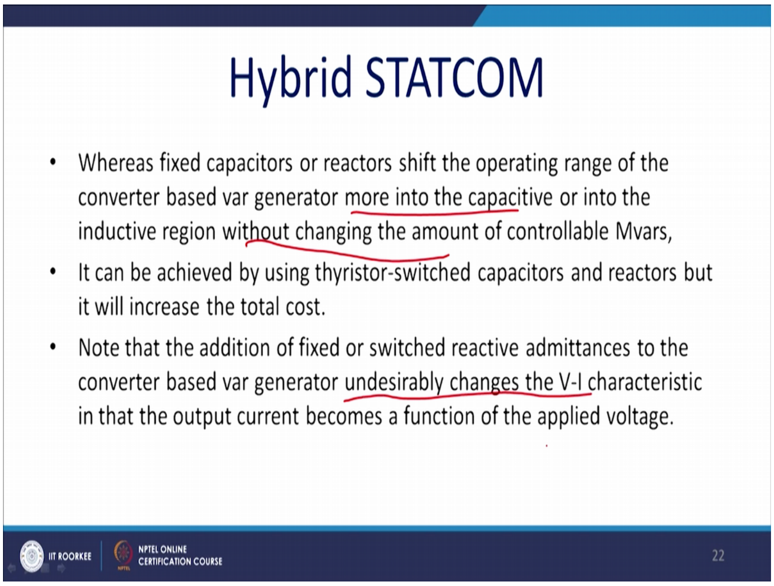

Now, what is the advantage of hybrid STATCOM? Fixed capacitor and the fixed reactor shifts the operating point to a level, converter based on the var generation more or the capacitive or in to the inductive region without changing the amount of the controlled

Mvar, but it just actually shifts the actually the y axis and it can be achieved by the thyristor switched capacitor or the reactor.

But it will increase the total cost of the system with is obvious state, but note that the additional addition or the fixed switched capacitor admittance due to this converter based generation. Undesirably changes the V I characteristics of that of the output current and output current becomes the function of that applied voltage problem lies.

So, what we have said that it can actually compensate at a very low power factor and all very low sac and all those voltage. So, these features actually will be diluted if we use the hybrid STATCOM, but you can increase the power handling capability reactive power handling capability of this transform.

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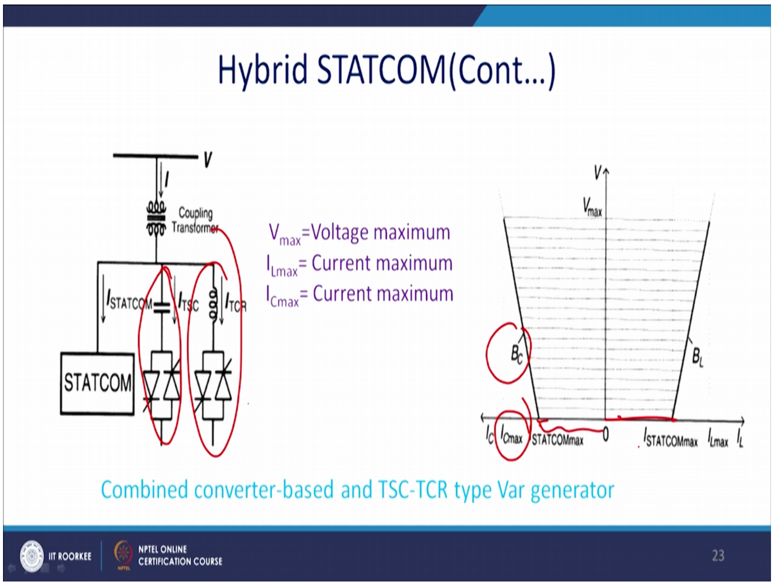

So, again you can put to balance it you can have the STATCOM that thyristor compensated capacitor thereafter can have a thyristor compensated reactor. So, accordingly then you can have a homogeneity, you can see that it is symmetric a y axis. So, you can have a v max value were zero current flows and thus you can have the slope BL and BC, but it will be shifted this side due to the essentially I STATCOM max, they have to IC max and this can go this direction without any contributions of this IL max or IC max thus both will add up and will give you the total IC max.

So, this is the principle of the operation of the hybrid STATCOM; now this is put in to the operation very well because of its enhanced reactive power handling capability.

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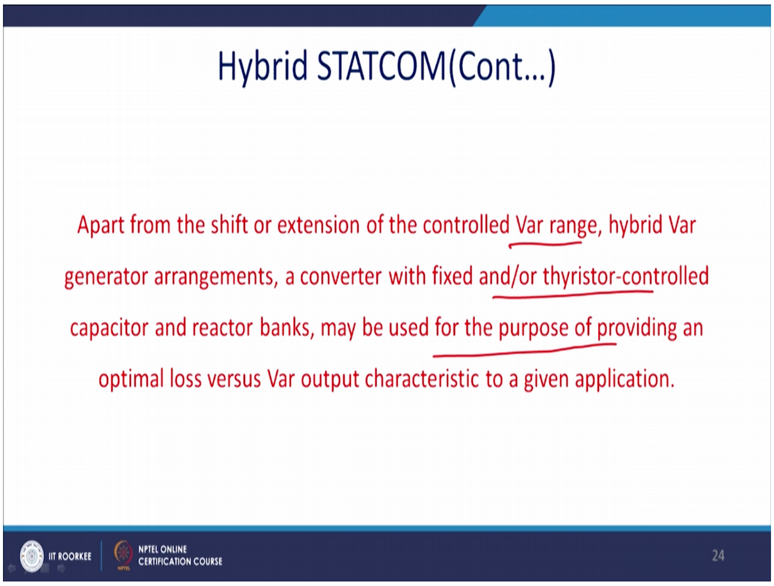

Now, what else apart from the shift or the extension of the controllable var range, hybrid var generator arrangement a converter with the fixed or the thyristor controlled capacitor or reactive banks, may be used to the purpose of providing the optimal losses verses var output characteristic given application.

Because switching losses in this case will be lower; So, we can design optimally what will be the solution for it some portion, which is dynamical changes will be in the STATCOM and some portion can be fixed this is the typical design problem for the facts engineers. Thus let us conclude it this is basically the hybrid STATCOM with 1 pu TCR and FC.

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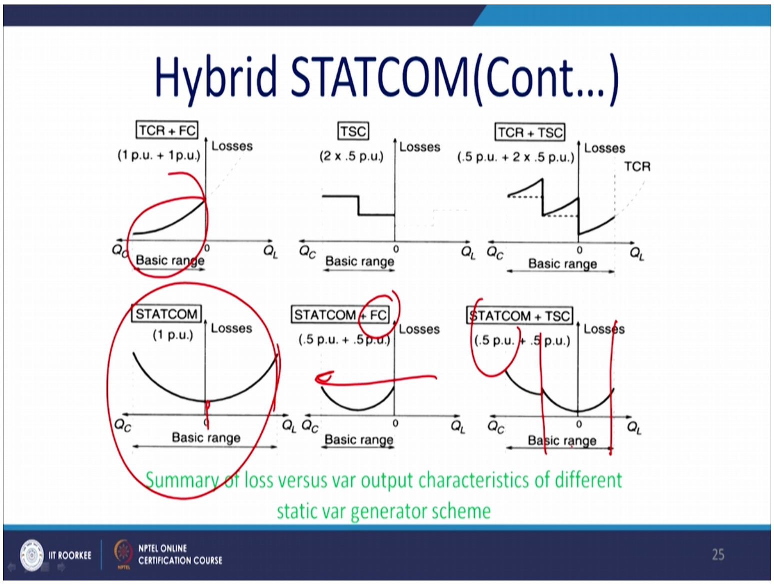

So, you will have this is the basic range and this is the losses and this is the TSC and this is actually TCR and TSC where will have a step changes we have discussed it and in case of the only STATCOM you will have this range of the losses because you have to maintain little bit of decibels voltage thus it is not 0, and in both the direction it increases.

And if you add FC a fixed capacitor so, this curve will be shifting this direction and it is in a operating only for a compensating the capacitive power. And if you put STATCOM and TSC this part is for the STATCOM thereafter TSC comes. So, this will add up this point characteristics. So, thus this explain the overall characteristics with a hybrid STATCOM.

Thank you for attention we shall continue our next discussions with the more compressor with the SVC and the STATCOM.