Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 15
STATCOM

Welcome to our NPTEL lecture series of Flexible AC Transmission System FACTS Devices. Today we are going to discuss another shunt compensation technique; by namely it is called STATCOM.

Today this will be our content or the presentation layout.

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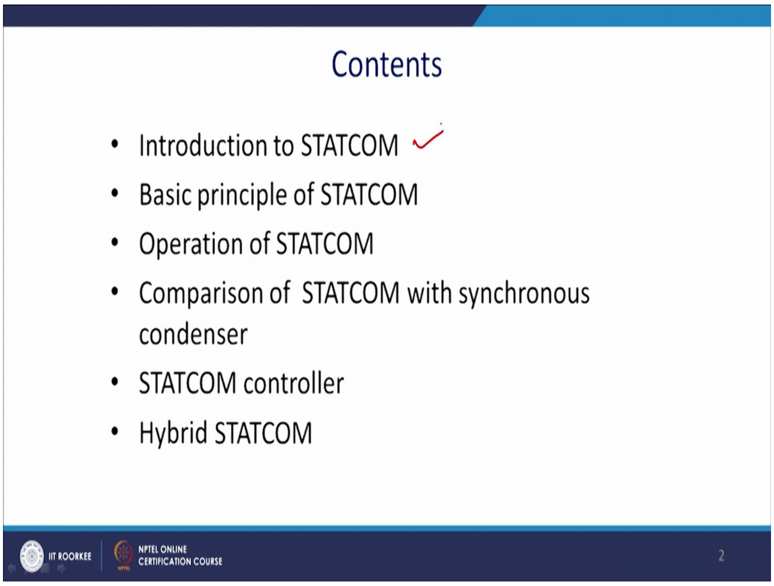

That is introduction to the STATCOM. Then the basic principle of operation of the STATCOM and then how it will be operated that is operation of the STATCOM? Comparisons of the, static solution with the rotational solutions STATCOM is essentially a static solution, and synchronous condenser essentially is a rotational solution. So, shall compare between both the 2 and what is advantage of the STATCOM? We will see that, then we shall discuss the how to design the STATCOM controller, then Hybrid STATCOM also will be discussed.

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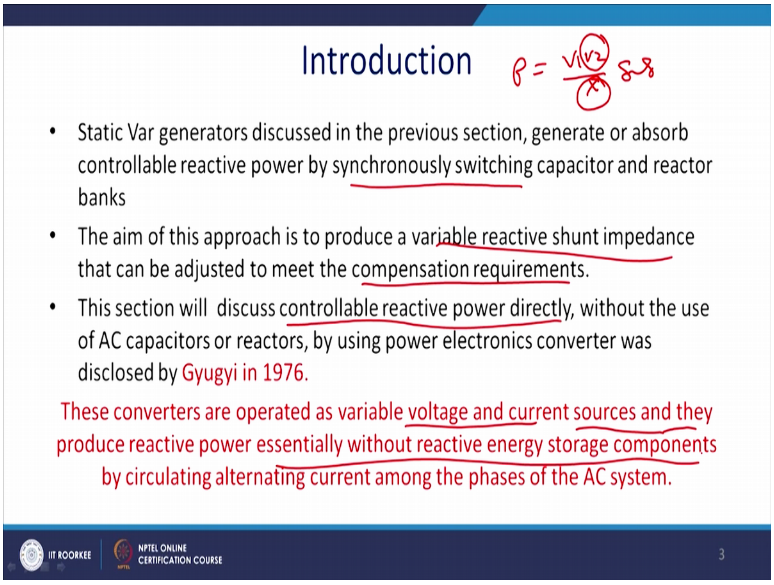

Now, static Var generation discussed in the previous sections S V C, generates or absorb controllable reactive power by synchronously switching the capacitor at the reactor banks.

So, this is the a principle operation of S V C, but here the aim is aim of this approach is to produce variable reactive shunt impedance and that can be adjusted to meet the compensation requirement. So, we change the actually you know that P equal to sending end voltage receiving end voltage by X into sin delta in case of the real power generally.

So, we generally change the value of X to change the actually power handling capability as well as the reactive power handling capability and the voltage stabilization. And this section will discuss controllable reactive power directly, we will not introduced any impedance we rather control the V 2. Without use of the extra capacitor reactor by using power electronics converter as discussed, by the Gyugyi who was the famous writer of the famous book of Hingorani and Gyugyi of the fact devices.

This converter are operated in a operated in a as a voltage source current control inverter or converter. Voltage source and the current control inverter, they produce reactive power essentially without any storage of the actually reactive elements.

So, inductor and capacitor will not be there that is a one of the basic advantage of this STATCOM. Essentially, without effective energy storage components by circulating the alternating current along the phase of the AC system so, it will be dynamically control and it will be faster in action than the S V C.

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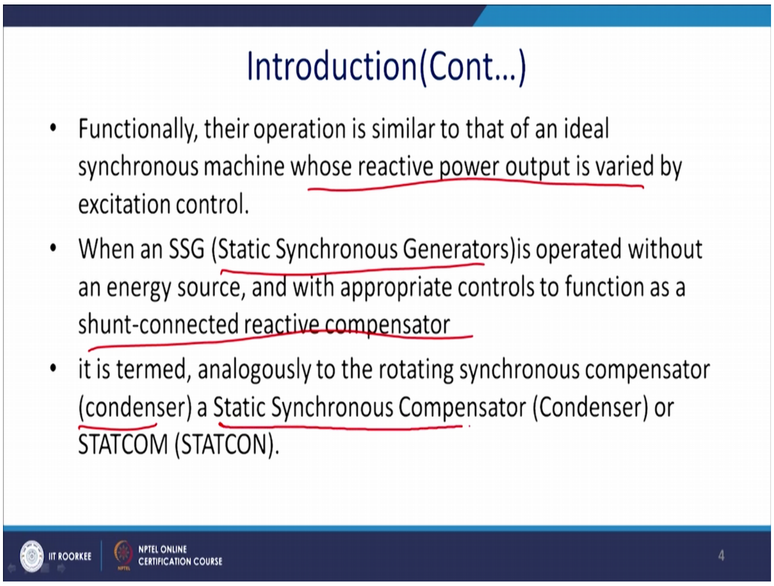

And functionally this operation is similar to the, to an ideal synchronous machine over excited synchronous generator if it is compensating the Var, whose reactive power output is varied by changing the field excitation. Essentially, you have a static solutions what you generally had the rotational solution?

When this static synchronous generator is operated without the energy sources, with appropriate control to a function as a shunt connected active compensator, where it is a rotational solution we have to we have to rotate the system as synchronous speed. So, which amount N H is consumed. Thus, that you see that how this terminology STATCOM came? Thus analogously rotating synchronous compensator or condenser and a static synchronous compensator, has been coined together and the what STATCOM is formed. So, essentially it is a stationary over excited synchronous condenser.

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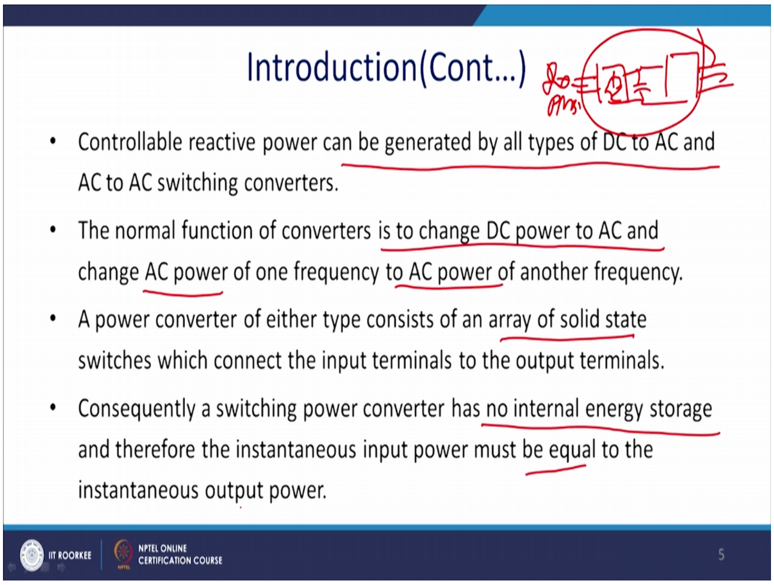

Now, how it works? It controllable reactive power can be generated by all type of AC and DC switching converters. Please understand that what essentially it do we know that it we you we know that, you have you may have a AC system may be it is a PMSM. Thereafter you have an inverter or converter that will convert the DC, thereafter you can convert into the AC.

So, you have for this reason all type of DC to AC and AC to AC switching converters is example and this task can be done by a matrix converter. So, that is a AC to AC converter. Here in this actually topology this converted as well as DC as well as AC we will see it how it has been done?.

The normal function of the converter is to change DC power to the AC and AC 1 frequency to the another frequency that is the actually the example of the matrix converter. The power converter either type it consisting of an array of the solid state switches, which connected into the input terminal the output terminal. Consequently the switching power converter has no internal storage capability. And therefore, instantaneous output power equal to the instantaneous input power assuming that the system the losses quite negligible.

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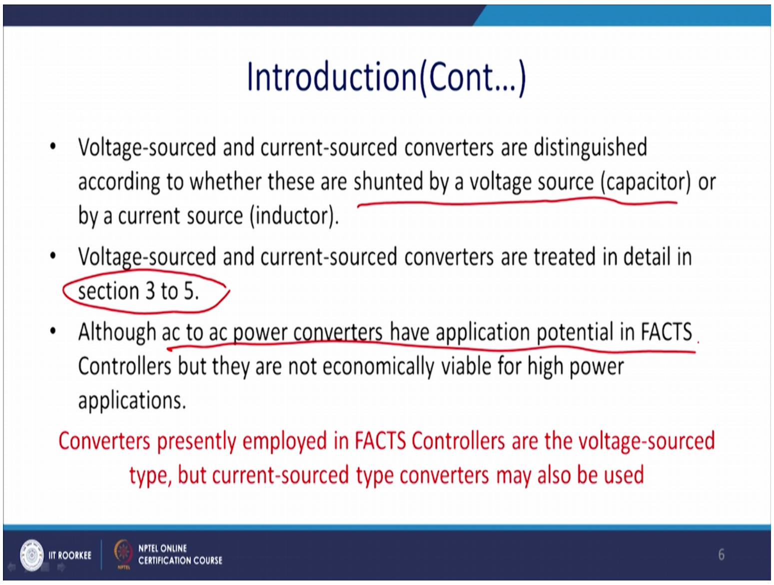

So, voltage source current control volt voltage source current control inverters or the converter distinguish according to whether the shunted by a voltage source, or if you have actually the DC link is an inductor then it will be a current source. Both the topology is possible, but voltage source is actually more advantageous and it is it can handle huge amount of power, otherwise size of the inductor and the cost of the inductor will be too high for this we will prefer the voltage source converter.

Voltage source and current source converter are treated we have already discussed in this in the our lectures 3 to 5. So, we are not elaborating date here, but and we have stated that actually this sections is been actually in this section. So, here we will see that actually we will mostly consider on the voltage source converter.

Although, power to AC to AC power converter have an applications in a facts devices, but they are not economical for the and it is not viable for the high power application. We know that when we have a we have a AC to AC converter we required to use a matrix converter, if it is a matrix converter it will have a 9 switches and single switch cannot handle that kind of power.

So, we require to cascade it so, number of switches will go high. And, for this reason we cannot apply this converter S to AC converter for very high voltage applications. Though the material of is coming like silicon carbide based material, which may be enable us to use higher rating till now, it is not been practically used. Converter present the employee enough facts controller are for this reason, voltage source type voltage source type and current source type also may be used in a few cases, but mostly they are voltage source type.

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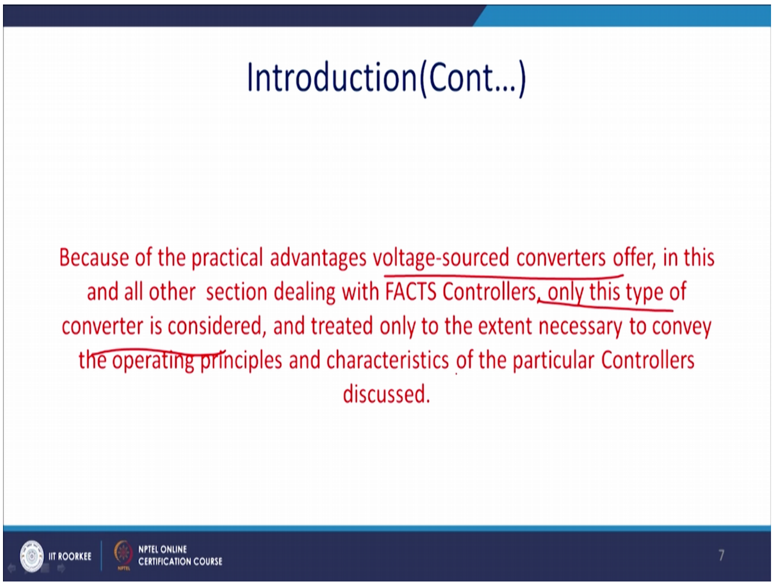

Because of the practical advantage of the voltage source converter it offers and all the other section dealing with the facts controller. Only this type of voltage source type of converter is been considered and treated to the extent necessary to convey the operating principle characteristics and the particulars of the controller here it will be discussed.

So, we will restrict our discussion limited to the voltage source converter and that is more practicable as well as more used in actually practical application.

Now, let us come to the point of basic principle of the STATCOM basic principle of the reactive power generation, by the voltage source converter is same like to the conventional rotating synchronous machine.

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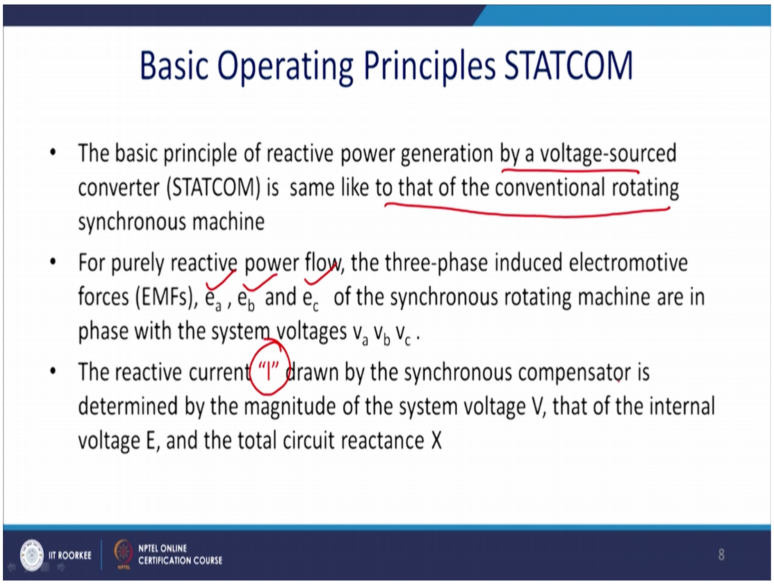

It is there is no difference in it actually, but is a static solution and it is a dynamic solution rotary solution. The purely reactive power flow the 3 phase induced electromagnetic forces e a e b e c of the synchronous rotating machines are in a phase with the system of V a V b V c.

The reactive current I we shall derive it drawn by the synchronous compensator is determined by the magnitude of the system. Depending on whether e is more than V and vice versa system V and that of the internal voltage or the back m f e and the total circuit reactance is treated as X. So, thus what will happen you know that the reactive current that is I equal to V minus E by X and If E or it is it should be the difference, it may be E minus V by X. So, direction of the current will change.

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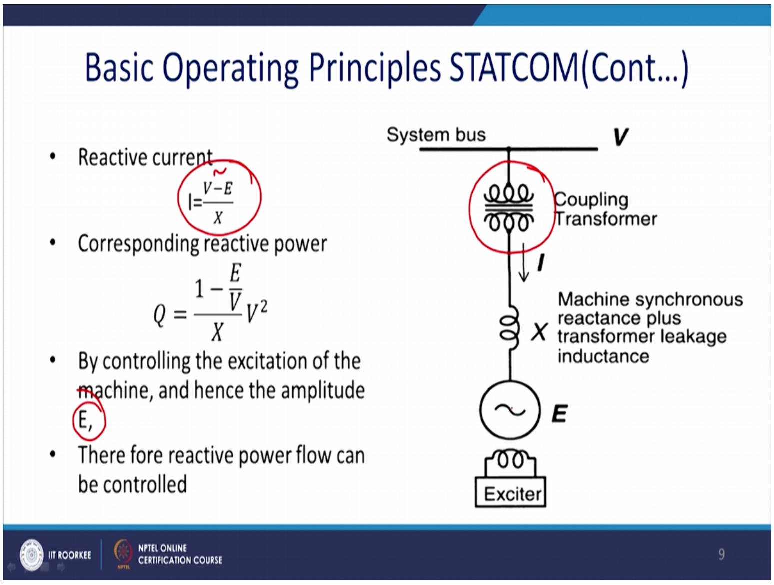

And, thus corresponding to the so, corresponding reactive power will be given by 1 minus E by V by X into V square. By controlling the excitation of the machine hence the amplitude of the E can be controlled and thus therefore, reactive power flow can be controlled.

So, this is the principle operation of the rotational transformer and same thing we can use in case of the STATCOM. So, generally we require to use a full control switches. So, for this is in rating is also a questionable one, for this we prefer for the low frequency application G T O and little high frequency application IGBT and thus for this reason we require to connect coupling transformer.

That essentially reduce the operating frequent operating voltage of this devices and the machine synchronous reactance is X and you have a exciter this is the rotational solution of the synchronous condenser. We will have a same thing, but it will be replaced by a static switching device that is the STATCOM.

So, how what is a principle of operation that I just we have told let us formulate in a moresystematic manner.

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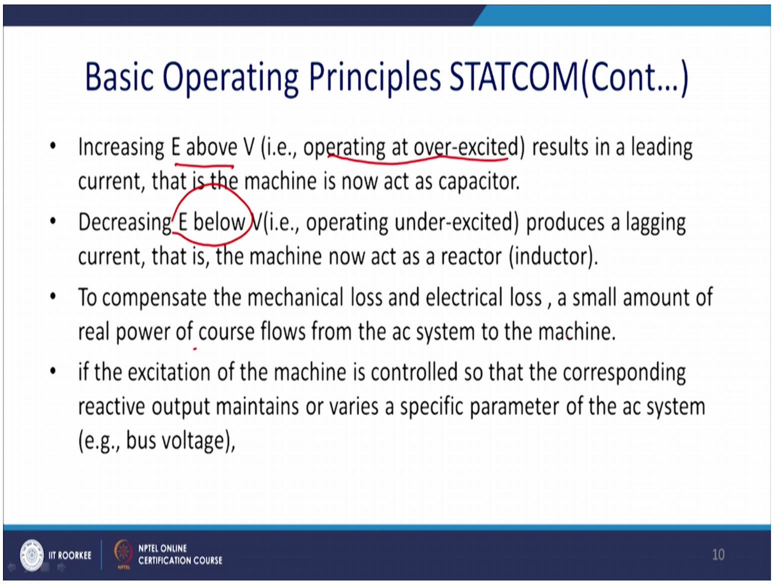

Increasing E above V the operate it is in a over-excited state. Thus result in leading current and that is the machine now acts as a synchronous condenser or a capacitor. Decreasing the value of the E below V the operating as under excited, producing the lagging current and that is a machine acts as an inductor or the reactor.

To compensate the mechanical loss and the electrical loss small amount of the real power actually flows to the system to the machine and that is to meet the losses. If, the excitation of the machine is controlled so, that the corresponding reactive power maintains or the varies in a specific manner to the system or the bass, then we can actually generate the requiredrequire reactive power required by the bass.

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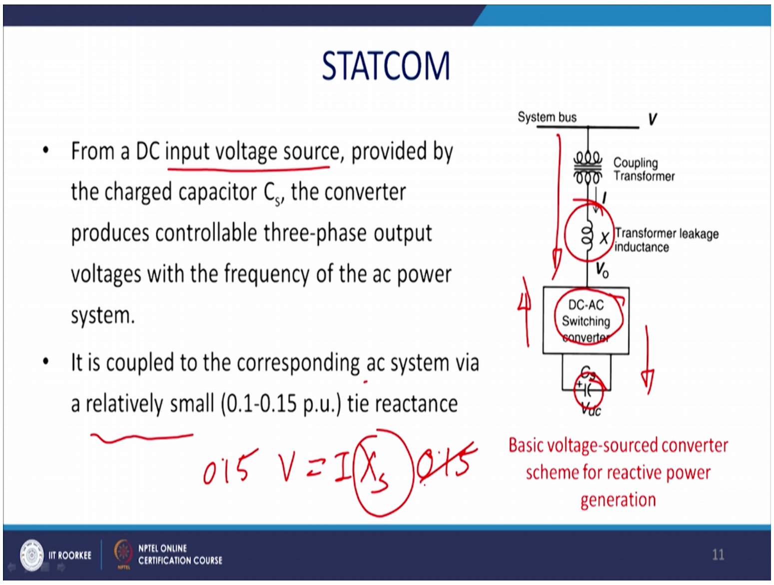

Now, what is STATCOM the principle operation will be same, but here you will have DC to AC switching. So, here also have a actually AC to DC switching we will have a both generally it will in this direction. So, these devices will acts as a converter. So, it will convert and DC energy it will convert to the DC voltage and in this direction it will generate AC.

So, bidirectional energy will be actually propagating. Here and that is we require a bidirectional current should be bidirectional and that is a features of the one of the voltage source converter, from a DC input voltage provided by the charged capacitor C S, and generally you do not have any extra sources here.

The converter produces controllable 3 phase output voltage with the frequency of the AC power system. And, it is coupled to the corresponding to the AC system via relatively small reactance this reactance is basically this is generally 0.1 to 1.5 of p u of this value.

So, sometimes student ask how to design the inductor of this STATCOM. So, range of the X should be varying to 10 percent to the 15 percent. So, you know you have a base voltage V. So, I I will be the rating of this devices, whatever rating of the devices depending on the factor of safety you will choose the rating of this actually the STATCOM or the power rating of the STATCOM into X S.

So, from there and into 0.15 sorry so, this is this will be here only into 0.15. So, from there you can calculate the value of X S and thus you can calculate the value of the inductor. So, generally the reactance value will be actually 0.1 to 15 percent 10 percent to 15 percent of this of these base voltages.

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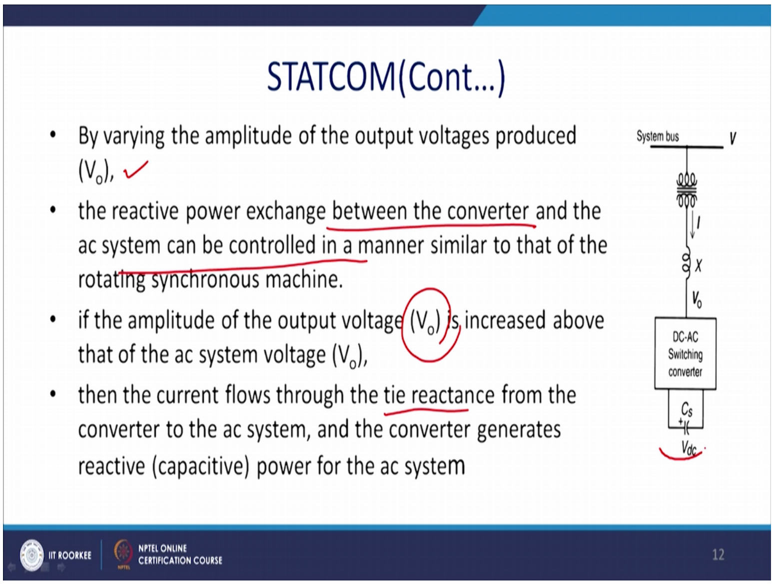

Now, by varying the amplitude of the output voltage produced that will be V 0 when please remember that it is a PWM converter. So, you are switching generally and in may be a multilevel inverter most of the cases. The reactive power changes between the converter and the system can be controlled in a manner similar to that of the rotatary synchronous machine.

If, the amplitude of the output voltage V 0 is increased above the system AC voltage. Essentially, it will acts as a synchronous condenser, then the current flow through the tie reactance from the converter to the AC system and the converter generates the reactive or the capacitive power to the AC system.

This is the principle operation and thus for this reason this voltage require to be higher than the rectified DC voltage. Generally, it will be thirty percent higher depending on the how much you are going to compensate. Now, if the amplitude of the output voltage is decreased below that of the AC system.

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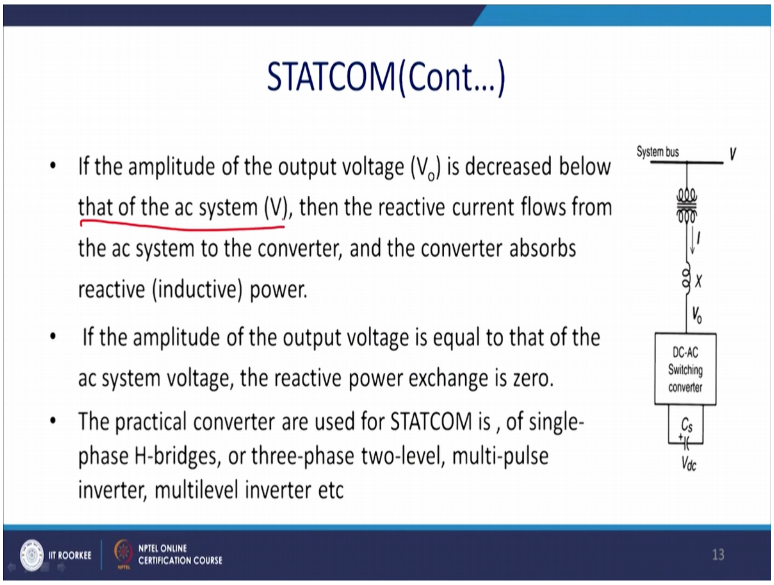

That is a quite clear case; sometime nowadays actually STATCOM is fitted with the solar panel to also supply in case of the distributed generation. So, supply the real power. Then sometime when actually you do not have when actually radiation goes low then this kind of situation may arise. So, your voltage dc link voltage is less than the rectified voltage, then what will happen? Then essentially you will inject the reactive power, the reactive current flow from the AC system to the converter and the converter absorb the reactive power.

If, the amplitude it is in a floating condition generally we do not do that. If the amplitude of the output voltage is equal to the system voltage the reactive power exchange is 0. So, it is in a floating state. The practical converter are used for the STATCOM is a single phase H-bridge or the three-phase two-level or the multi-plus inverter, or multilevel inverter, depending on the rating and size of the inverter.

If it is connected to the high voltage, then generally it is a multilevel inverter, it may be a cascade H-bridge for that gives a flexibility, and it may be on G T O based converter. So, that can be a pulse can multi pulse converter. So, many kind of topology is possible here.

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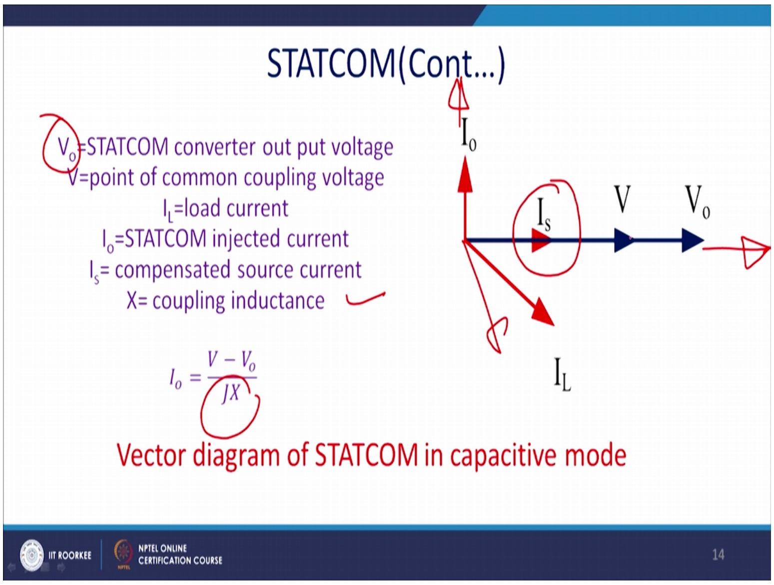

So, what happen here let us see? Let us consider that the output voltage of the STATCOM is V 0 and V the point of the common coupling voltage. What is point of common coupling? This point generally we say that P C C or this point.

Because, it is generally stepped it down by a voltage. And I L is a load current and I 0 is a current injected whereas, STATCOM generally it will lead in case of the V 0 is greater than system voltage. And I S is the compensated source current and X L is a inductor couple inductor.

So, I 0 essentially is V minus V 0 by X. So, from there this is a vector diagram we can see that our requirement is to maintain the power unity power factor that can be achieved by this. So, if you require to if it is this an essentially you require to increase V. So, that this V 0 will increase ultimately resultant will go to the unity power factor. Same way if you have a load leading current generally it is very few occasion you can have this kind of situation, but STATCOM has a this flexibility also.

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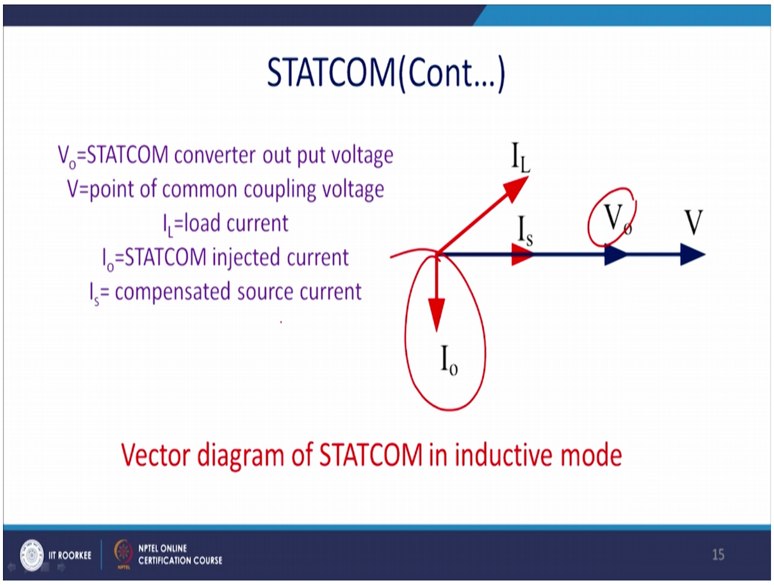

So, STATCOM converter output voltage is V 0 and the system voltage is V and I L is a load current which is leading, and thus STATCOM current will be lagging and it can make the current unity power factor.

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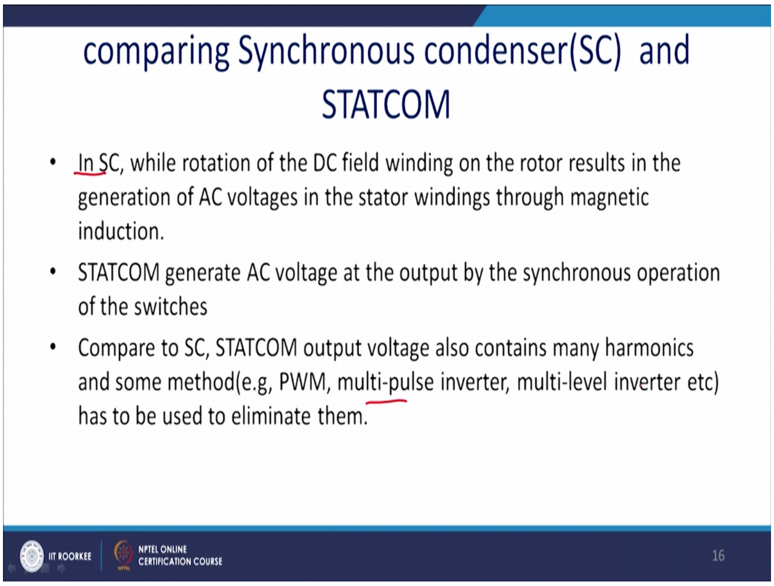

So, thus what we can say? So, what is the difference of the synchronous condenser and the statics and the STATCOM. Synchronous condenser generally have a huge amount of energy requirement in SC the while rotating the DC field winding of the rotor results in the generating the AC voltage in the stator winding through the magnetic induction.

So, since it a rotating part it require the maintenance. STATCOM generate AC voltage to the output by synchronous operation of the switches. So, that is a static in nature. Compare to SC the STATCOM output voltage also contains many harmonics due to the switching harmonics mainly.

But, please understand than you know power system is a low pass filter thus the switching harmonic will automatically mitigate or you can pass or you can put actually a low actually low pass filter. So, ultimately those harmonics will sink. And, some methods of P W M, multi-pulse and multilevel inverter, etcetera has to be used to eliminate. May be you can use also selective harmonic elimination technique, if you are dominating harmonic to eliminate in that way we require to suppress the harmonic.

This is one of the disadvantages of the STATCOM that it generates the switching frequency harmonics. And what are the advantage of it, it is faster in response because you know that is the STATCOM generally this over excited synchronous generator has inertia. So, this in so, if you wish to change the voltage it cannot be done instantaneously, it will take a certain amount of time to response it.

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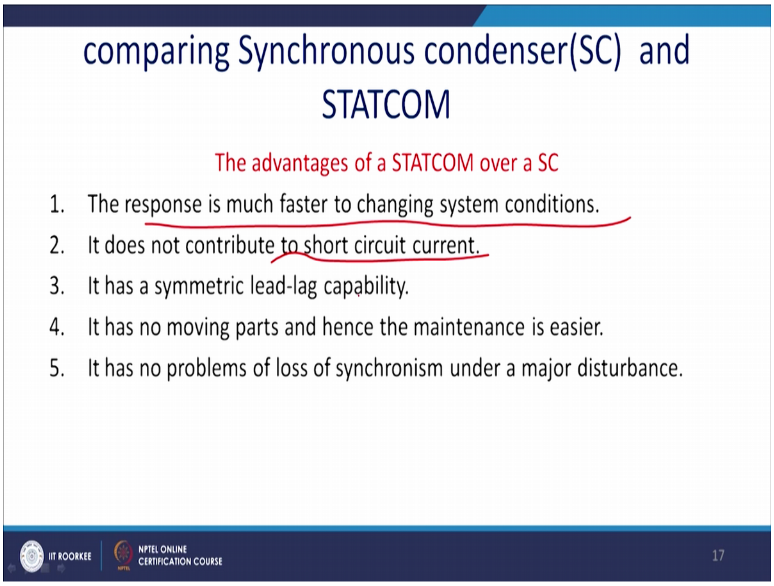

For this reason there is a response time is much faster than the changing the system condition. So, you cannot change very fast the I at the operating condition.

It does not contribute to the short circuit current, it has a symmetric lead and lag capability. So, both in a symmetrical nature, it has no moving part and thus maintenance is easier and we can put a redundancy of this by putting only extra lags or something like that. So, that you have a more reliability.

It has no problem of loss of synchronization, because if sometime let say prime over is required to be shut down, because of the low power flow of the steam or water whatever may be. So, this kind of situation does not arise under major disturbances. So, it can operate by itself and it just require the getting pulses of the switches thus it require a very less energy to work on. Operation of the voltage source converter generally we use a voltage source converter at the STATCOM.

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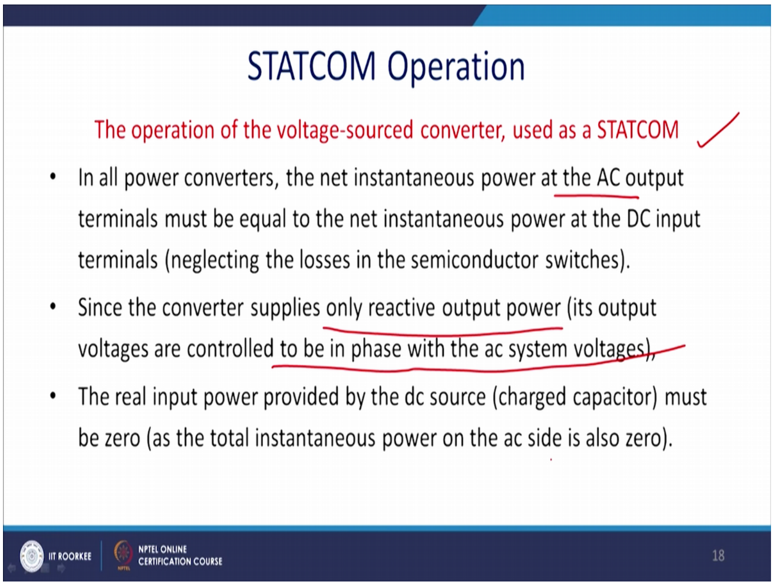

So, for this it is mentioned that operation the voltage source converter at STATCOM. The in all the power converter the instantaneous power at AC output terminal must be equal to the net instantaneous power at the DC output terminal, neglecting the switching losses and other losses neglecting the losses of the semiconductor switches also the hysteresis and (Refer Time: 24:35) losses of the coupled inductor and also those things.

So, this should balance. Since converter supplies only the reactive power, it is output voltage is controlled to be the phases with the system voltages. So, this is the one of the requirement. The real power is provided by the DC source or the charged capacitor must source must be 0 as the total instantaneous power AC side is always 0. So, thus you require the DC source to fit only the losses, because you are actually supplying the reactive power you are not supplying any real power right. So, for this reason you should have a 0 DC voltages.

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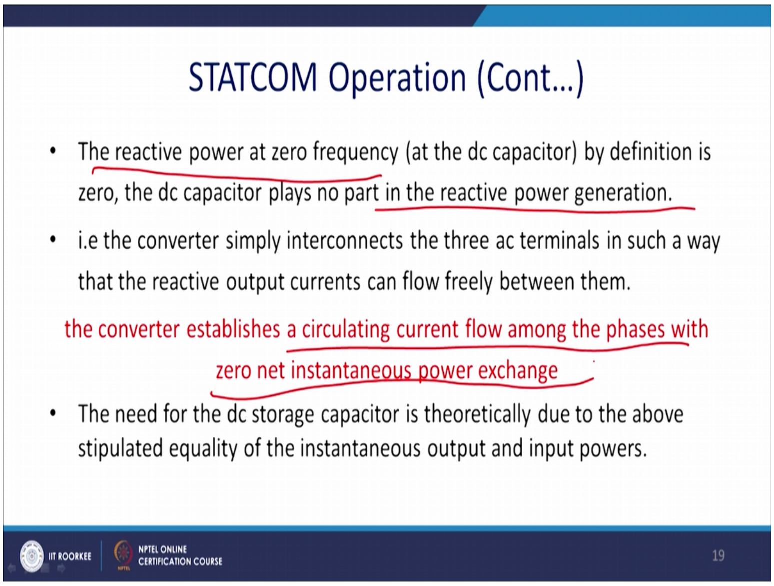

Moreover, reactive power at 0 frequency by definition the reactive power at 0 frequency at that capacitor by definition is 0. The DC capacitor plays no part in fitting the reactive power generation please note that. So, DC capacitor and nothing to do with the reactive power generation. That mean the converter simply interconnect this 3 terminal in a such a way that produces the reactive power. In such a way the reactive power and the voltage and current has to be made at 90 degree phase shift.

So, in individual phase voltage and a current and thus it produces the reactive power for this reason this is a beauty of it the converter establishes a circulating current among this phases with 0 net instantaneous power exchange. So, this is one of the major features of the STATCOM and thus it handles very low amount of real power that real power is just to meet the losses.

So, for this reason the need of the DC storage store is theoretically not required is theoretically due to the above stipulated quality, and instantaneous output and the input powers right.

So, this is a this is advantage of it you do not require any reactive storage element in case of the STATCOM, that is a very big advantage, the system become compact for this reason.

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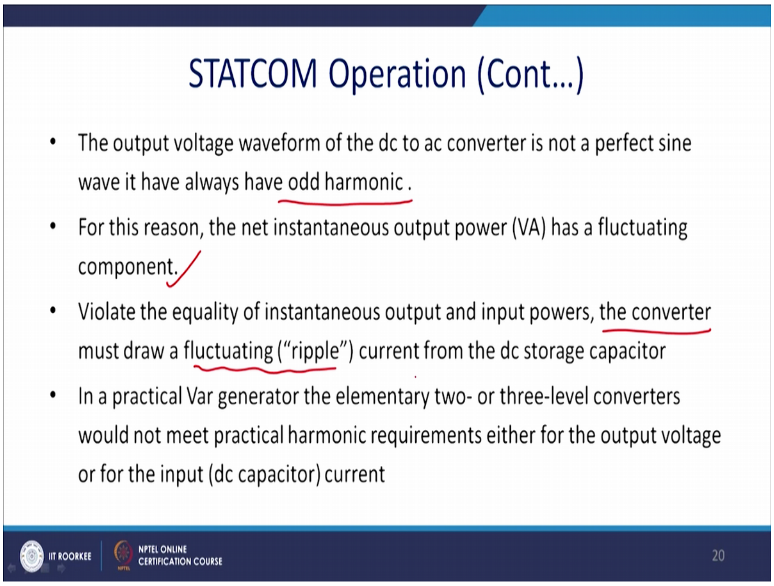

And so, the output voltage wave form of the DC and the AC power is not perfect sine wave and it had always have a odd harmonic, depending on the symmetry we can we can actually eliminate the even harmonic, but odd harmonic will be present. And for this reason the instantaneous output power has a fluctuating component.

Violate the quantity of the instantaneous power and the input power the converter must draw a fluctuating "ripple" current from the storage capacitor that is something you require to fit that is basically the ripple power, that will be 0 over a period of time, but instantaneously there is a power available. In practical for this reason the Var generation the elementary 2 or 3 level converter would not meet the practical harmonic requirement, either to the output voltage or the input DC capacitor current.

So, for this reason essence is that we require to use multi pulse or the multi-level inverter. Thank you for your attention we shall continue with our next discussions with a STATCOM in a next class.

Thank you.