Flexible AC Transmission Systems (FACTS) Devices

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Lecture - 40
Practical Application and Conclusion

Welcome to our lectures on a Flexible AC Transmission System, today is going to be our last three lecture we shall see some practical considerations and practical installations of the facts devices, and we shall conclude the is the course.

So, nowadays there many facts devices are installed various part of the world. These are the three four facts devices has been installed In USA around 40 years ago still it is working thus it can talk about the reliability of the system.

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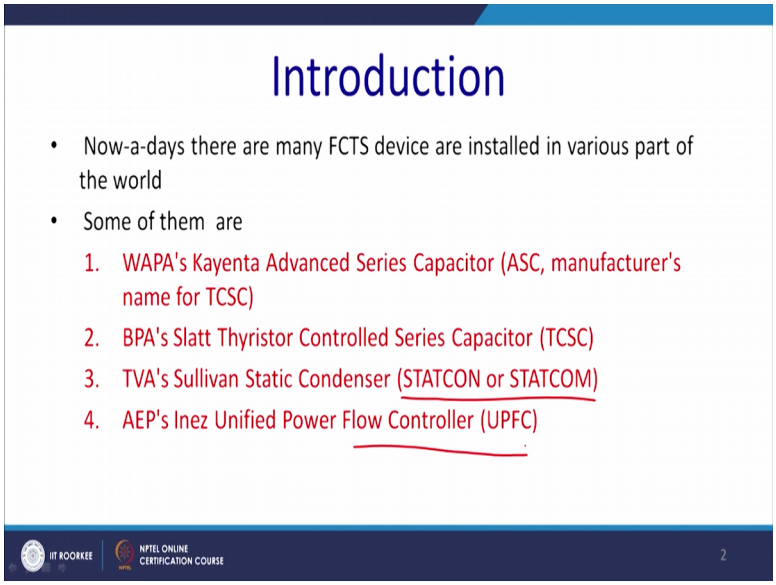

So, one is actually WPA advance series capacitors, that is actually they used to say it is a advanced is capacitor is essentially a TCSC. There after VPS slaughter thyristor controlled series capacitor and this is also TCSC, there after you have ATVR is the state basically shall be and state condenser that is essentially the STATCOM first put into the operation, and AEP first come out with the actual unified power flow condition.

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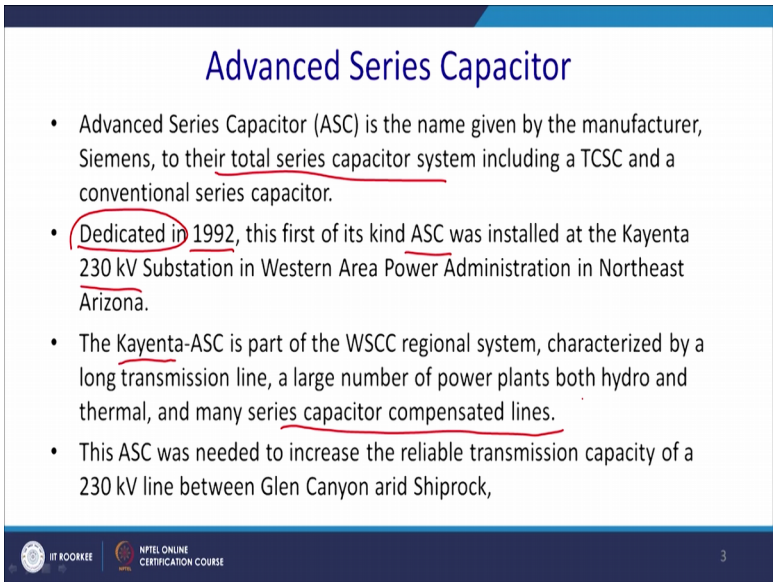

So, actually we shall take the out the first case, there is advance series capacitor as described the essentially it was the TCSC was name given by the manufacturer Siemens, there is the history behind it actually the writer of the famous book of facts devices you give me and the hingorani were both working in the Washington house, then that part of the basis was purchased by the Siemens and thus they become the part of a Siemens business.

To their Siemens to their total series capacitors system including a TCSC, and a conventional series capacitor that is mechanical interval. It was put into the operation in a in diplomatic term with your brocritic term wish we shall the dedicated to the nation, in 1992. This first of this kind of ASC was installed and it was installed in 230 kV substations in western area of the north the Arizona in 1992 thus. So, there after around 35 years ago, the advance condenser part of the WSCC regional system is characterized by the long transmission line. So, you can see that there is a delta difference of it, and a large number of power plant both hydro thermal and many series can series compensator was (Refer Time: 03:24) in that line.

So, for this reason that particular site was chosen for the shunt compensation for series compensations and fact devices was placed. And this a c was needed to increase the reliable transmission capacity of 230 kV line between the Glen Canyon and Shiprock. This is the two place we required to send power in between and thus replace it.

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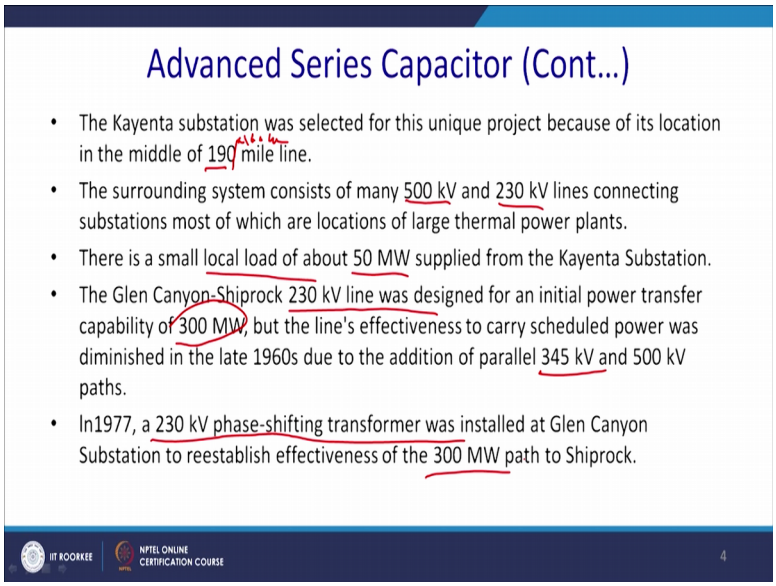

And the Kayenta substation was selected for the unique project because of its location or the middle of the line middle out 190 or 400 kilo meter line 190 mile or 400 kilo meter line.

The surrounding system consisting of many 500 kV and 230 kV line connecting the substations, most of which locations of the large thermal power plant and also there is a small local load about 50 megawatt, supply to the Kayenta substations, and Glen Canyon shiprock 230 kV line was designed for a initial power transfer of 300 megawatt, but you know it has been found this line effectively carry a schedule power was diminished in the 1960 due to the addition and of parallel line up, 345 kV and 500 kV path. So, actually its capabilities been reduced because of the parallel path.

In 1977, 230 kV phase shifting transformer was installed at the Glen Canyon substations and reestablishes the effectiveness of the 300 megawatt path line through this Shiprock. With the power transfer on the interconnected network approaches the transmission lines ability, to reliable serve the increasing load with the restrictions of the new building with the restriction of the building new lines.

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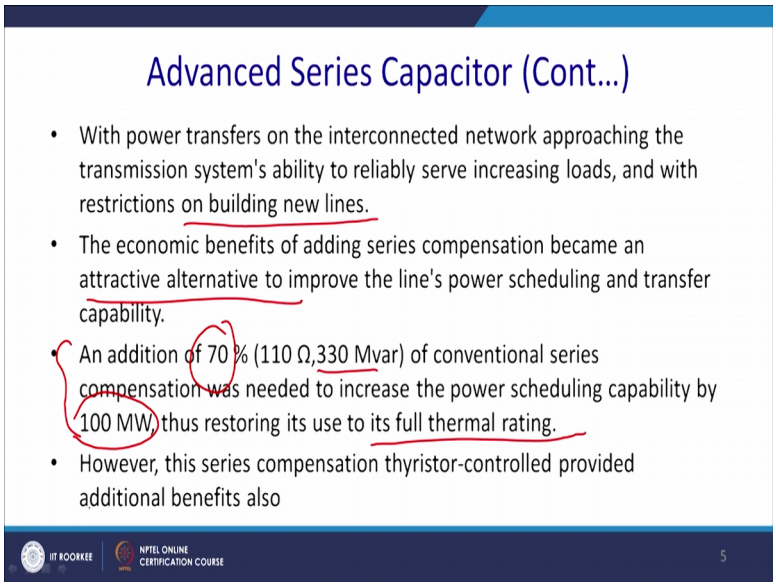

Because new line will have a lot of constant for this is we want that capability of the existing line required to be enhanced that is the basic philosophy of the fact devices.

The economic benefits adding a series compensation become a attractive alternative to improve the power lines scheduling, and transfer capability. In addition 70 percent that we knew no actually 110 ohm and 330 var 330 megawatt of the conventional series compensation was needed to increase the power scheduling capability by 100 megawatt. Thus restoring is useful of its full thermal rating. So, we have to check the thermal rating. So, these ensure that it is within the limit of the thermal rating.

However this series compensation thyristors controlled provide additional benefit also. We know that damping can be provided and all though all though this is actually the single line diagram of this ASC advance series compensator or capacitor.

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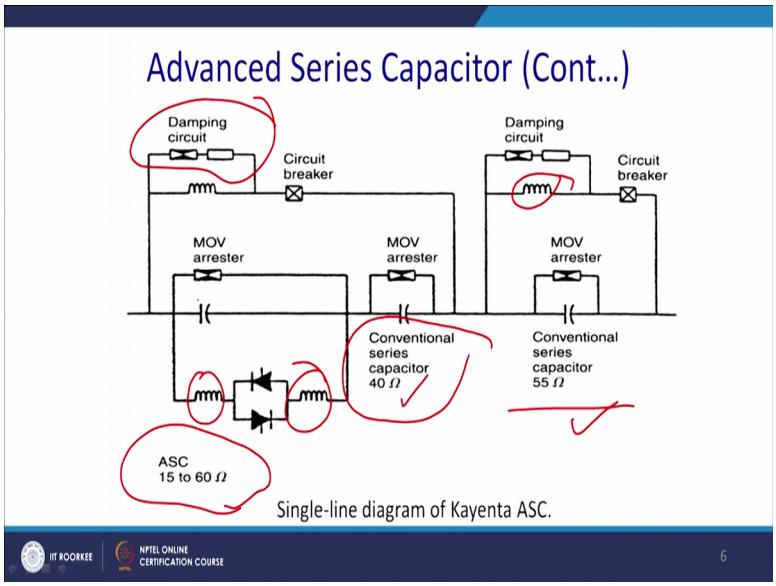

So, this is basically the damping circuit and this is a MOV and this is basically your ASC. Whose impedance can be changed to 50 to 60 ohm and there after you have a conventional series capacitor which had been placed to the line, and you have a circuit breaker placed with an inductor and you have also thus circuit breaker placed with an inductor, and this is the damping network. And this is basically the single line diagram of these facts devices.

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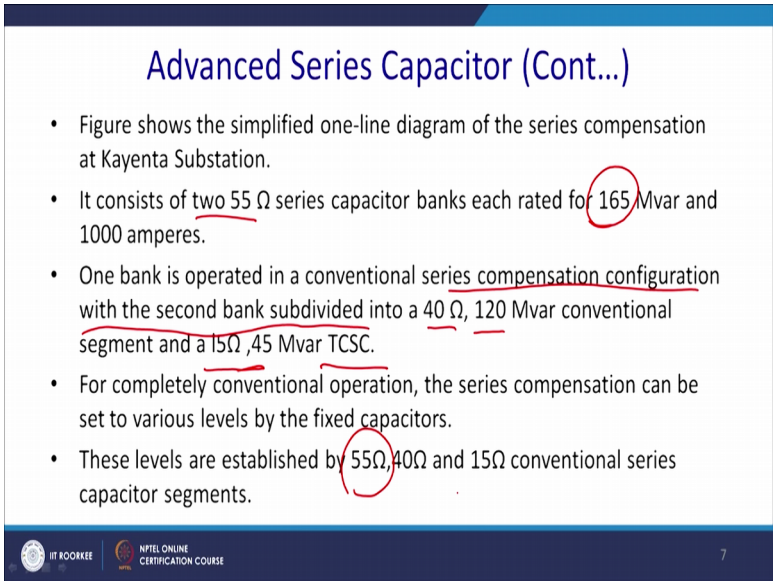

The figure shows a simplified one line diagram of the series compensation in this Kayenta substations. It consists of 255 ohm series capacitor bank each rated for 165 Mvar of 1000 ampere. One bank operate in a conventional series compensation configurations with second one bank sub subdivided to 40 ohm, 120 megavar conventional segment and 15 to 40, 15 to 45 ohm it is changeable megavar with TCSC. Thus for completely conventional operation the series compensation can be set to various level by the fixed capacitor.

These levels are established by 55 ohm, 40 ohm and 15 ohm conventional series capacitor system, you can see this. This is 55 ohm this is 40 ohm and this is generally 15 ohm.

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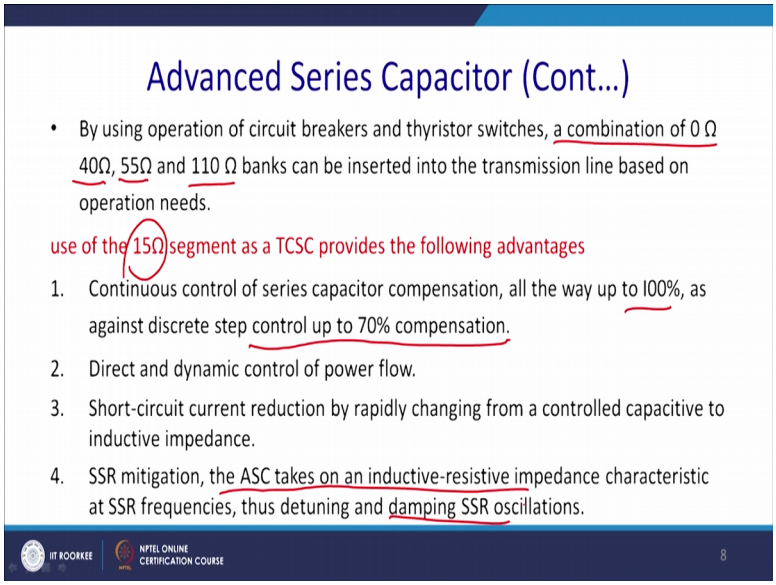

By using the operations of the circuit breaker thyristor switches a combination of 0 ohm, 44 ohm, 55 ohm 110 ohm banks can be inserted into the transmission line based on the need of the operation.

The use of 15 ohms segments, as the TCSC provides the following advantage what? Continuous control of the series capacitor compensations all the way up to 100 percent, as again the discrete step control of about 70 percent, direct and dynamic flow of power so, that is also possible; short circuit current reduction by rapidly changing the controlled capacitive to the in inductive impedance that can be done with the help of this segmentations.

So, you trigger it. So, at prevently current will flow through this inductor and we will bypass the capacitor and SSR means mitigation that is sub synchronous resonance or sub synchronous oscillations, the ASC takes and inductive resistive impedance characteristics at SSR frequencies; and thus actually detuning the damping of sub synchronous oscillation, that is basically upgrade cause of concerned in any power system network.

There after what else; improvement protections and rapidly reinsertion of the series capacitor during the fault system.

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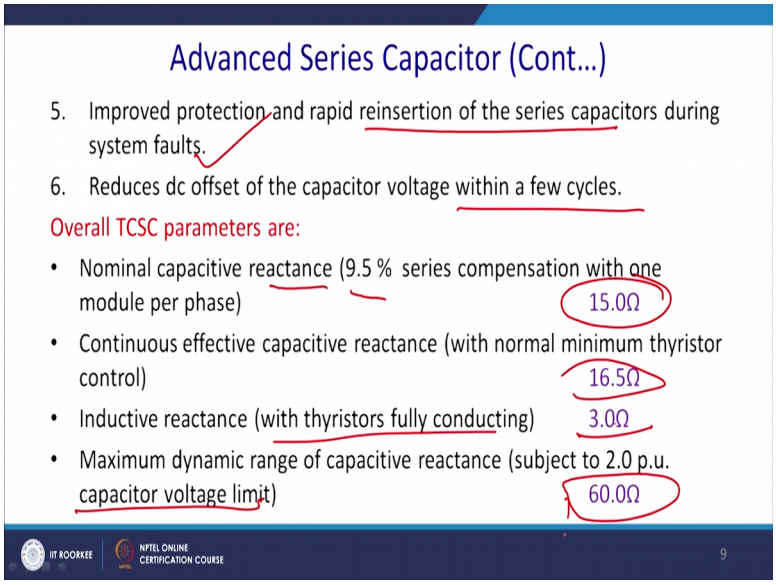

And so, thus what it will ensure that you know actually d c upset because you know it will block d c, will not presents. Reduces the d c upset of the capacitor voltage within the few cycle. So, these are the few overall TCSC parameters, nominal capacitive reactance 9.5 percent series compensation, with one module for phase it gives you 15 ohm, continuous effective capacitor reactance with nominal minimum thyristor control of 16.5 ohm, inductive reactance will fully thyristor conducting it is 3 ohm, and maximum dynamic range of capacitive reactance subject to 2 per unit of the capacitor voltage unit.

So, this is something insulation payment has been prescribed and that can go to this capacitive reactance equal to 60 ohm.

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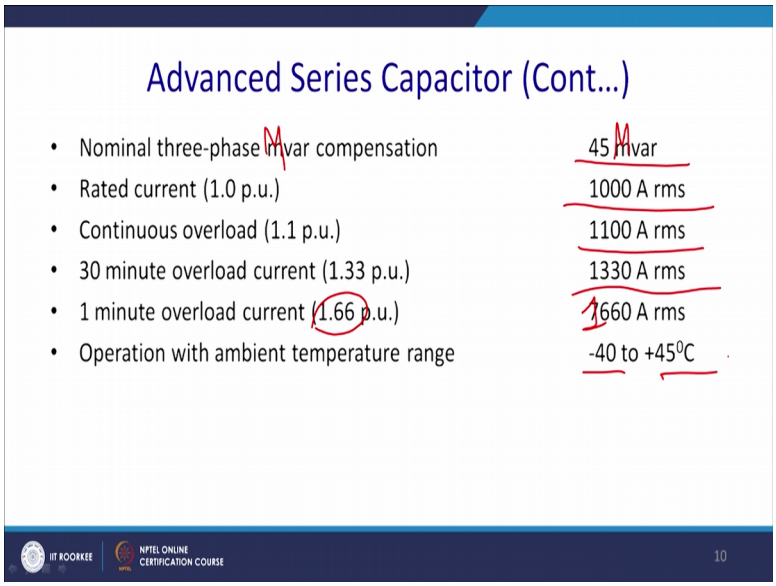

So, thus these are the ratings and thus these are the advantages also. Nominal three phase Mvar compensation it is 45 Mvar, current rating per unit has been chosen for 1000 ampere based, continuous overload will be around10 percent that is 1.1 it will be this value, and for 30 minute overload current we can go to the 33 percent more.

So, current can be allowed to flow about 1330 ampere, one minute overload current that should be actually this much of value and it should be actually 1660 amperes. And operation with the ambient temperature range will be 44 40 to 45 ampere.

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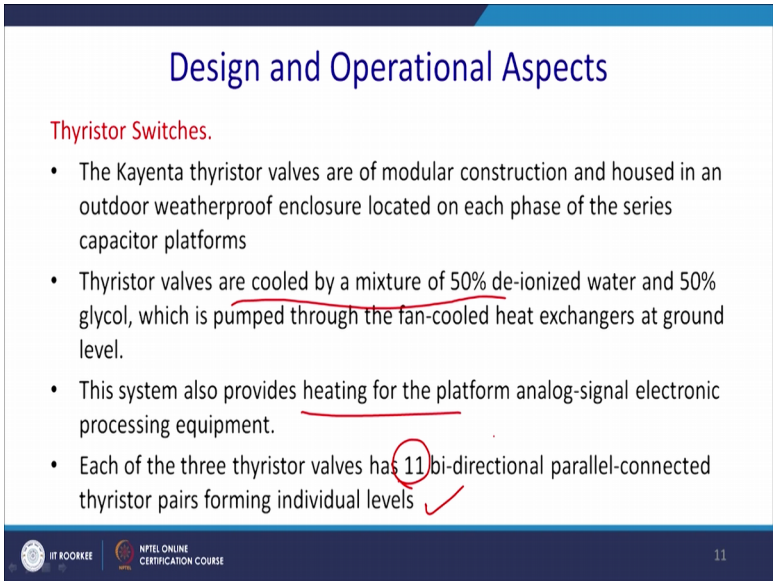

So, the Kayenta thyristor valves are of modular construction and housed in an outdoor waterproof enclosure located one each phases of the series capacitor platform.

Thyristor valve are cooled by mixture of deionized water and 50 percent glycol, which pumped through the fan cooled that made actual it is air cooled, heat force air cooled, heats exchanger and ground level. This system also providing provides heating for the platform of the analogs signal electronic processing equipments. So, it will also maintain the ambient temperature for those components. Each of the three thyristor valves has 11 by directional parallel connected thyristor pairs, forming individual levels and having a current handling capability of 100 ampere each that makes it basically the 1000 ampere.

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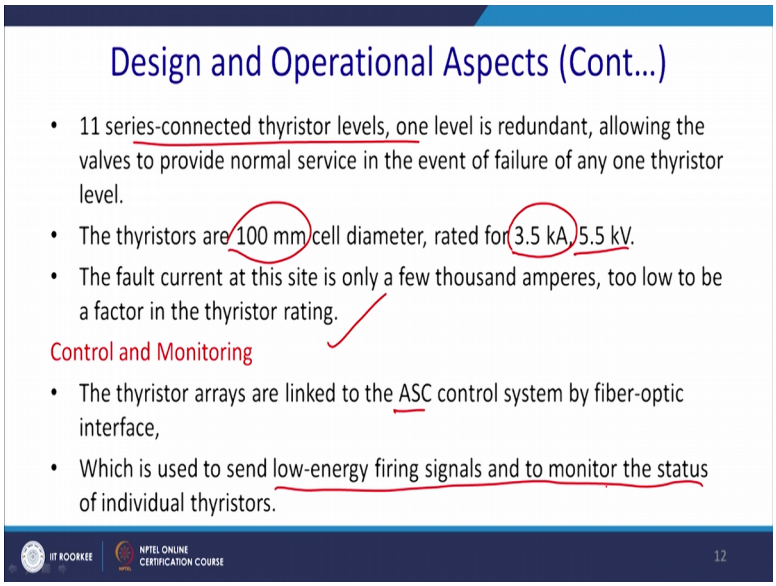

So, 11 series connected thyristor level. So, we have this is actually put into operation in 92.

So, you know actually the one of the oldest facts devices. One level is redundant allowing to allowing valve to provide normal service in the event of the failure of, any one of the thyristor module thyristors are 100 m m cell diameter and rated for 3 point k of 5 5.5 kV. The fault current at this site is only few thousands ampere to low to be the factor in the thyristor rating. So, this is the one of the reason that facts devices can be phase and the cost of the facts devices does not increase.

The thyristor arrays are linked to the advance control system by fibre optic interference, that gives you the rated required isolation and that helps you to operate from a distance also with scan over another interfacing requirement, which is used to send low energy firing signals and monitor status of the individual thyristors.

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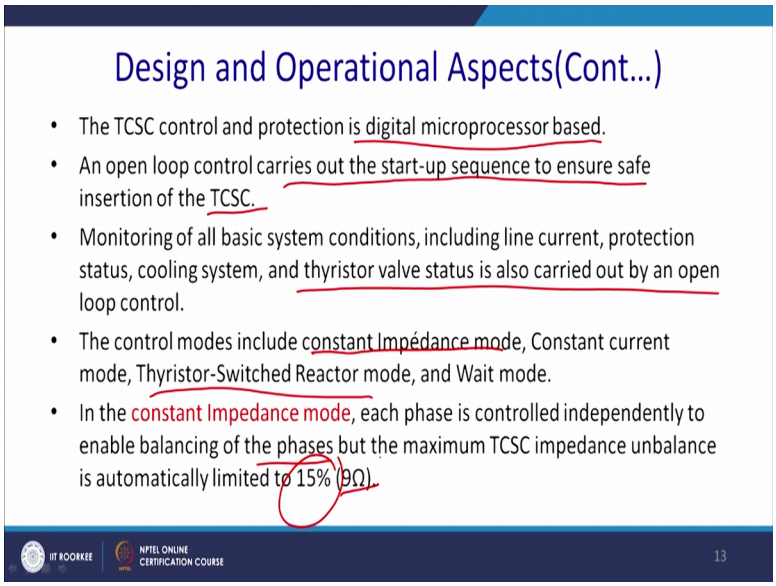

The TCSC control and protection is digital microprocessor based, the open loop control can its output startup sequence to ensure same insertion of the TCSC, monitoring of the basic system conditions including the line current, protection status, cooling system and thyristor valve status is also carried out by open loop control. The control module the control mode requires constant impedance mode, constant current mode, thyristor switched reactor mode as the wait mode.

So, it will change the status. In the constant impedance mode each phase control is independent to the independently to balance the phase, but maximum TCSC impedance unbalances, automatically limited to 15 percent that is equal to the 9 ohm.

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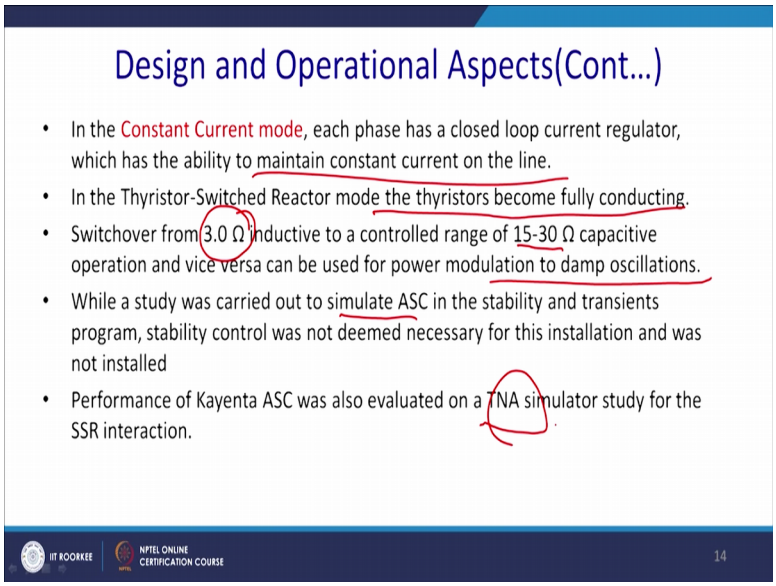

In case of the constant current mode each phase has a close loop current regulator, which has ability to maintain constant current in the line, but there might be a impedance this much and due to that load imbalance can be there.

Thyristor switch reactor mode is the thyristor becomes fully conducting so, that it is bypassing; the switch over from three ohm inductive to control range to 15 to 30 ohm capacitive operation and vice versa can be used for power modulation damping and oscillation. When it is required to be damping, then it will current will flow through LNR for reduce the SSR that is sub synchronous resonance. While the study was carried out to stimulate SSC stability and the transient program, the stability control was not deemed necessary for the installation and was not installed. The performance of Kayenta a ASC was evaluated with the another one.

So, I have one software called actually TNA simulator with the s r SSR insertion.

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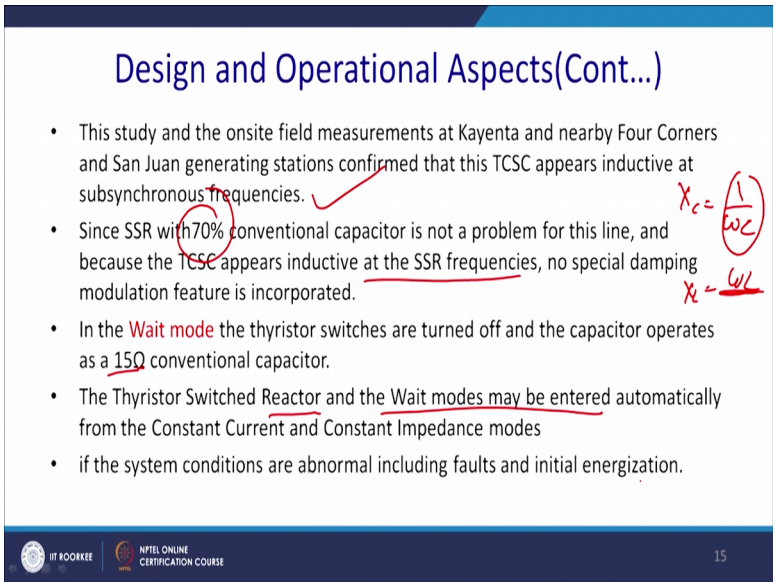

So, you have done it and we are it has been found that the study and the onsite field measurement of the Kayenta and the nearby 4 corner of the San Juan generating station is confirm that, this TCSC appears inductive in the sub synchronous frequencies. So, it has the capability to damp out the sub synchronous oscillations. Since SSR is with 70 percent conventional capacitor is not a problem for this line, and because this TCSC appears inductive at the SSR frequencies, no special damping modulation features is incorporated.

So, this is a inherent that is there has got a SSR damping features. Please understand that any circuit because you know capacity impedance generally it is bicycle X equal to 1 by omega c, and X L equal to actually omega L. So, what happened if frequency is reduced? This value basically is actually increased and this value is decreased.

So, essentially at a lower frequency what it is say you know the 70 percent. So, it will have it will offer huge impedance series impedance series capacitors, and it will do not have a much problem in the line right. The wait mode of the thyristors is between actually changing of the configuration, once you try to change one configuration to the another configuration it will take some time because there is a transient phenomena involved we have seen that TCSC actually required to switched on, minimum transient requirement. And the capacitor operates at 15 ohm conventional capacitor mode and that will ensure that transient field changes over.

The thyristor switched reactor and the wait mode maybe entered automatically from the constant current and constant impedance mode.

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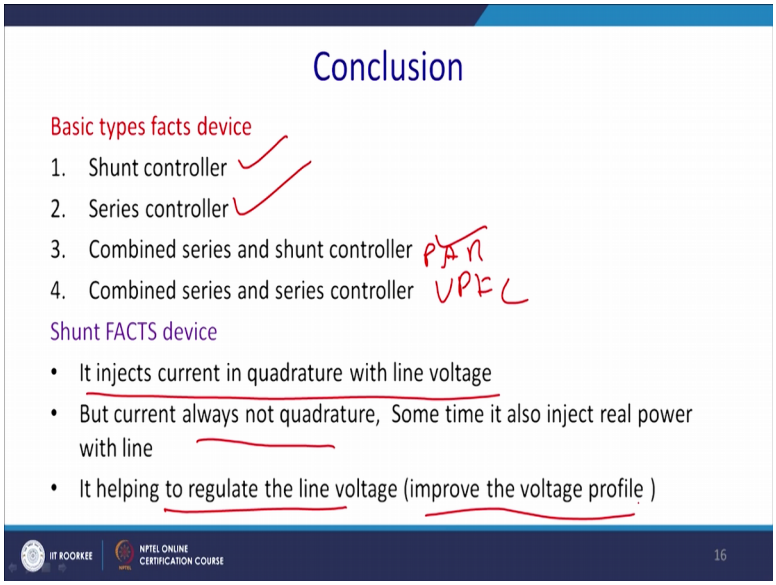

If the system condition or abnormal during fault or initial energization, then we can actually go for this change over this mode. So, we know that basic type of the facts devices are shunt controller, series controller power, power angle regulator, combined series and shunt controller combined series and shunt controller this is basically PAR and this is basically UPFC. Now we start discussing the overall facts devices and its philosophy.

So, what does this shunt controller do alone, it injects the current in quardature with the line voltage. Since, the current is not always quadrature sometime it is also inject the real power to the line, mostly to meet the losses of the switches and the different part of the circuits. And it helps to regulate the line voltage and improves the voltage power voltage profile.

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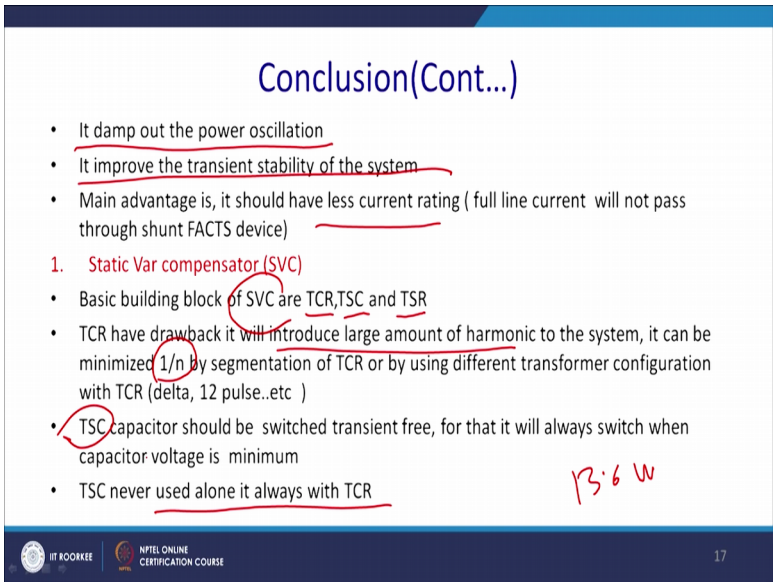

And what it can do? It damps out the power oscillation we have seen that you know actually while discussing the shunt that from the equal area criteria. So, it increases the stability as well as the rate can damp out the oscillation. It improves the transient stability of the system. Main advantage of the of the shunt phase fact devices is that, it should have a less current rating. So, only it sees the fraction of the current rating that required to be compensate the reactive power.

So, what happen you know that is a biggest advantage of the shunt devices that, cost of the shunt devices will be less it will we can gives you the good voltage profile, it can ensure the stability, it can actually suppress basically the problem of the transient. Full line current is not pass through the shunt type of facts devices then that is, but what is the disadvantage of it or what is the limitation of it I should not call it disadvantages it is the limitation, that it cannot enhance the power handling capability of the line.

So, basic building block of SVC that is a series valve compensation, is basically are that is TCR TCS and TCR. TCR have it we have seen just TCR have the drawback that will introduce a large amount of the harmonic into the system because of the switching, and it can be minimized by 1 by n segmentation of TCR by using different kind of transformer configuration like delta transformer with the different valves the actual valves, and multiple of the 3 36 valves in that way you can reduce these actually harmonic content into the system.

Another device we can use that is TCSC capacitor and it should be switched in transient frame out. So, for therefore, actually you have to wait for the time either it is the supply voltage or the voltage across this TCSC voltage across is capacitor is same or it is at the minimum. TCSC never used alone it is always is with a combination of the TCR. So, when fraction let us you require 13.6 Mvar to be compensate you know you will have let us say multiple of 2.

So, 7 TCSC will be open actually opened that will give you the value of the 14 capacitive Mvar and thus you require to compensate minus 4 m v r that definitely will come from actually TCR. So, in that way it will operate. So, we have seen that SVC can be classified as actually mechanically switches SVC fix SVC that you have seen right now as well as a TSC SVC.

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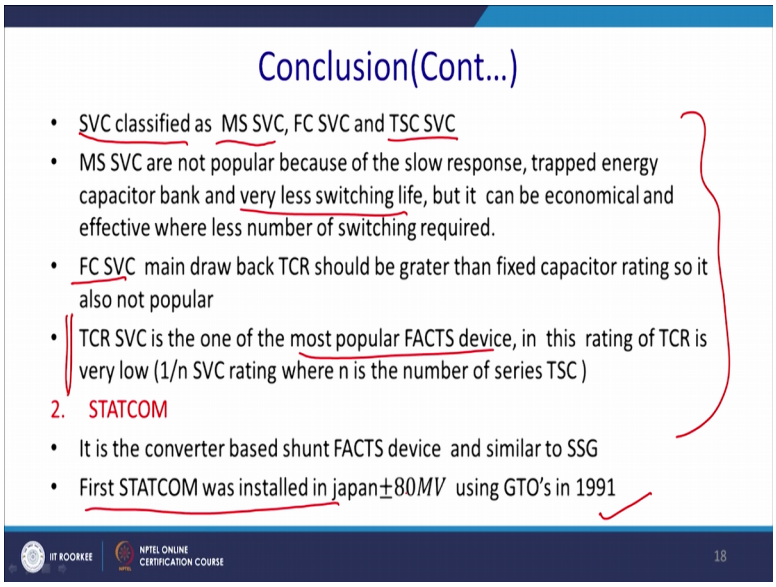

Mechanically switch SVC are not very popular because of the slow response, trapped energy capacitor bank and very less switching life, but it can be economical and effective where actually number of switching is less. Same way we can have actually fix which fix we FC SVC it is actually kept for the operation for the longer duration of time, and thus it will be keep on operating and advantage is definitely what we have seen recently that is actually TCR SVC. So, that is has a huge advantage and it is most popular fact devices in the rating on the TCR, and it is actually very low and we have the splitting of this rating by 1by n, where n will actually we have a modular switch.

And above all this shunt compensation this is basically a passive kind of devices, it is essential inject a passive component capacitor, variable capacitor, but we can have a solution with the STATCOM where it generates this actually reactive power and the current by manipulating angle between the voltage and current, and the STATCOM is definitely it is more preferred.

So, there is a figure facts; first STATCOM was installed in Japan above up to plus minus 80 megawatt within GTO in 1991. And these are the actually comparison with SVC and the STATCOM injecting current is independent of the AC system voltage, we have already discussed all those issues, but we cut recapitulate in conclusions.

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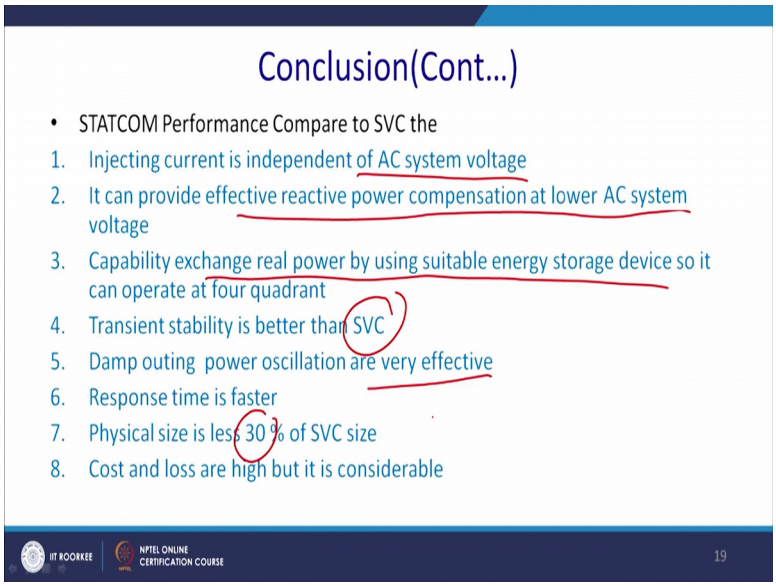

It can provide effective reactive power compensation at lower AC system voltage, it is same because voltage actually sag compensate it is independent of the voltage sag of swell. Capability of the exchange real power using suitable energy storage devices and thus it can operate all the four quadrant, transient stability is better than SVC, because you have to wait for in TCSC for the transient operation.

Damp out letting power oscillation is very effective, response time is very fast compared to this actually the passive element of SVC, basically size is around 30 percent less than SVC, and cost and losses are little high considered to the SVC, but with the invent of the new technology and the new switches and its rating ever increasing rating, we hope that this statement will change soon already have changed.

So, for high voltage applications can be implemented with the multi plus converter it is to be used, but for the, but it has a drawback, it required as zigzag transformer, and a polygon transformer will increase the losses and the cost of the system the. So, presentant is essentially to implement STATCOM with actually to suit the requirement of the voltage level we use actually multilevel inverter. Now let us talk about the fact devices it inject some voltage in quadrature with the line current.

So, it is always thought in quadrature and same for the actually the study shunt devices, sometime it also injects a real power with the line by using the energy storage device, it makes the system behave like a step voltage source.

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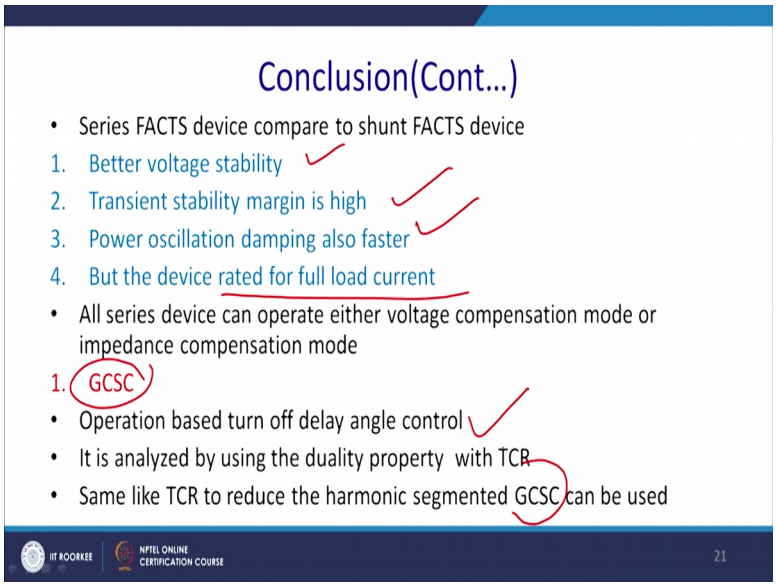

So, what does the series fact device can do? It provide better voltage stability, transient stability margin, we all have discussed all those issues in the series compensation, power oscillation damping, but one of the basic disadvantages that it has to provide the rating has to be rating in series.

So, it is series that total voltage and the current rating device will be rated for the full load current. The series devices can operate either voltage compensation more or the impedance mode these are actually GCSC are a impedance mode, operation based on the transformer actually turn off delay of this actually GTO, is analyzed by using the duality property of the TCR, and same like TCR to reduce the harmonics segment of segmented TCSC can be used.

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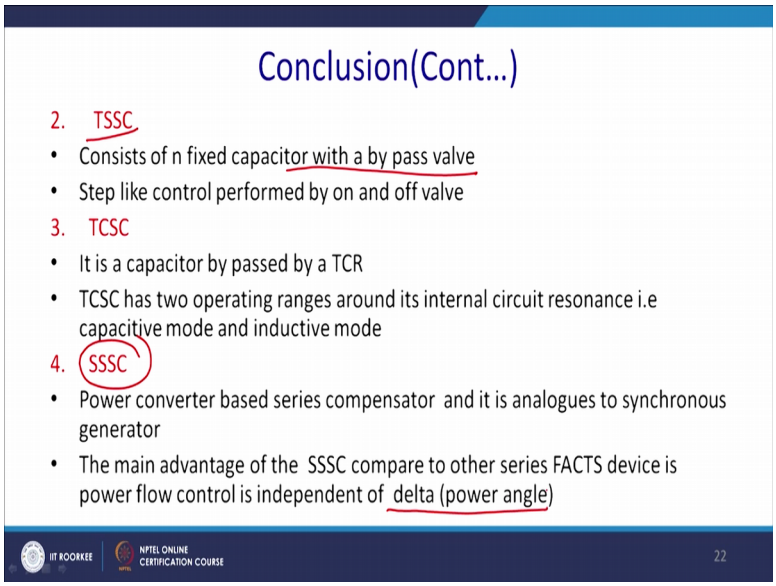

So, same way we have another facts devices in series compensation that is T double SC consists of the n fixed capacitor, with the bypass valve and steps like a and it will have a step like control. And TCSC it is a capacitor bypass by TCR, TCSC has two operating range around the internal circuit resonance in a capacitive mode as well as the inductive mode generally both are operate in simultaneously. But of course, you know preferred series device is triple SC, it will inject the voltage the power converter based series compensator it is analogous to the synchronous generator. The main advantage of the SSC is that a compared to this other facts device, power flow is independent of the delta.

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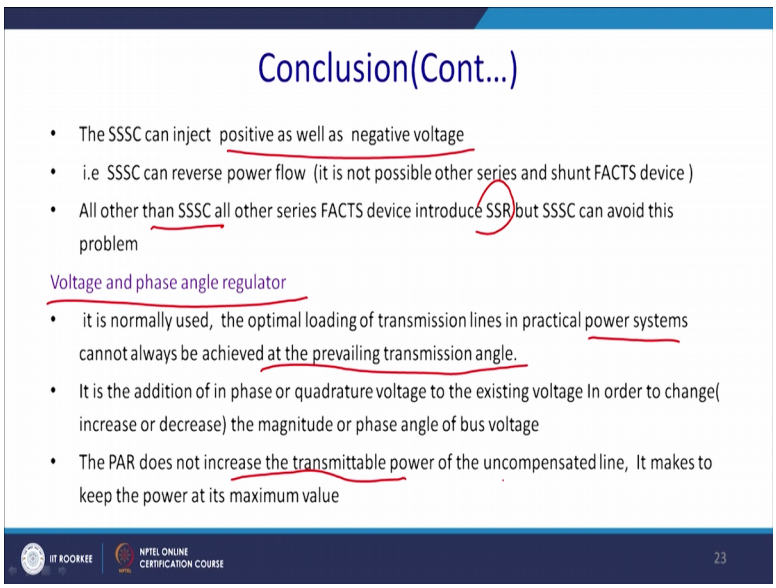

So, it can in facts devices STATCOM was independent of a sag here actually it can it independently control the flow of power, in it is independent of the delta. SSC can inject positive as well as the negative voltage; SSC can reverse the power flow though it is actually not required most of the cases. All other SSC all other than SSC all facts devices introduces actually sub synchronous resonance and problem of the sub synchronous oscillation, and this problem is not at all there and the no damping at no damping device separately require to be placed.

And another is actually series parallel combination that is essentially of voltage and phase angle regulator what is we say PAR and it is normally used for optimal loading of the transmission line in practical power system, cannot always be achieved by the prevailing transmission angle. So, it is prevailing in case of the short transmission line, it is in the addition of the phasor or the quadrature voltage of the existing voltage in order to change or increase the power flow of the line. PAR does not increase the transmittable power of the uncompensated line, it makes it keep the maximum value constant only it changes the actually the power flow in the wide range of hiding delta.

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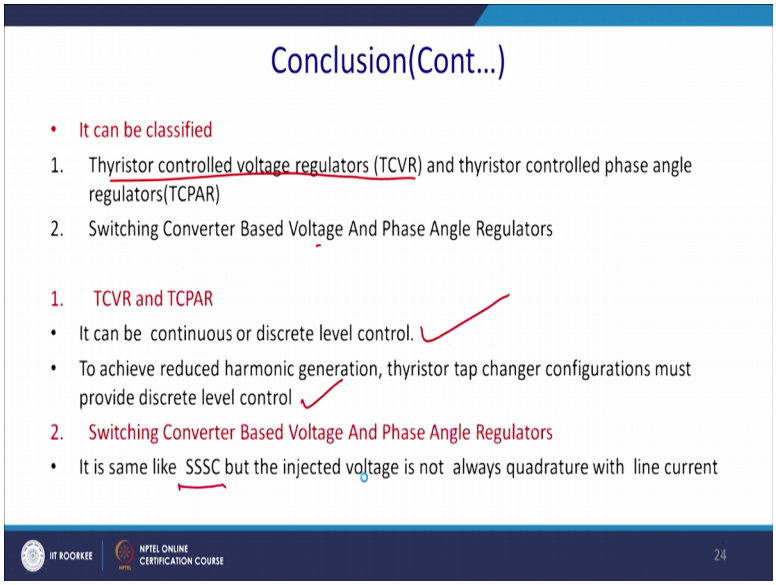

So, it can be classified as that is thyristor control power angle regulator and thyristor control phase angle regulator, switching converter based voltage and phase angle regulator, and TCVR and TCPR, it can be continue it can be continuous or the provider discrete level of control in steps. To achieve the reduced the harmonic generation

thyristor tap changer configuration must provide with the discrete level of control. Switching converter based voltage and the power angle regulator it is same as triple SC is same likes triple SC, but inject the voltage not always quadrature with the line.

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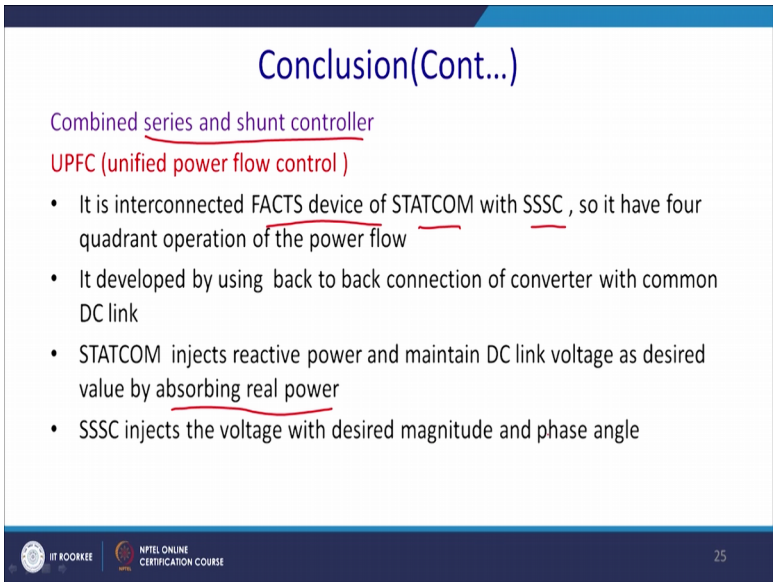

And it is a combined series and shunt compensation and from there we have actually the most modern compensation technique that is UPFC, it is a interconnected facts devices of combination of STATCOM and SSC.

So, it has a all the four quarded operations and the power flow, it develops by using a back to back connections of the converter with the common DC link, STATCOM injects the reactive power and maintains the DC link voltage as desired by absorbing the real power triple SC injects the voltage with the desire magnitude and the phase angle.

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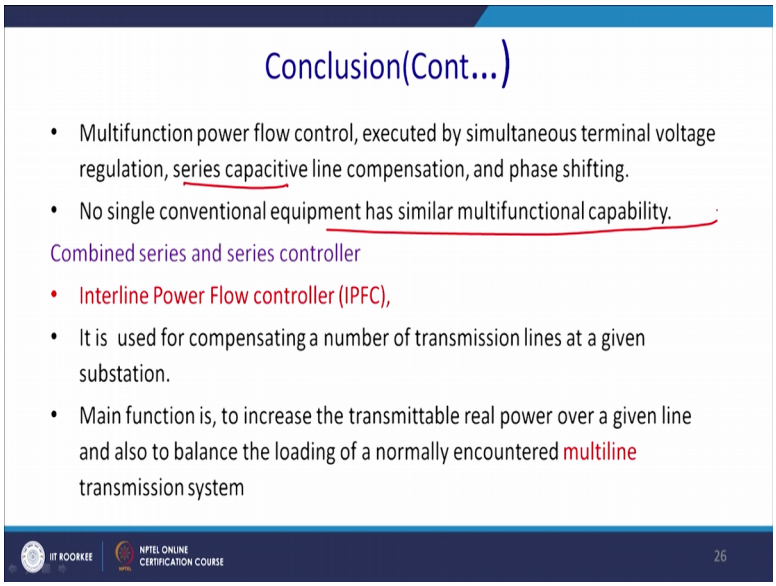

And multifunctional power flow control executed by simultaneous terminal voltage regulations, series capacitive line compensation and the phase shifting all is possible that it is quite versatile device, no single conventional equipment has the similar multifunctional capability.

So, thus UPFC is basically the solution, and thus there after you have intermittent power line condition it is essentially series compensation, it is used for the compensating number of transmission lines in a given substations we have discussed in previous class. The main function is to increase the transportable real power over a given line and also balance the loading of a normally encounter multi line system.

So, facts devices in distribution systems are the follows.

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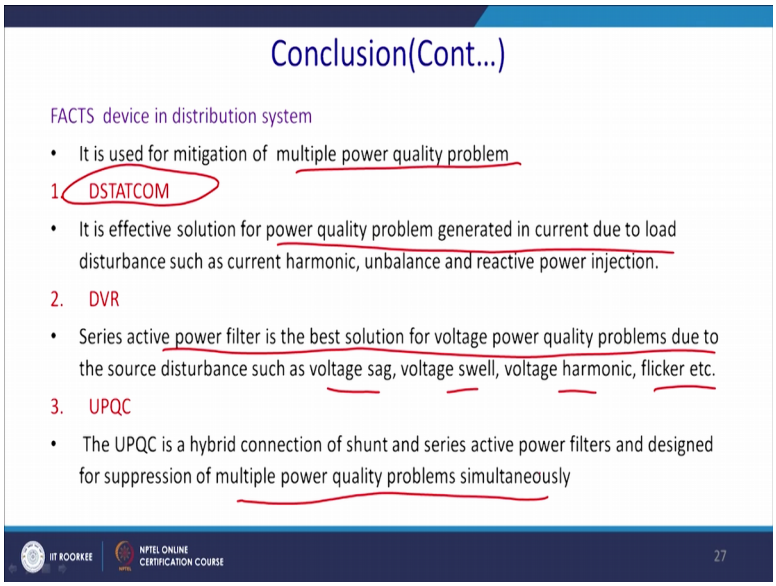

It is used for the mitigation on the multiple power quality problems. It is basically that DSTATCOM. So, just rating will be less and thus we can make it with the IGBT and is a very popular for the power electronics people and they placed it in a wide range of applications.

It is effective solution for the power quality problems generated by the current due to the load disturbances such as current harmonic unbalanced and the reactive power injection. These are the problem of the power quality rather more than the power transmission. DVR same way we have a series active power filter it is best solution for the voltage quality problem, due to the source system in such as voltage sag, voltage swell voltage harmonic liquors etcetera. And they are it will come to UPQC. UPQC is a hybrid connection on the shunt and series active power filter and designed for suppression of the multi power quality problems we have seen in UPFC.

Thank you for your attentions. I am thankful to the team NPTEL for their valuable support, and I am thankful to my student Harish and Munir for actually for actually make a make me ready for this presentations. Thank you all we hope that is classes will be beneficial for all your future courses for industry research as well as in academics.

Thank you very much at it.