Introduction to Smart Grid
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Lecture – 33
Simulation and Case Study of AC-DC Hybrid Microgrid

Welcome you all to the online NPTEL course on smart grid, today we will be a focusing on a case study, with respect to AC-DC smart grid and, we will try to take up an application, where we will try to explore the benefit of having a AC-DC smart grid. So, that the main objective here is to highlight the advantage of a AC-DC hybrid grid against the conventional AC grid.

So, in this context we will take up an case study, that is coordinated voltage controls scheme applications and we will see, how this coordinated voltage control or CVC scheme can be adopted well, with our AC-DC hybrid grid instead of a conventional AC grid. And perhaps we will take advantage of the presence of a DC grid DC microgrid along with a AC distribution system.

Now, first of all what is voltage regulation I mean or voltage control and, what are those devices, what kind of schemes are in practice and, during different state of operation, how do they react and what sort of you know modification, or improvement is being expected looking into a merger of AC-DC smart grid.

Now, first of all if you concentrate on voltage regulating devices, we can just focus on OLTC DSTATCOM and all the converters connected to my renewable energy systems.

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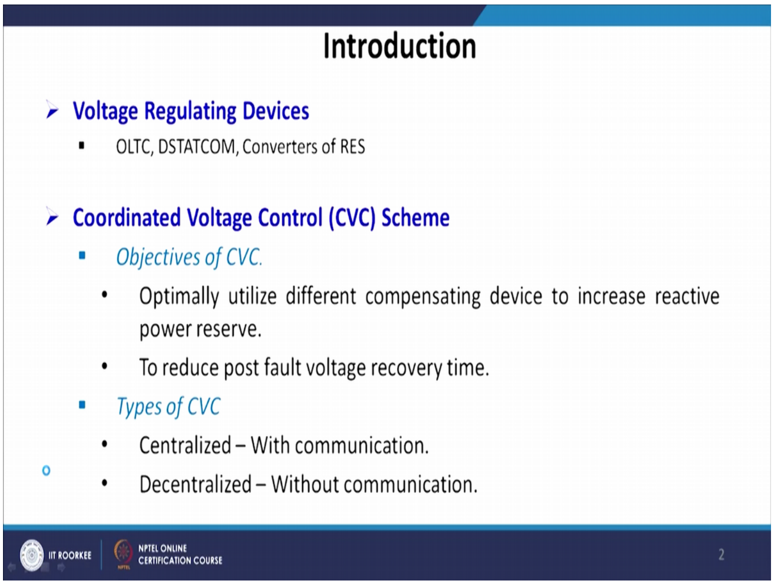

Now, if you come focus on coordinated voltage control, or CVC scheme the main objective of the CVC is to optimally utilize different compensating device to increase reactive power reserve, means the objective here is how to increase the reactive power available within the system to take care of the voltage control.

Now, mean time we can also try to achieve, the post fault voltage recovery time can be reduced as soon as possible may be or the time the post fault voltage recovery time can be reduced with the help of CVC scheme. Now, there are two major type of CVC one is decentralized and the other one is the centralized, centralized where we have communication system in place, decentralized where we do not have any communication among the devices.

Now, focusing on a simple test system, so, we have considered I triple E 33 bus distribution system, which is as conventional efficiency.

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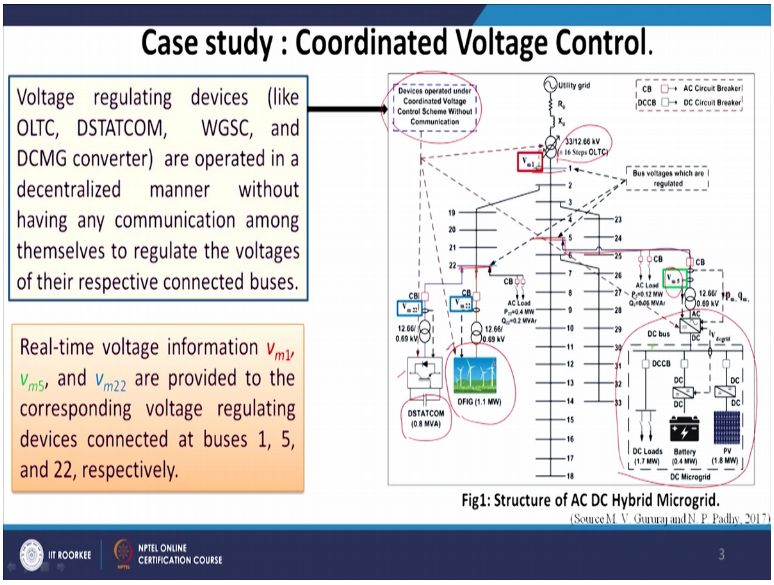

Whereas, we have connected a DC microgrid, we have connected a DC micro grid at a particular bus number 5, bus number 5 and this is the bus where we have connected a DC micro grid and, we also have connected a DSTATCOM at bus number 22 and we also have connected a DFIG at bus number 22.

And we do have a OLTC at bus number 1 so, what are the major changes we have incorporated, we have taken I triple E 33 bus system and we introduced OLTC at bus number 1, DSTATCOM as well as DFIG wind generator at bus number 22 and at bus number 5 we have introduced a DC microgrid. So, excluding all those devices and the rating the rest loading and the dimension as well as the variable, the parameters of the lines and cables remains same as far the I triple E system.

Now, voltage regulating devices like OLTC DSTATCOM etcetera, as well as DFIG converters are operated in a decentralized manner; that means, all this system, if you see all the devices do operate without any communication means those devices do try to you know improve the voltage profile at that particular bus where it has been connected through different schemes.

But they do not communicate to each other for the overall system benefit at large, and hence they perhaps regulate the voltages in their own way at the respective buses, but they do not look at other buses. Real time voltage information at bus number 1, 5 and 22 are provided to the corresponding voltage regulating devices connected at bus number 1 5 and 22.

So, over ally what I what we wanted to focus that this devices do control the voltage at the respective buses like bus number 1, 22 and 5 but they do not really communicate among themselves to see, what kind of scenario other buses do face. There are different voltage regulating devices and the very common is OLTC.

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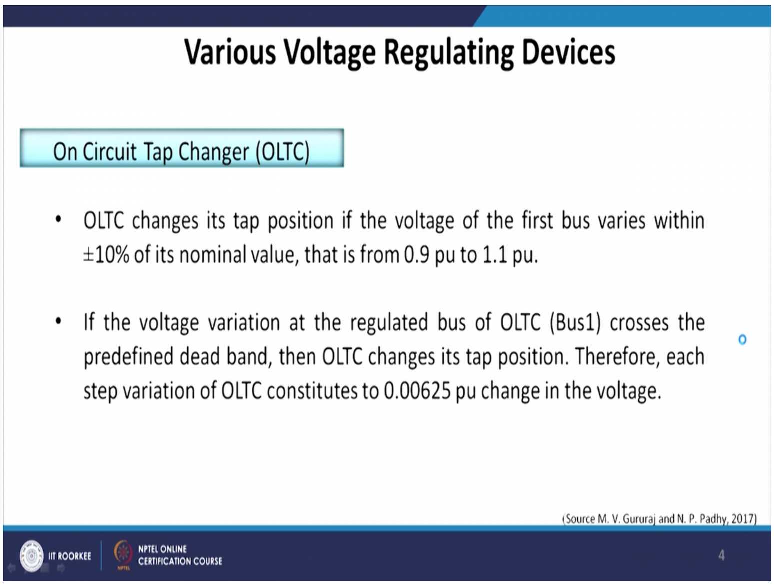

OLTC changes its step position if the voltage of the first bus vary within plus, or minus 10 percent of it is nominal value, that is if the voltage is varying between 0.9 to 1.1, and then they can you know take action is the voltage variation at the regulated bus of OLTC, crosses the predefined dead bend if it crosses between 0.9 to 1.1 minimum as well as maximum, then the OLTC try to change its tap positions.

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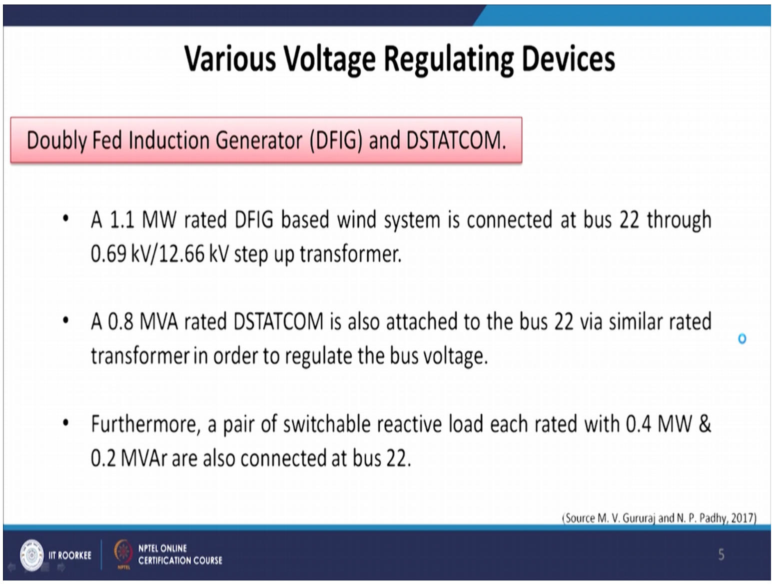

Now, similarly the DFIG and the DSTATCOM, what we have done those are the additional devices have been placed to look into a to take care of the system reactive power scenario. So, a 1.1 megawatt rated DFIG based wind system is connected at bus number 22 through a 0.69 k V slash 12.66 k V step up transformer. A.8 MVA DSTATCOM is also attached at the same bus, furthermore a pair of switchable reactive load each rated with 0.4 megawatt and 0.2 MVAr also connected at bus number 22.

So, these are the three things which has been additionally connected to my I triple E 33 bus system at bus number 22.

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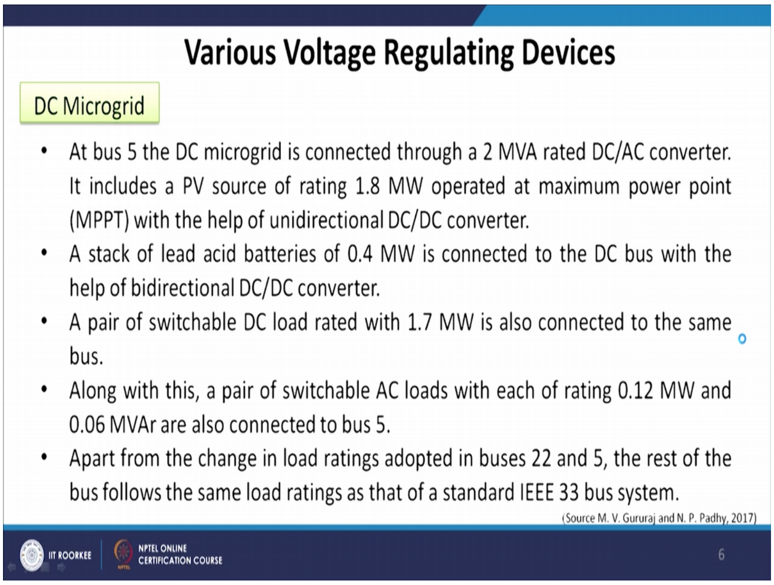

Now, we also have you know included a DC micro grid at bus number 5, where at bus number 5 the DC microgrid is connected through 2 MVA rated DC AC converter, it includes a PV source operating 1.8 megawatt operated at its MPPT with help of unidirectional DC, DC convertor.

A stack of lead acid batteries with capacity 0.4 megawatt is also connected at the same bus. A pair of switchable DC load rated with 1.7 megawatt is also connected at the same bus, along with this a pair of switchable AC loads with each of the rating 0.12 megawatt and 0.06 MVAr also connected at bus number 5.

Apart from the change in load rating adopted in bus number 22 and 5, the rest of the parameter as I mentioned earlier now similar to I triple E 33 bus distribution system. Those parameters, which has been chosen for this analysis need not be a fixed variable, just for a case study we have chosen this parameter, but you are very open to choose your own parameter own settings and carry out the similar simulation.

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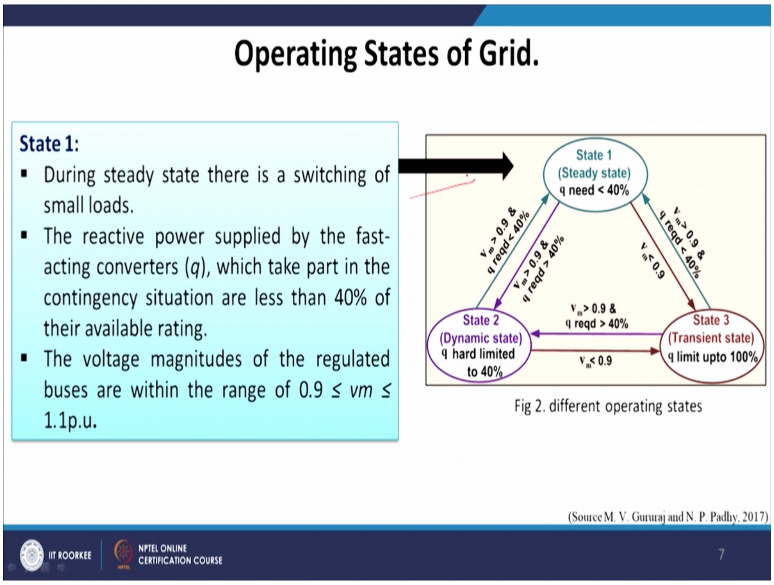

Now, in any system we do have come across three different states are the first one is steady state and, then dynamics state and finally, or transient state and now what kind of you know reactive power in voltage scenario during all those states a first of all if you consider the state number one, where actually we say the steady state at which small loads are being you know switched on the variation is not significant very you know minor change on your load. And the reactive power supplied by the fast acting converters, which takes part in the contingency situation are less than 40 percent of there a rated capacity or available rating whereas, the voltage magnitude of the regulated buses are within 0.9 to 1.1.

But if you move to a dynamic state where actually any sudden load changes will fall under this stage two category, the reactive power support required from the fast acting converters are more than 40 percent of their available capacity during the steady state it is below 40 percent and during dynamic state, we expect it is to be more than 40 percent on their valuable rating.

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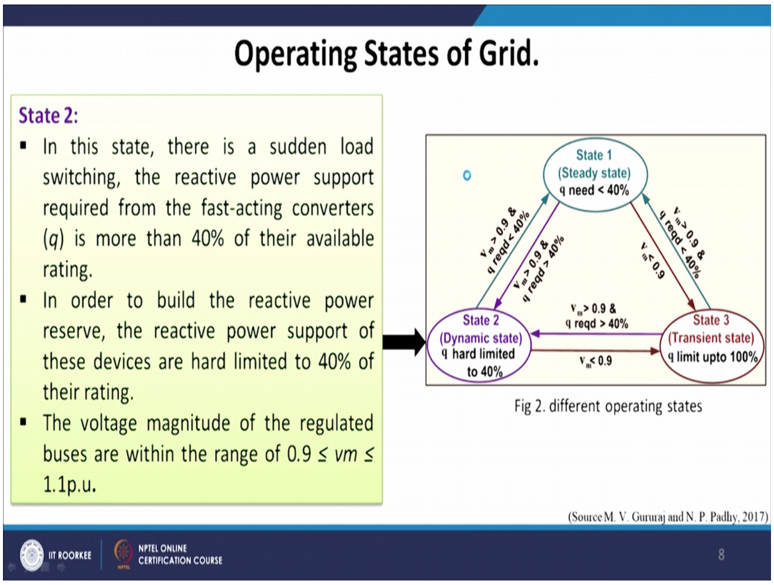

In order to build the reactive power reserve the reactive power support of these devices are hard limited 40 percent of the limit ok.

So, we limit hard at 40 percent whereas, the bus voltages are the magnitudes are regulated between 0.9 to 1.1, the final one which is a very important the transient state

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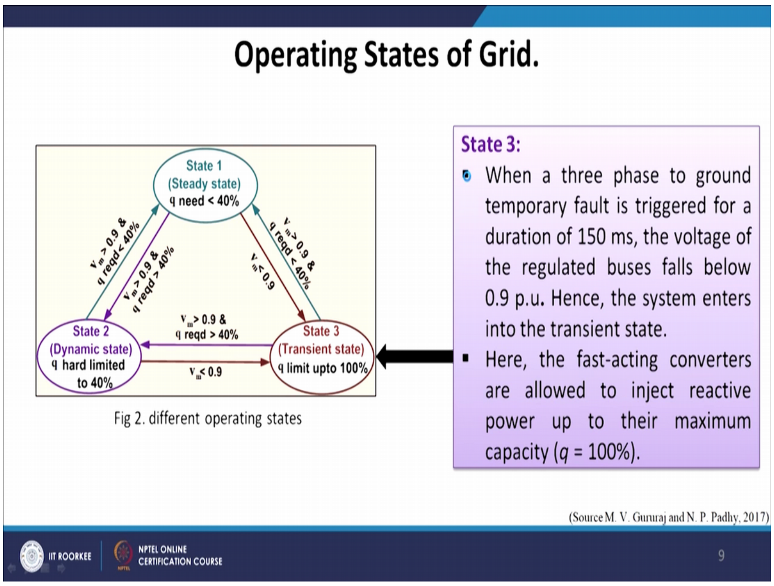

When three phase to ground fault, or three phase to ground temporary fault is triggered for a duration of 150 millisecond, the voltage of the regulated bus suddenly falls below 0.9 per unit. And hence the system enter into a transient state here, the fast acting converters are allowed to inject reactive power, up to their maximum capacity as maximum as 100 percent.

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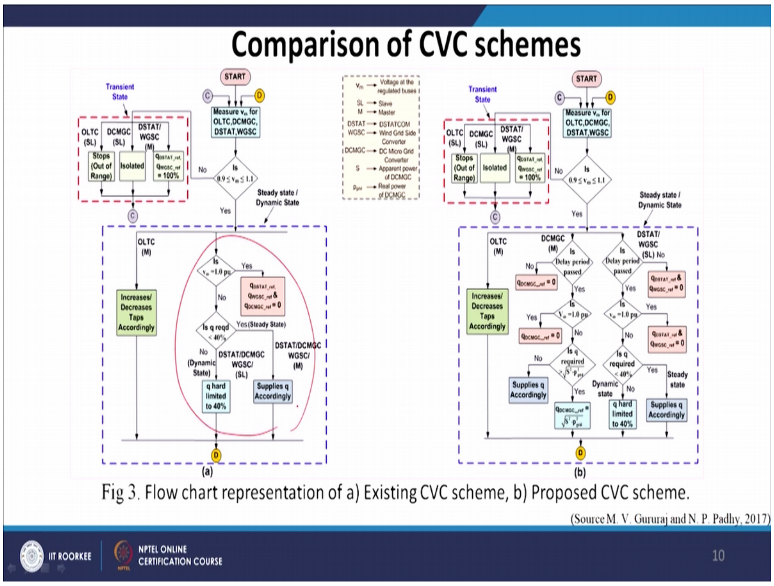

Now, if you look into this two different flow charts, the CVC schemes are not very new they are very I mean very old and being practiced across the world and, where as the conventional scheme you can see that you know, it is bus simple algorithm whereas, in the proposed CVC scheme what I am going to talk about today is slightly different where we taken care of the handling of different converters. So, that you know the overall performance of the system is being improved and, further if you see what are the challenges with the existing CVC scheme. Now, the current limitations of the CVC scheme coordinated voltage control schemes.

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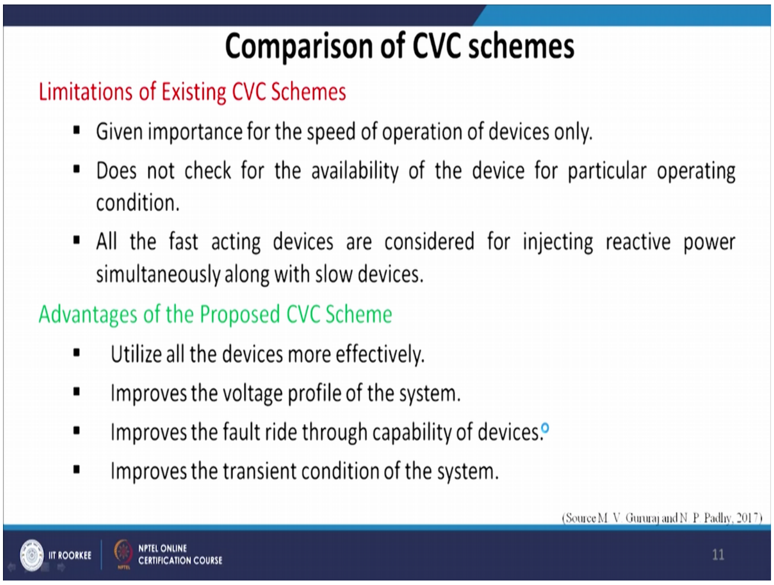

Given the importance for the speed of operation of devices only because it really takes care or it give importance to those devices where past, does not check for the availability of the devices for particular operating conditions, all the fast acting devices are considered for injecting reactive power simultaneously along with slow devices.

So, what we do when it is from stage one or stage two or stage three all the reactive power injected devices are instructed to you know inject as maximum, they can and in that process the fast acting devices are always you know regularly participating in injecting reactive power and, the slow devices unfortunately may not be able to contribute by the time all the fast acting devices do contribute, whatever major contribution they can make.

But that is not a good idea in the proposed model what we have suggested, utilized the devices more effectively even though OLTC, DSTATCOM, DFIG, DC micro grid all of them have to participate simultaneously, by which it improves the voltage profile of the system at large, it improves the fault ride through capability of the devices, it also improves the transient conditions of the systems.

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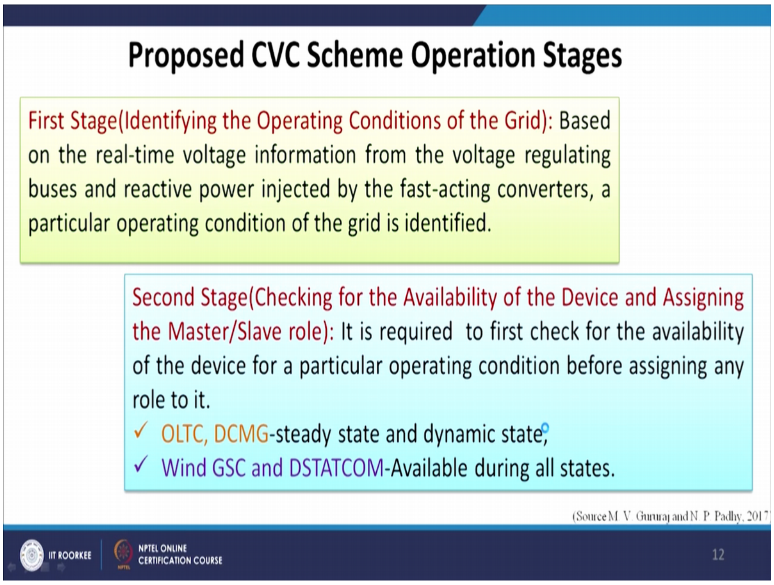

Now, how it is being proposed here in the first stage, identifying the operating conditions of the gird. Based on the real time voltage information from the voltage regulating buses and, the reactive power injected by the fast acting converters a particular operating condition of the grid is identified. And then in the second stage checking for the availability of the devices and assigning the master and slave roles.

So, who will act as a master and who will act as a slave depending upon the fast acting, or slow acting devices. It is required to first check for the availability of the device, for a particular operating condition before assigning any role to it for example, OLTC and DC micro grid are you know used during steady state and dynamic state whereas, the wind generators and this DSTATCOM comes are available throughout all the three states.

Now, the final state introducing the time delay in operation for example, you want some slow device to be you know acted before the fast devices, than a delay in action on those fast devices can be incorporated. So, that the slow devices can you know inject the reactive power and further the fast acting devices can come to action.

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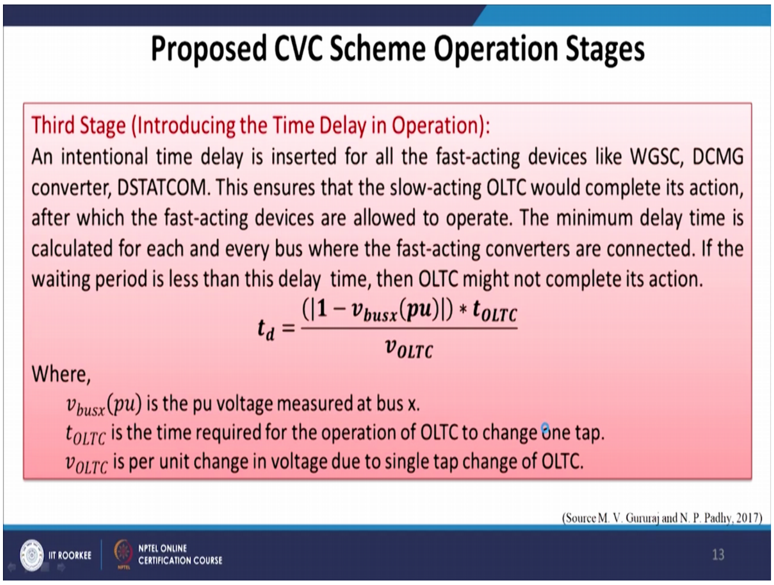

So, as an intentional time delay is inserted for all fast acting devices like WGSC and DC microgrid DCMG converter along with the DSTATCOM, this ensure that the slow acting of OLTC would complete it action.

So, as we discussed earlier when all those fast acting devices come to action, then the slower acting devices may not be able to contribute much. So, please allow the slow device like OLTC to act first and, then the fast devices can come and follow them. After which the fast acting devices are allowed to operate. The minimum delay time is calculated for each and every bus, where the fast acting converters are connected. If the waiting period is less than this delay the time, then the OLTC might not complete its action.

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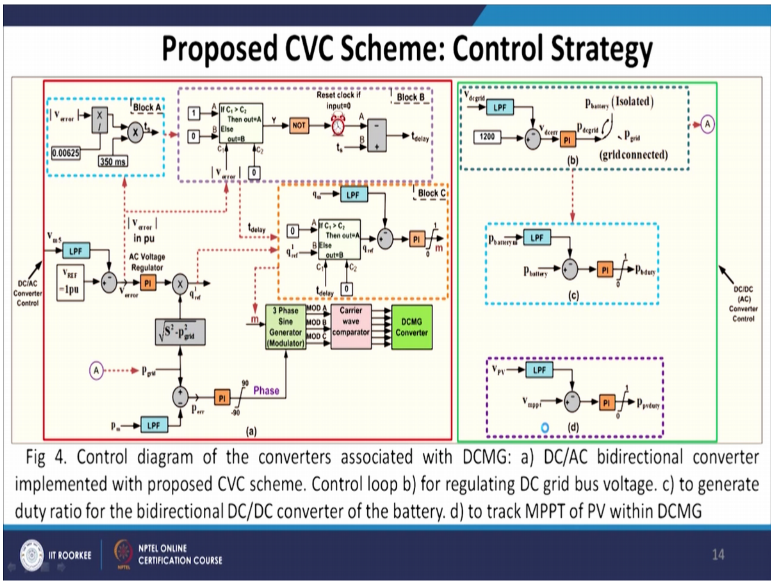

Fig 4. Control diagram of the converters associated with DCMG: a) DC/AC bidirectional converter implemented with proposed CVC scheme. Control loop b) for regulating DC grid bus voltage. c) to generate duty ratio for the bidirectional DC/DC converter of the battery. d) to track MPPT of PV within DCMG

And this is what the proposed CVC scheme, because most of the control schemes we have discussed in past. So, I am not taking lot of time here, but is your whole you can see that this is basically DC-AC bidirectional converter implemented with the proposed CVC scheme and whereas, we talk about actually the modelling for a DC grid bus voltage and, this talk about the generated duty ratio for the bidirectional DC DC convertor of the battery and, the final one talking about the track MPPT of PV within DC microgrid.

So, you can see different control algorithms, or control schemes or the strategy being developed to execute the proposed case study. Now, in the result and discussion section, we will see what kind of outcome it is because by adding a time delay and, allowing all the you know devices to act in a different phase of time not simultaneously through which the slow devices do not contribute much.

And hence with the proposed CVC scheme, we will see what kind of advantage of merit has been achieved.

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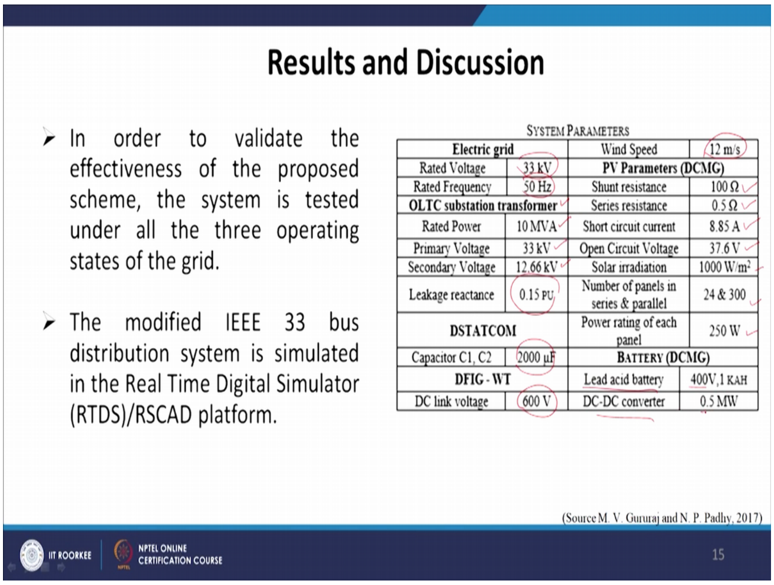

In order to validate the effectiveness of the proposed scheme, the system is tested under all the three operating states of the grid, the modified I triple E 33 bus distribution system is simulated in the real time digital simulator RTDS platform. And we have consider the grid rated voltage of 33 k V and frequency of 40 hertz and the OLTC substation transformer of rating 10 MVA primary voltage 33 kV, secondary voltage 12.66 k V and the leakage reactance assume to be 0.15 per unit.

The DSTATCOM capacitors 2000 microfarads and DC link voltage of 600 volts and windshield speed considered to be a 12 minutes 12 meter per second. The PV parameters of a DC microgrid its 100 ohms shunt resistance series resistance of 0.5 short circuit current of 8.85 ampere open circuit voltage of 37.6 volt and, solar irritation of 1000 and number of panels in series and parallel 24 and 300 power rating of each panel is 250 watt the battery lead acid battery of four 100 volts and DC DC converter of 0.5 megawatt.

So, this is basically the system parameters being discussed before we proceed further simulation.

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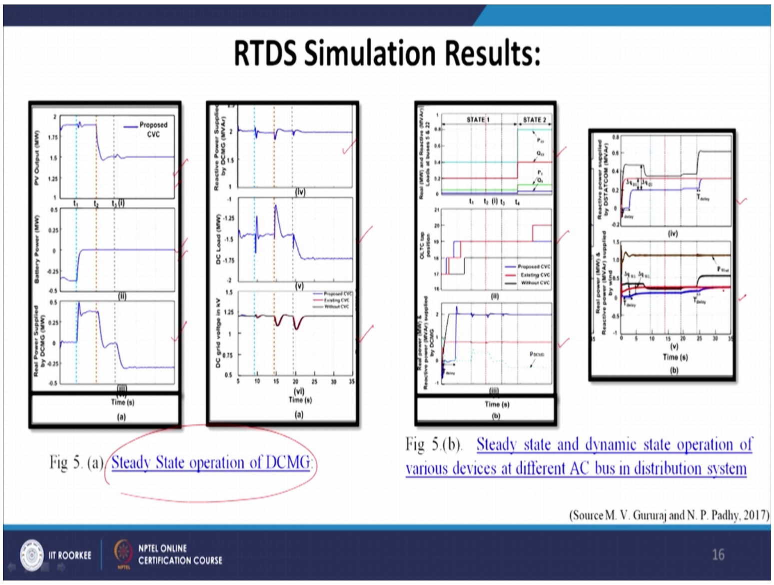

And during the RTDS simulation we have seen, this steady state operation for the PV output and for battery power, real power supplied by the DC microgrid and, reactive similarly the reactive power supplied by the DC microgrid and, this is the DC load and this the DC grid voltage parameter. So, during steady state operation of DC microgrid all you know parameters being interest whereas, steady state and dynamic state operation of various devices at different AC bus of the distribution system, we have seen the real and reactive power loaded bus number 5 and 22.

Whereas this is OLTC tap positions how they are keep on changing real power and reactive power by the DC microgrid and, reactive power supplied by the DSTATCOM and real power and reactive power supplied by the wind generator. So, this all a simulation results for your reference.

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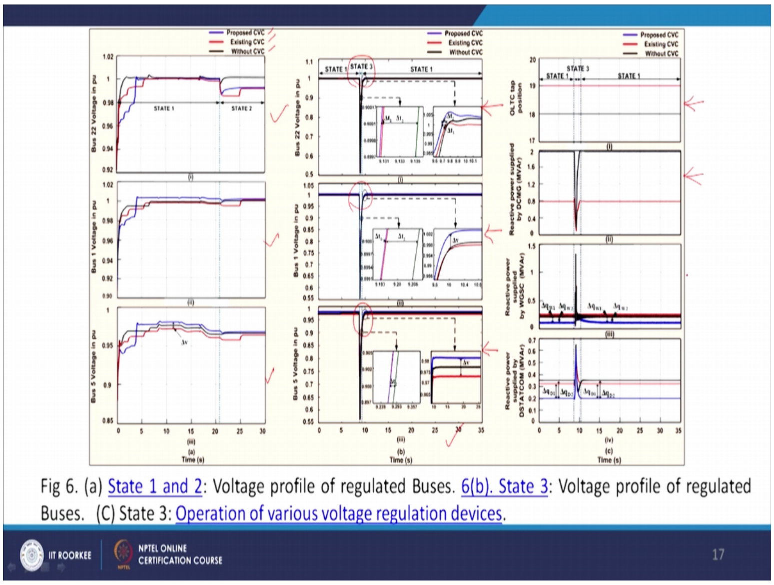

And perhaps we can say the blue line represents the proposed CVC and red one is the existing CVC and the black one is without CVC.

So, we compare if you do not have the CVC scheme, how does it behaves and if you have based on the existing practice how the scenario would be and the proposed one so, all three have been compared the first you know, if you see the bus number 22 and this is at bus number one and bus number 5.

So, this is how actually we have traced at different location bus number 22 where we had both DSTATCOM and wind generator, bus number 5 we had a microgrid and bus number one we had a OLTC. Now, the state numbers one and two that is steady state and dynamic states have been, you know considered and the voltage profile of regulated buses are being plotted.

Whereas in this diagram it is the state number 3, that is the transient state which is very important from the state one and you can see the state three is being created at each and every bus, we can see the voltage profile of regulated buses. Now, the state three, where we are during the transient state the operation of voltage of regulated devices are being plotted. So, during the state three these are the bus positions and these are the device positions OLTC DC micro grid and wind generator and my DSTATCOM, RTDS simulation results.

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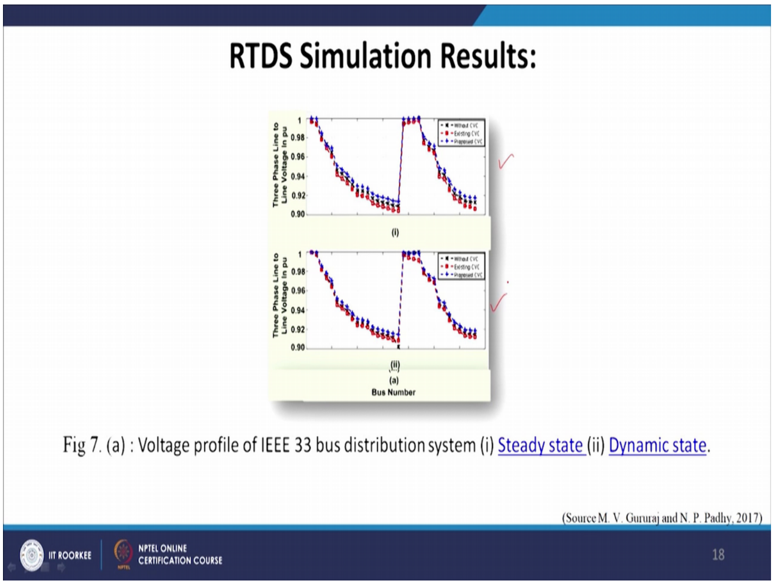

Where the voltage profile of 33 bus are being plotted and with both steady state, as well as dynamic state. So, the first one is during steady state and the second one is during a dynamic states are being plotted.

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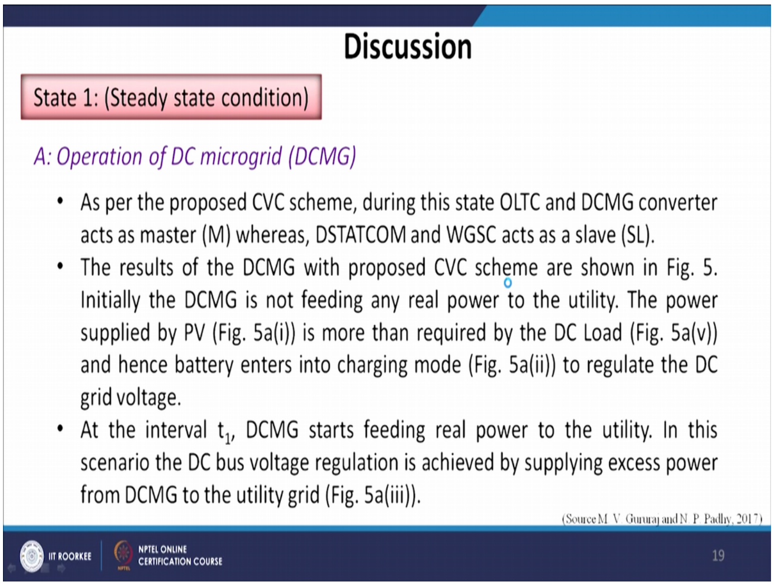

Now, let us see what exactly happened during the state number 1, that is steady state conditions, how the DC microgrid operated or behaved as per the proposed CVC during this state the OLTC and the DC microgrid converter act as a master whereas, the DSTATCOM and wind generator act as a slave. The results of the DC microgrid with proposed CVC scheme are shown in previous figures, where initially the DC microgrid is not feeding any real power to the utility, the power supplied by the PV is more than required by the DC load.

And hence the battery enters into charging mode to regulate the DC grid voltage at, the interval t 1 as you have seen interval t 1 DC microgrid starts feeding real power to the utility and, in this scenario the DC bus voltage regulation is achieved by supplying excess power from the DC microgrid to the utility grid.

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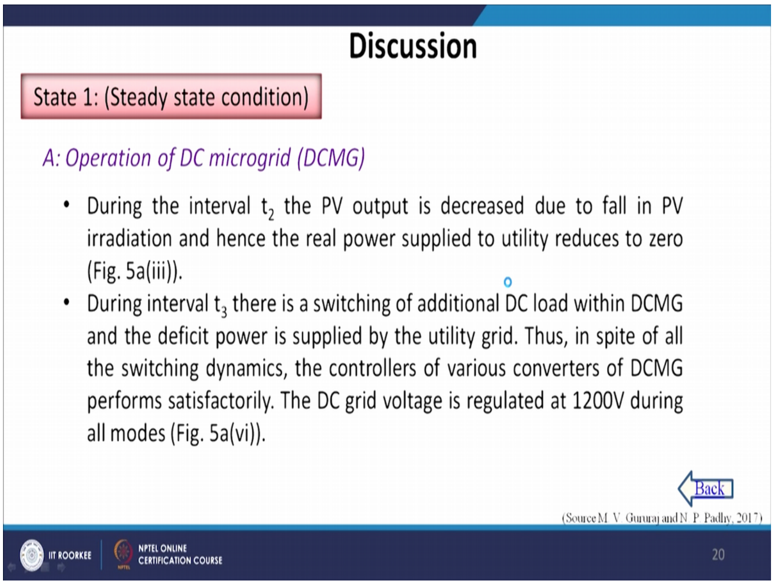

Now, during the interval 42 the PV output is decrease, due to fall in PV irradiation and hence the real power supply to the utility reduces to zero.

During the interval t 3, where there is a switching of additional DC load within the DC microgrid and the deficit power is supplied by the utility grid. Thus in spite of all the switching dynamics the controller of various converters of DC microgrid perform satisfactory, the DC grid voltage is regulated at 1200 volt during all modes.

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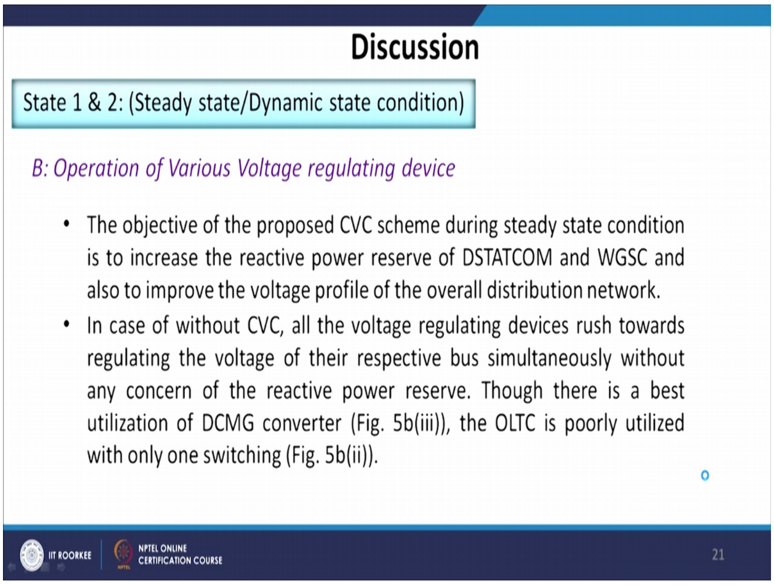

Now, in case of state one and two both steady state and dynamic state conditions when the operation of various voltage regulation regulating devices, the objective of the proposed CVC scheme during steady state condition is to increase the reactive power reserve of the DSTATCOM and the wind generator and, also to improve the voltage profile of overall distribution system.

Now, in case of without CVC all the voltage regulating devices rush towards regulating the voltage of their respective bus, simultaneously without any concern of the reactive power reserve. Now, as we discussed like you know during emergency, or if you do not have a proper CVC scheme, then they all try to you know help the system at their own locations and perhaps without looking into how much reserve, they carry with them though there is a best utilization of DC microgrid converter the OLTC is poorly utilized with only one switching.

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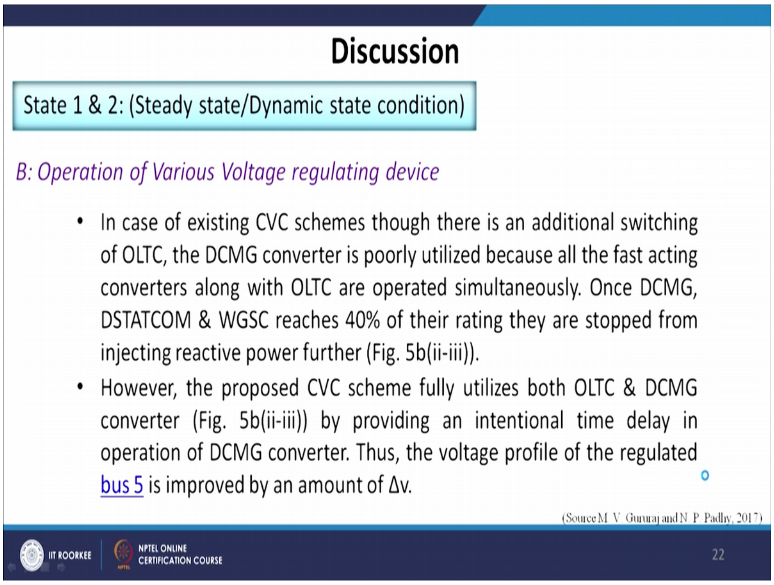

In case of existing CVC scheme though there is an additional switching of OLTC, the DC micro grid converter is poorly utilized, because of all the fast acting converters along with OLTC are operated simultaneously. Once DC micro grid DSTATCOM wind generator reaches 40 percent of the rating, they are stop from injecting reactive power further.

The major problem is that they all acts simultaneously the moment, they reached to their 40 percent capability they have not mono more allowed to act; however, the proposed CVC scheme fully utilized both OLTC and DC microgrid converter, by providing an intentional time delay in operating the DC micro grid converters thus the voltage profile of the regulated bus 5 is improved by an amount delta v as shown in the previous diagrams.

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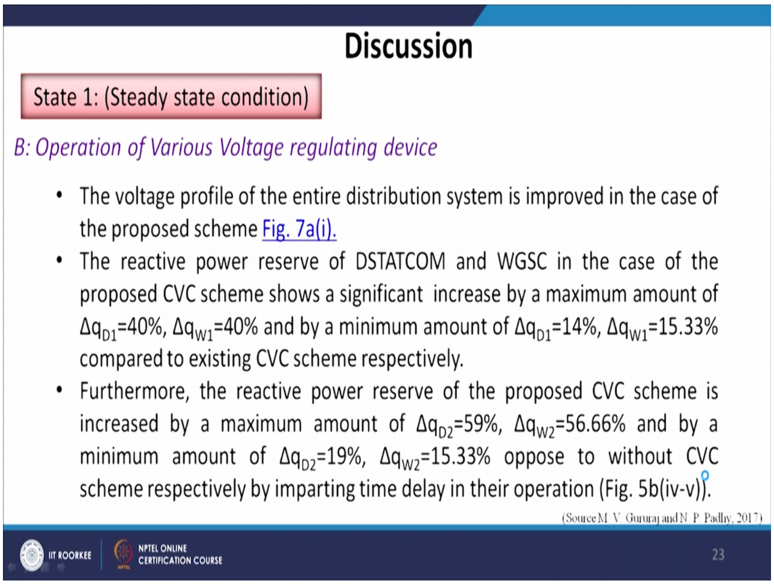

Now, the voltage profile of the entire distribution system is improved in case of the proposed scheme, that can easily be verified the reactive power reserve of the DSTATCOM and the wind generator. In the case of the proposed CVC scheme shows as significant increase by a maximum amount of delta q D of 40 percent and, delta q W of 40 percent both DSTATCOM, as well as wind generator to 40 percent and by a minimum amount of 14 percent and 15.33 percent respectively compared to the existing CVC schemes.

Furthermore the reactive power reverse of the proposed CVC scheme is increased by a maximum amount of 59 percent and 56 percent by both DSTATCOM, as well as wind generator and by a minimum amount of 19 percent and 15.33 percent respectively opposed to without CVC scheme respectively by imparting time delay in their operation.

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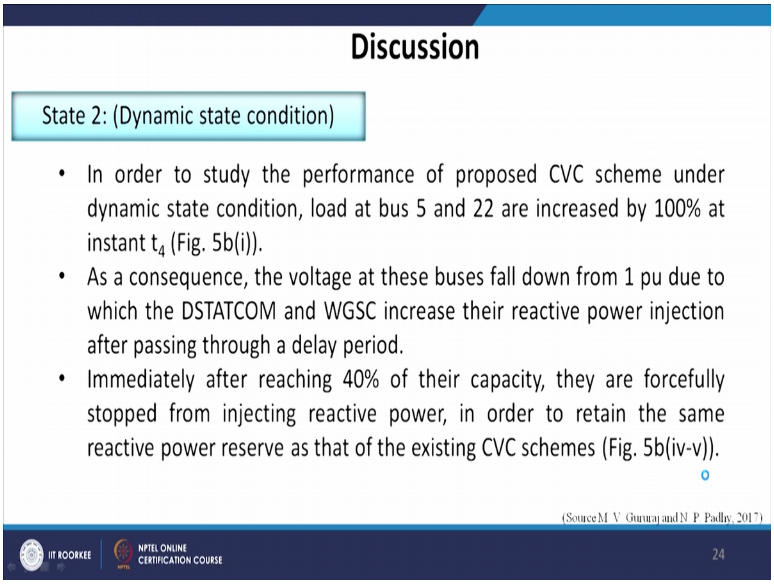

Now, state number two dynamic state condition in order to study the performance of proposed CVC scheme under dynamic state condition load at bus number 5 and 22 are increased by 100 percent. So, to introduce a sudden load change 100 percent load change have been introduced at both bus number 5 and 22.

At instant t 4 as a consequence the voltage at these buses fall down from 1 per unit due to which the DSTATCOM and WGSC increase the reactive power injection after passing through a delay period. Immediately after reaching 40 percent of the capacity they are force fully stopped from injecting reactive power, in order to retain the same reactive power reserve so, that the existing CVC schemes.

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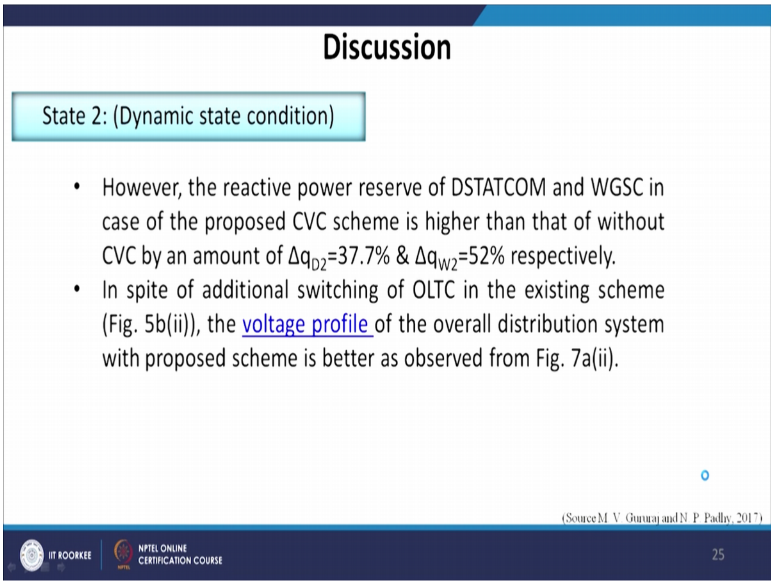

However the reactive power reserve of DSTATCOM and WGSC, in case of the proposed CVC scheme is higher than that of without CVC by an amount 37.7 percent and 52 percent respectively for both the DSTATCOM and wind generators. In spite of additional switching of OLTC in the existing scheme the voltage profile of the overall distribution system with propose scheme is better and, which has been observed in the previous pictures.

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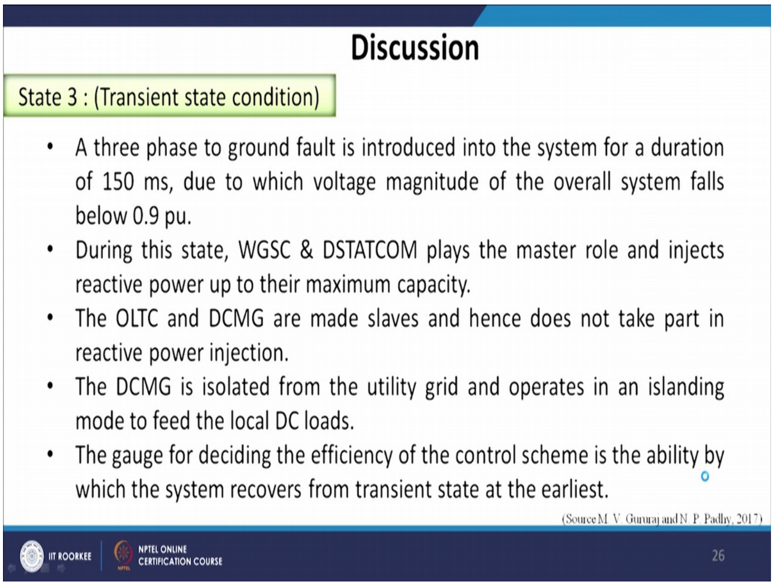

Now, let us move to the transient state conditions a three phase to ground fault introduced into the system for a duration of 150 milliseconds due to which the voltage magnitude of the overall system falls below 0.9 per unit.

Now, during this state both WGSC and DSTATCOM play the master role and inject reactive power up to their maximum capacity, now it is reverse not necessary for those WGSC and DSTATCOM currently, now act as a masters and try to evacuate all the reactive power available to them. The OLTC and DC micro grid will be made slave and, hence does not take part in the reactive power injection under transient state conditions. The DC microgrid is isolated from the utility grid, and operate in an islanding mode of and the feed the local DC loads.

The guage for deciding the efficiency of the control scheme is the ability by which the system recovers from the transient state at the earliest. So, the very interesting part here that you know we try to take advantage in the presence of DC microgrid, along with other devices like DSTATCOM and the wind generator. And sometimes we force the OLTC to act in the beginning, but if it is emergency then we do not allow OLTC to action in the initial stage. So, the control strategy the propose CVC certainly, you know takes care of many other issues those have not been identified or addressed in case of the existing CVC.

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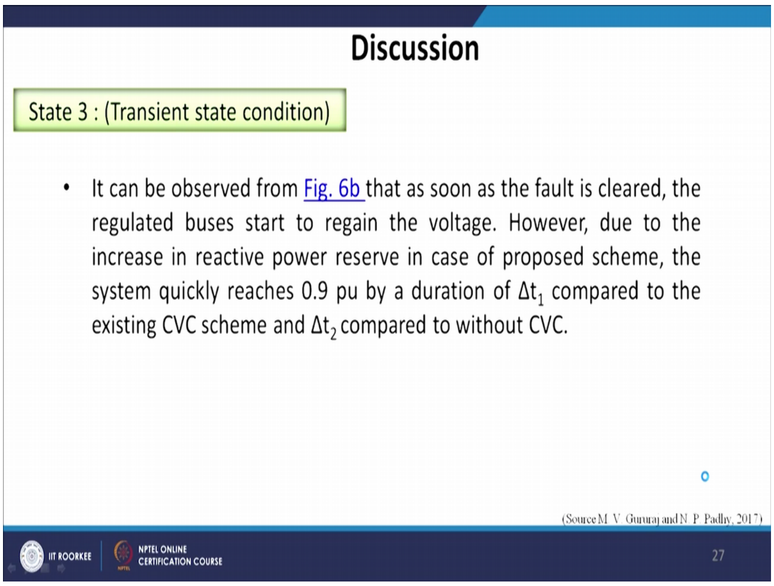

Ah it can also be observed that as soon as the fault is cleared the regulated bus start to regain the voltage however, due to the increase in reactive power reserve in case of propose scheme, the system quickly reaches 0.9 per unit by a duration of delta t 1 compared to the existing CVC scheme and delta 2 compared to the without CVC. So, that time of recovering got reduced with the propose CVC scheme compared to the other schemes.

Thus the proposed CVC scheme needs less fault voltage recovery time in contrast to the existing schemes.

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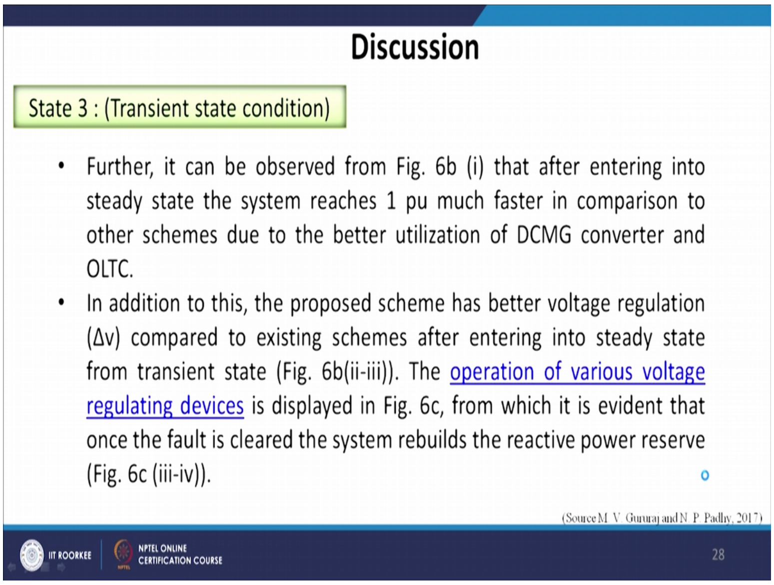

Further it can also be observed that after entering into steady state the system reaches 1 per unit much faster in comparison to other schemes, due to the better utilization of the DC microgrid converter and OLTC. In addition to this the propose scheme has better voltage regulation compared to existing schemes, after entering into steady state from the transient state.

The operation of various voltage regulating devices is displayed from which it is evident, that once the fault is cleared the system rebuilds the reactive power reserve. And to conclude what we wish to highlight the propose CVC coordinated voltage control scheme.

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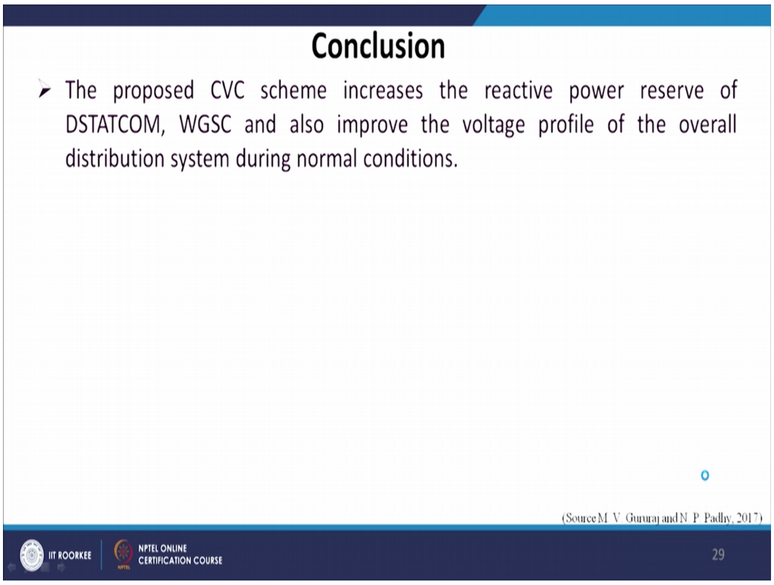

Increases the reactive power reserve of the DSTATCOM, as well as WGSC, and also improve the voltage profile of the overall distribution system during normal conditions.

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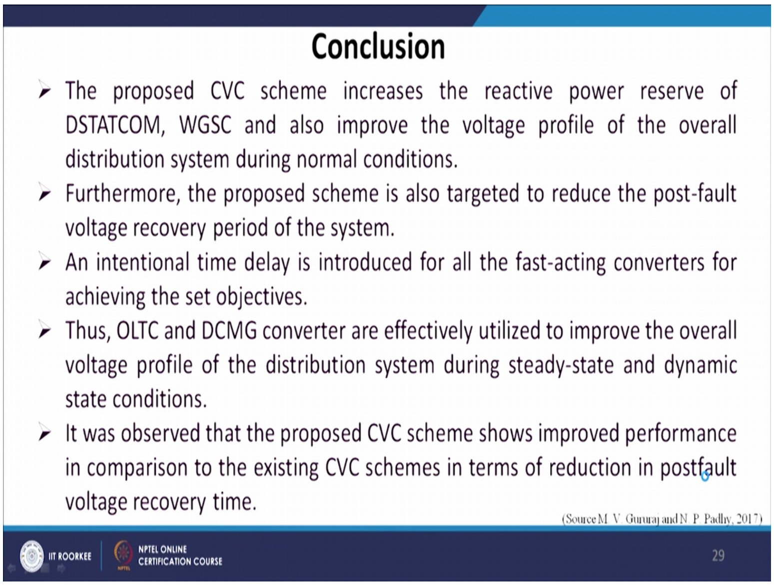

Furthermore the proposed scheme is also targeted to reduce the post fault voltage recovery period of the system. An intentional time delay is introduced for all the fast acting convertor for achieving the set of objectives.

The OLTC and DC microgrid converters are effectively utilized to improve the overall voltage profile of the distribution system, during steady state and dynamic state conditions. It was observed that the propose CVC scheme shows improved performance in comparison to the existing CVC schemes, in terms of reduction in post called voltage recovery time.

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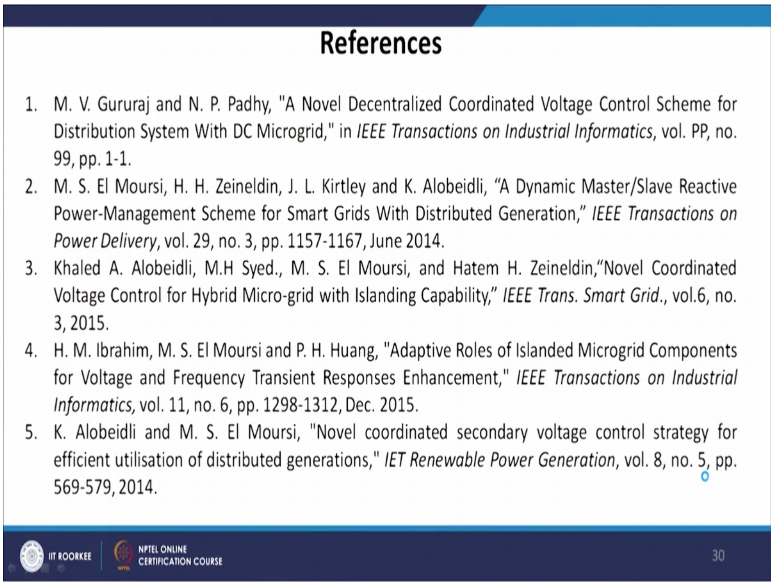

These are the following references can be used, this is a very interesting case study where you can see the benefits of having AC-DC smart grid together to address the voltage control scheme.

Thank you.