DC Microgrid and Control System
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Lecture - 26
DC Microgrid System Architecture and AC Interface

Welcome to our lectures on the Microgrid and the Control System. Today we should talk about the microgrid system architectures and the AC interference. So, why AC interface and that is also for the DC microgrid maybe.

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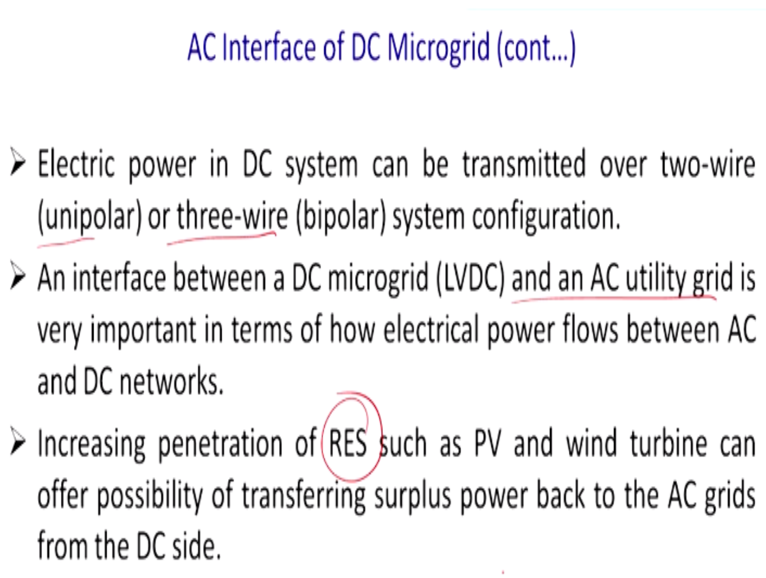

With the increasing demand for smart and the efficient load and rapid growth in the renewable energy sources, low voltage DC that is LVDC power distribution systems can be suitable power suitable power grid for the many applications that we have discussed. In order to accommodate the new technologies such as the resources, that is RES called the battery plus solar it is called the electrical resources, RES modifications in existing, DC architectures are required to further enhance the flexibility and the controllability.

Electrical power in DC system can be transported over, that is the advantage of it, two-wire, unipolar, or the three-wire, bipolar system. That is if you have a plus/minus voltage, you require the three-wire, and if you require just a plus voltage, then you require the unipolar system. An interface, quite important please understand, between the DC microgrid and the AC utility grid is very important.

So where you get power or sent power from the DC and DC microgrid power or same power from the main grid, so it absorbs power from main grid or when it has got an energy surplus, it will send back the power to the main grid. So, essentially you require an AC to DC converter and vice versa. Increasing penetration of these resources such as PV, wind turbine can offer possibility of transporting surplus power back to the grid, back to the AC grids, from the DC side, that is quite phenomenal aspects. So, whosoever can pay, they can pay.

So, once you have an energy surplus like you may be a maybe you can think of winter you know vacations in the institutes like us and what load has come down may be 50%, then we become the net supplier and we sell power to the grid. So, that is possible. If it is a DC microgrid, then of course, you have to sell, you have to convert again DC to AC and sell power.

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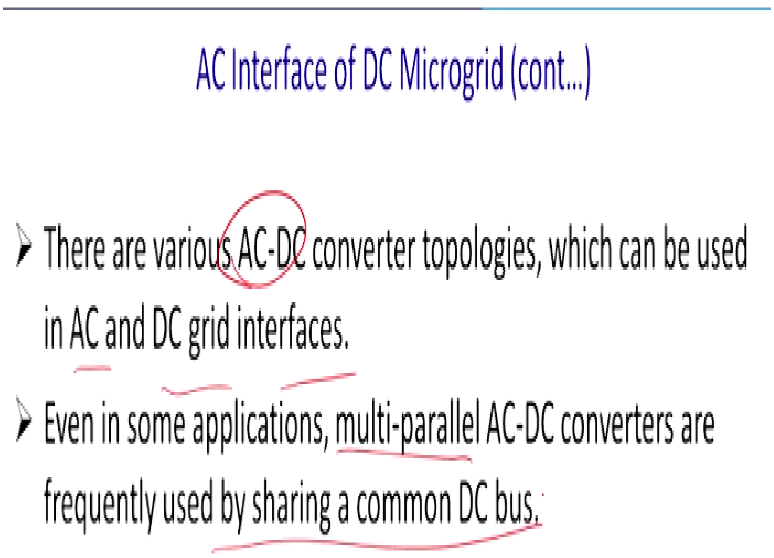

For this reasons, there are various AC to DC converter topologies, which can be used in the AC and DC microgrid interfaces. Even in some applications, multi-parallel, we can do if your power rating is more, then one path is not sufficient, you can have and also to give the redundancy, multi-parallel AC to DC converters frequently used by sharing the common DC bus.

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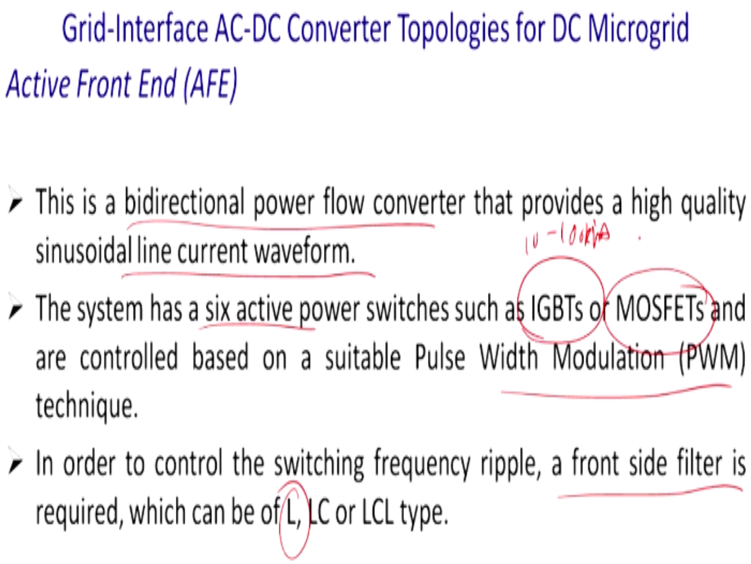

Grid-interface AC-DC converter topologies for the DC microgrid. This is a bidirectional powerful converter. It can take power in a unity power factor from the grid with low THD and that provides high quality sinusoidal current waveform. So it doesn't inject any harmonics and other power quality issues. The system has if it is a two level three phase, two level inverter has been employed, then you can have the power switches such as IGBT or the MOSFETs.

If you have IGBT, the rating in an around of 10 to 100 kilo kilowatt or let us make it KVA that is more realistic, and if it is a MOSFET, it is below rather 5, below rather 10 KVS and generally we prefer though I have written here 10, above 5 KVA as IGBT, instead of the MOSFET and the control based on the suitable pulse width modulation technique and we have studied that unipolar PWM, you can refer to my courses in Advanced Power Electronics. So, different kind of modulation techniques can be used.

In order to control the switching frequency ripple, a front side filter is required and though generally it will be a PWM, the switching frequency is quite high and thus filter size will be very small, and depending on this cut off, if you have a L, then you have a 20 dB cutoff, you have LC, you have 40 dB cutout, if you have a LCL, you have 60 dB cutoff, and accordingly, you can think of to have a different kind of configurations and thus you can give proper continuations of your switching frequency.

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Active Front End (AFE) (cont...)

- The LCL filter is a very common as it can remove high frequency current and clean the line current at the grid side, where this filter is connected (see Fig.1).

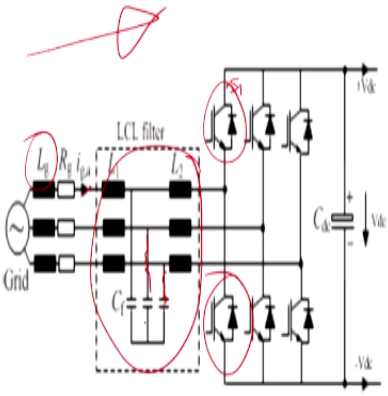

Fig.1 Active Front End (AFE) with integrated LCL filter.

So, this is the one of the circuit diagram of active power filters. Assume that power is going from AC to DC side and this is a grid and you have a grid inductance, that is leakage inductance, may be coming from the transformer, essentially the leakage stage of a transformer constitute the grid inductance, thereafter whatever the resistance of the total side has been put as a lump parameter as Rg, and thus you have a grid current.

Since it is switching, you have a switching frequency ripples here and that can be suppressed well by LCL filter. An LCL filter is a very common and it can revoke the high frequency current and clean the current at the grid side and where at this point and it is accepted within a power quality range.

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Active Front End (AFE) (cont...)

- However due to a stability issue of the converter, a proper damping method is required.
- Possible control methods are:
  - Passive damping, by adding a resistor in series with the capacitor, which can affect the efficiency of the system.
  - Active damping by adding one of the state variables in the control method such as capacitor current in order to develop a virtual resistor.

However, due to the stability issue of the converter, proper damping also require, generally LCL filter will give you oscillations and thus there is a they are required to be damped out this oscillations and it is with a phenomenon when there is a pre-switch is a transient. So, it has a because its state will be changing, let us consider the switch is 1. Once it is turned on, the connector is then, it try to increase the current. Similarly, once this is turned on in negative cycle, it tries to increase the current.

So, a pre-switching is a transient and thus there will be a huge problem if this filter is under-trapped, please understand that. It is not that it is fluctuation of the load or source gives you the transient and thus it is required to be actively damped. Of course, you can damp it, then contempt that is a challenge because you can put a resistance here and we will find that it has been damped out, but if you provide damping, you will find that your response or that whatever desired case you want to have that has also come down.

So there is a challenge, and there are many researchers working on it on the active damping of this LC filters. You can refer a paper or you can mail me, I can sign the papers. The possible control techniques are definitely that is I am going to say. The passive damping, that is what I was saying by adding a resistor in series with the capacitor, which can affect the efficiency of the system, of course, the losses occurred in the resistance is simply a loss.

It is a hitting, doesn't have any purpose, but apart from that, you also get higher THD if you have high value of the resistance because time constant matters. Active damping, that is something like have to work with the control system by adding one extra variable in the control, so you have you got a PI controller and we required to do something there and adding the one extra state variable in the control method such as capacitor current in order to develop a visual resistor. So previously, so what, so what is the demerit of it.

Essentially, you know you require extra sensor, so cost to go up, as once this information of the current sinking into the capacity is available, so that becomes another state variable and you can control it and thus it is called actively control. So, either you put a resistance that is passive control, so system become lousy and also performance is quite poor, but you can have active control, then you have to provide extra transducers. So, either of it, then you know that the cost of the transducers how many days you can pay off, this kind of economies will come into the picture.

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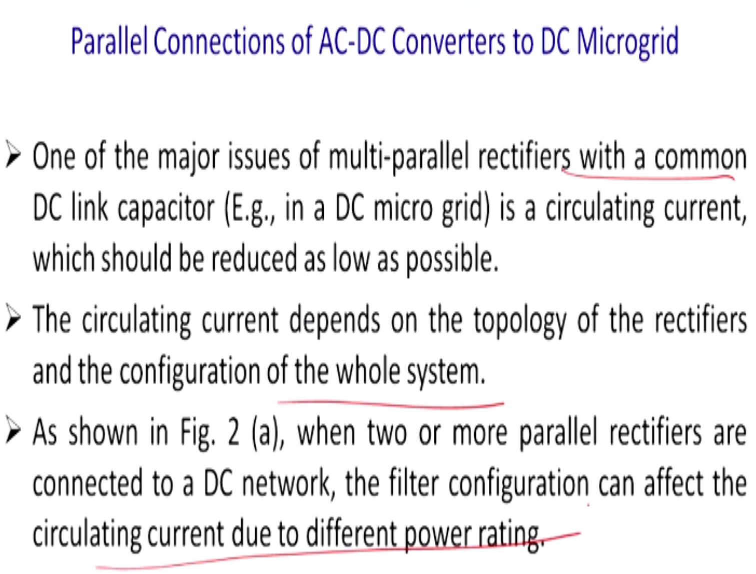

So, one of the major issue in the multi-parallel rectifier with a common DC-link capacitor and for example in microgrid is a circulating current, that is also quite main problem if there is a little mismatch between the pole voltage of this of this to dc of this multi-capacitor, there can be a circulating current in between and we have to and thus, the circulating current will welcome the heating and thus it will welcome the losses.

Circulating current depend on the topology of the rectifier and configuration of the overall system, that I will show you the next figure. As shown in the figure 2a, that is with the next slide, then 2 or more parallel ratifies are connected to the DC network, the filter configuration can affect the configuration current to do the different rating. So, this is something we require to understand here.

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Fig.2 (a) Parallel connection of two three-phase rectifiers with different DC-link filter configurations (b) equivalent impedance loop in the positive DC bus legs and (c) the negative DC bus legs.

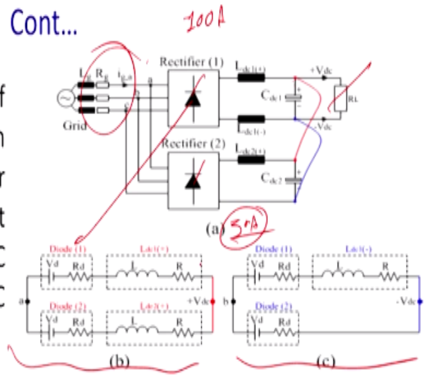

Fig.2 (a) Parallel connection of two three-phase rectifiers of different power rating, (b) equivalent impedance loops in the positive DC bus leg and (c) the negative DC bus leg.

- E.g., in Fig. 2 (a), two diode rectifiers with a same DC link filter are considered. Even though the topologies are the same, the power rating can be different.

So, see that, this is one converter, this is one grid and you can have one rectifier and another rectifier in parallel and you may have a loading and you may not have a loading here, but due to this loading and due to this capacitor's value little mismatch also, what happens, if you connect these two points to meet this loading, then there will be different voltages across it and thus there will be a circulating current within this two points A and B.

So that is what we say the parallel connections of the 2 three-phase rectifier different DC-link filter's configurations has been shown. Equivalent impedance loop in the positive DC bus legs and the negative DC bus legs can be referred here. So this is red portion of it is a positive DC bus. You got it can you can model it here, that is your diode plus RD, thereafter you got LNR and thus you reach this point here. Similarly from here, you got the diode boost rectifier RD and you reached here, and then this point and this point can have a little voltage difference, thus current can circulate in between this point.

Similarly for the negative terminal. The parallel connections of the 2 three-phase rectifier of different ratings, equivalent impedance loop in the positive DC bus legs and see the negative DC bus leg has been shown here. And in the figure 2a, the two diode rectifiers with the same DC link filters are considered, even though topologies are same. The power rating can be different. So current passing through it may be less because you are using a different diode and thus also may cause the potential difference in between these two.

There is very simple thing you know, here let us consider that it carry 100 ampere of current and it is carrying 50 ampere of current. Then voltage drop will be 1.4 x 100 ampere and voltage toll will be 1.4, that is 0.7 volt, two diode is conducting simultaneously is you assume. So and this will be into 50. So, power loss and all those entities will be different in between these two rectifiers.

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- The inductance values of the filters are determined according to the base impedances in Per Unit (x% PU).
- Therefore the inductance values are changed with respect to the power level as well.
- As shown in Fig.2 (b and c), two parallel legs (*the positive or the negative DC link legs: rectifier 1 and 2*) are connected to the same terminals ($V_{phase}(t)$ and V_{dc}).

Thus what happens the inductance value of the recti of the filters are determined according to the base impedance in per unit. Therefore, the inductance values are changed with respect to power level as well. So, generally we say that inductance value is 5% or in a per unit value. So, once you change the different power handling capability, your design constraint also comes into the pictures.

As we can refer in figure 2b and 2c, this one and this one, the parallel legs, the positive or the negative DC links of the rectifier 1 and 2 are connected to the same terminal of phase and the Vdc, that is something we required to see that, so these are AA, BB, and CC.

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- A major issue in this topology is that the DC current depends on the resistance of the DC link legs (mainly diode and DC link choke), while the ripple current depends on the inductance value.

- Therefore, the current sharing significantly depends on the quality and the tolerance of the components.

$$L = \frac{N\phi}{I}$$

Now, the major issue in this topology is that the DC current that is available the output depends on the resistance of the DC link legs, mainly the diode and the DC link choke, while the ripple current depends on the inductance value. So, more the value of the inductance, it will smoothen the ripple quite well. Therefore, the current sharing significantly, therefore the current sharing significantly depends on the quality and the tolerance of the component. So, that is something very important.

So, once because you know that a material comes into the picture, for example, the cheapest material for making the inductor is a ferrite, but it has a very fast roll off, that mean the value of the inductance will drop very fast, you know that L = N5/I, and if it saturates, then if you increase the value of the current, then L will come down. So, for this reason, that also depends on the quality of the component and its tolerance. So, you have loaded those inductors, then what will happen.

If you have loaded that inductor with a better material like Kool mu, it will have a different characteristics and if you loaded that induct a a the inductor made of by ferrite, you will find a very great roll off and value of the inductance will come up drastically, from its 100% to may be the 30% value. So, those variations have to be considered in our design.

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Grid-Interface Electronic Transformer for DC Microgrid

- The Electronic Transformer or Solid State Transformer (SST) is considered as a key enabling technology for implementation in future electric power distribution architecture such as smart grid.
- The application of SST has been already visualized in microgrid, traction and data center.

The electronic transformer that is another important thing, it can be a matrix or indirect matrix converter or the solid state transformer SST is considered as a key enabling technology for implementing the further electric distribution architecture such as smart grid, where you can have not only the voltage, but also the frequency control. The application of SST has been already visualized a microgrid in tractions and the data centres.

So, in various kind of loading, so you require a V/f control, so it is directly a AC to AC conversion, and in between and it may have a fixed AC to DC link in case of the indirect ma indirect matrix converter and so that you can inject the real power and take out the DC power there and generally this is the mode has been preferred in our microgrid.

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Grid-Interface Electronic Transformer for DC Microgrid

- Dual active bridge (DAB) based SST topology shows its application in DC microgrid system, in which it can replace the existing passive distribution transformer operated at the line frequency of 50Hz/60Hz, while providing a direct connection to the LVDC system.
- The SST concept enables equal functionality feature as that of an AFE with passive distribution transformer (shown in Fig.3(a)).

Now grid-interface electronics transfer electronic transformer for DC microgrid, it is quite interesting new topic. Dual active bridge or DAB based solid state transformer show its application in DC microgrid, in which it can replace the existing passive transformer, which is made of this is a a dump transformer, operated at the line frequency of 50 and 60 Hz, while providing that direct connections to the LVDC side. So, there it has got a flexibility.

So it can buck, it can boost, it can accommodate the change and frequency and control, is an intelligent devices. The SST concept enables equal functionality features that often AFE or active rectifier or active filters or the passive distribution transformer, I will show this figure in the next.

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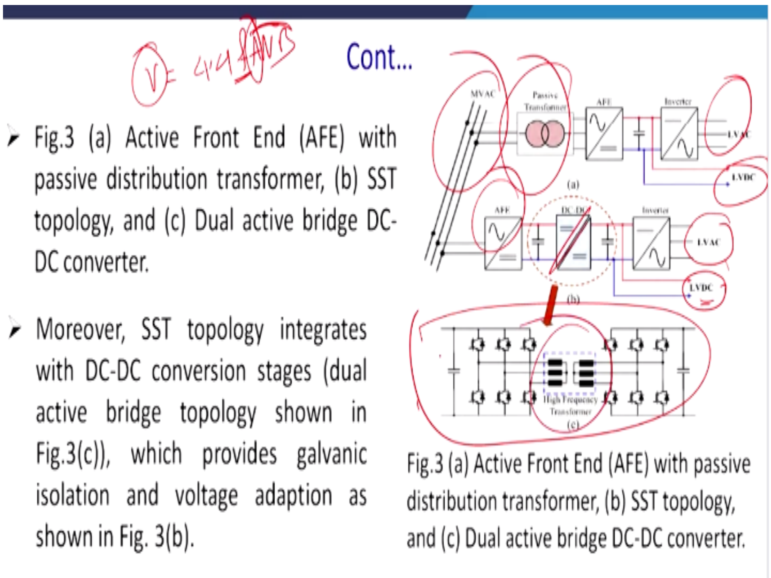

So, this is your high voltage AC transmissions and generally what happen you will have this active rectifier AFE link this side. It converts AC to DC. Thereafter, you will have a DC to DC converter, generally it is of high frequency DC to DC converter, isolated high frequency DC to DC converter that provides you the galvanic isolations and thereafter it has been an inverter. Purpose of the inverter, it can generate any voltage of the desired kind and the from there, you can also take the low voltage output of DC.

So, this flexibility is available. Also there is a possible, I first took the case of the b and there is a possible of a and you have a passive transformer, then generally it will be stepping down and thus it is a very bulky because you know that V = you know 4.44 FAMB. So, if you are a very high voltage setting if your frequency is less in a transformer like 50 or 60 Hz, then ultimately N is something it is the trans ratio, so b and a has to be more, be something it is a material.

So, you cannot have a drastically increase the size of the value of the b and a is the window area of the transformer. So, you have to that makes you the size. So, this transformer of course is employed employ a high frequency transformer, but that since it is a 50 Hz and this can be 10 kilohertz. So, the size of the transformer will be 200 times less as simple as that, and in this case let us, so what happened.

We step it down from the high voltage and then you rectify it and from there you take it to the DC, it can be a controlled rectifier and thereafter you can reconvert into the desired level of AC in case of the adjustable split time. So, what we can say that the first one and this active rectifier is active front end we sometimes say with the passive distribution transformer is a class a and b is SST topology with the in between high frequency DC link and the dual active bridge of the DC to DC converter.

This is basically this one we have to have a dual active bridge because if you have a handling a bulk power. Then resetting a flux is an issue. You can, there are many DC to SC converter depending on the power rating. Of course, the least power rating is your flyback converter, that is your laptop charger. Thereafter, you have a forward converter, thereafter you couple them, the 2 forward converter that becomes a push-pull converter. Thereafter, you got a half-bridge converter, thereafter you got a full-bridge converter.

This is a full-bridge three-phase converter. It is operated in high frequency, and for this reason, size becomes low, size becomes less. So moreover, SST topology integrates the DC to DC conversion stage, dual active bridge topology shown in the figure c, which provides the galvanic isolation and the voltage adaption as shown in figure 3b.

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- An SST typically includes a high voltage AC to DC power conversion to generate a high DC link voltage, and then a high frequency DC-DC converter stage is required to regulate the DC bus voltage.
- Therefore, the SST is basically a three-energy port system:
  - where one port is interfaced with high AC voltage and
  - The other two ports are DC port (LVDC) and low voltage AC port (LVAC).

Now, the typically SST includes the high frequency AC to DC power conversion, generates a high DC link voltage and then a high frequency DC to DC converter stage is required to regulate the DC bus voltage. This is the way it will work. Therefore, the SST is basically a three-energy port system. So, that is the flexibility of it unlike your passive transformer, where one port is interfaced with the high voltage AC and the other two ports are DC port and low voltage, low voltage port of LVSC.

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- The three-port characteristic of SST makes it very suitable for DC microgrid application, where the input side is connected to an AC grid and/or a distributed energy source and the DC side to PV, Fuel cell and battery systems as shown in Fig.3(b).
- The SST based AC-DC conversion has a better power factor regulation, VAR compensation capability and also can provide galvanic isolation to the DC bus system.
- Overall, the SST based DC microgrid will be more compact with better functionality in which an AC grid interface is required.

The three-port characteristics of SST make it a suitable for the DC microgrid applications, where the input side connections, connections of AC or the grid, AC grid or the distribution energy sources and the DC side of the PV, fuel cell and the battery system is shown in the figure 3b, that we have shown here, the overall system. The SST based AC to DC base conversion is a better power factor regulator because we can have a control by the active rectifier.

Also VAR compensation, we can employ the PQ technique for the VAR compensation, and also it can provide the galvanic isolation in the DC system. So, for this reason, the research topic is totally shifted to the second topology of 3b. The overall SST based microgrid will be a more compact because of the high frequency and with the penetration of the high bandwidth devices like, like silicon carbide, you will see that this power handling capability can go up to the megawatt level also, with the with the better functionality with an AC grid interface it is required.

Thank you for your attention. I shall continue with the discussions with a different component of the DC microgrid in our next application, but before that, I just wanted to conclude one thing that this is the hype, all these challenge here lie in designing this transformer. So, that is something one has to be a very good designer of the magnetics and so, and it has a trans ratio and that will essentially will be almost same of that, but this will be the compact by 200 times. The area that it will have here an area it will have there is thus 200 times less. So, for this reason, your compactness will come into the system. Thank you so much.