Economic Operation and Control of Power System

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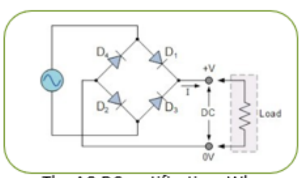
Week - 12

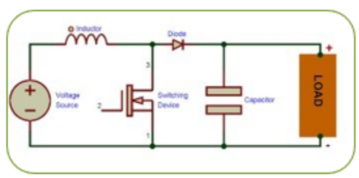
Lecture – 60

Hello and good morning everyone. Welcome you all for the NPTEL online course on Economic Cooperation and Control of Power System. So in today's discussion we will discuss with respect to electric vehicle various challenges and the converters which are used for electric vehicle charging. First we begin with the different types of converters. The first one is non-isolated converters. So it is very simple.

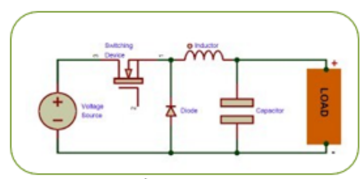
There is no isolation. Non-isolation means there is no isolation. So there is a diode bridge rectifier based charger. You can see there is a AC, the diode bridge rectification will help to convert from AC to DC and there is a load as shown below:



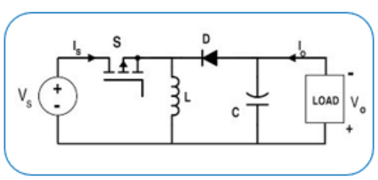
The AC-DC rectification: When EV needs to be charged by Grid



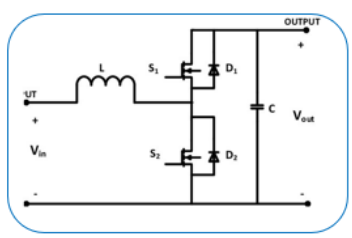
Boost Converter



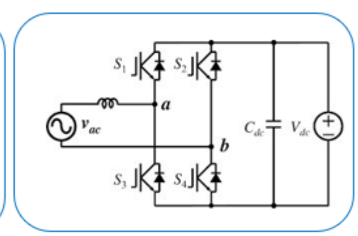
Buck Converter



Buck-Boost Converter



Bidirectional Converter: Both Charging and Discharging Possible with the DC bus.



Bidirectional DC-AC Converter: Both Charging and Discharging Possible from the AC Grid

Load could be a battery present in electric vehicle. So it is very simple but yet there could be many challenges because when you are, when the diodes are there, there will be harmonic injection, then there will be significant power quality deterioration that one can see. There is also boost converter based charger. So it depends like you know battery voltage requirement is higher as compared to the available DC voltage source, then one may think of going for a boost converter based operation and there is a boost converter based charging. There is a buck converter is just exactly opposite to that.

The battery voltage requirement is less as compared to the battery, the DC voltage source then one can prefer for a buck converter based operation. There is a buck boost converter operation where there is possibility to operate in a boost mode and a buck mode and there is a bidirectional converter that means both charging and discharging is possible with the DC bus. You can see here there is input side inductor and there are two switches, bidirectional switches are there and there is a battery which may be present here. This could be a battery. So there is a input voltage source.

So by using this bidirectional converter one can think of vehicle to grid that is V to G and G to V grid to vehicle operation that means if there is excess of power available in the battery vehicle, electric vehicle and there is a power requirement at the grid side. So the battery can inject power into the grid and if there is requirement of power from the battery perspective then the battery is used to get the power back from the grid and there is also bidirectional DC to AC converter both charging and discharging possible from the AC grid. So this is with respect to DC converter, DC to DC charging and if there is a AC to DC charging that has to be done. So one can think of using a bidirectional DC to AC converter as well. So both V to V to G and G to V operation is still possible in this sort of converter of configuration and there is isolated converter topology.

You can see here there is a isolation, there is a isolation transformer being present. This high frequency transformer usually we manufacture, we use the ferrite core type of material to build this sort of high frequency transformer. So you can see there is a DC bus here, there is a battery here. This topology is called as dual active bridge converter DAB. So what is happening here is there is a DC input side then there is a DC to AC conversion as shown below:

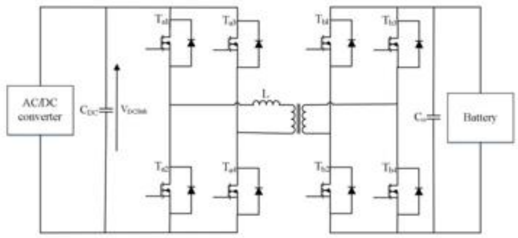


Figure 1. Dual Active Bridge

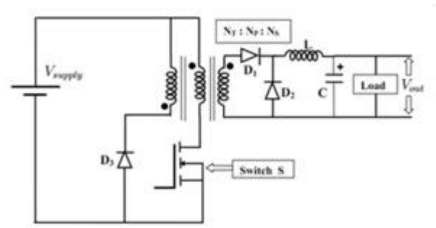


Figure 2. Forward Converter

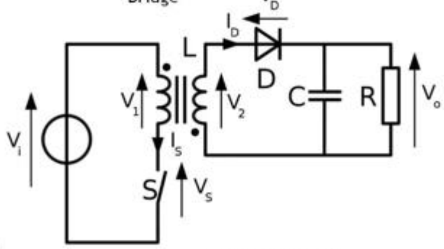


Figure 3. Flyback Converter

So this is a full H bridge inverter single phase. From DC there will be a DC to AC conversion and there is a high frequency transformer that means there is high frequency AC and then by using this isolation transformer the power is transmitted over a considerably good amount of distance and then at the receiving side there is a AC to DC conversion and then there is a battery being charged. So this is with respect to V to G steady, sorry G to V steady and then V to G means it is a back power flow that means from battery vehicle to battery, vehicle to grid. So the battery which is a part of a vehicle now is discharging to the grid that means V to G operation. So because we have bidirectional switches in both the sides.

So either power DC to AC conversion or AC to DC conversion can happen on either side. So making it a suitable viable option for V to G and G to V application. And then there is a forward converter again there is a isolation being seen. There is a fly back converter where the switch is open and close. So similarly whenever it closes and opens and then there is a power transmission is happening and with respect to fly back conversion operation.

The main key features with respect to isolation converter is the source side and the load side is isolated. So that makes it sort of independence with respect to the power handling that means there is no scope for fault current being transmitted from one side to another side. If there is a fault happening at the primary side or one side of dual active bridge converter the other side may not be getting any impact of it. So that is a key benefit of this kind of topologies. And then now we will discuss about the EV impact on power system.

Now you have electric vehicle. Electric vehicle is very important. Now is there any impact on of electric vehicle on the power system that is what we are interested to discuss. So as listed out here there is a impact on overall power quality, impact on voltage stability, impact on the transformer life, impact of EV charging stations, impact on stability of power grid, impact on supply and demand balance of power grid, impact of current harmonics on utility grid, impact on environment as well. So let us discuss about impact of electric vehicle on the distribution system.

You see here there is a power quality being defined for the distribution system. So many features the transients, events, harmonics, reactive power, network unbalance, different phases have a different power carrying power being carried at a different instant of time. There is oscillations, voltage variations, flickers. So there is so many power quality considerations. So large scale electric vehicle charging causes under voltage conditions, power unbalances, voltage and current harmonics.

There is a vehicle, so let us say there are different phases, single phase charging is happening and the vehicle is being connected. So naturally there could be variation in current being carried by different phases and there is a voltage, under voltage scenario may be seen actually the reason being if multiple electric vehicles are plugged in and being charged from the point of common coupling, so the voltage may drop down. Then there because the converters are present then there are harmonics being injected as well. So these are the important power quality issues that one can see if the electric vehicle is present in the distribution system and not only that if the vehicles are continuously charging at a specific distribution transformer side, so what it may happen is the distribution transformer have tap changing transformers. So because it has to adjust the voltage back to the nominal value, so there will be tap changing, frequent tap changing operation being carried out.

So this may hamper the life of a conventional or mechanically operated on load tap changing transformer, so that thereby affecting the life of the transformer as well and increased load due to simultaneous EV charging would cause serious voltage drop and pertaining power quality, voltage quality issues and by proper charging algorithm and knowing unbalance in a particular phase the EV can also be used to mitigate this issue. On one side I spoke about the demerits, but the same electric vehicles if being called for the improvement of power quality that is also a possible solution. Let us say if there is already existing unbalance in the system and can you call this electric vehicle to charge or discharge at a specific bus or a node, so that you can try to balance the phases that is one such of improvement that can be achieved with the electric vehicle or you can also shave the load peak shaving can also happen. If there is a load curve certainly load curve is not a flat load curve, so can you bring in the electric vehicle and then use this electric vehicle for charging and discharging such that you can make the load curve as a flat load curve. It depends upon the charging algorithm smart EV charging algorithm that one can develop using may be artificial intelligence techniques, so that one can come up with a very viable technical solution accommodating electric vehicle into the system.

So just a nutshell of whatever we have discussed, transformers the growing electric vehicle can put strain on transformers causing overloads, premature aging and potential failures. The capacitors because the system will have the shunt capacitors being placed for either for power factor correction or for reactive power injection. So the harmonics introduced by a non-linear load may interact with nearby capacitors if the harmonic frequency is in resonance with the LC time constant because there will be non-linear loads and there is a harmonics being generated by the converters and these capacitors and there is a sort of harmonic frequency being generated and resonance may happen and this may hamper the stability of the system and the power cables the primary effect of harmonics on power cables it increases the losses. And not only that there could be effect on or impact on the operation of protection devices you have various protection devices the circuit breakers, the relays, distance relays and so many over current relays so many types of relays are there when the electric vehicles are there or present in the system. So they may vary the power flow they may be a cause for varying power flow.

So this may be a sort of threat from the perspective of protection system actually. So what it happens is when the relay is supposed to operate it may not operate when it is not supposed to operate it may operate. So the mal operation of relays can lead to serious protection threats as well. So what are the other power quality issues observed phantom loading when the charging station is there, charges are present some minimum charging may be happening some leakage current some charge flow may be happening. So this is what we call it as phantom loading so there will be some drawing without the presence of the load also and there is a load imbalance that we have discussed and there is a DC offset due to harmonics as well.

Now I will discuss some of the real time case studies with respect to electric vehicle how we can use the electric vehicle to harness the potential of electric vehicle to improve grid resiliency.

So because nowadays as I have discussed in the previous discussion forums that resiliency is a very important aspect. So especially when we are moving forward for renewable based system so there could be serious threat with respect to meeting out the requirement of emergency loads. So how can we utilize the electric vehicle to improve the performance of the system in terms of the resiliency aspect. So we have considered a system where there is a conventional grid there is a DC to AC inverter and we have created a DC microgrid.

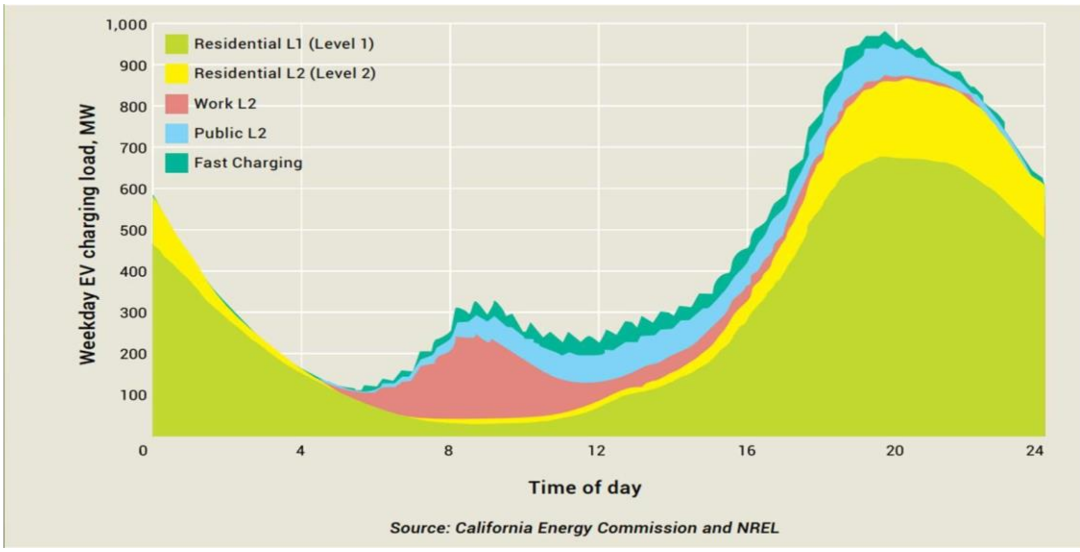
So here in the DC microgrid one can see there is a solar PV panel which is connected to DC bus using boost converter there is a wind turbine also being connected to a DC bus there is a battery and there is also UPS based system and there is also a electric vehicle. So there could be so many events like natural disasters or fault or so many scenarios during which the resiliency study may be of primary importance. So what we have done is we have developed a smart energy management scheme whereby we have defined the operating regions for the electric vehicles and the UPS during different operating scenarios whether it could be a grid connected operation or isolated operation. So we have preserved the state of charge SOC of the batteries especially the electric vehicle EV battery so that that can be utilized during the emergency scenarios to meet out the requirement of the home loads bare minimum home loads. Let us say if there is a main grid failure at least can we meet out the bare minimum home loads for some days so that when the system is restored the home is can continue to get power from the conventional grid.

So we have considered the G to V V to G operations during the normal operation scenarios and this is the proposed control strategies you can see here. So basically either the grid side converter or the UPS converter or the EV converter is being given a sort of role and responsibility being defined for them depending upon the operating scenarios so that they would be able to maintain the DC bus voltage. So inherently the EV is given a last option to maintain the DC bus so that we can have bare minimum SOC storage. So these are the real time simulation results. So we have implemented in OPAL RT and you can see to it that if there is a varying irradiation the DC bus voltage is being maintained constant while the UPS or in some scenarios the EV battery or the grid side converter they are maintaining the DC bus so that we can improve the resilience of the system.

So further moving forward I have also considered the international case studies. One is a California case study to discuss about the impact of electric vehicle on the distribution system. You can see here so time of day is in the x axis and weekly EV charging is given in the y axis. So you can see here mostly the electric vehicles are brought in during the late evening hours. So the charging of electric vehicle is mostly taking place during evening hours where the vehicle may be resting at home.

So in the California it is observed that due to continuous power demand from the electric vehicles during the late evening hours you can see at certain places or certain nodes in the distribution system of California state one can see the red spots, so many red spots especially you can see here with increase in electric vehicle especially. Earlier it is 1 million a vehicle then 2 million, 3 million, 4 million, 5 million and then you see the comparison between 6 million and 1 million electric vehicle. So naturally the red spots are quite high that means it is giving an indication for all of us that significant increase in electric vehicle will surely crowd or overheat the cables when it is connected to the distribution system. So and there is also a Maldives case study. One can see that if the vehicles number is increased, the vehicles number is increased this number of 2 wheelers and there is a number of 3 cars and as seen here over a period of time the vehicle purchase is increasing especially electric vehicles.

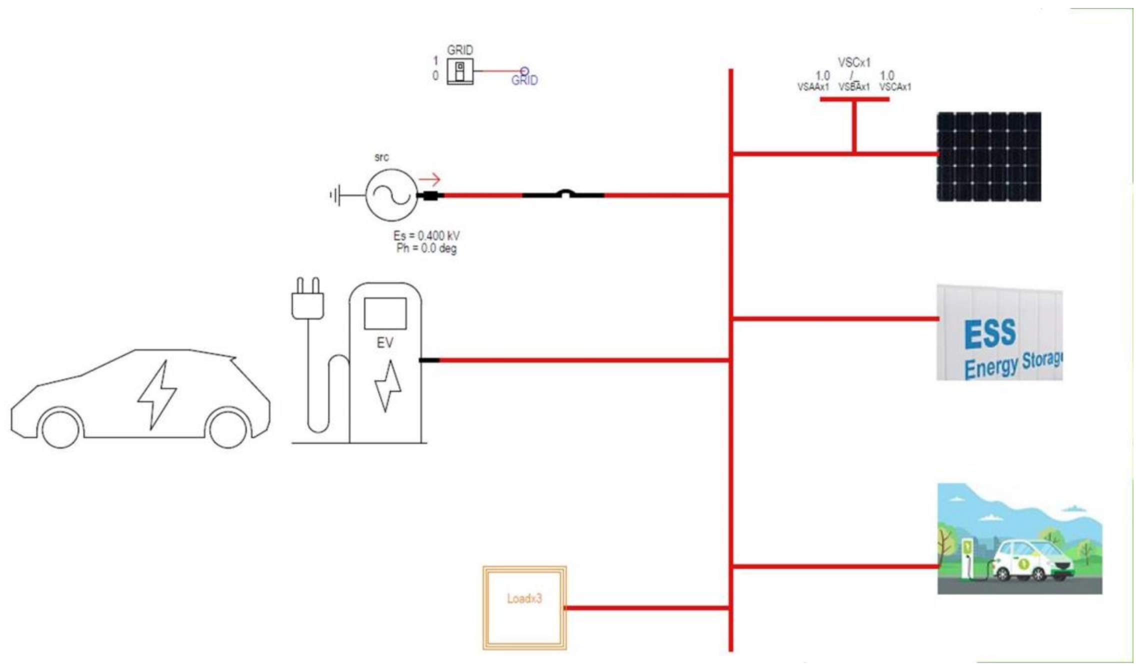
So you can see here there is a significant increase in the peak demand and peak demand increases then naturally you have to increase the generation resources also as shown below:



So challenges to EVs as source of grid resilience there is infrastructure vehicle to grid modernization, bi-directional EV and new charger management system, development of codes and standard for electric resiliency but as we have discussed EV can also bring in advantage in terms of improving resiliency if it is properly utilized and there is also a latest generation Nissan Leaf E plus electric vehicle being launched. The electric vehicle manufacturer is marketing the electric vehicle with the notion that this vehicle is not only meant to help you move from one place to another place rather this can also act as a small power station where it can feed in the emergency load during the emergency scenarios. So you can see here full charge 72 kilowatt hour battery can provide enough electricity to power the average European household for 6 days. As a disaster recovery vehicle the RE Leaf vehicle can power multiple devices simultaneously.

Here are some of the examples you can see here electric jack hammer, pressure ventilation fan, the 10 liters soup kettle, intensive care medical unit, the ICU ventilator, 100 watt LED flood light that means there is a kitchen bare minimum kitchen set and there is a ICU unit, there is a minimum lighting and all these minimum home loads can be metocked by using this electric vehicle itself for 6 days. This is a good delivery for the customer actually. And we have also created a AC microgrid. So you can see here there is a renewable solar panel and there is a EV charging station. So vehicle is also being modeled and being connected there and then there is a grid.

Now this forms a AC microgrid.



So this is a RTDS based study where we have connected this AC microgrid into the system to study its impact basically. You can see here this is a network microgrid being modeled and developed in the RTDS platform and then we have also seen that you know the microgrid being modeled and connected to the distribution system we have observed that through various results the electric vehicle charging station may get overloaded if multiple electric vehicles are being plugged in at a given point of time. So with this we have completed the course, but I would like to give a recap on whatever we have covered till date. So in various topics that is being covered are dynamic programming. So this is a tool that we had discussed by using which how effectively we can carry out the economic dispatch and then economic dispatch of thermal units using Lagrange multiplier method that we have discussed and economic dispatch using various numerical methods that we have covered.

Economic dispatch using dynamic programming, unit commitment if there are multiple thermal power plants then we have discussed about the start up time, minimum up time, down time and how when these units are being committed and there is also various challenges with respect to crew management and manpower resources, the availability of spinning reserve and all these things we have covered and unit commitment we have also solved using dynamic programming and unit commitment we have solved using Lagrange relaxation. Then we have also considered the hydrothermal scheduling where we have hydro power plant and the thermal power plant and how the combination of hydro and thermal can help to minimize the fuel input or the overall cost of operation involved with respect to the thermal power plant operation. We have also discussed various hydro constraints like there should not be a flooding and there should be a minimum flow, river flow should be taken into consideration. So many challenges with respect to hydro station being administered and we have also discussed about pumped hydro storage where the same hydro power plant can also be utilized to help improve the storage capacity where during a peak hours the water is being used which is stored in the upper reservoir to generate the electricity and feed it into the grid and during the off peak hours the same water which is being stored in the lower reservoir can be pumped into the main grid so that you can carry out the storage operation as well and then we have also covered about the real time case studies on reactive power dispatch where we have multiple reactive power units in place how we can utilize them so that we can achieve better voltage profile, improved reactive power margins so that that can be utilized for the transient operation and we have also tried to help you understand how the maintained voltage profile can also help to reduce the overall system losses. Moving forward we have discussed about the power system security in terms of N minus 1 and N minus 2 contingency operations and then we have covered about the state estimation if there is a meter data that is available then how to ensure that even if there is a malfunction in the operation of the meter that can be utilized we can able to you know figure out the data which is a bad data and which is a reliable data and then we have discussed about the weighted least square of state estimations where we assign different weights for different metering based on their past records so that we can come up with a proper estimation technique and there is a automatic generation and control load frequency control where we can manage the active power output and reactive power output from a thermal power plant and various control loops have been covered and then we have discussed about the optimal power flow where there may be various objective functions can be defined such as loss minimization, the load flow studies can also be brought in and there is a economic dispatch is also important aspect of this optimal power flow.

So there are multiple objective functions being defined and how we can solve using various techniques being also covered and there is also the contingency analysis studies that we have covered and then pump storage and gravity storage that have already mentioned and then advanced distribution system management where we have covered about various aspects of ADMS, the features of ADMS which includes the volt work control and the loss minimization and there is a fault location isolation and service isolation. So various features of ADMS and how it is very significant in terms of improving the overall operation control and the economic management of the system is being covered and today we have also covered about the electric vehicle and how it can create an impact in the operation of the overall distribution system. So we hope that this course will be beneficial for all of you in terms of building your fundamental aspects and for research scholars it will be also beneficial for your research studies.

So wish you all the best. Thank you so much. Thank you.