Power Electronics
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Module 12: Power Electronics
Lecture 24: Power Electronics Applications

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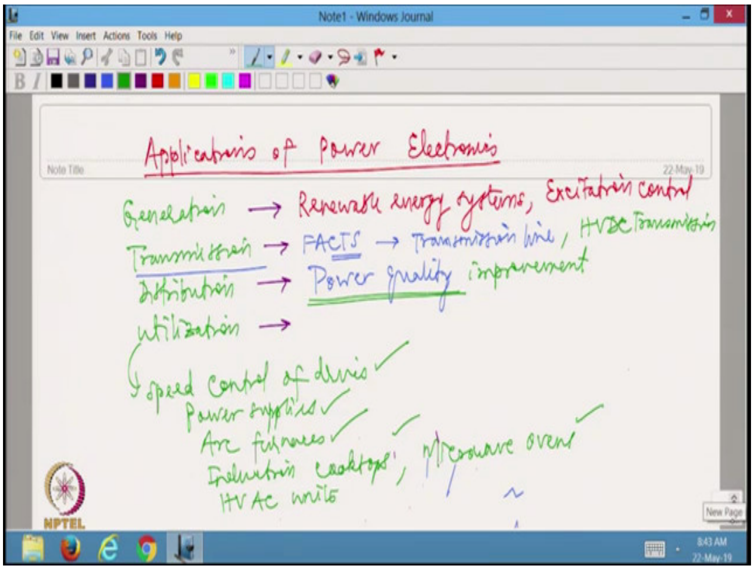

So we are going to start on the applications of power electronics. We had seen already different type of converters that is AC to DC, DC to AC, AC to AC, DC to DC. Many of them are applied in different sectors. If you look at the power sector, I should divide them into four sectors mainly, Generation, Transmission, Distribution and Utilization. These are the four sectors we normally have. So I am going to take up one by one. How we are going to have different sectors getting the application of power electronics.

Especially in the wake of renewal energy systems which have come into existence now and also whatever was the original system existing for generation that is, let us say that excitation control mainly. These are mainly the two major application areas of power electronics as well as generation is concerned. In Transmission sector, we have something called FACTS Flexible AC Transmission system in which we are going to actually improve the capacity of transmission for any transmission line by having switched capacitor and switched reactor.

So those are going to be actually useful only if I have the power electronic switches, switching them in and switching them out. So there also we are going to have transmission sector applications of power electronics. As far as distribution sector is concerned, the major thing we worry about in this particular case is power quality. We have too many power converters these days for speed control of DC AC motors, so speed control of drives.

And we also have many power supplies, then we have arc furnaces and you know many of us use induction cook top. We use microwave ovens. All these things use a lot of power electronic converters and they are going to definitely switch in and switch out the currents. Because of which we are going to have the current being non sinusoidal in nature. So, if we want to make it sinusoidal or if we want to have the negative impacts of that non- sinusoidal current removed then we have to do some power quality improvement so for that also we use power converters.

Then in the utilization sector, whatever I said here, these all are applicable we are going to have drives in the utilization. When we utilize the electrical energy, we are going to have power supplies, we are going to have arc furnaces, we are going to have induction cook tops, microwave ovens. These are home appliances. We also have heating, ventilating and air conditioning units and so on. One major application I have forgotten in transmission is HVDC transmission. So, we need to talk about this as well.

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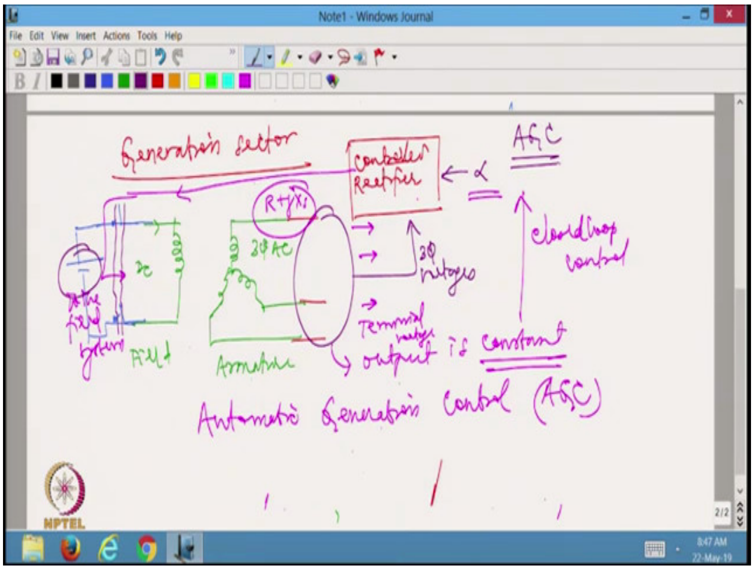

So let me talk about each of these applications one by one. So let me start of with generation sector. So all of you know that in generation sector, conventionally what was being used was a synchronous machine. So I am going to have basically a synchronous machine which is having a three phase armature which is delivering power to the generator transformer or to the power transformer which is going to actually deliver it ultimately to the transmission line.

And here is my excitation system. So normally what we try to do is we give DC to this excitation system and three phase AC comes out of the armature. This is the field. So, what is done normally is just to have a control over the voltage we actually take the same three phase AC and then we use a rectifier. The rectifier will be normally a controlled rectifier. So, let us say there is a controlled rectifier.

To this controlled rectifier, we are going to give these three phase voltages. Now this output is going to be passed on to the field system. So I have every control over the firing angle α. This firing angle can be adjusted such that the output voltage is held as a constant. So, if I have to maintain this as a constant, I am normally going to have this firing angle controlled. So, there will be a close loop control which will maintain this α at a particular value depending upon what is the voltage I have require here.

Please understand that I am going to have definitely some inherent R and Xs for this particular machine. Depending upon how much is the current that is drawn out of this machine the drop is going to change. Depending upon the drop I am going to have a variation in the terminal voltage. If I look at the terminal voltage of the machine, that is going to change. So, the terminal voltage can be held as the constant by adjusting the α which will adjust the excitation and because of which the voltage can be held as the constant.

So, this is generally known as Automatic Generation Control AGC. So Automatic generation control can be effectively implemented by making use of an excitation system which is linked to the generation voltage itself through a controlled rectifier, but you will also have the question. Initially, there will not be any voltage generated. If I do not have any excitation, so how will the initial generation take place. So that initial generation is generally started of by having a battery.

Only for the initial condition we will have a battery. It will be connected through a switch. This switch will be opened, once the Automatic generation control loop is closed. Until then we are not going to have any generated voltage at all. So, you will need this battery for initial startup alone, so, this is generally known as the AGC or Automatic generation control loop.

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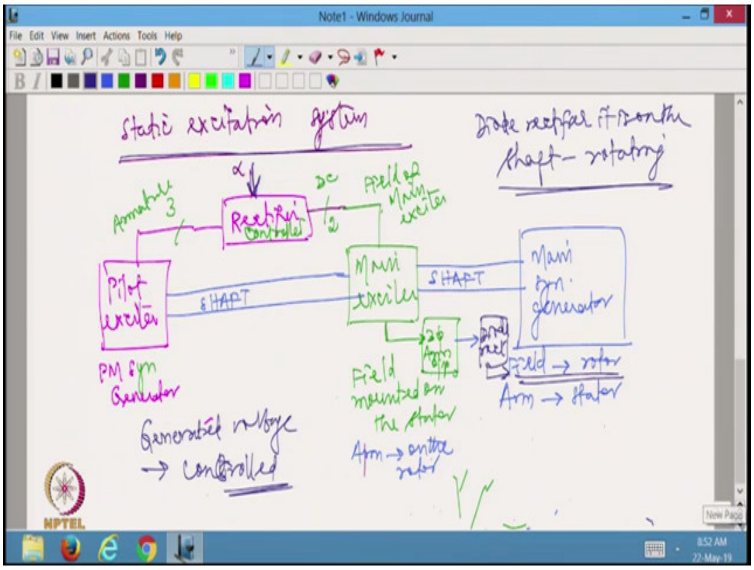

There is one more thing called static excitation system. So, in static excitation system, what is normally done is I am going to have a pilot exciter which generates actually a three phase voltage. So, this is normally like a permanent magnet synchronous generator so the excitation is not by giving field current it is by permanent magnet. So, what is coming out of the pilot exciter will be given to a rectifier. So, this rectifier generally is a controlled rectifier.

So, we are going to have an input angle, firing angle α. Now this rectifier output is normally given to another exciter which is called the main exciter. So, in fact I can show the two sides of this electrical connection. So, this is essentially a permanent magnet synchronous generator. I am going to have essentially this as three phase output of the armature. So that is given to a rectifier which is a controlled rectifier whose firing angle α is controlled. Now what is coming out of this is DC.

Of course, the power forward and return path so there will be two lines coming out I can show, this is going to the field of the main exciter. So, this is the main exciter. Now this main exciter is going to have the field mounted on the stator whereas armature is going to be mounted on the rotor. So, I am going to have armature on the rotor. So, what is coming out of this, please remember one more thing all these things also need the mechanical power.

So, I will have the same shaft which is coming out of the turbine exciting the pilot exciter, exciting the main exciter and also the main synchronous generator. This is the main synchronous generator in the power station. Now the same shaft is going to go and provide the mechanical energy to all three of them that is the main exciter, pilot exciter and the synchronous generator main synchronous generator.

In this particular case like any other synchronous generator I am going to have the field on the rotor and armature on the stator. So, if you look at it here, I am going to have a rectifier external to the machine completely whereas here the output of the rectifier is directly given to the field which is mounted on the stator. So, you do not need slip rings and brushes but here the three phase what is available that is going to be actually rectified using a diode rectifier.

So, I am going to get actually a three phase output of the armature. This is going to be rectified using a diode rectifier. There is no control, please remember there is no control here. So, diode rectifier and diode rectifier output is going to be given to the field. So, I do not have to really have slip rings and brushes here also. The diode rectifier will be mounted on the shaft itself.

The diode rectifier is a rotating rectifier here. It is on the shaft. So, it is a rotating rectifier it is rotating along with the shaft. So, we really can avoid completely any slip ring and brush configuration at this particular aspect. But we will also have the control over the excitation to the main exciter because of which we can have a complete control over the generated voltage, so generated voltage from the main generator is controlled completely. So, we call this as static excitation system because there is no really moving part in terms of slip rings and brushes, so we call this as static excitation system. This is very commonly used in most of the power station what we see as of today. So, this is two applications I wanted to discuss about generator.

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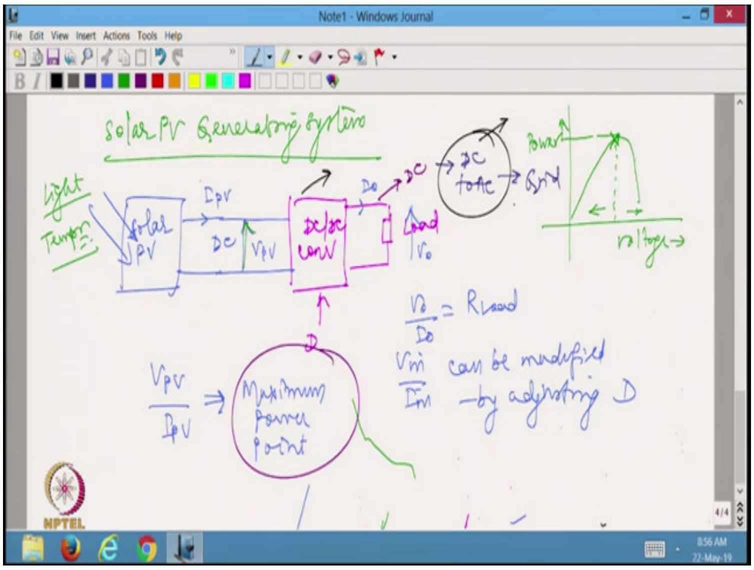

One more application is solar PV generating system. So, in solar PV generating system invariably I am going to generate DC from solar PV so what is generated is DC. So, I am going to have certain value of current and certain value of voltage. What is incident on the solar PV is actually two inputs one is light the other one is temperature. These two are the once which are going to decide how much voltage and how much of current is generated.

But solar PV will be having a characteristic somewhat like this. At a particular value of voltage, I am going to have maximum power so if I try to plot power versus voltage at a particular light intensity it will reach maximum power at a particular voltage only. If I try to go less, then that voltage and higher then that voltage I am going to have less power. So it is very important for the solar PV to see a voltage here or see an impedance here such that it is going to operate at the maximum power point.

So, what we normally do is I may have a particular load impedance here that load impedance is a fixed value, If I put a DC-DC converter here in between the two. According to the duty ratio what I give as the duty ratio I am going to vary. This is essentially I naught and this is what is V_0. So $\frac{V_0}{I_0} = R_{load}$ or load impedance. But $\frac{V_{in}}{I_{in}}$ can be modified for the DC-DC converter by adjusting duty ratio.

So, I will adjust the duty ration in such a way that $\frac{V_{pv}}{I_{pv}}$ corresponds to maximum power point. So normally a DC-DC converter is very very commonly used in a solar PV application just to make sure that maximum amount of power is harvested, from the solar PV generating system. This is one of the applications of power electronics in solar PV generating system.

One more application is because the output ultimately is DC. If I want to feed it to the grid we have to convert into AC before feeding into the grid. So, we can have a DC to AC converter as well. So, there are two major applications of power electronics in solar PV. One is DC to DC conversion, the other one is DC to AC conversion for enabling the DC power to be fed to the grid in the form of AC.

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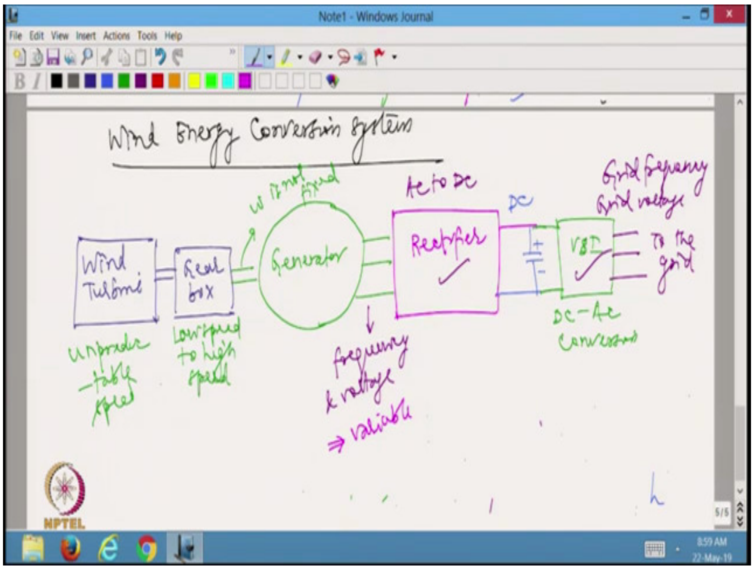

The next one in generating system is wind energy conversion system. So, in the case of wind energy conversion system, this is going to be my wind turbine. On one side I am going to have a wind turbine. Wind turbines are generally very huge, they will rotate at a little lower speed. Because of which we will require a gear box. Because most of our generators run at 1500 rpm or

3000 rpm, it will be four pole or two pole configurations. So, I will need a gear box to increase from low speed to high speed.

Now this is coupled to the generators shaft so let us say this is my generator, may be it is a synchronous generator, may be it is running at a particular speed and it is generating three phase electricity. Wind speed is unpredictable; this speed is not going to be the same definitely. This is unpredictable speed because of which this speed whatever speed we have is not fixed.

If this speed is not fixed whatever is the frequency and voltage that is also not going to be a constant that is going to be variable. I am not going to have a constant value. If this is variable, I cannot feed it to the grid directly. So, I will normally have a rectifier here which will convert this into DC.

So, what I get here is a DC. I may have a capacitor to filter out the DC in most of the cases. And this DC for to be fed to the grid and I have to first of all convert that into AC. So, I will have a voltage source inverter. VSI will be there so this is DC to AC conversion obviously I am going to have the rectifier which is converting from AC to DC. This is variable frequency variable voltage AC and finally what I would convert this into will be grid frequency and grid voltage. It has to be exactly converted so that it matches with the value of the frequency and magnitude of the voltage of the grid.

So, I am going to feed this to the grid after doing all this jugglery. So, you can see very well that rectifier and VSI, both of them really form two of the major portions of wind energy conversion system. So, without this it will be impossible to really get constant frequency and constant voltage which can be fit to the grid. So, these are some of the applications in generation sector.

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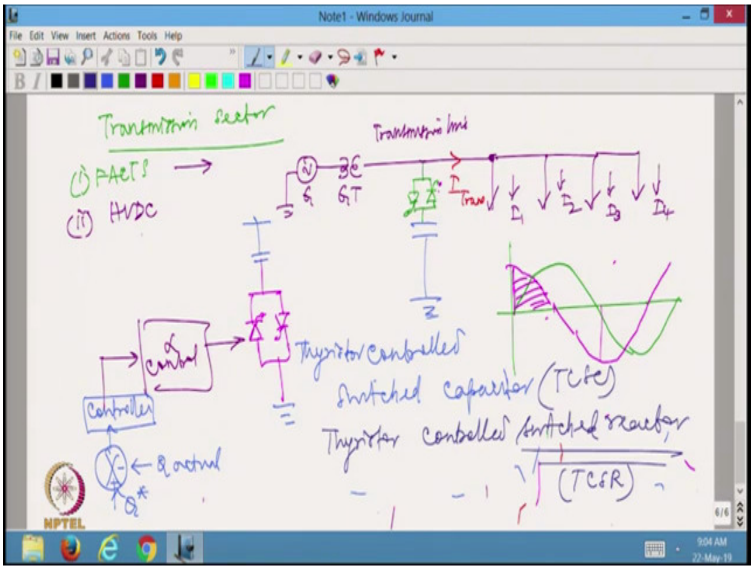

Now let us go over to transmission sector. So, in transmission sector, I am going to mainly look at two things, one is FACTS – Flexible AC Transmission system. The second one is HVDC. In Flexible AC Transmission system, generally what happens is let us say this is my source three phase source of course I am showing it as a single line diagram.

The output of this source is connected through a transformer to the transmission line. So this is the generator transformer, this is the generator and this is the transmission line. And at every point I may have some substation from which I will tap to different load centers so depending upon how much current is drawn. Let us say this is I_1, this is I_2, this is I_3 and so on. Depending upon how much of current is drawn. I am going to have a variable current flowing through the transmission line on the whole. So, the drop that takes place in the transmission line is going to change.

If the currents are very high, I am going to have huge drop. So, if I look at the voltage at this point it may be much less then what I normally anticipate. To boost up the voltage and most of these currents will be probably lagging currents because most of them are motors which will consist of inductance. I can have a capacitance connected like this. But if I have a fixed value of capacitance whether the current is lower or higher, the capacitance is always going to be connected. Which is not a good thing because sometimes the voltage can go very high.

So, if I can make them a switched to capacitor so I can just remove this and instead I can try to put this through back to back connected thyristor pair so I am going to have two thyristor which are connected like this. Of course, this has to be done in every phase so that has to be three capacitors and three back to back connected thyristor pairs cannot help it but if you look at this, we are looking at basically this as the voltage.

So voltage is going to be like this the current in this case basically is going to be leading because it is capacitance I will have the current somewhat like this. This is how is current is going to be so I have to decide at what angle I will fire this particular thyristor, whether I will try to fire it at this point or earlier than this or earlier than this so if I fire it only at this point I am essentially going to get only portion of the current that is going to come up.

May be it will come up for sometime then it is going to come up for later on. So, I can decide how much of reactive power I am giving to the entire system by adjusting the firing angle of this particular back to back connected thyristor pair. So, I am essentially going to look at firing angle control based on reactive power requirement. So, I should say here is my α which is going to the two thyristors and α control will be based on what is the reactive power that I am having currently and what is the reactive power I want to have.

So I have to look at the difference between the two and this will be given to some controller. It can be PI controller, PID controller whatever is the controller I can think of then that will essentially adjust the α. And then it is going to make sure that appropriate value of this capacitance is rather depicted to the entire system.

So this is going to be thyristor controlled switched capacitor. Similarly, if I want to rather take up some of the reactive power here, I am supplying reactive power. If I want to take up some reactive power if there is some excess amount of reactive power, then I can have thyristor controlled switched reactor. So, I would be able to have DCSC and DCSR. Both these things are very good for improving the power factor close to unity and that will improve the capacity of the transmission line. So, I have just discussed only two of the FACTS devices, there are n number of facts devices. I am just giving you couple of examples.

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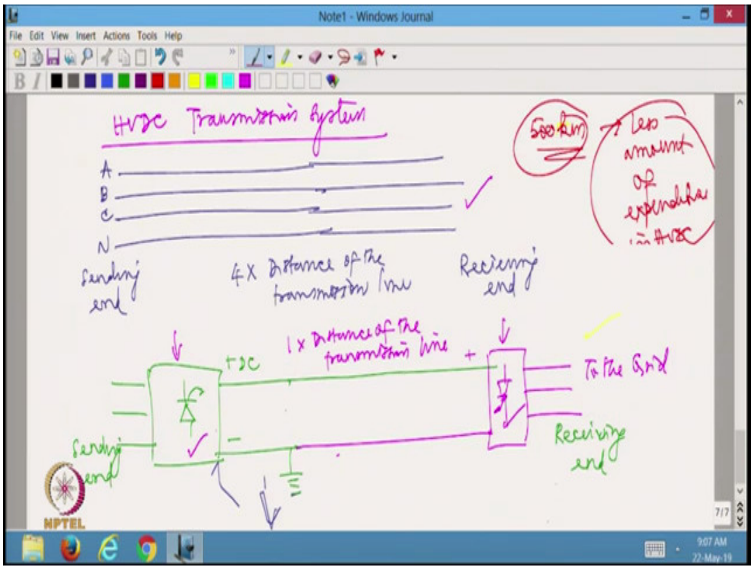

Now let me go over to HVDC application, High voltage DC transmission system. If you look at normal transmission system, it has three conductors plus a neutral. So, I am going to have A, B, C and neutral. So all over the distance may be this is the sending end and I am going to have receiving end here.

It may have thousands of kilometers like this. So, I am going to have long transmission lines going all over the country. So, the amount of copper that I will require will be 4 multiplied by distance of the transmission line. So, the amount of copper involved is way too high. Whereas if I look at a DC transmission, I can convert these three phases whatever three phase I have got into DC using a thyristor converter. So, let us say this is the DC output, this is plus and this is minus. I can use this as ground if I want to theoretically and I can just take it all the way to the receiving end.

Let us say this is my sending end and I am going to have the receiving end on this side, and I can have one more converter which is working as a line commutated inverter. So this is plus now this is going to again give out three phase and this is going to be the connectivity to the grid ultimately. Now this can be ground, and this is directly only one line which is running all over the distance.

Of course, I have to add the cost of this and cost of this no doubt but never the less if the distance is really long enough, I can manage only with one copper conductor. One times the distance of transmission line that is good enough theoretically so which means I am going to save on a huge amount of copper, copper expenditure but I will definitely incur expenditure on these two.

So I have to look at which one works out to be smaller in terms of cost whether this works out to be smaller or whether this works out to be smaller. I have to look at these two so it is found that around 500 kilometers when we come close to 500 kilometers we are going to have less amount of expenditure in DC HVDC transmission. So, we are going to have basically, less amount of expenditure only in this particular case, if the distance is higher than 500 kilometers.

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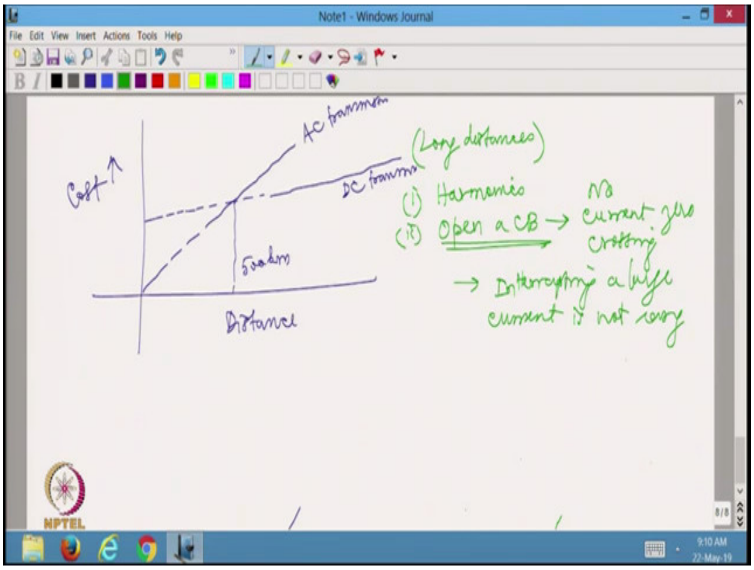

So, we are essentially looking at if I try to plot the cost of transmission versus distance of transmission, I am going to have actually as the distance increases the cost is going to increase in both the cases, no doubt.

But if I tried to look at let us say this is for AC transmission. I am going to have the transmission cost like this, I would see that for DC transmission initially it is quite high, but after certain distance it is going to really not increase too much. So, this is corresponding to DC transmission.

And this distance happens to be something like 500 kilometers. So HVDC transmission is used only for long distances. But definitely there are two major disadvantages to HVDC transmission one of them is because of my thyristor converter we are going to have huge amount of harmonics coming up in the filter.

So, we are not going to be able to eliminate the harmonics. The second thing that I am going to have is that the current when we want to interrupt or open up the circuit breaker, I am definitely going to have a problem of not having a current 0 crossing. So, because of which I have to interrupt a large current interrupting a large current that is going to be difficult. Where as if it is AC, I will always have a zero crossing possible, where I would be able to open a CB circuit breaker quite easily, so from that view point DC transmission becomes a little difficult

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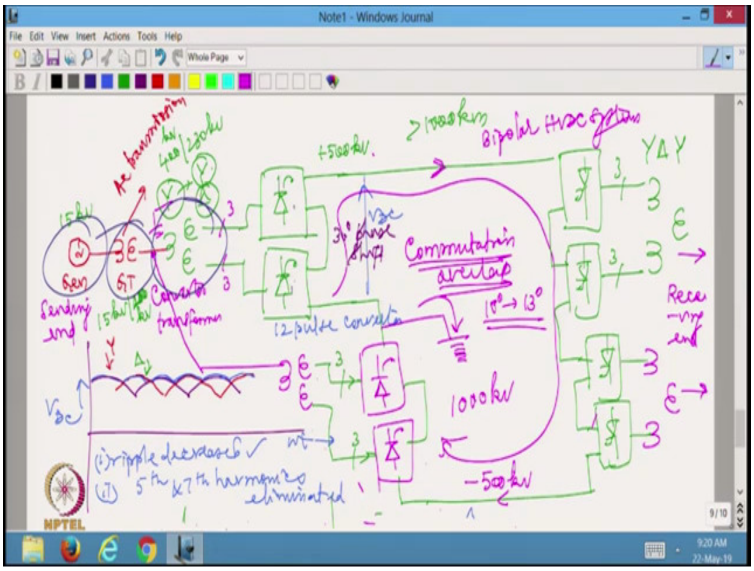

Now let us look the details of the DC transmission how it is. So, in a DC transmission, let us start from the generator so this is my generator. I will normally have a generator transformer. After this from here it may go to AC transmission also. It will go to the switched and it will go to AC transmission. But apart from that we are going to take this here with a transformer again which is known as converter transformer. The converter transformer normally has the configuration of star-star-delta.

So, it has three windings normally one is connected in star that is primary, secondary and tertiary there are star and delta. So, this is generally known as the converter transformer. Now this converter transformer output is going to be taken here. This is also three line, this is also three line, and we are going to have one thyristor converter here, one more thyristor converter here. So these two are connected like this.

Now I can connect these two in series. Let me give the voltages roughly. This may be of order of 15 kilo volts. Most of the times generator transformers step up to 230 kilo volts or 400 kilo volts depending upon what is the kind of transmission line I am going to have. Here I will have 400 to 230 kilo volts on either side. So, the terms ratios have to different in star and delta. So, I will have 400 all these things are line voltages. What I am talking out about are line voltages. So, this is going to be 400 kV by 230 kV.

Now what I will get here will be roughly 500 kV. Because 250 kV you will get here, 250 kV you will get here. Both of them are added together because it is star and delta that will be 30 degree phase shift between these two, So, if I say that one of them is going to have a voltage like this the other one will have a voltage like this.

Rectifier voltage I am talking about so I would say for star rectifier it is like this for the delta rectifier it is like this so when you add it you can see that addition is going to be something like this whatever I show in blue this is how it going to be. So, we are going to have ripple decreased that is one of the major advantages, so this is with respect to ωt I am plotting what is the DC link voltage. If I am talking about this V_{DC}, I am plotting V_{DC} here.

Ripple is decreased and second thing is because they are 30 degree shifted, we would have eliminated 5 th and 7th harmonics. So, we are going to have a good amount of reduction in the harmonics and we are going to have reduction in the ripple also and the overall voltage is increased to 500 kV. This entire configuration is known as 12 pulse converters because we are getting 12 pulses of voltage. This is one pulse, this second pulse, third pulse and so on,12 pulses of voltage in one particular cycle.

So, this is known as 12 pulse converter. Now this 500 kV is taken all the way all through the distance may be more than 1000 kilometer distance most of the times. Now on the other side I will also have a similar 12 pulse configuration. And these two are connected together. Now I am going to have this is 3 and this will also be 3 and I am going to have very clearly again star delta star transformer on the other side.

And of course, this will go to the receiving end. So, this is my sending end. If you look at it I can ground this I can call this is the overall ground of the HVDC transmission system. But whenever there is harmonic current and especially third harmonic current if it goes through this or even the DC current goes through this it can saturate the transformers which is deadly.

That is the reason why we tend not to use this kind of configuration instead what we do is we insert two more converters like this and from the same transformer we tend to again connect as star-delta-star transformer like this. And we are going to connect from here to here. This is also 3, this is also 3 now this is connected from here to here. This is connected like this.

And this is connected like this and we are going to have two more here. I am just replicating the same thing on the other side. So, this is going to be connected like this, this is going to be connected like this and this connected like this. So again, I will have the star-delta-star transformer here. Now this if I ground if I ground this portion this will become minus 500 kV, this will become plus 500 kV, so total difference in voltage will be 1000 kv although each of them is only corresponding to 500 kV.

So, what I get out of this will be here I am going to have 1000 kV voltage multiplied by whatever is the current that is flowing that is going to be power transmitter. The return will be carried by minus 500. Forward will be carried by plus 500. So, this will eliminate any possibility of current flowing into the ground. No DC current will flow into the ground. You understand it is going to essentially the current is going to circulate like this. This is how it is going to go because of which I am eliminating any possibility of DC current flowing into the transformer.

Because, here also the transformer, generator transformer, generator and this star, all these things will be grounded the ground is a common ground basically. So, I do not want DC current to go into transformer so I can have this kind of a transmission line. This is known as bipolar HVDC system

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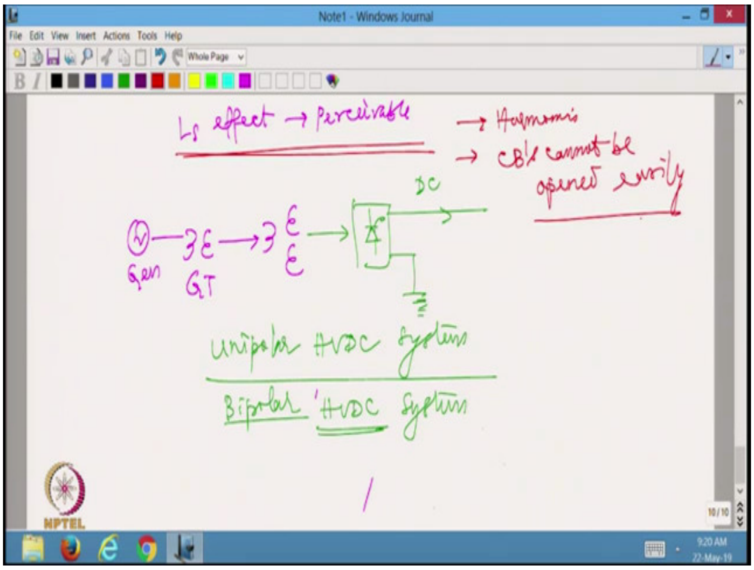

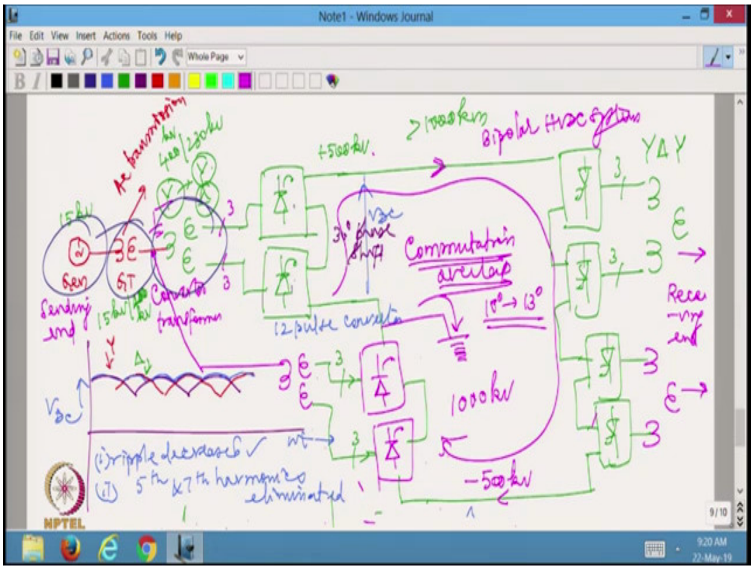

Whereas if I am going to have simply the generator then the transformer, then the converter transformer all these things if they come then I am going to have the converter what I showed you. I am showing only one.

If I ground this and if I take out the DC voltage out of this, this is generally known as unipolar HVDC system. Unipolar is hardly ever used because we do not want the saturation problem to crop up whereas bipolar is very very commonly used. Because we want to make sure that saturation problem does not exist in this particular case so these are the two different type of HVDC configuration.

One more small fact I would like to mention is because I have one generator here. One generator transformer here I have converter transformer all of them are going to have a good amount of leakage impedance because they have a good amount of leakage impedance. In these two converters we will able to see a good amount of commutation overlap. The commutation overlap seen in each of these converters will be anywhere between 10 degrees to 13 or 15 degrees easily.

Quiet a lot of commutation overlap effect is seen on the HVDC transmission system because of the source impedance. That is the source impedance effect LS effect is very much perceivable in the case of HVDC transmission system. So, the negative effects of HVDC transmission system are. One is source inductance effect. The other one is harmonic and the third one is circuit breakers cannot be opened easily, because there is no current 0 crossing available.

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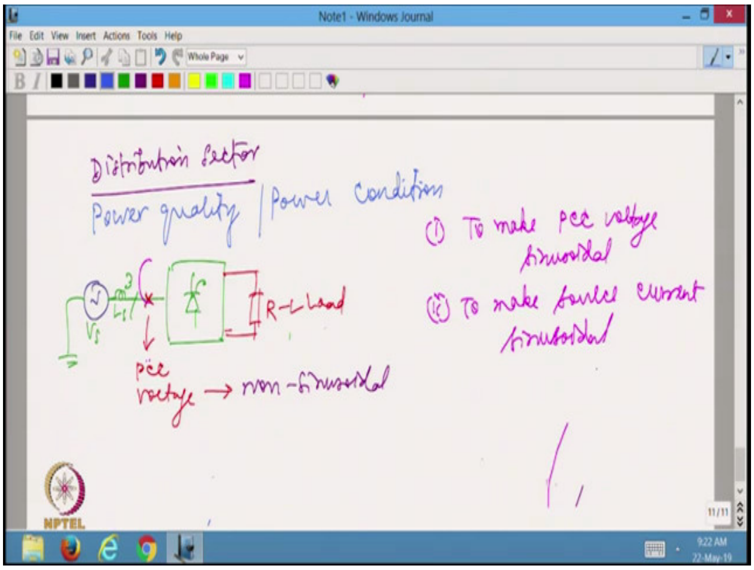

Now let us try to look at distribution sector applications of power electronics. The major emphasis in distribution sector is about power quality or power conditioning. How I am going to condition the power in such a way that we are going to have continuously sinusoidal voltage and sinusoidal current. You must be recalling that when we talked about a three phase converter with sumptuous amount of source inductance so let us say I have a converter here. And I am going to have source inductance here, so this is L_S, so this is V_S. If I look at the voltage here which is at PCC, the voltage is far from being sinusoidal. Here is the load the load can be R load or RL load does not matter.

But I am going to have this is not sinusoidal. So, if I want to make the voltage sinusoidal so in distribution sector, we are worried about to make PCC voltage sinusoidal. Similarly, to make source current sinusoidal, these are important things we will like to do so that first of all other loads that are connected at the PCC will not get effected. That is one thing and second thing I am really worried about is whether the power factor will get deteriorated, the harmonic content will increase because of which the power system authorities are going to shout at me. So that is also one of the problems I may be having. So, I will have to make sure that that is really not the case.

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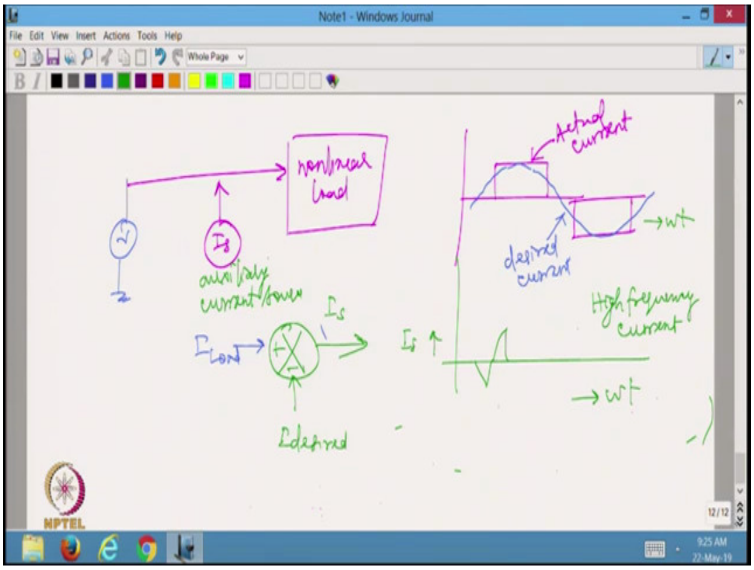

For this what we do is let us say this is my source. And here is my rectifier or non linear load. And let us say the current that this is drawing is something like this I am going to have a current somewhat like this per phase. What I want this current to be is I want the current to become somewhat like this may be something like a sinusoid. I want the current to be sinusoid like this. So this should be my desired current whereas this is my actual current.

So whatever is the difference between the two, if I am able to supply it through another source. So let us say I have one more current source here which is going to inject whatever are the portions which are different from the sinusoidal current. So, I can look at what is the load current? And I am going to look at what is the desired current. So, I am going to look at the difference between these two. Now this should be the current that we need to supplied by this auxiliary source.

If I may call this as the auxiliary current source, now this will be definitely something very very different. I am probably going to have some current like this and then some current like this. I have to look at exactly how the entire I am just looking at the subtraction between these two. So, this will be my I_S approximately. I am just showing it only for a short while. So, I know that this is not going to be any sinusoidal current for sure. This is probably a high frequency current.

Because I am not going to be, or it will consist of all harmonic current, High frequency or harmonic current put together.

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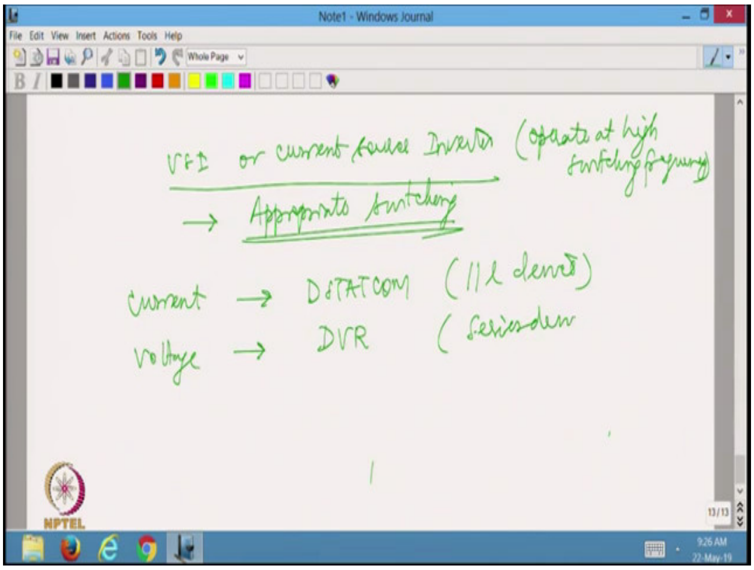

So, if I know what this current is then I can have a voltage source inverter or current source inverter which can generate this kind of current by appropriate switching so I can use suitable switching methodology so I can use a CSI or VSI which operate at high switching frequency.

So, when it compensates for current, we call this as DSTATCOM because most of the time it is going to compensate for reactive power, harmonic compensation, unbalance compensation. All those things it is going to do so that is generally known as DSTATCOM. And this is a parallel device. When we want to compensate for voltage, we call that as dynamic voltage restorer DVR. It is a series device.

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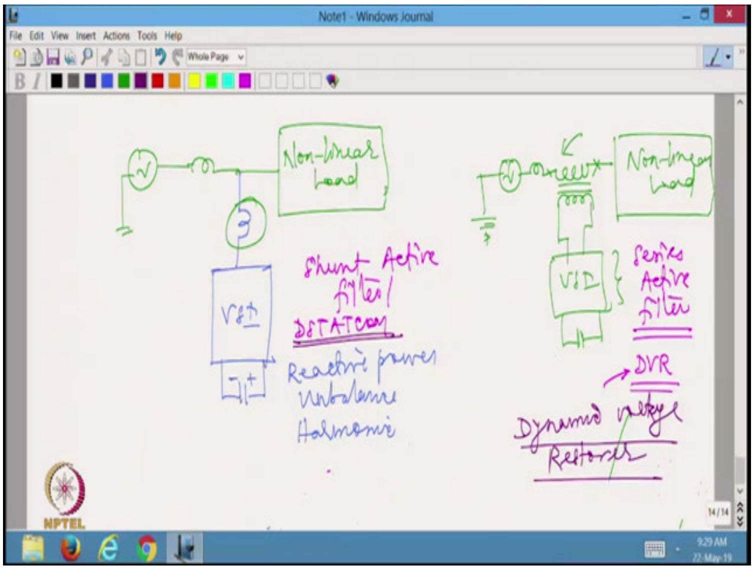

So, most of the times what we do is if this is my source and this is source inductance, and this is going to be the non- linear load if I want to connect a DSTATCOM or a parallel or shunt device. I will connect it using as inductance and I will connect this VSI here and I would connect a capacitor here.

So, this capacitor mainly is compensating for reactive power, unbalance and harmonic components. It is not going to really give any real power component of current. So, this is generally known as shunt active filter or DSTATCOM in certain cases. If it is going to mainly compensate for reactive power only. On the other hand, if I am going to have again a source here may be I have a source inductance also but I am going to add or subtract a voltage and I have some non – linear load here.

The adding or subtraction of the voltage will be done with the help of a transformer. This transformer is going to serve the purpose of the reactor which we saw in shunt active filter. Here I will have a VSI and it will also have a capacitance. Now this transformer is going to make sure that the voltage generated by this VSI is added and then whatever I look at ultimately, I am going to see only a sinusoidal voltage here ultimately.

So, I am essentially calling this as series active filter. So, series active filter is again a voltage source converter which will be able to compensate for any abrasion in the voltage waveform. And sometimes only when we take care of there is a reduction in the voltage or increase in the voltage. Temporarily and we want to compensate for that we use dynamic voltage restorer which is also a series device. So, this is generally dynamic voltage restorer.

So, dynamic voltage restorer is a series device whereas DSTATCOM dynamic static compensator, this is essentially a shunt device. We look at the utilization sector shortly. So, in the utilization sector we are going to look at the applications of power electronics. I am going to look at mainly at two configurations. One is, how power electronics is useful in drive sector.

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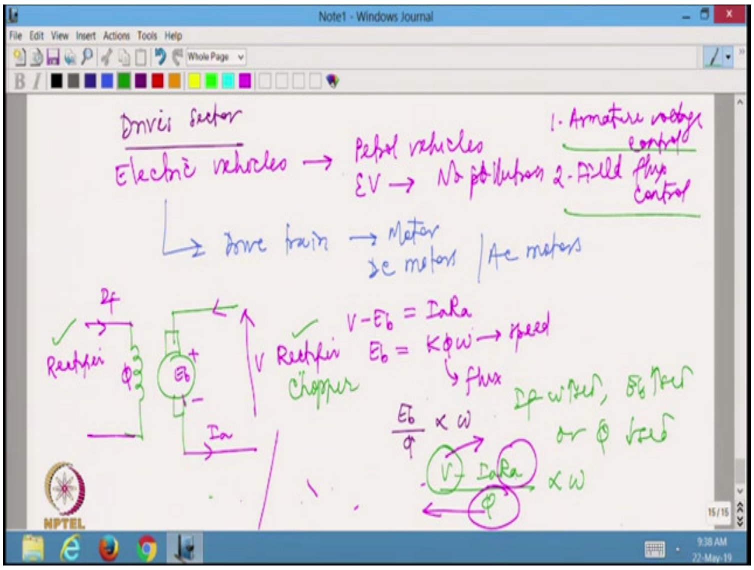

All of you must be knowing that electric vehicles are really having a huge amount of impedance now. Because of reduction in the pollution people want to have. Previously we used to have only gasoline vehicles, petrol vehicles with IC engines. But we want to transfer over to basically electric vehicles because of the impetus that is receiving towards reduction in pollution. No pollution. So, in this case generally the drive train is with the help of a motor.

So, we have several types of motors of course DC motors as well as AC motors. So, if you look at DC motors. Normally, we have the DC motors consisting of an armature and it also going to have a field. And if you actually look at the field the field current is going to be proportional to whatever is the flux that is needed so we will push that much amount of field current as to how much flux is required.

Similarly, if we look at what is the back emf. We are going to say $V - E_b = I_a R_a$. Eb is the back emf that is generated within the armature when the motor is functioning and rotating. And V is actually the voltage that is being applied and armature current is flowing through the armature like this. So, this is essentially Kirchhoff's Voltage Law. Now I am going to have $E_b = k\phi\omega$ where Φ is the flux and ϖ is the speed.

From this I can directly say that $\frac{E_b}{\phi} \alpha \ \omega$. So, if I want to increase speed if I want to increase if ϖ has to be increased then E_b can be increased or phi can be decreased either way is fine. So, let me write now this $\frac{V - I_a R_a}{\phi} \alpha \ \omega$. So I can either play around with V or I can play around with Ra that is second criteria or I can play around with this particular flux, so I can put a rectifier here which I can be play around with flux or I can put a rectifier here on the armature side which can play around with the armature voltage.

Actually, if we try to modify the resistance we will be incurring more loses. Definitely it is not a good thing to incur more and more loses so that is the reason why generally we either go with controlling the armature voltage which is generally known as armature voltage control. Or we go along with controlling the field current which we call as field flux control. So, we have armature voltage control or field flux control in the case of DC machine.

So, these are the two methods that are being used normally for the control of the speed of the DC machine. I told you that you can have a rectifier on either side. We can also think of having a chopper, buck converter or boost converter.

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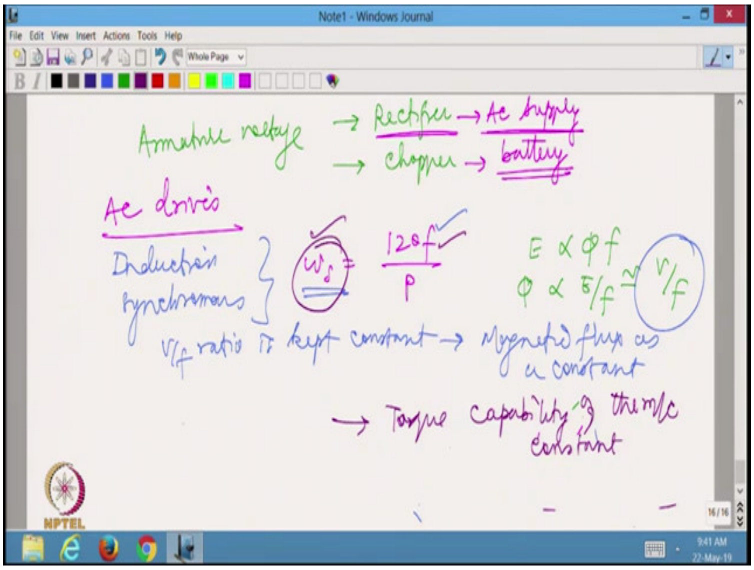

So, armature voltage control generally is implemented either doing using rectifier if we have AC supply voltage. If I am going to have DC supply voltage in that case, I have to use a chopper. So, this is very commonly used in battery driven vehicle typically for example an electric vehicle will be always be going along with the battery. So, in that case we think of chopper controlled battery driven vehicle that is fine. But if we are looking at some other like Delhi metro for example where we going to have power supply available all the time then that can be AC in which case you can think of having a rectifier for controlling the speed of this particular machine.

If we look at AC drives you have induction and synchronous machines primarily, conventionally, these are the two machines which are being used so in both the cases if I try to look at synchronous speed $\omega_s = \frac{120f}{p}$. So the frequency plays a vital role in deciding what is the synchronous speed. But we also know in any of the AC machine $E \; \alpha \; \phi f$. So, if I want to keep the flux at rated value I do not want to increase it I do not want to decrease it then I can say that $\phi \; \alpha \; \frac{E}{f} \cong \frac{V}{f}$.

So normally in most of the AC machines when we control it using inverter $\frac{V}{f}$ ratio is kept as a constant if we want to keep magnetic flux as a constant. If we keep magnetic flux as the constant, we would also be able to keep almost the torque capability of the machine as a constant. So, I do not have to compromise on the torque capability. I do not have to compromise on the speed also because as I vary the frequency, I am going to correspondingly get higher and higher speeds.

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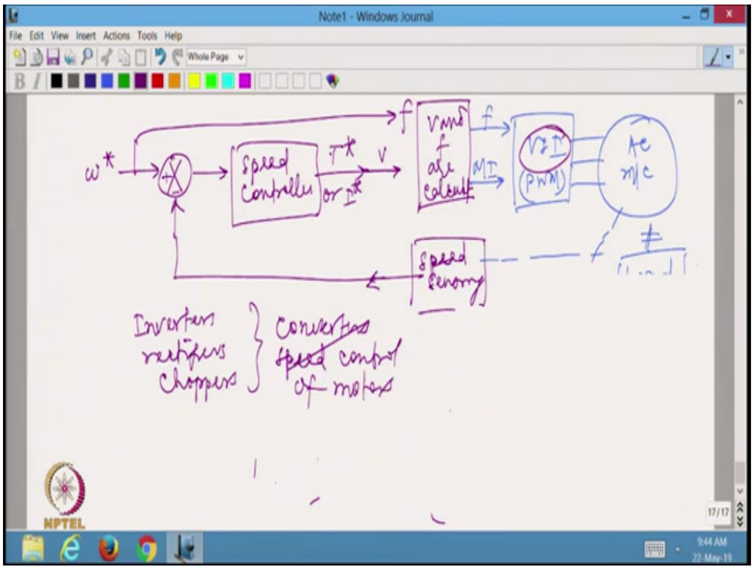

So, most of the times what is done is in the case of an AC machine. Let us say I need a particular speed then what I am going to do is from here if I look at what is the actual speed that is available, I will pass it through a speed controller. This speed controller output can set what is the kind of torque value I require. This is also indirectly an indication of current or flux so from this I should be able to say what is the kind of first of all this ω will also fit the frequency. What is the kind of frequency I require and this will indirectly tell me what is the kind of voltage I require. So, I had to essentially make sure that V and f are fixed calculated using this.

Now, this will go to my voltage source inverter in the form of frequency and modulation index if I am talking about PWM inverter. Now this is the three phase output that is available. Now this will go to my induction machine or AC machine whichever machine I am talking about and from here this is actually couple to the load, this is couple to the load. So I can directly sense what is the value of speed from here, so I can directly say a tacho or speed sensing mechanism I have.

From this speed sensing mechanism, I am going to be able to get what is the value of the speed here. So, in general the major apparatus that is used in this particular case is inverter. So, invertors, rectifiers, and choppers these are majorly the three converters that are used in speed control of motors.

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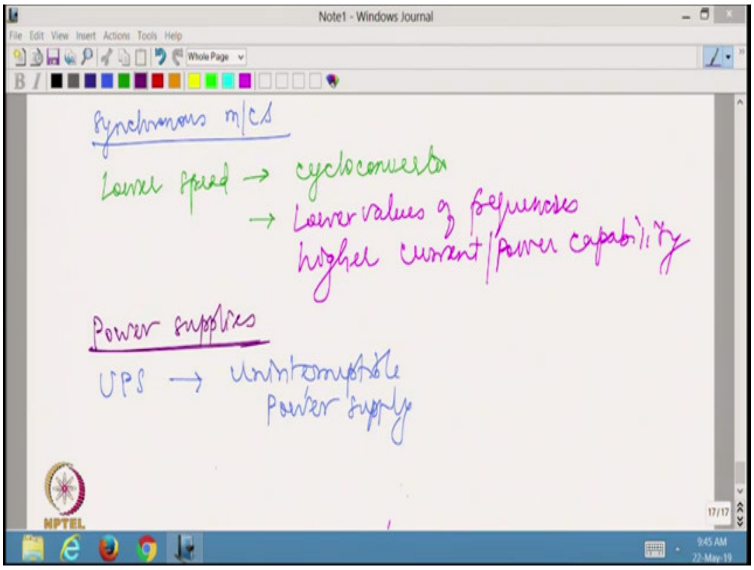
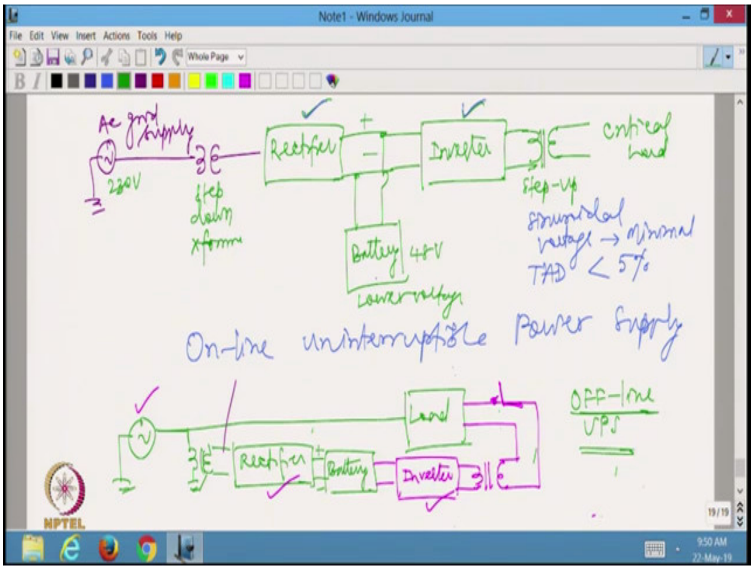


Apart from this for especially when you talk about synchronous machines because they are normally run at low speed in many cases. At lower speed we might use sometimes cyclo converter as well because we do not really require higher value of frequencies, so this is generally meant for lower values of frequencies and higher current or power capability. So, all these converters come in handy basically for controlling the AC machines.

Now the last one that I would like to touch upon is power supplies which are very commonly used. I am sure you guys must have heard of UPS Uninterruptable power supply. So, in Uninterruptable power supply basically we do not want any power grid to interrupt our process control.

Let us say I am having some life support system. So, in that case if there is a power supply cut occurring, I would not like to really interfere with the process that I have. (Refer Slide Time: 61:48)



So, I am going to have let us say that this is my AC grid supply. Normally, I will have a battery backup. So, I will have transformer which will step down, so this is essentially a step down transformer. So, after this I will basically have a rectifier. This rectifier output will be the DC that is available to the same DC bus in all probability I will be connecting my battery. So, battery charging is also controlled through this particular rectifier. Now this output is generally given to an inverter. If I have step down because of which the battery voltage is going to be at lower value.

Let us say this is 230 volts where as this may be 48 volts battery or 24 volts battery. Now the inverter what it gets out will also be only of the order of 50 volts or something. So again, I might have to have a step up transformer. Unless I have a step up it is going to be difficult and then this is going to go over to my critical load. Please note in this particular case always the rectifier and inverter are very much there in service. So, I am going to have even if there is a glitch in the AC grid power supply the inverter will make sure that it gives only sinusoidal voltage with very minimal THD or total harmonic distortion. It is going to be very minimal total harmonic distortion.

So, if you look at the harmonic content it may be less than 5 percent or even less. So, this particular kind of uninterruptable power supply system is known as on-line uninterruptable power supply. So, whenever you are going to have power cut then the battery will take over. Battery has already stored energy so it will be able to give away that voltage that charge and then inverter will convert that into AC and that will be given to the critical load.

So, this is known as on-line UPS. Whereas in off-line UPS what happens is if this is my AC supply and this is my load, I am going to directly connect this to this particular load but in case there is a power cut. Just to take care of that what I will have is I will try to tap from here a voltage. And with this I will have a rectifier and I will charge a battery.

The battery is charged, this is going to be plus and this is going to be minus. Now after this from the battery I will connect it to an inverter. And after the inverter if I have step down, I definitely have to have a step up, this is the step up transformer. This output will go to the load but I will normally have a switch here so I should show a switch here until there is no power cut this switch will be open. Whenever there is a power cut this switch will be closed so you are going to have this rectifier and inverter always off-line as long as the power grid voltage is available.

So, this particular thing this particular inverter is known as off-line UPS but this generally cost lower although you will see a small interruption in power before this switch is close. You are going to see a very very short interruption in power, but the inverter, battery and rectifier are not always used. Because of which the life of inverter and rectifier are generally larger, so this is generally lesser less costly as compared to the on-line uninterruptable power supply.

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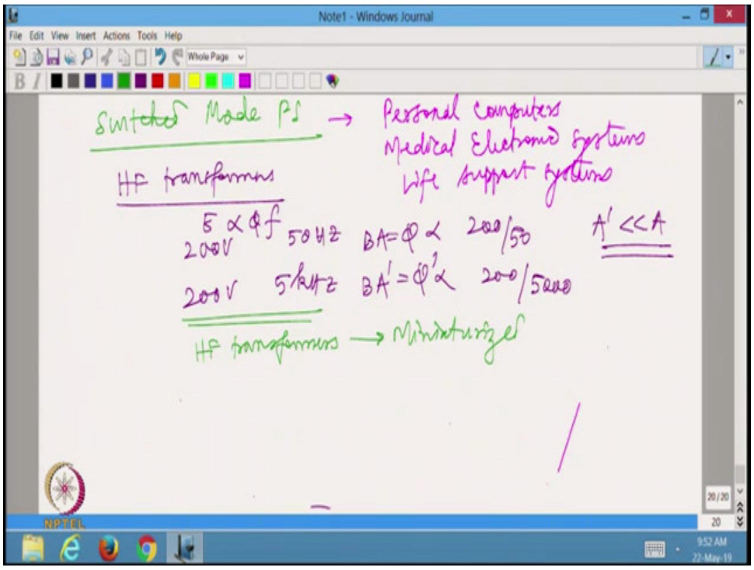

The last one I like to discuss briefly is switched mode power supply SMPS. An SMPS is very very commonly used in personal computers and many other electronic systems like medical electronic systems, life support systems all of them used switched mode power supplies. So, in this case what we mainly use is a small transformer which is operating at high frequency. So high frequency transformers are generally a very very small because $E \propto \phi f$.

If I am talking about 200 volts and if I am talking about 50 hertz $\phi \propto 200/50 = BA$. If I am talking about the same 200 volts but 5 kilo hertz I am going to have $\phi^{l} \propto 200/5000 = BA^{l}$. So, I can very well see that $A^{l} << A$. So, the area decreases as the frequency increases. So high frequency transformers are always miniaturized. They are really small in size. That is the reason why you see that the SMPS that is available in your PC all are miniaturized, they all use high frequency transformer.

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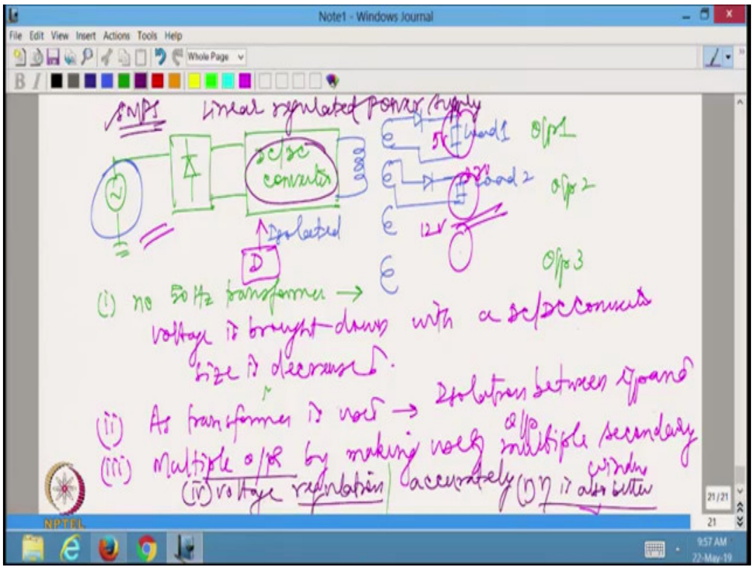

In this particular case what we normally do is let us say I have a sinusoidal single phase supply. I will have a normally a diode rectifier. The diode rectifier output is generally given to a DC to DC converter. This can be isolated or non isolated converter. Most of the times, it will be isolated converter, because I do not have any isolation between the power supply and this output unless I have a transformer in between.

So, let us say the DC to DC converter output is coming through in the form of pulse through a transformer. This can have multiple secondaries. Each of the secondary can have a diode rectifier or something like that which can give the output voltage to a load. So, let us say this load1, I am showing only one diode but I can definitely have a full bridge rectifier also. Nobody prevents me from having that so this is load 2 and so on and so forth.

So, this is essentially I am going to have multiple outputs so this is essentially my output1, then this is output2, then output 3and so on. So, I am essentially doing two or three things here. In SMPS, one is no 50 hertz transformer, voltage is step down or voltage is brought down with the help of a DC DC converter.

So, first of all size is decreased. Second thing is because of transformer being used. Still although it is high frequency transformer as transformer is used I have isolation between input and output. That is a very big plus point. Because if there is a glitch on this side that will not affect anything on the other side. That is the second thing.

Third thing is I will be able to get multiple outputs by making use of multiple secondaries. So here I have used multiple secondary windings. So, I would be able to get multiple outputs for example in the personal computer I will require 5 volts, 3.3 volts, 15 volts or 12 volts. All these things will be required. I will be able to get all different voltages just by using one single power supply, one single diode rectifier, one single DC DC converter but multiple secondaries. That is the major advantage.

Finally, one more advantage is I can definitely control this duty ratio of the DC-DC converter to adjust the output voltage stiffly. So, I would be able to get voltage regulation accurately. So, these are the major advantages of SMPS. Over the normal power supply which we had been using, which is known linear regulated power supply. In linear regulated power supply we would normally drop some of the voltages in resistance so in this particular case, the DC-DC converter is taking care of stepping down the voltage which means efficiency is also better.

So, I should say there are five advantages, size is decreased, isolation is provided, multiple outputs are possible, voltage regulation can be achieved accurately and efficiency is better. So SMPS is really a boon as far as many of the small sized systems are concerned where there is a space scrunch. And this is very commonly used in aerospace electronics systems and so on where the space is really at a premium. So, I have only covered a few applications of power electronics.

In this particular lecture, I have taken a few from the generation sector, a few from transmission sector and a few from distribution and utilization sector. In utilization sector, especially there are vast number of applications which we can think of but we are just due to crunch of time we are just finishing it with only these two applications in mind. Thank you so much for your attention.