Power Electronics
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Lecture 01 – Introduction to Power Electronics

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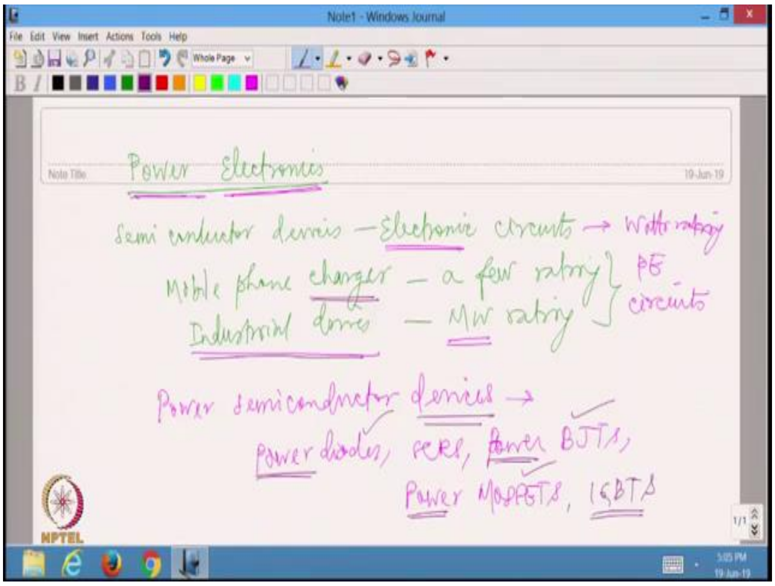

We are going to start the course on Power Electronics. I am sure all of you know what is electronics? Electronics is basically going to have semiconductor devices which control electronic circuits. Whereas if you look at power electronics, you should know the applications, basically the applications are right from mobile phone chargers which is of only about a few watts rating to, if you look at industrial drives, which may be of megawatt rating. So the entire range generally is covered by power electronic circuits. So if we talk about industrial drives, they are of megawatt rating. Whereas when we talk about normal electronic circuits, they are only of a few watts rating, but we are looking at power electronics, which is consisting of both power which is high power circuit as well as electronics which is low power circuit. So power electronics essentially deals with power semiconductor device circuit.

That is the circuits that are made up of power semiconductor devices. Some of the power semiconductor devices are like power diodes, SCRs, power BJT's, and power MOSFETs. So, all these devices, when you talk in electronics you will be talking about just BJTs or just MOSFETs and you will be talking about diodes. Whereas here we are adding a prefix power, so power diodes, power BJTs, power MOSFETs and IGBTs.

So all these things are going to be ultimately connected in different circuit form to make either rectifier which is AC to DC converter or inverter which is DC to AC circuit and so on. So we will be dealing with power semiconductor devices which are connected into different circuit format and they will be used for different applications. Be it mobile phone charger, be it a big rectifier or be it an inverter for industrial drives, that is what we are going to talk about in this particular course.

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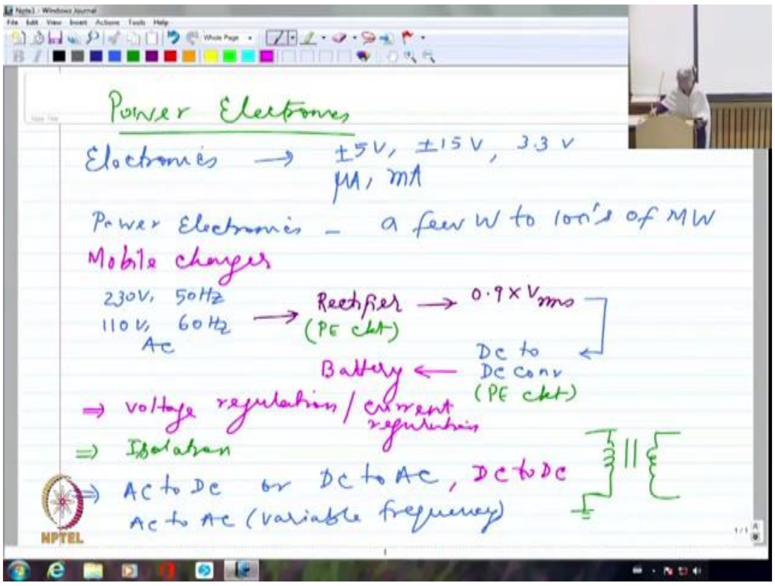

In electronics normally we handle 15 volts or 5 volts, nothing more than that. What is power electronics versus electronics? In electronics, you are going to handle only 5 volts, 15 volts, I would say ±5 volts ±15 volts, 3.3 volts and so on and so forth. And as far as currents are concerned, they may be microampere, milliampere, at the most a few amperes, not even 10 amperes it will be generally less than that. Most of the time you will handle very, very small power levels which will go of the order of a few watts or a few miliwatts nothing more than that. Whereas in power electronics, normally the same electronic circuit may be made bigger to handle higher current, cross sectional area should increase. To handle higher voltage the length should increase.

So if I increase the length, it will be a high voltage device. If I increase the cross-sectional area, it will become a high current device. So if I can handle higher currents and higher voltages, in that case I would call that as a power electronic device. And when I put several devices or one or two devices in a circuit, I call that as a power electronic circuit and it can handle generally controlling an electrical machine or controlling maybe a transmission system, maybe controlling the power that is delivered through the UPS (uninterruptible power supply) or SMPS (switched-mode power supply) within your computer, all those things. Whatever circuits we see in these things are all power electronic circuits because they handle a little larger power.

What I mean by a little larger power is power electronic circuits can handle right from a few watts to 10s of or 100s of megawatts.

So it can handle a wide range of power normally. You are going to have right from a few watts to hundreds of megawatts, that can be handled by all these power electronic circuits. Typical applications: Why should we study about it? Unless there is some importance we should not be studying about it. So your mobile charger, that is typically a power electronics circuit. If you look at the mobile charger, it is connected to a 230 volts AC mains. If you look at the carefully it will say 90 volts or 80 volts until 270 to 280 volts. So it is known as the universal adapter. It will be able to charge your mobile phone, whether it is in the US where it is 110 volts, or whether it is in Europe or India which is 230-240 volts. So it would be able to adapt itself to any kind of AC supply voltage as long as it is within 50-60 hertz range.

India has 50 hertz and Europe has 50 hertz, USA has 60 hertz, so you will have different frequency ranges. But from that 230 volts or 110 volts AC voltage, first of all there will be a rectification that will be taking place; rectifier is a power electronic circuit there. So it will rectify to DC, after rectifying to DC it has to step it down to a smaller voltage, whatever be the mobile battery's voltage. Maybe it is 1.5 volts, maybe it is 3 volts, whatever it is, it will correspondingly step it down, no transformer of course, because transformer cannot work on DC obviously, so there will be a step-down converter which is also a power electronics circuit.

If I try to look at the mobile charger, I will have first of all 230 volts, 50 hertz or 110 volts, 60 hertz AC. This is now connected to a rectifier. The rectifier is going to convert this into corresponding DC voltage. If it is an uncontrolled rectifier with the help of diodes, just diodes, then I am going to have very clearly $\frac{2V_m}{\pi}$. So whatever is the voltage that we get, it may be $0.9 \times V_{rms}$ roughly.

Now this has to be stepped down to the voltage that is corresponding to the battery voltage of the mobile. So from here I may have to have a DC to DC converter which is again a power electronic (PE) circuit. Now the output of this will go to the battery and it has to be regulated. In case from 230 V suddenly the voltage comes down to 180 V, in the grid, still I should be able to give the same value of voltage to the battery, so there should be some amount of adjustment.

So very clearly there are several functions that are associated with a power electronics circuit. One is regulation, so I have to regulate the voltage, definitely voltage regulation has to be done irrespective of variation in the input voltage irrespective of variation in the load, because battery may be fully charged in which case the voltage will be close to whatever is the rated voltage. If it may be very, very low charge level, then in that case the voltage is going to be somewhat lower. If you talk about a 5 volts battery for example, it can go until 5.5 or 5.75 volts when it is fully charged, slightly higher than rated voltage. When it is completely discharged, it can be as low as 4 volts or 4.2 volts. So you can have that much of variation. Despite those variations, the current that is going into the battery to charge it, that has to be regulated, the voltage has to be regulated. So it is not only voltage regulation, even charge or current regulation, both have to take place. Second thing we may require is, we will have some kind of isolation required between the input and output side. Isolation is you do not have to have a common ground like a transformer. In a transformer the primary and secondary are not connected to the same ground. So, the isolation takes place whenever I use a two winding transformer, not auto transformer. Auto transformer is a single winding transformer where the primary and secondary are connected together. So whenever I use a transformer, I am going to have isolation between the primary and secondary. Similarly, isolation will be possible when I use a power electronic circuit, probably I will insert a transformer somewhere, probably I will insert something else. I will have to check what are the stuff I have to insert. So these are two primary functions of a power electronic circuit generally, regulation and isolation.

Apart from that I would also convert probably AC to DC or DC to AC or DC to DC or I may convert AC to AC with variable frequency. That is I give a 50 hertz supply, I might like to have a 100 hertz AC output. So, AC to AC conversion is also possible. All four types of conversions would be possible. So I might like to convert the frequency, magnitude or both. Either any of them is possible with the help of a power electronic circuit. So one example I gave you was the mobile charger.

Another example is a variable frequency induction motor drive. This drive contains a rectifier which was initially converting the 50 hertz AC into DC. Subsequently there was an inverter which will convert that DC into any variable frequency, AC. So that is a typical example of creating an adjustable speed drive. If I want an adjustable speed drive, I would be able to use AC to DC converter and then the DC to AC inverter, that will essentially enable me to get a variable speed drive or adjustable speed drive.

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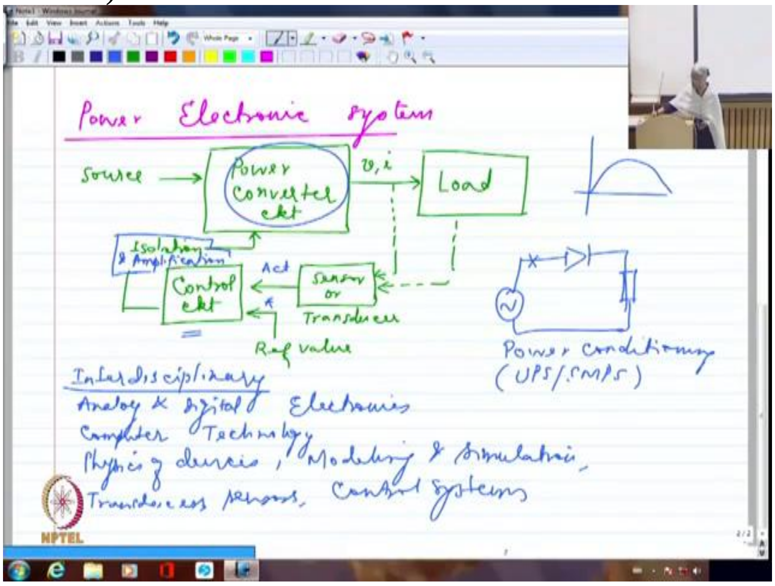

So, if I look at power electronics system in general, what consists of a power electronic system? In a power electronic system, I am first of all going to have a source. That source could be a DC source or an AC source. From here I am going to have a power converter circuit which is the heart of the power electronic system. So it is going to convert maybe AC to DC or DC to AC. Whatever it does, it is going to have some functionality. Now this power converter system will give an output. The output will be in the form of a particular voltage and particular current.

So I will have some voltage and some current, so let me say them, I may call them as instantaneous values v and i. If it is three-phase, of course I will have v_A, v_B, v_C, i_A, i_B, i_C, obviously. So I am going to have voltages and currents. Now I will have a load, which could be an induction motor or a battery of the mobile or it could be like a musical keyboard. Now the load might require only 5 volts. It may require 400 volts and 50 hertz if it is an induction motor, line to line voltage. It might require maybe 25 hertz and 200 volts if I want to run it at lower speed.

So I need to know the requirement of the load. So what I will have here will be a sensor or a transducer. So what I will do is to sense from here the voltages and currents. Maybe, if it is a battery it is good enough for me to sense only the voltage and current. If it is an induction motor I need to sense voltage, current as well as maybe torque and speed. So depending upon the kind of load, I may have more than electrical quantities being sensed. So I would rather call it as a sensor or transducer because transducer converts mechanical signal into electrical signal, thermal signal into electrical signal and so on and so forth.

Invariably I would like to convert that into electrical signal because I am by and large handling electrical circuits. So everything converted into electrical signal will give me a lot of advantage in terms of processing them. So I would first of all like to sense the mechanical quantities or electrical quantities or thermal quantities and so on. For example, in an air conditioning system, how does the compressor go off? Because it senses the temperature, maybe you have set it at 25 degrees and the room has already reached 25 degrees, so the compressor will go off. For that you have to first of all convert the temperature into an equivalent electrical quantity in all probability so that, the control system realizes, that it has already reached the temperature so that the compressor can be turned off. So you will have basically a sensor or a transducer.

Now what comes out here is actually the sensed quantity in the form of an electrical signal. Now, I may have a controller here or a control circuit. I may call this as a control circuit, so in the control circuit, one will be a reference value. The reference value will be given as one of the input and the sensed value will be given as the other input. Now the control circuit is the intelligence or the brain of this entire power electronics system, that is going to make a decision based on what kind of inputs it is getting. It is going to make a decision whether I have to reduce the current, reduce the voltage, or increase the frequency. All those things will be decided by the control circuit.

So once it decides, it is going to give this to the power converter in all probability through an isolation circuit. Because I would not like to mix the ground of the control portion with that of the power portion because power portion will have a thick conductor going to the ground. So the currents that are flowing are of the order of hundreds of amperes, whereas electronic portion will have only milliamperes or 1 or 2 amperes. So if something goes wrong in the power portion, I do not want that current to circulate through the electronics portion. If it circulates, it will end up burning the entire electronics portion, so the grounds invariably have to be isolated.

So the isolation circuit essentially functions as a protection against burning the electronic portion of the circuit. If there is a problem in the power portion, that will not affect the electronic portion and apart from that I might require an amplification also. The isolation is meant for decoupling the grounds of the electronic portion from that of the power portion, whereas amplification is required because the power electronics circuits are big, they will not work on milliampere. So if it is a transistor, if the base requires let us say 1 ampere, the amplification factor probably is about, 10 ampere or 15 ampere maybe is going to flow through the power circuit, but the base will be some fraction of that.

Collector current will be much higher. Base current will be much smaller. So maybe the base current is 1 ampere, in all probability my electronic circuit, which is actually this control circuit that may not be able to give even that 1 ampere. So, an amplification circuit is needed. In all probability I will need isolation and amplification, both have to sit in between the control circuit and the power electronic circuit. So this is the overall structure of a power electronic system. So we will have a source, it will go to a power converter circuit, which is going to convert the voltage magnitude and frequency as per the requirement of the load. The load will function once it gets the supply.

The load is going to give some output. So the voltage, current and output, everything will be sensed. After sensing everything, we compare it with the reference values that we want to achieve normally and then accordingly we take a corrective action until the error becomes zero.

Reference values are normally denoted with a star, for example v^*, i^*, ω^* (reference speed) and T^* (reference torque). So star is generally indicated for reference values. And the actual values are generally specified with a subscript "act". I generally say v_{act}, $i_{act,}$ ω_{act}, T_{act} and so on. So, the reference values and actual values are compared, which actually comes out in the form of an error. This error is processed by the controller circuit and that is what actually adjust the voltage or current or whatever output of the power electronic circuits, such that the error becomes zero.

This is the overall configuration of the power electronic circuit. We are going to mainly concentrate on this portion, but as a power electronic engineer, I need to know some amount of sensor and transducer working. If I do not know, I cannot deal with power electronic circuit. I have to know how to isolate and how to amplify. If I do not know, I cannot again design a power electronic circuit. So I need to know some amount of analog electronics, some amount of digital electronics, some amount of sensors, some amount of transducers, large amount of characteristics of the load.

So if I am talking about a battery, I should know at least something about the battery. If I have to control a machine, I better know what the machine can do for me. So I should know the dynamics of the loads. I should know the dynamics of all the electronic circuits, sensors, transducers, amplification circuits, isolation circuits and so on and so forth apart from knowing the actual power circuit. And most of the times we model and simulate these circuits before we really put it on the hardware.

So modelling and simulation is another aspect we need to know, how to model a power electronics circuit, how to make a control system configuration for a power electronics circuit. Power electronics basically becomes interdisciplinary because of all these areas involved. These days we use a lot of computers and microprocessors and digital signal processors, so we need to know definitely at least something about the assembly language and other internal machine language of the processes at least to some extent.

We definitely need to know to some extent physics of the devices. We need to know how much of heat is going to be generated within the circuit. If excessive amount of heat is generated, then it will get overheated and it will conk out and for dissipating the heat we use something called a heat sink. If I connect IGBT or MOSFET to the circuit, it will generate a lot of heat and it will conk out eventually. So to dissipate the heat, if I put a black body attached to its body, then the heat is going to be transferred to the black body. Black body will radiate it.

So typically for knowing how much heat will be dissipated, I should know at least the physics of the device. So I should know device physics to a large extent. I should know modelling and simulation and I should know transducers, sensors. I should know the working of control systems. Power electronics happens to be interdisciplinary in nature because of these things. In the case of a simple half wave rectifier, only in the positive half cycle the current will flow, negative half cycle current will not flow. So if I look at the current at this point it will have only half of the sinusoid. The other half will be missing. What we want from the power system normally is the currents and voltages should be as much as possible sinusoidal so that it does not create a headache.

I do not want harmonics. I do not want DC, because the machines are generally generating sinusoidal currents. They would like to supply sinusoidal voltage and sinusoidal current. If I am asking them to deviate from that, they can misbehave, so the power electronic circuits create automatically some amount of misbehaviour whether we want it or not, when convert AC to DC with the help of a half wave rectifier, I am automatically creating an aberration in the wave form. The wave form is non-sinusoidal. So there is something called power quality we talk about.

Power quality essentially deals with whether the voltage is sinusoidal, whether the current is sinusoidal, whether it is only 50 hertz, not deviating from 50 hertz, whether the power factor is unity. All these things are generally specified as the power quality indices. There are several power quality indices, one is voltage, the second one is current. Whether they are sinusoidal in nature, whether they are at unity power factor, whether they are at 50 hertz, all these things are examined and said that if all of them are adhering to the normal standards, we say power quality is very good.

If they are not adhering to the standard, then we say it is not good. For example our power system is supposed to be a very weak power system because most of the times our demand is higher than the supply. The demand is always larger than the supply because of which voltage sags, voltage will not be at 230 volts or 240 volts. It may come down to 180 volts, so the equipment which is expecting 230 volts, if it gets 180 volts, it is not a good thing for the equipment.

So our power quality normally is not good most of the times and added to that we put so many power converters, so obviously power quality becomes worse. Power electronic engineers are the culprits who make the power quality much worse. But power converters definitely help us in controlling the voltage, controlling the speed, controlling the torque, controlling any process. So obviously we employ a large number of power converters these days. But we also essentially make the power quality bad, so power electronics again comes to the rescue to improve the power quality.

So on one side we create the problem. On the other side we try to solve the problem. So power electronics is the root cause of the problem. But some of the power electronics circuits we again employ to improve the power quality. So we call them as power conditioning or power quality conditioning. For example, SMPS and UPS. Uninterrupted power supply (UPS) will make sure that 230 volts, 50 hertz is given to the computer, no matter what. SMPS make sure that ±5 volts, ±15volts, 3.3 volts; all of them are given to the computer circuits whichever require whatever voltage. So I am creating a problem with other power electronic converters. But SMPS and UPS take care of these problems; they essentially insulate the actual computers from these problems. They supply the actual value voltage and frequency that is needed by the computer. So power conditioning is generally done by UPS, SMPS and such circuits. Those are also power electronic circuits. So, if you look at the application of power electronics, it is plenty.

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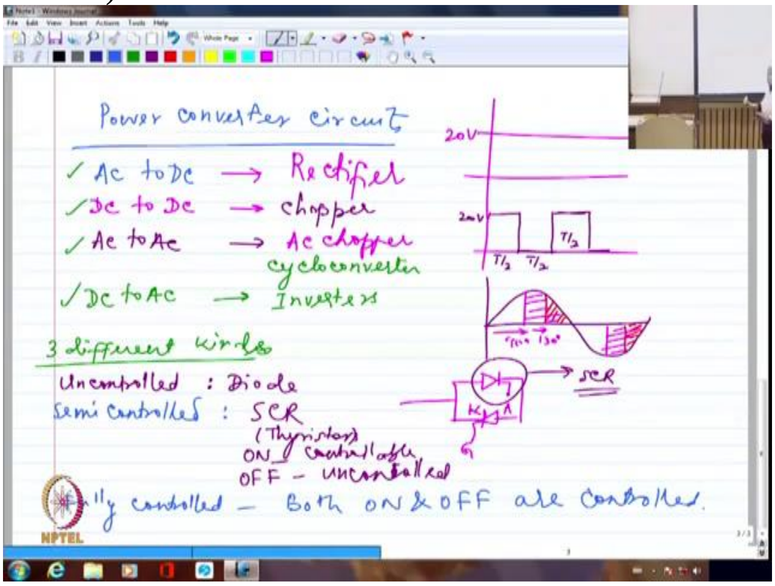

But before that, let us try to see what all different types of power converters are there. As I told you in power converters, I can have AC to DC, which I may call as rectifier. When I convert AC to DC, normally we will call that as a rectifier circuit. I may have DC to DC, which normally are known as DC to DC converters in most of the cases. But some people call it as choppers, as they chop the voltage and then convert it into another value of DC. If let us say originally the voltage is 20 volts. I want only 10 volts on an average basis. I cannot make 20 V to 10V, obviously, if I have to do that, I have to use two resistors, say 10 ohms each, drop off half the voltage in 10 ohm and other 10 ohm will have 10 volts.

I do not want to do that because it is lossy. So rather than using a potential divider, if I try to do it this way, maybe I have 20 volts coming for T/2, again 0 volts coming for T/2, again 20 volts coming for T/2, 0 volts coming for another T/2. The average value will be 10 volts. Looks kind of strange. Because how will the motor know, you are giving supply only for half the time. It will start rotating. That is what you might think but this I will do at kilohertz or higher frequency, hundreds of kilohertz whereas motor has a huge time constant. Mechanical time constants are generally very large. It is going to take a while for the motor to realize that it has to pick up speed quickly because they have given 20 volts and it has to reduce the speed to zero because they have not given any voltage. It is not going to happen because the inertia is going to take a while before really the motor responds to the variation in the voltage, because of which the average value seems to be 10 volts. So, this is what is DC to DC conversion. For example, we chop the voltage for 50 percent of the time. We apply the voltage for 50 percent of the time, so we call this sometimes as chopper. This is DC to DC conversion.

We will have AC to AC converters as well. So I can do the same chopping in AC. Imagine, maybe I have a switch. So, if this is my original AC voltage, I keep the switch ON for only some duration and again I keep the other switch probably in the opposite direction ON only for some duration. Then the RMS value will decrease. If I have it ON for longer, I am going to have a higher RMS values, if I have it ON until here, for example, so which means this entire thing will become my voltage.

So I can vary the magnitude by controlling an ON-OFF switch. I can simply have an ON-OFF switch in positive direction as well as in negative direction. So imagine I have one diode like this, another diode like this. But if it is diode, I cannot control. So I have to have another gate terminal, the gate will open the conduction or close the conduction. So generally, we call this terminal as gate, this terminal as anode and this terminal as cathode, three terminals.

So the gate will allow a device to be turned on or turned off. So, I will be able to delay the conduction. It can start at zero or it can start at 90 degrees or it can start at 130 degrees depending upon when I give the gate signal. So the RMS value can be definitely adjusted. So this is a typical AC to AC converter circuit. But please note the frequency is not changing, if it is 50 hertz, it will be still 50 hertz at the output.

So, transformer is like AC to AC converter. The frequency does not change, but I can reduce the voltage. Transformer is bulky because you have iron core and windings and so on and so forth whereas power semiconductor devices generally are very small, they are miniature. So miniaturization if it is required, power semiconductor devices are the solution, really.

So, AC to AC converter is sometimes known as AC chopper. There is one more type of AC to AC converter, which is known as cycloconverter. Last but not the least, DC to AC converter. DC to AC is generally known as the inverter, so inverters are used in plenty of applications. For example, for induction motor speed control, you will need an inverter. At home many of you guys will be having an inverter, especially the power outage is very frequent in some places they will require inverter. So inverters really find application, UPS has an inverter. SMPS might have an inverter inside. So there are many applications where inverters are used. So what we will do during this course is each of these circuits we will be looking at with different configurations.

For example, if I am looking at AC to DC, it can be single phase AC, three phase AC, half wave rectification, full wave rectification. So there are different configurations we will be dealing with, we will be looking at different cases like resistance load, RL load, RLE load. E is a battery, or if it is a DC motor drive E is the back EMF. So we will have to look at all those things.

So I am just telling you for example for the rectifier; single phase AC, three phase AC, half wave, full wave, R load, RL load, RLE load, RC load and so on. So many things we will have to look at. So we will be looking at each of these circuit configurations with variety of inputs and different kinds of outputs we want. For example, DC to AC, I may require single phase AC, three phase AC, So we will be looking at all those circuit configurations and how to control them, and finally what are their applications. And how to implement the hardware, at least I will give a small hint.

I will have to at least give you a little bit of idea as to how to implement the hardware as well, So, this course is about all these converters, their control configuration and their implementation aspects and finally application. So we will start this course with the devices first because you guys have not really studied devices except the physics of the device as such. We will be talking about three different kinds of devices kinds of devices. One is completely uncontrolled devices. For example, if I forward bias, it will conduct no matter what. If I reverse bias, it will stop conducting. I do not have any control.

It just will conduct no matter what if you forward bias it. So uncontrolled device typical example is diode. We will call it as power diode because it is going to handle a larger power. Otherwise, it behaves exactly like the normal diode. Normal silicon diode if you say 0.7 volts is the voltage drop, if it is a diode of 6 kilovolt rating ,for example, it will have a larger voltage drop because it will be longer. So it is like a little larger resistance, as simple as that.Otherwise the behaviour is essentially the same, there is hardly any difference between an electronic diode and a power diode.

There are devices which can be controlled during turn on, which cannot be controlled during turn off. Once you turn it on, it is as good as opening a tap, that is it, you cannot close it. It will keep on conducting. So those devices are known as semi-controlled or it is only ON controlled, OFF not controlled. You cannot control the turn off. Typical device which we will be looking at will be SCR or silicon-controlled rectifier which is also generally commonly known as thyristor. The thyristor will have three terminals, an anode, a cathode and a gate. In the gate if you give a signal, it will start conducting. You cannot turn it off, unless it is reverse biased. When it is reverse biased, and the current goes to zero, it will automatically go off.

The third type of devices is fully controlled; it can be controlled during turn on as well as turn off. For example, a transistor, you give a base drive, it will conduct; you do not give a base drive, it will not conduct. So it can be turned on and turned off as per your requirement. So both ON and OFF are controlled. And those devices are the most useful generally because you can control everything about them. But unfortunately the ratings of these devices are still limited. A lot of research is going on in devices because of this reason. The research is only concentrating on mainly four factors. One factor is to increase the power rating. Voltage rating should be increased, current rating should be increased. Ideally, we would like to have infinite rating.

You apply any amount of voltage, any amount of current but we are not yet there clearly. So the first and foremost is to increase the voltage as well as current rating or overall power rating. The second is to make sure that the drop across the devices are minimal. How much ever we may say, these devices are close to ideal, there is hardly any resistance, then diode conducts, it is only 0.7 volts but every 0.7 volts matter, So we would like to as much as possible reduce that forward voltage drop if it is possible. And the forward voltage drop multiplied by the current carried by the device, that is the power loss across the device.

That is what is heating the element that particular device. And that is what is the reason for the device conking out ultimately. So you have to put big heat sinks and so on. So the second effort is generally towards ON-state losses or ON-state resistance reduction. And the third effort generally in many of these devices is towards high frequency of operation. So if I look at that, I cannot say which is the highest priority and which is the lowest priority.

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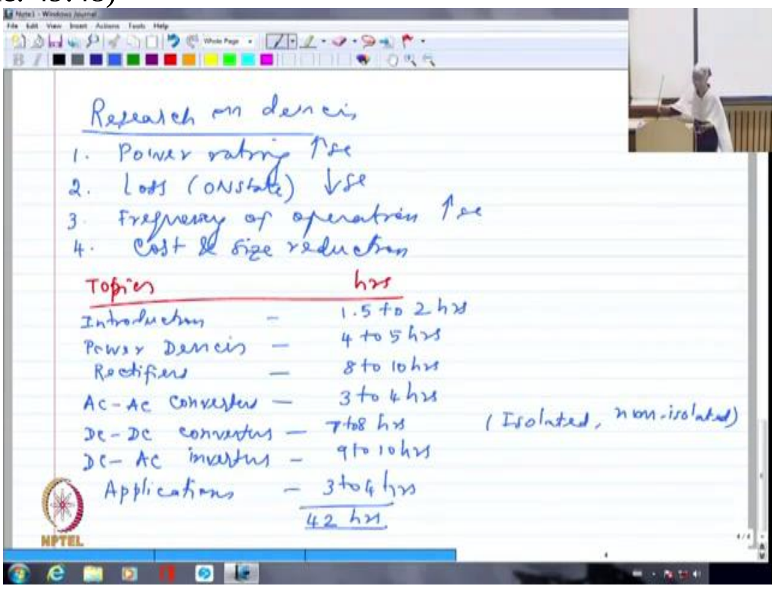

So research essentially concentrates on power rating increase, loss, rather on-state loss, reduction. The third one is frequency of operation. How much ever we may say that it turns on in microseconds, it turns on in nanoseconds, we want to bring it down to zero literally. Until now it has not been possible. If we are able to reduce the turn on and turn off time to really really minimal, we must be able to go to 10^{12} hertz or even more.

But right now we are able to go until megahertz, not really beyond that. So if the frequency of operation of the device is increased, that means turn on and turn off is very very quick. But turn on and turn off can be quick only if the charge carriers can be emitted quickly and charge carriers can recombine quickly. Recombination essentially causes the off-state of the device. And emission of the charge carriers causes on-state of the device. So this requires some finite time. Maybe nanoseconds, maybe microseconds but still, so a lot of research is going on towards this, reducing the ON and OFF time of the device which will enable it to operate at higher and higher frequencies,

So frequency of operation whether it can be increased further, this is the other effort. And last but not the least, nobody is making devices for charity. Everybody is essentially doing business. People would go for your device if you bring down the cost, Taiwanese devices are really really low in terms of their cost. So if we are given say from Fuji, Mitsubishi and say international rectifiers which is in America and Taiwanese device, many of us go for Taiwanese device if it is not a very critical application because it is generally lower in terms of cost.

So the fourth one is cost and size reduction. So these are the major focus of many of the device research and we are essentially seeing giant leaps almost every decade. So apart from all these devices what is available, although diodes are uncontrolled, they are also used extensively in many applications although they are uncontrolled because they are the cheapest and they are available at the highest power level.

So wherever I want a very high power rectifier, generally diodes are the best choice. Then come thyristors. That is the way normally we go for. So the choice of the devices depend upon what is the frequency of operation you want, what is the kind of power level you want, and what is the kind of size limitations you have and so on and so forth. All those things decide really what kind of devices you are going to choose for your particular application, I will not really go into the details of application now because it may not make sense now. We will try to devote a couple of classes towards the end for applications of power electronics.

I only told you a few applications what you know about already so that you realize power electronics is an important course. So let us try to first of all look at the topics that we are going to cover and roughly how many hours that we are going to devote in each of those topics. So I am hoping that today I will complete introduction, I do not expect it to spill over beyond 2 hours. So I am saying 1.5 to 2 hours, not more than that.

Then we will have to look at power devices, what are all the different power devices, how are they having you know specific characteristics, why they are having that kind of characteristic, to some extent we will look into the physics. I am definitely not a device physics person, so I will not be able to really deal with that in great detail. But we will try to look at basically how the structure of the devices, why the ratings are limited, why maybe on-state losses are high or low and such things.

So we look at devices, their characteristics and so on. I think it should take anywhere between 4 to 5 hours because I am not really going to deal with it in great detail. So I should be able to finish it within this. After this we will start off with rectifiers, so in rectifiers we will have to look at half wave, full wave, uncontrolled, fully controlled, semi-controlled, that is we can use thyristor, we can use diode, a combination of thyristor and diode, R load, RL load, RC load, RLE load. All those things we have to look at.

So it is going to take a while. I expect that it should be between 8 to 10 hours. After this I would like to deal with AC to AC converters. So we will look at AC voltage controller and cycloconverter both. But these are not dealt with in many of the books because they have specialized applications. So I am also thinking that I will not concentrate on this to a very large extent. So hopefully it should be over in 3 to 4 hours. I do not want to really dwell on this for too long.

Then comes DC to DC converters. So in DC to DC converters, I just showed you 20 volts can be reduced to 10 volts but we also have the opportunity of increasing from 10 volts to 20 volts which is known as boost converter. What I showed you just now was a buck converter. So we might look at boost converter which is a step up, buck converter which is a step down converter. We will look at a converter which can do boost or buck which is step up or step down converter.

So these are the basic configurations of converter we look at. If time permits, I would like to go for a few more converters which are used extensively in power supplies. Power supplies generally require isolation, because which there will be a transformer in between. So when you insert a transformer, the behaviour of the converter becomes somewhat different. So we will have two configurations, whichever has isolation we call them as isolated DC-DC converters, whichever do not have transformer which will not be isolated from the input to output we call them as non-isolated. So I would like to touch upon isolated converter as well although we will concentrate more on non-isolated converters.

So I expect that if I include isolated converter, I will required at least 8 hours, maybe I would say 7 to 8 hours we will required for DC to DC converter. Then comes DC to AC inverter, DC to AC inverters mainly we will be talking about. I have a DC voltage and I want an AC voltage. Maybe single phase, maybe three phase, maybe I have R load only, maybe I have RL load or I may have an RLE load like a motor because that also have a back EMF. So we will be looking at all those configurations in single phase and three phase.

So this will require more duration for us to deal with. So let us say 9 to 10 hours if I am talking about voltage to voltage, DC voltage to AC voltage conversion. If I talking about DC current to AC current conversion, it is a different ballgame altogether. So let me see if I have time, I deal with the current source inverters. If I do not have time, I will ignore current source inverters for now but let me see how the time goes, how many hours are over according to this.

So I have three more hours, I think I will require those three more hours for applications because I think if I do not tell you the application it does not make much sense. So I will have to have some applications. In fact, there is more to power electronics than this, but I am only uncovering some portions so that you would be able to proceed further if you are seriously interested in a particular topic. So I would say applications may be 3 to 4 hours. And this includes problem solving as well.

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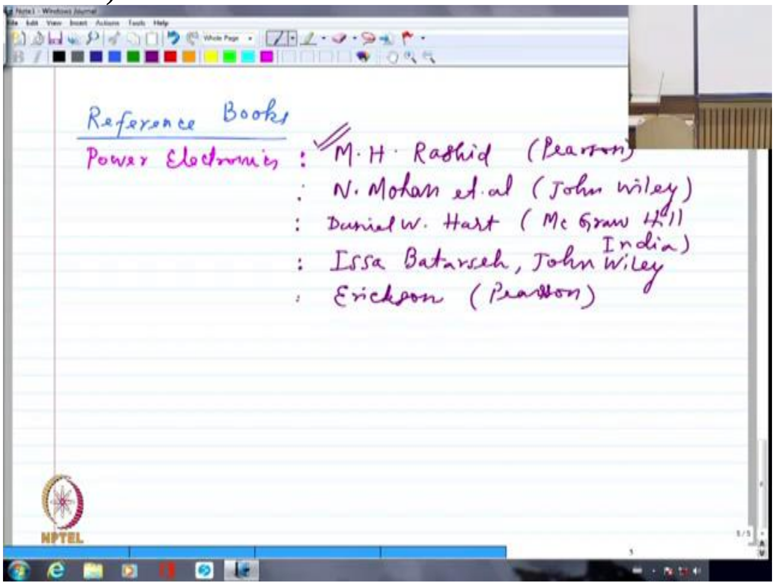

Let me give you the reference books. There is one book by M. H. Rashid, this is from Pearson, this book at least older edition had some mistakes. So I would like you guys to study this with a little bit of caution. I know where the mistakes are, I will tell you. As I go along, I will tell you if there is a mistake in this book in a particular chapter. But the latest edition I have not looked it, I have to look at that as well. Older edition had some mistakes in rectifier as well as AC voltage control, so let me take a look at this and then tell you.

So, this is one of the reference books which is easily available.

The second one is N. Mohan *et al.* There are three two more authors. Okay. This is from John Wiley. This book does not have any mistakes but this is like a typical foreign author book which does not have many problems to work out. You might have one or two examples that are done and it is a little of higher level.

Another book which is pretty good is by Daniel W. Hart. This used to be some Tata McGraw Hill, now I think Tata has dissociated themselves from McGraw Hill, so it is McGraw Hill India, that is what it is. So this book is written in a very simple manner. And he has done a pretty good job of all the circuits but he has done an especially good job in DC to DC converters. This is from McGraw Hill India, so it is not very expensive.

There is one more book, Issa Batarseh, this book is very good for DC to DC converters. In fact, anybody who works on SMPS and all, I generally ask them to study this book first to understand DC to DC converters thoroughly. This is from John Wiley. And of course you might have heard of this book, there is one by Erickson. Erickson is also from Pearson. This is also from Pearson Education.

There are further several books available but if you actually primarily refer to this book that is good enough. But if there is something I am dealing with from some other book, I will let you know.