Fundamentals of Power Electronics
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Lecture – 03
Applications, Definitions and Nature of Power Electronic Circuits

Hello and welcome to Fundamentals of Power Electronics. So, in the earlier lectures I introduced you to some of the basic day to day life examples, pertaining to power electronics. The idea was to familiarize you about the usefulness and importance of power electronics. Now, I want to talk to you a little bit about some advanced applications, just to motivate you a little bit more.

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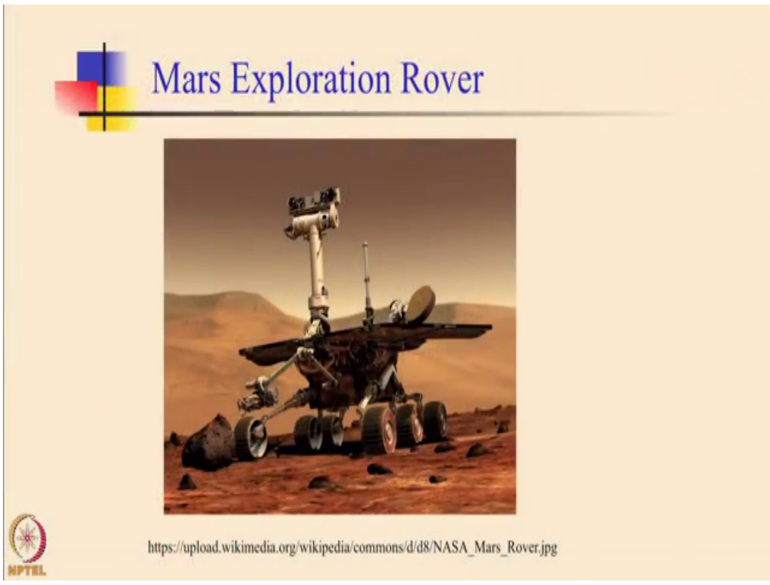

So, what you see on your screen right now is the mars exploration rover, which is on the mars surface. You can see 6 wheels there actually. Are you aware how these wheels are driven and how they are controlled? There is a very extensive use of power electronics in the driving of these wheels, in the control of these wheels each of which is having a dedicated motor which is controlled power electronically. Apart from the wheels there are several other tasks which are performed by power electronics. For example, rock drilling for experimentation, it controls cameras, their orientation and so on, ok. So, they are all actually carried out by power electronics, ok.

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Now, let us look at this Mars orbiter, our own India's own Mars orbiter, the Mangalyaan which has been orbiting the Mars. Now, what you see at the front are the solar panels which are used to power you know this orbiter.

As is the case the electricity produced by the renewable energy sources such as the solar photovoltaics that is seldom compatible with the loads with the electrical loads which are supposed to be fed from it, and same is the case here on this orbiter. So, the electricity produced by the PV panels is actually conditioned appropriately, to actually get it in the right form DC or AC and the right level of the voltage before it is applied to the various nodes inside this orbiter. All this is done with the help of power electronics.

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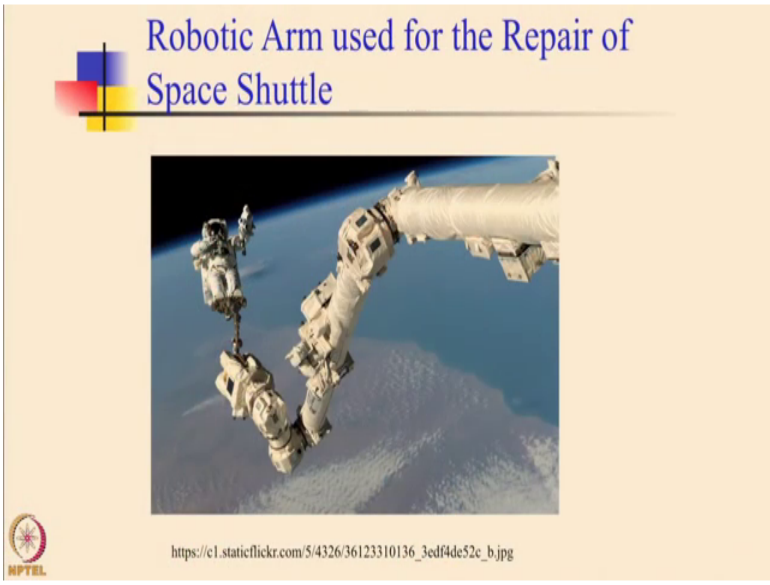

Now, the next image shows you robotic arm that is used for the repair of space shuttle. So, there are several drives, electric drives which are controlled through power electronics which are working in this arm, ok.

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After some of these space applications let me show you some more familiar applications of power electronics such as the home appliances. So, what you see you know is a bunch of kitchen appliances like the mixies, and the grinders, and you see certain other you know appliances such as the refrigerator, and the air conditioner. All of these they use power electronics. To increase for example the efficiency, to reduce the energy consumption, the motor that is used for the compressors in the refrigerators, and the air conditioners is nowadays controlled with the help of power electronics.

Same is the case with the motors which are used in a mixie for example, so that is done to power electronics control and we try to conserve the energy. And we also try to improve the power quality the power drawn from the socket by these machines, so that they do not spill distorted waveforms into the power system.

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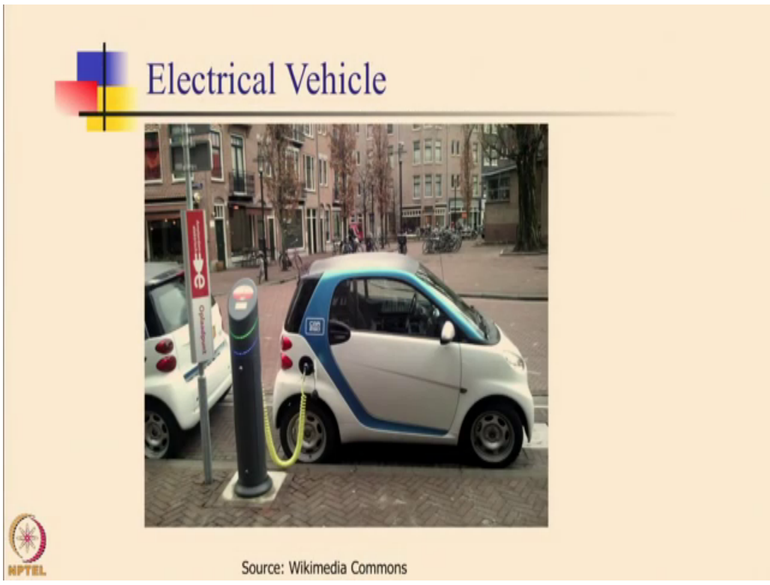

Another very famous example is of the electric vehicle, Now, what you see here is an electric vehicle which is parked and it is actually being charged. Inside this electric vehicle we do not have the conventional internal combustion engines which are run by gasoline, by the petroleum products. Rather there is basically one or two or more electric motors which are driven by the battery, and the battery is being charged through charging stations such an arrangement obviously, does not cause any pollution in the environment environmental pollution which is a matter of great worry these days and in future we can expect many of these vehicles to be actually electric vehicles which are using electric motors.

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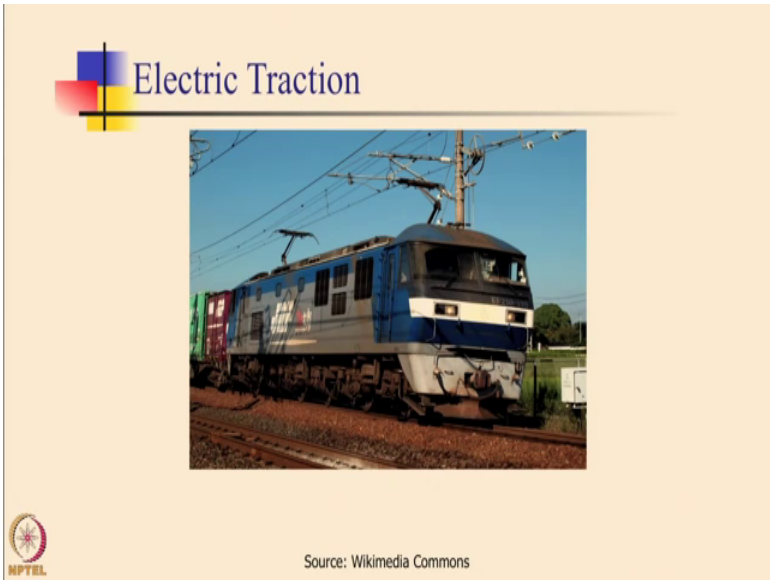

The picture shows electric, locomotive it shows and you can see the pento graphs on the roof of the locomotive which are trying to trap the electric power from the overhead lines. This power is tapped through the pento graphs and inside the locomotive this power is appropriately conditioned and applied to the motors which are then used to drive the wheels of the locomotive. There are several other applications in inside this locomotive. Inside these electric trains which are all actually managed through power electronics for their high efficiency and compactness.

Moving to another arena, now let us look at some of the examples of the renewable energy systems. Now, everyone is concerned about the deterioration in our enrollment quality, the ozone layer is depleting and people are actually exposed to harmful radiations. So, there are health hazards. And many organizations who are actually concerned about this have already raised and around. So, there is a constant search for alternative energy options which will actually reduce or eliminate the use of for example, thermal power plants which run on coal and emit a lot of toxic gases into the environment.

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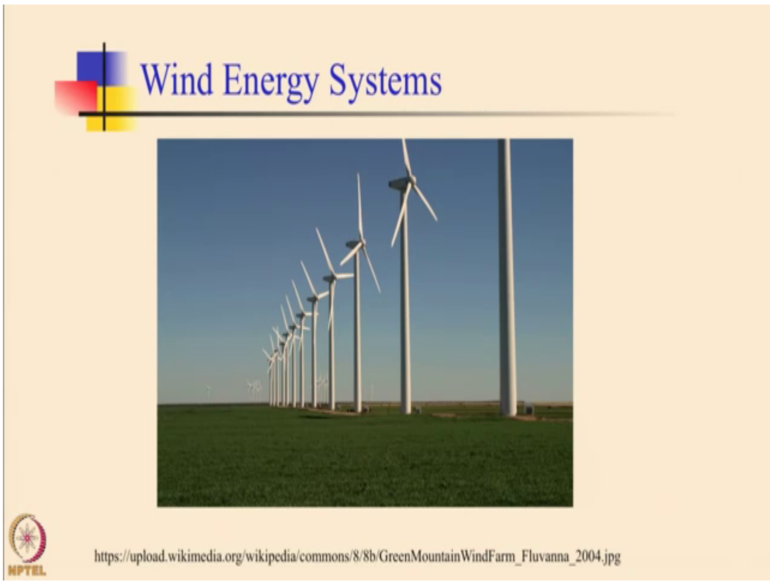

What you see in this picture is a series of windmills, the windmills they are connected, the shaft is connected to the electrical generators which generate AC power. And because this AC power does not have a fixed frequency it varies with the speed of the wind, it is converted into a DC form of power by using rectifiers and then using another power electronic stage a power converter which converts DC to AC this is converted into AC and then actually it is mixed with the power grid to transformers.

Here is another example of a renewable energy system in which a solar PV panel is mounted on a rooftop. Since the electricity produced by solar panel is a DC electricity, it must be converted into an AC form using an appropriate DC to AC converter configuration, so that it can be either used for these AC loads or it can be fed into the grid.

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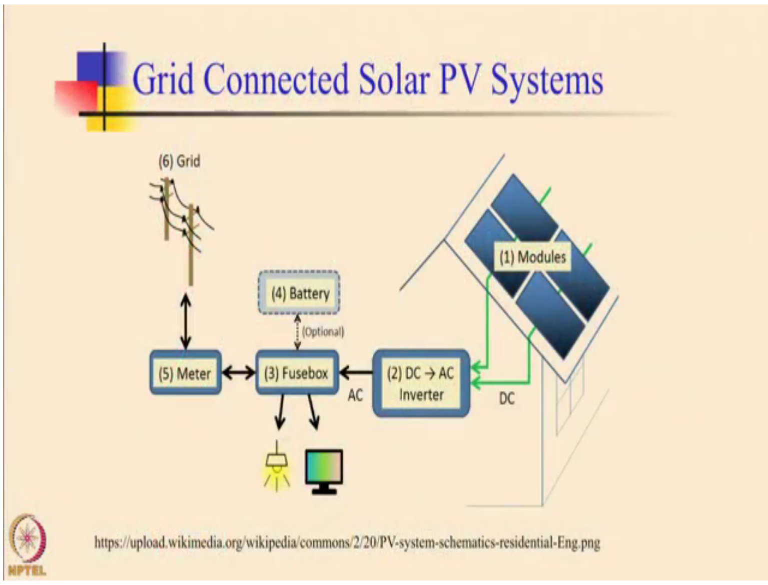

Now, you will notice that apart from the fuse box which is used for protection there is also a meter. The specialty of this meter is that it can actually measure power in both the directions. So, basically you can measure the power which is coming from the grid into the household or you can measure the power which is going into the grid from this household through this solar PV system. Hence you are able to do what is called net metering and are able to calculate the tariffs appropriately having seen several examples.

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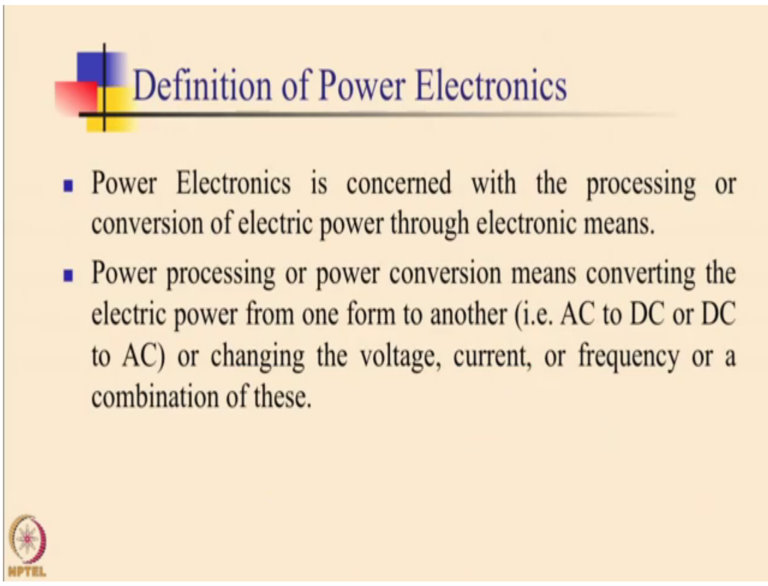

Now, let us try to see how we can define power electronics, we would like to actually assign a formal definition to power electronics. So, in the very simplest form power electronics is actually concerned with the processing or the conversion of electric power through electronic means. When we say power processing or power conversion, we mean converting the electric power from one form to another that is AC to DC or DC to AC or changing the voltage the current or the frequency or a combination of these. So, all this actually constitutes what is called power processing or power conversion, and this is what power electronics does for us using the electronics and using the control.

Now, the definition of power electronics has taken various forms over the years. There are various authors who have actually defined power electronics one way or the other. Now, these definitions might appear different in terms of words but they all actually amount to the same basic definition.

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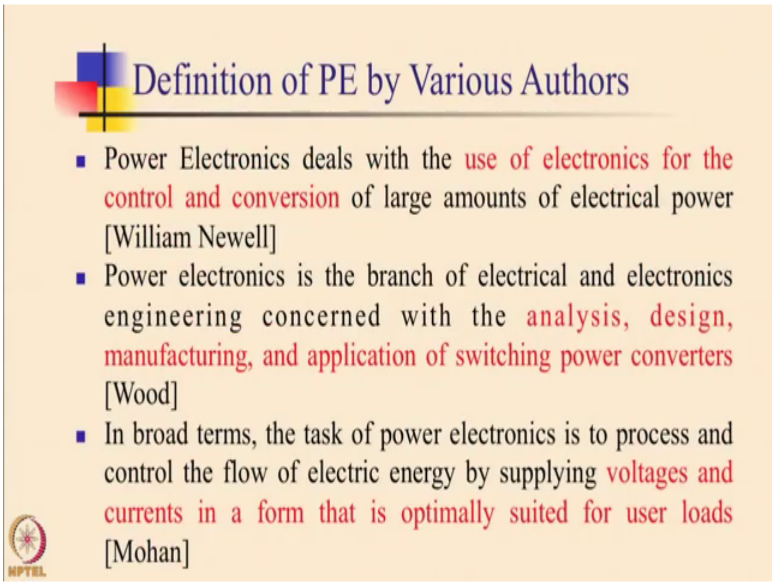

Professor William Newell, he says that power electronics deals with the use of electronics for the control and conversion of large amounts of electrical power. So, this is actually one of the earliest definitions given by William Newell who is considered to be a very covering personality in power electronics. He seems to emphasize the use of electronics for the control and conversion, of power.

Then Peter Wood, he has described in his book power electronics to be a branch of electrical and electronic engineering that is concerned with the analysis, design, manufacturing, and application of switching power converters. So, not only that you know he has given it the definition a different form, various brought in analysis design and manufacturing, he is also focusing on the application and on the switching power converters which are actually the heart of any power electronic system.

Professor Ned Mohan, he says that, in broad terms the task of electronics is to process and control the flow of electric energy you know by supplying voltages and currents in a form that is optimally suited for user loads. So, he is actually stressing on the importance of the right configuration and the right kind of control which can then provide the exactly the right form of current and voltage, which a load needs.

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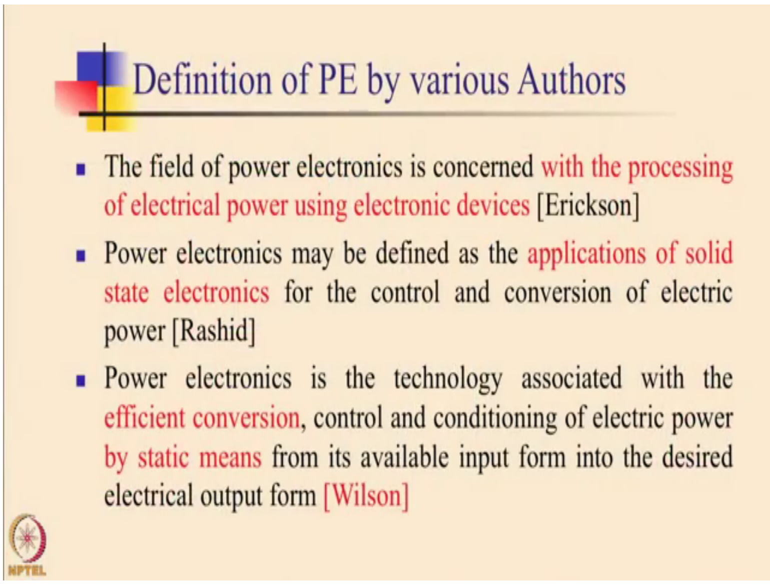

Likewise, there are many other definitions, one of the definitions that I will like to quote is from Professor Wilson, which says power electrons is a technology associated with the efficient conversion control and conditioning of electric power by static means from its available input form into the desired electrical output form. So, this is what is the definition given by Professor Wilson in one of his papers.

Now, here in this definition he seems to emphasize is something that is different from other you know definitions, he seems to emphasize when efficient conversion. So, basically you know we are trying to see; that means, less energy loss and also he is talking about static means. So, basically you know he seems to be ruling out anything that will be used for energy conversion which will have let us say you know some were and tear associated with it because of its moving nature.

Like for example, rotary converters they are one such possibility to do power conversion but then they are less efficient and they also have moving parts and are you know, therefore, subject to were and tear which reduces the overall life and reliability. So, Professor Wilsons obviously, emphasis seems to be on a lot of you know efficiency, reliability, and longevity, and also availability you know of the power electronic system, ok.

Now, one thing that is very important about power electronics that I would like to share with you is you know that it is truly a multi-disciplinary area, it is a multidisciplinary topic. One of the things very important things which Peter Wood says in his book is that you know the reason people use power electronics, the reason people need power electronics is because people do not use electricity. What it means is that we use electricity you know not directly as electricity we actually convert this into mechanical energy or heat or light. So, therefore, you know there is a need for not only you know power conversion but also to control the rate of power conversion, ok.

So, you know you should be able to control for example the intensity of the light, you should be able to control the heat. For example you should be able to control the speed of the motor. So, basically this is where the power electronics lies and the power converters seem to do just this they are able to do power conversion, they are able to change the form either AC to DC or DC to AC or they can keep the form same they change the levels of the voltage for example, or they change the frequency plus they also almost always are able to control the rate of energy conversion.

Now, looking at the power electronics as an interdisciplinary field you know we can actually divide electrical engineering into three major disciplines - the power engineering, the control engineering and the electronics engineering.

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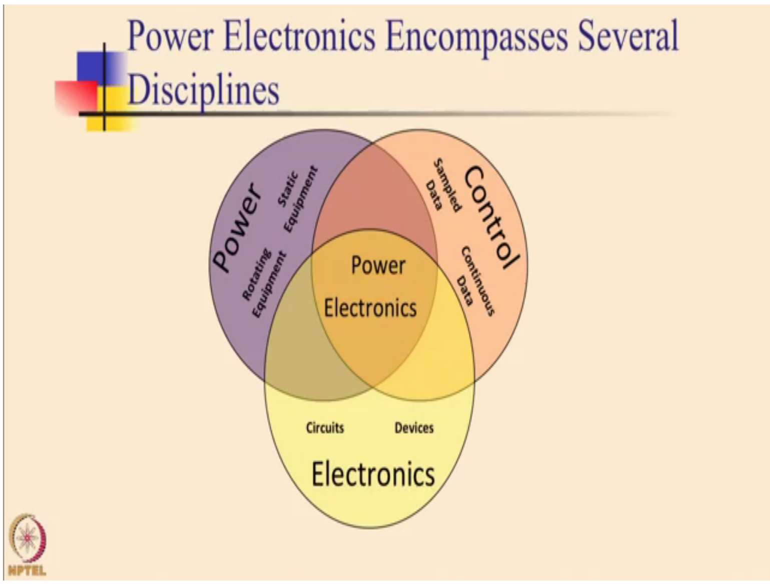

And actually, we will see that the power electronics borrows concepts from the power engineering field, the control engineering field, as well as the electronics engineering field and that is how the entity of power electronics comes into being, ok. So, you can see that in this picture power electronics is shown as an overlap of the three main sub disciplines of electrical engineering, the power, the control and the electronics engineering.

The electronics engineering deals with the, you know devices power devices which are used as switches and also with circuits which are used for processing information. The power engineering which consists of you know rotating equipment and static equipment related to the generation transmission and distribution as well as utilization of electric power and power electronic, actually plays a role big role in that as well. Similarly control, so power electronics uses several concepts of control, there are many in fact, the majority of power electronic systems are closed loop systems and the control engineering concepts are required to control these systems to understand the stability issues and to be able to see their response characteristics.

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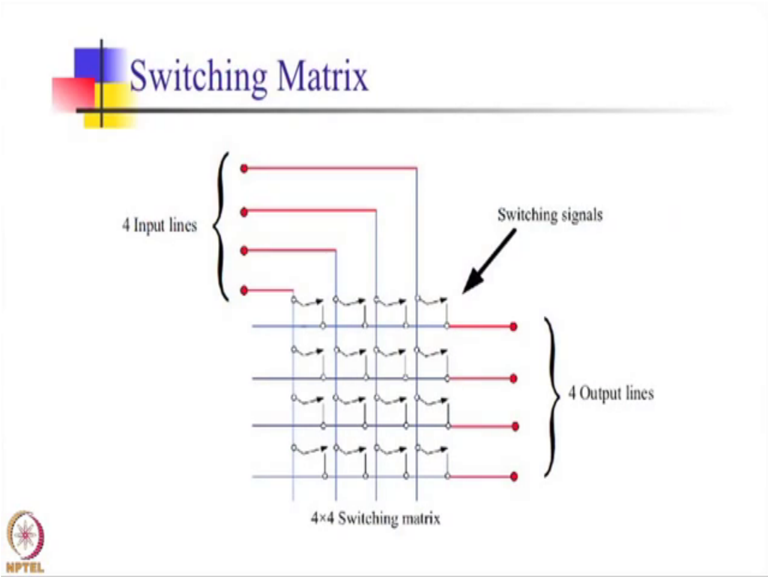

When we talk about electricity, we talk about three phase or poly phase AC or one-phase AC or DC however, it is a poly phase AC which is the most general form and other forms can be derived from it. While one-phase AC is clearly a subset of poly phase AC the DC form can be thought of as a special case of one-phase AC with zero frequency keeping this in mind it is possible to represent any type of power converter by a switching matrix, a matrix of switches.

Now, let us say that we have m input lines and n output lines of a power converter system, ok. Now, on the screen what you see is a special case where m is equal to 4 and n is equal to 4 is considered. So, you have 4 input lines and 4 output lines. So, the way actually this whole thing is configured is shown. I will just draw this diagram and show that.

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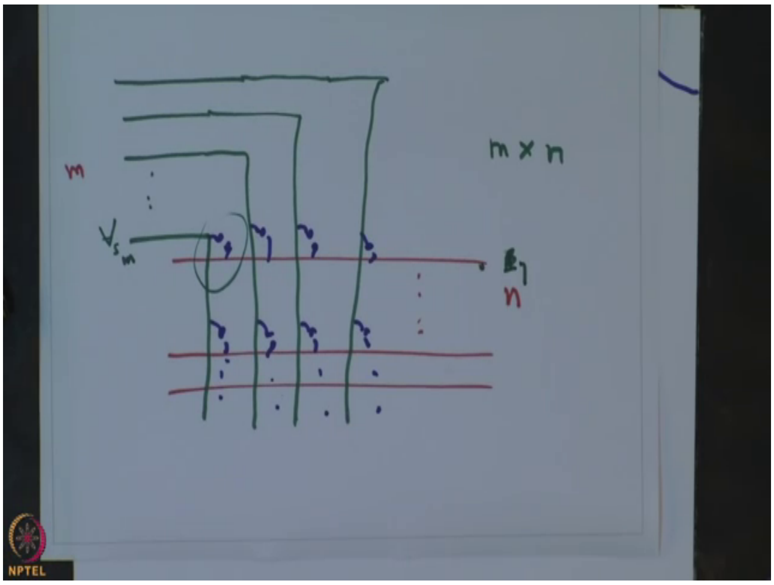

So, these are the m input lines and with the red pen let me just draw the output lines. So, these are n output lines and m input lines, ok. Right now, they are just actually plays in this crisscross fashion. Now, if I connect at each of the points where the input and the output lines meet one switch, ok.

So, then I would actually have a switch which will be here, here, here, here, here. So, we will have all these switches and so on. So, basically if there are m input lines and n output lines, I can say that there would be m into n switches which will be required to complete this matrix. Then whenever any switch is closed or turned on, we can say that that particular input line is connected to the output line. So, for example, if I choose this particular switch if I connect or if I turn on this switch, I can say that this line if I can just if I just mark this as v s m that is connected to you know this line which I can just mark as I 1 its connected to there.

Now, since the devices the switching devices are usually unilateral, they are could be conducting in one direction, and if we want the power to actually be able to travel both ways in both direction, we actually must also connect one more switch along with each of these switches in anti parallel which means that it will be having the other polarity. So, basically the number of switches will now, become 2 m into n.

Now, in many converter systems there is a possibility that you know one of the lines like for example, this line in the input and this line at the output they might be connected as a common ground reference. And in that case one of the switches which will be connecting this line and this line will actually not be needed, and this actually corresponds to the degeneration of this line.

So, we will actually have at the max 2 into m into n number of switches which will be required, ok. In the switching matrix which actually represents a power converter, it actually uses a combination of the input lines and it produces an output you know at the output lines.

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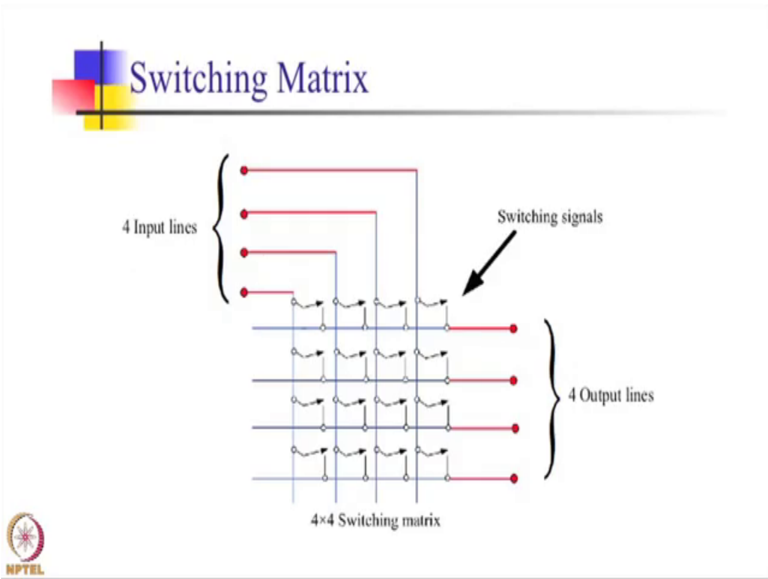

So, basically it depends on which of the switches are activated what kind of control signals are applied and what type of switches are used. Now, one of the requirements you know of high efficiency is that you know you cannot have the basic control element, you know the switch in this case you know to be actually a continuous variable, you would actually want this to be working as a switch as an on off device and it cannot be work as a continuous variable because it will then result in loss of energy and will actually result in poor efficiency. Therefore, we must always operate these switches or these switches are always operated in what is called switched mode or on off manner.

Now, what is the effect of this? What is the effect of you know having this basic control element the switch operating in the on off in the discontinuous manner, ok, not as a continuous variable? What is the result of this? The result is that, what we get at the output, ok, it is the you know whatever is synthesized to appear at the output it may be close to what is desired but it is not exactly what is desired. The reason is that these switchings, the on off switchings or the switched mode operation of these switches as we will see later it actually causes certain gaps to appear, ok.

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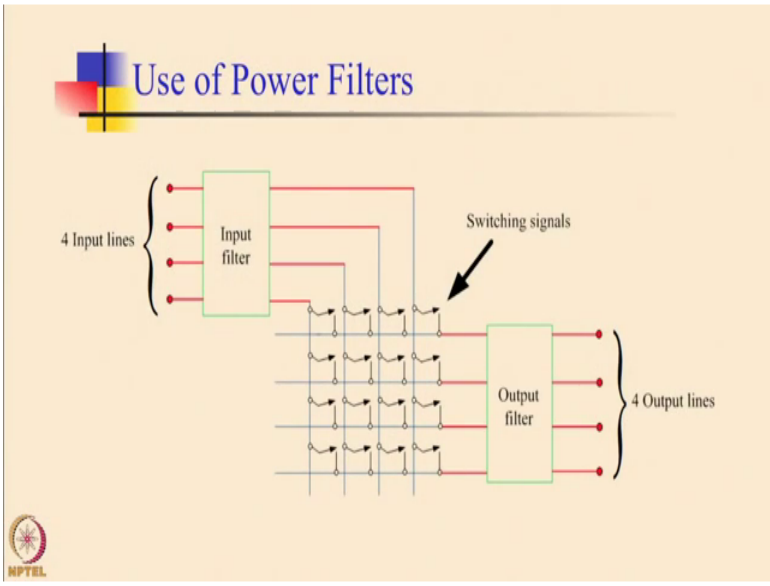

Likewise, these gaps may also cause distorted currents to be drawn from the input side which are which is not desirable for the supply. So, the result is are the consequence of this is that we use filters. So, you see in the in this picture that you see on your screen you see an output filter and an input filter.

Now, what is a filter? A filter is nothing but a combination of the energy storing elements such as L and C which are appropriately actually connected and they form a filter. These energy storing elements they store energy and whenever it is available and then they use it this energy to fill this gap you know these values which might appear due to switching of the switching metrics. So, that your output actually approaches the desired form.

Similarly, on the input side this filter the filter components the user store energy to supply those components those values, in the waveforms they try to fill those values which would have otherwise been drawn from the input side which is not desirable. Hence filters are very important. But at the same time filters contribute to the weight than the cost and the volume of the system because they are made up of you know magnetic components such as l.

Now, one of the things on which the filter size would depend is the rating of the system of course, the other ways the frequency of the system. So, if you are operating these switches at high frequency, the gaps that will appear in the output or the input waveforms input current waveforms and the output voltage waveforms, ok. They would be very small these gaps will be small and they would need much less energy and hence much smaller L and C components to fill those you know gaps.

Therefore, updating a pi electronic system above much above you know a nominal frequency or operating it at a higher frequency is highly desirable its highly desirable, because it helps us to reduce the size the weight in the volume of the filters. But it must be remembered that when we increase the switching frequency or when we increase the operating frequency we actually are increases or losses which takes place when switching devices is switched, we will see these details a little later in the course.

Now, an important aspect of the switches though we have not done the switches in details here. But I must tell you at this point something that, I also mentioned in the first one or two lectures that there are basically two types of devices the switching devices, and today most of these switching devices they are all semiconductor devices, they are all made up of semiconductors.

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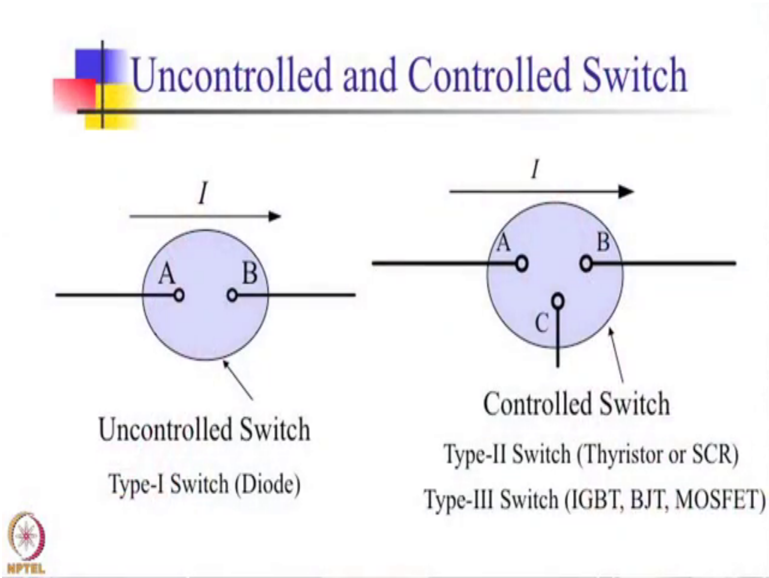

Uncontrolled and controlled these are the two types of switches, when we talk of about diodes these are uncontrolled switches. And we call them type one devices, when we talk about a thyristor and or when we talk about a bipolar junction transistor or a metal oxide semiconductor field effect transistor or we talk about an insulated gate bipolar transistor we are talking about the control switch. But within the control switch there are two categories, one of them is the thighs which we call as type two devices and the other is the other switches such as the BJTs, the IGBTs, and the MOSFETs which we call as type 3 devices.

Now, the difference is that with a thyristor. You know the thyristor has a forward blocking, forward voltage blocking capability, so till a gating signal is applied it would not start conducting but the problem is that it becomes like a car without a break. Once it starts when it actually once it has a current which is gone beyond the latching value then the thyristor does not switch off, till this current is brought to 0 and for a stipulated time a reverse voltage is applied across the device. It cannot be turned off through its control terminal.

Now, this is not the case with other devices like MOSFETs, BJTs, and the IGBTs which can be simply turned on as well as off by applying appropriate control signals to their control terminals. A diode on the other hand is a completely uncontrolled device it has no forward blocking capability; the moment a forward voltage comes across the diode it conducts. So, we have all these types of switches which are used in power electronic circuits, ok.

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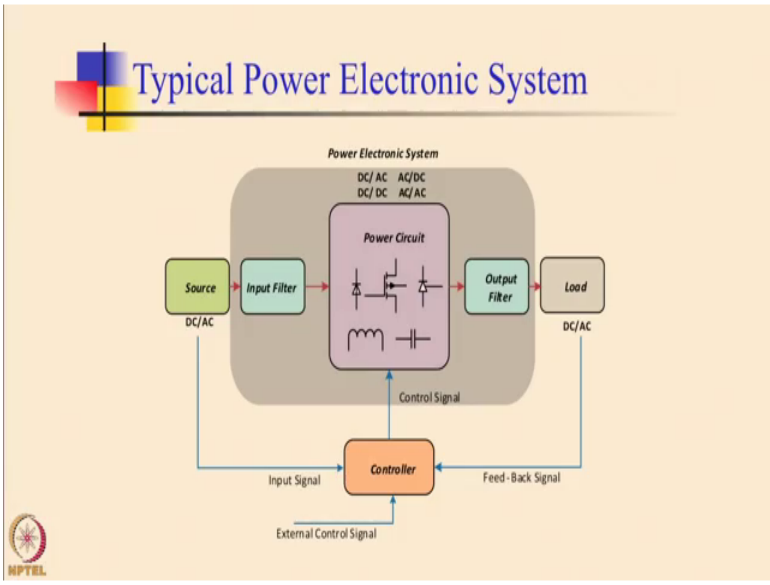

Now, very briefly now we will come to this point again we will just briefly see how a typical power electronic circuit looks like, ok. So, here is a typical power electronics system, ok. So, what you see at the heart or at the center of the system is a power converter and as we have been every, as we have seen before it is able to change the form of electricity.

So, you can see that it mentions DC to AC, AC to DC, DC to DC and AC to AC these are the various forms you know which the power converter is able to convert, ok. Now, at the input side and the output side are the filters about which we discussed some time back. These are the storing element, elements L and C which are connected in some combination, LC filters, as LC filters which actually are able to fill up the valleys and prevent the gaps, and read, and actually result in the desirable wave forms, ok.

Apart from this there is a controller which is shown at the bottom which actually takes a feedback signal from the output site from the node side, ok. This is a typical feedback system I briefly talked to you about the output voltage regulation in one of the earlier lectures. And this is just exactly a feedback that is taking place as part of some sort of a regulation. It also, the controller also accepts external control inputs or into signals such as for example, set points. So, if you know we want to have the fan running at a certain speed, so we can actually just move the knob and we can just externally you know you know adjust the set point and then you know the output actually tries to follow that.

You also see on the diagram one input signal which is drawn from the input of the source side, you know of the system this could be for example, the AC waveform which is feeding this entire power electronics system and you are using these voltage information voltage templates, just because you need to decide the switching instants for the devices which are present inside the power converter based on you know this information that you get in terms of the input voltage AC voltage.

While discussing the AC voltage controller in one of the initial lectures, I mentioned about the delay and advancement in the control pulse application to the device to control the output voltage. And you know there are other applications like for example, the input signals are also used when somebody is trying to do what is called a feed forward control. So, we will see some of these aspects later in the course. But this actually diagram should give you an idea that how a typical power electronics system looks like.

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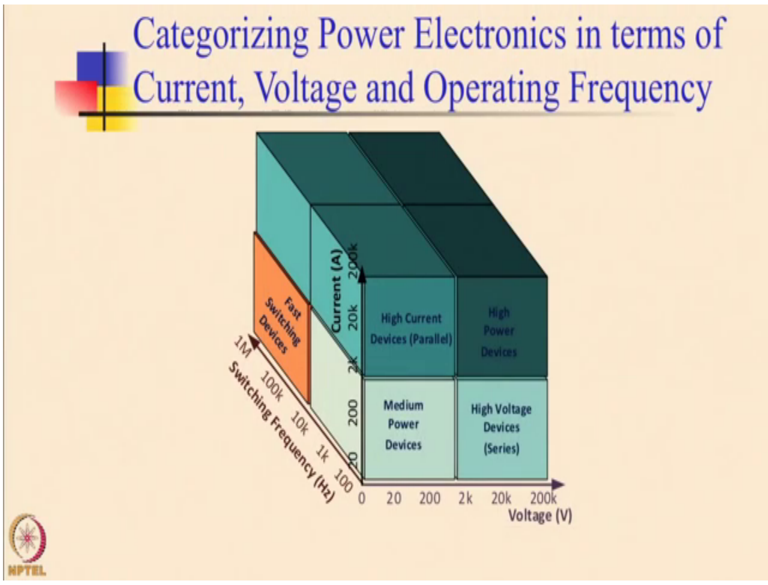

Now, one way of categorizing power electronics you know is you know by looking at this diagram which shows the three space three-dimensional space of voltage current and frequency, ok. Now, what it means is that, basically it means that you know if I consider a device the basic device which is let us say existing today with maximum current and voltage capability, ok. And then I say that, I just use this device for my power converter then the resulting power electronic system actually will come in what is called medium power domain, ok. The unit the device which are available they are actually compatible for you know their basic rating, the basic highest rating which is available.

Now, it is not uncommon that we want to actually go to sometimes higher voltages and higher current ratings. So, in which case these devices can be connected in series and parallel they connected in series to get you know a higher voltage and there they result in as I will show you, ok. So, this is you know the power level that is achievable in this domain which is the medium power domain, you know the basic device with the highest rating of current and voltage. But now, if I add if I just add in series too such basic devices, I actually go into what is called the high voltage domain which is actually shown on it on this side.

And it is also not uncommon to parallel the devices to increase their current ratings in which case I go to the high current domain. And sometimes I want to do both series and parallel combination of the devices to go to both high current and high voltage domain which actually leads me to what is called the high-power domain which is several mega watts as you can see from here. Now, this is one way in which we can actually categorize power electronics it forms in the medium, power domain, high power domain or you know we can say that high current domain, high voltage domain, high current domain and medium power domain and high-power domain, these are the 4.

Similarly, the frequency also plays a role what you see typically is that when you are actually going for very high frequency operation you know usually the power levels are less from here this diagram; what you see here this one. So, the power levels are actually less. So, there are all sorts of devices which are coming up almost every with different speeds, with improved speeds, with improved current and voltage ratings. So, therefore, there is nothing sacrosanct about the values used in this graph. The idea is to show you that how qualitative categorization or the various power electronic systems or power electronic circuits can be done you know using the voltage, current and frequency information or capability of the devices, ok.

Now, a special comment about, and AC to DC converter has been you know its among the first circuit it is called actually a rectifier its among the first power electronic circuits, which were developed in early night and early 20th century, ok. And they actually are more interesting because they have several implications, and they have several applications. Now, what you see of this diagram this is a very important aspect associated with power converters.

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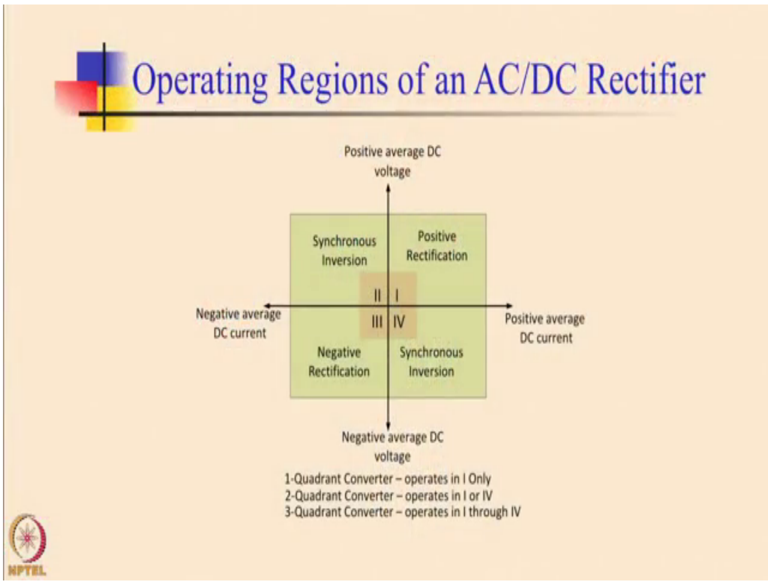

You know that is the capability to operate in how many quadrants. Now, these quadrants are defined by the voltage and the current that appear at the terminals of interest. Now, in an AC to DC rectifier we obviously, have one port with AC the other port with DC. So, if I look at the DC side, and I look at the AC if I look at the voltage in the current then if both the voltage and the current are positive, it basically means that the power is going from the AC side to the DC side, ok. So, this is actually a rectification which is taking place. It is also called a positive rectification.

But if you go to quadrant 3, you will find that the voltage as well as the current they are negative both are negative. So, the power is still because the product of current and voltage is still positive, so the power is still flowing from AC to DC, and the rectification is taking place, but here we call it negative rectification.

Now, what you see in the second and the fourth quadrants is what is called a synchronous inversion. Now, what is happening here is that you will find that the power that you see the DC terminals is actually negative, because either the voltage is negative or the current is now negative but both of them are not negative or positive. So, you have a negative sign coming with power which means that the power is now flowing from the DC side to the AC side. Now, this is something which was actually called as inverter by people like prince who was the first to invent such rectifier circuits. But actually this inversion is not to be confused with the dedicated DC to AC conversion which takes place and for which we need either force commutation of the you know specific switches such as thyristors or we need to use certain even advanced which is like the BJTs and the IGBTs or the MOSFETs. During the synchronous inversion the thyristors that is type two switches undergo natural communication, ok.

Now, having talked about the various quadrant of operation having talked a little bit about the devices you know and their capability. Now, let us try to see what are the various possible types of power converters which are realizable, and how they are associated taped with the switch properties the switches which are used in making the power converters or the power matrix or the switching matrix. Now, the first quadrant rectifiers which are you know having both voltage and the current is positive they actually can be realized with just diodes, and we just call them as type 1 switches. The diodes is a type one switches or the uncontrolled switches.

But if you go to the second and the fourth quadrant AC to DC conversion operation, then you can use you will need type 2 switches such as the thyristors as we will see, ok. Several frequency changers you know and AC voltage, regulators, converters that you can do with type 2 switches as well as with you know part of these can be realized with force commutated inverters.

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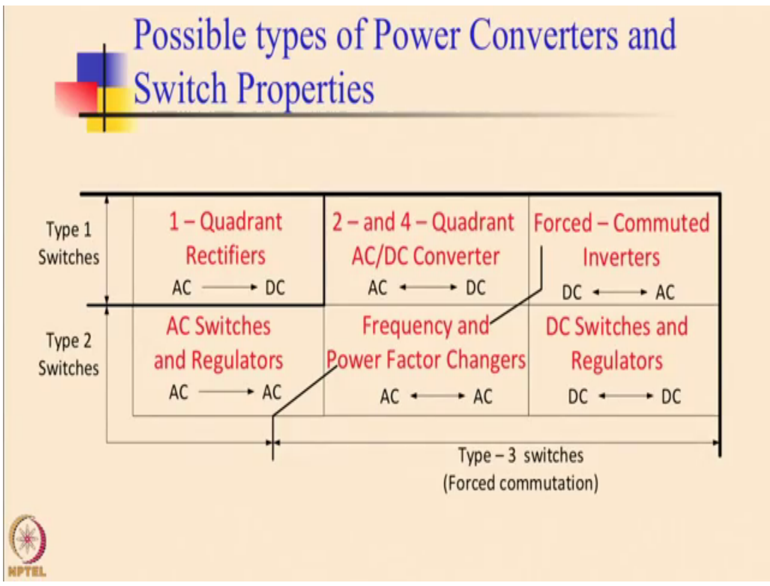

Similarly, the DC switching and the regulators the DC to DC converters that is, they are realized with the type three switches you know the IGBTs, the MOSFET from the BJTs or with the type two switches, the thyristors which are actually subjected to forced commutation. So, this is how we can actually define the various types of power converters and associate them with switch properties ok.

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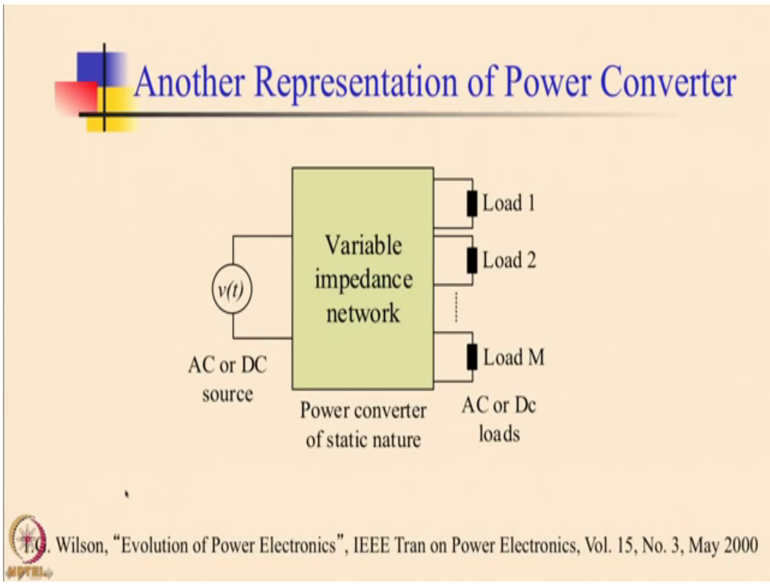

Now, what you see on the screen is another representation for power converter. Now, clearly this is very different from the switching matrix representation of the power converter it is a different approach. Now, what you see here is that a power electronic converter, of static nature it can be represented you know something that lies between the source and the loads and each of you know these paths which connects the source to the loads is actually having a variable impedance, ok, an impedance that varies and we need to. Now, see we will see now, what are the property of these impedances, what is the property of this variable impedance network, ok.

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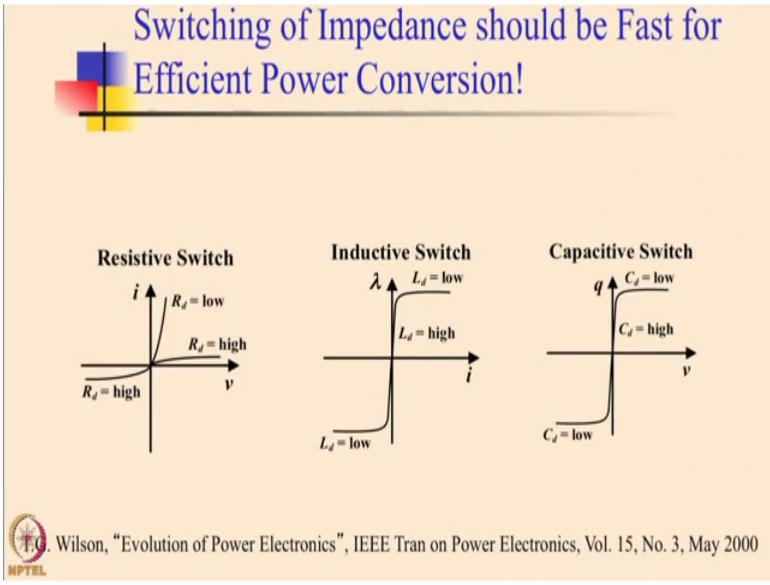

So, the property of these you know of these impedances or the switching of impedance should be actually what nature it should have that is depicted by these pictures. So, what you see here you know a resistive switch which changes the impedance from very high to very low value, and that is shown in you know as a first image on the left, first figure on the left side.

Similarly, there is a possibility of a switch which is an inductive switch which actually switches and inductive impedance to a very high value, from a very low value. And here this is also called a settle saturable reactor because actually what we do is when we want the i l to be extremely when we want the inductance will be extremely low we saturate the inductor and when we want this to be very high the inductance to be very high we bring it out of saturation.

So, this works this is as inductive switch and similarly a capacitive switch. So, the various power converters that we have the four basic forms you know they can make use of one of these three types of impedance switchings. It is important to know that high efficiency demands that the switching of the impedance should be as fast as possible.

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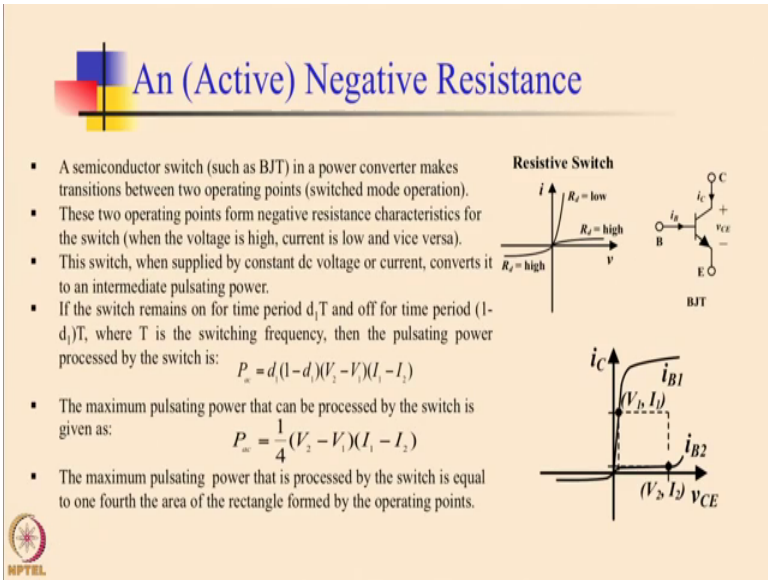

So, for example, if you are talking about a DC to DC converter or if you are talking about a DC to AC converter this negative resistance active switch which actually switches between a very high value of resistance and a very low value of resistance, is shown. You can see that we have drawn the same switch characteristics on the right side. So, this is basically. So, you can see here the characteristics of the switch that we have also seen in the previous slide and this is a switch, this is the switch you know. Just we talked about several switches which will be placing at the intersection of the input and output lines in a switching matrix. This is that switch.

Now, it can be shown that if this resistance switch you know which is realized through a transistor, a bipolar junction transistor is actually switching between two operating points V 1 I 1 and V 2 I 2; it is possible to show that you know the pulsating power which can be processed by the switch, by this switch is given by you know this expression P ac is equal to d 1 into 1 minus d 1 into V 2 minus V 1 into I 2 minus I 1. V 2 minus V 1 and I 2 minus I 1 obviously, are if we are switching between the two extremes of the voltage rating and the current rating of the device, then obviously, this is the complete vi rating of the device. So, if you have d 1 and 1 minus given is 0.5 you actually have this maximum power that can be processed by the switch which is given by this expression.

Now, this is a little involved proof which can be shown but if you see graphically on the right side on this picture, this particular rectangle which is formed by this you know where these operating points either here or there this area which is one by fourth of this you know this particular rectangle that is what constitutes the maximum power that can be processed by the switch.

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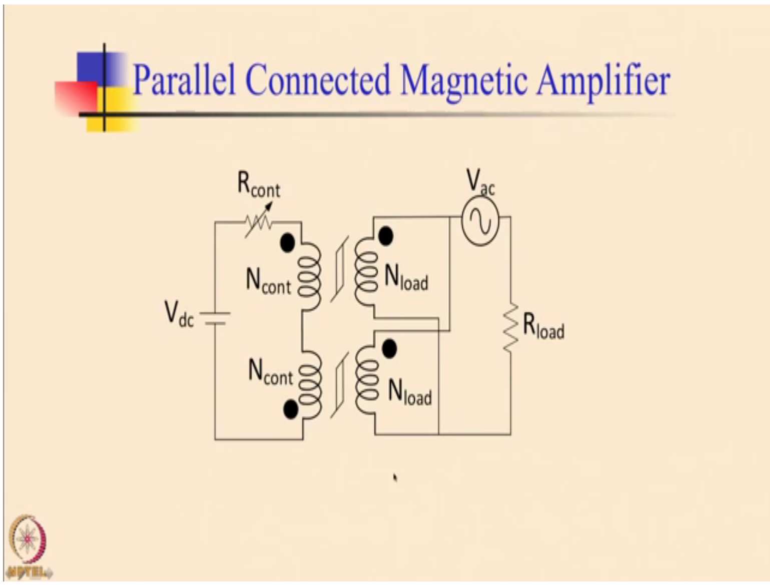

Now, here is an example of you know an inductive switching. So, what you see here on the right side is a load which is supplied by a V ac or source and on the left side we have coupled a DC source along with a control resistor. So, actually you apply a DC current into this coupled inductors. So, you can see here these coupled inductors. You are actually trying to inject through this a DC current and in the process what we do is we saturate the core.

In the positive for cycle at a certain AC voltage one of the cores saturates and in the negative half the other core saturates. Since the two windings are in parallel when the core saturates a low inductive impedance is offered. And you actually have the power you know that is flowing into the into the load from V ac and when you do not have saturation then this actually offers a very large inductive impedance and actually nothing can flow into the load at that time. So, by using are very small DC control here, DC level control here we are able to actually control large chunks of AC power. Now, this is highly suitable for AC to AC power conversion.

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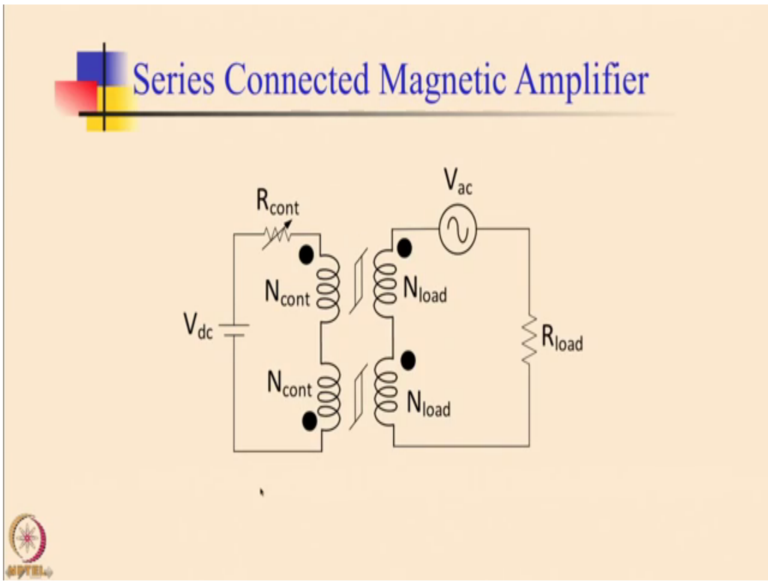

This is another way in which a magnetic amplifier can be coupled. Here you can see that the load side circuit is not connected in parallel it is actually connected in series. And this was widely used this concept of amplification was widely used in magnetic amplifiers which became very popular in the 1920s, 30s and had played a major role in the World Wars, World War II many of the applications were actually run with the help of magnetic amplifiers. However, the magnetic amplifiers importance, it waned when people actually brought in the vacuum tubes and the vapor tubes into the market you know in in around the same time in 1930s and 40s, ok.

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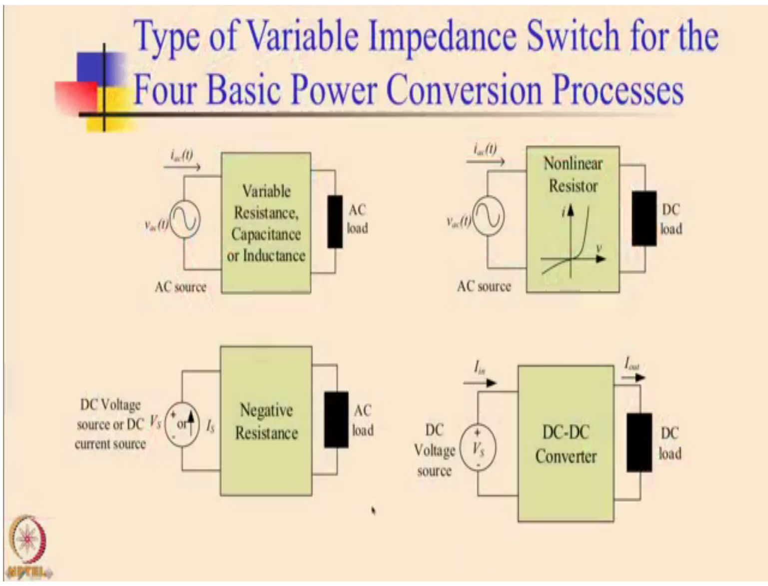

So, just to quickly summarize that you know you can actually have AC to AC conversion when you can have a variable resistance or capacitance or inductance. We saw the example of a magnetic amplifier where it was an inductive impedance you know that was switched from the maximum value to the minimum value, and vice versa to control power.

Likewise, you want to have a rectification like AC to DC we will have to use these non-linear resistors. So, if you look at this graph it shows you the property of such a device. So, the diodes for example, in which case will be an uncontrolled rectification and the thyristor there see as will have these kinds of characteristics, and they actually lead to controlled rectification. Because you know we are having an AC source the use of thyristor is fine because it actually provides opportunity for natural commutation of these devices.

When we are talking about DC to AC conversion, in fact even in DC to DC conversion the use of a negative resistance device, the kind of one which we saw just now some time back which switches between a very high resistance to a very low resistance just like a BJT example that we gave, they can be used for DC to AC applications. And in DC to DC applications also we have to understand that there is an intermediate stage, which actually pierce a DC voltage, into a pulsating power first, ok. And the same principles apply for the switch as we have discussed before.

So, with this you know I end this particular session. And in the next one we try to go back to the diagram of the power electronics system, and we will try to see what are the various components of this power electronics system and how they work. We will look at some of the basic aspects.

Thank you very much for your attention.