Basic Electrical Technology
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Lecture - 5
Kirchoff's Law

Hello everybody; last class we studied sources, discussed about the various types of sources and we discussed that there were two major categories of sources which is the voltage sources and the current sources and within this you had two different subdivisions: the DC sources and the AC sources and the last class we looked at few of the sources; one being the battery, and then we discussed about the photovoltaic cell as a source; apart from these there are so many other sources which we mentioned in the last class like a power supply. If you look at the laboratory power supplies which gives plus minus 12 volts, plus minus 15 volts in the lab in the laboratories of your Engineering colleges, they are all DC outputs but they get the energy from the 32 volts mains wall outlet.

So, apart from this laboratory sources you have few other sources like the wind generators which are becoming popular, you have the sources like the SMPS the switched mode power supplies which you would probably see within most of the gadgets; if you have opened personal computer inside the main source which powers up all the boards will be a switched mode power supply. However, today we will see one of the most important sources of all which you will be using most commonly and it is most ubiquitous and that is the wall outlet.

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The wall outlet is one of the most popular ubiquitous sources that you will be seeing probably in every home, every industry, every enclosure that you will you will find these wall outlets. The wall outlets will look something like this. You have an empty unplugged wall outlet on the other side, on this side you see a wall outlet being plugged by some load. These wall outlets……….. let us have a look at these wall outlets and how they behave.

You see that there are three holes or sockets in this wall outlet switch which you would find in most of the homes because in some of the homes older homes you will find two sockets two pins that is one here and one here but almost all of the today's wall outlets consists of the third pin also. One is called the live L which represents live, the other one is called the neutral N which is neutral and the third one the centre top one is called E and E is for Earth. This in general is how almost all of the sockets are wired: you have the live, you have the neutral and you have the earth. Between this live and neutral is where the load is connected. The earth here is connected to the chassis of your equipment. This is because earth is always at absolute zero potential. So, if it is connected to chassis of your equipment so even when you touch your chassis you will never get a shock. This is a useful safety pin and a safety connection which has to be made and today it is mandatory by regulation to have the earth pin connected to the chassis of your equipment.

Now, if you look at the live and the neutral; the voltages across this live and the neutral it will be a pure sinusoidal voltage waveshape.

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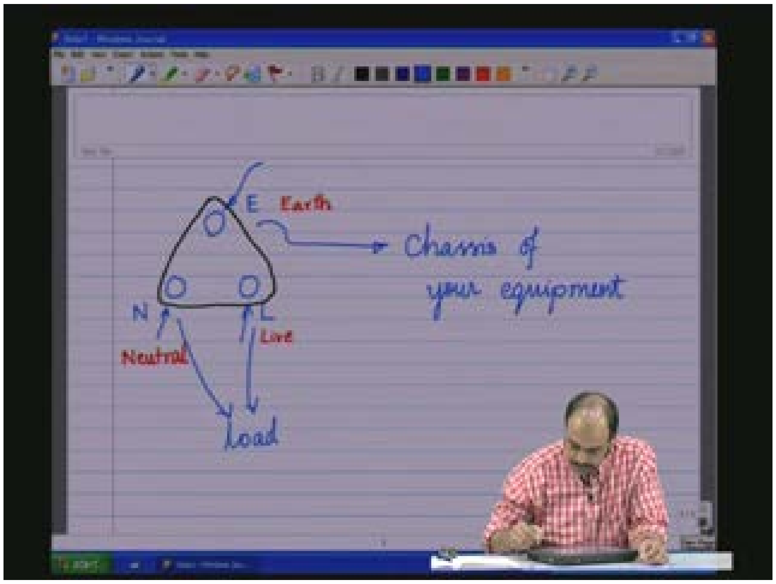

Let us see how it looks like. The voltage across the live L and the neutral pin N: the voltage across these two has a pure sinusoidal wave shape. Let me draw the X and Y axis; the X axis is the time axis, the Y axis is the voltage amplitude axis so we draw a sinusoidal wave shape. Hence, this is one period of the sinusoidal wave shape and this continues this continues.

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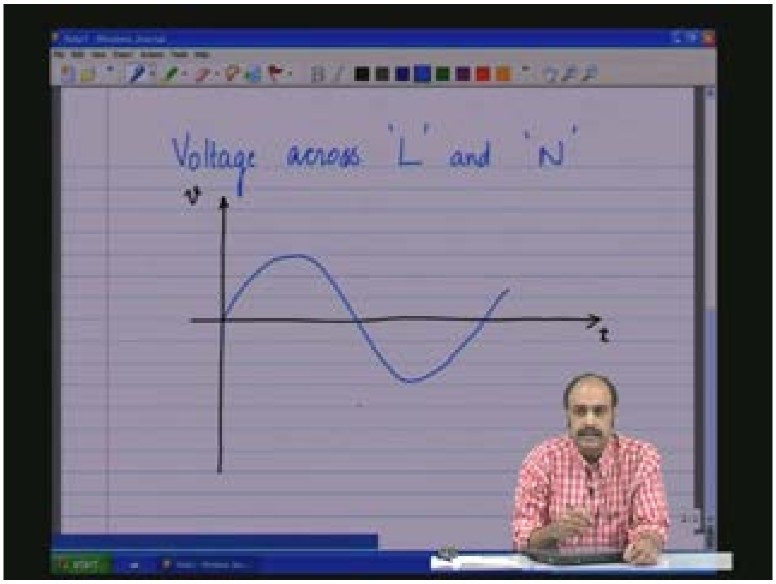

Now this has a character. So, for a country this is a more or less fixed and for most of the countries there are probably two sets of standards in terms of amplitudes and two sets of standards in terms of frequencies. Let us see what these standards are.

In terms of the amplitude this peak amplitude is 325 volts for our country this is 325 volts for our country this is the nominal value; of course there could be some fluctuations above this nominal value and the time period is fixed at 20 milliseconds. So this is the time period which is fixed at 20 milliseconds and this is the maximum voltage peak voltage which is set at 325 volts. This is the specification for the wall outlet voltage waveform in our country and for most of the European countries.

Therefore, in terms of frequency this will boil down to………….. frequency will be 1 by T 1 by period which is 1 by 20 milliseconds and this will turn out to be 50 hertz. So we have a frequency of 50 hertz.

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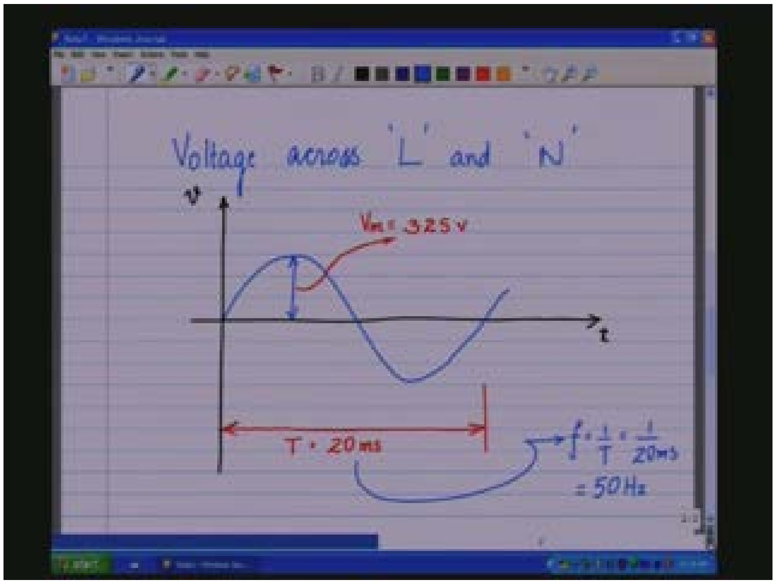

Thus, if you want to mathematically represent this wave shape we write it as: v equals V m sin (omega t) this is the equation or the representation of the sine wave and in our case this is 325 volts; omega is the radiant frequency so it is actually 2 into pi into f so it is basically 2 into pi into 50 hertz. So the two variations in the standard is the frequency is either 50 hertz or 60 hertz in different countries and the amplitude instead of being 325 it could be either 325 or 200 volts in the case of some of the other countries. But in our country it is 325 volts peak amplitude, 50 hertz is the frequency of the waveform.

So we can write it as 325 sin (2 pi 50t). So this is the equation or the mathematical representation of the voltage waveform that you will get from the wall outlet; all the wall outlets in India.

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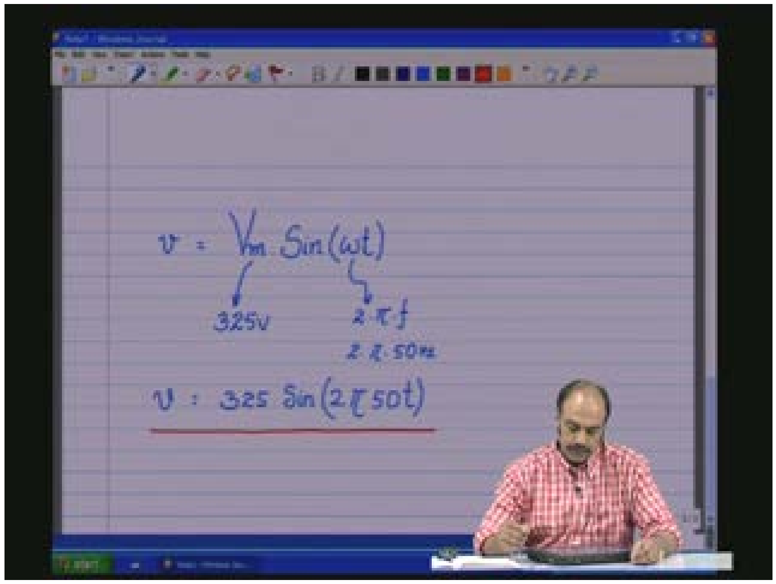

Now we saw that we saw that in the wall outlet that has this three pins type of configuration one was the earth pin and the other two pins the live and the neutral across it you get a voltage waveform and there is only one voltage waveform across that one and this is a single phase wall outlet (Refer Slide Time: 12:58). So wall outlets also can be categorised as a single phase power source or a three phase power source.

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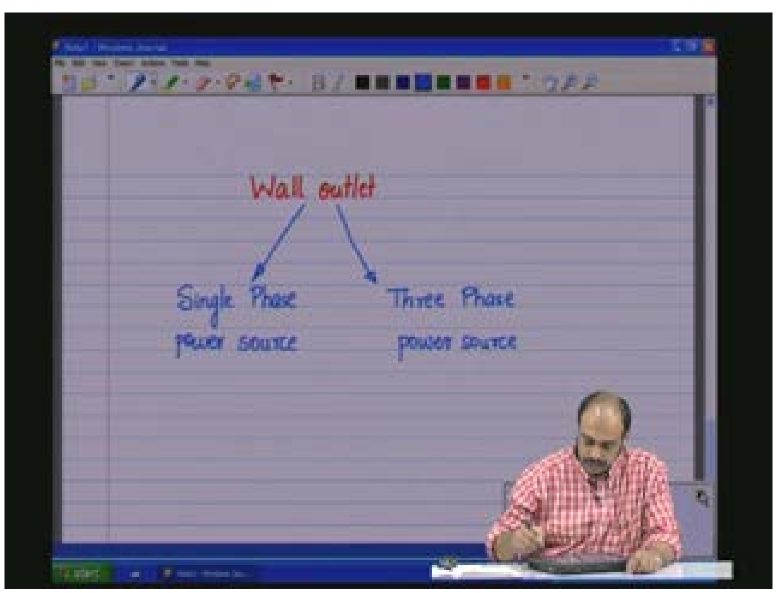

In the literature you see that the single phase power source is also written as; like this for shock (Refer Slide Time: 14:05) and the three phase power source is written like this: 3 followed by phi. The single phase power source has an rms value of 230 volts this is the rms value; this is generally the number that is used for the single phase wall outlet power sources so normally it is called as the 230 volt source. Therefore, when they say 230 volt source it is the voltage value that represents the rms which is the root mean square value the voltage source.

We will discuss about the rms values much later probably in a few classes from now. But for now just remember that the 230 represents root mean square value and not the peak value. Likewise, the three phase power source has an rms value of around 400 volts rms and it has a peak value of 560 volts peak, the single phase as we already saw 325 volts peak value. These are some of the key numbers that you have to remember in the case of these wall outlet sources; 230 volts, single phase is 230 volts rms, 325 volts peak; three phase is 400 volts rms 560 volts peak.

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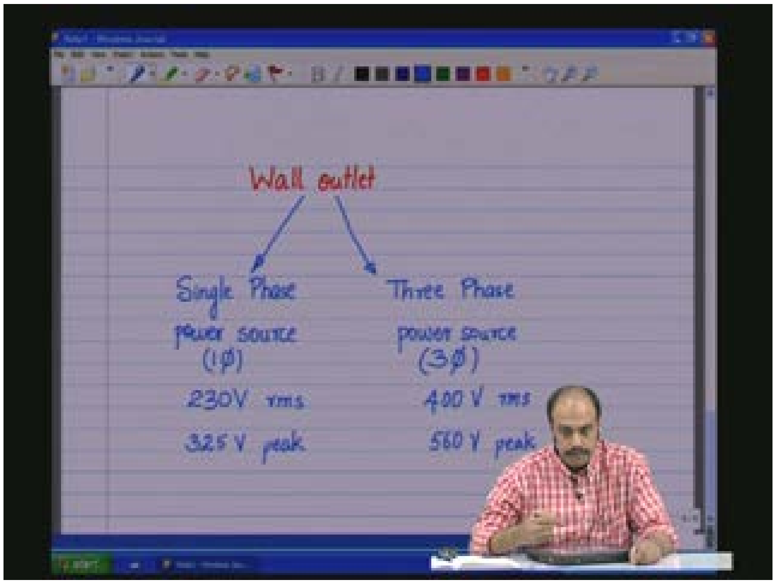

Now let us look at some of the symbols associated with these three phase sources. We saw that in the case of the single phase source there were two lines which will be coming into their home or the building: one is the live L, the other is N the neutral, there is a third which is going to be grounded or earthed near the building and that of course is the earth. In the case of three phase sources you have three lines this is called R, Y and the third one is called B. RYB are the three phases. You will also have one fourth line called the neutral and this may or may not be there in all the three phase sources depending upon the type of the connections which of course we will see later on, in a later class.

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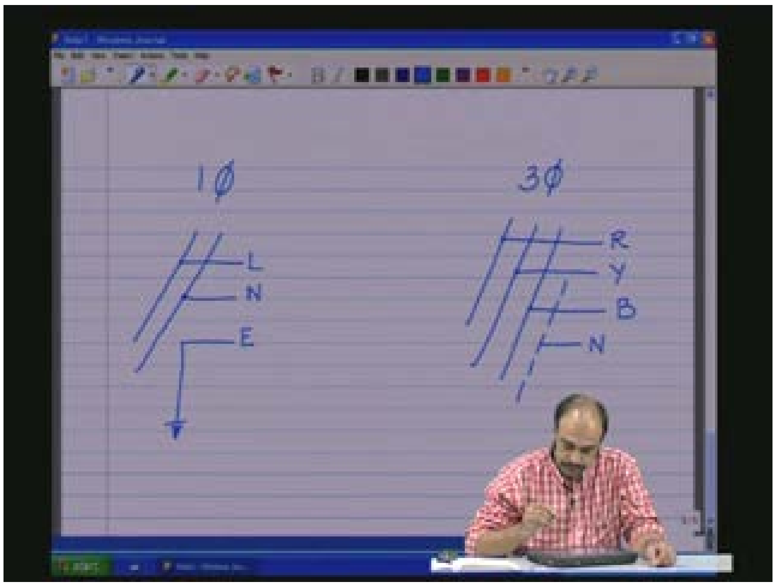

Now let us look at how a three phase voltage waveform will look like. That is also a sinusoidal voltage source; but how do they look like together, all the three phases put together.

In the previous slide here we saw that you have R Y B and the neutral. let us express the voltages in terms of the voltage with respect to neutral for each that is R with respect to N, Y with respect to N, B with respect to N which means let us try to see how V RN, V YN, V BN look like.

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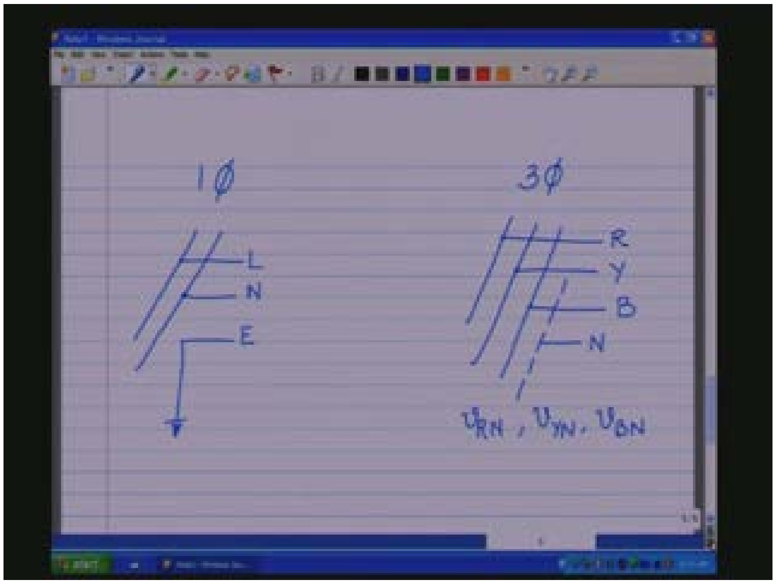

Now we look at the three phase voltage waveforms. Let me first draw the X and the Y axis like before because the Y axis………… and let me have the X axis; the X axis as usual the time axis; the Y axis is in this scale amplitude. Let us write this three waveforms in three different colours. So first R, I am choosing the red colour for the R you have and it is sine wave here, this is V RN, then for Y I will choose the yellow. But see that I am starting a bit away, I will explain to you why I am starting like that. This is V YN and then I am going to choose the blue for the other waveform that is the B waveform and that looks like this, this is V BN.

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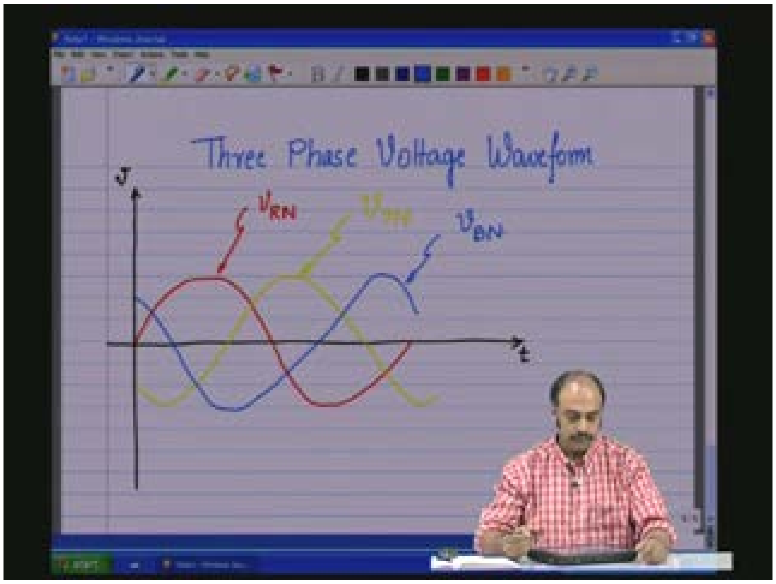

These are the three phase waveforms and frequency 50 hertz; each of the phases that is the V RN is 325 volts 50 hertz; V YN is 325 volts 50 hertz but………….. so if you look here the R phase waveform is starting from zero, the Y phase waveform is starting with let us say crossing zero 120 degrees away from the R phase waveform and the B phase waveform is starting or going positive cutting across zero at 240 degrees from the R phase waveform. So, except for the phase shifts the wave shape of each of the phase of the waveforms are sinusoidal and same frequency and amplitude.

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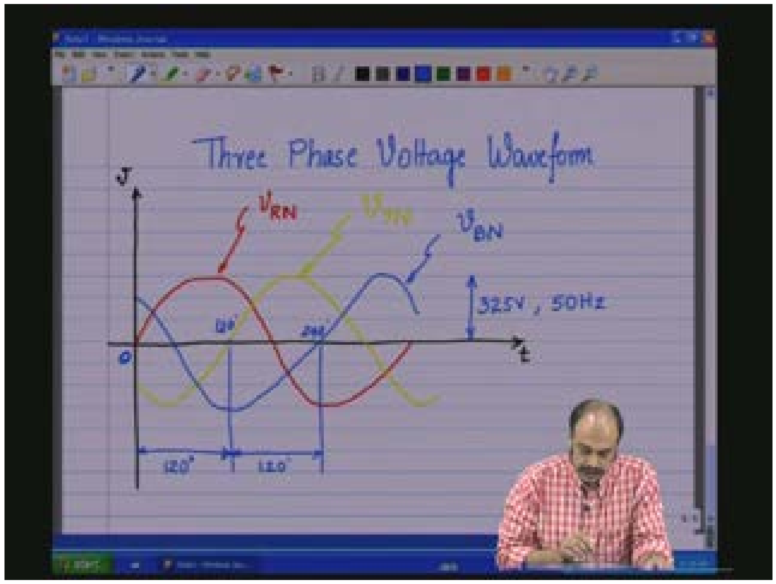

Let us mathematically write down the equations for these three phases. Equations for three phase waveforms: V RN equals 325 sin (2pi into 50t) this is nothing but 325 sin omega t; it is understood that omega represents 50 hertz in radiance the radian frequency.

Now V YN is 325 sin (omega t minus 120 degrees) that is it is lagging the R phase by 120 degrees, V BN is 325 peak sin (omega t minus 240 degrees) it is lagging the R phase by 240 degrees. So these three equations are the mathematical representations of the three phase phase voltage waveforms.

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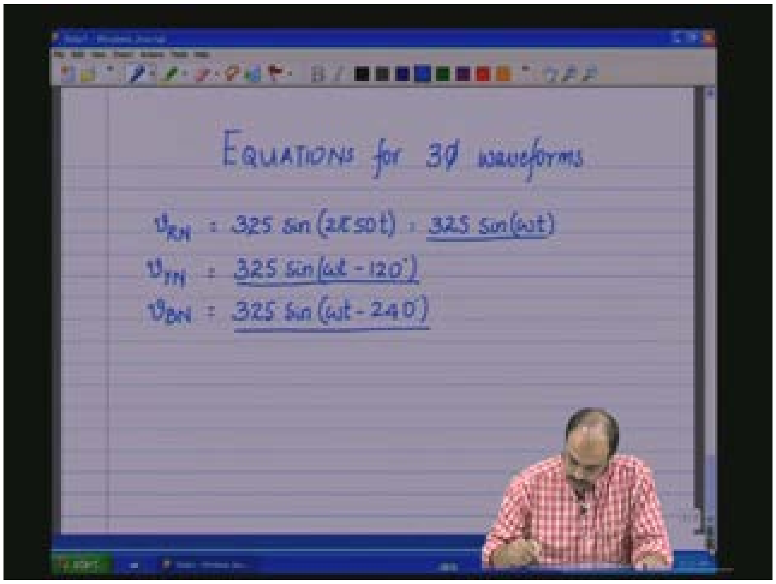

Here we have to understand one more small distinction: V RN V YN V BN all the voltages with respect to the neutral they are the phase voltages. V RY V YB V BR that is voltage with respect to each of the lines that is between R and Y line, between Y and B line, between B and R line these are called the line voltages. Now there is a relationship between the line voltage amplitude and the phase voltage amplitude. The line voltage amplitude line voltage amplitude is related to phase voltage amplitude amplitude by a factor by a factor either 1 or root 3, this depends upon the way the phases are connected. if the phases are connect…… if the phases are connected either as a star R Y B or they are connected as a delta R Y B.

If they are connected as star, line voltage we will call this one as V L and we will call the space voltages as V let us have P then line voltage V L will be root 3 times phase voltage in terms of the amplitude and if it is in the case of delta connection V L and V B have related by a factor of 1 because the phase voltage and the line voltages are same.

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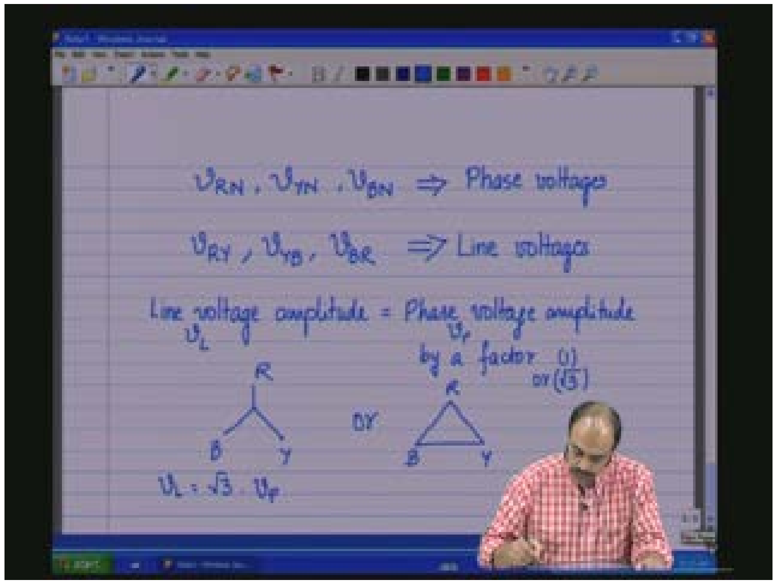

Now there is one more important thing though it may look trivial; you will be drawing this three phase waveform quite frequently where you are analysing your circuits; the three phase circuits or single phase circuits. We saw that it was a bit cumbersome to draw the three phase waveforms. So I will suggest, I recommend that we use a simpler easy method of drawing the three phase waveforms. This is how we draw the three phase waveform in a much more simpler way.

So what we do?
We first draw just these plain triangles like this (Refer Slide Time: 29:45) keep drawing these triangles, at least six of them. Once we have drawn these triangles you interconnect these triangles with these curved superstructure as I am showing and likewise in the bottom as shown here; you can extend this triangular line out like that and here also out like that.

Now this gives you a three phase waveform structure. Let us draw the axis; right through the centre will be the x axis which represents the time and you can let us say designate this waveform as the R phase and corresponding to that you can have the y axis and that is your zero.

So now you have the R phase waveform like this as shown (Refer Slide Time: 31:25), then you have the Y phase waveform and of course you have the B phase waveform.

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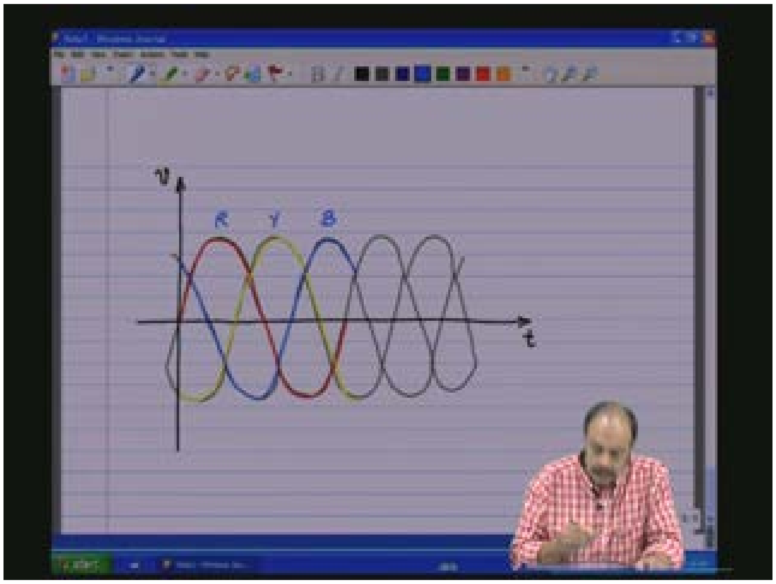

This is one of the simplest way to draw the three phase waveform structure and you will be using it quite frequently because in most of your three most of the future circuits like the motor circuits and the three phase rectifiers, converters so on and so forth you will need to do the analysis with the three phase waveforms and it is good to know how to write them in a fast quick way. With this we conclude the topic of sources.

There may there are many more sources. But I think they will now know what to look for in the sources. The ideal behaviour of the sources; what are the non-idealities like the source impedances and what happens when loading, what happens to the characteristics when you load the source these are the issues aspects that you have to look for in the source.

Now we shall take up the next topic and that is one of the most important topics in the analysis of your circuits and that is Kirchoff's laws Kirchoff's laws. Kirchoff's laws are something that you will be widely using in analysis of any electronic circuit and they operate on the principle of conservation of energy. Before coming to the Kirchoff's laws let us discuss some character of the electronic circuits.

Electronic circuits is made up of junctions and there are two types of junctions only two type of junctions in all electronic circuits and they are the voltage junction and the current junction. The voltage junctions are also called LOOPs, the current junction are also called NODEs. These are the only two types of junctions that are existing and you can make any type of electronic circuit with these two types of junctions and analyse any electronic circuits with the help of these types of categories of junctions.

Why do we call these as voltage junctions and current junctions?
of course as the name implies a voltage junction is a meeting point of all voltages, while in the loops all the voltages meet together in the loop and that is why it is called a voltage junction and at the nodes all the currents meet at the node and therefore it is called the current junction in the electronic circuits.

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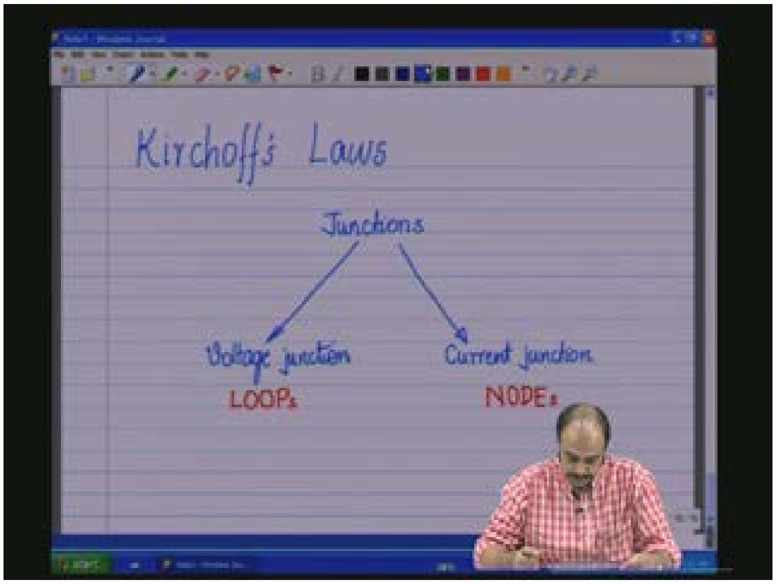

Now let me give a simple example of the loop and the node. A loop may be something like this means simple, say in its very simple form. Let us say I have a circuit with a resistance and an inductance let us say a capacitance. This is a loop.

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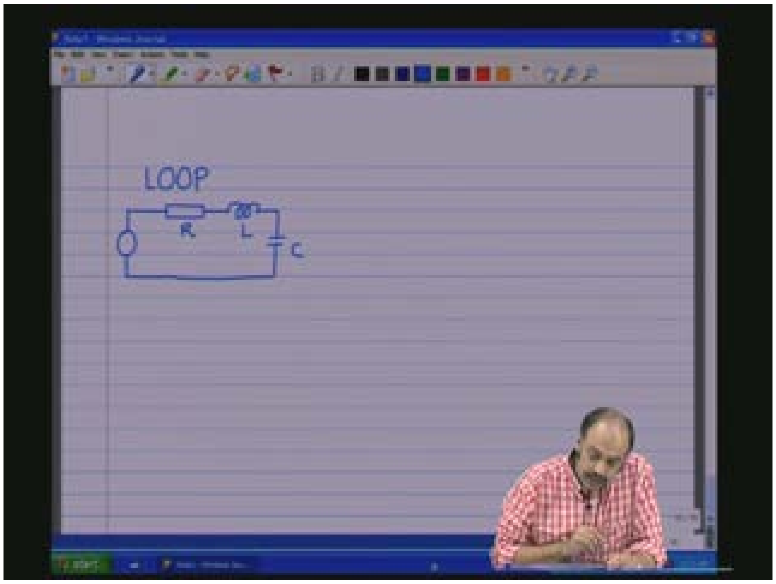

Now each of these divisors here they have let us say a voltage across that, there is a voltage across this component, there is a voltage across this component, there is a voltage across this component; now all these components meet at this junction and this loop this loop is called the voltage junction.

Likewise, if you look at a node in electronic circuits you may have some sources providing current to the node; there may be some passive elements connected to the node, I could have a resistance here, a capacitance like this so it could be an L R C and some current i which flows so there could be a current flow here, a current flow like that, a current flow in that direction. So this node here this node here is the meeting point of all these currents therefore it is called a node or a current junction current junction.

One thing that you should notice in this is that in the case of a loop where all the voltages meet there is one parameter which is common throughout and that is a current. So all components in the loop share the same current that is one important character of the loop, and in the node all the branches share the same voltage in the case of the load node, that is one of the important character in the case of the current junctions.

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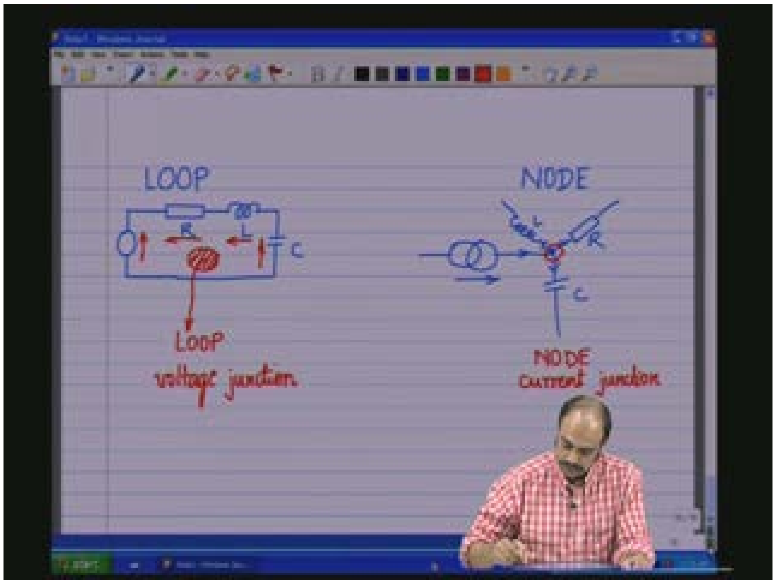

And it should be noted most important that both the voltage junction or the loop and the current junction or the node are energy conserving energy conserving junctions. Both these being energy conserving they obey all the natural laws.

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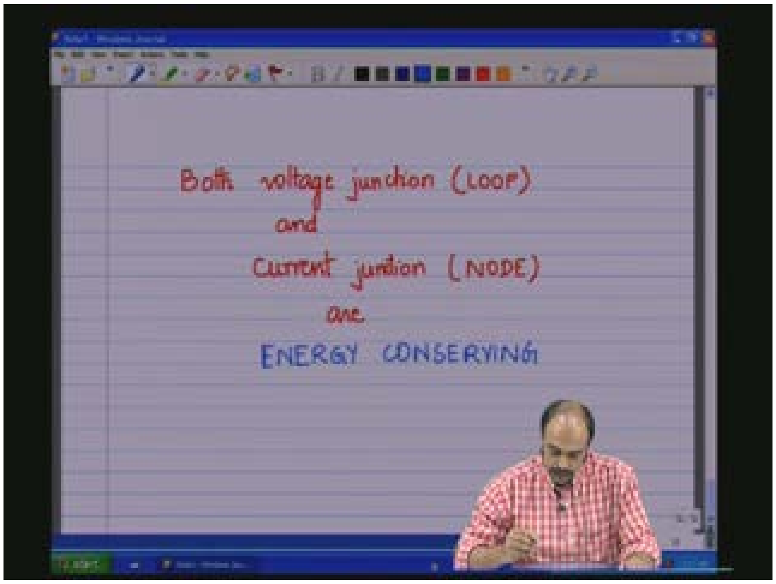

So let us now consider the loop now consider the loop which means I will write the circuit like that a simple loop which contains components, it could be any number of components but let us just put few components here RLC circuit. Now each of these components will have a voltage across that, there will be a voltage across this, now there is a voltage across this and a voltage across this and also to be noted that they all share the same current they all share the same current. So the current that they share is the same and only the voltages are different but the voltage has a meeting in this loop here (Refer Slide Time: 41:55). So let us say this voltage is e 1, this is e 2, this is e 3, this is e 4. What I mean is e 1 is the voltage across this component, e 2 is the voltage across this component, e 3 is the voltage across the next component and so on.

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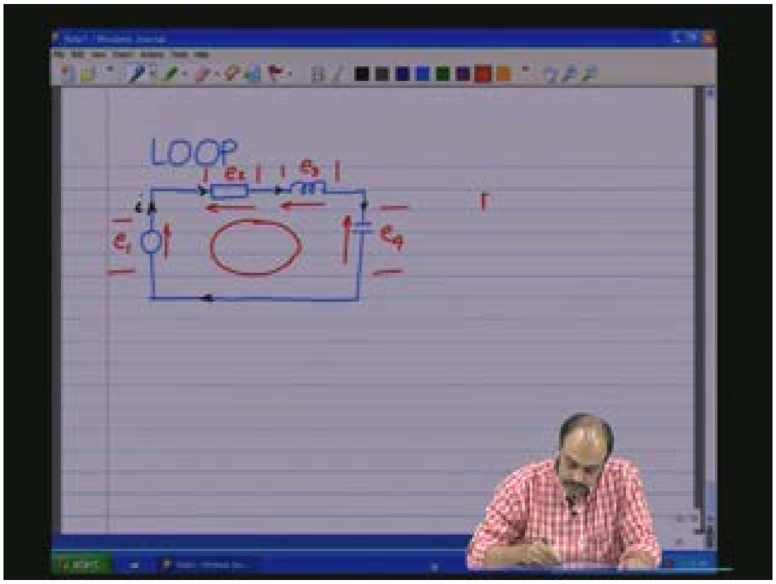

So, for energy to be conserved to be conserved all power that is generated by this will have to be given to the components that are within the loop. So within this loop if you look at energy has to be conserved which means if I have if I have e 1 into i which is the power that is even at any given instant it should be equal to e 2 into i plus e 3 into i plus e 4 into i. Now these i’s being common we can just cut it off to do the algebraic manipulation and we land up with e 1 minus e 2 minus e 3 minus e 4 equals 0 and it could be any number of components really does not matter but what is important is sigma all e's sigma e i iek all K will be equal to 0 which means that the algebraic sum of all the voltages across every component in a loop will always add up to zero; this statement is the Kirchoff's law.

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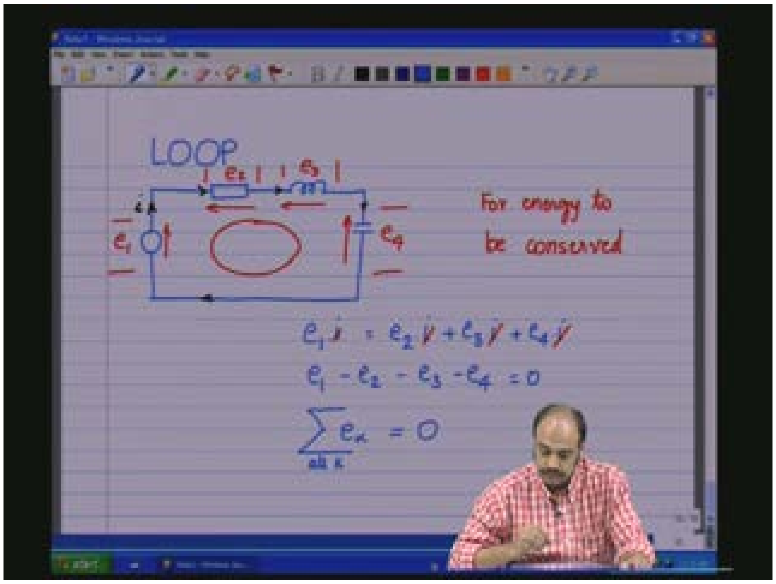

So what it basically…………………… the voltage law what it basically states is: Kirchoff's voltage law: The algebraic sum of all voltages in a loop or voltage junction is zero at every instant of time. This law is called the Kirchoff's voltage law or in short the KVL KVL or the Kirchoff's voltage law. Likewise, if you now consider the node a node which can have few branches connected to it you could have resistance like that, you could have capacitance all connected to it, here there is a current flowing here and each branch will have current flowing depending upon its impedances so this could be let us say i 1 i 2 i 3 i 4 so one thing you should know is that this node voltage is e and this node voltage e is shared by all to the same node voltage.

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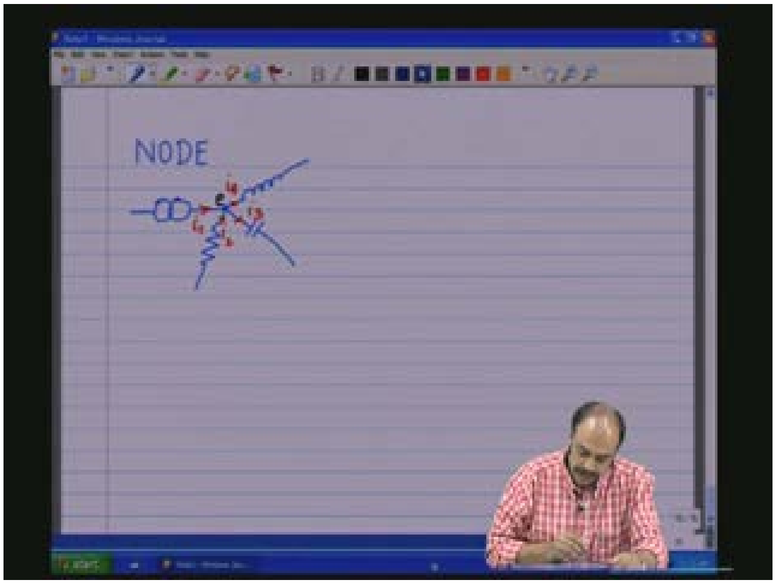

Again if we apply the energy conservation principles you will see that there should be no accumulation of charge at the node; e into i 1 equals e into i 2 plus e into i 3 plus e into i 4 e being the same as they all share the same potential same voltages, we have i 1 minus i 2 minus i 3 minus i 4 equal to 0. Or in other words, sigma K all K i is equal to i K is equal to 0. This means that summation of all the algebraic summation of all the currents at the node is always equal to zero only then there is no accumulation of charge at the node and we know that there is no accumulation of charge in the node due to conservation of energy principles.

Therefore, if you state this particular thing this particular law we find that the algebraic sum of all currents at a node or current junction is zero always zero and this statement is called the Kirchoff's Current Law or simply KCL. So KVL and KCL Kirchoff's Voltage Law and Kirchoff's Current Law are two of the most important laws that you will be using in almost all circuit analysis and we will of course see how we try to use these two laws in the analysis of electric circuits.

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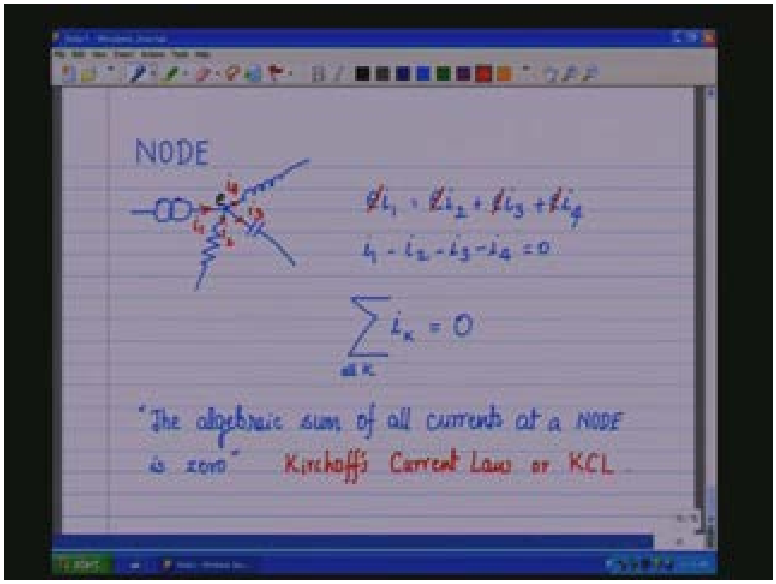

Before that some examples of these junctions. Examples: here you have a simple R and a C. now this is a loop. Now to this I am going to add few more components like this let us say circuit is becoming more and more complex, there is another loop here and there is something else here, there is a node (Refer Slide Time: 50:28). So you see that electrical circuits are composed of loops and node; loop node, loop node they keep alternating like this. Now using this loop and node concepts that is the energy saving concept that is the KVL and KCL how do we go about analysing a circuit and how do we go about getting the mathematical representation of the circuits. This is the main topic of discussion in the following class obtaining the state space equations or the linear differential equations for any given circuit.

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