Basic Electric Circuits

Module -01

Basic Circuit Elements and Waveforms

Lecture-01

Basic Concepts

By

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Hello and welcome to the course on basic electrical circuits. My name is Ankush Sharma. I am working with department of electrical engineering at IIT Kanpur. In addition to the academic experience, I also have experience in IT industry for around 18 years.

So, today we will discuss about some core concept of the basic electrical circuit. I will try to teach why this particular subject is required. So before going into the detail first question you may be asking that why do you want to study this particular subject.

Although electricity and magnetism were known to mankind since ages, the technical aspect or we can say the conceptual scheme of electricity and magnetism was not developed until 19^{th} century. So, when scientists like Volta and Galvani developed the concept of getting electricity generated from chemical processes; the fundamentals of electricity came into the picture. Other scientists like Henry gave the concept of induction and then around 1873 Maxwell's equation, which was the compilation of all the previous works related to electricity and magnetism, was published.

Now, if you see the electricity and magnetism equations of Maxwell they are mostly talking about the electric field. And if you check the commercial interest, they are more into voltage and current. So, that is why we are interested in basic electrical circuits. Here we are more interested about analysing voltage and current than the electric field. So, in this particular course we will try to understand the basic circuits and try to analyse what is electricity and its magnetism and its relationship with voltage and current.

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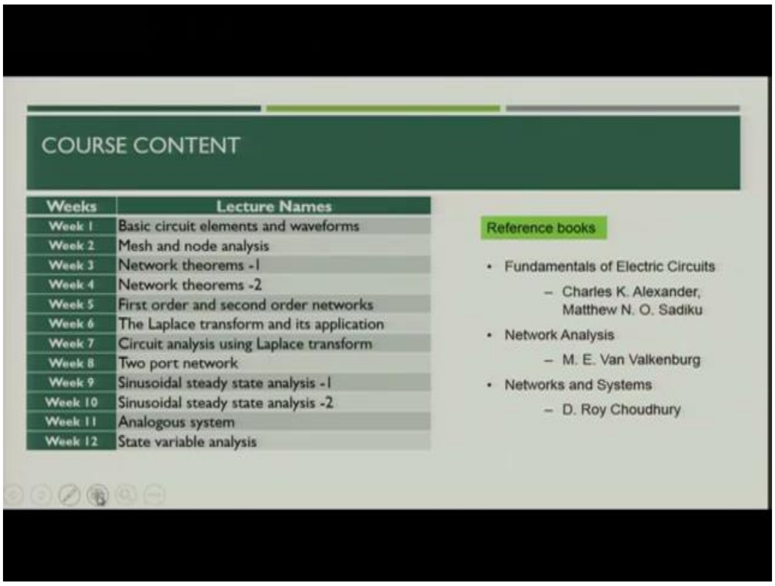

So, we will go through the course content. First week, we will discuss the basic circuit elements and waveforms and in week 2 we will discuss mesh and node analysis. Since, we know network theorems are very important we will devote the next 2 weeks for network theorems. First order and second order networks will be discussed after that. Laplace transform and its application will be discussed in the 6^{th} week. In the 7^{th} week we will discuss circuit analysis using Laplace transform.

In week 8 we will talk about 2 port networks and since sinusoidal analysis is also one important element in electric circuits we will devote at least 2 weeks for sinusoidal steady state analysis. Then, we will see the relationship between electricity and other type of systems. Here, we will establish the analogy between the electricity and other analogous systems and finally talk about the state variable analysis. The reference books which you can follow are Fundamentals of Electric Circuits by Charles Alexander and Matthew Sadiku. You can also follow Network Analysis by Van Valkenburg and Network and Systems by D. Roy Choudhury.

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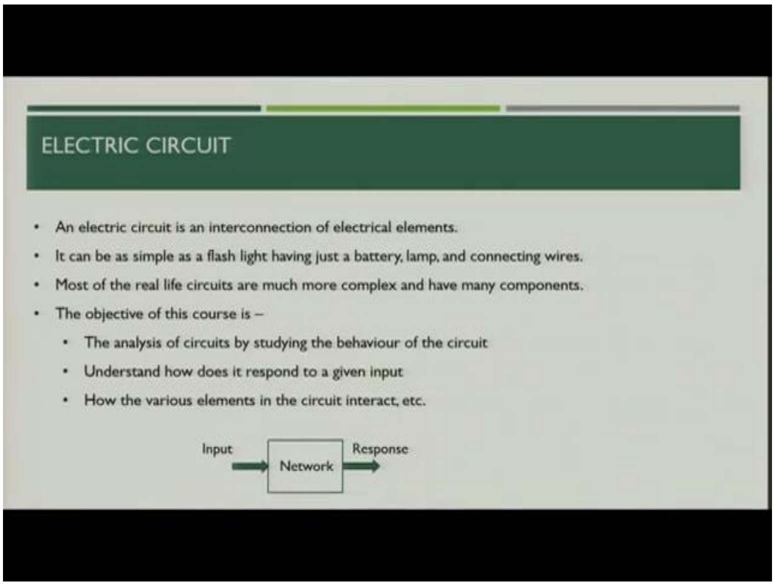

Now, in this session we will talk more about the basic concepts of electric circuits. So, what are those concepts? Let us first talk about the electric circuit itself. So electric circuit is nothing but interconnection of electrical elements. You can think of a flash light where you have only one voltage source, the lamp, and the wires. So, it is a simple electrical circuit.

But in reality, you will not see such simple circuits, rather you will see lot of complex circuits having multiple components. So, in this course, we will try to analyse the circuit by studying the behaviour of the circuit. Why do we need to study the behaviour? This is because we need to understand how the circuit it responds to a given input. You can see that when you give input to a particular network, it will respond based on the input which you have provided. So, we have to somehow to establish the relationship between input and response and then we will see how the various elements in the circuit will interact.

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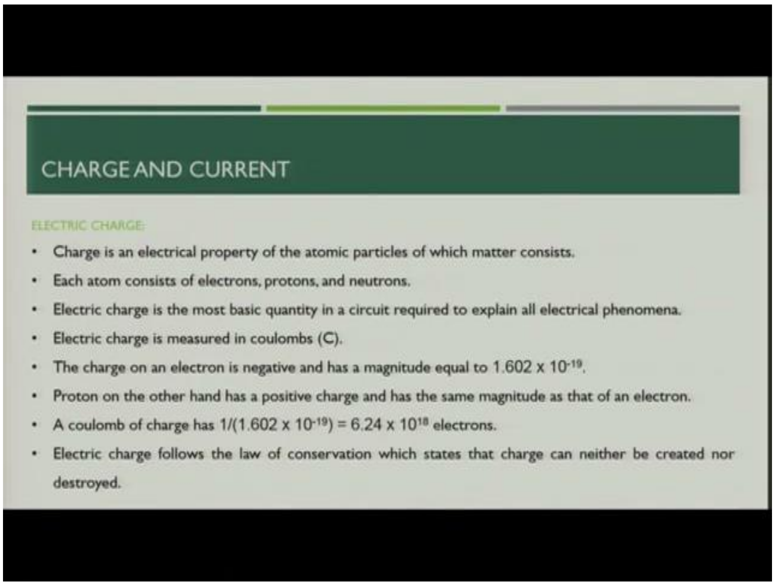

Now, let us talk about the charge. What is charge? Charge is an electrical property of atomic particle of which matter is made of. So, if you see anything around you, you will see it is composed of molecules and then molecules are composed of atoms. Inside the atom you will have electrons, protons, and neutrons. So, basically each atom will consist of 3 major elements that are electrons, protons, and neutrons.

Electric charge is the most basic quantity of circuit required to explain all electrical phenomena. You know that the electron is negatively charged particle while proton is positively charged particle. Each electron will have a charge equal to $-1.602 * 10^{-19}$ coulomb because electric charge is measured using coulombs. Now, proton on the other hand is positively charged and it will have the same magnitude as of electron but with a positive sign, i.e., $1.602 * 10^{-19}$.

Now, if you are asked to find out how many electrons would be there in 1 coulomb of charge; you will simply divide 1 by $1.602 * 10^{-19}$. You will get the number of electrons which would be there in 1 coulomb of charge as $6.24 * 10^{18}$ electrons. Now, the electric charge follows the law of conservation which states that charge can neither be created nor can be destroyed.

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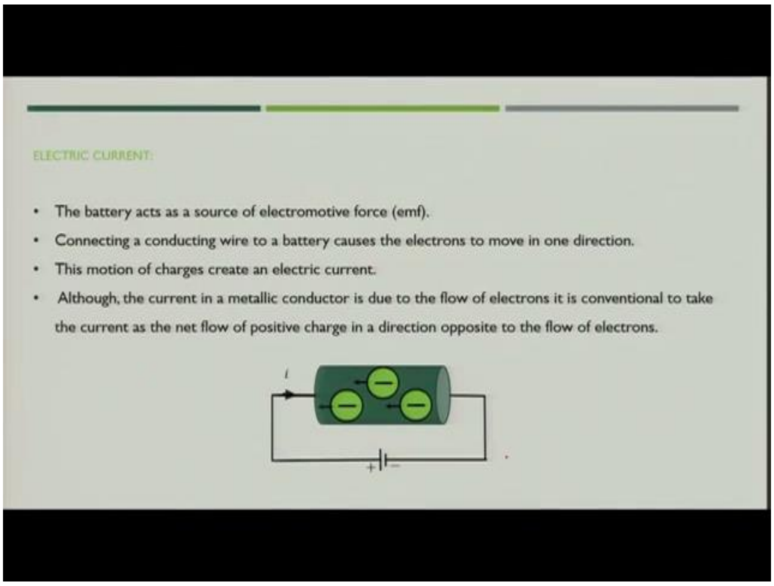

Now, let us talk about electric current as electric current is derived from the charge which is flowing in a particular element. In this figure, the battery will act as a source of electromotive force (emf). Now, when you connect a conducting wire to a battery it will cause electron to move in a particular direction. This motion of charge creates the phenomena called electric current. Although current in a metallic conductor is due to flow of electrons, conventionally it is taken as the net flow of positive charge. So, if you see the figure you will see that the flow of current is opposite to the direction of flow of electrons. This is the convention we follow when we define electric current.

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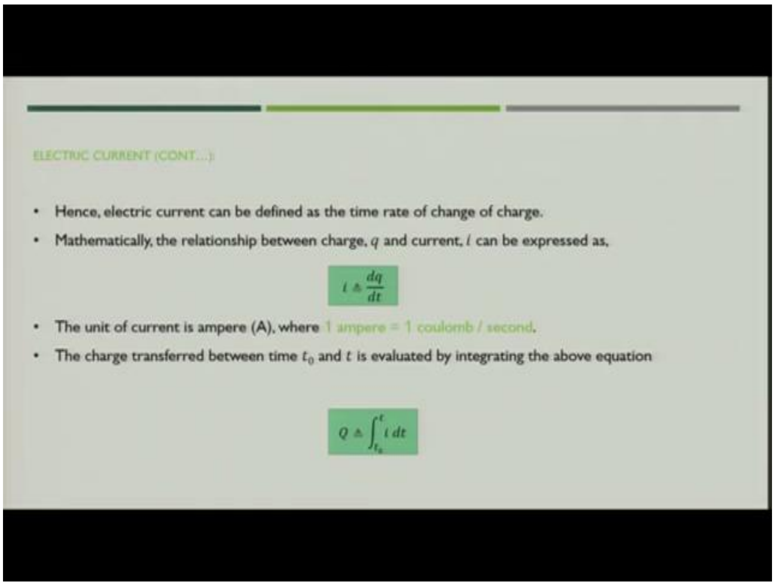

Now, since electric current can be defined as the time rate change of charge, you can simply define $I = dq/dt$. It is defined as the amount of charge flowing across a particular surface in a unit time. Current is expressed using amperes and 1 ampere is defined as 1 coulomb per second. Now, if you are asked to find how much charge is transferred between time t_0 to t in a particular surface, you can simply evaluate by integrating the above equation for current. So, you will get Q as

$$Q \triangleq \int_{t0}^{t} i\,dt$$

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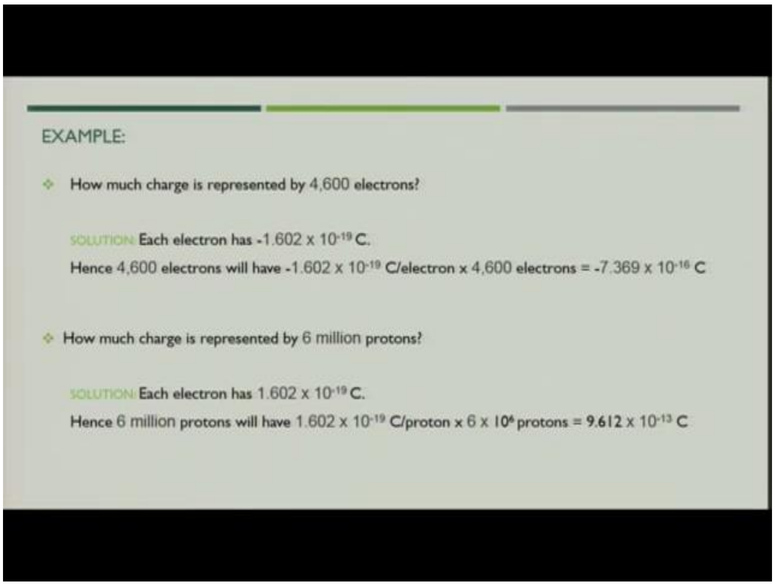

Now, let us take few examples so that you can better understand the concept. Let us take one example, how much charge is represented by 4600 electrons? Now, since you know that the charge of 1 electron is $-1.602 * 10^{-19}$. So, for 4600 electrons the total charge would be simply multiply 4600 by $-1.602 * 10^{-19}$. So, you will get minus $-7.639 * 10^{-16}$ coulomb.

Now, opposite to that, if you are asked to find out how much charge is being represented by 6 million protons then you have to be careful, since the proton will have charge $+1.602 * 10^{-19}$. Now, for 6 million protons multiply $1.602 * 10^{-19}$ that is the coulomb charge per proton multiplied by $6 * 10^{6}$. So, you will get $9.612 * 10^{-13}$ coulomb.

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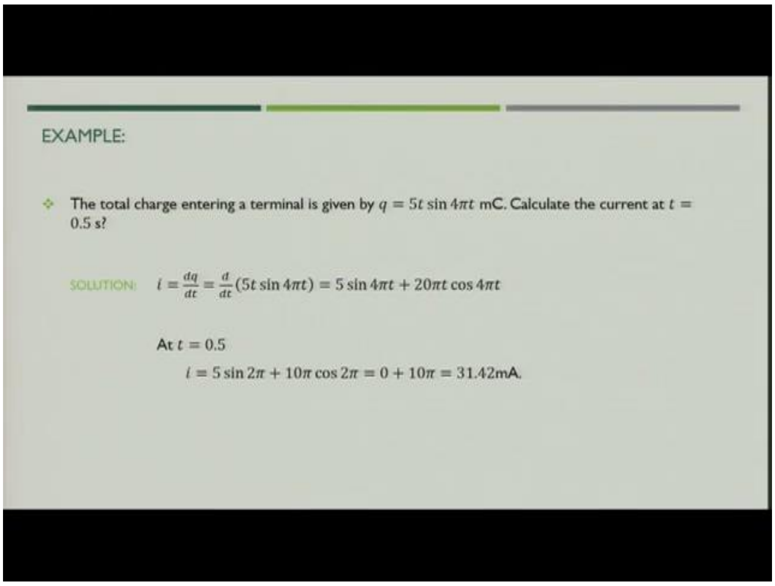

Now, let us take another example, if the total charge entering a terminal is given by some expression like $q = 5t \sin 4\pi t$ mC. How will you calculate the current? Since, you know that the current $i = \frac{dq}{dt}$, you have to simply differentiate q with respect to time t. So, you will get $\frac{d}{dt}(5t \sin 4\pi t)$. So, that is simply $5 \sin 4\pi t + 20\pi t \cos 4\pi t$ that is the derivative of coulomb charge which was given in the question.

Now, we have to calculate current at time $t = 0.5$ second. This means whatever current value you have got you have replace t with 0.5 and solve the expressions. So, here you will get current $i = 31.42 mA$.

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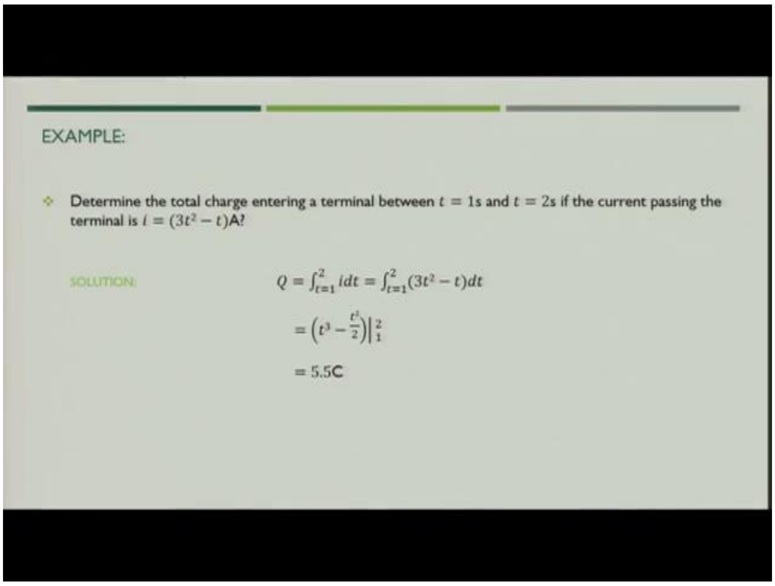

Now, instead of charge if current is given that is say in this example we are saying that $i = (3t^2 - t)$A. Now we have to find out the total charge entering in an electrical terminal between time t=1 second to t=2 second.

To calculate you need to integrate the current value between time $t = 1$s and $t = 2$s. So, if you solve by putting the value of I is nothing but $(3t2 - t)dt$ and solve you will get the amount of charge entering in a terminal between time 1 second to 2 second and that is 5.5 coulomb in this particular case.

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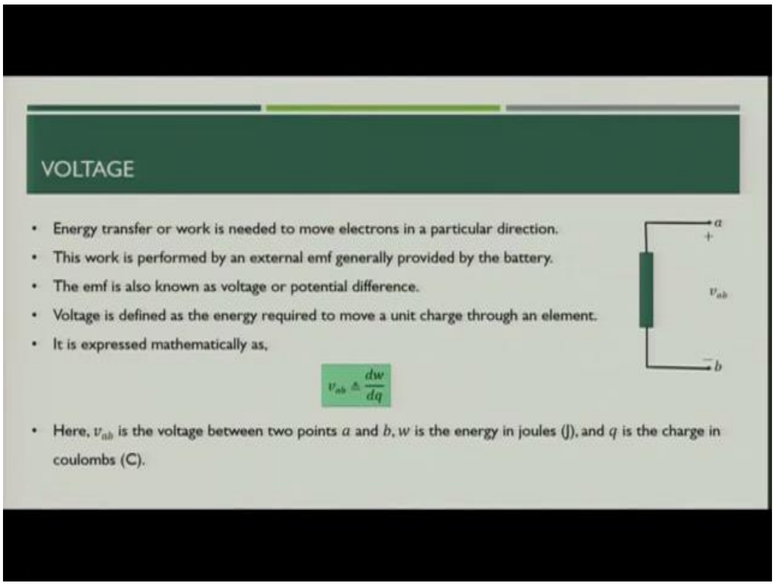

Now, let us talk about voltage. Energy transfer or work is needed to move electrons in a particular direction. So, who will provide this energy? This energy is supplied by the external emf that is provided by the battery. So, battery will work on the electrons to move it from one side to the other side. This emf is also known as voltage or potential difference. Now, how will you define the voltage? Voltage will be defined as the energy required to move unit charge through an element. If you see this figure, the element represented here has two terminals, one is positive and the other is negative.

One terminal is identified as a and the other as b. So, potential difference that is voltage is given as v_{ab}. Now, you need to find out the value of v_{ab}. What you will do? You will try to find out the work done by battery, which is connected externally to this element, to move 1-unit charge from point a to point b. So how you will express it in mathematical terms. You will simply say v_{ab} is nothing but dw/dq, that is. work done divided by the unit charge or the differential charge, in this case. That is why we are representing it as dq. Now, v_{ab} is represented as volt, energy is represented using joules and q is the charge which we generally represent in coulombs.

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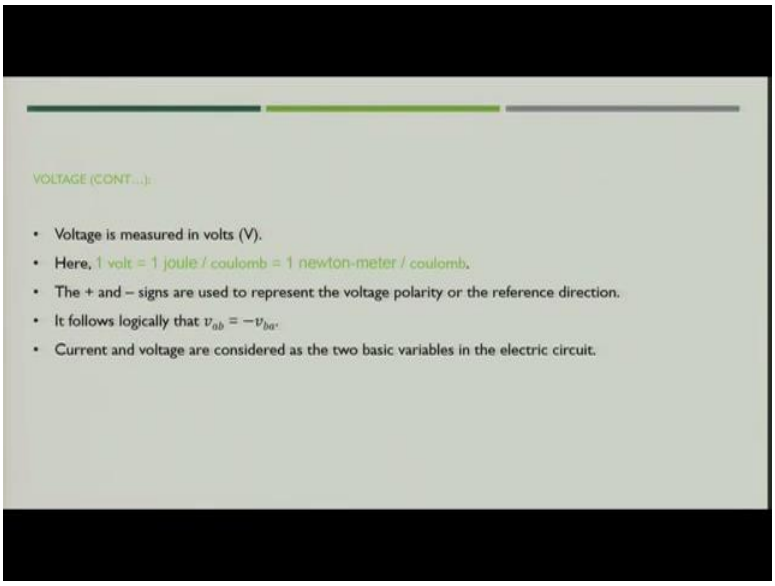

Now, how is 1 volt defined? 1 volt is nothing but 1 joule per coulomb, i.e, 1 newton metre per coulomb as 1 joule is nothing but 1 newton metre. Now, positive and negative sign has its own importance because when you change the sign you will simply get opposite of v_{ab}. So, if you replace, in the previous figure, plus with minus sign and minus with plus sign at the terminals v_{ab} will be opposite of what we have calculated in this particular case.

Now, if you do not want to represent in this form but you want to represent in the form of v_{ba}, that is opposite of v_{ab}, how will you represent? You can say v_{ab} is nothing but minus of v_{ba}. So, basically you are interchanging the terminals of the element and you eventually get the negative of what we have shown in the previous figure. So, in circuit theory, we generally represent the answers in the form of voltage and current until and unless it is specified, because these are the two basic elements in our electric circuit.

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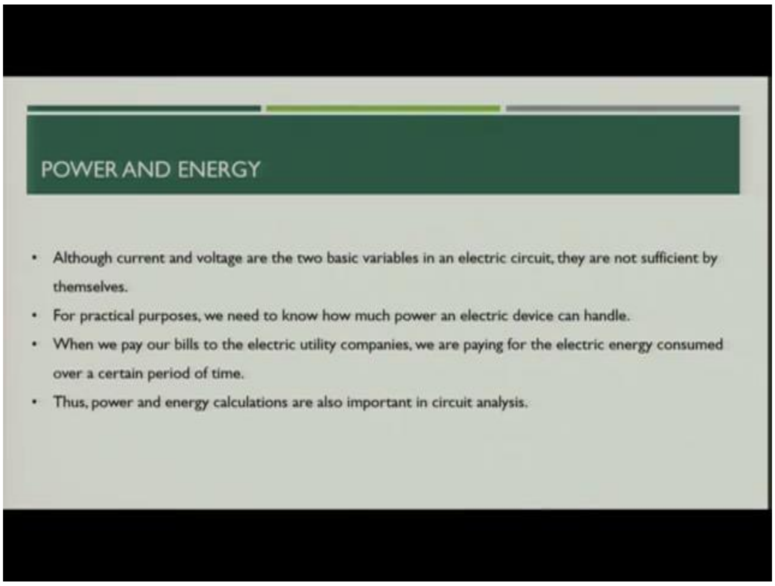

Now, it is not that we always go with voltage and current as an output; we sometimes need power and energy also as an output. So, for practical purpose we need to know how much power an electric device can handle because when you pay your electricity bill you pay electricity bill in the form of how many units you have consumed. 1 unit is equivalent to 1 kilowatt hour. 1 kilowatt means the power multiplied by the duration for which you consume the electricity.

So, it means that you need the power calculation sometimes to find out how much energy you have consumed at that particular instant. To obtain the energy you will multiply the power with the time duration of usage, to know how much energy you have consumed. So, that is why for our day to day electricity bill calculation you need calculation of power as well as energy. So, the power and energy are also important portion for our circuit analysis.

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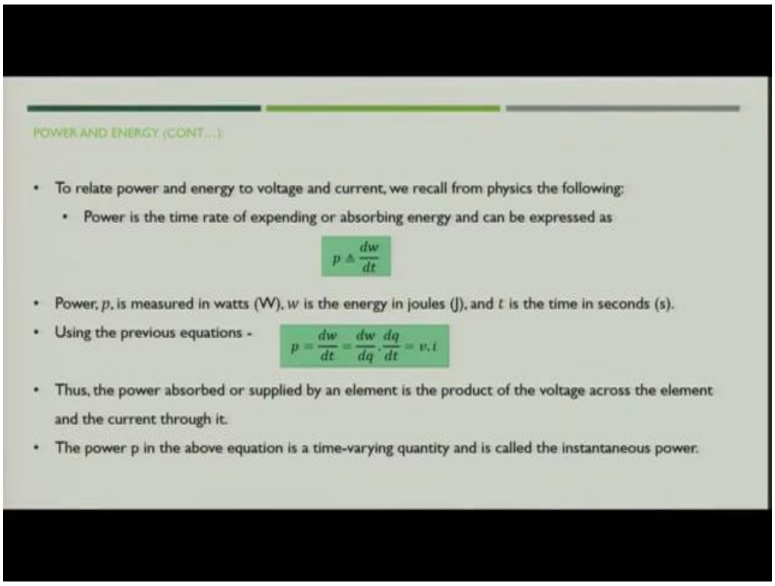

Now, let us try to find out how to calculate the power and energy because these are derived from voltage and current. So, how will we calculate? Power is nothing but time rate of expanding or absorbing the energy. So, in mathematical terms we can represent it like $p \triangleq \frac{dw}{dt}$, that is rate of change of energy. Power is measured in watts and the energy is measured in joules. Now, if you want to find out the value of power p in the form of the two basic quantities which we discussed previously, that is voltage and current, how will you find out the value of power p? You just see the equation $p \triangleq \frac{dw}{dt}$.

Now, if you express $\frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt}$ you will simply get the expression of power p in the form of voltage and current. How? $\frac{dw}{dq}$ is nothing but the voltage which we discussed in the previous slide and current is nothing but rate of change of charge passing through a particular element. So, with this you can simply calculate the value of p as a multiplication of voltage and current. So, by this you can find out how much power is being absorbed or supplied by an element because it is a product of voltage across the element and current passing through that particular element.

But you have to keep in mind this power p is a time varying quantity and is called instantaneous power. So, when we will discuss in detail the sinusoidal waveforms we will try to establish the relation between instantaneous power and average power because that is also the important concept which is more important for ac currents rather than dc currents because in dc currents you can simply say that power p is nothing but a product of voltage and current but in ac it does not, at least for average power it does not, follow like this.

Instantaneous power will be definitely a product of instantaneous voltage and instantaneous current.

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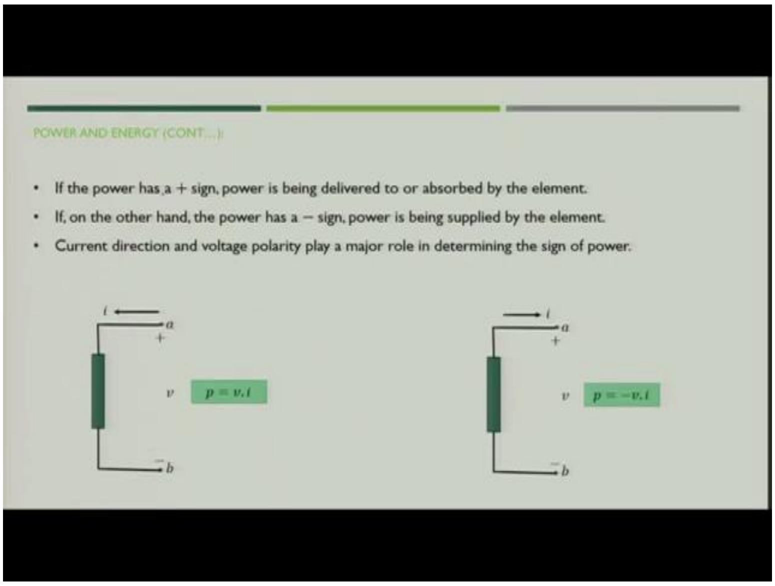

Now, the power has positive sign it means that power is being delivered to or absorbed by the element. So, now look at this particular figure. If the current is flowing inside the through the positive terminal you will say that power is being absorbed by that particular element. But, if the current is coming out of the positive element the power is being supplied by that element. That is why the negative sign is coming in this expression. So, the sign convention is very important to understand because if you make a mistake in representing the signs properly you will do some mistake in calculating the value of power.

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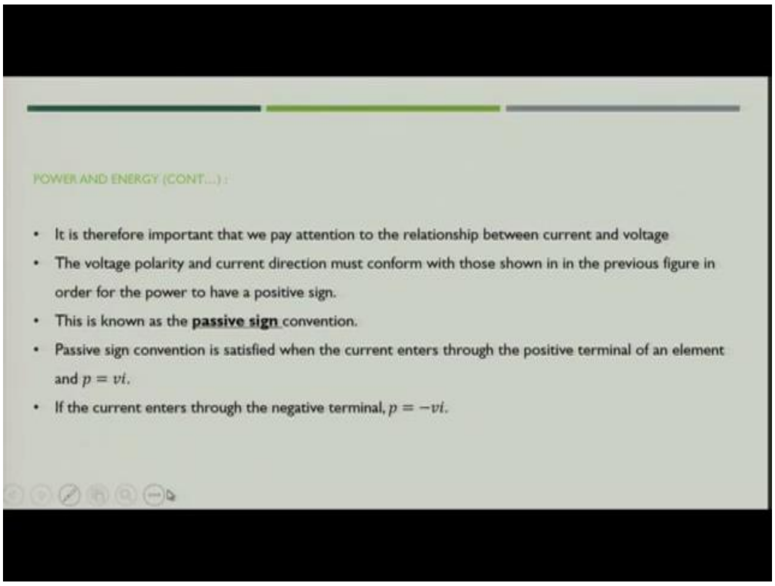

Now, the voltage polarity and current direction should confirm to those shown in the previous figure. So, what do we represent by these particular sign conventions? This sign convention is known as passive sign convention. It is satisfied when current enters through the positive terminal of element. The power consumption is positive. And when current enters through the negative terminal then power p is $-v.i$, that means power is being supplied by this element.

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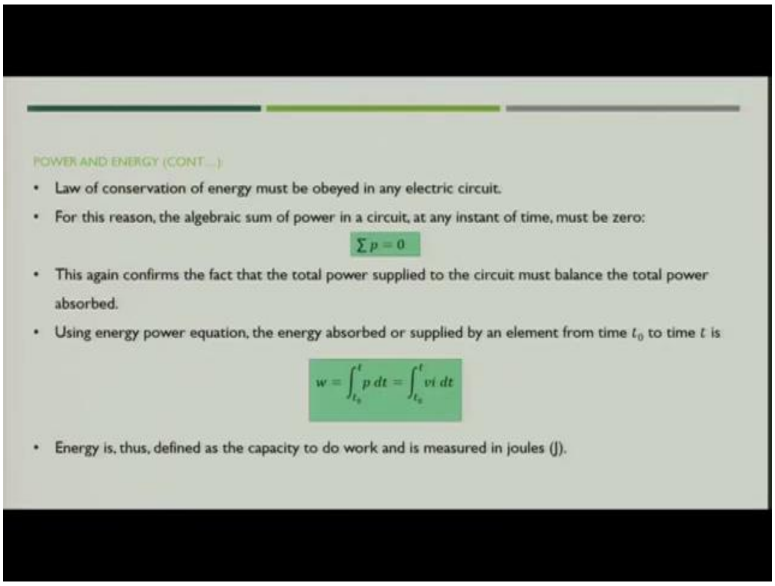

Now, this particular aspect will follow the law of conservation. It means one should supply the power other should consume the power. And for this reason, your algebraic sum of power in a circuit will always be 0. Now, suppose you are asked to find out the value of energy absorbed or supplied by some element from t_0 to time t, how will you calculate? You have to just simply integrate the power with respect to time between t_0 to time t and you will get the value of energy supplied or absorbed by the element based on the convention which we discussed in the previous slide. So, what is energy? Energy is nothing but the capacity to do some work and is measured in joules.

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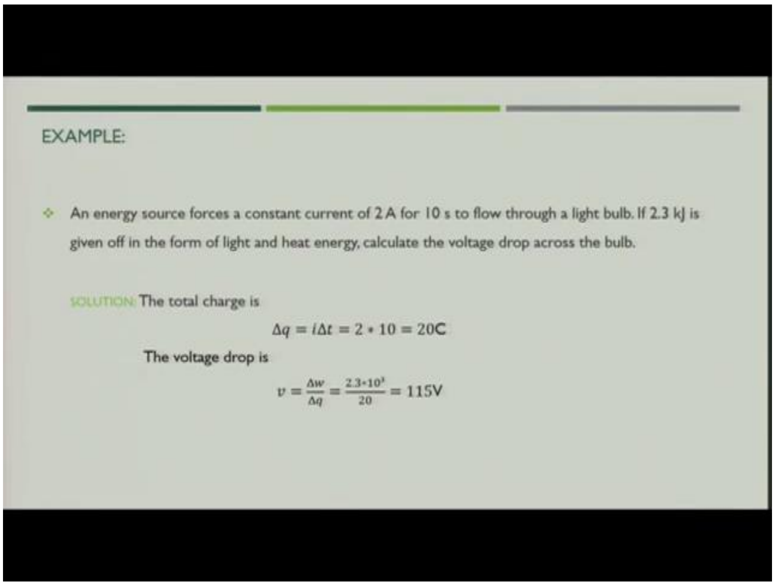

Now, let us take examples so that you can better understand the concept of power and energy. Suppose the question is given like this. An energy source forces a constant current of 2 ampere for 10 seconds to flow through a light bulb. If 2.3 kilo joule is given in the form of light and heat energy what is the voltage drop across the bulb. Now, what is given? You have got current i you have got time Δt and now you have also got the value of energy which has been consumed.

So, first what you have to do? You have to recollect what is the expression for voltage, that is nothing but change in energy with respect to charges flowing through that particular element. Now, this particular quantity is given in this question. You need to find out the value of Δq. Δq is nothing but product of current and time. Time is given as 10 seconds. Current which is flowing through the element is 2 amperes. It means that 20 coulombs of charge is being transferred from through the element. And now using this value you can simply calculate the value of voltage drop across the element. So, in this case the element is light bulb. So, voltage drop across the light bulb would come out to be 115 volt.

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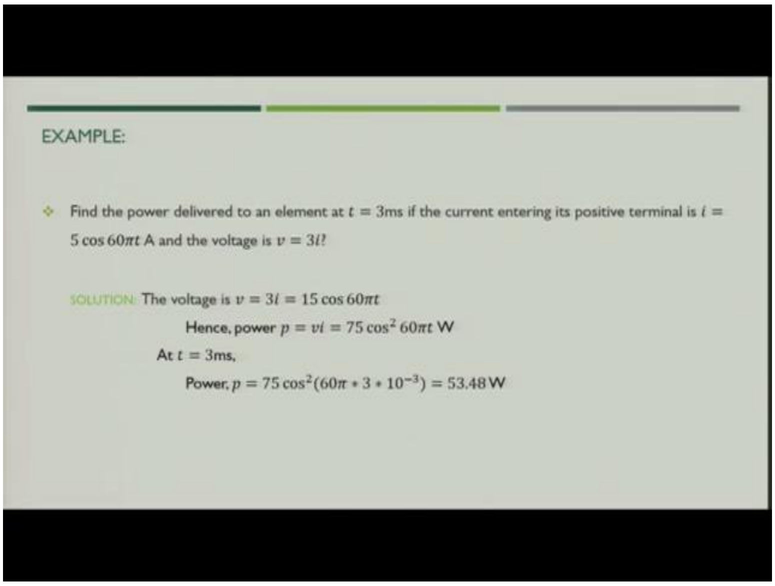

Now, let us take another example. If you are asked to find the power delivered to an element at time t is equal to 3 millisecond if the current entering its positive element is $5\cos 60\pi t$ A and voltage v is 3i. So, 3i means voltage is depending upon the current. So, what do you have to do?

You have to first find the expression for voltage. So, voltage is nothing but 3i that is 3 multiplied by the value of current i that come out to be $15\cos 60\pi t$. Now, you need to find out the value of power $p = vi$. So, that comes out to be $75\cos^2 60\pi t$. Now, you need to find out the power delivered to an element at time t is equal to 3 milliseconds. It means you have to simply replace t with the value of 3 milliseconds. And when you simplify you will get the power delivered to an element that is 53.48 watts.

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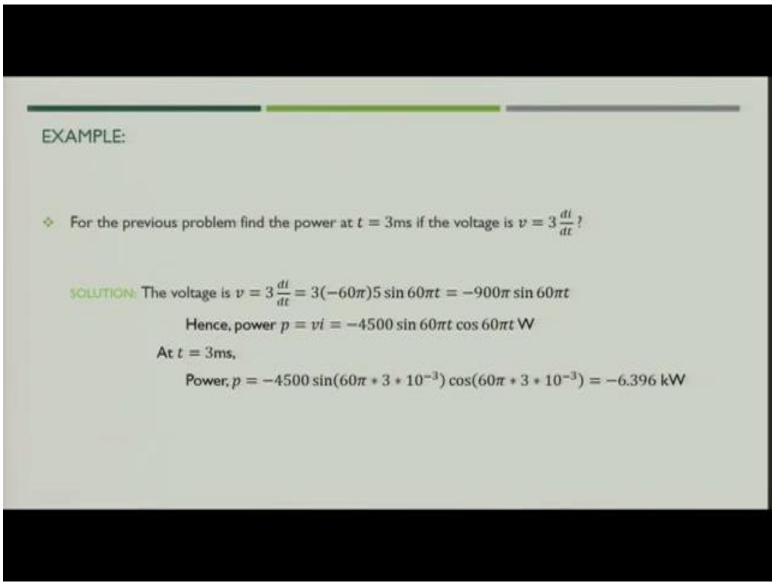

Now, if in the previous problem if voltage $v = 3\frac{di}{dt}$ instead of 3i and other things are same and time t is again equal to 3 milliseconds. How will you calculate? Now, voltage value you will have to find out by simply differentiating the value of current i. So, current i which we saw in the previous example was $5\cos 60\pi t$. So, if you differentiate you will get $(-60\pi)5\sin 60\pi t$ and with this you will get the value of voltage v as $-900\pi \sin 60\pi t$.

But, the power $p = vi$. You have to simply multiply voltage v with the current expression which we got in the previous example. We will get $p = vi = -4500 \sin 60\pi t \cos 60\pi t$ W. Now, for time is equal to 3 millisecond you simply have to replace t with 3 millisecond and simplify the expression you will get the value minus 6.396 kilowatt.

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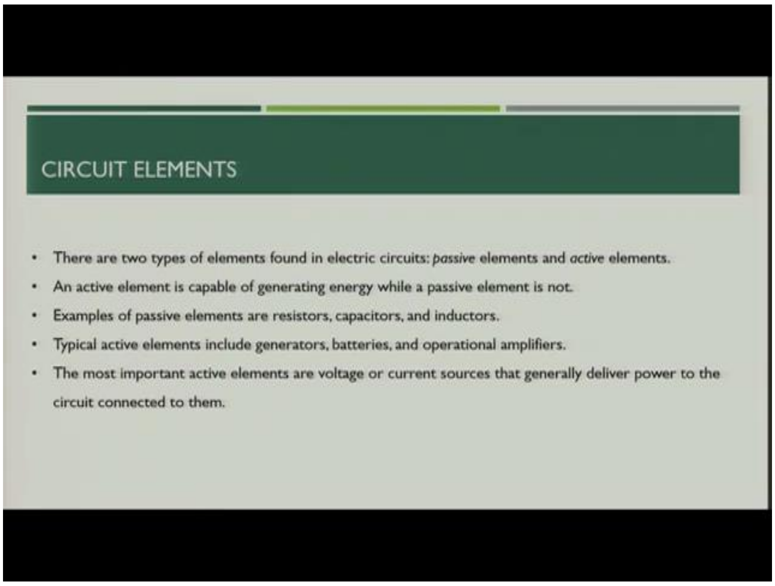

Now, let us try to understand, what are the various circuit elements in the electrical circuit you will see. So, basically there are two types of elements which you will see. One is passive element and the other one is active element. So, what is active element? The element which is capable of generating energy is called active element while the passive element does not generate the energy. So, what are those passive elements? These are resistors, capacitors and inductors and what are the active elements? Active elements are like generators, batteries, operational amplifiers. So, what are the most important active elements for our circuit analysis?

The most important are voltage and current sources because generally when you will solve any electrical circuit you will generally see that voltage and current are given as a source for the supply of power.

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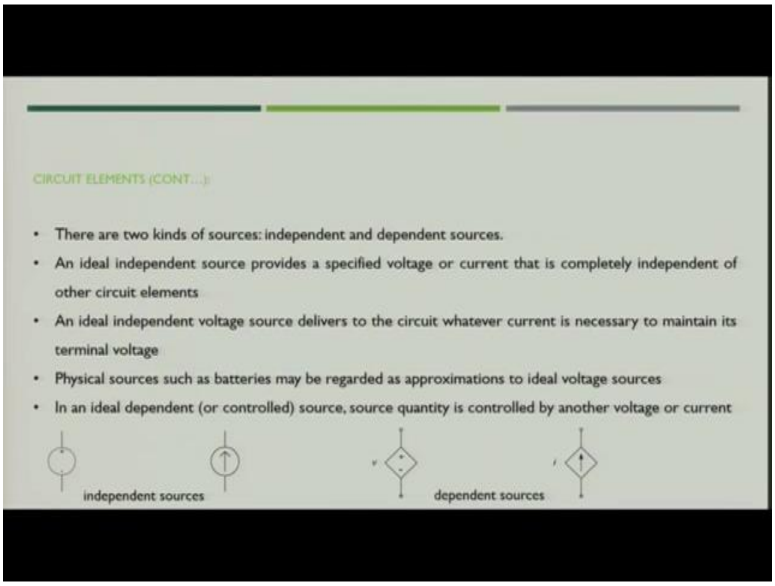

Now, you will see there are two different kinds of sources, i.e., independent and the other is dependent. So, if you see the ideal condition, in ideal condition the ideal independent source will provide specific voltage or current that is completely independent of other circuit elements. In this case the ideal independent voltage source delivers to circuit the whatever current is necessary to maintain its terminal voltage, because in case of ideal voltage source your terminal voltage will always remain constant and it will supply power which is necessary to satisfy the power balance equation in the circuit.

Now, physical sources such as batteries maybe regarded as approximation to the ideal voltage sources. Those are not ideal voltage sources because battery has its own losses. Because of that when you keep on supplying power from the battery after some time the terminal voltage will go down. But for a practical purpose we can consider battery as ideal voltage source. So, ideal dependent source, if you are talking about it, means that the source quantity is controlled by another voltage or current.

It means that when you see the particular source that is dependent voltage source or dependent current source its value is derived from the output of any other element. That may be like if the circuit element has a resistance the voltage drop across resistance will derive the value of voltage source. So, how will you see those sources in the circuit? There are certain symbols specified for those sources say in case of independent sources you will see this is the general convention followed for ideal voltage source that is dc voltage source.

Ideal current source is represented by the symbol shown in the figure. When you see the dependent sources, you will voltage is represented using a diamond shape. It means that you will see the diamond in representation while in ideal see the circle. Similarly, in case of current you will see square as a dependent current source and in case of ideal current source it will be circle.

So, with this you can differentiate whether in the circuit there is a independent voltage or current source or a dependent voltage and current source. So, with this we can conclude the today's session. In next session, we will discuss more about the other elements. Thank you!