Basic Electrical Technology
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Lecture - 16
Power Ports

Hello everybody, till now we have been discussing in detail about how we go about modelling circuits and in some various methods of modelling the circuits starting from the state equation approach. We performed the process of obtaining the state equation, we went through the process of obtaining the sinusoidal steady state model and then the transfer function model and then we did the analysis of the circuit using the transfunction model, following this we performed the analysis based on phasor notations and we saw that by the phasor notations we have three basic triangles: the impedance triangle, the admittance triangle and the power triangle; using these we can get very useful information about the circuit and the system.

Now from this class onwards we shall discuss about the systems. So mainly we would like to cover in this set of courses following major systems that is one is being the transformer and then the motors slash generators. Both these come under the category of electromagnetic systems. The motors and generators apart from being electromagnetic they are also electromechanical. This means that three major domains will come into the picture while trying to understand to model these systems. One is the electrical domain, then we have the magnetic domain and we have the mechanical domain.

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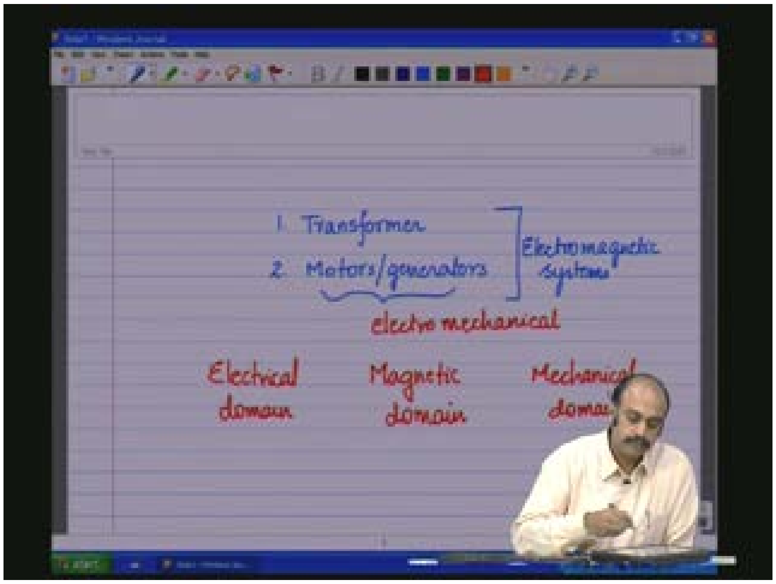

So the modelling with respect to these domains those systems we call that one as the electromagnetic the electromagnetic systems. Systems that also involve the mechanical we call them electromechanical but in actuality it is electromagnetic electromagnetomechanical systems. So all the motors the motors cover all these domains. The transformer covers these two domains (Refer Slide Time: 5:06). So, for the major portion of the rest of the course we will attempt to categorise and discuss about these two major categories of equipment which will be using very frequently in practice.

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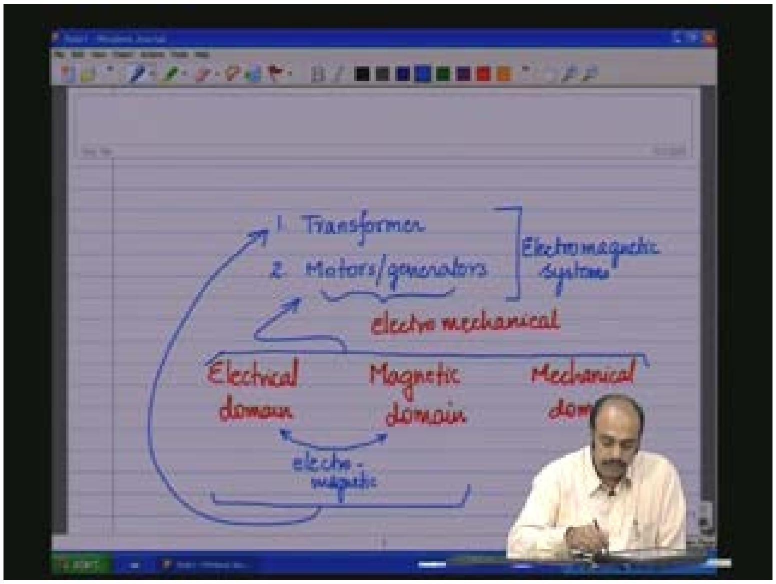

Hence, the transformers themselves will have the single phase transformer and the three phase transformer sorry the three phase transformer and even in the transformer you have the power transformer, pulse transformer so on and so forth. However, for the purpose of the course we are going to stick to power transformer.

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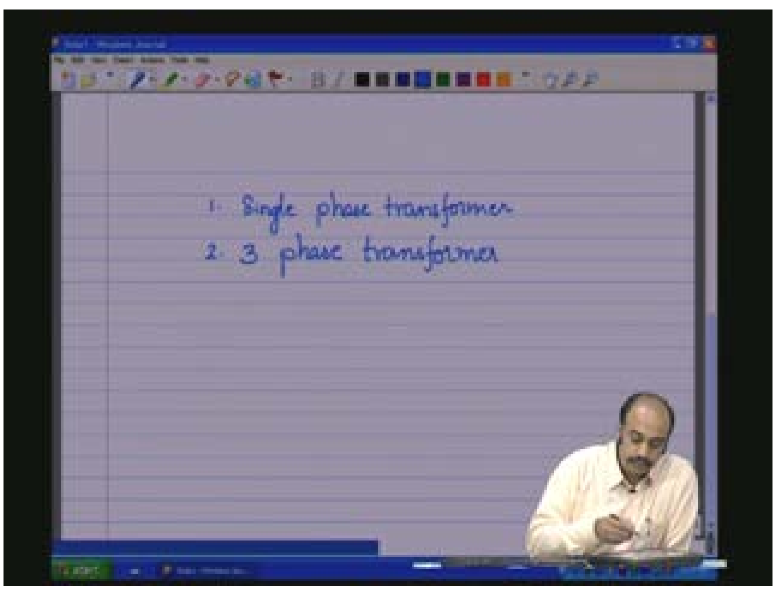

And in the case of the motor generators we are going to discuss about DC motors and generators. We are going to discuss about the AC machines which can be classified as the induction machine the induction machine, the synchronous machine and there are various other machines like (…………..07:23) motors and stepper motors so on and so forth. However, we are going to stick ourselves to these types that is the induction motors, induction generators, synchronous motor and synchronous generation also called as the alternator.

So these various categories of equipment we will be studying in depth looking at its mathematical model using the various tools that we have used till now; the state equations, the phasor, the spatial, space phasors and spatial phasors and the spatial coordinate systems all those things we will try to study, analyse and get information about all these equipment.

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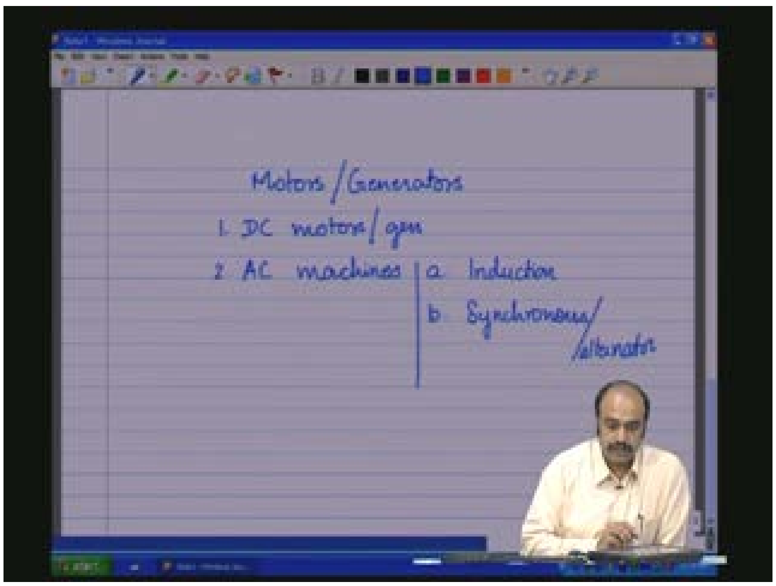

So, before studying about these various equipment we need to understand a bit about how the energy flows how the power flows into various ports. So that would be the focus of the discussion now.

If you recall, very early in our course, in a very early session we had stated that energy emanates from a source and from that source it goes to a sink or the destination or the load. So, in the process of going from the source to the load the following things can happen to the energy: it could get dissipated, it could get dissipated in a resistance R, or it could get stored, or it could get transformed into another domain, it could get transformed into another domain that is from electric domain to magnetic domain or magnetic domain to electric domain or magnetic domain to mechanical domain so on and so forth and if it gets stored we also mentioned there are two ways in which it could get stored. It could get stored as potential energy in the medium of the capacitor C or it could get stored as kinetic energy in the medium of inductance in the case of electric circuits and it gets stored here as half Cv square and here as half Li square.

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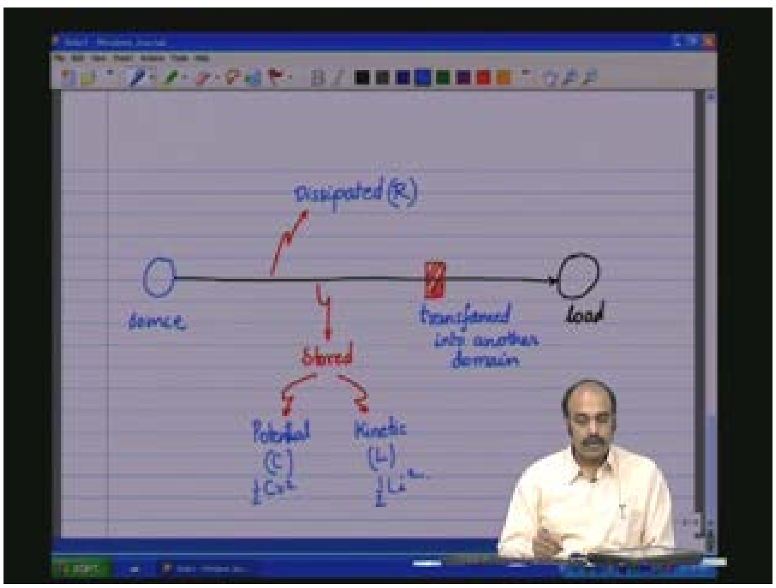

So all these things can happen when the energy emanates from the source and goes towards a sink and load. Three main things can happen which is dissipation in a resistance, storage in a potential form in a capacitance; storage in kinetic form in the inductance and a fourth thing that can happen is yet transform into another domain. These are the things that can happen. This we have discussed earlier.

Now energy or the power, power is basically rate of energy has two variables. You see in all our electric circuits we have two variables associated with the power or energy power variables let me call them as. So, one of the power variables is called the potential variable which enables storage of energy the potential form like half Cv square half Cv square and that variable V which is voltage in the electric circuit is the potential variable. The other variable is the kinetic variable which enables the energy to be stored by virtue of the motion or virtue of the flow the charges being in flow and in this case the current here Vi which is the current. So there is a potential variable the voltage in the case of the electric circuit kinetic variable current as the kinetic energy storing variable.

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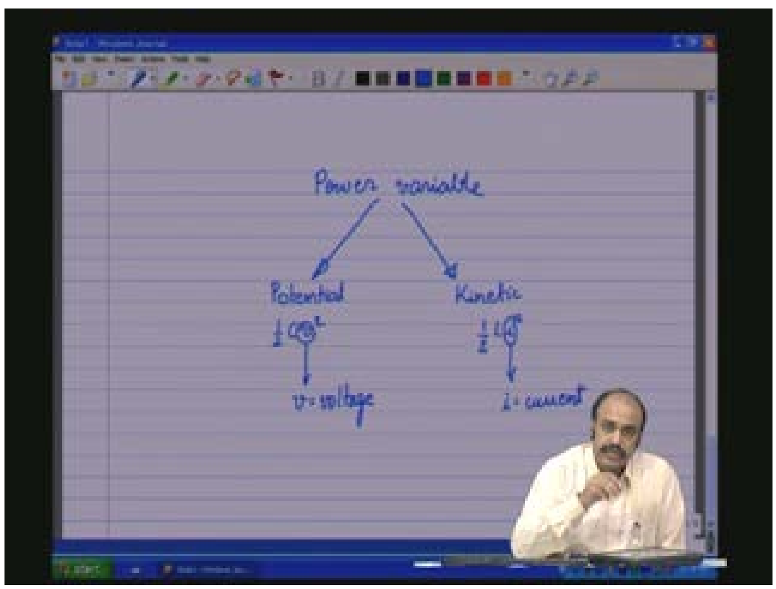

So power or energy in whichever domain is associated with these two variables which is the potential variable and the current variable. These two variables have been called by various other names also. So they are called the potential variable, there are also called across variable and it is also called effort variable; across variable because it is the voltage across a device that is why it is called across variable in some literature, it is the effort variable it is used in some literature especially in Bond graph modelling methods.

The current variable or the kinetic energy storage variable is also called the through variable in some literature; through variable because it is a current through the device. It is also called the flow variable because it implies energy is stored by virtue of something being in motion or something flowing so that is called the flow variable. So these kinds of variables are there in every domain.

Wherever there is energy associated you will have these two types of categories in the variables: one being the potential variable or the across variable or the effort; the other being the kinetic or the through variable or the flow. So in every domain we have these two variables.

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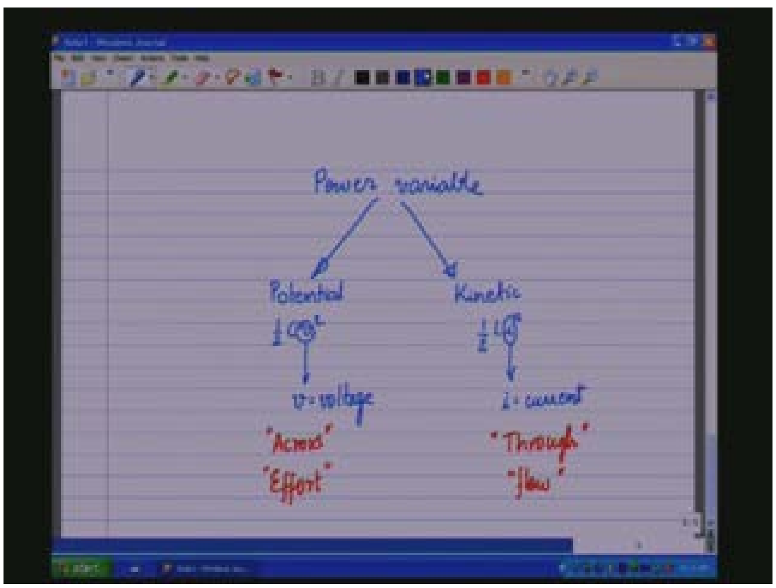

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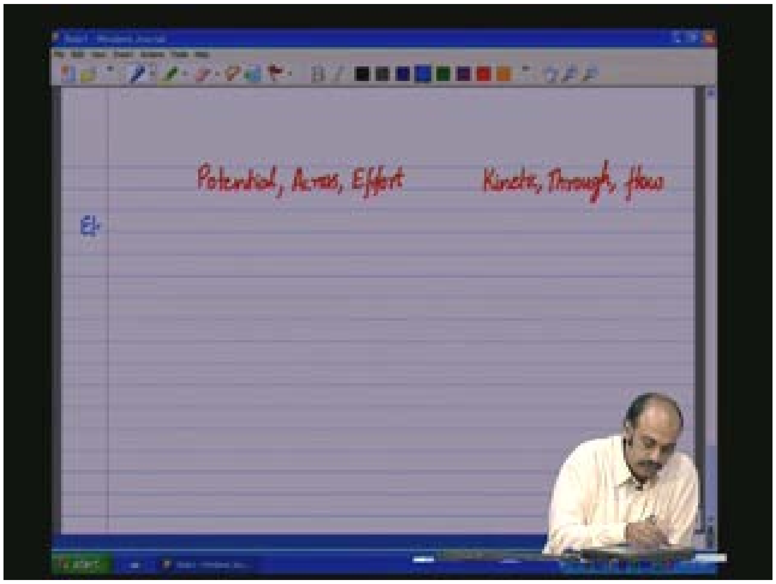

Therefore, in the electrical domain this is nothing but voltage. Voltage is the potential variable and the kinetic variable is the flow variable is current. This is expressed as volts and this as amps. But always note that the product of the two variables that is the product of the potential variable and the kinetic variable is always power. That is if you multiply them this always will be equal to watts whichever be the domain. If you look at the mechanical domain in the mechanical domain you have the rotational and the linear rotational linear so in the rotational you have the torque Newton meter as the potential variable and you have the speed or angular speed speed omega in radians per second as the flow variable.

In the case of the mechanical linear we have force tons of Newton kg force and velocity meter per second, always the product is watts. So, if this is omega and this is t then t omega is the product which is watts; force into velocity FV is in the watts, magnetic magnetic domain mmf and it is not flux as it is normally assumed to be, it is d phi by dt rate of change of flux because only then that product is going to be watts because mmf is Ni d phi by dt is V by N by is Faraday's law we will mention that later, product will be V into i which is watts. So like that any domain if you take hydraulics you have a potential variable which is pressure and the flow or the kinetic variable which is the d by dt of Q which is the flow; Q is the flow d by dt Q is flow rate so much meter cube volume per second.

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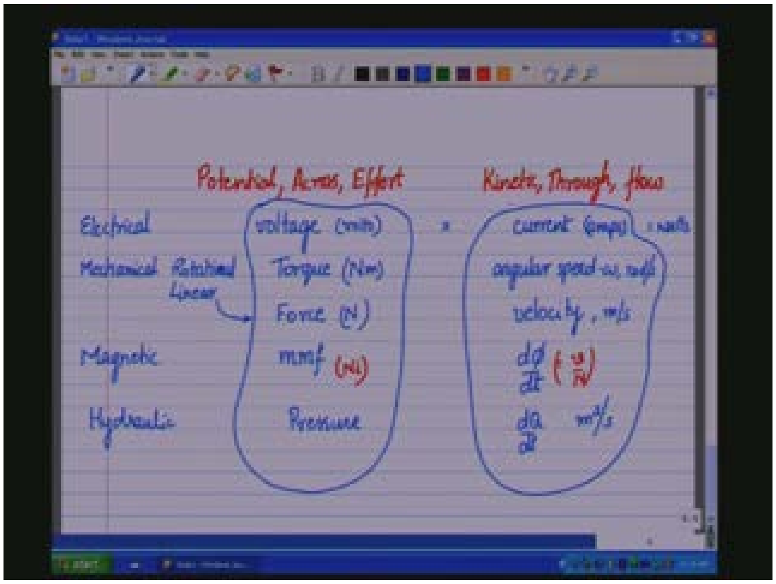

So like this, whichever be the domain you will have two sets of variables always. One is the potential variable or the across variable or the effort variable; the other is the flow variable the through variable or the kinetic variable and always the potential variable into the kinetic variable will always be the power variable watts.

Now let us discuss some about ports. because We need to discuss about the ports because the power is going to interact with various components various systems and various equipment only through ports. So if you take this if you take this whole page, this whole page let us divide this into two and if you look at this page here the left side of the page and the right side of the page they have no interaction because it is divided by these assumed imaginary lines.

Now let us make a hole here, now this left side of the page and the right side of the page can interact through this hole and we call this normally this hole as a window or a port. So port is like a window which is the mains through which two things can interact through that particular interface. Now, suppose we have on this side electric circuits and the power has to interact with a particular component let us say which is on this side and let us say that is a resistance R which has two terminals, now these two terminals are connected to the port like this. So now the port has two connections two terminals to which the resistance is connected.

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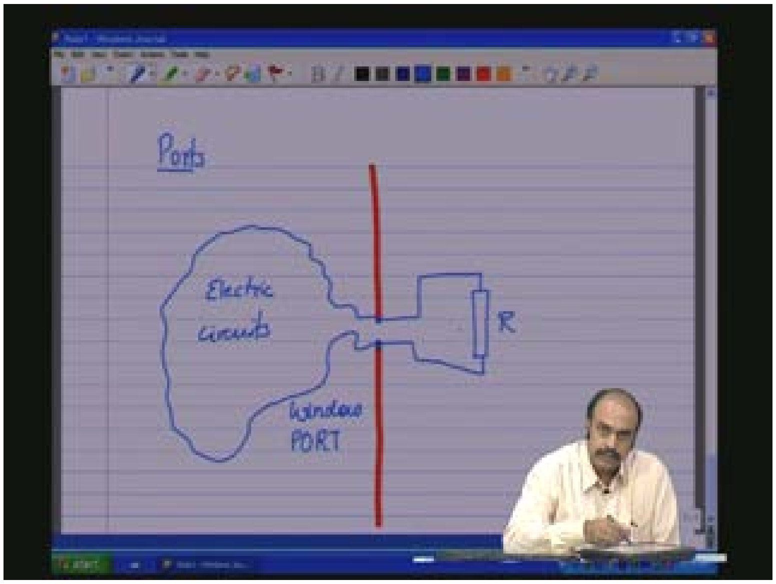

Now all interactions of power and energy is with the resistor in that domain. If it is an electrical domain in the electrical domain it has to be through this port, has to be only through this port nowhere else and this port here has two variables associated with it like the power variables; we have the two power variables is it not? One is the e and that is e is the effort voltage across variable through variable sorry not through variable across variable the potential variable that is the effort then there is one more variable which is let us say the i the i is the flow variable, the current variable, the through variable, kinetic variable all these mean the same thing. So this port at the port there are two variables which is the potential variable and the kinetic variable that is voltage and the current product of which is the power and the interphase at the interphase that power is what is going to interact with this side of the circuit and this side of the circuit.

Now this element R as it interacts with any other circuit only through this port this is called A ONE PORT, the resistance R is called a ONE PORT. likewise we could say all elements and all equipment that interact with other equipment and circuits in the same domain through only one port are all called ONE PORTS.

For example; if we take instead of a resistance an inductance L this also has only one port that it has two terminals, so in the electrical domain if you have two terminals you can have only one port. so early is also ONE PORT because it interacts with other circuits in the same domain with only one port.

Likewise, you could also have a capacitance; see capacitance also has two terminals and interacts with the external circuits with these two terminals only which means one port and therefore C is also a one port element.

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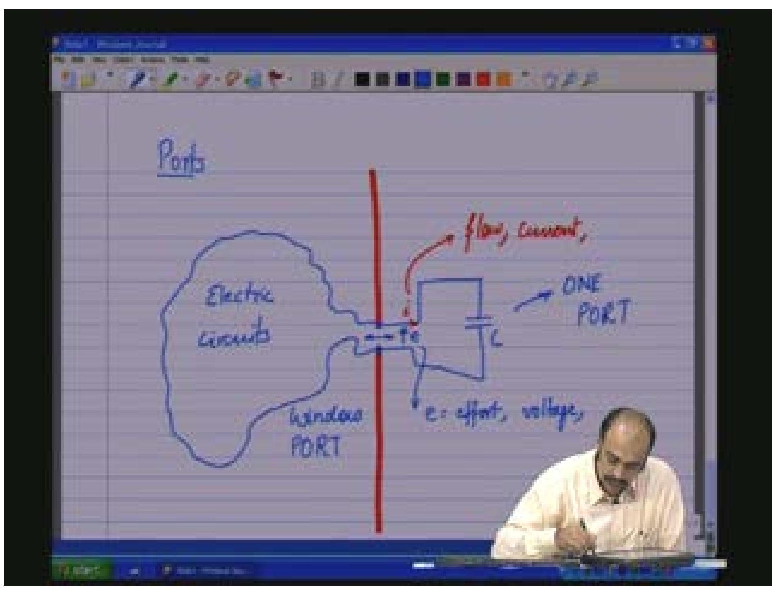

So, if we have one port therefore we can expect to think about are there two ports; meaning, let us say are there devices where there are two power ports with which it can interact with the external circuits in the external world. So here we have port 1 you have port 2, port 1 and port 2.

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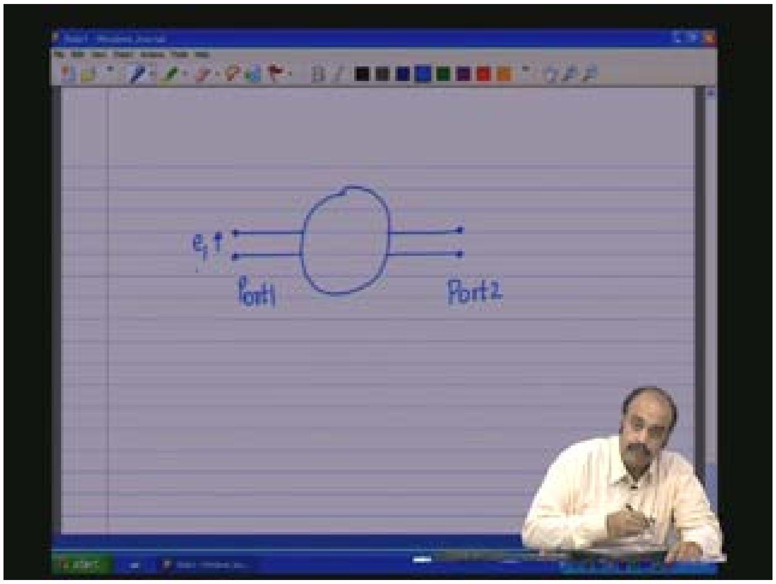

Now each port will have an across variable that's the e 1 and this port also will have an across variable let us say e 2, this port will have a through variable which is i 1 and this port is also going to have a through variable whatever be the direction i 2. So each port each power port is associated with two variables: the effort variable and the flow variable; the potential variable and the kinetic variable.

Now this has a two port. This particular equipment on a system is a two port system is a two port system. So we have the one ports and we have the two port systems; and we should also have probably the multi-ports where we have system which interacts with which interacts with the external circuit with multiple ports.

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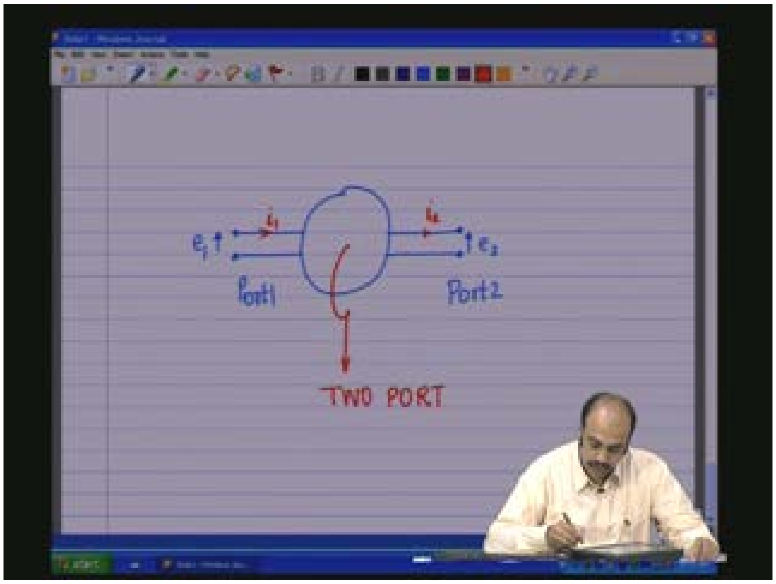

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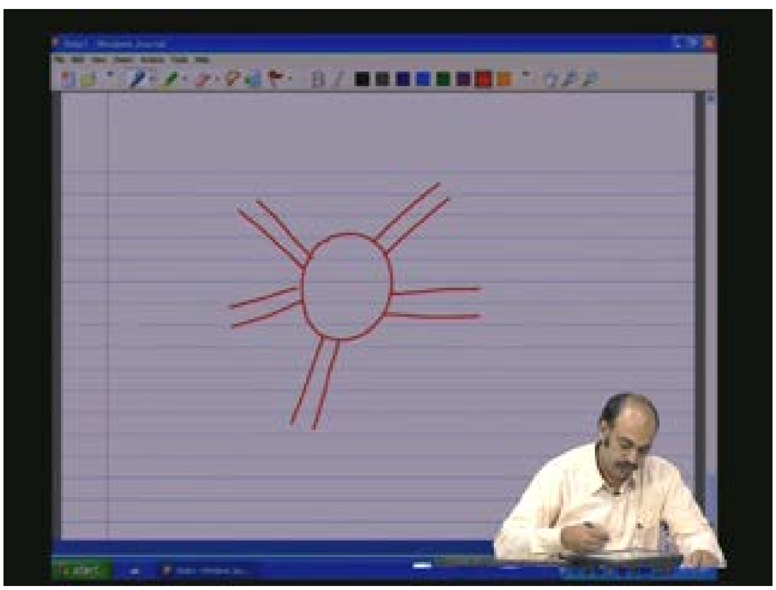

So you have port 1, you have port 2, you have port 3, port 4 so on we can have any number of ports and this is port n and each port is associated with an effort variable e 1, a through variable i 1, an effort variable e 2 and a flow variable i 2 and an effort variable e 3, flow variable i 3, effort variable e 4 i four4 e n i n, so each port is associated with an effort variable and a flow variable and such a system is called a multiport system. So we have the one ports we have the two ports and we have the multiports.

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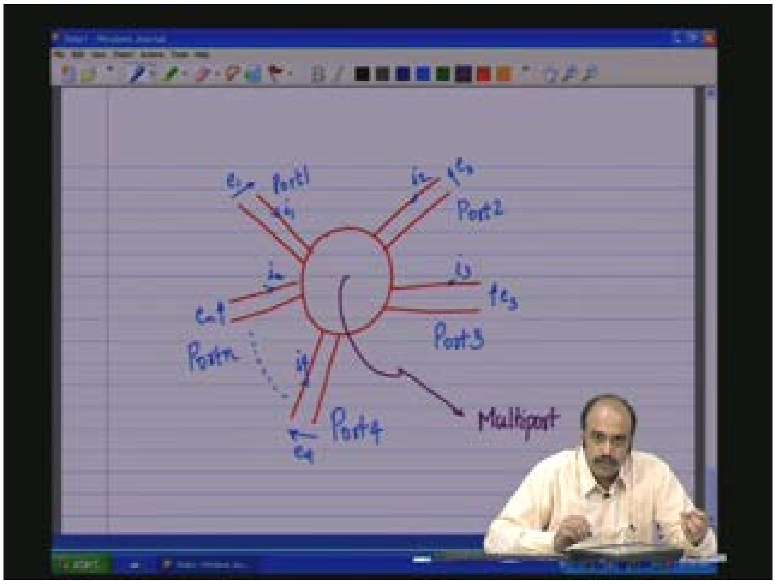

The examples of the one ports are one ports all ports which have two terminals, two leads; all devices which have just only two terminals and two leads they all fall into the category of one ports. So you could have batteries, you could have voltage source, you could have current source, resistance, inductance, capacitance so these are one ports because they have just two terminals just two terminals.

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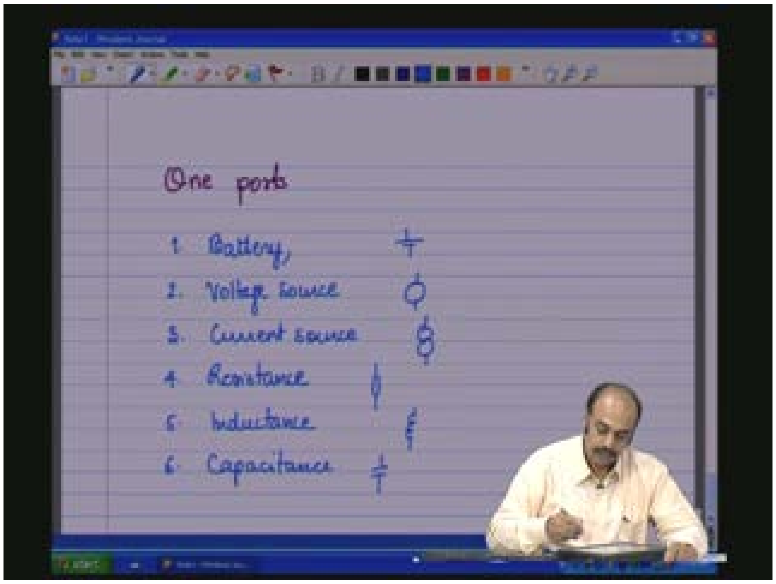

So what about the two ports?

We saw that in the case of two ports there were two power ports port 1 and port 2 each associated with the effort and variables, this the two port. This is a two port device. Now two things can happen in the two port device between the port 1 side and the port 2 side.

The port 1 voltage variable can be related to the port 2 voltage variable, port 1 current variable is related to the port 2 current variable so the relationship is voltage to voltage current to current and always seeing that between the between the port 1 and port 2 there is no storage of energy, all the energy that comes in port 1 is going to the port 2 in which case the conservation of power has to be maintained.

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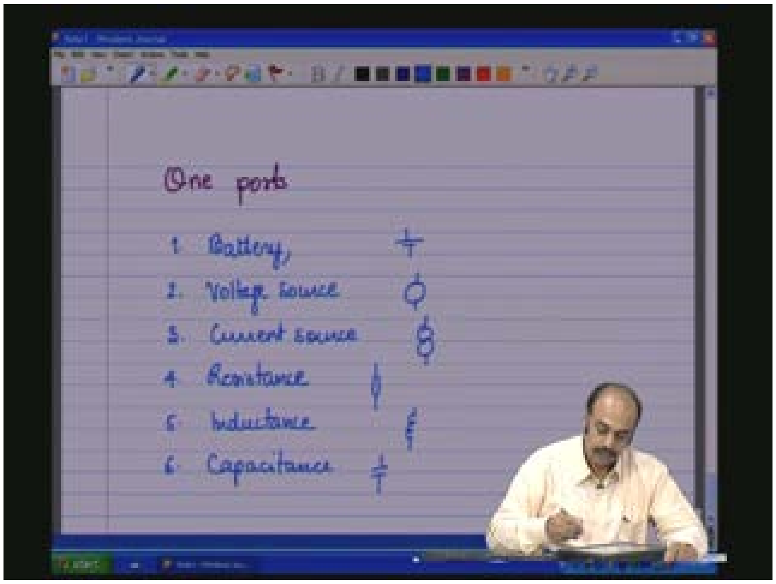

Now an example of this of course would be a transformer, we will come to that one that is e 2 is equal to let us say m e 1 so you see that the voltage variables are related and i 1 is equal to m i 2 this is obtained by the energy of the power relationship that is the power which is there at the primary and the power which is there at the secondary are equated that is e 1 i 1 should be equal to e 2 i 2. This is the equation for a transformer.

There is another area in which the port variables can also be related that is crosswise that is e 1 and i 2 can be related, i 1 e 2 can be related that is e 2 is equal to m i 1 and e 1 is equal to m i 2. So this cross linking of variables that is potential variable on one side linked to the kinetic variable on the other side such equipment such devices is called gyrators. So, when potential variable of one side is linked to the potential variable of the other ports, kinetic variable of one port linked to the kinetic variable of the other port that is same type variable linked to the same type variable to the other port such devices are called transformers. If one time variable potential for example is linked to the other type variable the kinetic in the other port then such crosswise linking of variables is called gyrators. So these are the two types of two ports that you will come across.

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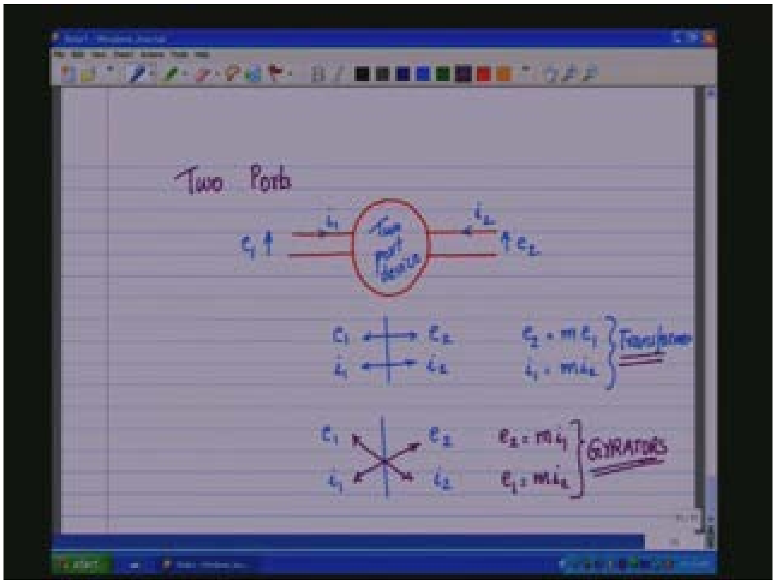

A DC motor can be modelled as a gyrator; we will look at that shortly.

Multiports: what are multiports?

Few sessions ago when we were discussing about the Kirchoff's voltage law and the Kirchoff's current law we made a mention about the junctions: the voltage junction and the current junction. The voltage junctions and the current junctions are nothing but multipower ports. If you take for example the circuit like this (Refer Slide Time: 36:36) we have the R L C circuit, this is a voltage junction is it not? This is basically if you look at it in a way we have the voltage source; I will rewrite it using a different colour. We have the voltage source, we have the resistor, we have the inductor, we have the capacitor these are all one ports. See, I have 1 2 3 4 four one ports they are all connected in series and they interact with the external circuits in this manner through just one ports so this so this is a junction and each is having……… let us say this is e 1 and this is e 2 e 3 this is e 4 across variables. So you see port 1 port 2 port 3 port 4all connected together and that is a junction and this is a voltage junction.

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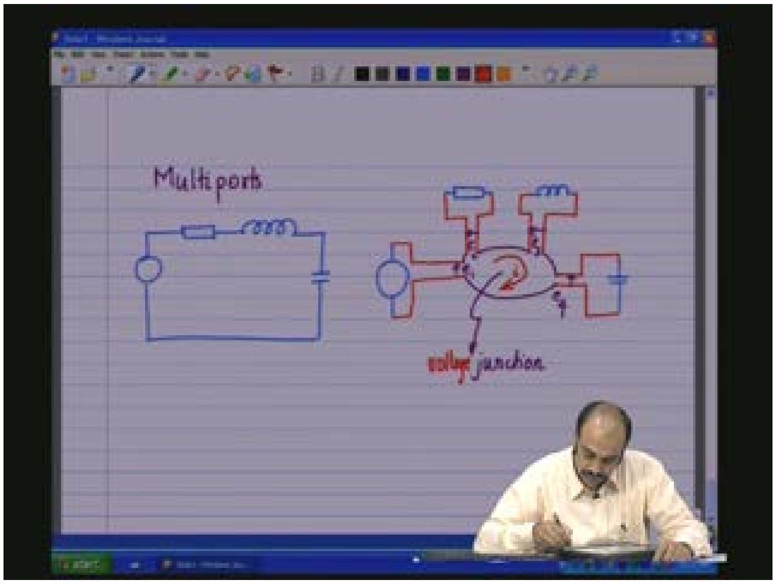

Why is it a voltage junction because e 1 e 2 e 3 e 4 all add up and obeying Kirchoff's law they sum to zero therefore this is a voltage junction. The voltage junction has something in common; all have the same flow, they all have the same current. This is called a voltage junction.

Likewise we also have the current junction. You could have a current source, you could have capacitance, resistance all connected to here. Now if we look at this junction here (Refer Slide Time: 40:08) that junction there has this junction here has current flow in current flow out current flow……….. KCL is obeyed, summation of all currents is zero but the voltages is common. So the voltages of all these power port junctions is common, they all have the same which means if I have if I have an imaginary junction like that to which I have collected let us say a current source I have connected this is only a power equivalent, I have connected a capacitance and then I have in this port a resistance and something.

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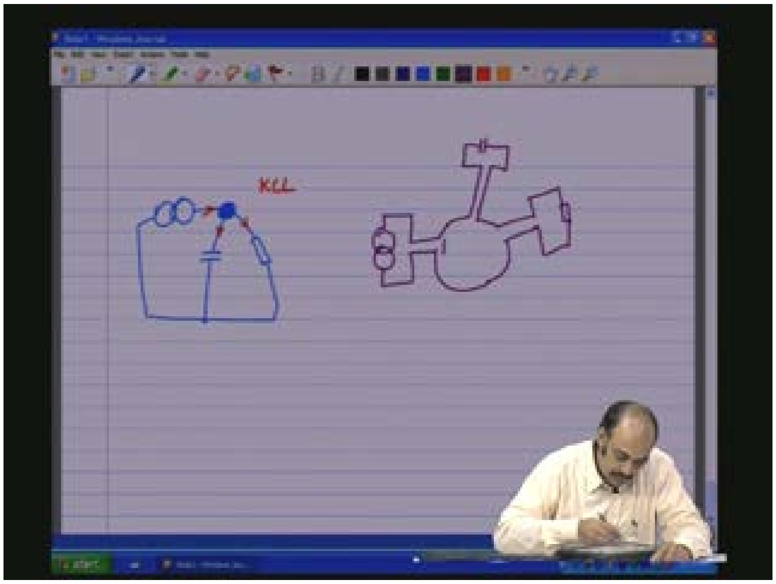

Now all these junctions have the same potential V they all have the same potential V so the voltage is same but the currents the currents are different; each have different currents i 1 i 2 i 3 so on such that i 1 plus i 2 plus i 3 will add up to zero obeying Kirchoff's current law, such junctions are called current junctions. This is what we discussed few sessions ago about the voltage junctions and the current junctions while discussing the Kirchoff's voltage law and the current law. So these current junctions and voltage junctions form the multiports. In fact, in the electric circuits only these two junctions come under the classification of the multiports. So you have the one ports, the two ports and the multiports and in the two ports which is what our focus is going to be in the forthcoming classes sessions you have the transformer.

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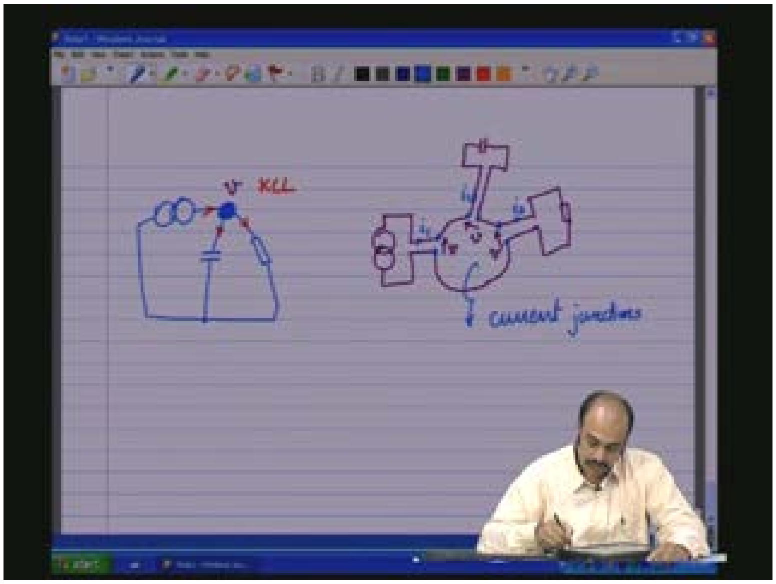

The transformer is having four terminals because it has two ports. It has e 1 and i 1 here and it has e 2 and an i 2 here (Refer Slide Time: 43:30) so inside it goes into the magnetic domain; the energy in the electric domain flows through into this device, goes into the magnetic domain then again gets converted from magnetic to the electric domain and then flows out of this port. So it enters as electrical energy through one port converts to magnetic domain energy in the magnetic domain does some work and then gets converted into the electrical domain and then comes out through the other port. So that is how the flow of energy would be in a transformer flow of energy in the transformer. This port where energy is being sourced is called the primary and this port where the energy is interacting the load is called the secondary.

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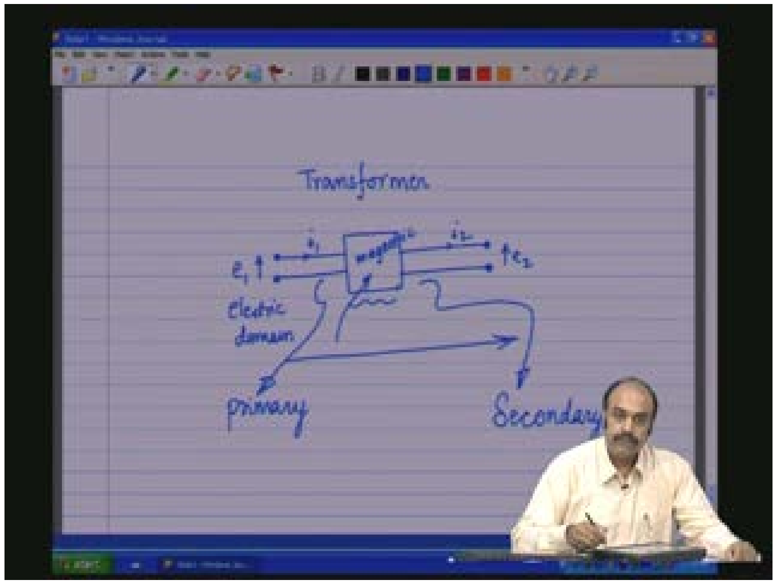

Likewise if you take a DC motor as a black box here it has two ports. However, there is a domain conversion. This is electric domain and this is mechanical domain (Refer Slide Time: 45:44). In the electric domain there is of course a voltage and current and in the mechanical domain there is a torque and angular speed omega. The torque is related……… now the torque is torque is your potential variable on the mechanical domain, e is the voltage e is the potential variable in the electric domain, current is the kinetic variable in the electric domain, omega is the kinetic variable or the rotational variable in the mechanical domain. The link if we make it like that let us say the torque is equal to some Ki I; torque is proportional to i or torque is equal to Ki; K is proportional proportional the proportionality constant K and e is equal to K into omega; K here is again the same proportionality constant as written here only then you will have power balance or the energy balance.

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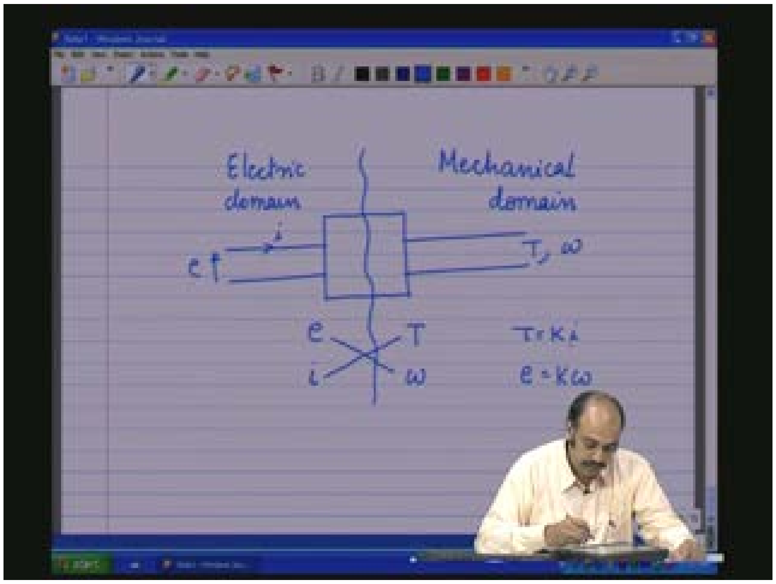

Therefore, if you see here the cross variables are linked that is the potential variable and the kinetic variable in the other domain the potential variable and the kinetic variable in the other domain. Therefore, this equipment is a gyrator. So, that is a gyrator. But this equation (Refer Slide Time: 47:52) you see torque proportional to the current armature current ia or the back emf proportional to the angular speed these are equations of motion or the motor, so this is a motor.

So we saw one example of a transformer and an example of a gyrator in the two ports.

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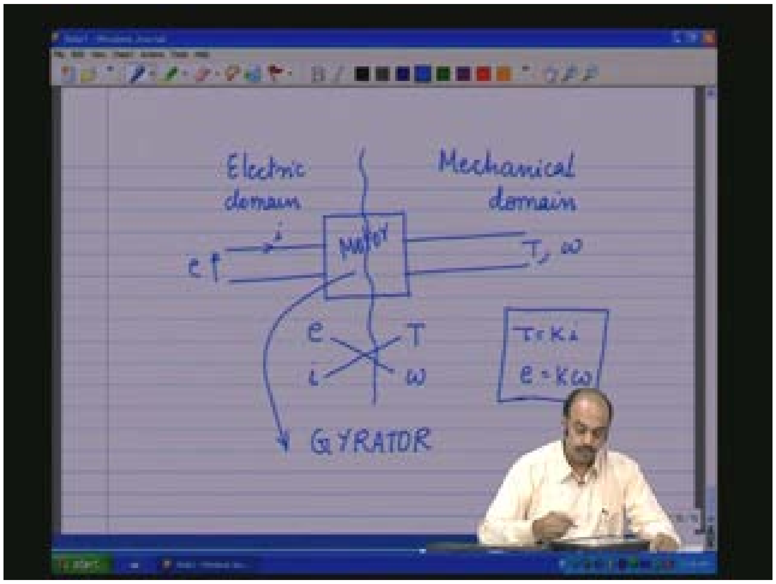

Hence, in the case of a transformer we have the primary port in the electric domain and it is the energy is taken from the primary into the transformer which is in the magnetic domain and then back again through the other port which is again in the electric domain. So this is your transformer, this is your primary, this is the secondary.

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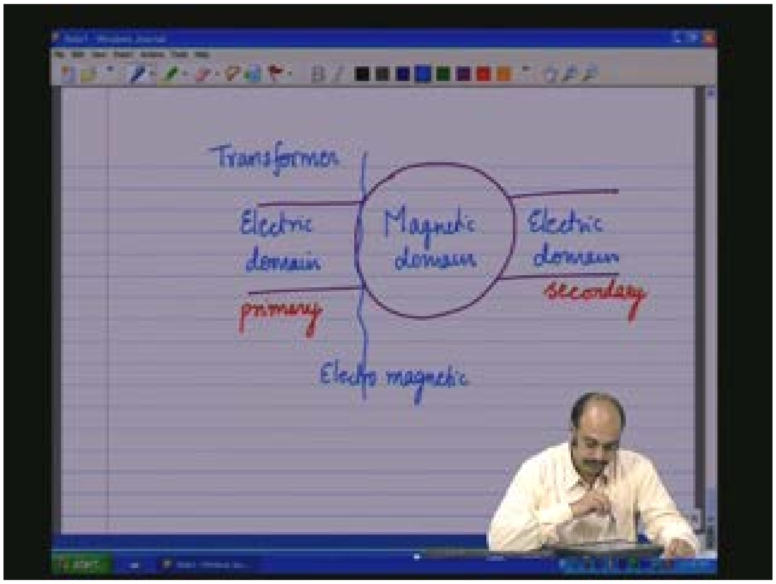

We need to now study this interface the electromagnetic interface to understand the power flow from the electrical to the magnetic, magnetic to the electrical which will give us the understanding of the transformer.

Transformer is physically made up of two major components: one is a core. This core is a ferrite material or iron or something that can carry the magnetic flux in it a magnetic material. So, on to this core you have to wind some copper coils. So let us say we wind some windings on the core we wind some windings on the core one on this leg and then also on this leg (Refer Slide Time: 51:27). So we have four terminals here. So this will be the primary, this is the magnetic domain and this is the secondary. Thus, energy from the electric domain comes to this port, transformer as just these two: just a magnetic core, this is a magnetic core which could be ferrite material or it could be steel, more metals so on and so forth.

Now this core on this core is wound a copper coil. So this coil is copper coil or aluminium coil, that is all the transformer. The link between the port 1 and port 2 that is the primary port and the secondary port is only through the magnetic domain otherwise electrically there is absolutely no connection between them. So the energy enters the electric port and somehow it has to get collected into the magnetic domain and the energy has to energy has to get converted into the magnetic domain and energy in the magnetic domain gets linked to the secondary port and the energy goes out through the secondary port into the electric domain into the electric domain. This is how the energy flow would occur and somewhere here the electromagnetic energy or the energy gets converted from electric to magnetic by the loss of electromagnetism. electromagnetism

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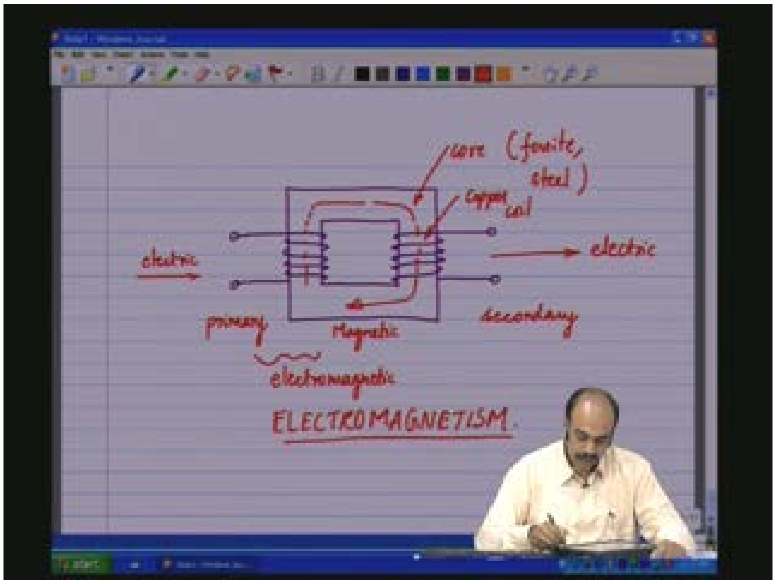

This fantastic contribution was made very early by a scientist an eminent scientist Faraday Michael Faraday and he proposed the law of electromagnetism and it is in fact named after him, it is called the Faraday's law of electromagnetism. He proposes a simple law. What it states is that if there is a flow of current here if there is a flow of current here in the coil and if that coil is wound in a magnetic core, within the core within the core there is a motive force setup and as it is in magnetic domain in the electric domain we call the electromotive force the voltage is the electromotive force which derives the current and the magnetic domain a motive force gets developed and that is called the magneto motive force or the MMF that gets setup and this magneto motive force drives the flux within the core and this flux links with the coils of the other port and that will generate an EMF in the electric domain, electro motive force in the electric domain; this is electro motive force in the electric domain which is a means which is by means of how the energy gets transformed.

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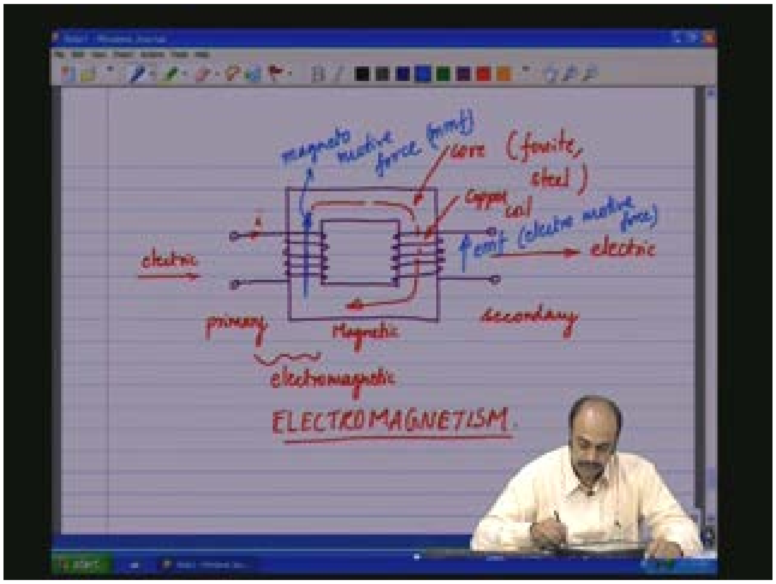

So he proposes this basic relationship V the voltage induced across a coil is equal to N d phi by dt voltage across a coil; it could be the applied voltage across the coil or the induced voltage across the coil. this is number of terms in the coil which is wound around the magnetic core, the ferrite core or the steel core and this is whenever there is a current I said there is going to be magneto motive force setup within the core and that magneto motive force is going to drive a flux and the rate of change of flux is what is going to withstand the voltage applied voltage or induce a voltage in the coil and this is the rate of change of flux. This is essentially the basic principle of electromagnetism called Faraday's law of electromagnetism.

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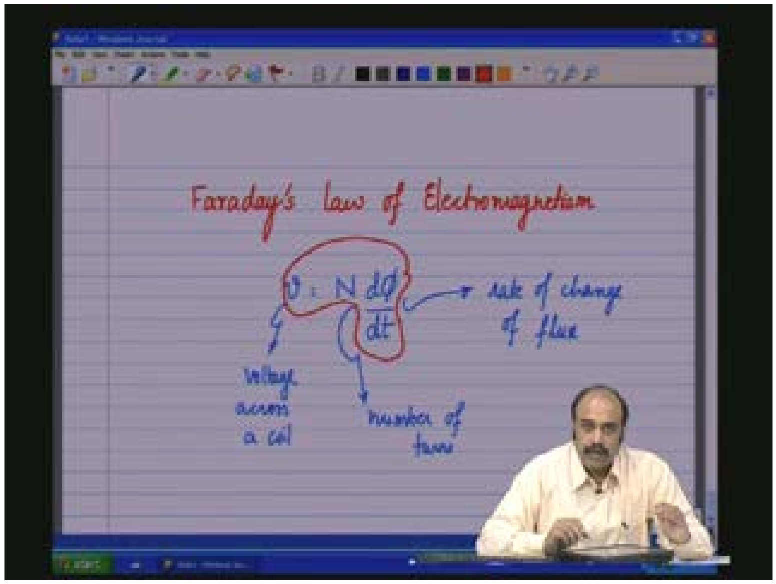

What it means?

If you apply at current in a coil that is going to setup an MMF and that MMF is going to drive a flux and the rate of change of flux is going to induce a voltage on the coil and that voltage will be given by this relationship voltage V which is equal to N d phi by dt. Or if you apply a voltage across the coil that is going to cause a current to flow through the coil which will setup a MMF, which will setup a flux and the rate of change of the flux will be such that it will match the applied voltage V. This is the most important law in electromagnetism.

We shall use this Faraday's law of electromagnetism will frequently in future because we will be dealing with electromagnetic equipment like the transformer and electromagneto mechanical equipment like the motors.

In the next class we will see how we go about modelling and understanding the transformer using the principles of electromagnetism or the Faraday's laws of electromagnetism that we just discussed and also the concepts of ports that we discussed in this session, thank you.