Electrical Measurement And Electronic Instruments
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Lecture - 30
Single Phase Energy Meter (Contd.)

Hello we are studying energy meter.

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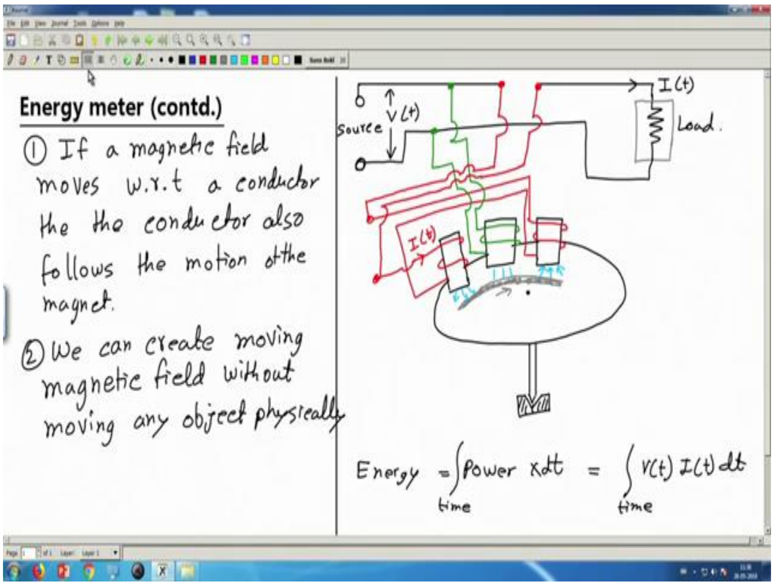

In our last class we have studied two important principles, number one so, if if a magnetic field moves with respect to or relative to a conductor, then the conductor also follows or try to follow the motion of the magnet and another principle that we have studied is that we can create virtually moving magnetic field without actually moving any physical object ok, now using these two principle we are going to make a energy meter, how is it.

So, the energy meter that we are going to make is made up of an aluminium disk. So, it has a aluminium disk like this, which can rotate around a spindle or an axis and this above this disk we will have a number of coils. So, let me draw them here say this is one coiled so this is one coil, let me draw two more coils. Let me connect these two red coils in series so that the fluxes of this and this coil are in opposite direction ok. So, these are the two terminals of these two coils and similarly this green coil will also have two terminals and now you know that if we have currents in these two sets of coils out of phase with each other, then these three coils together will produce a virtually moving magnetic field below them.

So it will have the some magnetic field like this, it will have the magnetic field in the opposite direction and the magnetic field of this coil will be out of phase from these two coils. If we do so, then in this region so this part which is the region below these three coils will have a virtually moving magnetic field and therefore, now this virtually moving magnetic field is moving with respect to this aluminium plate this aluminium disk ok. So, if we can create a, if we can pass appropriate current through these two sets of coils, then there will be a virtually moving magnetic field with respect to this aluminium disk.

And therefore, due to the eddy current motoring phenomena which we have studied previously this disk will experience a force. So, this disk will experience a force in this direction if the magnetic field is moving in the from left to right or in the other direction ok. So, the disk will start to rotate. So, there is a force on the disk or a torque so, the disk will start to rotate ok. Now in an energy meter what we do. So, suppose we have a circuit where this is the source; this is the source side ok. So, these are the two say live and neutral phase of the source and here we have some load.

Think of this load as a resistive load for ease of understanding and this is connected like this. So, the source is delivering some current and power to this load and call this voltage as V, this can be AC as well, this also can be AC. Now we are interested in measuring the energy consumed in this load now what is energy,

Energy = $\int_{time} power\ xdt \ \ = \int_{time} V(t)\ I(t)\ dt$

Now so, therefore, to measure energy we have to take the product of voltage and current just like we did it for ammeters ok. So, basically our energy meter needs to have two sets of terminals which will take the voltage as a input and current as a input and the energy meter is supposed to take the product and integrate the product over time. So, let us and this is actually going to be our energy meter we are making the energy meter out of this disk and this electromagnet and see we have 2 coils red and this green, what we will do, we will say connect this green coil directly across the source.

So, therefore, this green coil is sensing the voltage V t. So, the green coil you can call it as the voltage coil or pressure coil like wattmeter this is sensing the voltage ok.

And now this coil I can use to sense the current through the load and to sense the current what I have to do, I have to say open this circuit at some place and connect this coil in series like this. The diagram seems a bit clumsy, but essentially what I have; I have these two red coils in series with the load ok. So, now, these red coils are carrying the same current as the load current. So, this current is I t and this green coil is sensing this voltage. Now so for ease of understanding, let us assume that this is perfectly resistive. So, let me copy this.

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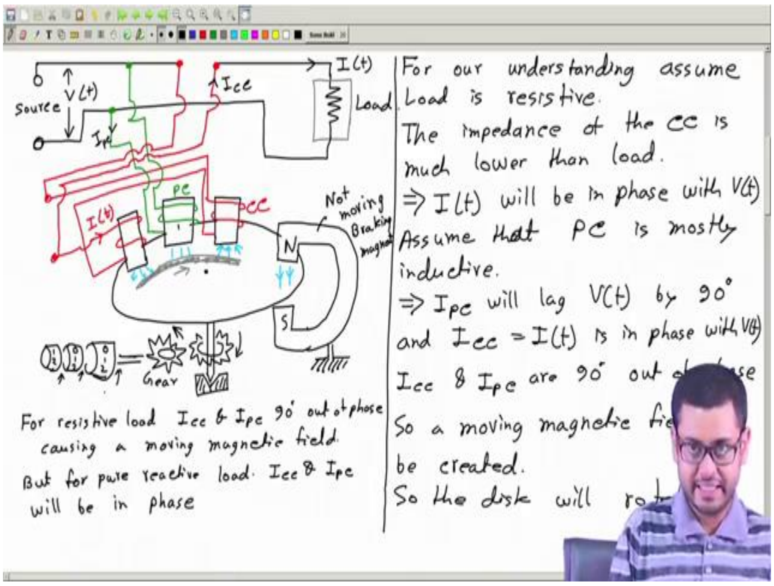

So, for our understanding assume load is resistive and if so and the impedance of these coils; so, these are coils, coils means it will have some inductance of course, so, but assume that the impedance of these coils are much lower compared to the impedance of the load. So, the and these coils are current coils and this is, this green is the pressure coil voltage coil.

So, assume the impedance of the current coil is much lower than load ok. So, this will imply that this circuit, so this circuit these coils and this load they are in series, that is mainly resistive because this is much dominating than these small inductances. So, this circuit is mainly or mostly resistive therefore, the current I t will be in phase with V t the supply voltage, because this is resistive circuit. So, current or voltage there will be in the same phase, but this circuit this pressure coil circuit is assume this is inductive this is definitely inductive, it is mainly a coil it also has some resistance of course, it also has some resistance it is not perfectly a inductor.

But assume for ease of understanding that the pressure coil is mostly inductive if so, then this current call this I_{PC}; that means, current in the pressure coil that will be out of phase or lagging V t by 90 degree. So, I_{PC} will lag V t by 90 degree and we already have said I t which is the load current is also same as this I_{CC} the current coil current and I_{CC} is same as I t is in phase with V t.

So, what do we see, that this current is in phase with volt this voltage and this current is 90 degree out of sorry, this current is 90 degree out of phase with from this voltage and this current is in phase with this. So, I_{CC} and I_{PC} are 90 degree out of phase.

So, these two currents are 90 degree out of phase the red and green therefore, the flux will also be 90 degree out of phase and we know then there will be a virtually moving magnetic field. So, a moving magnetic field will be created. So, there will be a force acting on this disk and the disk will rotate so the disk will rotate. Now so, there is a force on this disk or a torque on this disk.

So, basically; that means, the disk will have an angular acceleration, because there is a torque. So, torque means there will be an angular acceleration so, the disk will keep accelerating ok. So, as long as there is this force this moving magnetic field the disk in principle we will keep accelerating, its speed, its angular speed will increase continuously, but what we will do.

I mean essentially what we want, we want to measure the energy consumed and so for that what we will do, we will apply a controlling or a braking or a stopping mechanism, a mechanism which will try to stop this rotation of the disk. So, what we will do actually, we will put a magnet say U shaped magnet like this say this is the North side North Pole. So, this is the South Pole and this is put I mean over this disk like this. So, this side in from the side view it will like look like this, this will be the cross the side view of the disk and we have the magnet here North and South.

So, flux lines are like this, here also we have the flux lines and this magnet is rigidly attached to the frame of the instrument. So, this is a fixed non movable magnet so, this magnet is rigidly attached. So, it is not movable ok, not movable this is not movable, not moving actually not ok.

So, this is a fixed stationary magnet and if the disk is rotating with respect to this magnet then what will happen, now once again the eddy current breaking mechanism will start. So, the disk is now trying to rotate with respect to a magnet and the magnet and the so, there will be a relative velocity between the magnet and this disk and we know that a conductor does not like to have a relative velocity with respect to a magnet. So, there will be a force which will try to stop this disk ok, there will be a braking action. So, this magnet is called braking magnet ok.

So, we see there are two magnetic fields one which is moving which is created by this AC currents, another magnetic field is by this permanent magnet. So, this is the permanent magnet and this magnetic field is trying to rotate the disk, this magnetic field is trying to stop the disk. So, basically there will be a kind of fight between this two magnetic fields, one is trying to rotate the disk, another is trying to stop the disk and there will be some equilibrium established between these two magnetic fields.

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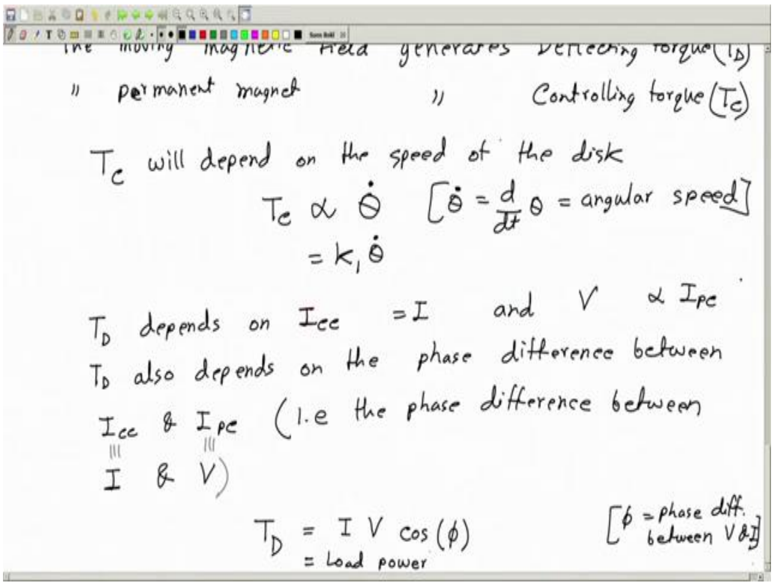

Let us state some facts without a rigorous justification now. So, there is a moving magnetic field, the moving magnetic field generates deflecting torque T_D. So, the moving magnetic field tries to deflect or rotate or turn the disk and the permanent magnet generates this stopping torque, which we will call the controlling torque T_C ok. So, this is like once again the situation is like our galvanometer or ammeter where we have two torques, one is the deflecting torque which tries to move the pointer or in this case the disk, another is this controlling torque which tries to stop it. We do not have a spring instead of having a spring we have the braking magnet.

Now, intuitively the controlling torque T_C this will depend on what. So, this will depend on the speed of the disk ok, because if the disk if this disk is rotating faster; that means, this disk is intersecting this flux at a faster rate. So, there will be more emf generated so, there will be more eddy current induced, so the torque will also be higher right. So, the deflecting sorry, controlling torque will depend on this speed. So, let us take it I mean without a proof let me just tell you that say that T_C is proportional to the angular velocity of the disk.

Tc will depend on the speed of disc

Tc $\alpha\ \theta'$ $[\theta' = \frac{d\theta}{dt}]$

Tc = $K_1\ \theta'$

Td depends on Icc =I and V $\alpha\ Ipc$

So, if we have more current here then definitely this magnetic field will be stronger. So, it will apply more torque more deflecting torque ok. So, therefore, this will depend on I t this current. Similarly this will also depend on this current I_{PC} because if this current is more we will have more flux. So, the strength of the moving magnetic field will be more we will have more torque intuitively without much rigorous math ok.

So, it depends on this current I and this current, now this current is same as this voltage divided by the impedance of this coil, now impedance of this coil is a constant once we have this instrument manufactured the impedance is a constant. So, this current therefore, depends directly on this voltage. So, we can say that the deflecting torque will depend on this current and this voltage. So, the deflecting torque depends on I_{CC} t or which is same as I t and V t so, this is supply voltage so, which is proportional to I_{PC} t. So, T_D depends on these two factors, it also depends on the phase difference between I_{CC} and I_{PC}.

So, let me not write the t here let me just write the; so, this is like the RMS value or just proportional to the peak or magnitude whatever. So, this is. So, T_D depends on these two values if the RMS value is more of course, instantaneous value will also be more. So, let me just write it this way ok, now ok. So, T_D also depends on the phase difference between these two currents; how.

So, which also means so, the phase difference between this or which also depends on so that is the phase difference between I_{CC} is same as I t load current ok. So, this is load current and this is proportional so this, this is nothing but the supply voltage divided by the impedance of the pressure coil so, let us write V. So, this is equivalent to this and this is equivalent to this.

There is a Z or impedance that we have to divide V with, but this depends on this and this depends on this. So, the phase difference between I and V will also decide the value of T D how, say here; so, we have assumed previously resistive load ok. So, if we have a resistive load, then we have seen that this current is in same phase with V t let me find some place to write it let me write this here. So, for resistive load this I is in same phase with V and this I this current is 90 degree out of phase from V.

So, so we have for resistive load I_{CC} and I_{PC} 90 degree out of phase causing a moving magnetic field, but for say purely reactive load like inductive or capacitive load for pure reactive load, what do we have we will have current 90 degree out of phase from V in phase with V or sorry 90 degree out of phase with V and this current is also 90 degree out of phase with V this is always 90 degree out of phase with V, but if this is reactive this will also be 90 degree out of phase with V so; that means, these two currents will be in same phase.

So, for pure reactive load I CC and I PC will be in phase will be in phase or will be 180 degree out of phase. So, there will be no I mean it will it would not have this 90 degree phase lag and in a demonstration yesterday we have seen if these two currents are in same phase then the magnetic field produced by them that does not move. It only fluctuates it is it creates a pulsating magnetic field, but it does not move with time, if these two currents are in same phase.

So, for pure reactive load we will have no moving magnetic field so, T D will be 0, right. So, what we observe, we observed therefore, that T D also depends on the angle between this current and this voltage, if this if this is this current is in same phase with V then we have a magnetic moving magnetic field.

Else we will have only a pulsating magnetic field which will not create any T $_D$. So, that is what we have written T $_D$ also depends on the phase difference between the between the current and the voltage ok. So, if you think a bit more we then you will possibly realize that T $_D$ is like I $_{CC}$. So, this is the magnitude or RMS value or this is same as load current I multiplied by voltage ok.

$T_D = IV (\cos\emptyset) =$ load power

So, let me use phi here stands for the phase difference between V and I. So, you see if V and I are in same phase if this is 0, we will have maximum deflecting torque, but if these two are out of phase by 90 degree; that means, for reactive load so, then I $_{CC}$ and I $_{PC}$ becomes in phase. So, this and also here this will be 90 which means this will be 0, so that is correct that is what we expect ok. So, T $_D$ is like this. So, and then this is same as the power load power let me just write so, this is load power.

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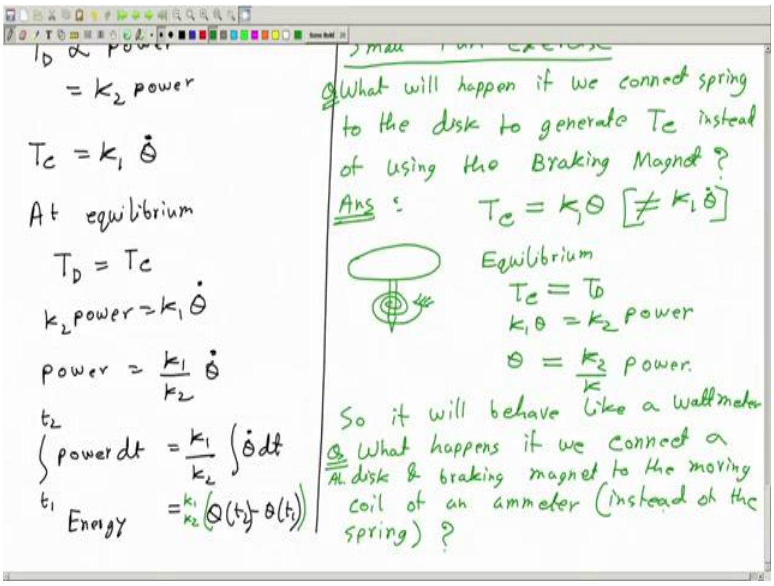

So, note that we have not gone through any rigorous mathematics, any detailed derivation of this fact that T $_D$ depends on the power ok, but we have tried to motivate this fact by stating. Firstly, T $_D$ will depend on the strength of the I $_{CC}$ current coil current which is same as load current.

Secondly depends on the voltage applied across the pressure coil which is proportional to the pressure coil current, because if either of these two currents are is more we will have a stronger magnetic field. Thirdly we have seen with examples that the angle between the load current and the voltage also decides the angle between the I_{CC} and I_{PC}. If I_{CC} and I_{PC} are in same phase then the magnetic field does not move, if they are out of phase then only the magnetic field moves and a torque is created.

So, with this we have tried to physically in I mean convey you the fact that T_D depends on the power. If time permits later on we will do a rigorous mathematical derivation or we will do it in an additional video, but for now we are not doing any rigorous mat detailed derivation. So, for now let us try to understand only the physics of the device. So, T_D is proportional to power and so we can write T_D is some constant time power and we already have seen that T_C is proportional to the velocity of the disk ok. So, this is what we have already seen.

Now, this torque tries to rotate the disk, this tries to stop the disk. So, there will be a equilibrium when these two will be equal so, at equilibrium ok.

Tα $power = K2\ power$

Tc = K1 θ'

At equilibrium

$T_D = T_C$

K2 power = K1 θ'

Power $= \frac{K1}{K2}\ \theta'$

$\int_{t1}^{t2} power\ dt = \frac{K1}{K2} \int\ \theta' dt$

Energy = $\theta'(t2)$- $\theta'(t1)$

So, let us put some gear arrangement I am not good at drawing these gear ok. So, as in this is a mechanical gear and so, you may have more gears and then we can connect this mechanically to a set of rotating dials.

So, these are some rotating dials with a digit written on them like 0 1 2, 1 2 3 etcetera. So, we have a set of such dials 0 1 2 and this is mechanically coupled ok, these are gears I am not good at this drawing. So, these are mechanical gears and this is a set of dials.

Now, when this disk is rotating these gears will also cause this, this thing to rotate and then this will rotate, this will rotate. So, we will have some numbers displayed by this set of dials and then by reading this numbers we can count how much this disk has rotated ok. So, we can look at this value of the dial say at time t equal to t 1 and we say see the reading is equal to say 1 0 0, then after say 4 days or after a month we look at in this numbers and then if the reading becomes 3 0 0 then; that means, the total amount of rotation is proportional to 3 0 0 minus 1 0 0 or to proportional to 2 0 0.

So, that will give us the amount of energy consumed in BTH British thermal unit some in kilowatt hour ok. So, that is how it works. So, that is the working principle of energy meter ok.

So, for this video this class this is the main content you can stop it here, but I will just give you a small thought exercise or fun exercise if you like. So, some small fun exercise, thought exercise ok, what would have been the situation if we had springs connected to the disk, what will happen if we connect spring to the disk to generate the controlling torque T_C instead of using the braking magnet. So, this is a small question that I would request you to think.

So, you may pause the video and think of it and then I am going to now tell you the answer. So, you know think yourself before you see the answer. So, what we have; we have this disk and instead of having the braking magnet. So, we are connecting a spring may be a spiral spring like this just like we had in ammeters in galvanometers, then what happens;

$Tc = K1\,\theta \;\; [\neq K1\,\theta'\,]$

At equilibrium

$Tc = Td$

$K1\,\theta = K2\, power$

$\theta = \frac{K2}{K1}$ power

So, now, if you look at the position of the dial of the disk then you directly have a knowledge of the power being consumed at that point of time. So, then this arrangement will act like a power meter wattmeter instead of energy meter. So, it will behave like a wattmeter that is the answer.

Now another small question what happens if we connect a disk and a braking magnet to the moving coil of an ammeter or galvanometer of an ammeter instead of using instead of the spring. What will happen if we use a controlling torque which is denoted by a braking magnet and a aluminium say aluminium disk instead of using the spring. So, think of it, you may share your answer in our forum, you may email us; we will be very happy if you do so.

Thank you.