Electrical Measurement And Electronic Instruments
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Lecture - 28
Single Phase Energy Meter

Welcome. We are talking about measurement of power and energy and in our last class we have talked about wattmeter so, in this class we will talk about measurement of energy that is energy meter. And so this is going to be so we call this type of energy meter as an induction type energy meter and this is going to be very interesting, but you have to listen a bit carefully ok. So, before we start let me tell you about a small experiment; the experiment is as follows. So, I have say a metal plate, non conducting metal plate like aluminium, copper sorry I mean conducting but non magnetic metal plate ok.

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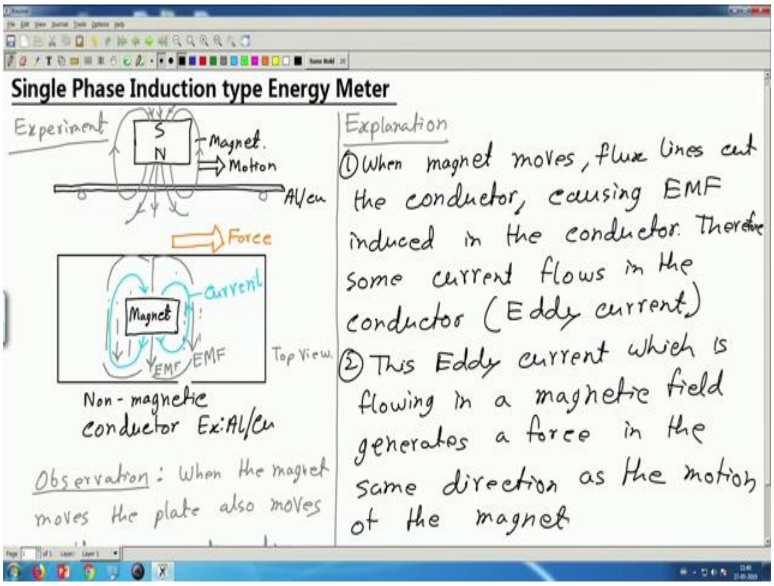

So, this is nonmagnetic and of course, conductor, like example aluminum or copper so we have a plate like this and we have a magnet ok. So, we have a small magnet which we can hold on top of it so this is a magnet so this is a small magnet ok. So, this is a plate rectangular plate and a magnet on top of it ok, so, on.

So, from the top from this view side view this is the top view, from the side view it will look like this or plate and a magnet on top of it. So, this is the conductor and this is the magnet ok. Now the experiment is that we will move this magnet in one direction say from left to right. So, this is the motion of the magnet and we will make sure that the magnet does not touch doesn't touch this conductor plate ok.

So, if we move it what we will see is that, there is a force between this magnet and this plate which will also try to move the plate in the same direction ok. So, if this is a magnet like with two poles north and south ok, so flux lines are like this. So, they come out from the north and they enter the south like this, so this is the flux lines ok. So, we are moving the magnet from left to right and say if we if we have some wheels on which this plate can move then we will see that as the magnet is moving the plate is also moving in the same direction so this is the observation ok.

Now the question is why is it happening, we cannot say that there is a force like a between the magnet and a iron plate. So, because it is not a magnetic plate, so we cannot say it's the force usual force between a magnet and a magnetic material, no because this is a nonmagnetic material, but still there is a force as this magnet moves the conductor conducting plate also moves in the same direction ok. So, this is the observation, when the magnet moves the plate also moves in the same direction.

So, now, the question is why what is the explanation ok? So, experiment you have some observation now we need some explanation why is it happening ok. To get the explanation we have to apply Fleming's left hand and right-hand rules. And so let us see what happens if this magnet is moving ok, so from the top this is the top view this is the side view. So, from the top we will see the magnetic lines of fields are entering this plate and this as this magnet moves these lines of forces they also move. Therefore, if you consider any particular say lying on this magnet on this conducting plate any line you consider at this line a imaginary line on this plate then magnetic flux is intersecting or cutting through this line.

Therefore, some EMF will be induced in this along this line on this plate ok. So, you can consider any line ok. So, you consider any line and you will see that there is some EMF induced. Now how can we find the say the direction of the EMF? So, you have to apply Fleming's right hand rule that is the rule for the generator. So, let us apply so let us switch back to the overhead camera ok. So, this is the magnet we have to apply right hand rule to get the direction of the EMF, flux lines are entering through the plane because North Pole is at the bottom so flux lines are like this.

And the magnet is moving from left to right ok, the magnet is moving from left to right which means these lines or this conductor is moving from right to left relative to the magnet. So, the conductor is moving relative to the magnet from right to left. So, let me point my thumb from right to left and so this first finger is the direction of flux this is the motion of the conductors, with respect to the magnet then this middle finger is going to be the direction of the EMF and it is pointing downwards.

So, the EMF will be in this direction, so this is the direction of the EMF ok. Similarly we shall also see what happens say on this side of this plate, so consider some line say a line here or here and we want to find the direction of the EMF ok. Now the magnetic field once again here is like this down downwards and the motion is of the conductor is again from right to left ok. And therefore, the EMF is again downwards so we will see there is some EMF in this direction ok.

Now, and let us see a line here at the center ok, here also if we do the same analysis, we will see the EMF is in the same direction ok. So, all the EMFs are downwards, but now the magnitude of these EMFs are not equal why? Because the magnitude of the EMF will depend on the flux density which is cutting through that region; and the flux density we can assume here towards the boundary of the magnet to be low compared to the flux density near the center. So, flux density here will be much more ok, so flux density at this center will be much more compared to the flux density on the boundary.

So, this EMF will be stronger than this EMF and then this EMF. So, let me denote this strength of this EMF I with the length of these lines, so I am drawing shorter lines here to indicate that these EMFs are weak this EMF is weak, but this EMF is strong; now if I draw some closed path say like this imagine a closed path ok. So, in this circuit in this loop you will see that there is a strong EMF acting in this direction and a weak EMF acting in the opposite direction.

So, the net effect will be that, there will be a current which will flow in this direction along the direction of the stronger EMF. So, the current so there will be some current which will flow along the direction of the stronger EMF, so this is the current. Similarly consider this loop, here we have a strong EMF downwards and here are weak EMF again downwards. So, the net resultant effect will be that there will be sorry I mean this is a strong EMF and this is a weak EMF, so the effect will be a current which is flowing in this direction. So, this is the direction of the current ok.

So, immediately below this magnet the current is flowing from top to button ok. So, the current there is a current which is flowing from top to bottom directly below this magnet. Now there is a current in a magnetic field which means we will also have the motoring effect, because there is some current flowing in a magnetic field and how can we find the motoring effect? Now this time we have to apply the left-hand rule of Fleming.

So, let us apply that let us see from the top ok. So, now, the direction of the current first the direction of the field is downwards like this and the direction of the current is along this along the middle finger ok. And so the thumb should point towards the direction of the force. So, the thumb is pointing you see from left to right, so this is the direction of the force. So, we can say that the direction of the force is along my thumb which is from left to right. So, this is the direction of the force and the direction of the motion is also from left to right.

So, what do we see that if we move this magnet then there will be some induced EMF and some induced current ok, which will result into some force which again acts in the same direction as the motion of the magnet? So, this is the explanation of why this plate is moving when we move this magnet ok. So, the explanation in brief we can write that, let me write essential points, so when magnet moves, flux lines cut the conductor, causing EMF induced in the conductor. Therefore, some current flows in the conductor which we call the Eddy current and then this current, so this is the first part and the next part of this explanation is that this Eddy current which is flowing under a magnetic field will experience some electromagnetic force ok. Now this current this current means this Eddy current, which is flowing in a magnetic field, generates a force in the same direction as the motion of the magnet ok.

Now, and this is true no matter how this magnet is situated you could have this North Pole upwards and South Pole downwards. Even then the force will always be in the same direction as the direction of the motion of the magnet; you could also have said north pole here and south pole here or south pole here and north pole here you will still have the same effect ok. So, we may take another example for our better understanding ok.

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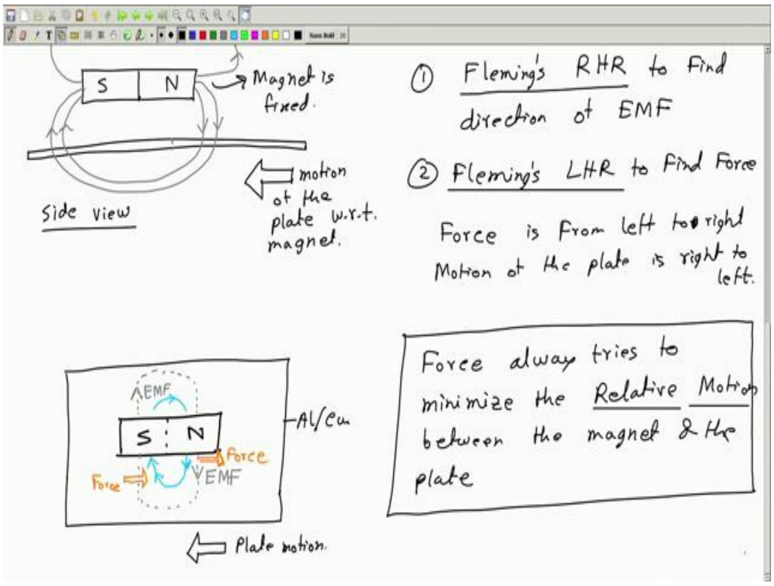

So, let us take let us consider the situation where we say we have the north pole here and the south pole here and the plate below it ok; therefore, the flux lines will be like this so it will come from the north and will enter the south, so this is the flux lines these are the flux lines. So, entering from top to bottom here and going from bottom to top here similarly we will have also flux lines like this which will have no effect. So, now, once again I will be very happy if you if you do the analysis yourself without looking at this video, but we will also discuss this now say the magnet is moving in the same direction from left to right.

So, or ought to make it more interesting let me let me move the plate from one direction to the other ok, say this is the motion of the plate with respect to the magnet and this magnet is stationary. So, the magnet is not moving this time we are moving this plate ok, to make the example a bit more interesting we are moving the plate instead of moving the magnet. So, let us see what happens ok.

So, once again let us apply Flemings first we have to apply Fleming's right hand rule to find the direction of the EMF to find direction of EMF ok. So, let me also draw the so this is the side view let me also draw the top view. So, from the top view we will have this plate, some conductor and the magnet on top of it north and south ok; and this plate is moving from right to left this is the plate motion.

Now, let us consider say a line here, let me make this magnet a bit bigger. And now let us consider a line on the conductor here which means some line here perpendicular to this plane. Now what will be the direction of the EMF here? So, let us see again from the top, flux lines entering like this ok, motion of the plate is from right sorry I seduced my right-hand right hand for getting the EMF.

So, this is the flux line plate is moving from right to left so this is the motion so this will be the direction of the EMF here, so the EMF is like this ok. Now let us see a line consider a line here under the south pole and apply the right-hand rule again. Now the flux lines are upwards because this is south pole so flux lines below south pole is upwards, the motion is again from right to left ok. So, this is the motion flux lines are upwards and this is the direction of the EMF ok. So, EMF is now up in this direction so, EMF is like this ok.

Now if we consider a closed path, then in this closed path current will flow like this ok. So, here below the north pole current is flowing downwards and below the south pole current is flowing upwards ok, so this is the direction of EMF. Now let us apply Flemings left hand rule to find force this is step 2.

So, left hand rule now ok, so this is my left hand let us consider the region below the north pole now below the north pole flux lines are downwards, current is like this is current this is flux lines and my thumb is indicating the force which is from left to right. So, here directly below this north pole force, here will be in this direction so, this is the force. Similarly considered directly below the south pole, flux lines are now in the opposite direction like this current is also in the opposite direction like this and then the force is again from left to right. So, here again the force is from left to right.

So, we see that the force is from left to right and the motion of the plate motion of the plate is right to left. So, which means the force is in the opposite direction to the motion of the plate, this force is trying to stop the motion of the plate, this is Lenz’s law actually because the force is trying to stop the cause which created this force what is the cause? The cause is the motion of the plate, so the force is trying to stop the cause.

In the previous case also here the magnet was moving, so the cause was the motion of the magnet and the force on the plate was trying to minimize the relative motion between these two ok. So, this is Lenz’s law, Lenz’s law says the cause which is the relative motion between the magnet and the plate should be opposed. So, the plate will always try to eliminate the relative motion between the magnet and the plate. If the magnet is moving in a r direction the plate will also move in the same direction. But similarly if we are moving the plate with respect to the magnet the plate will experience a opposing force ok. So, this is Lenz's law directly.

So, the force always tries to eliminate or minimize the relative motion this is important the relative motion between the magnet and the plate. So, this is the fundamental physical phenomena, the force tries to eliminate the relative motion between these two; if you move the magnet the plate will also move in the same direction this phenomena is called Eddy current motoring. And if you move the plate the plate will try to get stopped that is called Eddy current braking ok.

So, so if you move the magnet the plate will also move, if you move the plate the plate will try to stop one is called Eddy current motoring and another is called Eddy current braking ok. So, this is a fundamental phenomena we must know. Now next thing we will talk about is how we can create a moving magnetic field without physically moving any object ok.

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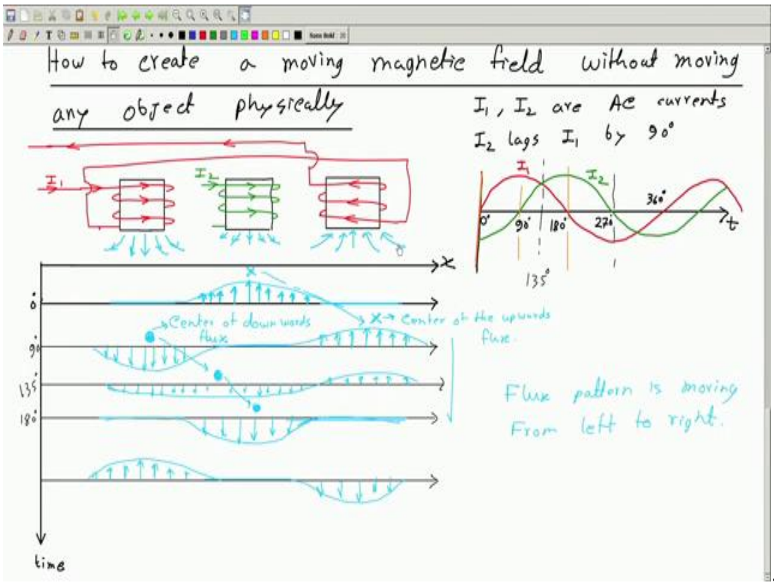

So, next thing we will talk about how to create a moving magnetic field ok, you can say of a virtually moving magnetic field without moving any object physically ok. So, this is the next topic ok.

So, now consider, I have say two or three coils which are like this. So, I have say one coil, which is like this and see I have another coil which is here and let me have another coil, which is like this ok. Now what I will do I will connect say these two red coils in a series and I will do it like this.

So, let us start the coil from here, so it goes around and round like this and then I will join this end of this coil, to this end and then the other end I will take out like this. So, the current may flow say like this entering through this and then going around and round like this and then here it will go in the opposite direction round and round and then it goes out ok. Now if some current I is flowing in this direction, then it will create some magnetic field and you can find the direction of the magnetic field using any rules you like. So, we will see that the magnetic field is in this direction ok.

So, the magnetic field will be in this direction, so they will close themselves I am not cluttering this diagram. So, they will have a closed path like this, but I do not want to make this diagram ugly. So, I am just drawing only here ok. Now, but here the current is flowing in the opposite direction, so the flux lines here will be also in the opposite direction and they will also be closed, but I am drawing only this part ok.

And then let me have another current, which call it I_2 which is flowing like this ok. So, basically I have two currents I_1 and I_2 this is I_1 which flows through this 2 coils and here I have another coil which carries a current I_2. Now say the current I_1 and I_2 these are AC currents ok. So, I_1 and I_2 are AC I_1, I_2 are ac currents and say I_2 lags I_1 by 90 degree ok. So, if I draw the timing diagrams then, if this is I_1. So, this is I_1 then I_2 will be lagging by an angle of 90 degree. So, this is I_2 this is I_2 and this is I_1 this is time ok.

Now what I want to do? I want to plot the strength of this magnetic field as a function of time ok. So, if for this also there will be some magnetic field like this ok. Now what I will do I want to plot the strength of this magnetic field as a function of time. So, let me let me make some space and now I will draw time along the y axis. So, this will be time and at different times I will plot this strength of this magnetic field and say time.

So, I can write the time in terms of the phase angle of this current. So, this is called this moment as 0 degree ok, so time is proportional to this value this angle is 180 degree. So, this angle is 90 degree 180 degree then, 270 degree then, this is 360 degree ok. So, instead of writing time I am writing the angle because time will be proportional to this value although it is not strictly time, but I think the meaning is get to you.

So, now, at 0 degree ok, so at this instant so at this particular instant, so consider this particular instant this particular instant then how will be this field strength below this magnet ok? And also let me call this axis as x this is x this is a spatial distance this x axis time axis. Now at say at t equal to 0 degree. So, this is 0 degree then the current rate current or I 1 is 0. So, the flux created by this coil will be 0. So, at t equal to 0 degree the flux created by this coil will be 0. So, we will have no flux almost no flux here so 0 flux.

Similarly this will also have 0 current, so we will have 0 flux below this coil and this coil is carrying a current which is negative and it is at its maximum value negative and at its maximum value. So, the flux below this coil will be actually upwards because this current is negative means actually in the opposite direction. So, flux will be in the opposite direction like this ok, so actually upwards and it will have a high value its maximum value here are no flux, here are no flux, but below this coil we will have some flux density which is upwards ok.

So, let me now join this three with an envelope like this, so this will be the flux density at time equal to 0 degree. Now what happens at say t equal to 90 degree ok? So, this is 90 degree; that means, here consider this point. Now I 1 is positive and maximum ok, so; that means, we will have maximum flux here and in the same direction like this.

So, the flux will be like this maximum, here flux will be in the same direction like this upwards and the magnitude will be maximum why these two are in the opposite direction because you see these two coils are in they are in series so that if this current is flowing in this direction then this kind is flowing in the opposite direction. So, their flux will also be in the opposite direction and what about this flux here? This current is 0 so there will be no flux here.

Now, I can join this with an envelope like this ok, so the flux lines are like this now how will it be at say 180 degree? So, it is like this which is here this is 180 degree.

Once again I_1 is 0, so no flux here, no flux here, no flux here and I_2 is positive and maximum. So, here the flux will be downwards and maximum like this. So, I can join all this with an envelope which will look like this. So, this is at 180 degree similarly you can draw for 270 degree. So, I am doing it quickly now. So, for 270 degree green or I_2 current is 0. So, no flux here I_1 is negative and maximum. So, flux here will be upwards here it will be in the opposite direction of course, so it will be downwards and let me join them so this will be the flux pattern ok.

So, how the flux pattern changes with time? This is the time axis and this is the spatial variation this is temporal variation this is spatial variation ok. So, if you see that as if these flux lines or this flux pattern is moving from left to right ok. So, maybe to make it more clear, let us see some intermediate positions say here which is 135 degree ok. So, 135 degree is here, so this is 135 degree ok, now at 135 degree I_1 is positive, but its less than maximum.

So, we will have some positive so flux downwards, but it will not be maximum it will have some lower amount smaller amount some small value, here also we will have some flux, but the value will be smaller. And here the red current is or I_1 is positive, so we will have downwards flux, but the value will be smaller because this is not at the peak again, so we will have some small value like this. Now we can join all this with an envelope like this ok.

So, you see that from say from here to here, so let us consider the move the time from 90 degree to 180 degree, you see this downward flux it has it is concentrated here ok. So, this is the center of the downwards flux and now at 135 degree the center of the downwards flux is here. And then at 180 degree the center of the downwards flux is here. So, as if these downwards flux is moving from left to right ok. So, you see this is the motion so this is the center of downwards flux.

Similarly, if you think about this center of the upwards flux, so this is the center of the upwards flux ok, so here this is also the center of the upward flux. So, let us consider from 0 to these 0 to 90 degrees, so you can draw also something between 0 and 90 degree which is 45 degree, then also you will see that this is also moving from left to right ok.

So, this plus pattern is moving from left to right, so flux pattern is moving from left to right ok. So, in this video what we see that, we have 3 coils all are stationary none of them are moving ok, these coils are not moving, but the current in them they are changing. These are AC currents and the currents these two currents red and green they are 90 degree out of phase, one lagging a green current is lagging the red current by 90 degree. And now if we consider the flux pattern below these three coils, then we see the flux pattern is moving from left to right as the time increases as the time progresses, but no object is physically moving only the current is varying.

So, this is how we can create a virtually moving magnetic field without any physical object being moving ok. So, this is what we will need in our next class. So, in this class we have seen two important phenomena one is Eddy current motoring and braking where we have seen, if a magnet moves with respect to the plate then the plate also tries to move in the same direction. Or if the plate is trying to move with respect to the magnet, then the magnet tries to stop the relative motion of the plate these are called Eddy current motoring and Eddy current breaking this is one phenomenon which we have studied in this class.

Another phenomenon which we have studied is that we can create virtually moving magnetic fields without moving any physical object ok. So, if we have time varying currents then we can create a moving magnetic field without moving any object physically. In our next video in our next class we will see some nice demonstration of this fact and then we will talk about the energy meter where these two phenomena are used ok. So, let us meet in our next class.