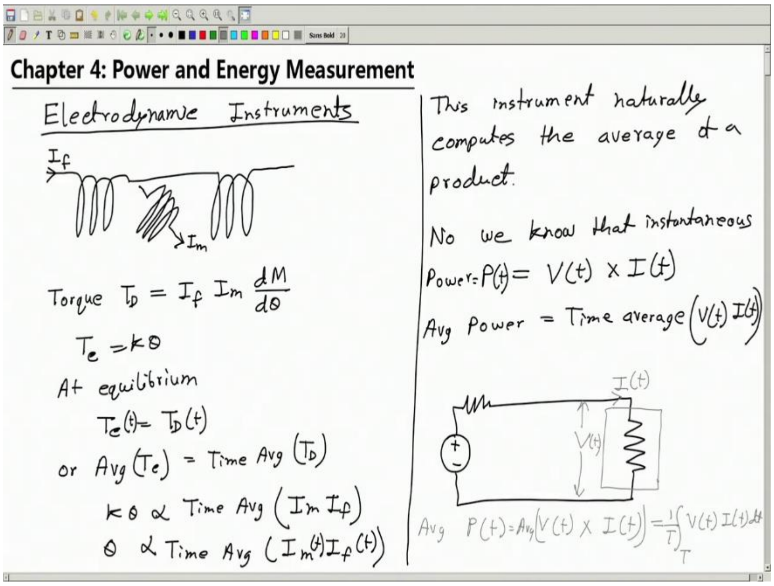
Electrical Measurement And Electronic Instruments
Prof. Avishek Chatterjee
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 27
Wattmeter Connection and Compensated Wattmeter

Welcome again so, today we are going to start a new chapter of Electrical Measurement. So, we are going to start discussing about power and energy measurement ok.

(Refer Slide Time: 00:35)



So, this is very important you know why so. So, we will start this chapter by with a small recapitulation of electro dynamic instruments. So, recall that an electro dynamic instrument has 2 sets of coils, a fixed set of coil; fixed set of coils and a moving coil which can turn or rotate between the 2 coils 2 fixed coils. So, this is and we can pass a current say called I is I f for fixed coil and a current called say I m, m for moving coil.

$$T_D = I_f I_m \frac{dM}{d\theta}$$

$$T_C = K\theta$$

you can equate this to which will give you that theta. So, at equilibrium at equilibrium you can write that T C = T D. If these constants if they are not changing or if they are time varying quantities, then you can possibly write it as that the average value of T C should be equal to average value of T D ok. So, if it is time varying and if it is varying with a very high frequency when can it vary it can vary if I m and I f they are varying then T D can vary.

So we know that if the frequency is small, then is low then the pointer can oscillate, but if the frequency is high then this pointer settles at some average position. So, it may it write it as average of T C time average of T C is same as time average of T D and then if the pointer is not moving, then the average of this is same as K θ and so this side we can write time average of this is proportional to I m and I f and this is a constant so, some constant. So, you may write just write it as a proportionality, also you can write it like this way and therefore, theta will be proportional to this is also a constant you can write this as time average of this Im If and we put a t because both of them are functions of time ok.

So, therefore, the deflection θ will be proportional to the average time average of this product Im and I_f ok. So, this instrument by it is nature so, this instrument naturally computes product and take average computes the average of a product average of a product of 2 quantities ok. So, this is the property or beauty of this electro dynamic instrument, the pointer naturally indicates naturally it in inherently it indicates the average time average of some of 2 of the product of 2 quantities ok. And now we know that power is nothing, but voltage times current so, this is instantaneous power and average power so time average; average power. So, this is nothing, but time average of these 2 quantities Vt and It.

P(t)= V(t) X I(t)

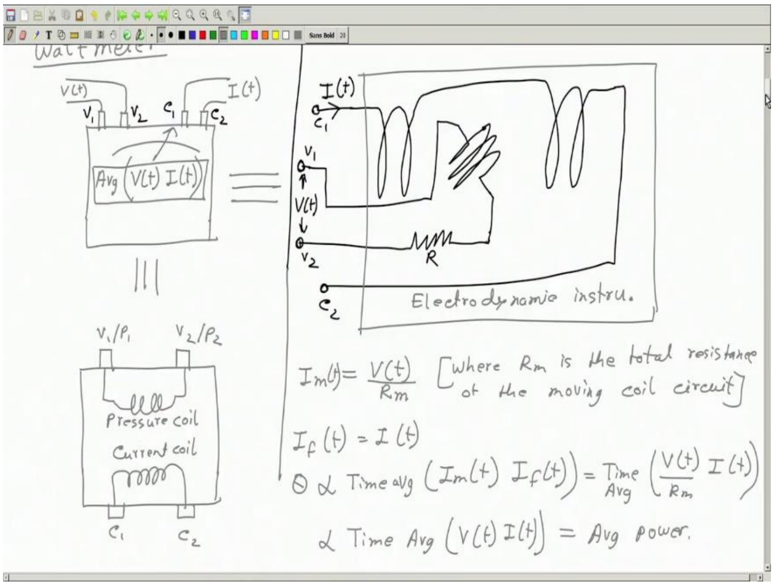
So we need to compute this product and then take an average that will give us the average power ok. So, suppose I have a power source battery and then I have a resistance ok. So, you can have also some other resistances here. So, this is a circuit and I am interested in finding out the power consumed in this resistance in this load ok. So, how much is the power consumed here by this resistance or what is the rate of heat generation here ok.

So, for that what we have to do, we have to find the current ok; so we have to find the current through this I and we have to measure the voltage V across this resistance and if it is time varying we can write it like this, then we can we have to take the product of V t and I t and then we have to average it; then we have to average time average. Time average means integrate it over a complete period and divide by the time period. So, this is like integration over a complete period

Avg P(t) = Avg [V(t) X I(t)] = $\frac{1}{T} \int V(t)\ I(t) dt$

This is what is average ok. Now, how do we find it? So, in general therefore, we need an instrument which can take 2 values as input, find their product and compute it is average and give the result and that instrument is called an wattmeter ok. So, what is an wattmeter?

(Refer Slide Time: 09:36)



So, wattmeter; so a wattmeter has a box it will have 4 terminals ok, 2 of them to take a voltage as input, 2 of them to take a current some current I as a input and this wattmeter it is task has a black box of this wattmeter is to multiply this quantities and then average and the pointer should indicate this value. This is the task of an wattmeter, it should have 2 inputs, one voltage, one current and it is task is to take the product of this 2 average over time and show that through the pointer ok.

Now, how can we achieve this? This is achievable if we use an electro dynamic instrument, because we have seen an electro dynamic instrument inherently naturally do does this it in it inherently computes an average of a product ok. So, what we can do so, we will do this. So, we will take a electro dynamic instrument, this is the moving coil and we will pass the current I this current I through this moving coil and we will have this sorry fixed coil this is fixed coil and then we will have this moving coil and we can connect say a resistance in series with it some resistance R ok and then we will apply this voltage V across this 2 terminals. So, we will apply V here ok.

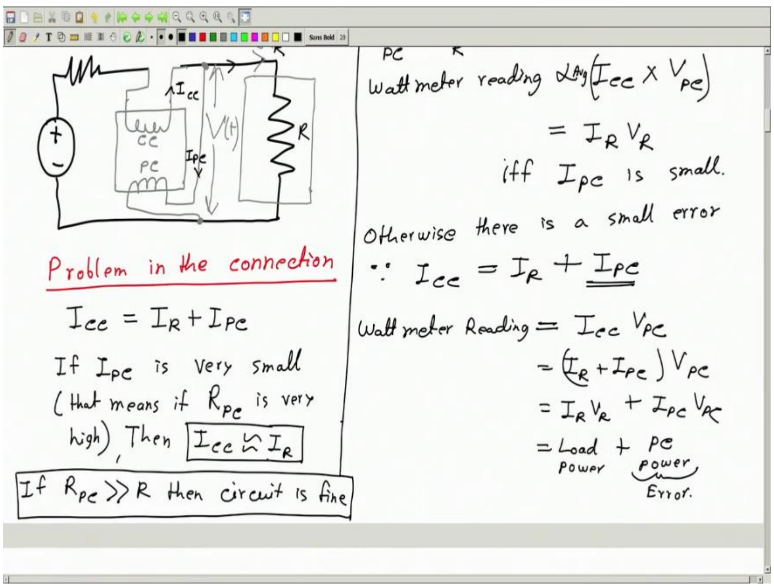
And we will apply and we will let this current I to flow like this. So, if I name this terminal call it V 1 V 2, C 1 C 2 ok, then we have V 1 V 2, C 1 C 2 these are the 4 terminals and this is my wattmeter this is my wattmeter ok. So, this is this wattmeter, here I have drawn it as a black box, but this is actually an electro dynamic instrument ok. Now, how much will be the current flowing through this moving coil I m ok. So, $I_m(t) = \frac{V(t)}{Rm}$ which is in this path. So, I am including this coil resistance so, let me call this R m, where R m is the total resistance of the moving coil circuit; moving coil circuit ok; that means, this plus the coil resistance everything this is I m I m t.

And what is I f t? This is nothing, but this I t ok. How much will be the angle of deflection of this coil theta. So, θ by principle of electro dynamic instrument is this time average of I m t and I f t ok. So, this is proportional to that ok

$$\theta \ \alpha \ time\ avg\ [I_m(t) I_f(t)] = \text{time avg } [\frac{V(t)}{Rm}\ I(t)]$$

Now, if we go back to this circuit where we wanted to measure the power consumed in this load ok. So, we wanted to measure the power consumed in this resistance, how can we do that?

(Refer Slide Time: 16:43)



So, we will take our wattmeter ok. So, we will take a wattmeter which is nothing, but an electro dynamic instrument and it has 2 sets of coils ok. So, one is this fixed coil, another is this moving coil, instead we can call them also a current coil and the voltage coil, the coil which whichever carries the current we will call that as the current coil and the coil that carry that is connected to the voltage we will call that the voltage coil ok. So, here so, this is equivalent to this and then this diagram instead of drawing it like this we can also draw it simply like this. So, we will draw a box and it will have 4 terminals, we can draw the 4 terminals also like this V_1 V_2 and C_1 C_2 here.

So this is equivalent to this and we actually have this coils inside, now we will depict this coils simply like this with the coil between this 2 terminals which is this coil and another coil between this 2 terminals which is this coil ok. This we will call the current coil and this we will call the voltage coil or you can call it pressure coil we generally call it pressure coil you can also name it as P_1 P_2 or you can call it potential coil as well whatever you like ok. So, this is an wattmeter which has 2 coils and the task of the wattmeter is simply to take a product of this 2 quantities, voltage and this current and compute the average that is what an a wattmeter is.

Now, in this circuit we want to measure this power. So, what we need, we need the wattmeter. So, let us bring our wattmeter let us put it here, it will have 2 sets of coils, one of them you can call the Current Coil in short CC, another you can call as the Pressure Coil in short PC ok. Now, this current coil should measure the current flowing through this resistance, how is that possible? for that we have to make a small disconnection here and connect this current coil like this in series. So, the same current flows through this current coil and through this resistance so, the current coil is measuring the current.

And then the pressure coil should measure the voltage between this 2 terminals right. So, we have to connect this like this one terminal here and the other terminal here. So, this pressure coil is getting a sense of this voltage across this resistance. So, the pressure coil is sensing the voltage, current coil is sensing the current, the wattmeter which is this electro dynamic instrument is taking a product of these two and an average and the pointer is showing the average of the product of this two, this is how to connect a wattmeter. So this is how to connect an wattmeter; how to connect an wattmeter, this is the way you can understand this.

Now, in the rest of the video we will talk about some problem in this connection and ask solution ok. So, there is a problem in the connection. what is that problem? Observe that the current which is flowing through this current coil ok. So, call it I_{CC}; I_{CC} part of it goes through the resistance call this current I_R and part of it is going through this pressure coil call this current as Ipc high pressure coil. So, the problem is I_{CC} is equal to I_R + Ipc ok.

Now, if Ipc is very small that is possible only if; that means, if the resistance of this pressure coil circuit call that R_{PC} resistance of this circuit is very high, then I_{CC} is almost equal to I_R and the voltage across the pressure coil this is definitely same as the voltage across the resistance. So, voltage across pressure coil is definitely equal to voltage across the resistance ok.

So, therefore, the wattmeter reading which is proportional to the current through the current coil and multiplied by the voltage across the pressure coil V_{PC} and an average if these are time varying quantity then you can take an average ok. So, this is the wattmeter reading, this will be same as I_R, V_R if this is true; that means, if Ipc is small if Ipc is small only if only then this is true ok. Otherwise there is a small error since I current called I_{CC} is equal to R plus this extra current Ipc this is the problem. So, this will be the error ok. So, the error will be so, the error or then the wattmeter reading then the wattmeter reading will be, so it will be proportional to and the proportionality constant is known to us. So, let me just write it as equal so, this then it will be

$I_{CC}=I_R+ Ipc$

Wattmeter reading = I_{CC} V_{PC}

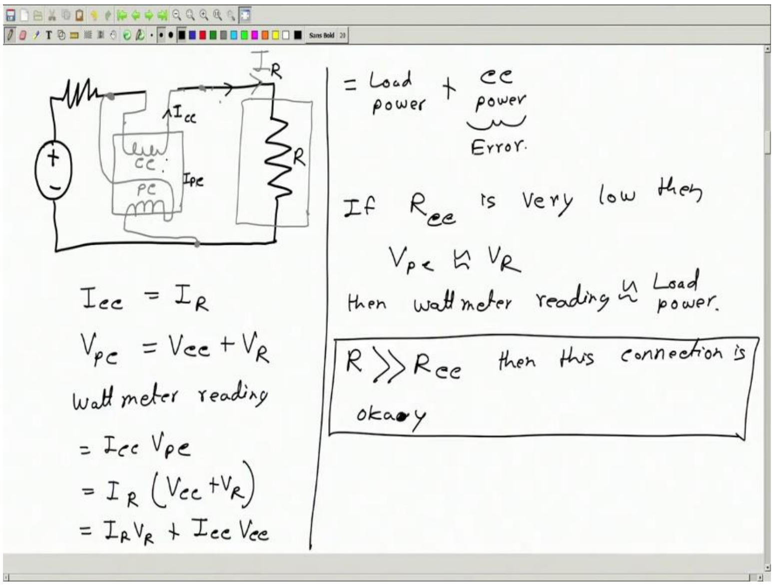
$= (I_R+ Ipc)\ V_{PC}$

$= I_R\ V_R+ Ipc\ Vpc$

=load power + Pc power (error)

And if you recall that we actually had a similar problem very similar problem when we were discussing about the measurement of a resistance using voltmeter ammeter method. Again then we were measuring the current through the voltmeter through the resistance with an ammeter and the voltage across it with the voltmeter and the problem was similar, because the ammeter was measuring more current than the current in the resistance. So, here also we have the same problem, we have an error and once again if you try to connect this in a different way like.

(Refer Slide Time: 27:30)



So, suppose we connect it in a different way so, that this current coil is connected after this voltage coil ok. So, we may connect this voltage coil this here ok. So, then the current coil is measuring the right current definitely Icc now is same as I R. So,

Icc = I R,

Vpc =Vcc +V_R

Wattmeter reading

= Icc Vpc

=I_R (Vcc + V_R)

=I_R V_R + Icc Vcc

= load power + CC power

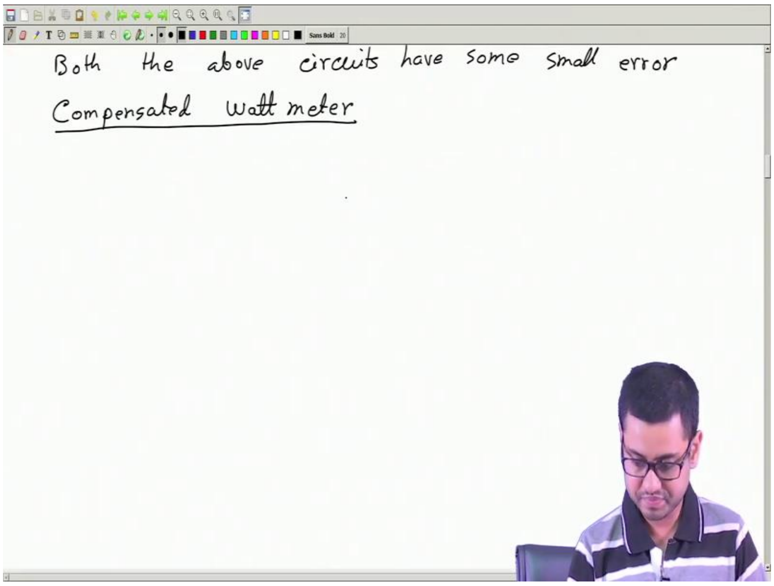
Once again if say a the resistance of the current coil is very small. So, this is like I mean like an ammeter ok. So, this is like an ammeter this is like a voltmeter and ideally an ammeter should have very low resistance. So, if it is very low so, then if R_{CC} is very low, then V_{PC} this will be almost equal to V_R because this will be of much smaller value, because this resistance is small. So, voltage drop is small and then wattmeter reading will be same as the load power ok. So, this coil as I was saying it behaves like an ammeter coil, this coil behaves like an voltmeter coil.

So, it should have a infinite resistance, it should have 0 resistance. So, if it is so, if it really has a 0 resistance or very small resistance, then no problem if it has high very high resistance then also no problem, but nothing is infinite nothing is 0 practically so, we may have some small error. And then it depends once again on the relative value of this resistance, this resistance and this resistance. If it happens that this resistance is much call it R, if this R is much higher than R_{CC} then this connection is fine ok.

Then most of the voltage drops here very little voltage drop occurs here. Similarly in the previous circuit sorry for this ok. So, in this circuit if this resistance is much much higher than this resistance R, if R PC >>> R then this circuit is fine. So, it all depends on the relative value of the 3 resistances R, R_{PC} and R_{CC} ok.

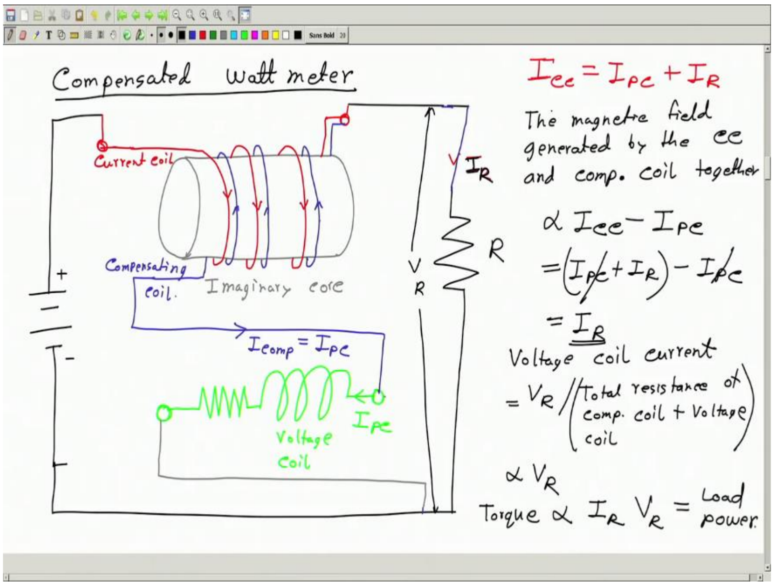
Depending on therefore, the value of this resistance, this and this resistance you may choose which circuit to use this circuit or that circuit. If you have a resistance which is very small if this resistance is very small, then you should use this circuit and if this resistance is very high, then you should use this circuit ok. But both the above circuits have some small error.

(Refer Slide Time: 33:56)



Now we are going to show you new solution; solution to this problem where this error will be avoided and that is called a compensated wattmeter. So, this is the next topic.

(Refer Slide Time: 34:42)



So compensated wattmeter so, it has definitely 2 coils ok. So, let me draw the 2 coils first, I will draw the 2 coils on a fictitious cylinder and you know that there is actually no code used in a electro dynamic instrument and wattmeter is nothing, but an electro dynamic instrument. So, it has actually no code so, this is a fictitious code. So, this is a fictitious imaginary so, imaginary you can call it imaginary code I am using it for imaginary code for ease of drawing.

And then we will have a coil which goes like this ok. So, this is the current coil ok, so this red one is the current coil, these are the 2 terminals and then we have let me draw the pressure coil, voltage coil. So, I can draw the voltage coil just simply like this and let there be a large series resistance added to it this is a voltage coil. So, this series resistance is added because voltage coil should have ideally infinite resistance otherwise and also this will be connected directly to the for voltage measurement, if it do not have enough resistance then a large current can flow ok.

Now, say I have the load resistance here so, this is the load resistance R which is being fed by a battery and we want to measure the load power or the power here ok, now for that this coil should measure the voltage ok. So, what we will do? We will connect the first the voltage coil and this current coil we will connect in series like this ok. So, now, we will have this current coil is actually measuring more current ok, because it is measuring this current I R plus this current ok. So, this is a problem, to get rid of this problem we will do this, we will take another wire which will start from here and we will wrap it on this fictitious imaginary cylinder in the opposite direction completely opposite direction ok.

So, if say so, that if the current was flowing like this; this wire should have current in the opposite direction and we will have exactly same number of turns as this current coil has and we will connect this here. So, now, this coil we call the compensating coil the blue one is the compensating coil ok, now let us see what happens. We know that the, so we know that the current that is flowing through this red coil ok. So, I_{CC}; I_{CC} current coil current is equal to how much this will be.

So, this current is going like this and from here a part of the current goes through this resistance which is I_R let me write it in black and part of this current goes through this blue wire and then through this voltage coil. So, let me write that in green. So, this current is same as I_{PC} ok, this current through this compensating coil ok, you can write it as I comp, comp is same as I_{PC} ok. So, I_{CC} is therefore, sum of I_{PC} plus I_R ok.

. Now, the magnetic field generated together by these current coil and compensating coil that is how much. So, let us write the magnetic field generated magnetic field or magnetic effect generated by the current coil and compensating coil together comp coil together, this will be proportional to how much, this forward current which is I_{CC} minus this backward current, because this backward current is creating flux or magnetic field in the opposite direction call that I that is how much I_{PC}.

Now, we have seen that I_{CC} is $I_{PC} + I_R$ so, therefore, this is equal to $I_{PC} + I_R - I_{PC}$ and this I_{PC} this I_{PC} cancels. So, this is equal to I R load current only and how much is this current or how much is the magnetic effect generated by the voltage coil ok? So, voltage coil current is same as the total voltage from here to here starting from here to here. So, this voltage call it V_R starting from here up to this ok. So, that is V_R divided by the total resistance in this path this blue wire, then this green wire, then this resistance so this total resistance so, total resistance of compensating coil plus this voltage coil V divided by this. Now, this is a constant this resistance is a constant. So, therefore, this is proportional to V R and then how much will be the torque?

Torque will be proportional to the magnetic field generated by this and the magnetic field generated by this ok or this magnetic field generated by this 2 together blue and red current coil and compensating coil and the current here through the pressure coil or voltage coil. So, this will be proportional to therefore, this which is I_R and this V_R this is nothing, but load power ok.

So, the beauty of this circuit is that the extra current that this current coil is carrying, extra current which is nothing, but this I_{PC} voltage coil current is going in a backward direction cancelling it is own affect cancelling it is own magnetic affect and then it is going through like this ok.

So, therefore, whatever the current through this voltage coil that that is definitely coming through the current coil, but it has ultimately no affect, because it is it is affect is cancelled by this compensating coil ok. So, therefore, the torque is proportional to the load power and therefore, definitely wattmeter reading will be proportional to the load power, the power in the voltage coil will not come in picture. So, this is compensated wattmeter.

Thank you.