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

Lecture - 42
Current transformer and potential transformer

Welcome, today, we are going to start a new chapter which is on Current transformer and potential transformer; they are called CT and PT in short.

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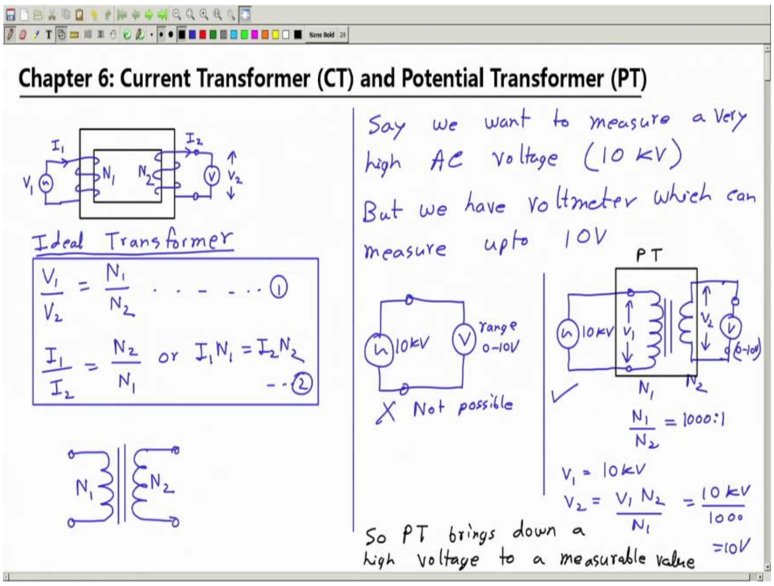

What is a current transformer or what is a potential transformer? So, as the name suggests these are basically transformers just transformer, what is a transformer? So, a transformer an ideal transformer basically has a magnetic core and we have a couple of coils 2 coils wound on top of it.

And, now, if we apply a voltage alternating voltage AC, in one of the coils and call this voltage as V_1, then we know that a voltage is induced in the other coil, which you call this secondary coil. If, this is the primary coil, then this is the secondary coil and here we will get some voltage.

So, if we connect a voltmeter, then we will have a voltage detected by this voltmeter. And, we know that if the number of turns for the primary is N_1 and the number of turns for of the secondary coil is N_2, then and if we call this voltage induced in the secondary is V_2, then we know that the relationship $V_1/V_2 = N_1/N_2$, this is true for an ideal transformer.

And, also if the current that is flowing in the primary coil is I_1 and if any current I_2 flows here in the secondary, then the relationship between I_1 and I_2 is given by, it is the opposite N_2 by N_1. Here, $I_1 / I_2 = N_2 / N_1$ opposite or you may write, this as this is what happens in an ideal transformer.

So, this is the property of an ideal transformer. And, we will call and transformer or an instrument as an ideal transformer, only if these two relations are satisfied true perfectly true. Then only we will call that transformer as an ideal transformer, but practical transformers you may already know that they do not obey this relationship perfectly, they deviate from this relationship some somehow somewhat, and that is practical transformer where this is not exactly true ok.

Now, let us start with an ideal transformer only. So, and how can we use this transformer for measurement, say we want to measure a very high voltage, very high AC voltage of course, say maybe around 10 kV 10 kilo volt, but we have volt meters we have a voltmeter, which can measure up to say 10 volt maybe.

And, so, can we can we connect can we use this voltmeter to measure 10 kilo volt? No not directly, why because firstly the voltmeter itself may get damaged immediately as soon as we connect this 10 volt voltmeter to a 10 kilo volt source. If, we connect it this way the voltmeter may get damaged immediately, because of this high voltage applied across it. So, high current will flow and it may get damaged immediately that is one thing. Even, if it is not damaged then you know that the maximum reading can be only 10 volt. So, pointer can never indicate 10 kilo volt. So, this is not possible. So, this is not possible to measure in this way

Now, what can we do? We can use a transformer to step down this voltage to a lower voltage and then we can measure it. So, what we can do? So, this is the source which is 10 kilo volt let us connect this to a transformer. And, the symbol of a transformer is often like this, you know. So, this is the schematic primary with N 1 turns, secondary with N 2 turns, and if I draw these lines between them, which means it is a iron core transformer.

So, what we can do? We connect this to a transformer; step down transformer, where N 1 and N 2 are the number of turns for primary and secondary with $N_1 / N_2 = 1000$. And, here we will connect the voltmeter; it is range is 0 to 10 volt. So, this voltage is 10 kilo volt, but this transformer is a 1000 is to 1 transformer.

$V2 = \frac{V1\,N2}{N1}$ = 10kV/1000 = 10V

So, this way we can measure a large voltage a huge voltage with a ordinary range voltmeter. And, then this transformer which is just a transformer will be called as a Potential Transformer or PT. The function of this potential transformer is to bring down this unknown this high voltage to a smaller range which we can measure easily.

So, PT, potential transformer brings down normally brings down, never I mean we generally do not need PT to increase the voltage. So, PT brings down the brings down a high voltage to a measurable value, suitable lower value, that is what a potential transformer does.

Now, So, now we know what a PT is now let us see what a current transformer is once again see I have a transmission line like this, where say 1 kilo ampere current is flowing.

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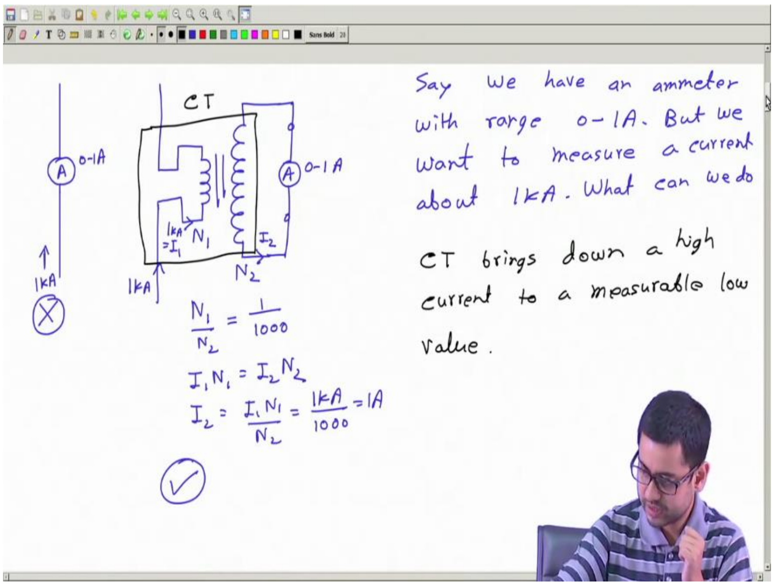

Now, I want to measure this current, what we normally do? We normally have to open this circuit insert an ammeter in series with this line and then this ammeter will indicate the current.

Now, say I have an ammeter with range 0 to 1 ampere, but we want to measure a current near current about 1 kilo ampere. So, what can we do? We cannot connect this ampere which has a range of 0 to 1 ampere like this, because immediately then this ammeter will burn such a huge current will flow through it will get damaged in no time. So, this is wrong circuit.

Now, what we can do? What we can do is this. If, this is the transmission line we will open it and connect a transformer here, the primary side of the transformer will be connected like this, and the secondary side we will connect it to an to this ammeter 0 to 1 ampere ammeter. And, now if we choose this ratio N 1/ N 2 primary number of turns and secondary number of turns such that, N 1/N 2 = 1/1000, then if this current is 1 kilo ampere then; that means, 1 kilo ampere current is flowing here, the current that will flow in this circuit I_2 this is I_1 ok.

So, we can write $I_1 N_1 = I_2 N_2$. So,

$$I_2 = \frac{I1\,N1}{N2} = 1\text{kA}/1000 = 1 \text{ A}$$

So, this is just 1 ampere, which we can measure with this ammeter. So, this circuit is fine; we can use this circuit to measure a huge current. And, then this transformer, this transformer we call this a current transformer. And, the function of the current transformer is to bring down a high current to a measurable low value; that is the function main function of the current transformer is.

Now, there are other functions as well we will talk about them soon.

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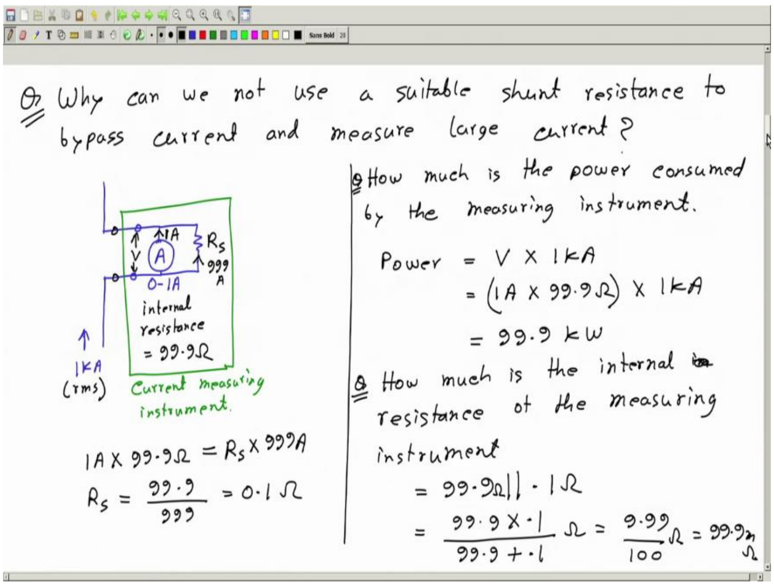

But, before that you may ask a question that why can we not use a suitable shunt resistance to bypass current and measure large current in this way?

So, that is also a possible way. So, if I want to measure a huge current like this one So, I have around 1 kilo ampere current. So, what I can do I connect an ammeter whose range is 0 to 1 ampere to this and we put a suitable shunt resistance a small resistance ok, such that most of the current get bypassed through the shunt resistance that is also possible. So, you may ask why should we not use this scheme instead of using a current transformer, what are the relative advantage and disadvantage.

So, let us take an example to understand this what is the merit of using a current transformer. Say for example, the internal resistance of this ammeter is 99.9 ohm. This is just an example, say this is the internal resistance. Now, let us ask what should be the value of RS so, that we can measure 1 kilo ampere with this arrangement.

So, now here this is this two together forms the measuring instrument. So, this is the measuring current measuring instrument, which is composed of a 1 ampere ammeter with a suitable shunt resistance. And, the value of the shunt resistance should be how can we compute this? So, we want that if this current is 1 kilo ampere only 1 ampere current will flow through the ammeter. So, this current here will be 1 ampere and remaining current will go through the shunt. So, this value will be this is 1000 ampere this is 1 ampere. So, we will have 999 ampere current flowing through the shunt.

Now, from this we can write 1 ampere which is the current through the ammeter multiplied by this resistance 99.9 ohm, which is the ammeter resistance ok, or meter resistance. This should be equal to the voltage across these 2 terminals, which is same as the voltage across these 2 terminals. So, we can write this as R s multiplied by the current through the R s, which is 999 ampere and then R s will come out to be 9 999.9 divided by 999.

So, this is 0.1 ohm right. So, R s = 0.1 ohm. And, if we choose R s to be so, then this will be my measuring instrument which will measure this current ok fine.

Now, let us estimate 2 quantities; number 1. How much is the power consumed by the this measuring instrument. So, the power consumed by the measuring instrument will be how much? It will be this voltage multiplied by the current, if I call this voltage as V. So, power will be same as the product of V and the this current as you mean these are RMS values, this is RMS value, by default in case of SCDS RMS. . And this is resistive so, power factor is 1. So, there I mean this is resistive this is also resistive. So, power factor is 1.

Power= V x 1kA =(1Ax99.9 ohm) x 1A = 99.9kW

Then, also let us ask another question, how much is the internal impedance or resistance of the measuring instrument that means this thing. Together this ammeter and the shunt resistance what is the internal resistance of this combined thing. So, this is nothing, but parallel combination of R s and this meter resistance.

= 99.9 ohm || 0.1 ohm

$= \frac{99.9 \ x \ 0.1}{99.9+0.1}$ ohm= 99.9mohm

Now, let us compare this with the scenario where we are using this current transformer ok.

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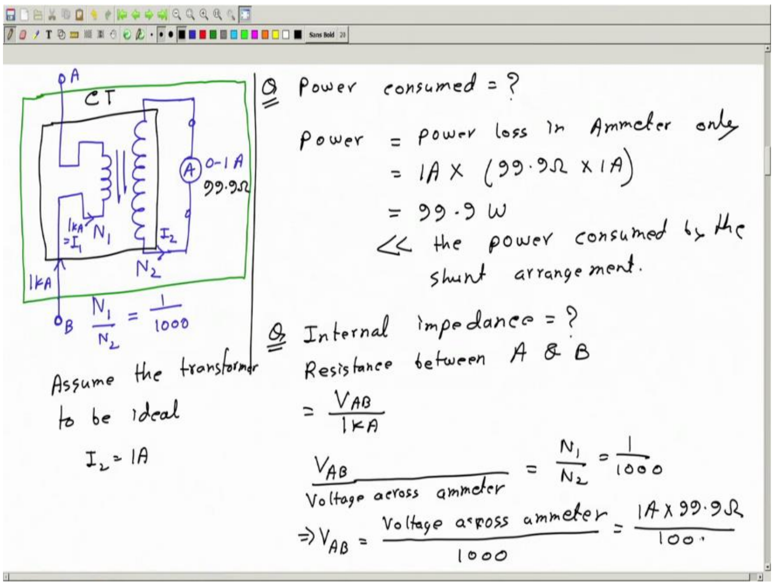

So, if we use this current transformer then, once again let us ask how much is the power consumed. Now, the power consumed so, this is an ideal transformer.. So, this is an assume the transformer to be ideal. So, there is no loss at all in the transformer. So, and practically no transformer is ideal so, there will be some loss. But since the transformer loss is very generally very low transformers are highly efficient instruments. So, we can ignore for to get a rough idea about the power consumed.

So, power will be equal to so, no power is lost in the transformer, the power is lost only in the ammeter. And, the ammeter resistance is 99.9 ohm and the current flowing through this I 2 is I 2 is equal to as we calculated before this is 1 ampere ok, I 2 is equal to 1 ampere we have calculated this before. So, power will be power loss in ammeter only, which is same as 1 ampere multiplied by I square R.

Power =power loss in ammeter only

= 1A (99.9 ohm x 1A) = 99.9 W

Now, let us ask the other question, what is the internal impedance of the measuring instrument? Now, what which is my measuring instrument? My measuring instrument is this transformer together with this ammeter. So, I can say that this two things together is my measuring instrument, the current enters through this and leaves through this.

So, how much is the internal impedance between this two terminals; terminal call this AB. So, impedance between A and B or resistance between this will be how much so, that will be this voltage that will appear between A and B, V_{AB} divided by the current, that is flowing from a to b which is 1 kilo ampere. Now, how much is V_{AB}? Let us find V_{AB} to find V_{AB} let us first find the voltage across the ammeter.

$$\frac{V_{AB}}{voltage\ across\ ammeter} = \frac{N1}{N2} = 1/1000$$

$V_{AB} = \frac{1A\ x\ 99.9\ ohm}{1000} = 99.9/1000$ V

So, this is V AB.

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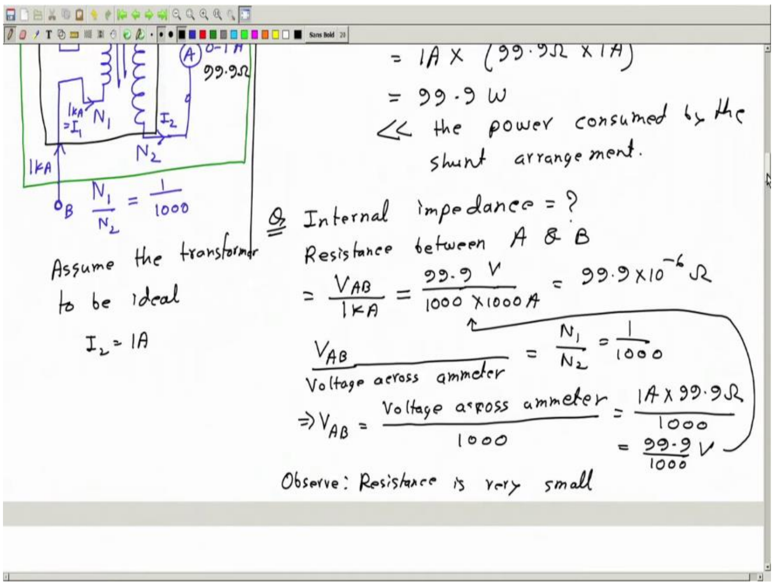

So, you see this resistance is very small. So, observe resistance is very small, and much smaller compared to this arrangement where we had 99.9 milli ohm but here it is 99.9 micro ohm. So, this internal resistance is much smaller and when measuring an current with any instrument we want the instrument to have small internal resistance right. So, ammeters we want to have ideally 0 resistance lower the resistance is better because then there will be less voltage drop across the meter across the meter or measuring instrument.

So, the original current will not change much and here we see if we use a city current transformer, then the arrangement, then the measuring instrument has much smaller internal impedance compared to a shunt scheme. And, we also have seen the power loss in the measuring instrument it is also much smaller.

So, these are some advantages of using a current transformer instead of a shunt resistance. So, these are the advantages of a some of the advantages of a current transformer.

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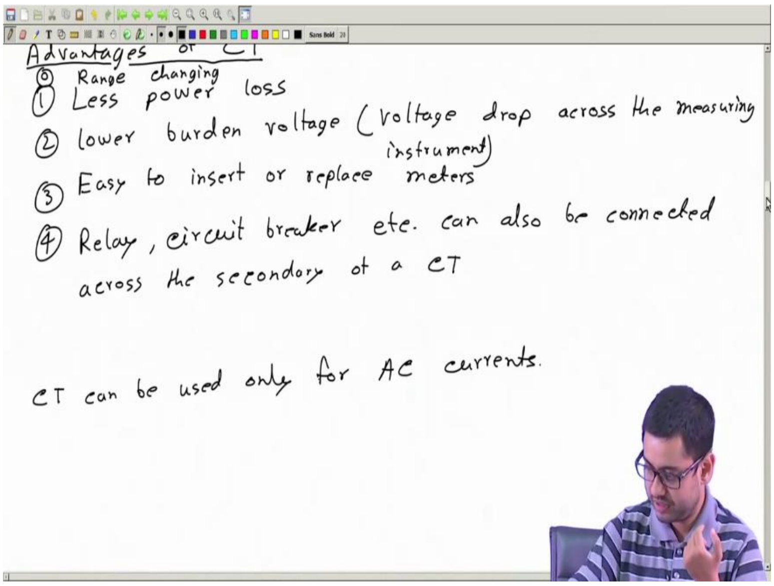

So, let us write advantages of CT number 1- less power loss, number 2- lower internal impedance, or which we can write as lower burden voltage. What is burden voltage? We have defined this burden voltage is nothing but the voltage drop across the meter, voltage drop across the measuring instrument.

Of course, the first advantage or you call it the zeroth advantage is range changing, which you have already have said, if we want to measure a high current with a normal ammeter we have to bring down the current to a measurable value. So, that is the first use of course. Another point I will; so, these are some of the advantages we have seen so, far ok fine.

Now, the of course, obvious fact is that CT can be used only for AC circuits, AC currents, because transformers do not work with DC at all. So, for DC circuits we cannot have a current transformer and ok.

Now, let us do a similar analysis with potential transformer.

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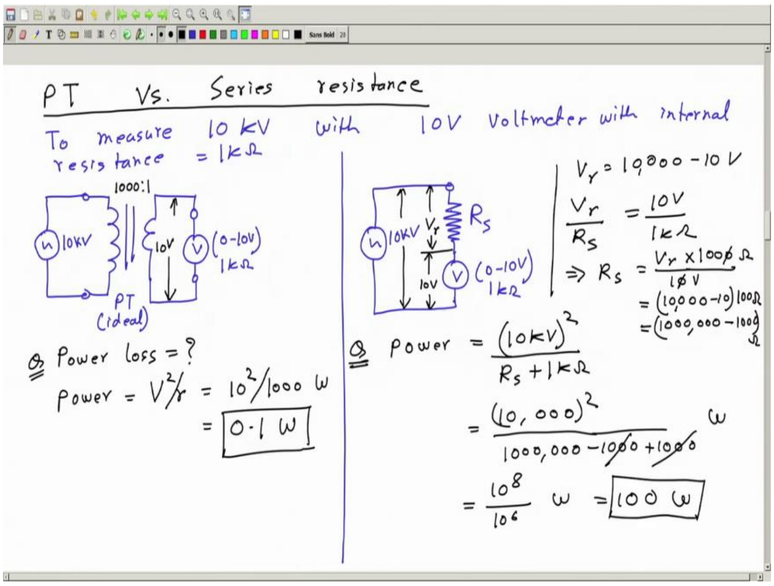

So, let us do the analysis of potential transformer PT versus series resistance, let me before that mention another small advantage, which is about CT. So, with CT so, this is how we use current transformer, the ammeter is connected across the secondary of this transformer.

So, therefore, if you want to change this ammeter due to any reason, you do not have to I mean operate with this 1 kilo ampere line, you can do everything on the secondary side. If, we had the ammeter connected directly in this 1 kilo ampere line and if we want to replace it, we have to I mean disconnect this power supply and this current line, then have to insert a new ammeter which we do not need here. And, also so, so let us write that easy to insert or replace in meters.

Since, the meters are connected only across this secondary of the transformer the main line is not touched at all. And, also one more I think I should know that, current transformer can also be used not to connect only ammeter. We can connect relay and other protective equipment's also in the power system. What is a relay? What is the function of a relay? Or a circuit breaker say, the function of a circuit breaker is to realize, whether the current level is going beyond our acceptable level, if it goes there then the then the circuit breaker and the relay will switch off the power supply.

It is a safety instrument, but the circuit breaker is in a sense also a measuring instrument, why? Because, it is measuring the level of current, whether the level of current is going beyond the safe level or acceptable level or not. It may not display you the number on a screen or with a pointer saying how much the current is, but it is essentially sensing the current, measuring the current, and if the current goes beyond the level, then it does something it stops the current.

So, circuit breakers, relays, they are also in a sense some measuring instrument. And, you can actually connect such measuring such relays, such circuit breakers, also across the secondary of this current transformer, not just meters which give you indication with pointer how much the current is, but also protect the instruments.

So, let us also write relay, circuit breaker etcetera, relay circuit breaker etcetera can also be connected across the secondary of a CT. So, you can connect actually multiple things together,

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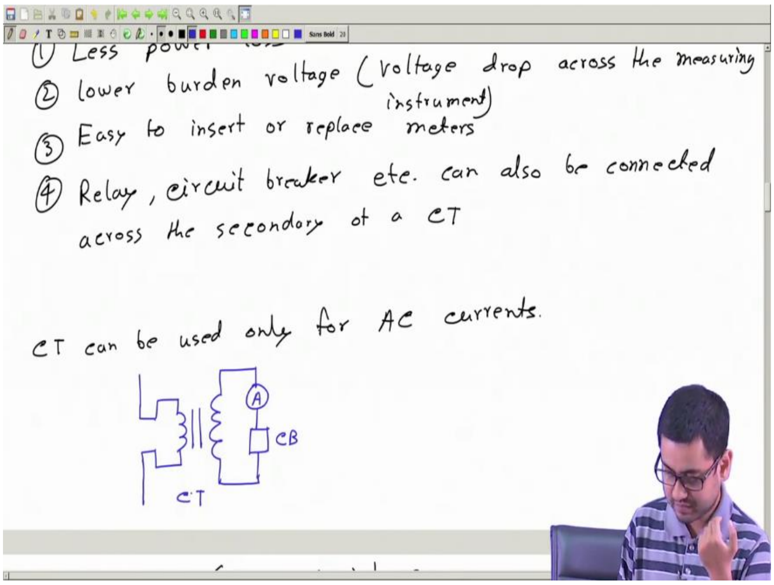

so it is possible that you connect it this way so, if this is the power line, then let this be the primary of primary side of the CT, you may connect multiple equipment's like an ammeter, which will display you the current you may connect say a relay or circuit breaker all across the secondary of the CT. So, this is the CT.

Now, let us come to PT. So, we will do and fast and small analysis a comparison between PT versus series resistance. So, let me take the example I had here. So, I want to measure a 10 kilo volt voltage and I have a 10 volt voltmeter. So, to measure 10 kilo volt with 10 volt voltmeter, we have 2 choices; one is use a potential transformer a step down transformer and then this voltmeter. This is one choice this is 10 kilo volt and it is range is 0 to 10 volt.

Another choice is connect a high very high resistance with the voltmeter this is 10 kilo volt of course, and measure it. So, you have 2 charges.

Now, we will ask the 2 questions of course, one is how much is the power loss. So, for this let us assume the internal impedance or resistance of this voltmeter is let us take it to be 1 kilo ah 1 kilo ohm. So, this is 1 kilo ohm this is this has a resistance of 1 kilo ohm ok. So, we are taking a high value, because voltmeter should have we know volt meter should have high internal impedance One small thing is that the numbers that I am taking is mainly for ease of calculation, mainly for ease of demonstration, practical numbers may differ a bit from this example..

So, how much is the power those here? That will be only the power loss in the volt meter, because we can assume that this PT is ideal. So, no drop I mean no loss occurs here. So, this put PT is an ideal PT. So, the loss occurs only in the voltmeter, then the

power loss = V^2 r 100/1000 = 0.1 V

power = $\frac{10kV^2}{Rs+1\ kohm}$

Vr = 10000-10 V

$\frac{Vr}{Rs} = \frac{10V}{1\ kohm}$

Rs = $\frac{Vr\ x\ 1000}{10\ V}$ = (10000-10)100 ohm

power = $\frac{10kV^2}{(10000-10)100\ \text{ohm}\ +1\ kohm}$ =100 W

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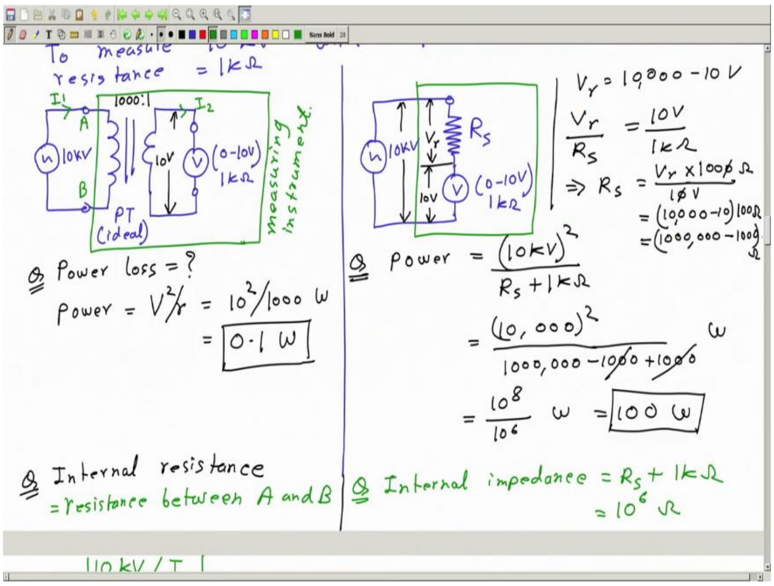

Now, let us ask the other question how much is the internal resistance of this gain internal resistance? So, internal resistance means the resistance of this measuring instrument. So, this together is the measuring instrument, voltage measuring instrument. Now, what is the internal resistance as seen between these 2 points A and B.? So, this is equal to resistance between A and B that you can write as say if this current is I and this voltage is 10 kilo volt.

So, you can write this as the voltage by current 10 kilo volt divided by the current I. Now how much will be this current I? So, for that let us call it I 1. So, this is I 1 and let us call this current as I 2, how much is I 2?

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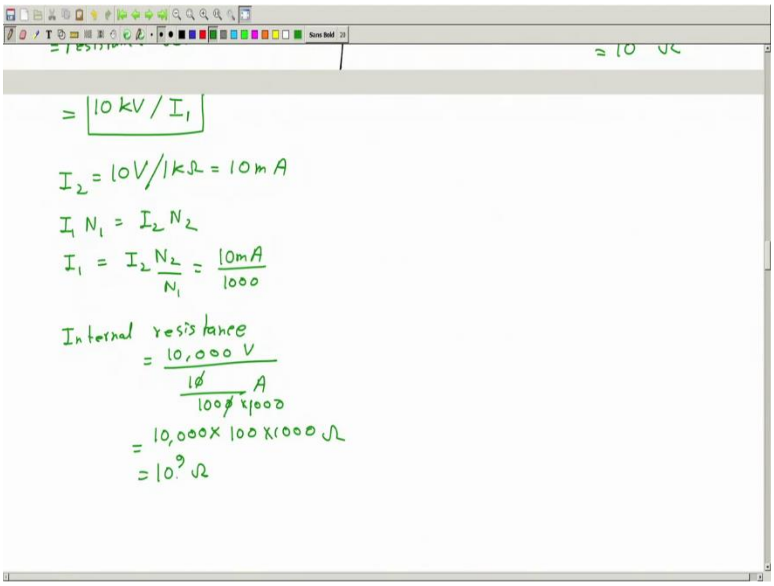

I2 = 10V / 1 kohm =10 mA

I1 = $\frac{I2\ N2}{N1}$ = 100mA/1000

Internal resistance = 10kV/ I1

= 10^{9}ohm

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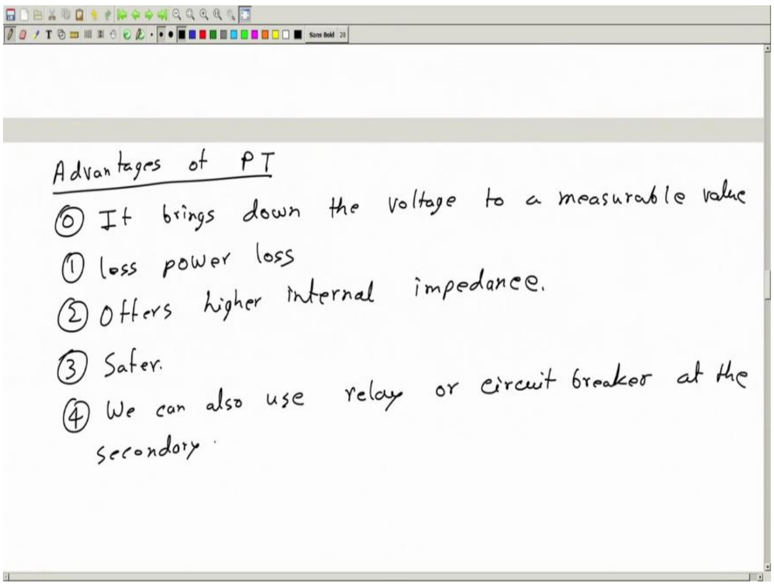

So, the advantages of PT we can write firstly, it brings down the voltage to a measurable value measurable range. Secondly, less power loss compared to series resistance, offers higher internal impedance and we know voltage measuring instruments or voltmeter should have in finite or as large as possible internal impedance, offers higher internal impedance.

Therefore, less current is drawn from the circuit and the original voltage is not changed much and then what else? We can also write that it is safer for the operating personnel, because if somebody wants to connect voltmeter directly to this 10 kilo volt is much dangerous than connecting a voltmeter or disconnecting a voltmeter to this 10 volt side. So, this is safer and you can also connect like in the case of ah CT, you can also connect other equipment's like circuit breakers relay like in this case a over voltage relay or something to this PT.

So, you can also connect relay or circuit breaker at the secondary.

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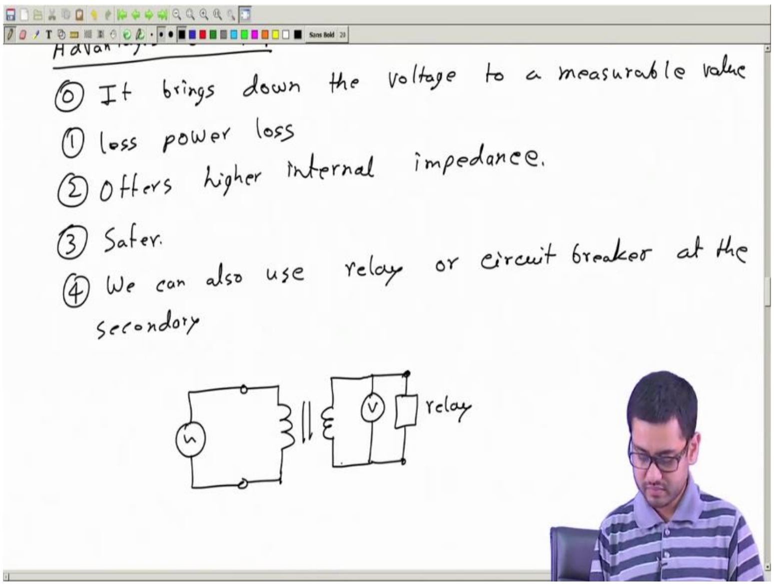

So, like this, so, if this is an unknown voltage we want to measure, So, we can connect it to a step down PT transformer and then here we can connect the voltmeter, which will indicate the voltage, we can connect relay circuit breaker, whatever we want other instruments like this.

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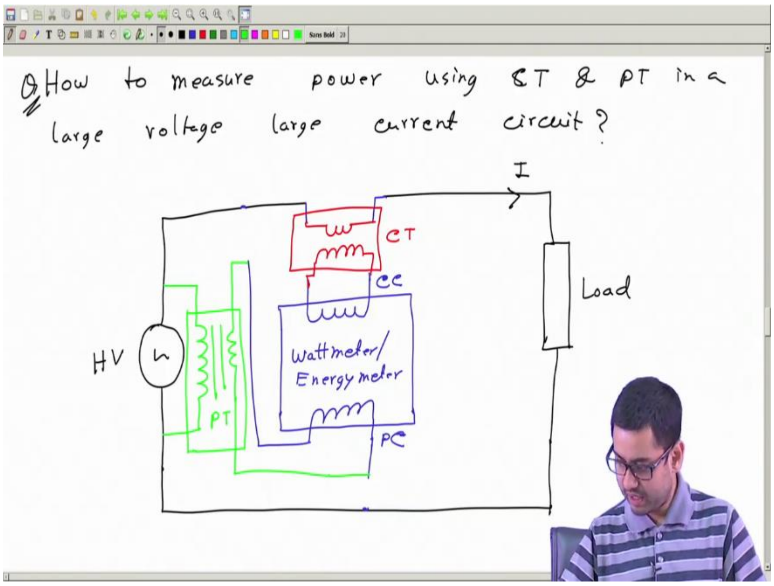

Now, the last thing we will discuss in this class is how to measure power using CT and PT. In a large voltage, large current circuit; see I have a circuit like this; so, this is a huge voltage this is a high voltage which is feeding this load and this current is also very high a high current, this current is also very high and we want to measure say the power being delivered by the source or consumed by the load.

So, what do we normally do? So, we do use a watt meter or if you want to measure energy then we use an energy meter ok. So, we use a watt meter or energy meter, which will have two coils, one to sense the voltage, another to sense the current. So, call one of them as the current coil; CC another as the potential coil P PC voltage coil.

Now, what we do? We normally connect the current coil in series like this and we connect the voltage coil; so, we may connect it this side or also this side ignoring the small power loss in current coil or in pressure coil, which we discussed before in much detail. So, ignoring that small error this is how we connect,

And, now the problem is this current is a high current and if this is a normal watt meter which cannot allow high current then what can we do, instead of connecting this current directly to the current coil we will use a current transformer. So, let us put a current transformer; so, this is CT and therefore, this current that flows here will be stepped down to a low value and we can connect it to the watt meter.

Similarly, if we cannot measure this voltage directly, because this is a high voltage what we can do, we will disconnect it from here and connect a potential transformer, which is a step down transformer this is PT and then we will connect the secondary side to the pressure coil of the watt meter. So, that is how to do it? So, simple.

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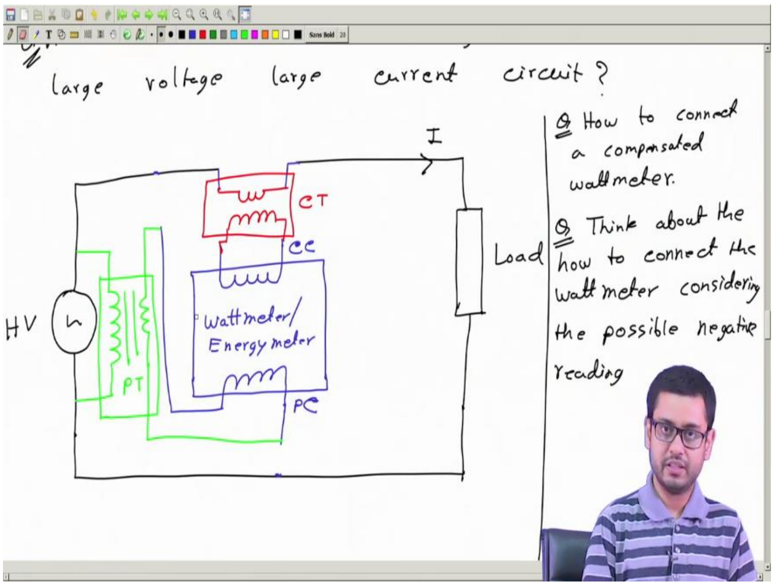

Now, that is so simple, but if you are interested I will just give you some thought exercise for you think of yourself. For example, how to connect a compensated watt meter? If, you recall a compensated watt meter is a watt meter where we have an additional coil, compensation coil, which goes over the current coil in opposite direction.

So, you recall that and that, the function of that compensating coil is to eliminate the small error due to the loss in pressure coil or in current coil.

So, in this diagram we have ignored that small error, which I have taken that to be negligible. Now, think if you do not want to ignore that and if you have a compensated watt meter, how to connect it? So, if you draw the circuit diagram you can post it in the forum which we will see it, I will be very happy if you try this. this is one question then also think about the plus minus sign of or the direction how to connect this current coil or and I put pressure coil, because the reading may come out to be negative.

So, think about how to connect the watt meter considering the negative possible negative reading, so, by this I mean if you have say this plus minus signs I mean not here.. So, if you have plus minus signs on the watt meter on the 2 coils then which is the correct diagram to measure the load power or the power supplied by the source.

So, think of it that will be very interesting thought exercise, in our next class we will talk about errors or non-idealities that CT and PT current transformer and potential transformers may have, because today we have assumed the transformers are all ideal where the relationship $V_1/V_2 = N_1/N_2$ is absolutely correct and $N_1 I_1 = N_2 I_2$ is absolutely correct, but that is not true in practice. So, what could be the effect and what how to take care etcetera we will discuss in the next class.

Thank you.