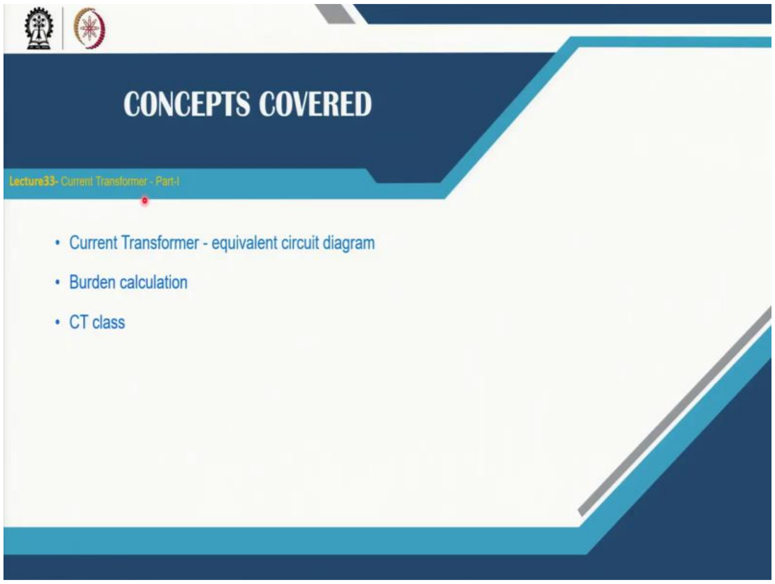
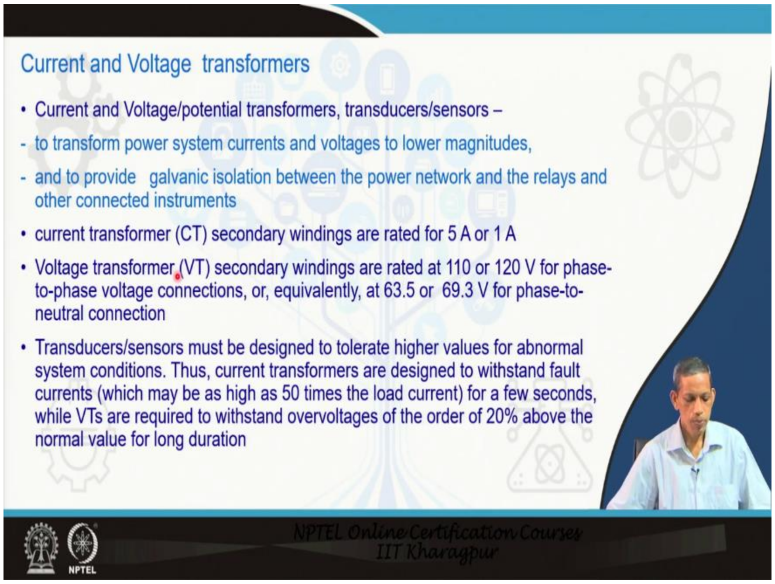
Power System Protection
Professor A K Pradhan
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur
Lecture 33
Current Transformer – Part - 1

(Refer Slide Time: 00:33)



Welcome to NPTEL course on power system protection. We will start with the current and voltage transformers. In this lecture we will discuss on current transformer, the equivalent circuit of the current transformer, the burden to the current transformer calculation and the classification aspects on current transformers.

(Refer Slide Time: 00:57)



To the relays the voltage and current signals are the inputs and these inputs as we have already mentioned are from sensors, current signals from current transformer, and voltage signals from voltage transformers. The whole objective of these sensors or transducers are to lower the magnitude to scale down the corresponding signals to a suitable level which is compatible to the relays and to provide galvanic isolation, electric isolation between the power network which is a very high voltage and the relays and the other connected instruments in the system. So, we will see that earlier in all our discussions on relays you assume that the sensors provide the signals of the systems perfectly and based on that considerations we see that.

Current transformers, secondary windings are rated 5A or 1A different countries used consider different perspective different system requirement may be different also an agency may be using in general either 1 ampere or 5 ampere, voltage transformer some countries used 110 V some 120 V phase to phase voltage or in terms of phase to neutral it is 63.5 or 69.3 V hold respectively.

The point here is that this higher voltage of 110 V is not compatible to numerical relay, because we are confined to low voltage like 5 V or 10 V. So, the practice of this CT and VT’s are pretty old and they are being used when electromechanical relays are there in the high voltage system also. So, to have a retrofitting perspective the corresponding CT’s and the VT’s are still continuing.

So, in that respect the numerical relay may be using subsequent scaling down the signals incompatible to its own internal arrangement. Furthermore, we know that the system like during fault see very large amount of current, so this current has to be scaled down by the CT's, therefore the CT primary we will see particularly during fault very larger current.

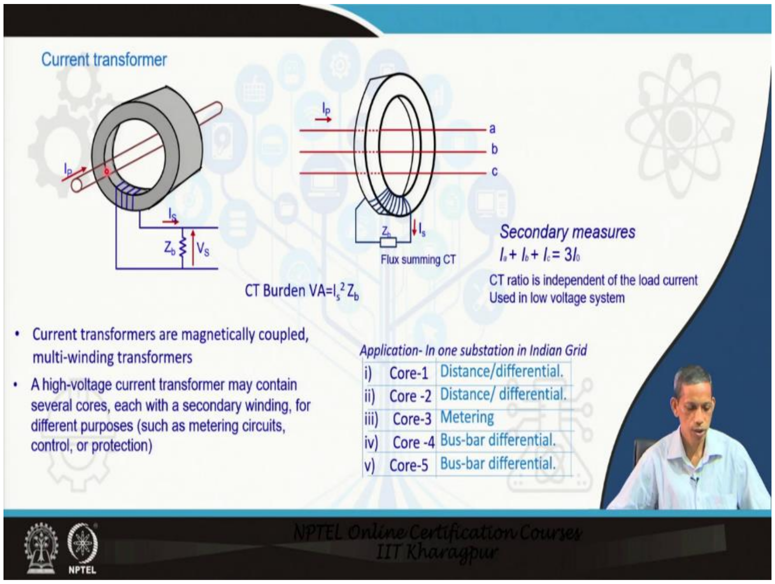
That means that the corresponding current may be as high as 50 times of the rated current, so corresponding CT has to manage that such a large value without any possible damage to it and that maybe for few seconds also because the fall may persist for that kind of period. On the other end system voltage may be sometimes higher during different dynamic condition in the systems; therefore the corresponding voltage sensors VT typically considered having 20% above the normal value to withstand for a very long period of time.

These sensors current transformer, voltage transformer subsequently discuss also capacitor coupling voltage transformer or simply capacitor voltage transformer, they are required to scale down the voltage to a lower level. Now, point is a voltage transformer and the current transformer in general is associated with a magnetic circuit, so that the galvanic isolation is being provided.

Any magnetic circuit if it goes to the saturation, then the corresponding transformer current ratio or the corresponding terminal voltage that becomes different one. In that perspective for a current transformer the current signal may be very large at times and if it reaches to the saturation region of the current transformer.

Then the information on the primary side which will be conveyed to the relay using the secondary of the current transformer may not be the correct you can say that corresponding correct value of the primary. That puts challenges and that is the reason we have this lecture on current transformers and voltage transformer.

(Refer Slide Time: 07:08)



We will continue with current transformer first and then we can say that in subsequent lectures we will see the voltage aspects. Coming to the current transformer; simply if this is the conductor in the high voltage system and we have a core and we have a winding, so this is the secondary winding and this is the primary of the current transformer.

So, you see here that essentially require large number of turns in the secondary, the reason behind that the current has to be reduced. Therefore the number of secondary turns will be accordingly should be as many. Now, there is another type of current transformer you will see in industry that is called flux summing CT.

So, what happens that in the gap of the corresponding core a toroid or so as it seems, then all the three conductors go through with proper insulation and because the this area available is smaller, that is why this is more suitable for only for low voltage system and this you can say that if the corresponding number of turns for the secondary and then we have to consider the corresponding connection to the relay and so and this relay you can say that different winding impedance Z_b including the corresponding connecting wires and so.

In this case the corresponding summing CT so all the currents I_a, I_b, I_c will be added which is nothing but gives us thing $3I_0$ or the corresponding residual current and so. In this case if we see from this difference all the current will be added, therefore the CT ratio is independent over the load current; so individual load current in all three will be added and that corresponds to that $3I_0$.

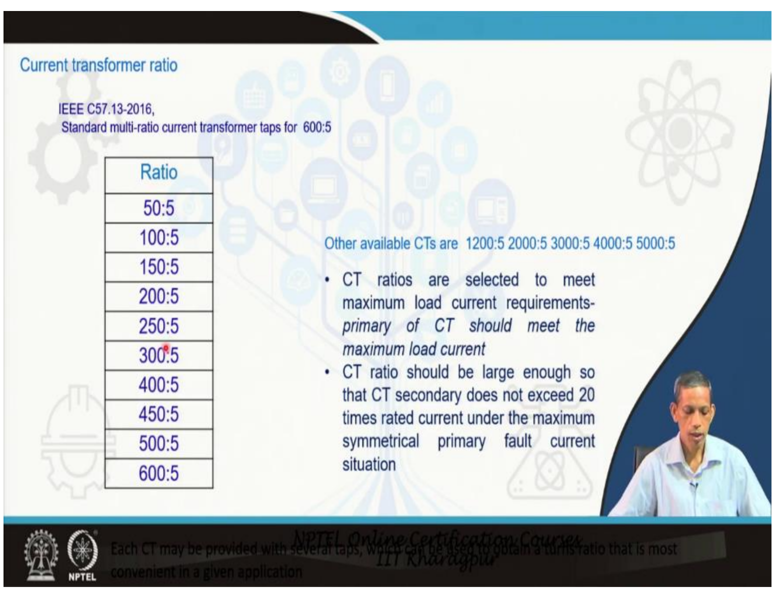
So, normally if it is a balanced systems that becomes 0 and during fault that unbalance amount of zero sequence current will be sensed by the secondary.

Therefore, it is the independent of CT ratio, load current. Whereas here if we think about the corresponding CT and the individual phase current associated in this arrangement and that's why it is associate also with load current perspective while thinking of the number of turns.

Note that such current transformers which are being used in the industry are magnetically coupled that we have already mentioned, so that is why need a core and they are having multi winding in transformers, there are multiple windings in this system. The high-voltage current transform may content also several cores, not single, they can have multiple cores and each with a secondary winding individually.

So, that you can say that each corresponding windings can be used for protection can be used also for control and also for metering, individual winding can be used for different applications. For example, in a substation in Indian grid it is found that there are 5 cores that the CT have, so 1 core is connected to the distance and differential relay, core 2 winding is connected to the further distance and differential relay. Core 3 is connected to metering, core 4 is connected the bus-bar differential and core 5 is connected to the bus-bar differential perspective. So, what you can say that all the cores and the associated winding are enclosed in one unit. That is what we can talk about multi winding and also we can say that multi-core CT's.

(Refer Slide Time: 11:23)



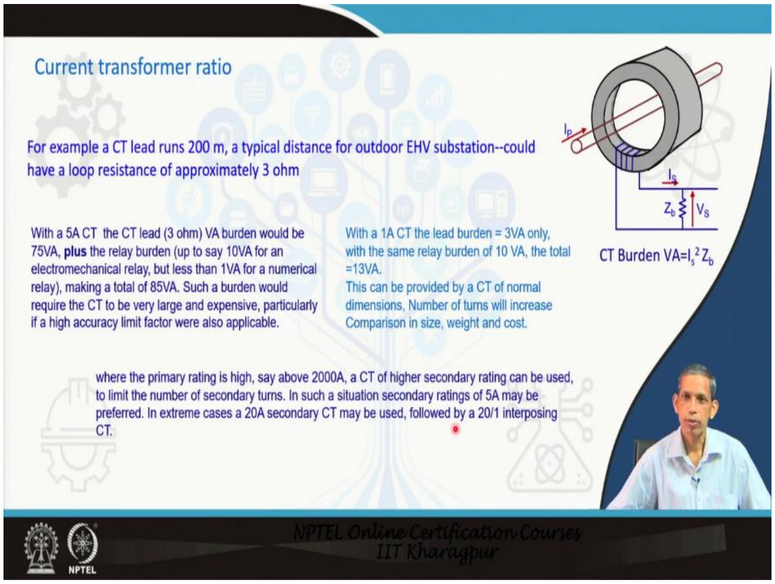
Current transfer ratio that $I_1 : I_2$ and 1:N, because there are number of turns you can say that in the secondary will be higher, so IEEE standard says you can say that the 600 : 5 you can say that multi ratio current transformer, now it is multi ratio. So, what is being done we can say that that from the 600 : 5 so this is 1 : 120, that means that the number of turns available in this secondary from the different number of turns you can have a tapings and then accordingly the ratio will also be different.

So, that you can say that tapings and the corresponding ratio can be used for different CT transformation, like for this 600 : 5 the manufacturer should provide the standard ratio of 50 : 5, 100 : 5 and continuing like this at the end 600:5. So, if we say from this 600:5 CT gives you 1:120 the turn's ratio, then 50: 5 it is 1: 10 turn ratio. From these different tapings you can have different current ratio available from the systems.

Other available CT's you can see that similar things are available as per the standard on 1200: 5, 2000: 5, 3000 : 5, like that 5000 : 5 and so. On the selection of the CT's the CT ratios that are selected to meet maximum load current requirement, because this is a continuous rating, faults are rare in the system, primary of the CT should meet the maximum load current, that is what we saw this also in the distribution system overcurrent relay design also.

CT ratio should be large enough, so that CT secondary current does not exceed 20 times the rated current under the maximum symmetrical primary fault current. So, we say that CT ratio should be large enough so that the CT secondary current does not exceed 20 times. It means that for fault conditions the CT secondary current should not go far beyond 20 times above its rating of this one that is what we can say that a guiding factor for this. Accordingly you can say that the CT ratio should be selected for a given system.

(Refer Slide Time: 14:06)



On furthering the current transformer ratio we say you can say that here one example let us say you can say that a CT lead runs 200 m in high voltage substation, so that resistance of you can say that the where the CT lead can be as high as you can see that around 3 **Ω**, Now, let us have simple calculations in terms of the burden, in CT burden we will define in terms of the burden if this Z_b you can say that is talk about the burden prospective, so then which is the corresponding wire impedance in the secondary and also the corresponding relay or any other you can say that the elements connected to the secondary of the CT's.

So, that impedance if you see Z_b then the burden to be consider transformer its I^2Z_b, so that is the load you can say that connected in the secondary load to the secondary winding, so that is what called as

$$\text{CT Burden VA} = I^2 Z_b$$

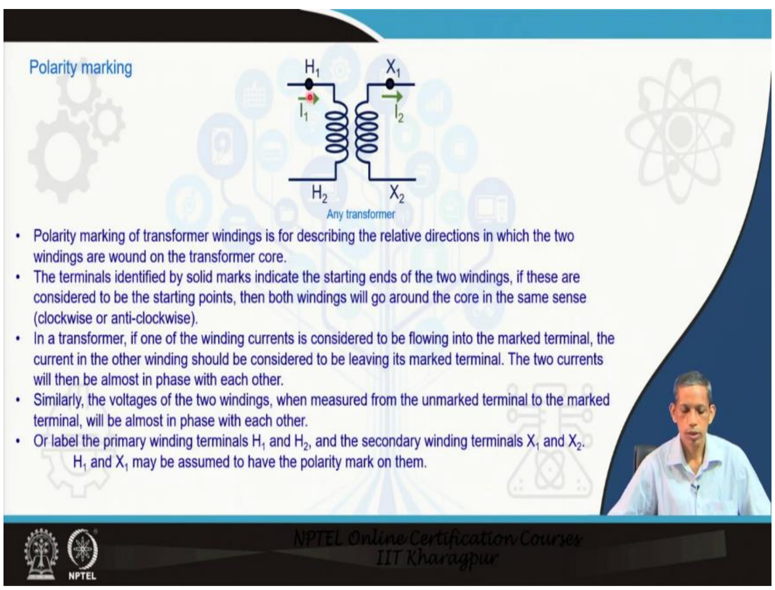
Z_b is the equivalent impedance of the connecting lead and the elements connected to the secondary winding. Let us, consider a 5A CT and we have 3Ω lead as in this system, so that leads to a burden amount of $I^2\times 3$, so this is continuous rating 5 A, 75VA, then we have a relay burden, let us say electromagnetic relay typical burden of 10 VA and for numerical relay maybe less than much lesser than 1 VA. So, considering the higher side (75 + 10) VA gives us 85 VA, but this 85 VA for the CT seems to be very high and accordingly you can say that because VA is more so the corresponding column so that the conductor size of receiver we consider will be thicker and which will remains pretty expensive. If you go to the 1 A CT the corresponding current rating is small, so $1^2 \times 3$becomes 3 VA plus the burden of the electromagnetic relay assuming 10, 10 + 3 becomes 13. So, as compared to 85 this becomes 13, so we can see say the see here that the burden is much smaller, so the expected you can see that the economic aspects should be smaller.

Only you can say that additional thing here is that the number of turns in case of 1 A will be a more you can say that that is compare to the 5 A CT. So, we can have a meaningful comparison of these corresponding size, weight and cost between these two and then someone and before this but those are you can say that again constants in turns to the utility what they have the common practice and so.

So on the basis of that preference technical difference between 5 and 1 A kinds of thing. Now, in case of very high that connecting in the high voltage system also, 2000 A and so we can say that the secondary current can be used to limit the number of secondary turns, sometimes you can say that we may prefer a 5 A over 1 A because of the reduced number of turns.

Sometimes in exceptional case you can go for 20 A CT, where you can use another level of transformation with an interposing CT that of 20: 1 also. So, this is about something on the current transformer ratio selection.

(Refer Slide Time: 18:03)

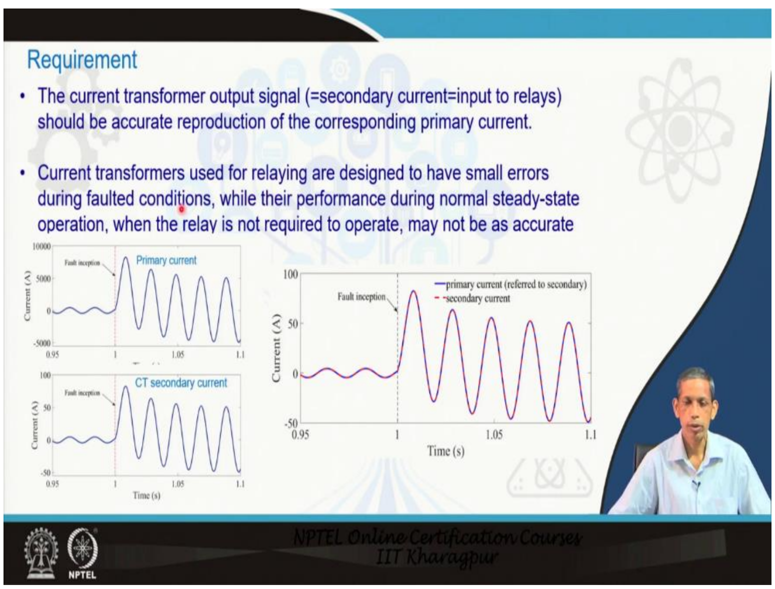


One thing that we see that for a 3-ϕ systems each phase you can see that current has to be taped and that should be the input to the relay, so the corresponding currents are being process in the relay and always there is a polarity of the corresponding current, then we cannot integrate the corresponding currents properly. Therefore, while connecting the CT's we essentially require the corresponding polarity of the transformer. CT or VT or so you can that any transformer with the corresponding polarity marking, so conventionally what is being done which gives us the corresponding direction of the winding in the core.

So, we put a solid mark at the both the high voltage and the low voltage or in the secondary side with this starting points, so we can say that this mark and this mark at the starting point, what it shows that with respect to this starting point then if you go to the other end, then in both that windings in the core will be wound in the same you can say that sense, either clockwise or anticlockwise.

So, that you can say that this is being reveal by this marking. In some of the cases you can say that if it is being mark you can say that also H_1, H_2, high voltage side, X_1, X_2 in the low voltage side also, so and so in the transformer also. And this helps is you can say if the current is entering to the marked terminal the solid mark or the H_1 and the current you can say that I which are leaving the mark terminal then both the currents will be almost in phase and the corresponding voltage from the other terminal to that mark one in this case also, these V_1 and V_2 voltage they will also in phase. So, that gives us you that scoop about the proper connection for the CT, if we have that polarity marking connect in accordance with that.

(Refer Slide Time: 20:39)



Now, what is the essential requirement from a good CT from the protection perspective? As we know that these CT should give us the corresponding current in the secondary, which current it will be a scaled-down current, but we know that all our analysis is based on the primary side that is system side current.

In a numerical relay if the corresponding CT ratio is being multiplied to the secondary current then the relay will produce the corresponding primary current that is what we have learned. Now, if that is so we can say that all the calculations can be done in terms of the primary level or the system level currents, for which we have only analysed in terms of that.

Now, this CT which we are discussing now is a magnetic coupling, it has a core and we know any transformer core may there is a chance of saturation at times, if that happens to be there, then the non linearity between B and H, I_m and the induced EMF maybe lost beyond the saturation and therefore you can say that the proposal may be, may not be there.

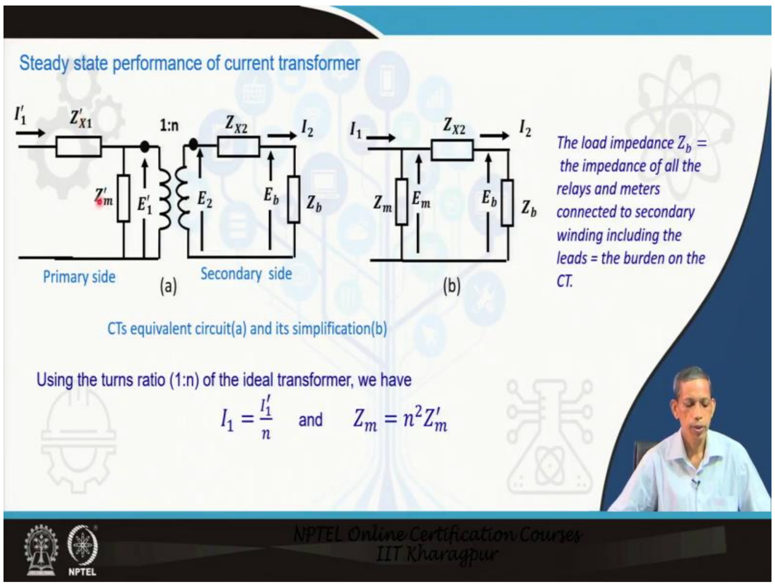
In that case, then there is challenge and so and that is what we say. Now, what is the expectation of from a CT that always the corresponding secondary current should provide the proportionate value of the primary current, the current transformer output signal which is the secondary current input to the relay, it should be accurate reproduction of the corresponding primary current accurate recovery production of the primary current.

Current transformer is for relaying are designed to have small errors during fault and while they are performs during normal steady state currents may be compromised to certain accuracy. We require that are correct reproduction for during particular is during all condition. Now, if we see this plot the situation this is a pre-fault current, all inception point and the current goes very high value primary current with a some decay and the secondary current is scaled down, this is depending upon the ratio and then this is the secondary current for this case.

So, what happens you can say here if you see you plot the both you can say that in terms of scaling and say that referring the corresponding primary current to the secondary current then only you can plot otherwise it is a these very large value going beyond 5000, this is only within 100 A if we convert the corresponding primary current to the secondary by dividing the primary current to the suitable turns ratio and if you plot then you can observe that the secondary current is red one and the primary current is blue one, then we say that this is exactly matching with this one.

So, it means that if this secondary current is fully available to the relay, relay will multiply simplify the CT ratio and you can get the correct value of the primary side current. That is why the reproduction is perfect. But this is ideal condition if the corresponding current becomes very large and decaying DC will be there and so there is a possibility of saturation of the core this you can say that reproduction of the primary may not be possible always, we will see that in the subsequent lectures.

(Refer Slide Time: 24:42)



Now, I will first analyse the steady-state performance of the CT and then we will go to the transient performance. So, at first we will draw the equivalent circuit diagram of this CT and from that you can say that we will try to analyse how it performed during steady state. So, this is primary side and this is the secondary side in the secondary side.

In the secondary side we have the burden and the burden impedance or resistance is already mentioned is the impedance of all the relays, meters connected with the secondary plus the corresponding lead you can see that impedance and that is the total burden to the CT. The CT has certain leakage reactance for the secondary leakage reactance is Z_{x2} and primarily reactance is Z'_{x1}. Magnetizing impedance is Z_m and then you can say that these are the windings where for every turn secondary maybe number of turns, 1: n. So, with this you can say that the corresponding current input to this primary which is the system conductor, transmission line conductor, transformer conductor or so. In that the corresponding current flows, note one point here for the

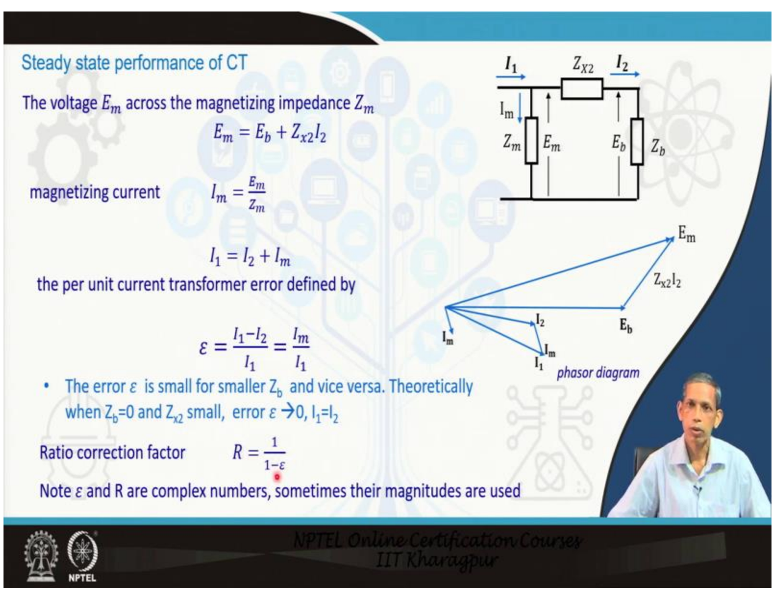
CT the current which is being input to this primary is the conductor current of the system and that does not depend upon the corresponding CT burden on so, that is independent of this corresponding CT. So, that depends upon the load and the system operating condition. Therefore, the corresponding current injected to the CT depends upon the system condition. The corresponding input signal becomes a current source kind of thing. So, the equivalent becomes a current source. Now, with this you can say that if we go with the transformation of this one referring everything to the secondary because our measurements are on secondary, so we say consider the equivalent becomes Z_m, I_1, Z_{x2}, I_2 and Z_b, everything referred to the primary. We neglect here the Z_{x1} here Z'_{x1} here and if you do not include here because as Z mentioned you can say that the current considered is independent of the CT parameters and so. That depends on the system condition, so that does not create any problem that you can say that have any influence on the I_1 perspective, and our objective here is that how the corresponding I_2 can reproduces the corresponding I_1, here this I_1 is already referred to the secondary side. Now, here you can see that this

$$I_1 = \frac{I_1'}{n}$$

$$Z_m = n^2 Z_m'$$

So, in terms of this we call this equivalent of this primary and secondary refer to the secondary side.

(Refer Slide Time: 27:58)



Now, with this we see you can say that the corresponding input current that I_1 which is that of the conductor current refer to the secondary, two components here one goes to the secondary side, secondary you can say that winding perspective and one component in the magnetizing component for the CT, any transformer has certain magnetic current component of current, because this is having a magnetic core. So, this I_2 goes to this burden, accordingly you can say that the burden onto the CT will be there. So, for this case you can say that if we see the corresponding phasor diagram, so if we say you can say that E_b as a reference, so to the E_b in terms of accordance with the Z_b there we corresponding current of I_2 and Z_b as

$$E_b = I_2 Z_b$$

Voltage across the magnetising branch is given by

$$E_m = E_b + I_2 Z_b$$

I_m the magnetic current obtained from

$$I_m = \frac{E_m}{Z_m}$$

That is lagging almost 90^0 to E_b because of this Z_m is very close having a large angle close to 90^0. I_1 is expressed as

$$I_1 = I_2 + I_m$$

So, we got that currents and voltages from the parameters of the CT. Then we define error terms, the that we can say as per unit current transformer error,

$$\varepsilon = \frac{I_1 - I_2}{I_1} = \frac{I_m}{I_2}$$

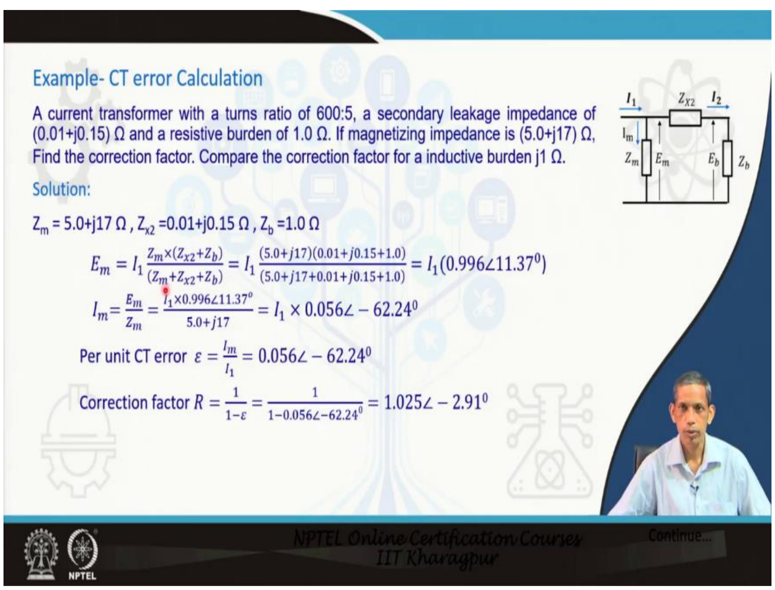
Here the I_1 is refer to the secondary that means I_1 corresponds to the primary current. Now, this I_2 should be equals to I_1. However, the I_2 should be equals to I_1, but that is not here and the reason against here is nothing but this I_m current. In an ideal case if this Z_m becomes infinity then this I_m become 0, so I_2 becomes equals to I_1, so that is what desirable, now you can say it seems here that if there will be I_m the corresponding core then depend on the I_m there will be inaccuracy you can say that in the CT's, it means that the relay which will be getting this current is I_2, not the I_1. So, what is the error component here? The error is only solely responsible you can say that the component is nothing but the magnetizing component of current. the error ε is small for larger Z_b. Theoretically ε is smaller for Z_b =0 that is a sorted terminal agree, for very large value of Z_m, I_m is smaller.

The ratio correction factor in divide I am say defined as R is defined as

$$R = \frac{1}{1 - \varepsilon}$$

so what we say that whatever I_2 at the relay if you multiply with R, the correction factor, then you can get the corresponding correct value of I_1. Why the inaccuracy? Because of this I_m. Therefore you require a correction factor to take into account this error, that is the epsilon and that correction factor is your R, so if the corresponding I_2 and by any means if it is known this corresponding R value if we multiply that R value then you can say that the correct value can be found out which will be proportional to the I_1. Note, the ε you can see that the R also the complex number all R we can say that in in terms of the phasor representation.

(Refer Slide Time: 33:40)



But many times the ε, R simply a magnitude is also adequate to for the expansion and so. Now, let us take an example.

A current transformer with a turns ratio of 600: 5, turns ratio, 1: 200 you can say that within number of turns, a secondary leakage impedance of (0.01+j0.15) Ω and a resistive burden of 1Ω. If magnetizing impedance is (5+j17) Ω this part, find the correction factor R, compare the correction factor for a inductive burden of j1Ω.

First you have considered for simple burden of resistive burden of 1 Ω and then we will go for the inductive burden of 1 Ω. So, in this case in the equivalent circuit diagram what we have discussed earlier that you know the different terminologies and note that in this case generally the Z_{x2} is much smaller.

$$Z_m = 5.0+j17\ \Omega,\ Z_{x2} = 0.01+j0.15\ \Omega,\ Z_b = 1.0\ \Omega$$

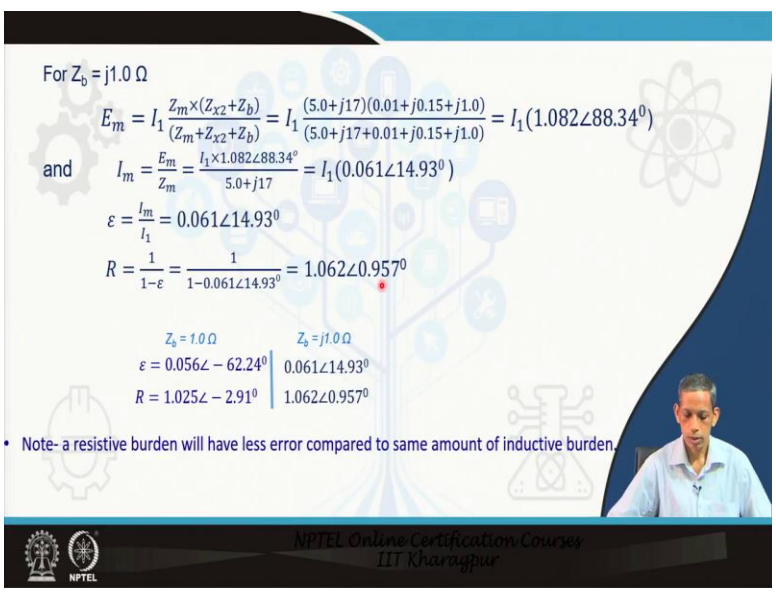
$$E_m = I_1 \frac{Z_m \times (Z_{x2}+Z_b)}{(Z_m+Z_{x2}+Z_b)} = I_1 \frac{(5.0+j17)(0.01+j0.15+1.0)}{(5.0+j17+0.01+j0.15+1.0)} = I_1(0.996\angle 11.37^0)$$

$$I_m = \frac{E_m}{Z_m} = \frac{I_1 \times 0.996\angle 11.37^0}{5.0+j17} = I_1 \times 0.056\angle -62.240$$

$$\text{Per unit CT error } \varepsilon = \frac{I_m}{I_1} = 0.056\angle -62.240$$

$$\text{Correction factor } R = \frac{1}{1-\varepsilon} = \frac{1}{1-0.056\angle -62.240} = 1.025\angle -2.91^0$$

(Refer Slide Time: 36:12)



Now, for the inductive load For $Z_b = j1.0\ \Omega$

$$E_m = I_1 \frac{Z_m \times (Z_{x2}+Z_b)}{(Z_m+Z_{x2}+Z_b)} = I_1 \frac{(5.0+j17)(0.01+j0.15+j1.0)}{(5.0+j17+0.01+j0.15+j1.0)} = I_1(1.082\angle 88.34^0)$$

and $$I_m = \frac{E_m}{Z_m} = \frac{I_1 \times 1.082\angle 88.34o}{5.0+j17} = I_1(0.061\angle 14.930)$$

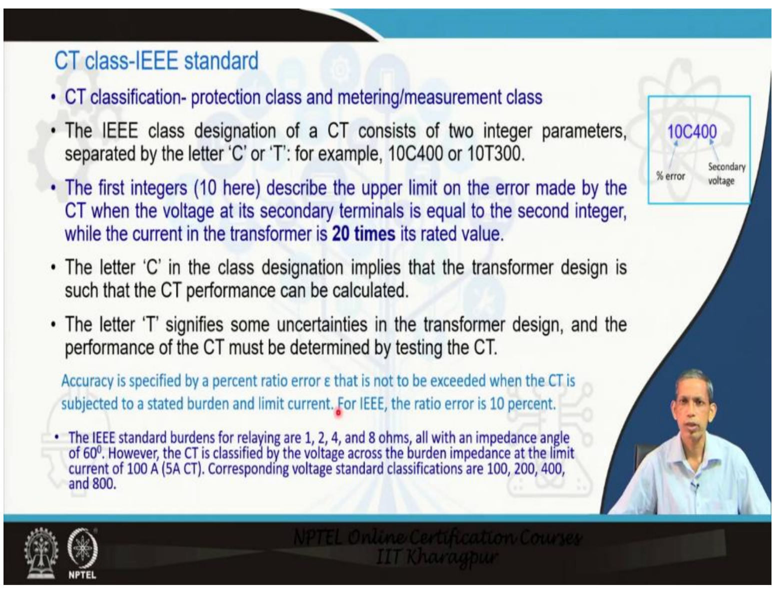
$$\varepsilon = \frac{I_m}{I_1} = 0.061\angle 14.930$$

$$R = \frac{1}{1-\varepsilon} = \frac{1}{1-0.061\angle 14.930} = 1.062\angle 0.957^0$$

So, if you compare both the case you can say that the ε is higher for the inductive case and so you can say that is also the corresponding correction factor become higher. In general for the resistive burden we will have lesser or compared to same amount of inductive burden.

So, if you know the corresponding inductive burden you can say that what are the corresponding ε error part, then if you are you can say that system will be connected to more resistive of the same value of the inductance, then you say that the corresponding error will be less than that. So, always you can say that the corresponding error to be as small as possible.

(Refer Slide Time: 37:26)



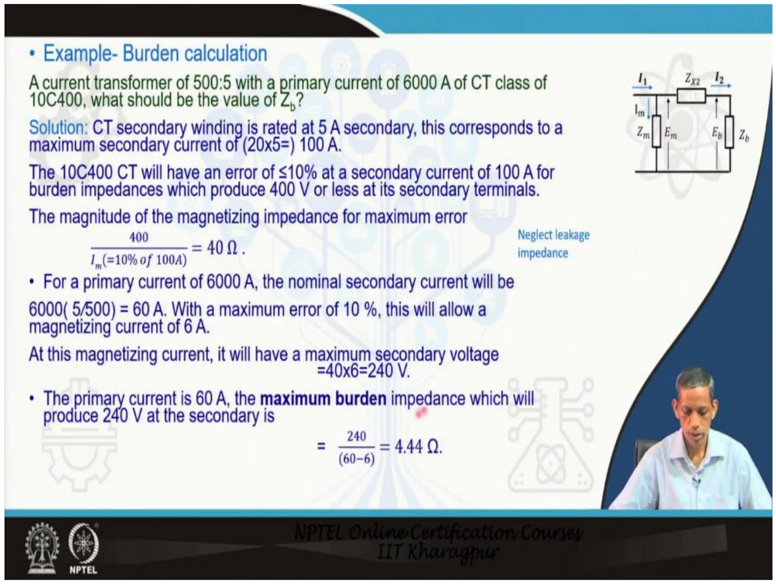
Note, class of CT as per the IEEE standard, so CT classification we can see we are discussing on protection perspective, but CT is available for both protection class and metering or measurement class, so we will discuss only on the protection class perspective. The IEEE class designations of a CT it defines in terms of two integer parameters C and T and for example 10C400 or 10T300.

So, we have integer before the C and 400 after it and we have integer before the T and after consider T also. Now, the letter C in the class imply the transport design is such that the CT performance can be calculated, C for calculated and the T signifies some uncertainties in the transformer design and the performance of the CT must be determined by the testing the CT's. That is T for the testing and C for the calculation. So, we can calculate the corresponding performance of the CT based on the data sheet provided by the manufacturer. Now, what these 10 and 400 and 300 in this tool reveal? The first integer 10 here described the upper limit on the error made by the CT when the voltage at its secondary terminal is equal to the second integer, when the voltage in the secondary terminals is equal to second integer that this voltage will be 400 V while the current in the transformer is 20 times the rated value, when this is being evaluated the corresponding transformer you can say that current will be 20 times of the rated value. So, if it is a 5 A CT for the corresponding current should be 100 A in this secondary that is you can say and what is this 10? The 10 reveals about the error you can say made by this in terms of 10 % error, percentage of this error and this 400 reveals the corresponding voltage in the burden error when you can say the corresponding current is 20 times of the rated one. So, if we see these 10C400 here this corresponds to percent error and this current correspond to the secondary voltage 20 time the corresponding current becomes 20 times of the it's rated value.

Accuracy is specified by percentage error and you can say that should not be considered a accuracy you can say that for that particular class as per the IEEE standard and the ratio you can say that error is always you can say that 10 in general, but there are other standards also IEC standard in all these things, so they have their own you can say that definitions and all this things.

But there are tables also available in terms of the competition that actually standard this class or this rating what is the corresponding IEC you can say that rating and so. The IEC standard burden for the relays are 1, 2, 4, 8, Ω standard burdens all with an impedance angle of 60^0. However, the CT is classified by a voltage across the burden that is we say this voltage, so the corresponding voltage becomes in terms of 100 V, 200 V, 400 V and 800 V this part you can say that which are talking about in terms of this sequence of impedances corresponds to 100 V, 200 V, 400 V and 800 V this is what as per the IEEE standard.

(Refer Slide Time: 41:07)



Now, you go for a burden calculation example,

Example: A current transformer of 500:5 with a primary current of 6000 A of CT class of 10C400, what should be the value of Z_b

Solution: CT secondary winding is rated at 5 A secondary, this corresponds to a maximum secondary current of

$$20 \times 5 = 100 \text{ A.}$$

The 10C400 CT will have an error of ≤10% at a secondary current of 100 A for burden impedances which produce 400 V or less at its secondary terminals.

The magnitude of the magnetizing impedance for maximum error

$$\frac{400}{I_m(=10\% \; of \; 100A)} = 40\,\Omega \, .$$

For a primary current of 6000 A, the nominal secondary current will be

$$6000 \times (5/500) = 60 \text{ A.}$$

With a maximum error of 10 %, this will allow a magnetizing current of 6 A. At this magnetizing current, it will have a maximum secondary voltage

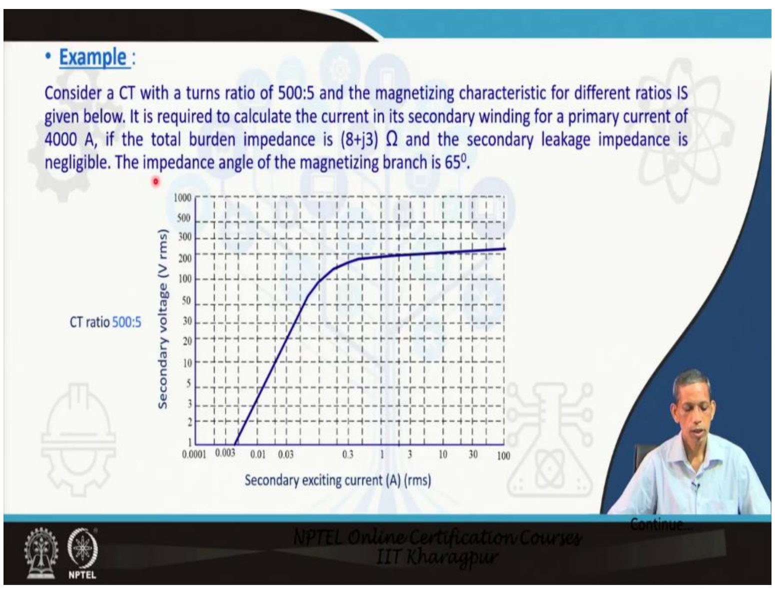
$$=40 \text{x} 6=240 \text{ V.}$$

The primary current is 60 A, the maximum burden impedance which will produce 240 V at the secondary is

$$= \frac{240}{(60-6)} = 4.44\ \Omega.$$

And that is the maximum one if the corresponding burden between is less than this burden, then you can say that the 10 % in the error will be less than 10 %, if it is more than that the error will be more than 10 %. So, that will reveal that in the for that kind of CT that how much you can say that burden impedance will be there. So, the corresponding lead and the corresponding number of relay and so the way it should be connected such that you can say that the burden impedance does not accept this 4.44 Ω.

(Refer Slide Time: 44:49)



Another example consider a CT with a turns ratio of 500:5 and the magnetizing characteristic for different ratios IS given below. It is required to calculate the current in its secondary winding for a primary current of 4000 A, if the total burden impedance is (8+j3) Ω and the secondary leakage impedance is negligible. The impedance angle of the magnetizing branch is 65^0.

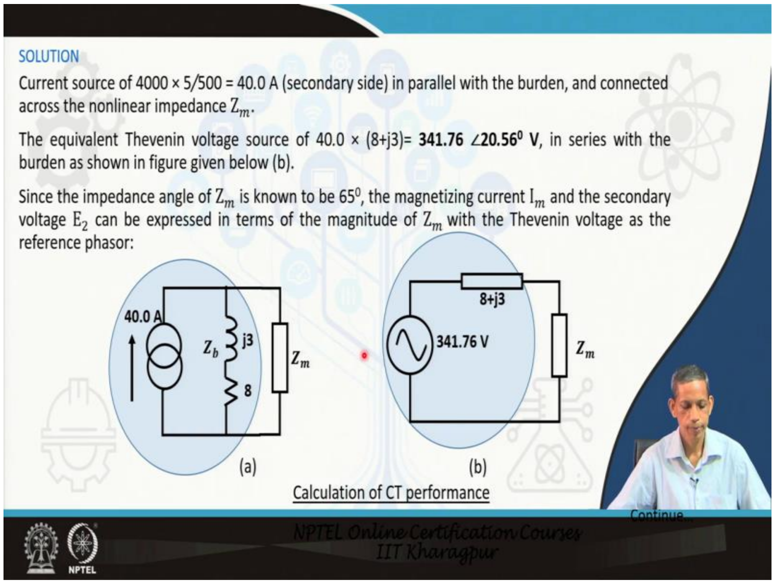
Solution: Current source of 4000 × 5/500 = 40.0 A (secondary side) in parallel with the burden, and connected across the nonlinear impedance Z_m.

The equivalent Thevenin voltage source of 40.0 × (8+j3) = 341.76 ∠20.56^0 V, in series with the burden. Since the impedance angle of Z_m is known to be 65^0, the magnetizing current I_m and the secondary voltage E_2 can be expressed in terms of the magnitude of Z_m with the Thevenin voltage as the reference phasor:

$$I_m = \frac{341.76}{[(|Z_m| \times (0.423 + j0.906)) + (8 + j3)]}$$

$$E_2 = I_m Z_m$$

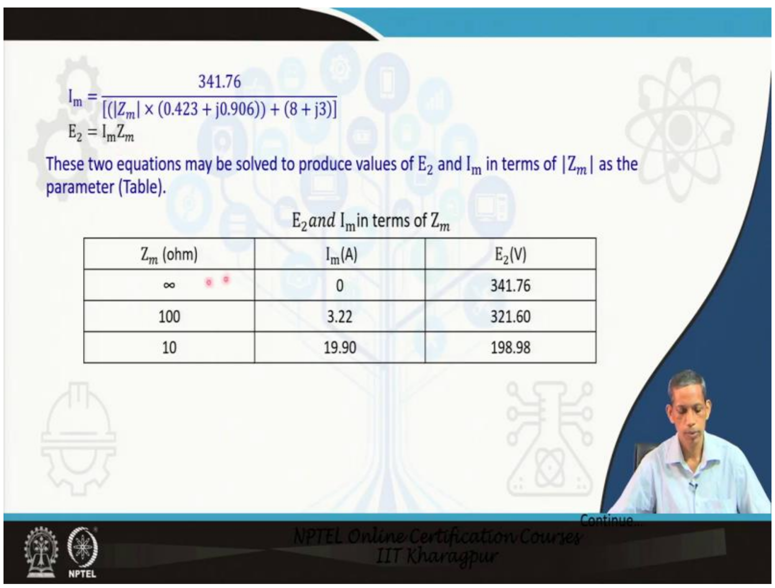
(Refer Slide Time: 45:53)



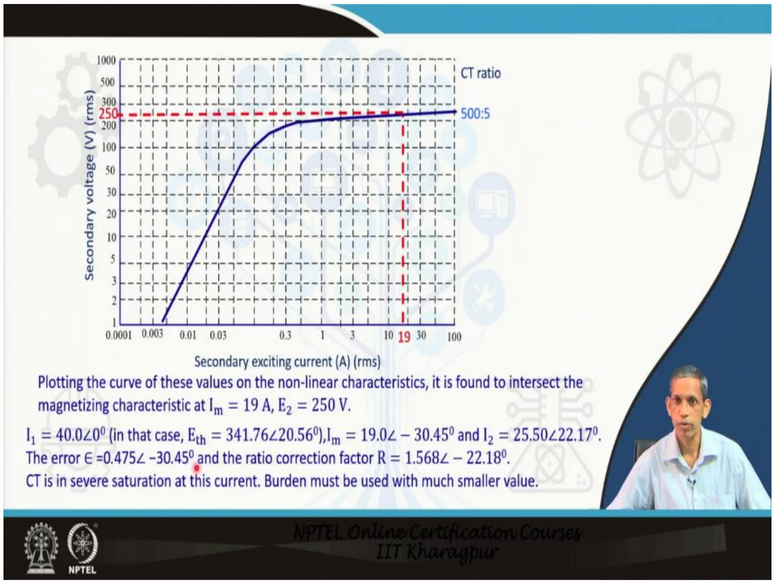
These two equations may be solved to produce values of E_2 and I_m in terms of $|Z_m|$ as the parameter (Table).

Z_m (ohm)	I_m(A)	E_2(V)
∞	0	341.76
100	3.22	321.60
10	19.90	198.98

(Refer Slide Time: 47:15)



(Refer Slide Time: 48:03)

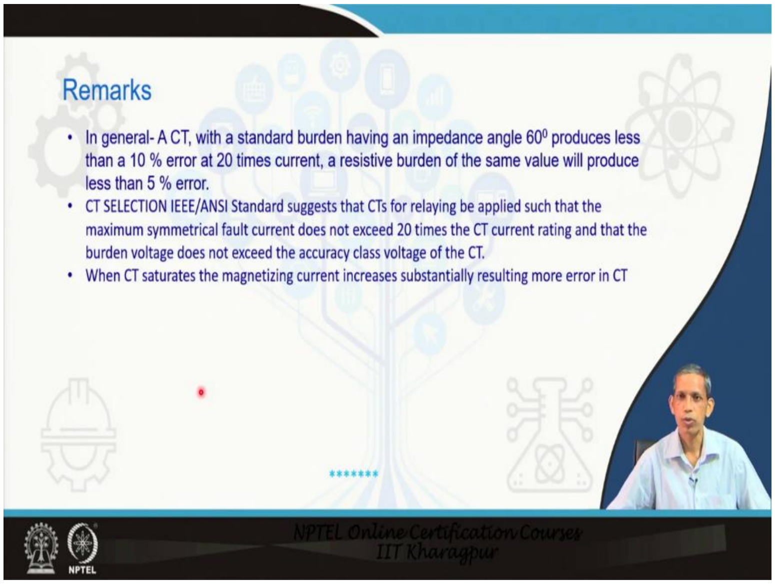


So, why did you do that you plot you can say that the corresponding E_2 verses the corresponding I_m line and that line you can say that crosses the considered at this point you can say that at this point to this the corresponding magnetizing characteristics and we got the value we can say that for that situation for that burden the corresponding 19 you can say that 19 A and then the corresponding value of we can say that the secondary voltage to be 250 V

Plotting the curve of these values on the non-linear characteristics, it is found to intersect the magnetizing characteristic at $I_m = 19$ A, $E_2 = 250$ V.

$I_1 = 40.0\angle 0^0$ (in that case, $E_{th} = 341.76\angle 20.56^0$), $I_m = 19.0\angle -30.45^0$ and $I_2 = 25.50\angle 22.17^0$. The error $\in = 0.475\angle -30.45^0$ and the ratio correction factor $R = 1.568\angle -22.18^0$. CT is in severe saturation at this current. Burden must be used with much smaller value reveals that the CT's in a severe saturation current because the ε value is very large here you see here as compared to the earlier discussion we made and that can said why the situation, that because it goes to the saturation in a region in the BH curve and there is the region of the corresponding error becomes this, what the error reveals that the corresponding I_2 which is being seen by the corresponding relay is having a much you can say that smaller value because of this significant I_m it is compared the injected current I1. So, the burden should be reduced is it seems to be very high.

(Refer Slide Time: 49:40)



So, in overall our remarks you can say that is that a CT with a standard burden having a impedance angle of 60^0 produces less than 10% error at 20 times current and it resistive burden of the same will produce less than 5% error, this is a general colour markings you can say that the calculation is we are that resistive burden will having less error as compared to the similar same value of inductive burden. CT selection in terms of IEEE standard suggests their CT's for relaying be applied such that the maximum symmetrical fault current does not exceed 20 times the CT current rating and that the burden voltage does not exceed the accuracy class voltage of the CT. So, preference will be that the CT current does not exceed you can see that 20 times of the CT rating and the burden you can say it should be solved that you can say that the corresponding class being satisfied. When CT saturated the magnetizing current increases a substantial resulting more error that we see for the burden should be incompatible to the requirement for the accuracy class of the CT. So, this is all on CT when say that steady-state behaviour. Thank you.