**Digital Protection of Power System**
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**Lecture 17**
**Digital Protection of Induction Motors - 2**

Hello friends. So, in the previous lecture, we have discussed regarding the faults and abnormal conditions that is going to occur in case of induction motor and in that we have discussed that a few faults are possible in stator winding of the motor, few may occur in the rotor winding of the induction motor and along with that there are certain abnormal conditions like overvoltage, under-voltage, over frequency under frequency, reverse phase sequence, unbalanced voltages and negative sequence.

So, all such conditions may occur in case of induction motor and induction motor may damage. If we wish to achieve protection against that, then we need to decide what type of protection we can provide to the induction motor.

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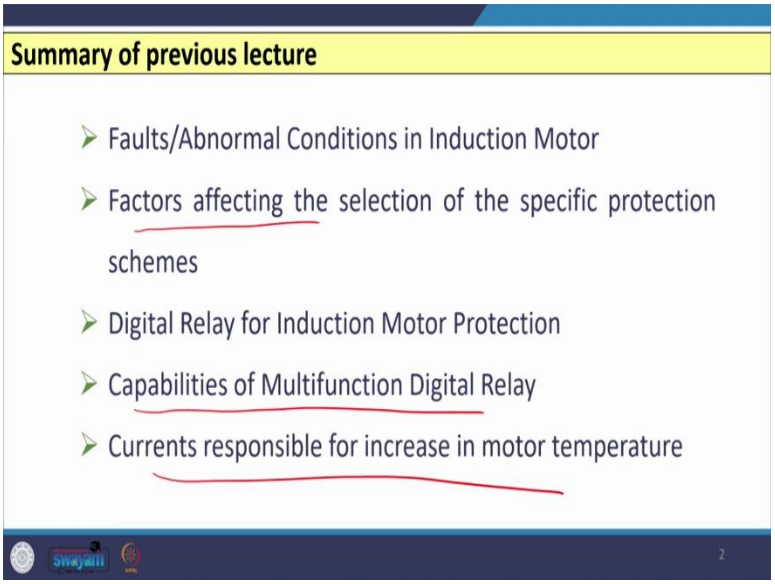


So, for that we have also discussed what are the factors that affect the selection of specific protection schemes and we have seen we have discussed different factors like what is the grounding conditions used for motor what is the rating of motor what is the application of motor, what is the starting current of induction motor?

What is the time current versus characteristic of induction motor especially in case of time, what is the acceleration time what type of drive we have used in case of induction motor what are the environmental conditions for which induction motor is utilized or resigned what is the short circuit current it can withstand.

So, several factors we have discussed and based on that we found that the digital relay or numerical relay is the best option for the protection of induction motor. And after that we have discussed what are the features or capabilities of multifunction digital relay or motor management relay that is used for the protection of induction motor.

And, we have seen that all types of features or functions are available in a single unit like overcurrent short circuit, maybe we have the low forward power or maybe we have the voltage protections related to under voltage over voltage or frequency under frequency stalling negative phase sequence maybe the winding temperature measurement is also possible communication is also possible.

So, all such type of features are possible if we use multifunction digital relay for the protection of induction motor. And then we have discussed that if winding temperature or motor temperature increases then 10 percent increase in the winding or motor temperature with reference to its specific limit that will reduce the life of the 50 percent life of the induction motor.

So, with this condition, we have seen that basically the motor temperature increases because of two reasons either insulation failure or mechanical failure. So, for that we have discussed that the heating is a major issue and if we wish to protect against heat, then we have to go for the digital thermal element that is used inside the digital relay which is one of the main or a vital function of the digital relay.

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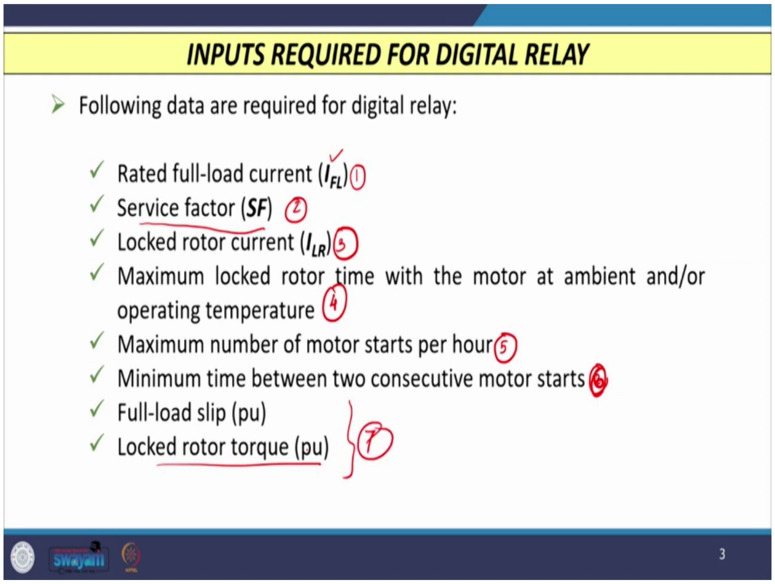


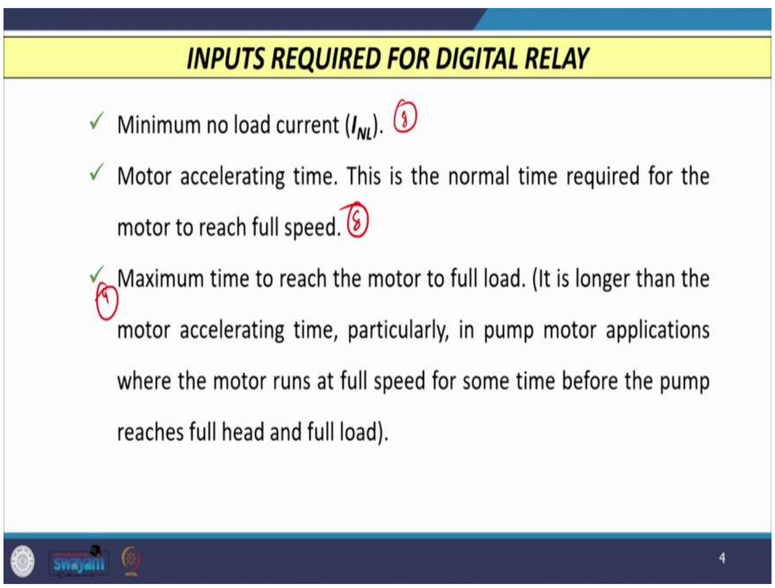


So, before we move into the other features of the digital relay, let us see what inputs are required or we need to give as an input to the digital or numerical relay. So if digital relay or numerical relays installed in the substation, then as an operator what input I have to give to the digital relay, so that digital relay can carry out the settings automatically based on this given inputs.

So, let us see what are the inputs required. So, the first input required that is known as the rated full load current of the induction motor. Normally, it is denoted by I full load ($I_{FL}$). Then you have to input the service factor, we will discuss what is service factor it is basically the percentage of the value of the current which motor can withstand above the full load current when the normal voltage sequence or voltages are available at the terminal of the induction motor.

The third thing that is required is the lock rotor current. Then it is also required the maximum lock rotor time with the motor at ambient temperature or at operating temperature, maximum number of the starting of motor in an hour that is also required.

Let us say you have started the motor five times six times or ten times in an hour. So, that number is also required minimum time between the two consecutive start of the induction motor that is also another important features and along with that the full load sliping per unit and lock rotor torque in per unit these two are also the important features we need to use or you need to input to the digital relay.

Along with that you have to also give as an input the minimum no load current of the motor, motor accelerating time is also required, because this is the normal time required for the motor to reach or to come to the standstill condition or full loads slip condition. And then, you also need maximum time to reach the motor to full load condition and this time is normally longer than the motor acceleration time particularly in pump motor applications when the motor runs at full speed for some time period before the pump reaches to the full load. So, this is also one of the important parameters you need to input to the digital relay.

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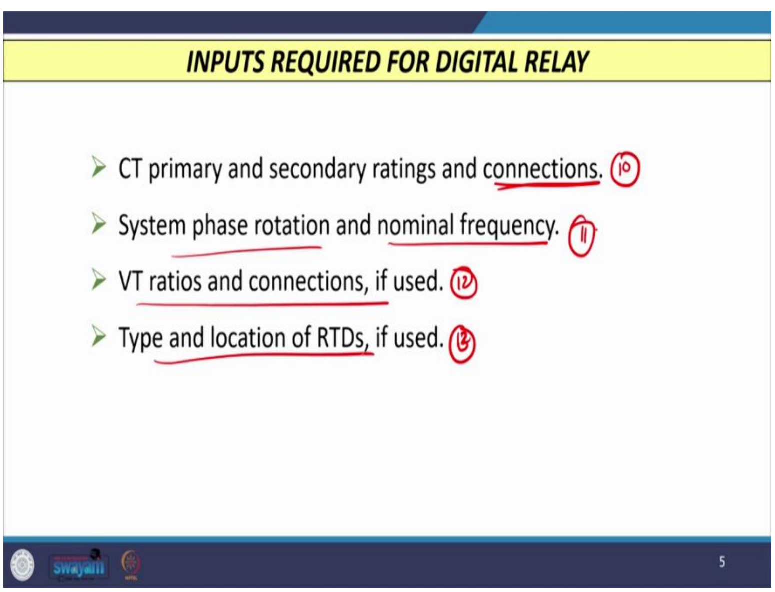

Then, you have to also give as an input the CT primary and secondary ratings. So, let us say the CT rating is 500/1 ampere or maybe 250/5 ampere. So, that that value is that ratings also you need to give. Along with that you need to also give the connections of the CTs then you need to give the system phase rotation sequence RYB, RBY and nominal frequency, in our case it is 50 Hz, and then you need to give the VT ratio and connections.

If you have used a voltage transformer or potential transformer, then that ratio also you need to mention along with the connections and then you need to mention the another important things that is the type and location of resistance temperature detector. So, if you are monitoring the temperature of the motor, then you need to give as an input the type and location of the RTD.

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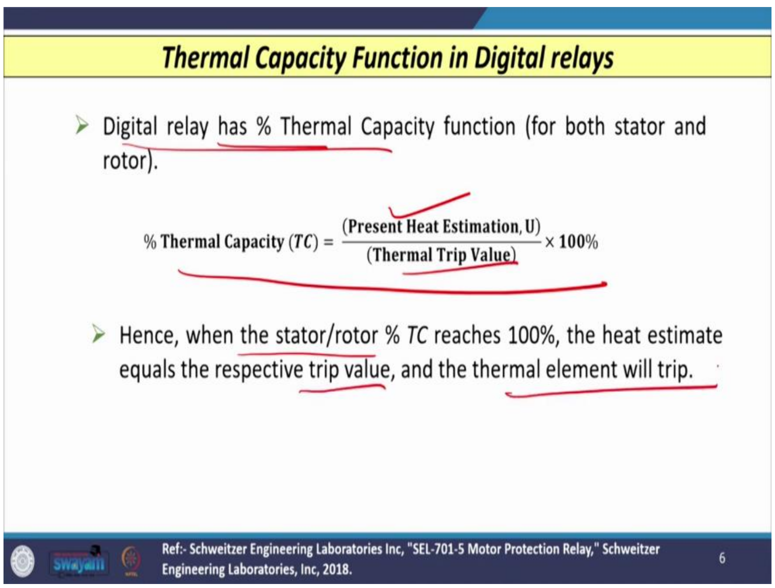


Now with this 12 - 13 inputs, if you give to the digital relay, then one of the important element which is known as digital thermal element, which comes under the thermal protection of the motor that plays an important role. So, in digital relay, if you observe let us see what is the thermal capacity function or digital thermal function that is available in digital relay and how it works what are the features of this function.

So, let us see this. So, in digital relay, it gives the percentage thermal capacity function both for stator and rotor and it is given by the equation

$$\%\ \textbf{Thermal Capacity}\ (\boldsymbol{TC}) = \frac{(\textbf{Present Heat Estimation, U})}{(\textbf{Thermal Trip Value})} \times \mathbf{100}\%$$

because normally, when you use any digital relay of any manufacturer, then each manufacturer gives its own logic for heat estimation, and this thermal trip value in the denominator is nothing but some threshold. So, if that heat value exceeds this, then tripping or warning that may be initiated. Hence, when the stator or rotor percentage thermal capacity reaches 100 percent, the heat estimate becomes equal to the respective trip value and thermal trip element will initiate a tripping command.

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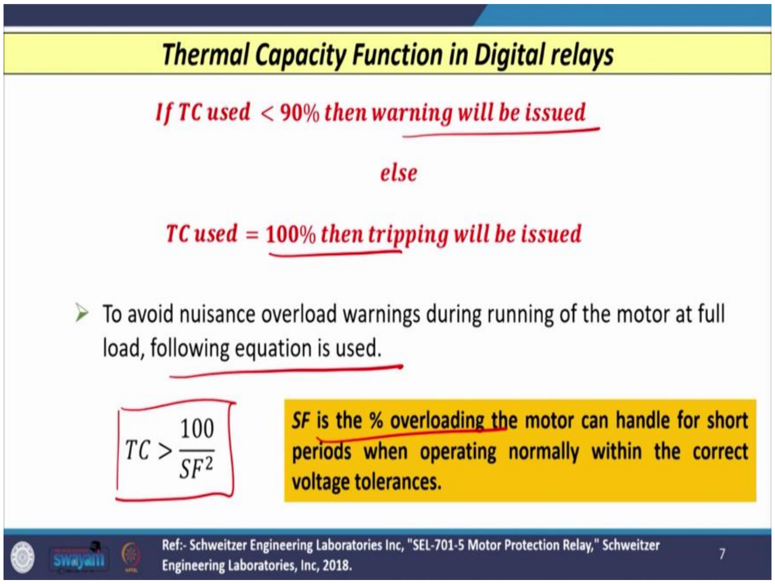


So, how this thermal capacity function works? So, if your thermal capacity is less than 90 percent, then warning will be issued by this element else if it is 100 percent then tripping will be initiated by this element or function. Sometimes we know that when we carry out the setting of this thermal capacity function of the digital relay, nuisance tripping that has also been observed in actual or practical field.

So, to avoid nuisance tripping especially when your windings or motor runs in overload condition. So in that case, to avoid the nuisance tripping, you may use the following equation $TC > \frac{100}{SF^2},$

where SF is nothing but your service factor which is nothing but the percentage overloading the motor can handle for a short period of time when motor receives normal voltages at the terminal.

So using this equation, you can carry out the setting in such a way that your induction motor may not initiate any nuisance trip and it will trip only and only when your thermal capacity functions that becomes 100 percent of the its value that is your pickup value or threshold value.

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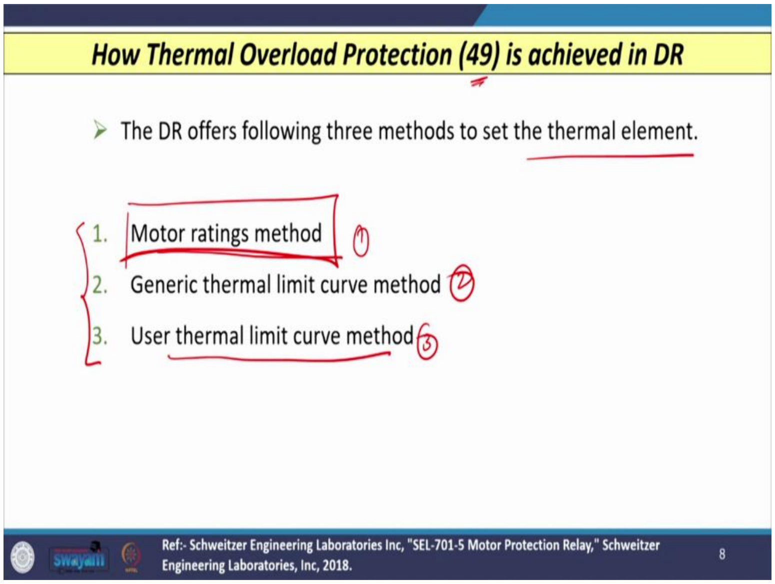


Now, after this background, let us see how my thermal overload protection which is given by the standard number 49 that is achieved in digital relay. So, digital relay normally offers three methods to set the digital thermal element. So, these three methods are like this, the first method is known as motor rating method. The second method is known as generic thermal limit curve based method and third is the user thermal limit curve based method.

So, motor rating methods depends on the some constants we will see and later on the second method that came and that is generic thermal limit curve. So, we have to give or use the readymade curve given by the manufacturer. So, I think different maybe 50 70 curve are provided by different manufacturers and depending upon your application and current and rating, you have to select a specific curve and accordingly the relay will automatically calculate the value of this percentage TC.

The third is the user thermal limit curve method where you need to enter your own curve and based on that relay will carry out the calculation and decide the setting. So, with these three methods, let us consider and discuss first method that is known as motor rating methods and this method is used as a digital thermal element in case of digital relay.

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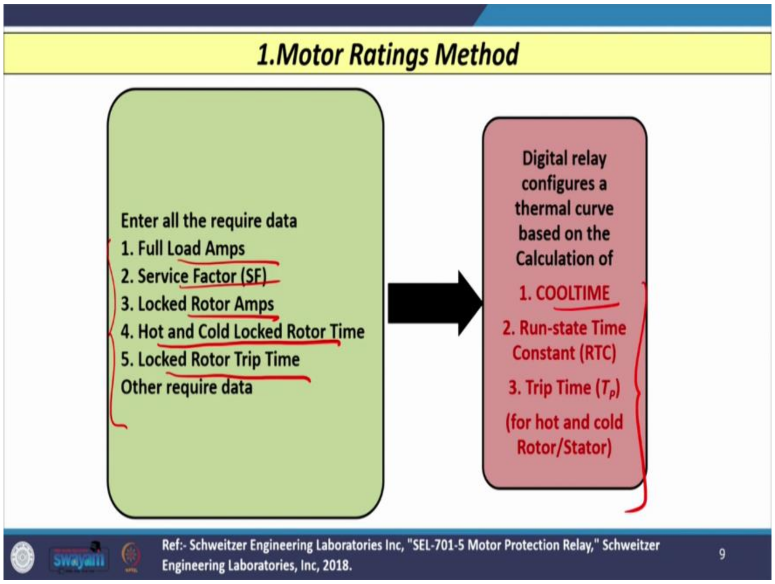


So, if I use the motor rating methods, then this method also needs some data. So, when you use this method, the following data you need to enter like full load current in Amperes you need to enter, service factor you need to enter the locked rotor in currents or locked rotor ampere value also you need to enter, locked rotor time in hot condition and locked rotor time in cold conditions that also need to be given as an input and locked rotor trip time and other required data also you have to give as an input.

So, once you give this data as an input to the digital relay, digital relay configures a thermal curve based on the calculation of these three parameters. So, this are the cool time of the induction motor. The second is the RTC that is the run state time constant and third is the trip time for hot and cold condition of the rotor as well as the stator separately.

So, these three things are calculated based on the data given as an input to the digital relay. So, let us see how these three parameters are calculated by the digital relay inside and what equations are used by the digital relay.

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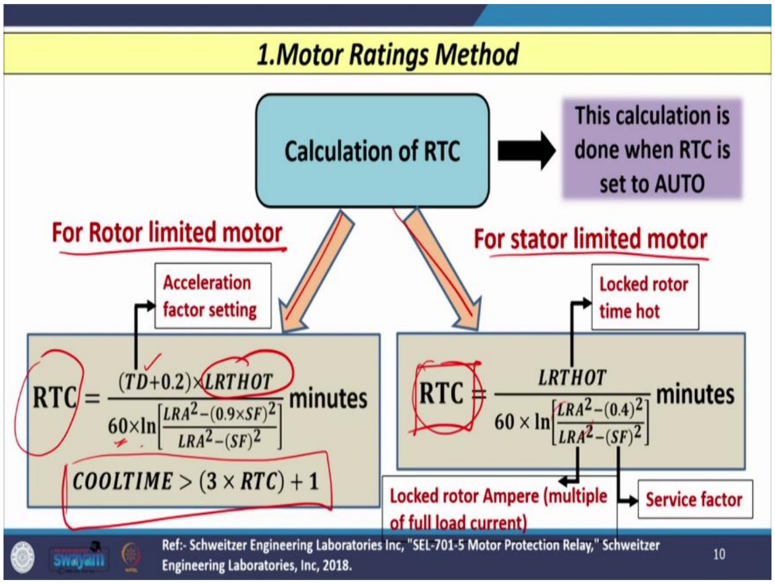


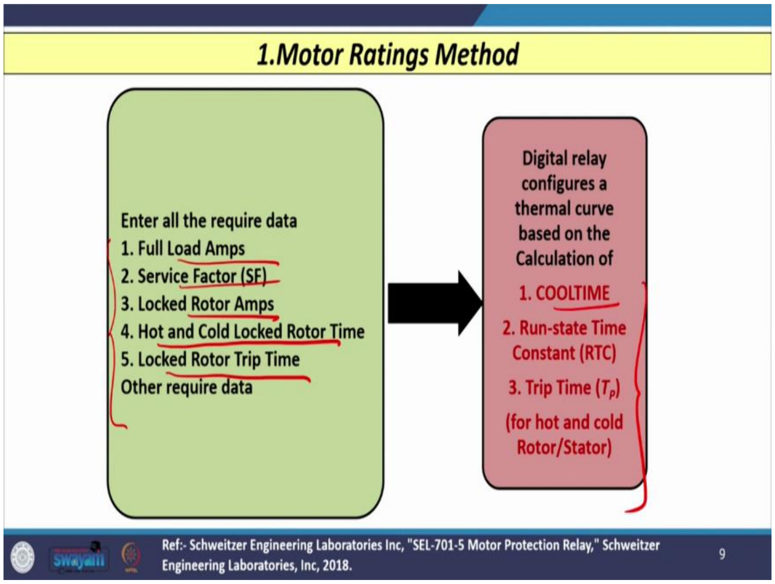


So, let us start with the first thing that is known as the run state time constant that is RTC. So, if we wish to calculate the run state time constant, then using motor rating methods, the important thing is that this calculation is done when RTC is set to the auto condition. If it is set to the manual condition then the the entire scenario will be different. But most of the cases your RTC that is runtime state constant is set in the auto condition and based on that we can go for the calculation of the time that is RTC based on two different category.

The first category is if you use your motor as a rotor limited motor, then you have to use this formula for the calculation of runtime constant. And in this formula, you can see it is given by

$$\mathrm{RTC} = \frac{(TD+0.2)\times LRTHOT}{60\times \ln\left[\frac{LRA^2-(0.9\times SF)^2}{LRA^2-(SF)^2}\right]} \text{ minutes}$$

where TD is known as acceleration factor, which is normally 1, and your LRA is nothing but the locked rotor ampere, which is nothing but the multiple of load current. So, if let us say your full load current is 5 ampere, and if your LRA is let us say 5 times the full load current, then LRA value that becomes 5, like that. If it is 10 times the full load currents your LRA values that is equal to 10 like that.

On the other hand, if you use stator limited motor, then you have to use this equation.

$$\mathrm{RTC} = \frac{LRTHOT}{60\times \ln\left[\frac{LRA^2-(0.4)^2}{LRA^2-(SF)^2}\right]} \text{ minutes}$$

and in that again the same LRT hot that is the locked rotor time when motor is running in hot condition that is already given, the LRA that is locked rotor ampere is also there and accept that is the service factor that is also given.

Once you have or once you calculate the value of runtime constant maybe for rotor limited motor or maybe for stator limited motor, then you can calculate the cool time of the motor using this equation $\boldsymbol{COOLTIME > (3\times RTC)+1}$. So, you can use this three equations for the calculation of runtime constant and cool time of the induction motor.

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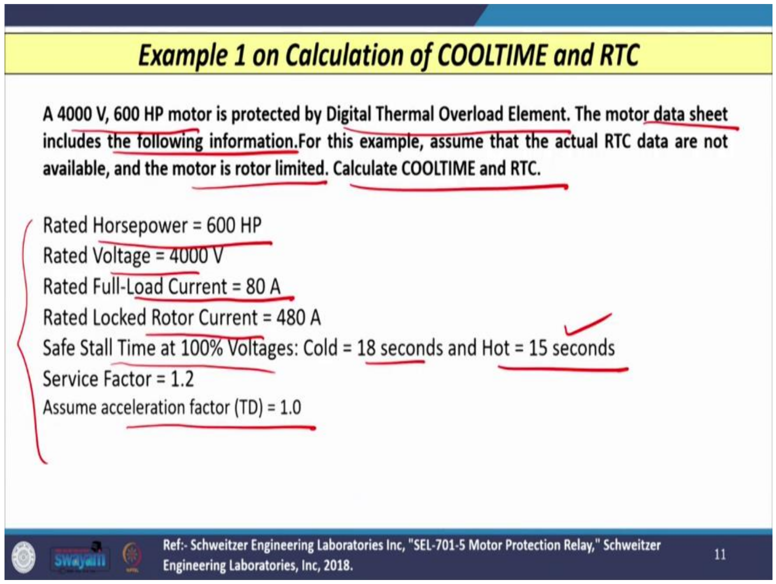


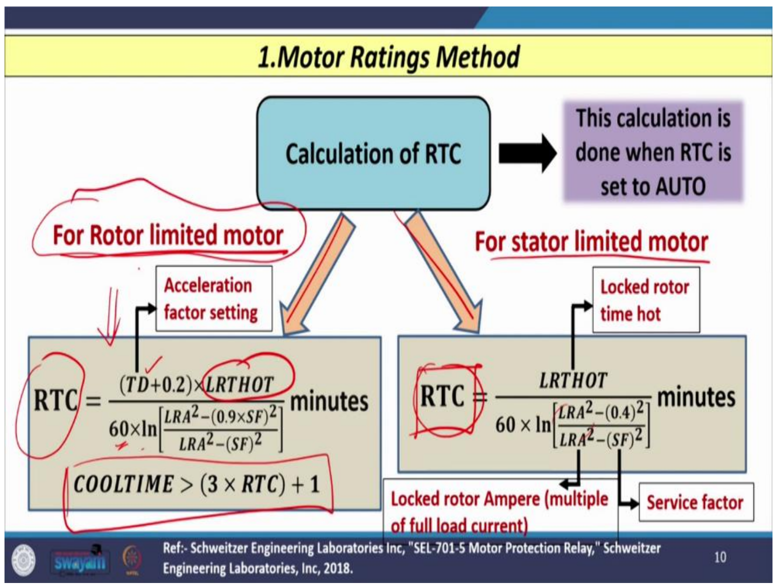


So, to understand this let us consider one example and let us see how we can calculate the cool time and runtime constant of the motor. So, for that let us consider a 4000 volt 600 HP induction motor which is protected by digital relay and which has digital thermal overload element inbuilt it is available, the motor datasheet includes the different parameters or different data which are shown here.

And for this example, let us assume that the actual RTC data are not available and the motor is rotor limited. So, and with this assumption we have to calculate the cool time and run state time constant of the motor. So, the different data available are the rated HP is available 600, rated voltage is also available 4000, full load current of the motor is also available that is 80 A, rated lock rotor current that is also available 480 A and save stalling time at 100 percent of the voltage in cold condition it is 18 seconds and in hot condition it is 15 seconds.

So, we will use the hot condition as this value for calculation, service factor is also given as 1.2 and acceleration factor we are assuming 1.0. And now based on this data, let us calculate the cool time and run state time constant of this motor when motor is rotor limited. So, as I told you, when motor is rotor limited, we have to use this equation for the calculation of run time constant.

$$\text{RTC} = \frac{(TD+0.2)\times LRTHOT}{60\times\ln\left[\frac{LRA^2-(0.9\times SF)^2}{LRA^2-(SF)^2}\right]} \text{ minutes}$$

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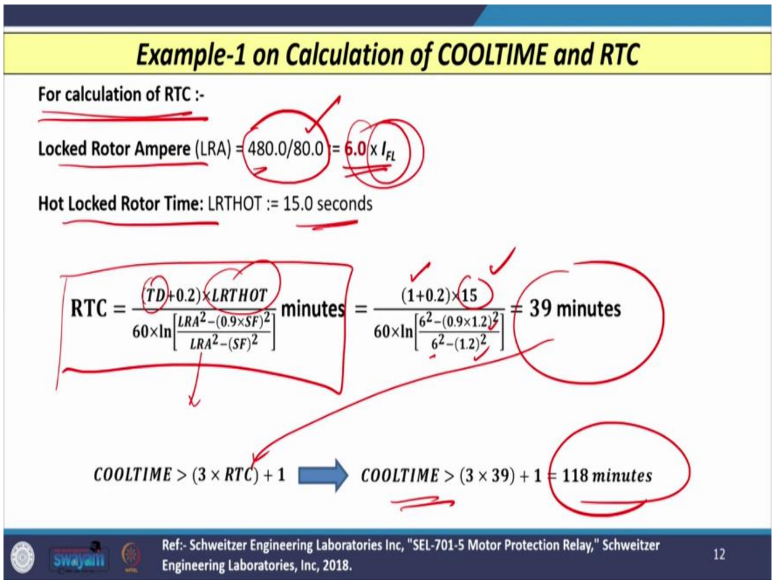

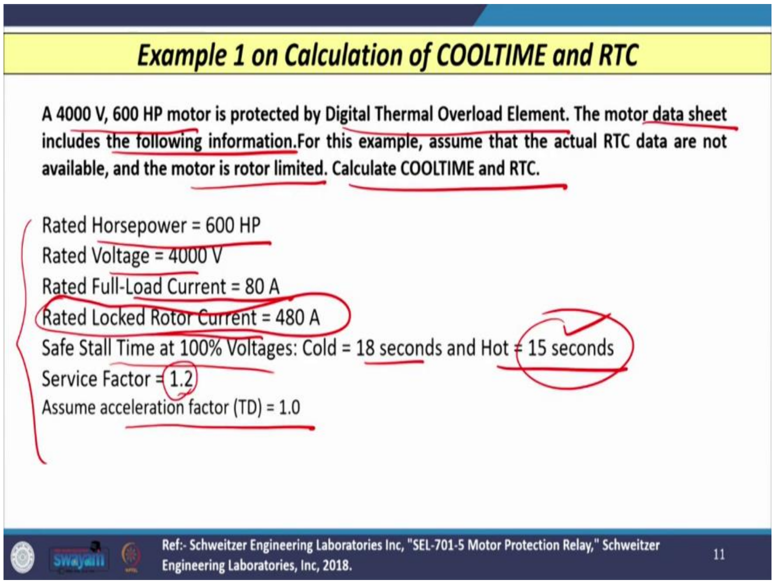


So, let us see how we can calculate this thing. So, for the calculation of RTC that is run state time constants, we have to first calculate the locked rotor ampere which is nothing but the ratio of 400/ 80 A. So, you can see here in this case 480 A it is already given that is your rated lock rotor current and your full load current of the motor is also given as 80 A.

So, you can see that it is 6 times the full load current of the induction motor. The locked rotor time when motor is running in hot condition it is already given that is 15 seconds. So, that we can consider here and with this value let us calculate the run state time constant of the this motor and in that we are considering TD as 1, LR hot we have considered that is 15, LRA we are considering that is 6 because it is 6 times the full load currently it is multiple of full load current.

So, whatever value you have, you can consider it here we are considering 6 and service factor as it is already given it is 1.2 So, that also we are considering here if you calculate this thing then you will get the value of RTC as 39 in minutes.

$$\frac{(1+0.2)\times 15}{60\times \ln\left[\frac{6^2-(0.9\times 1.2)^2}{6^2-(1.2)^2}\right]} = 39 \text{ minutes}$$

Based on this value if you use it here in the cool time calculation of the motor then cool time of the motor that is always greater than 3 times RTC plus 1.

So, your cool time should be greater than the 118 minutes. $COOLTIME = (3 \times 39) + 1 = 118\, minutes$

So, this is how we can calculate, this is a sample calculation the data may change the value and actual answer may change. But just this shows that how the digital relay can calculate the value of RTC and cool time if the data of induction motors are available.

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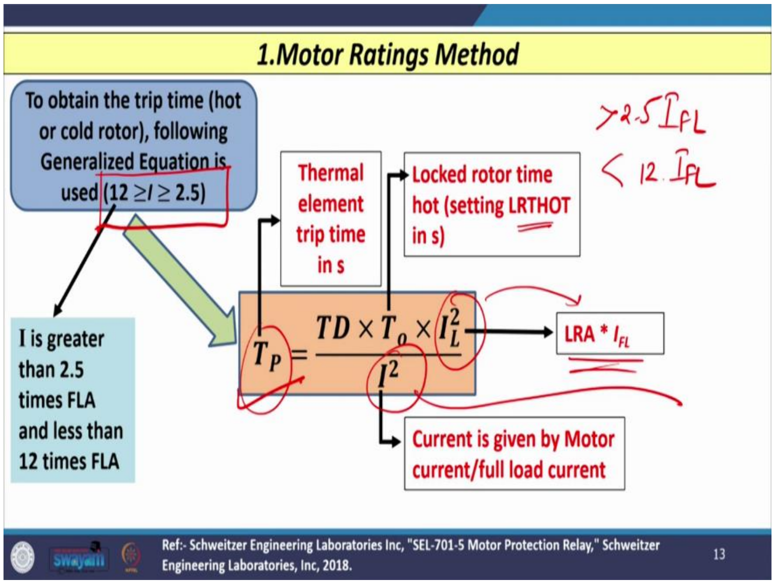


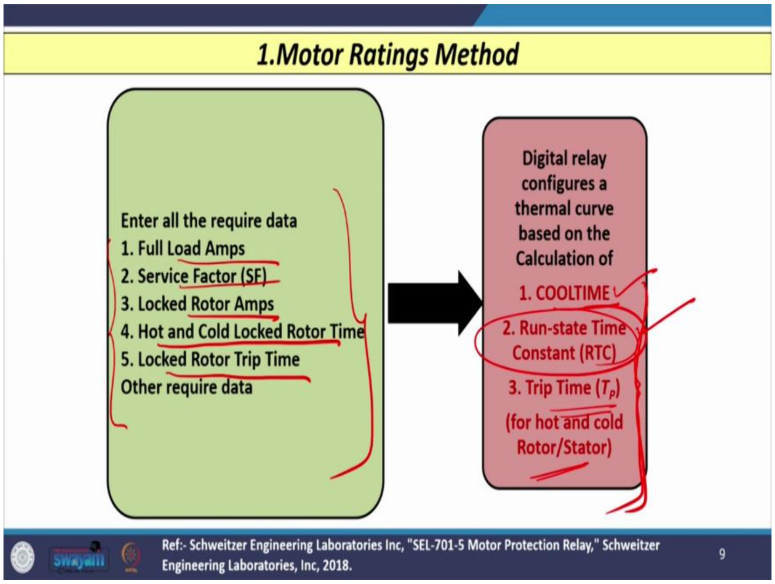


Now, with this background, earlier we have discussed that we can calculate the cooled time and run state time constant of the motor using motor rating method that is the first method, with with the condition that this data are available. So, the third thing we can calculate that is the trip time of the motor in hot and cold condition separately for stator and rotor.

So, now, let us see how we can calculate or we can obtain the trip time of the motor in hot or cold rotor. In that case if we wish to calculate the trip time of the motor, then one generalized equation we can use particularly when the value of current I which is greater than 2.5 times the full load current and it is less than the 12 times the full load current.

So, if the current is greater than 2.5 times the full load current $I_{FL}$, and if it is less than 12 times the full load current of the motor, then you can use this equation for the calculation of trip time of the induction motor.

$$\boldsymbol{T_P = \frac{TD \times T_o \times I_L^2}{I^2}}$$

And as you know in this equation, the trip time that is $T_P$ is the thermal element trip time. Normally, it is given in seconds, where TD we know it is the acceleration time normally it is 1 the $T_0$ is the locked rotor time when it is in hot condition. And we have already discussed that LRT hot time is normally given in earlier example, it was given as 15 seconds so, that we can consider here $I_L$ is nothing but the multiplication of LRA with the full load current of the induction motor and I is nothing but it is a ratio of the current given by the motor divided by full load current.

So, if some current is given by the motor, if you divide it by full load current, so, that value is nothing but your I. So, there is a fundamental difference between I and the load current $I_L$, I is the ratio of motor current by full load current, whereas $I_L$ is nothing but your LRA which is multiplied with the full load current.

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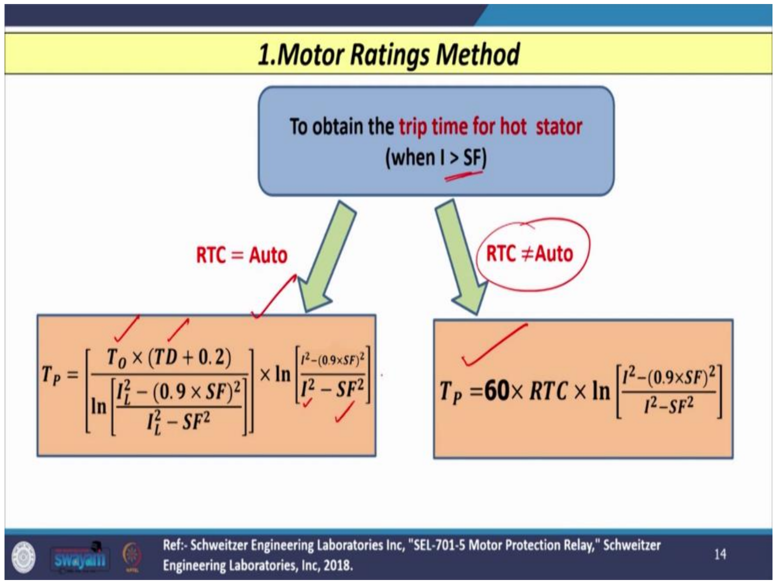


Now, if we wish to obtain the trip time for hot stator when particularly your current, I is greater than SF that is the service factor and if RTC is set in auto mode, then you can go for this equation,

$$T_P = \left[ \frac{T_O \times (TD + 0.2)}{\ln \left[ \frac{I_L^2 - (0.9 \times SF)^2}{I_L^2 - SF^2} \right]} \right] \times \ln \left[ \frac{I^2 - (0.9 \times SF)^2}{I^2 - SF^2} \right]$$

If it is not set in auto mode, then you can use this equation for the calculation of trip time.

$$T_P = 60 \times RTC \times \ln \left[ \frac{I^2 - (0.9 \times SF)^2}{I^2 - SF^2} \right]$$

And you can see in either of the equation when RTC is set to auto or not auto then in that either of the equation you have the parameter that is TD $T_0$, then you have I service factor $I_L$. So, these parameters are already available. And you can go for the calculation of the trip time of the induction motor.

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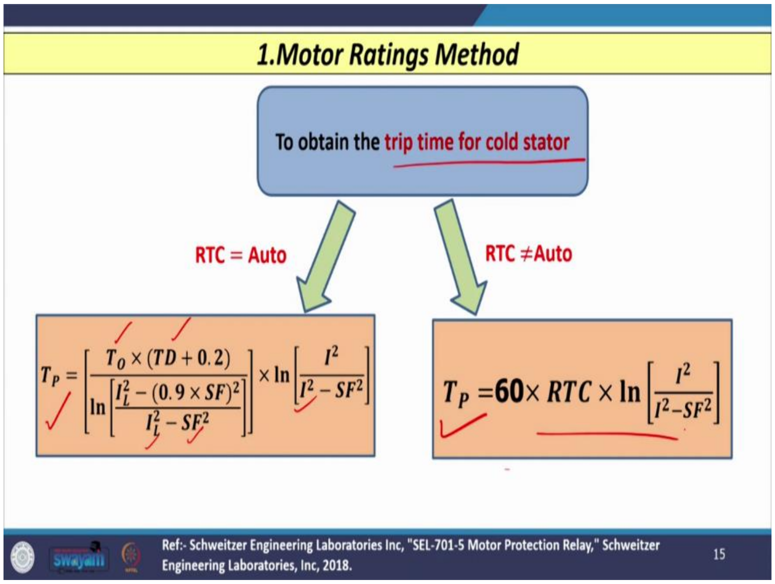


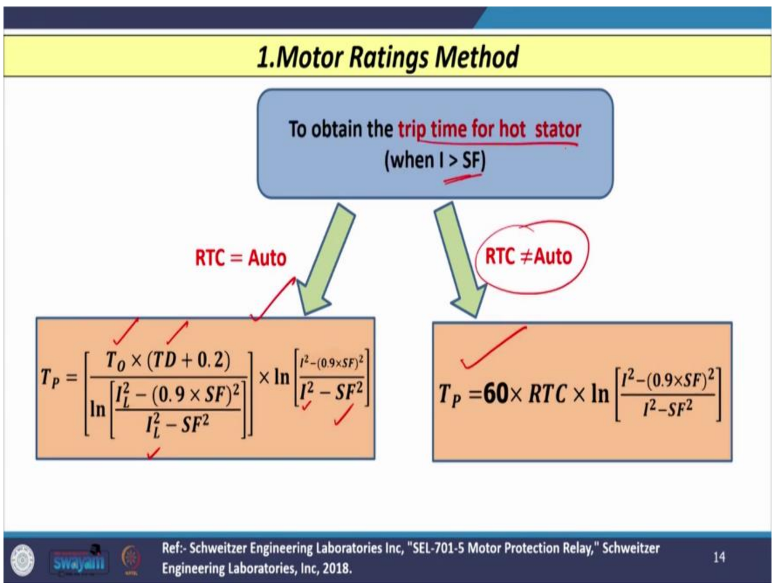


Again, if you want to obtain the trip time for cold stator in earlier case, we obtained the trip time for hot stator. Now if we wish to obtain the trip time for cold stator then again whether RTC it said to auto or non auto mode, you can use these another two equations for the calculation of the trip time.

$$T_P = \left[\frac{T_O \times (TD + 0.2)}{\ln\left[\frac{I_L^2 - (0.9 \times SF)^2}{I_L^2 - SF^2}\right]}\right] \times \ln\left[\frac{I^2}{I^2 - SF^2}\right]$$

$$T_P = 60 \times RTC \times \ln\left[\frac{I^2}{I^2 - SF^2}\right]$$

And again you can see the same parameters $T_0$, TD, SF, $I_L$ and I are available in both the equations using which you can easily calculate the trip time of the induction motor.

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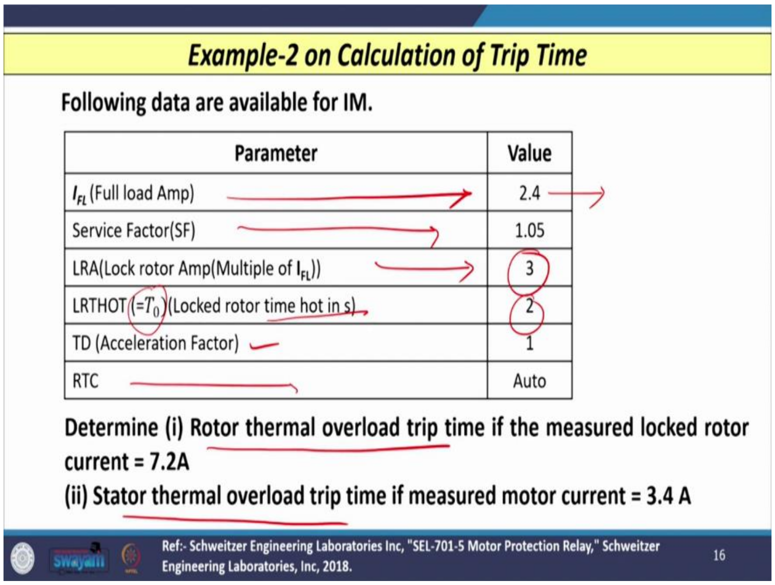


So, to understand this, let us consider one example for the calculation of trip time. So, let us assume that following data are given for the induction motor (as shown in above slide). So its full load current in ampere it is given as 2.4, the service factor is given as 1.05, the locked rotor ampere which is a multiple of full load current that is given as 3.

So, directly this factor is given, it is 3 times the full load current. So, basically our full load current is 2.4 A. So, 3 times of 2.4 that is 7.2. LR log rotor time in hot condition that is equal to $T_0$, that is given in second that is 2. The acceleration factor is also given as 1 if it is not given by default you can take it 1. And, RTC it is set in auto mode.

So, with this data here you need to determine the first rotor thermal overload trip time if the measured lock rotor current is 7.2 A this is given measured value of lock rotor current and in second case you need to calculate the stator thermal overload trip time if measured motor current is 3.4 A.

In first case you have to calculate the rotor thermal overload trip time. And in the second case you have to calculate the stator thermal overload trip time provided the measured value of locked rotor current and measured value of motor current that is given us 7.2 A and 3.4 A respectively.

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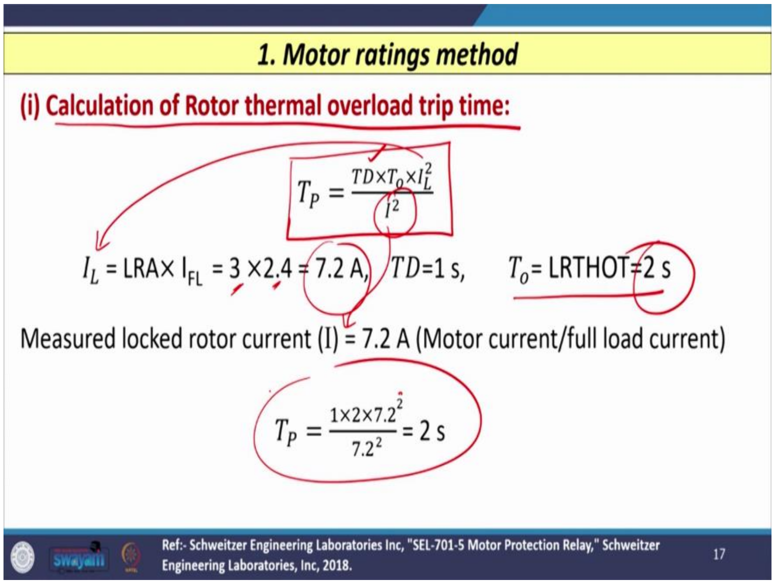


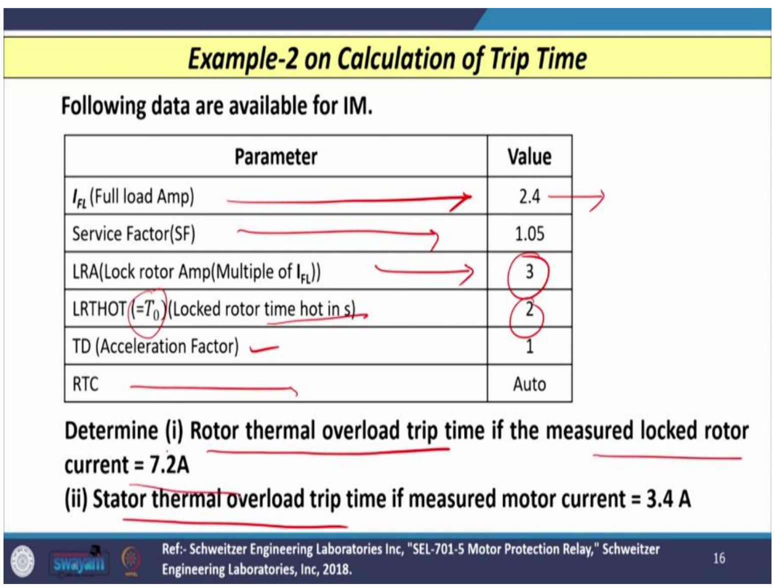


So, let us consider the first that is the calculation of rotor thermal overload trip time. So, we know that the equation of trip time is given by this equation, $T_P = \frac{TD \times T_O \times I_L^2}{I^2}$

$I_L$ = LRA× $I_{FL}$ = 3 ×2.4 = 7.2 A, $TD$=1 s, $T_O$= LRTHOT=2 s, and the measured lock rotor current that is I, that is nothing but the 7.2 A. So, with this given data if you put it here $T_P = \frac{1 \times 2 \times 7.2}{7.2^2}$ = 2 s

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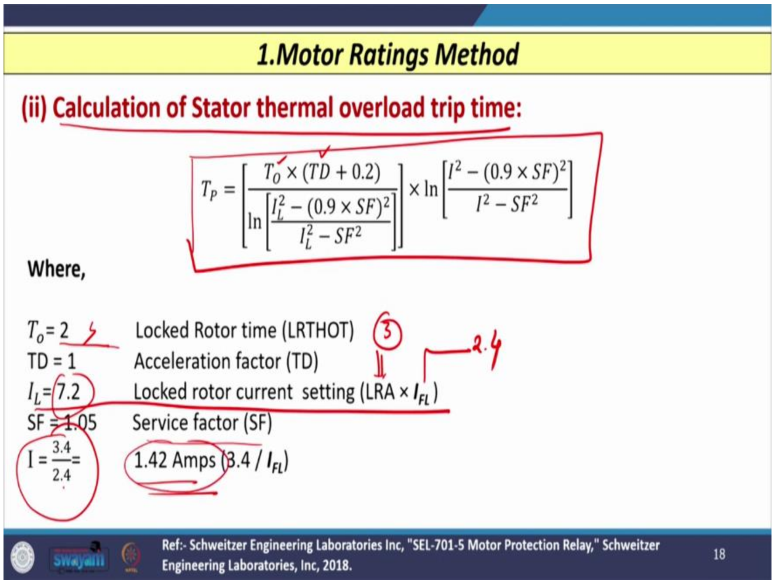


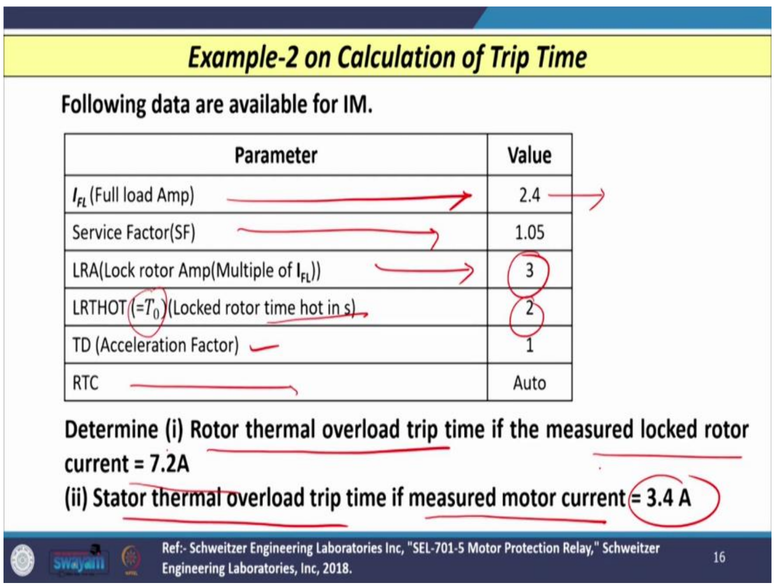


So, in the second case, if we consider the calculation of stator thermal overload trip time provided the motor measured current is given as 3.4 A. So, in that case we have to go for the equation of $T_P$ that is $T_P = \left[\frac{T_O \times (TD+0.2)}{\ln\left[\frac{I_L^2-(0.9\times SF)^2}{I_L^2-SF^2}\right]}\right] \times \ln\left[\frac{I^2-(0.9\times SF)^2}{I^2-SF^2}\right]$.

So, you can see here that $T_0$ that is your locked rotor time when motor is in hot condition that is given us two second, so, this is in second then the TD that is the acceleration factor is given as 1 then you have in the denominator natural log of $I_L$ where $I_L$ is given as 7.2 which is nothing but the locked rotor current setting which is nothing but the multiplication of LRA $\times I_{FL}$. So, your $I_{FL}$ is 2.4 A and your LRA that is 3, so 2.4 ×3 that is nothing but 7.2.

The service factor SF is given as 1.05 and your I which is nothing but the ratio of motor current to the full load current. So, this value of I, you can have that is 1.42, so it is 3.4 that is the motor measured current divided by full load current of the motor that is 2.4. So, you will have the value of I that is 1.42.

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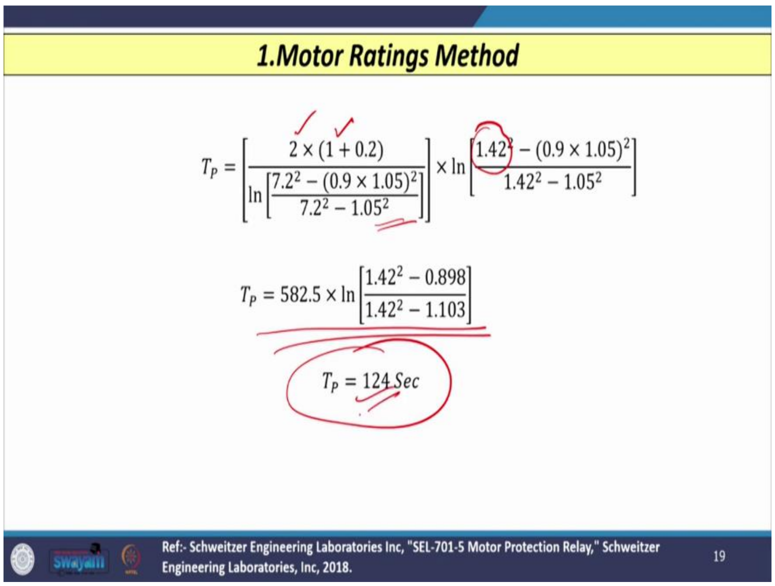


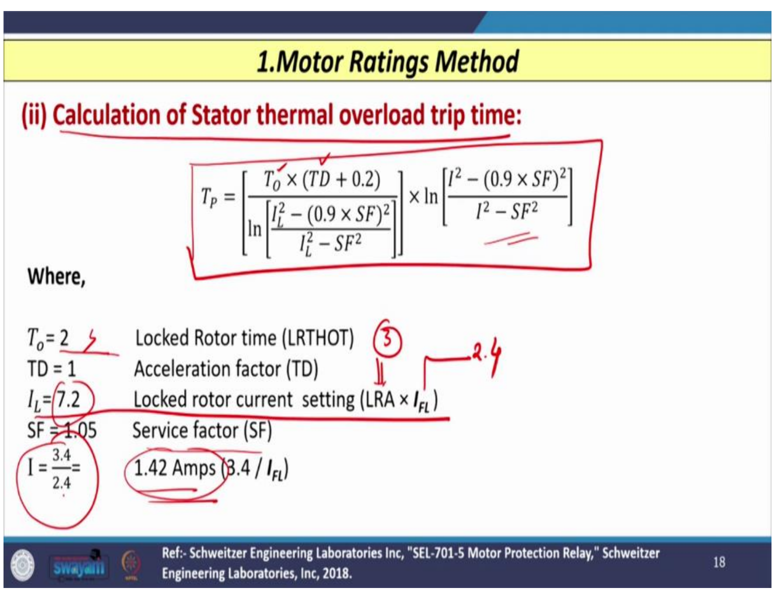

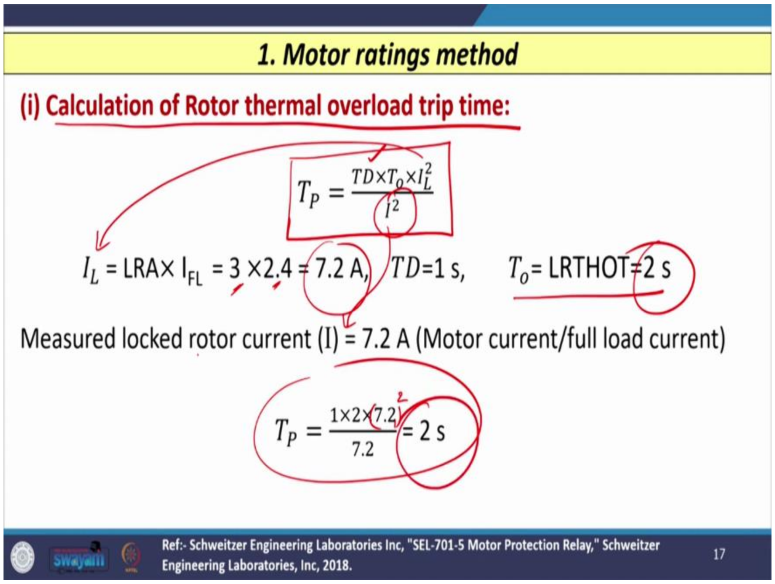


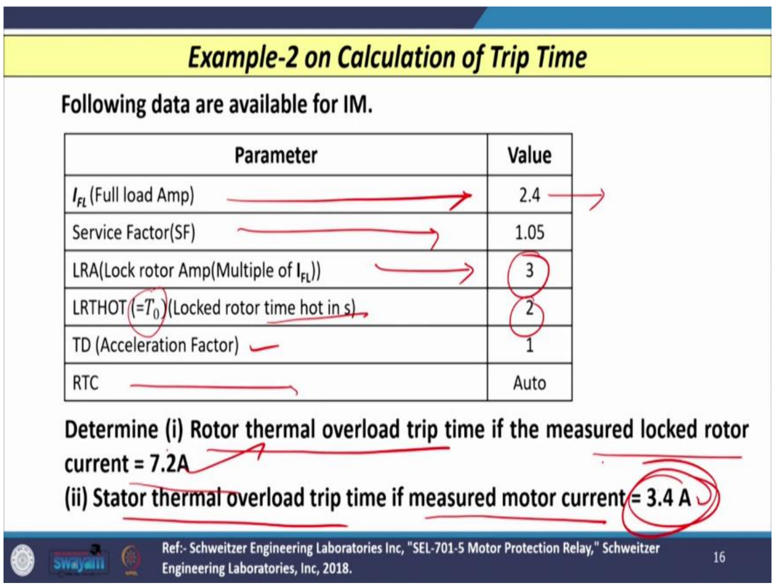


So, if you put this value here, $T_P = \left[\frac{2\times(1+0.2)}{\ln\left[\frac{7.2^2-(0.9\times1.05)^2}{7.2^2-1.05^2}\right]}\right] \times \ln\left[\frac{1.42^2-(0.9\times1.05)^2}{1.42^2-1.05^2}\right]$

$$T_P = 582.5 \times \ln\left[\frac{1.42^2 - 0.898}{1.42^2 - 1.103}\right]$$

$$T_P = 124\ Sec$$

So, here you can observe that the trip time in this case that is the second case where you have to calculate the stator thermal overload trip time which comes out to be 124 second, whereas in earlier case where you have to calculate the rotor thermal overload trip time, so, that comes out to be 2 second when we consider the measured current value that is 7.2 A and 3.4 A respectively.

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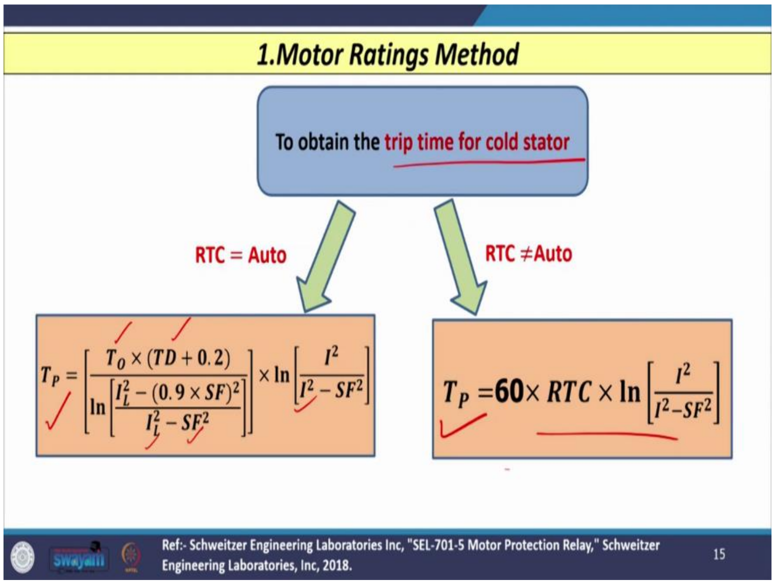


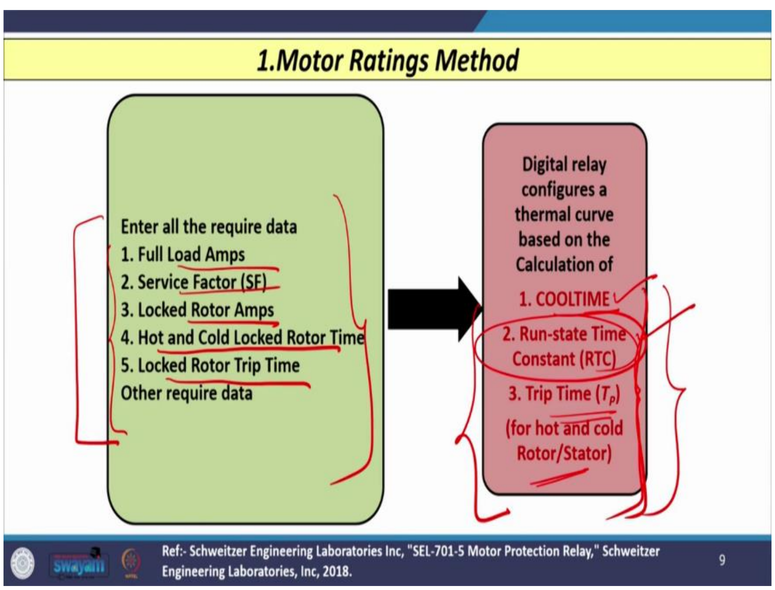


So, here you can see that if we go for motor rating methods, then what we have discussed is that with the available input parameter which are given as an input to the digital relay starting from full load current or maybe service factor or locked rotor ampere or maybe lock rotor time when motor is running in hot condition or maybe lock rotor time when motor is running in cold condition or maybe locked rotor trip time or maybe some other data like acceleration factor or some other data.

Then you can see that digital relay will automatically configures the thermal curve based on the calculation of these three values that is the run-state time constant that is RTC. Second is the cool time and third that is the trip time when motor is in hot or cold condition maybe in stator side or on rotor side.

So, in this method, we have discussed that calculation of these three parameters are important subject to the availability of the input data which are given to the digital relay and the digital thermal element which is a function available inside the digital relay, it can automatically calculates the value of this cool time run-state time constant and trip time of the induction motor subject to the availability of this data. So, this we have discussed.

Now, with this background, what we can say that, in this class or in this lecture, we have discussed the important point that is what calculations we need to carry out when digital thermal function is given inside the digital relay. So, then we have discussed that basically three methods are available, one is the motor rating method, second is the generic thermal limit curve and the third is the user data that can be inputted and based on that the calculation can be carried out.

And in this class we have discussed that the three important calculations that is the run-state time constant, cooling time and the trip time of the motors can be calculated depending upon the whether RTC is in auto mode or non auto mode. So, in the next lecture we will discuss the second method that is generic thermal limit curve. Thank you.