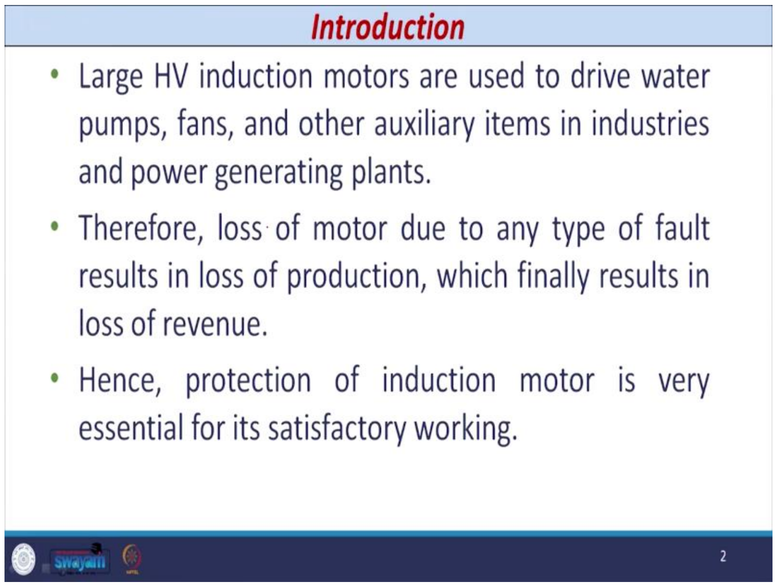
Power System Protection and Switchgear
Professor Bhuveshkumar Bhalja
Department of Electrical Engineering
Indian Institute of Technology, Roorkee
Lecture 30
Protection of Induction Motors

Okay. So, let us start the new chapter that is Protection of Induction Motors.

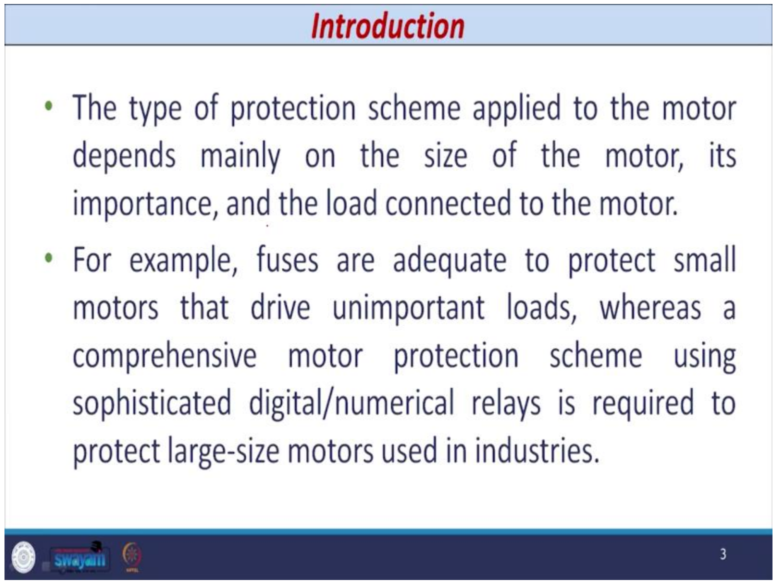
(Refer Slide Time: 00:30)



So, we know that large induction motors are used to drive water pumps, fans and other auxiliary items used in the industries as well as in power generating plants. So, we know that in industries like rubber industries, plastic industries, induction motors are extensively used. Similarly, in power generating stations, we have the forced draft fan that is FD fan, induced draft fan that is ID fan and some other auxiliaries used in primary crusher and secondary crusher house induction motors are widely used.

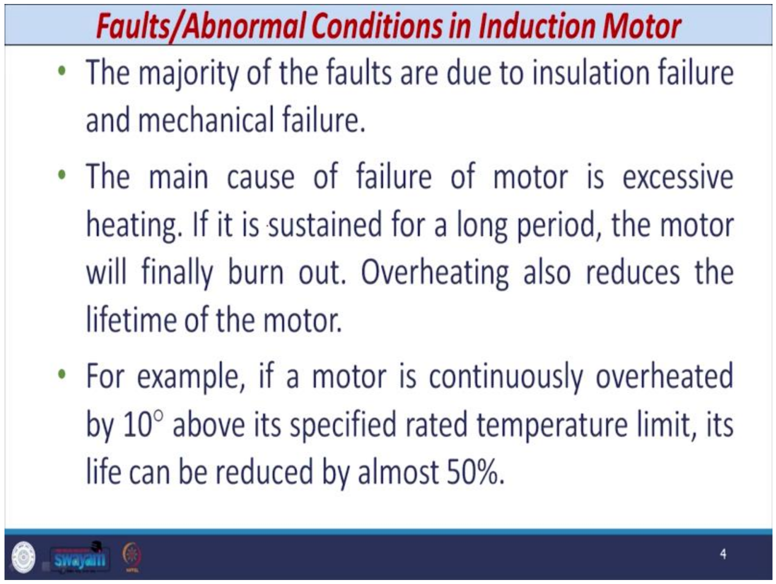
Therefore, loss of motor because of any fault in the motor may be the winding fault that is electrical faults or mechanical faults that leads to the loss of production, which in turn finally results in loss of revenue. Hence, protection of induction motor is very important and essential for satisfactory working of the motor as well as satisfactory working or production of the industries or power plant.

(Refer Slide Time: 01:29)



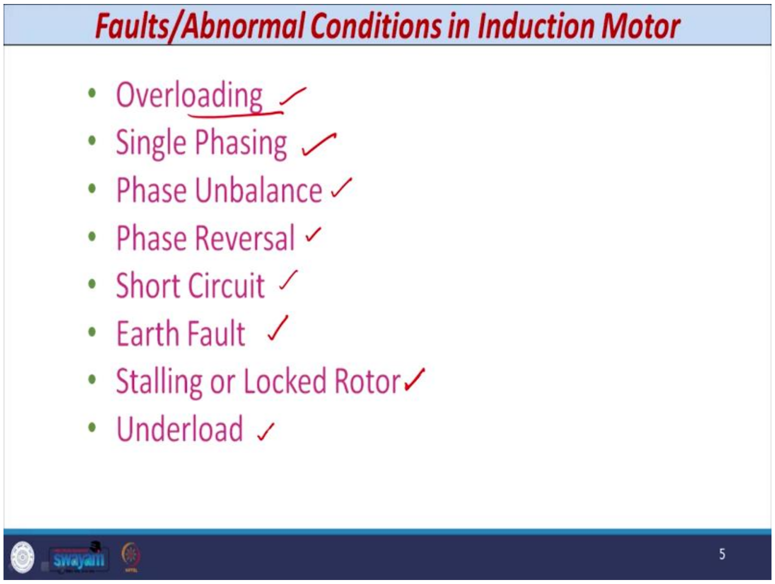
So, the type of protection scheme applied to the induction motor that mainly depends on three factors. The first factor that is the size of the induction motor; the second, what is the importance of induction motor; and the third that is the load connected to the motor. For example, if we use say fuses, those fuses are adequate to protect small motors that are used in some unimportant or to drive some unimportant loads, say for example, for household applications. Whereas if I use the induction motors at 6.6 kV or in some auxiliaries in large industries and large power generating plant, then in that case we need to give a separate sophisticated digital/numerical relays protection based on that protection, so that if any fault occurs then that can be easily detected.

(Refer Slide Time: 02:27)



Now, so let us discuss what are the faults and abnormal conditions in induction motor. So, the majority of faults in the induction motor that is because of the failure of insulation that is electrical faults and the other type that is the mechanical faults because of mechanical failure. So, the main cause of failure of motor that is because of excessive heating. If this type of heating is sustained by the motor for a longer duration, then the motor will finally burn out. Overheating also reduces the lifetime of the motor. For example, if motor is continuously overheated, say 10 degree above the specified temperature value in the data sheet by the manufacturer, then its life fun that can be reduced by almost 50%.

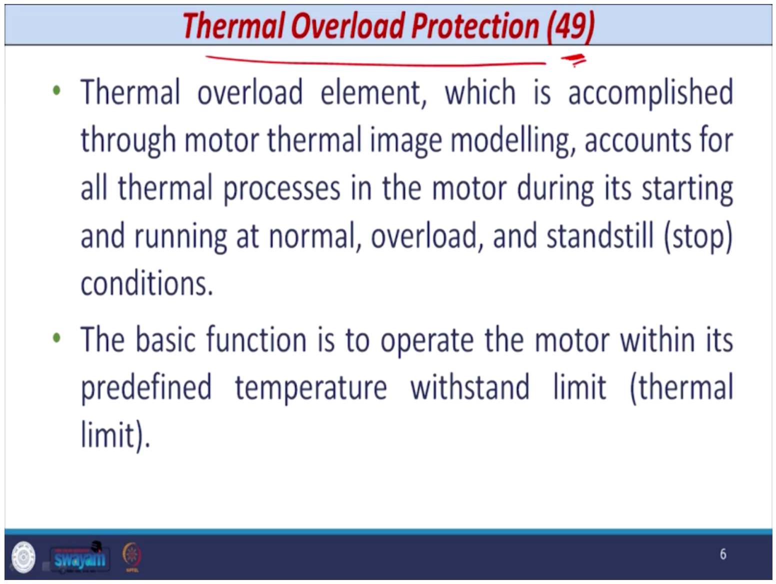
(Refer Slide Time: 03:13)



So, if I discuss faults and abnormal conditions in induction motor then that can be listed as the first that is known as the overloading. The second that is known as the single phasing, so one of the phase of the induction motor in three phase that is not there or that is not available. The third that is known as phase unbalance, so instead of giving RYB, we will give some other phase sequence RBY or some other. The phase reversal that is also there. Short circuit if any fault occurs in the winding then short circuit is there and large magnitude of current that flows.

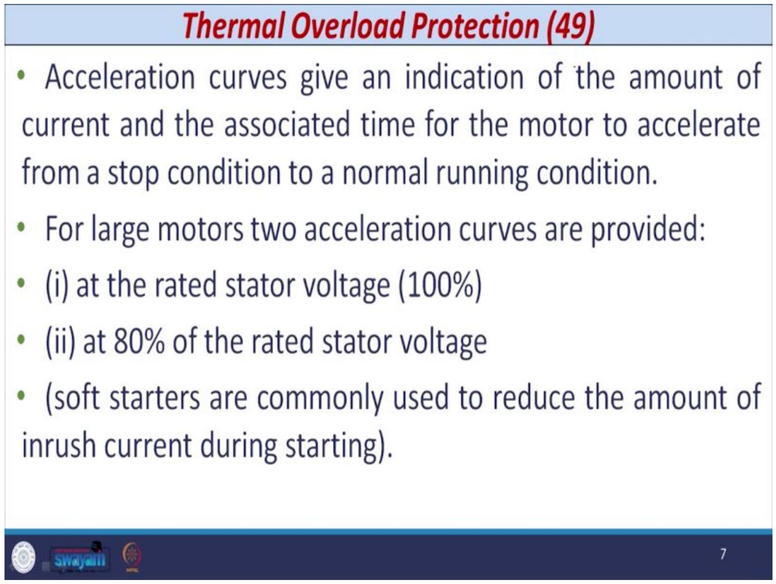
The third is the earth fault that is between the winding and the core. The next one that is the stalling or locked rotor, so any induction motor when you start the motor and if motor denies to start or if it started then it is just running at a very low speed than the normal speed, then this type of phenomenon that is known as the stalling. And the last one that is the underload.

(Refer Slide Time: 04:17)



So, let us discuss each and every phenomenon one-by-one. So, let us start with thermal overload protection. The number given to the thermal overload relay that is 49. So, thermal overload element that is accomplished by the modeling or image modeling of the motor and that is accountable for the all thermal process in the induction motor may be when you start the motor or when you run the motor in normal condition or you run the motor or start the motor in overload condition or in standstill condition that is stop condition. The basic function is to operate the motor within its prescribed temperature limit that is known as the thermal limit of the motor.

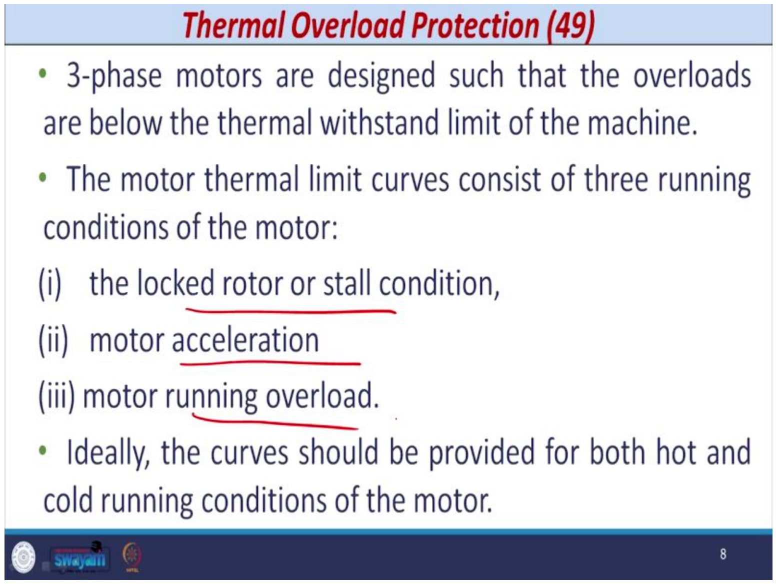
(Refer Slide Time: 05:01)



Now, the acceleration curves give, that the induction motor whenever any acceleration curve is defined or given by the manufacturer, then it specifies that the indication of an account of current and the associated time for the motor to accelerate from the stop condition to the normal conditional. So, when you start the motor, motor is in, at standstill condition. So, when you start the motor and after getting some speed, final base speed, whatever the time required by the motor that is known as the acceleration time period, and this time period is always associated with the some voltage, whether you start the motor at rated voltage or some reduced voltage.

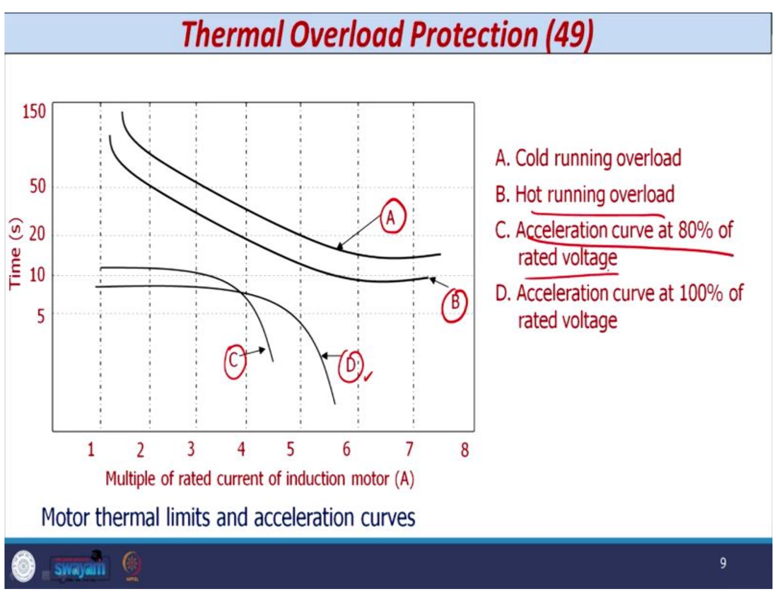
For large motors two acceleration curves are specified by the manufacturer. The first that is the, at rated voltage 100% voltage and second that is the 80% of the rated stator voltage. So, soft starters are commonly used in the induction motors to reduce the amount of inrush current or the starting current when you start the motor, because when you start the motor, starting current of the motor that is 5 to 6 times its full load current, but keep in mind this is not a fault and whatever device you use, it is capable to discriminate between these two phenomena.

(Refer Slide Time: 06:20)



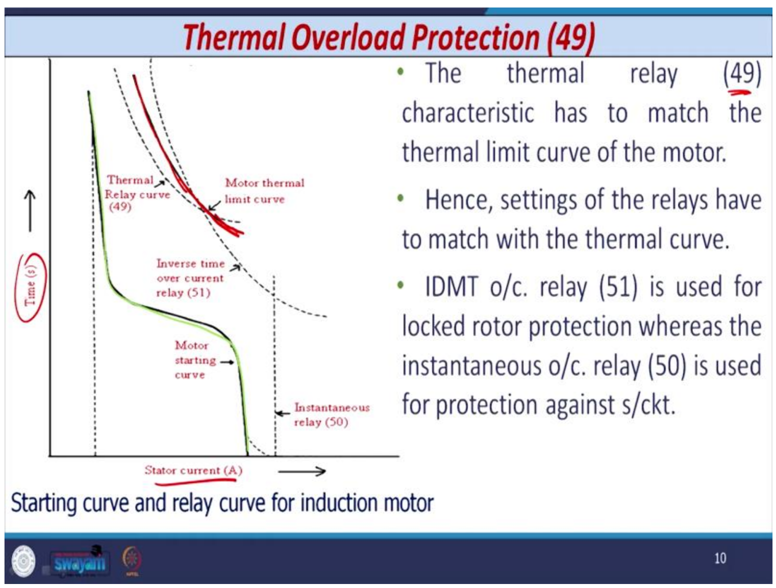
The 3-phase motors are designed such that the overloads are just below the specified withstand value of the motor. The motor thermal limit curve consists of the three running conditions of the motor. The first that is the locked rotor or standstill condition or stall condition. The second that is motor that is acceleration condition and the third that is motor that is in running with overload condition. So, ideally, the curves, all the three curves should be provided for both hot and cold running of the motor.

(Refer Slide Time: 06:53)



So if I just look at the curve, then you can see that the first curve that is the curve number A that is provided that is when you start the motor during cold condition and it is in running condition with overload. The just below this A curve, you have the another curve where the motor, you run the motor with overload condition when it is in hot condition. The other two curves that is curve C and curve D, you can see that is acceleration curve for the motor one that is C at 80% of the stator voltage and D that is the 100% of the rated voltage. So when you consider the setting of the relays, then you need to consider the acceleration curve with 80% of the rated voltage.

(Refer Slide Time: 07:40)



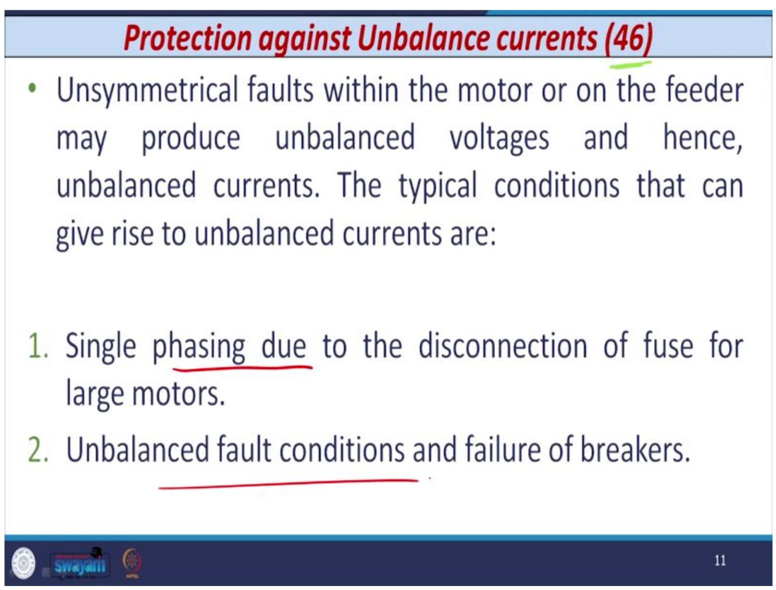
Let us see how we can apply the thermal overload protection in case of induction motor. So, as I told you, 49 number is used or specified or for the induction motor. So, you can see, this is the curve of the induction motor where on X axis you have the stator current and on Y axis you have the time. Now, you can see that there is a curve known as motor thermal limit curve that is shown by this curve that is the dark curve, this is the motor thermal limit curve.

So, the thermal relay characteristic that should exactly match with the motor thermal limit curve and it should be below just exactly below this curve, because if this curve is above the thermal limit curve, then the motor or insulation of the motor may burn. So it should be exactly below and it should not be very low with reference to this motor thermal limit curve otherwise you, motor cannot fully exploit its overloading condition because motor can easily withstand few percentage of overload condition. So, thermal relay curve that is 49 curve, you can see that is the exactly below this motor thermal limit curve.

You can also see that, just below that, I have shown the starting, motor starting curve that is this curve. So, if I just observe this motor starting curve then you can see that this curve is nothing but the motor starting curve. So, when you start the motor, motor starting curve should be below the thermal relay curve that is 49 curve specified by the manufacturer.

And along with this, you can also see the another two curves, one that is the inverse time over current relay that is 51 that is again for the short circuit in the induction motor and another that is the instantaneous relay curve that is of 50 number. Both 50 and 51 are used for the protection against short circuit in induction motor. So, this curve, this 51 curve that should be always separate with the motor thermal curve.

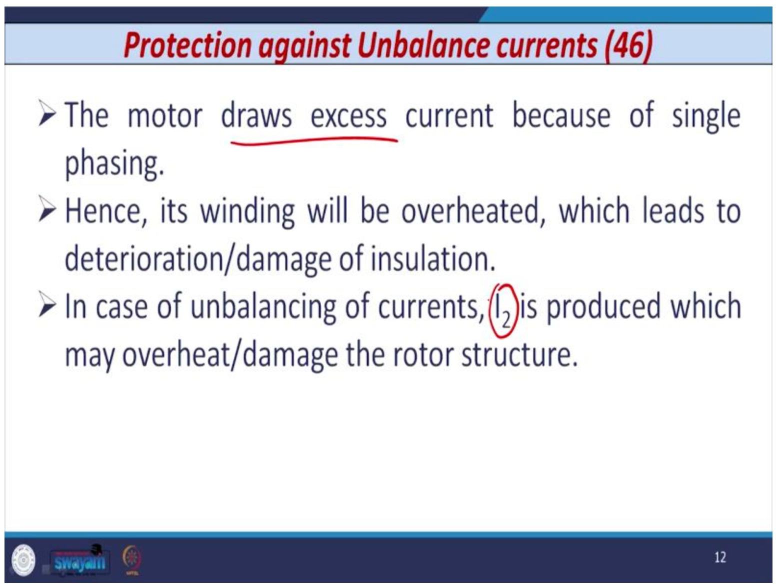
(Refer Slide Time: 09:52)



Now, the next phenomenon that is known as the protection against unbalanced current and this unbalanced current, the main number given to the unbalanced relay that is the 46 number. This type of relay is also known as negative phase sequence protection or negative phase sequence scheme. So we can say that in case of the unsymmetrical faults that may occur within the motor or on the feeder that is emanating near the motor then that may produce unbalanced voltages and hence finally currents become unbalanced.

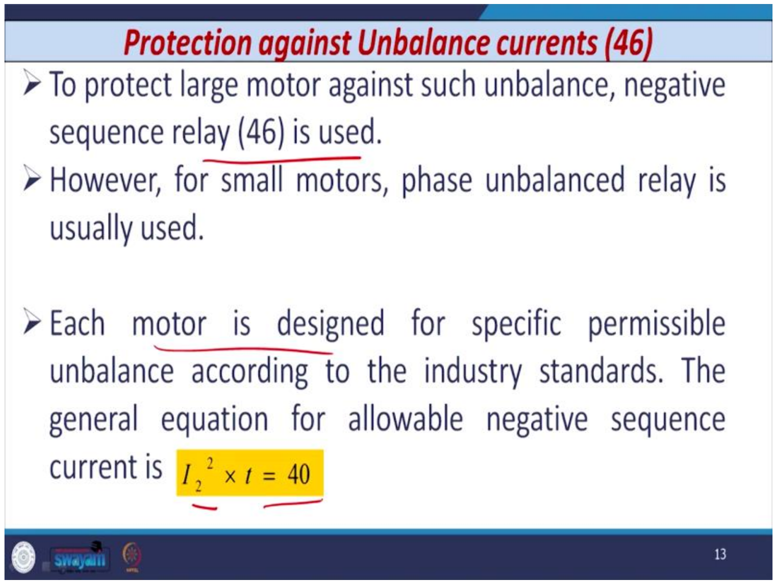
So, the typical conditions that can give rise to unbalanced currents are: the first, that is the single phasing and it can be because of the disconnection of fuse or disconnection of large motors; and second that is the unbalanced fault conditions and the failure of circuit breakers. So because any of these two reasons, the unbalanced currents may produce and motor has to be protected against such unbalanced currents.

(Refer Slide Time: 10:55)



Now, why motor needs to be protected against unbalanced current, because the motor in this situation draws very high current because of the single phasing, hence its winding will be overheated and which leads to deterioration of the insulation or sometimes in worst case damage of the insulation. So in case of unbalanced current, negative sequence current that is I2 that is produced, which may overheat or damage the rotor structure. It is written or specified in the literature that the heat produced because of production of negative sequence current that is 6 times the heat produced by the motor when positive sequence current flows.

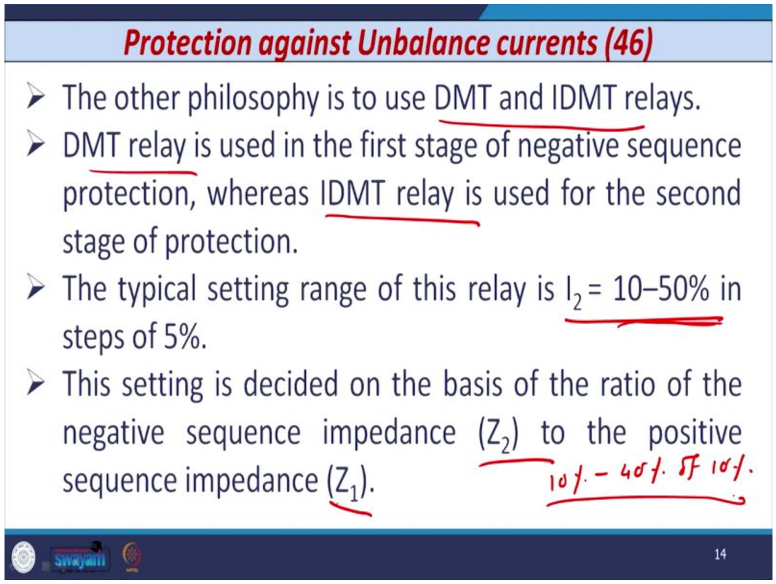
(Refer Slide Time: 11:36)



So, to protect the motor against such type of unbalance, negative sequence relay 46 that is used. However, for small motors, phase unbalanced relay that is usually used because it is not economically viable to use negative phase sequence relay for small motors. So, in negative phase sequence relay each motor is designed for specific permissible unbalanced current according to the standards.

So the general equation for allowable negative sequence current that is given by I2 square into t that is equal to 40, where I2 is the negative sequence current and t is the time during which the negative sequence current flows through the winding of the motor.

(Refer Slide Time: 12:19)



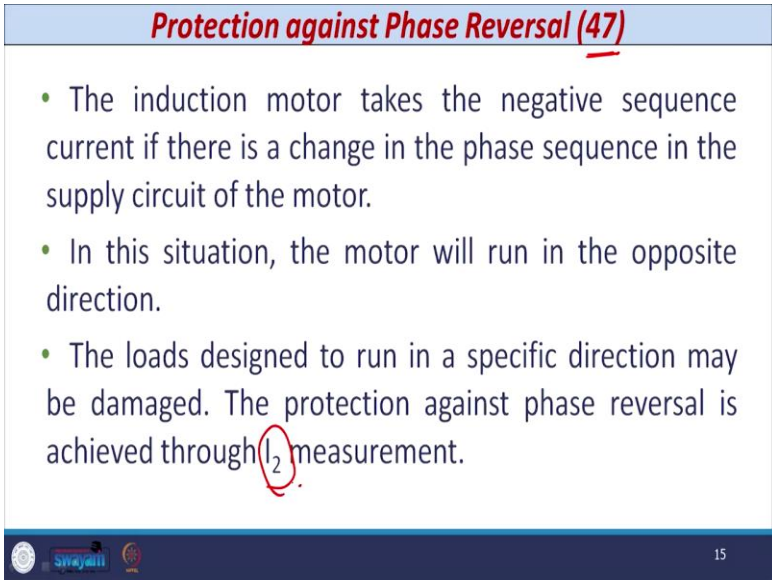
So, the other philosophy, suppose if I have small motors and its cost is low compared to the other motors, then it is not economically viable to use the negative phase sequence relay for protection against unbalanced currents. So, in that case, we may use the definite minimum time delay relay or sometimes inverse definite minimum time delay relays.

So, if I use the definite minimum time delay relay that is DMT relay, then the first stage of negative sequence protection that is given or covered by this relay, DMT relay, whereas the second stage of the unbalanced current protection that is covered by the IDMT that is inverse definite minimum time delay relay.

The typical setting range of the relay that is I2 that is in the range of 10% to 50% in steps of 5%. And this range that is with reference to the rated current of the induction motor, usually it is CT secondary current. Sometimes if I use the negative phase sequence current that is 46 relay, then its setting that is to be decided on based on the ratio of negative sequence impedance Z2 to the positive sequence impedance that is Z1.

So you take the ratio of Z2 by Z1 and whatever figure comes then you decide the setting according to the setting range given. In this case, the setting range given is 10% to 40% in steps of 10%. So, this is for 46 relay, whereas this is for the DMT or IDMT relay.

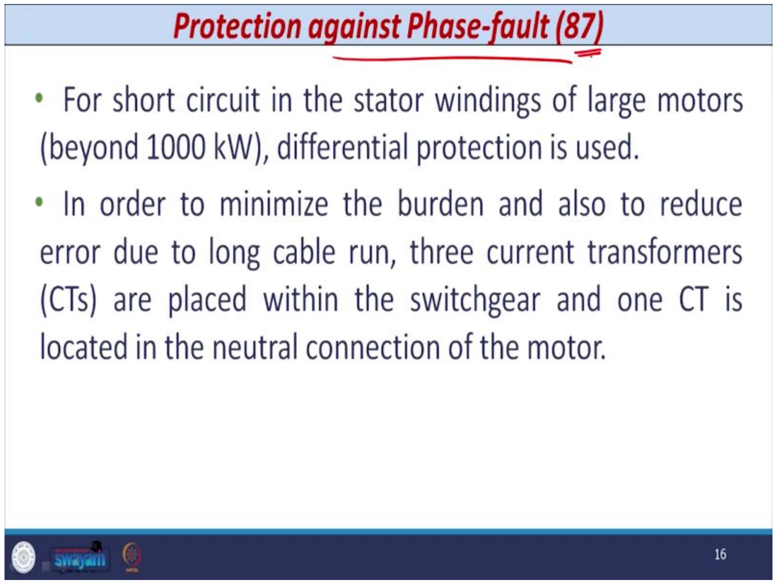
(Refer Slide Time: 13:55)



Now, the next type of protection or phenomenon that is known as protection against phase reversal. So instead of giving RYB phase sequence, you -- if the phase sequence is altered or changed, then motor needs to be protected. So for that the relay number given to the protective device that is 47, so the induction motor takes negative sequence current if there is a change in the phase sequence in the supply circuit of the motor.

So in this situation, motor will run in opposite direction. The loads whatever you have connected with the motor that is designed to run in specific direction only. So, if motor runs in opposite direction, then whatever loads you have connected that will be damaged. So protection against phase reversal that is very important and this is once again achieved with the measurement of negative phase sequence current that is the I2.

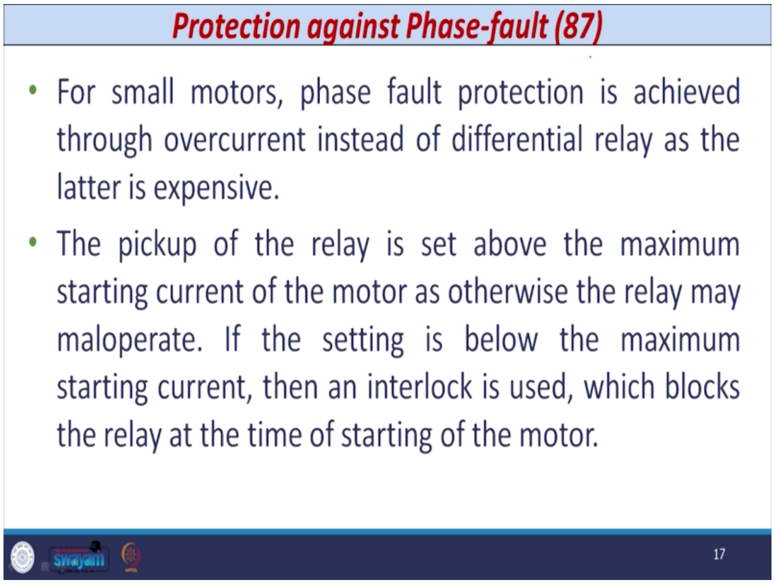
(Refer Slide Time: 14:47)



Now, for the next part or next phenomenon that is the protection against the short circuit and this is basically phase to phase faults and the relay number given that is known as the 87. So for short circuit in stator winding of large induction motors maybe beyond 1,000 kilowatt differential protection is used. Whereas, if I have small or medium range induction motors where we cannot use the differential protection for protection against short circuit, there we can go for the IDMT relay or instantaneous relays, because this relays are cheaper than the differential relay.

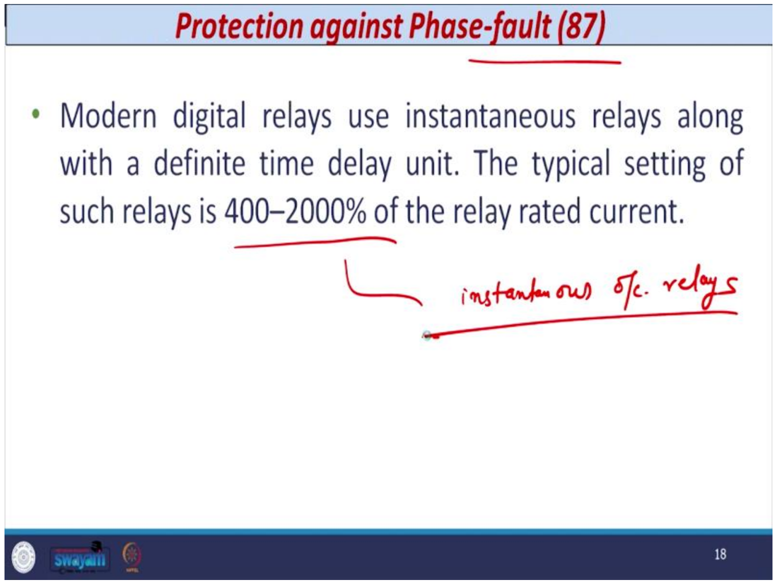
So, in order to minimize the burden and also to reduce the error due to long cable run, three current transformers are placed within the switchgear and one CT is located in the neutral connection of the motor.

(Refer Slide Time: 15:39)



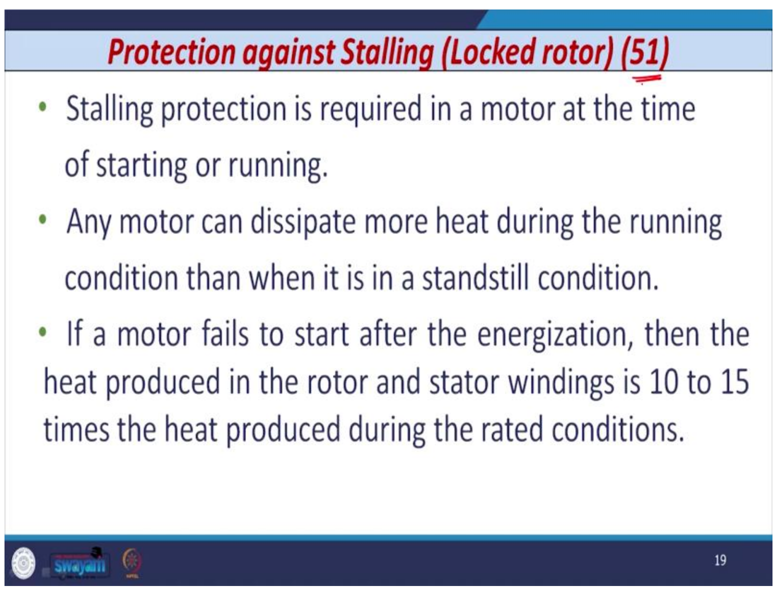
Now, for small motors, as I told you, phase fault protection that is achieved by the over-current relays IDMT or instantaneous instead of differential relay, the pickup of the relay is set above the maximum starting current of the motor, otherwise relay may mal-operate when you as soon as you start the induction motor. If the setting is below the maximum starting current, then sometimes if it is not possible to go for the or to reduce the setting of the over-current relay below the starting current of induction motor, then certain type of interlocking needs to be provided. So that that interlock blocks the operation of motor in case of starting. However, if, when you start the induction motor any fault is there, then such type of relay is not capable to detect the phenomenon.

(Refer Slide Time: 16:30)



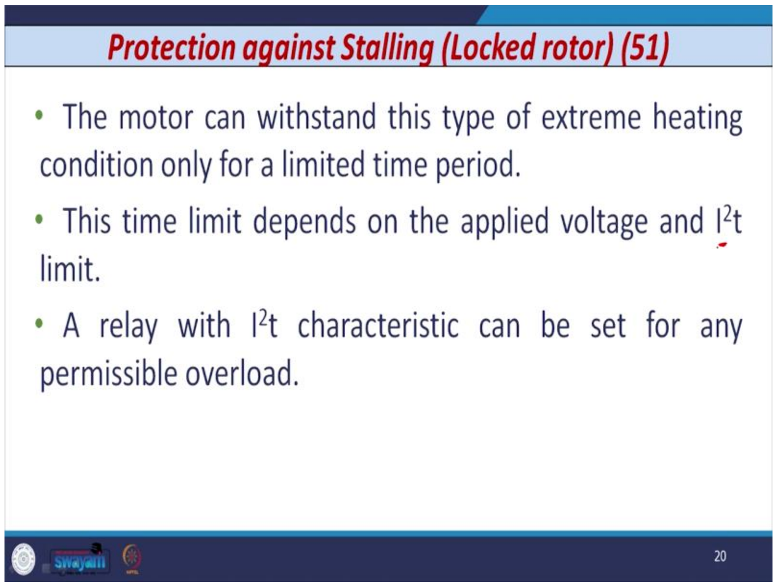
So, protection against phase fault in modern digital relays that is normally dealt with the differential relay and typical setting that is 400% to 2000% of the rated current. So, this setting is normally for the instantaneous relays, instantaneous over-current relays.

(Refer Slide Time: 16:54)



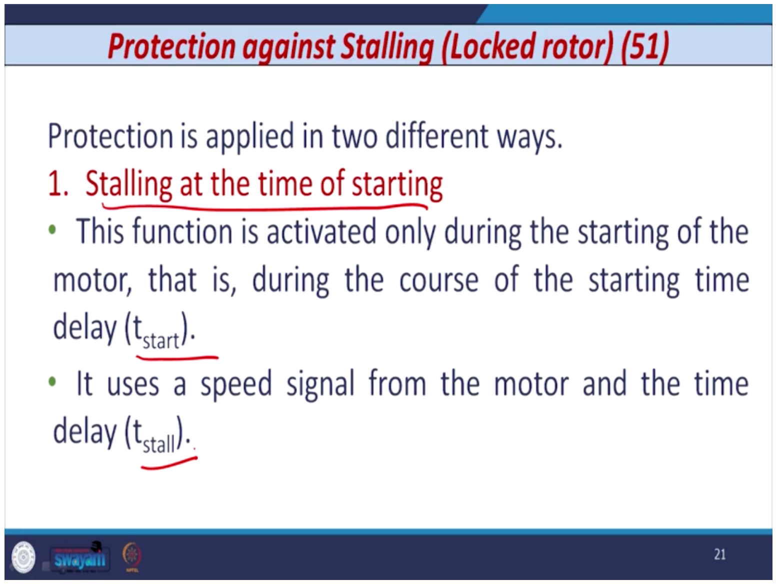
Now, let us consider the another point that is the protection against stalling or lock rotor. So, in this case the number given to the relay or protective device that is the 51. So stalling protection is required in a motor at the time of starting or running of the induction motor. So any motor can dissipate more heat during running condition than compared to when it is in standstill or steady state condition. So if the motor fails to start after energization, then the heat produced in the rotor and stator winding that is 10 to 15 times the heat produced during the rated conditions.

(Refer Slide Time: 17:34)



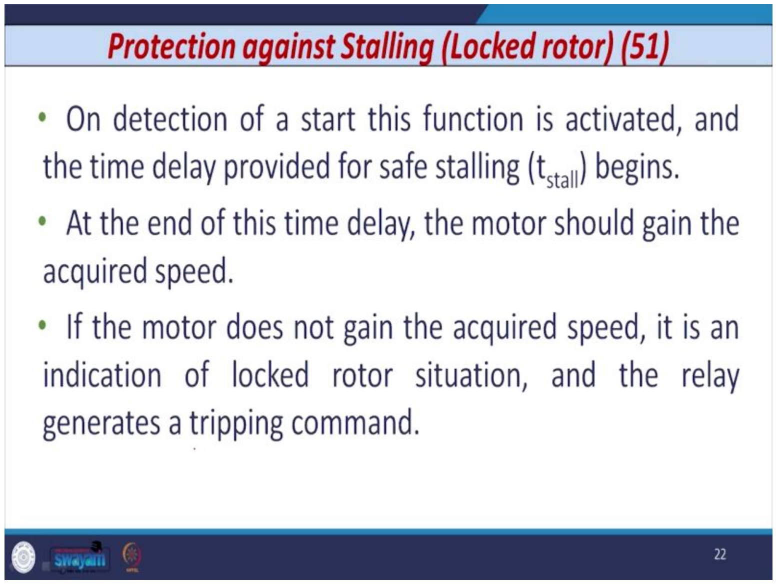
So, motor can withstand this type of extreme heating condition only for a limited time period or limited duration. So this time period or this time limit depends on the applied voltage and I square t limit, where I square that is the current that flows through the winding of the motor and t is the time. A relay with I square t characteristic can be set for any permissible overload.

(Refer Slide Time: 18:01)



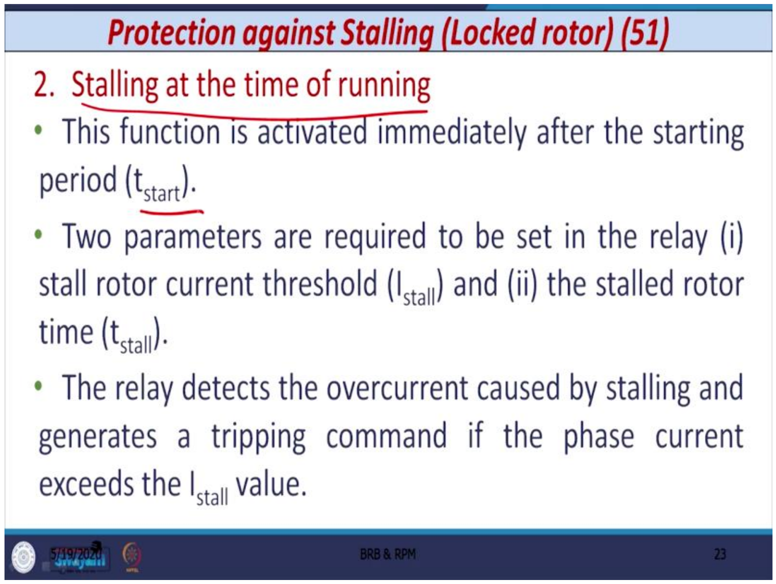
So, the protection in case of stalling that is applied by two ways. The first stalling protection is given at the time of starting of the induction motor. So this function is activated only during starting of the motor and that is during the course of starting time delay. So t start that is to be specified. It uses a speed signal from the motor and the time delay that is t stall. So, t stall is the stalling time that is specified by the manufacturer of the induction motor.

(Refer Slide Time: 18:37)



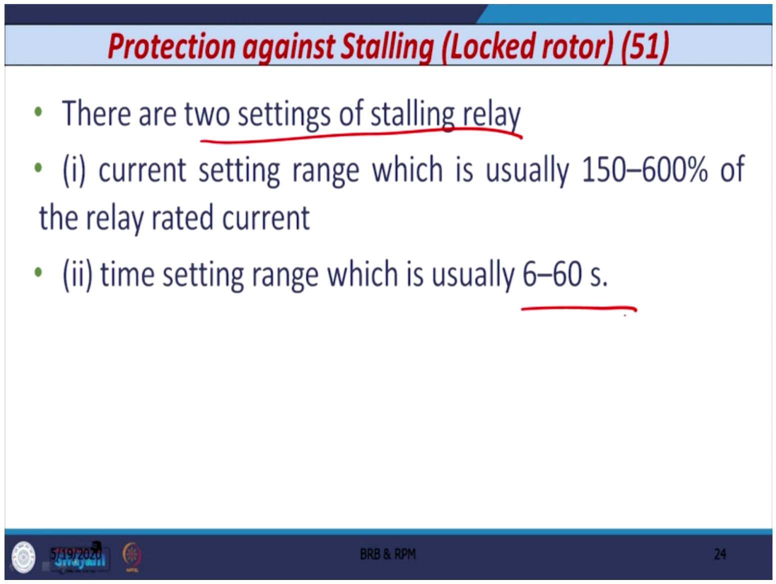
On a detection of a start this function is activated and the time delay provided for safe stalling t stall that begins. At the end of this time delay, the motor should gain the required speed. If motor does not gain the acquired speed or required speed, then it is an indication of locked rotor or stalling condition and relay generates a tripping command. So some safe stallings time that is to be provided and during that time period if motor gains a sufficient speed, then it is not a locked rotor condition, but if motor is not able to gain the sufficient or some specified speed before the stallings time expires then this is an indication of the locked rotor condition.

(Refer Slide Time: 19:21)



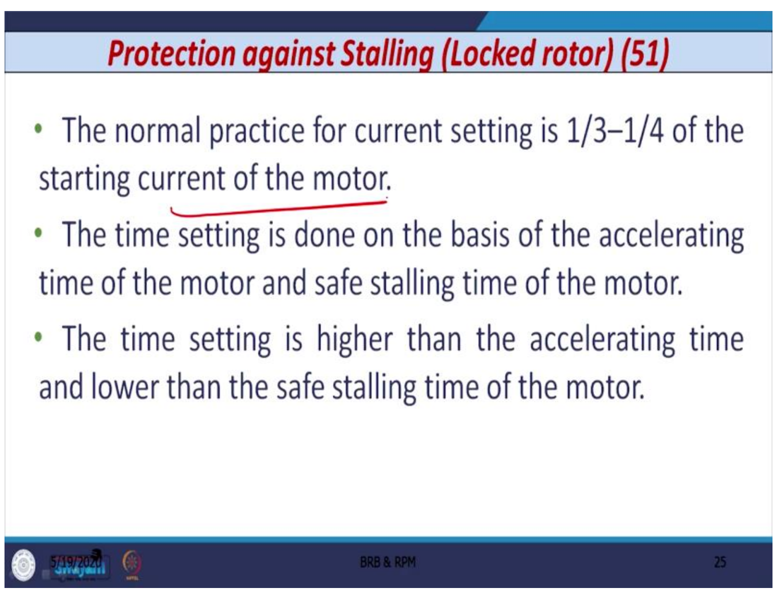
The second type that is known as the stalling at the time of running. So this type of function is activated immediately after the starting period that is t start. So, two parameters are required to be set in the relay. The first that is the rotor stall current threshold, that is I stall which is normally one-third or one-half of the full load current of the motor; and the second that is the stalling rotor time that is t stall. The relay detects the over-current caused by stalling and generates a tripping command if the phase current exceeds I stall value.

(Refer Slide Time: 19:56)



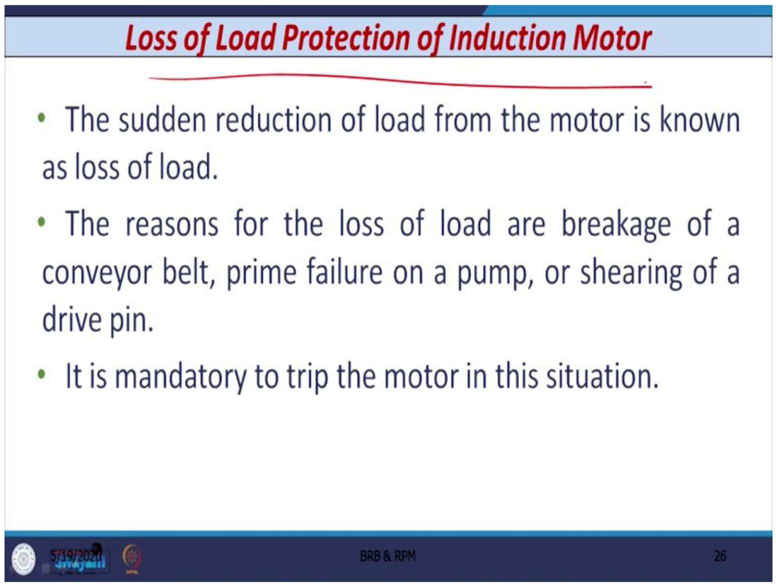
Two settings are provided in the stalling relay, the first that is the current setting, basically it is related to I stall and its range that is usually 150% to 600% of the relay rated current and the time setting range which is usually provided in 6 to 60 seconds in steps of 5 or 10 seconds.

(Refer Slide Time: 20:17)



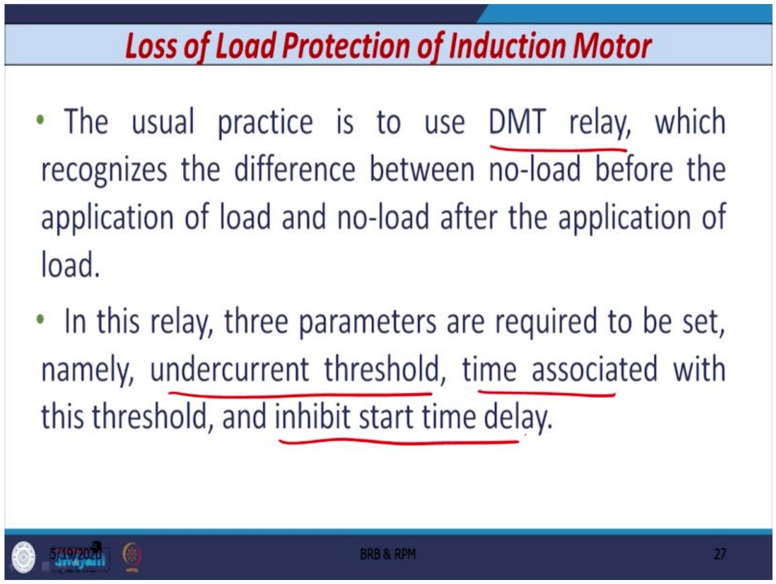
The normal practice for current settings that is I stall setting that is one-third to one-fourth of the starting current of the induction motor. So the time setting on the other hand that is done on the basis of the accelerating time of the motor and safe stallings time of the motor. So time setting should be such that should be higher than the acceleration time of the motor and it should be lower than the safe stalling time of the induction motor.

(Refer Slide Time: 20:45)



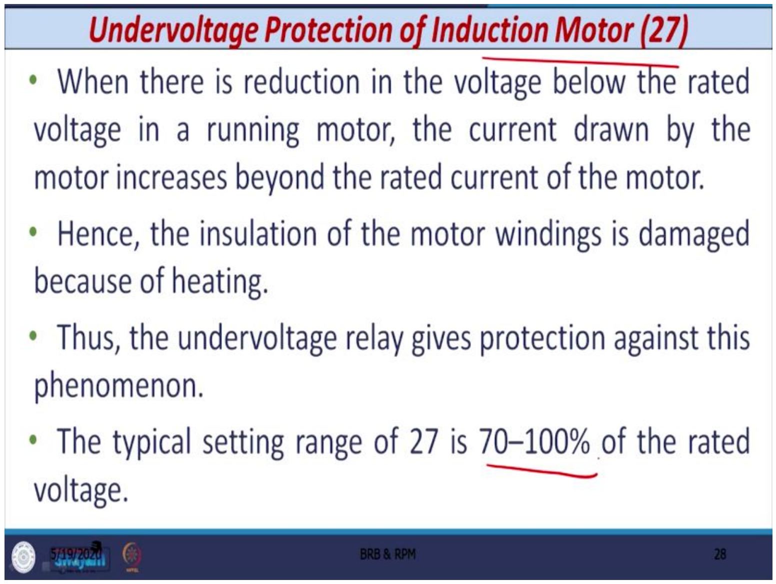
The next point or phenomenon that is known as loss of load protection of induction motor. So the sudden reduction of load from the motor that is known as the loss of load, maybe loss of load that is because of the breakage of conveyor belt or maybe because of the prime failure of the pump or shearing of the drive pin. So it is mandatory to trip the motor in this situation. When load that is suddenly taken away from the motor.

(Refer Slide Time: 21:10)



So the usual practice is to use the definite minimum time delay relay, which recognizes the difference between the no-load before the application of load and no-load after the application of load. So in this relay, three parameters are required to be set, that is first, undercurrent threshold, below which current this current is activated. And the second is the time associated with this threshold in how much time this undercurrent that is available or achieved. And third, that is the inhibit start time delay.

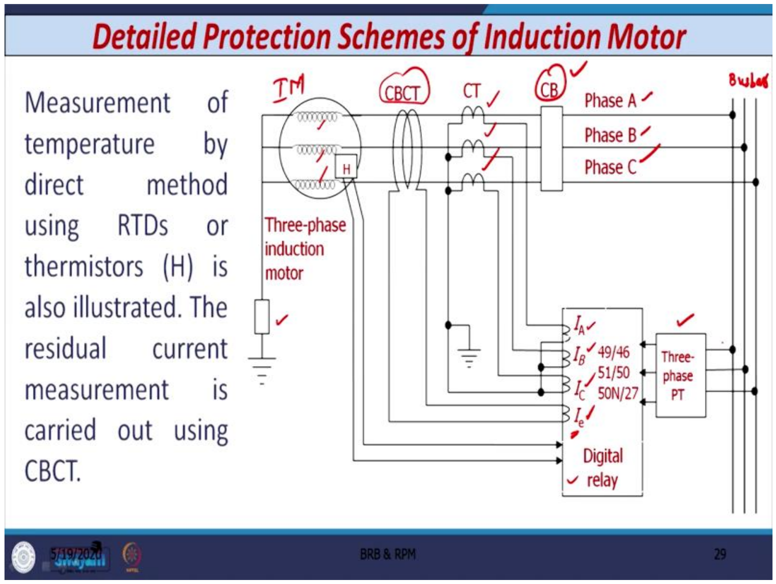
(Refer Slide Time: 21:49)



The next phenomenon that is known as the undervoltage protection of induction motor and the relay or protective device number that is given as the 27. So when there is a reduction in the voltage below the rated voltage in the running condition of the induction motor, then the current drawn by the motor that increases beyond the rated current of the motor or full load current of the motor. Hence, the insulation of the motor windings that is damaged because of the excessive heating, thus the undervoltage relay gives protection against this type of phenomenon.

And the typical setting range of this undervoltage relay that is 70% to 100% of the rated voltage. So, it is normally specified that if the voltage in case of induction motor reduces below say 80% or some value say 75%, then the undervoltage relay comes in picture and it activates and it is going to give the signal or tripping command to the breaker.

(Refer Slide Time: 22:47)

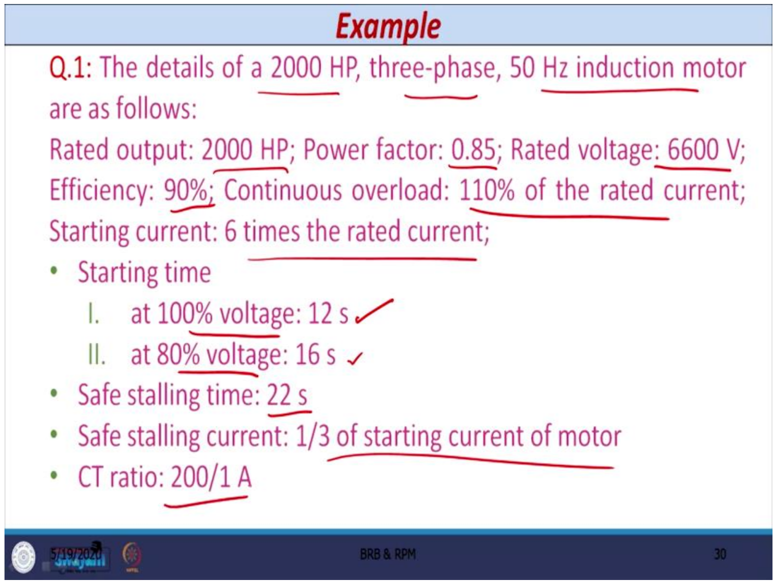


So, if I just draw the detail protection scheme of induction motor, then you can see here is the scheme, so this is the busbar and along with this busbar you have the three phase that is A, B and C, three phases are there along with the circuit breaker. And you have the induction motor here, this is your induction motor that is grounded through some resistor or reactor. These are the three windings of the induction motor.

And you can see that along with this induction motor the three CTs are there in each phase and this signals are given to here IA, IB, IC, one more CT that is also provided here that is known as the core balance current transformer that is for the just to acquire the residual current in case of induction motor. So, you have the four current signals are available, three phase and one earth.

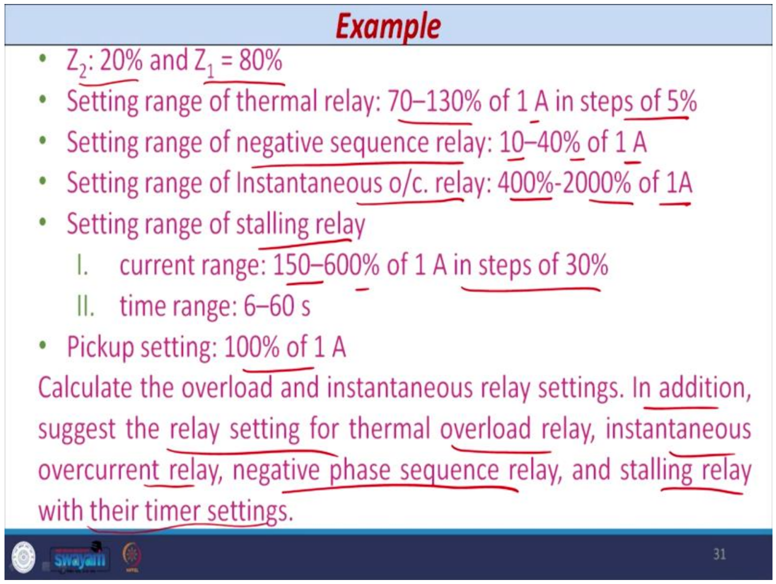
The one more thing is that the signal from this winding that is also given to the digital relay so that if any temperature measurement is required then that is also to be carried out by the digital relay. So measurement of temperature by may be some method like RTD resistance, temperature detector or thermistors that is to be also provided in the digital relay. You can see that the, along with the CTs, the PTs are also provided because if I wish to achieve the undervoltage phenomenon or like that then I have to connect the undervoltage relay on the secondary of this PT. So, PT is also required.

(Refer Slide Time: 24:19)



Now, let us solve one example based on this induction motor. So, let us consider that the details of the induction motor or the data of the induction motor is as under. The rating is 2000 HP. It is a three phase 50 hertz induction motor. Power factor is the 0.85. Its rated voltage is 6.6 kV. Its efficiency is 90% and the continuous overload that can, motor can easily withstand continuously that is 110% of its rated current. The starting current of the induction motor is 6 times its rated value. The starting time of the induction motor is also specified that is at 100% voltage it is 12 second, and at 80% voltage it is 16 second. The safe stalling time of the induction motor is also specified it is 22 second and the safe stalling current is one-third of the starting current of induction motor. The CT ratio given that is 200/1 ampere.

(Refer Slide Time: 25:19)

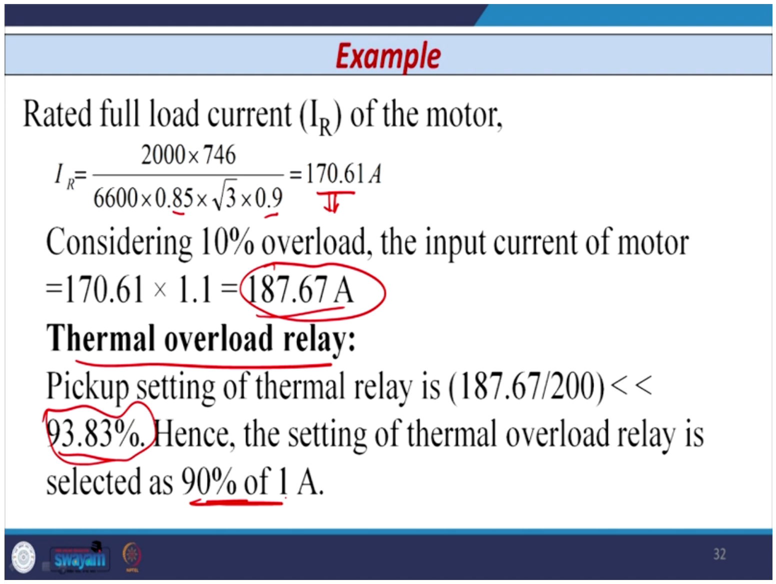


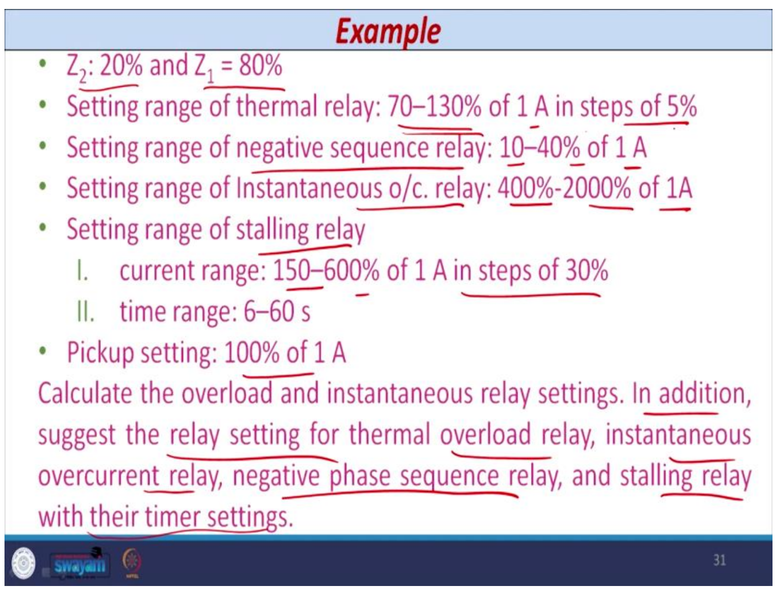
The negative sequence impedance is specified as 20% and the positive sequence impedance is also specified as 80%. The setting range of thermal relay, which is meant for the protection against overloading that is given as 70% to 130% of 1 ampere in steps of 5%. The setting range of negative phase sequence relay that is 46 relay that is also given it is 10% to 40% of 1 ampere.

The setting of instantaneous overcurrent relay that is provided against the protection against short circuit in the induction motor that setting is 400% to 2000% of 1 ampere in steps of 100% or 50%. The setting range of stalling relay that is also provided. The current range is 150% to 600% of 1 ampere in steps of 30% and the time range is 6 to 60 seconds.

The pickup setting that is 100% of 1 ampere and you need to calculate the overload and instantaneous relay setting that is thermal relay and the instantaneous overcurrent relay setting. In addition, you need to also suggest the relay setting for thermal overload relay, instantaneous overcurrent relay, negative phase sequence relay and stalling relay with their timer settings.

(Refer Slide Time: 26:39)



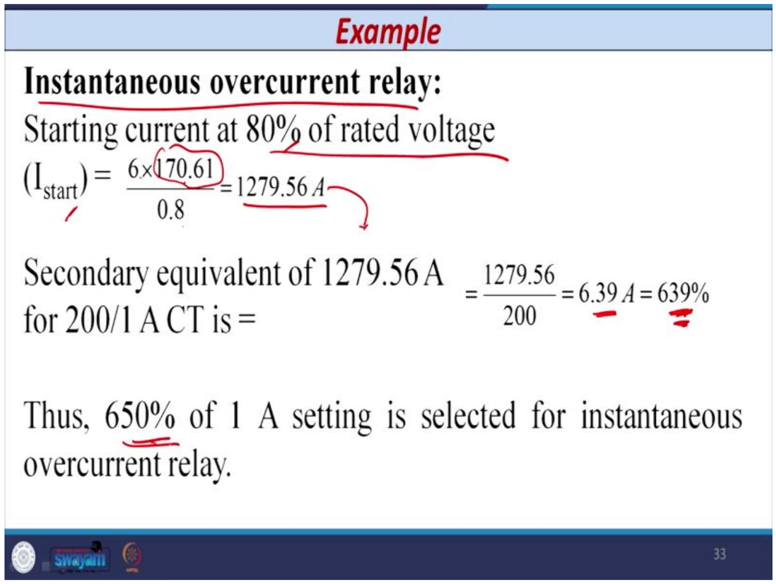


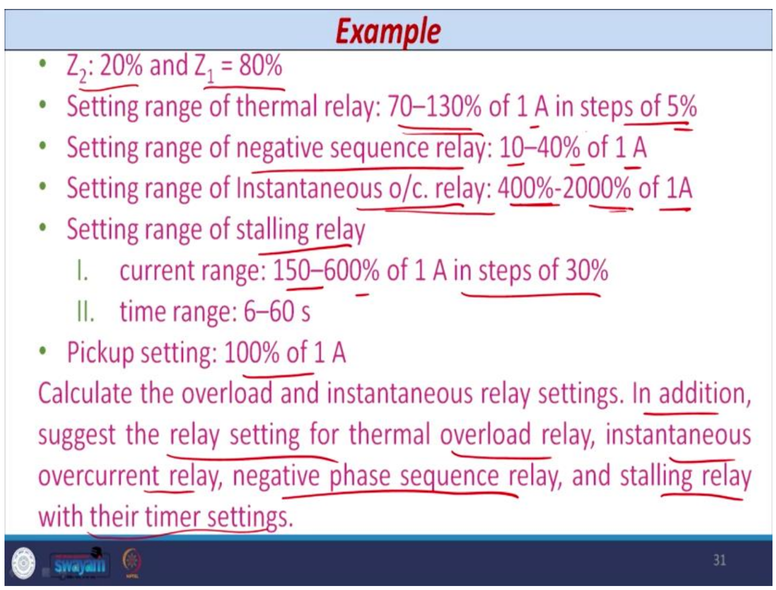
So, if I calculate, first, the rated full load current of the induction motor, then that is given by it is 2000 HP motor, so 2000 into 746 divided by voltage that is the root 3 into 6.6 kV so 6600 multiply by 0.85 power factor and 0.9 that is the efficiency of the motor. So, the current comes out to be 170.61 ampere. As it is specified that the induction motor is capable to take continuously 10% overload, so we have to take add 10% of this. So, if we take 10% of this, then it becomes 170.61 into 1.1, so it is 187.67 ampere.

Now, let us first calculate the setting of the thermal relay. So, for thermal overload relay, the pickup setting of the thermal relay, so to, if I wish to identify this, then I, this is the current that flows through the primary of the CT. So, let us convert this value into CT secondary as considering CT ratio is given 200 by 1 ampere. So, if you transfer it, then its value comes out to be in percentage that is 93.83%.

So, the thermal setting that should be below this value, it shouldn't be higher than this, it should be below this value whatever the next setting range available just below this. So, you can see that the thermal setting relay range that is given as the 70% to 130% of 1 ampere in steps of 5%. So, just below this I have the 90% setting available. So, the thermal relay setting that can be set as 90% of 1 ampere.

(Refer Slide Time: 28:27)



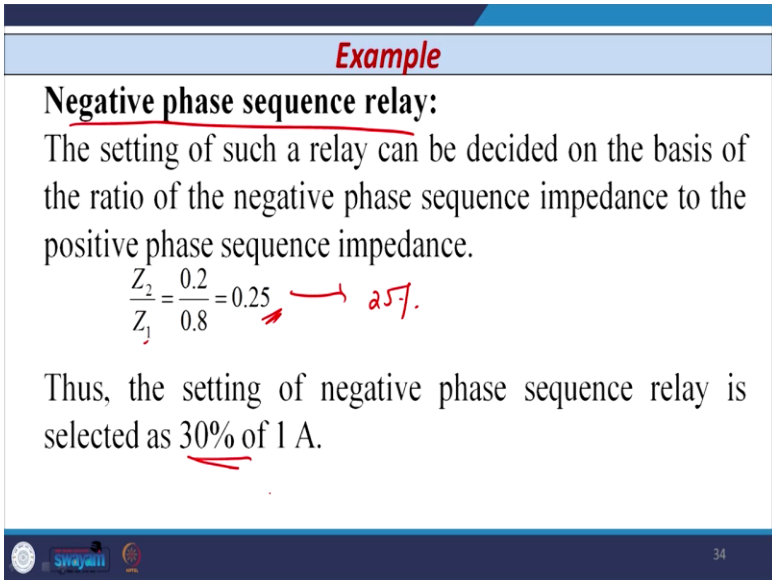


Now, let us calculate the setting of instantaneous overcurrent relay. So the starting current, let us find out the starting current of an induction motor at 80% of the rated voltage. So, I start that should be equal to, it is 6 times the full load current that is the 170.61. Please do not take the 187, because that is the current it can easily carry, but that is again when motor is in normal running condition. So, 6 times this value divided by 0.8 that 80% of the voltage. So the current comes 1279.56 ampere.

So, if I transfer this current on CT secondary side, 200 by 1 ampere, then its value comes out to be 6.39 or in percentage 639% of 1 ampere. So, if I just calculate the instantaneous setting, if I look at the setting range of instantaneous overcurrent relay, then it should be 400% to 2000% of 1 ampere in steps of 100%.

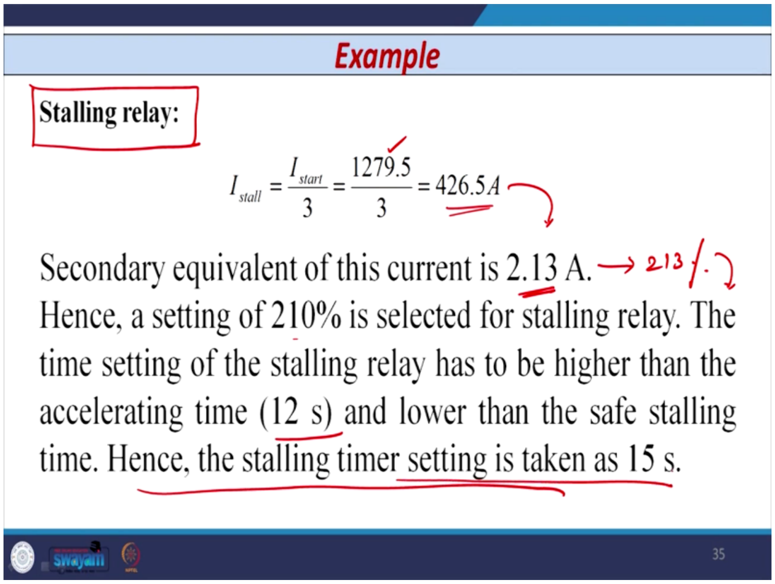
So, you can see that the next available setting range available beyond 639% that is 650% of 1 ampere, you can take 700% also if setting range that is given in steps 100%. If it is given in steps of 50%, then you can take just higher value of this that is 650% of 1 ampere for instantaneous overcurrent relay.

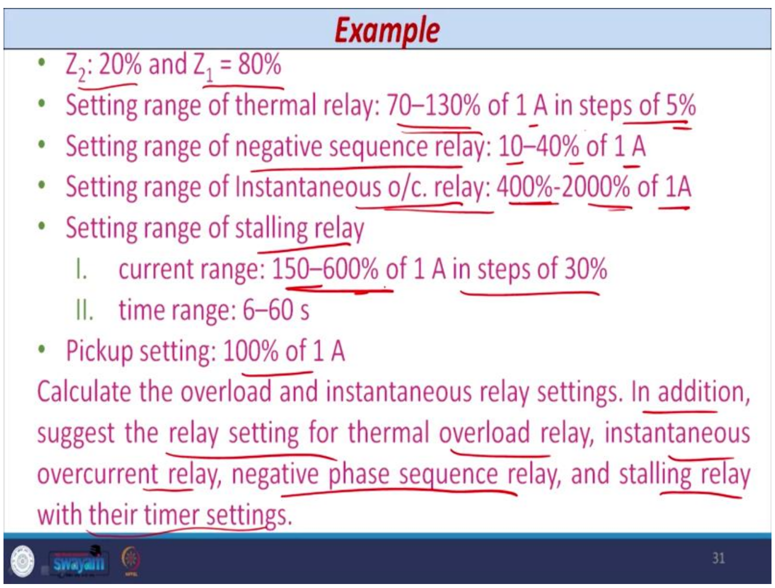
(Refer Slide Time: 30:00)



Now, let us consider the negative phase sequence relay setting. So, the setting range as I told you earlier for negative phase sequence relay that is to be done by taking the ratio of negative sequence impedance to the positive sequence impedance. So, this is specified as 20% and this is specified as 80%. So if I take the ratio then its value comes out to be 0.25 or in percentage it is 25%. So, setting range of negative phase sequence relay should be greater than the 25% of 1 ampere. So I can consider the 30% of 1 ampere as the setting of negative phase sequence relay.

(Refer Slide Time: 30:41)





Now, let us consider the setting of the stalling relay or stalling protection. So, as it is specified that the stalling current that is the one-third of the starting current of induction motor. So we have already calculated starting current of induction motor. So, you take one-third, the value comes out to be 426.5 ampere. If you transfer this value on CT secondary side by dividing with 200, then the value comes out to be 2.13 ampere.

Hence, obviously, whenever you decide the setting of the stalling relay, you can see that the setting range of the stalling relay that is given as 150% to 600% of 1 ampere in steps of 30%. So you can see that this is 213%. So you have to decide the value just below this, not about that. So the immediate setting available just below this that is 210%. So we can, we have to, we can decide the setting that is 210% of 1 ampere.

As far as the time setting of the stalling relay is concerned, it should be, as I told you, it should be higher than the acceleration time of the motor, which is specified as 12 second and it should be lower than the safe stalling time of the induction motor, so that is 16 second. So you can consider the safe stalling timer setting as 15 second.

So, in this class we have considered how the induction motor behaves whenever the fault occurs. So we have considered the all electrical faults and mechanical faults. In electrical faults, we have discussed different phenomenon starting from overloading, overcurrent, that is short circuit, negative phase sequence, phase reversal, stalling, phase unbalance, and so on, undervoltage. So, after that, we have also solved one example.

So, with this background, I stop here. Thank you.