Power System Protection and Switchgear
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Lecture - 04
Fundamentals of Protective Relaying - 4

So today, we will discuss regarding the different types of relay, how the relay works, what is its construction. So let us start with the first type of relay that is known as thermal relay.

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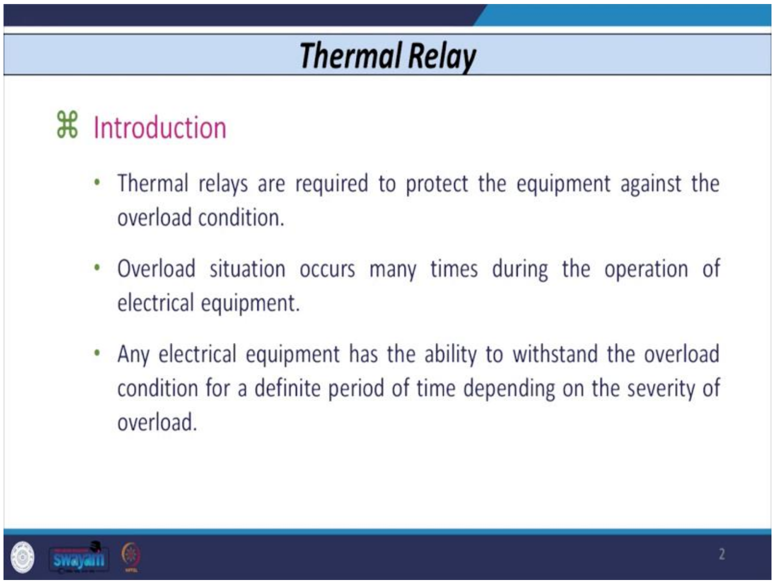

So thermal relays are used basically to protect the equipment against the overload condition. So, now, let us see first what is the difference between overload and fault.

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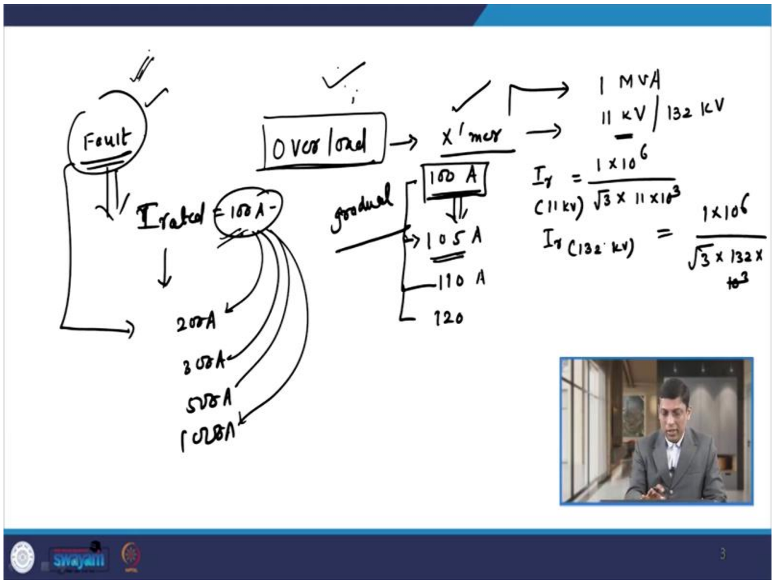

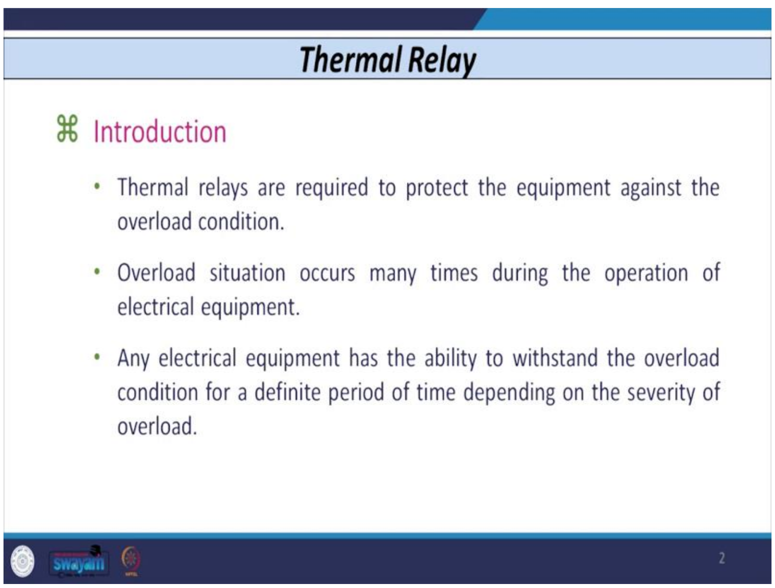

So, whenever I say that what is overload; so overload means if any equipment is there, let us say we have a transformer. Say, this transformer is rated to take the 100-ampere current. Let us say it is, it has some rating, MVA rating; it has some voltage rating, and based on that it is capable to take off the 100-ampere current.

So, for example, if I want to carry, calculate this current just for example, if I take 1 MVA transformer and if its voltage rating is 11 kV by, let us say 132 kV, then on 11 kV side, the rated current of the this 1 MVA transformer is 1 into 10 raised to 6 divide by root 3 into 11 into 10 raised to 3. So, this is the rated current of the transformer on 11 kV side.

And same way you can have the rated current of the transformer on 132 kV side, by using again the same formula, 1 MVA divide by root 3 into 132 into 10 raised to 3. So, let us assume that the rated current of the transformer on one particular side that is, 100 ampere. So this transformer can take continuously this 100 ampere current without any temperature rise, without any damage.

Now, if this transformer draws more current, higher, more than this 100 ampere, let us say 105-ampere current, then what will happen? Then again, and this increase in current from 100 ampere to 105 ampere that is gradual, that is not rapid, not immediately it reaches this value, it takes this current with some margin. So, when it draws 105-ampere current, then we are loading the, this transformer with 5 percent or 105 percent. Again, let us say it draws the current 110 ampere, so we are increasing the loading 10 percent more than the rated current. Let us say again it, we are, it draws the current 120 ampere.

So, gradual increase in, increase in current beyond the rated value that is known as the overloading of the equipment. So we can consider the equipment as transformer we can consider the equipment as induction motor or we can consider the overhead conductor. On the other hand, if I consider a fault, then in case of fault, the increase in current from with respect to rated current, I rated, that is very rapid.

Say, the rated current is same value, let us say 100 ampere and if the current becomes, let us say 200 ampere suddenly, within a fraction of second or 300 ampere or 500 ampere or 1000 ampere, then this is known as fault. Because, in case of fault, the path of current or the current follows the undesired path. That is why the increase in current from this rated value that is 100 ampere to directly or rapidly to 200 ampere, 300 ampere, 500 ampere or 1000 ampere. So, with reference to rated value, the current increases to becomes 2 times, 5 times, 10 times with a very, very limited time period. So that is known as fault.

So now, as both the phenomena, overload and fault both are different, so obviously, we have to consider overload phenomena as a separately than the fault and we need a protective device which can effectively discriminate between overload and fault condition, because in overload condition, as the increase in load is gradual, so there is no need to trip the relay or any equipment by the relay immediately.

Whereas in case of fault, as the increase in current with reference to rated value that is very rapidly, so we need instantaneous operation or disconnection of the equipment. So, that is the main difference between overload and the fault condition. So for, if we want to detect the overload condition in the equipment, then thermal relays are widely used. Though overload situation occurs many times when the equipment draws the current more than the rated value.

So any equipment that is capable to withstand the overload condition for a certain definite period of time and this time depends on the, how much overload that is carried out by the equipment. Higher the overload, less is the time up to which the equipment can withstand that overload condition. Less is the overload, higher is that period of time up to which the equipment can withstand that that overload condition.

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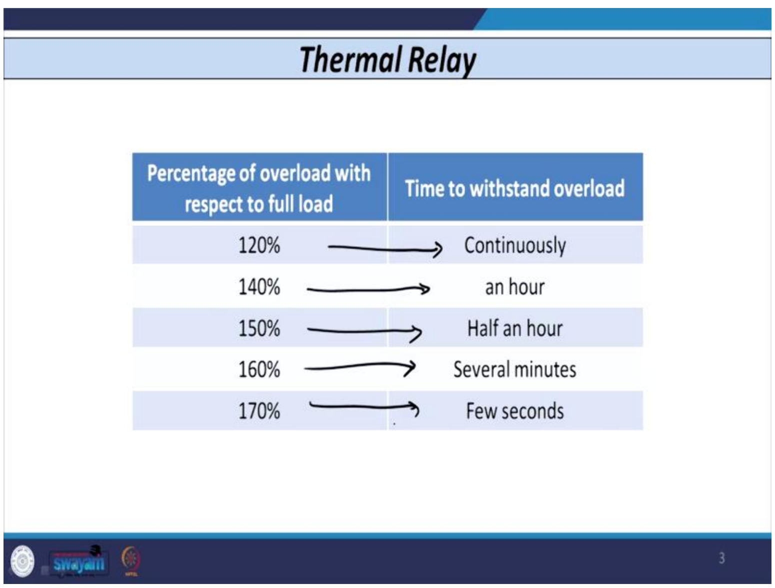

So as we have discussed, if this, here is the table which indicates the percentage of overload with reference to full load and the time to withstand the overload. So if any equipment, let us say same transformer whose rated current is 100 ampere, if it is overloaded at 120 ampere, then this it can withstand continuously, this it can withstand continuously.

So, in this case, if it can, this type of condition it can withstand continuously for 120 percent overload, then at 140 percent overload, it can withstand the same condition for an hour, let us say. If increase the percentage of overloading at 150 percent, the same equipment can withstand the overload for half an hour, and for 160 percent it can withstand several minutes, and for 170 percent it can withstand a few second.

So, as we increase the percentage of overloading on the equipment, the time to withstand that overload condition that goes on reducing. So in this case, let us see the, how the thermal relay works. Now, the thermal relay, as the name itself suggest, it is basically is indirectly measures the temperature. So, basically heating effect of the electrical current that flows through the equipment winding that is measured by the thermal relay.

So characteristic of thermal relay should exactly match with the thermal withstand characteristic of the equipment that, that we want to protect. So thermal relay requires longer time, usually in seconds or sometimes in minutes also or maybe a few minutes compared to the overcurrent relay, which is meant for the protection of equipment against overload, which is a rapid phenomena. So overcurrent relay operates in, maybe fraction of seconds or sometimes in millisecond compare to that, thermal relay operates in several minutes or seconds as the, in this case, the increase in current that is gradual.

Now, the question comes why in earlier case also, some several, a few times ago also, a few decades ago also, the people are using in thermal relay a simple metallic strip, bimetallic strip, they are, they were utilizing the remote temperature detector, they were utilizing thermocouple or some thermo-sensitive devices. But the main disadvantage of all these things that is their resetting time was very long. So, what will happen if the resetting time of these equipment that is very long?

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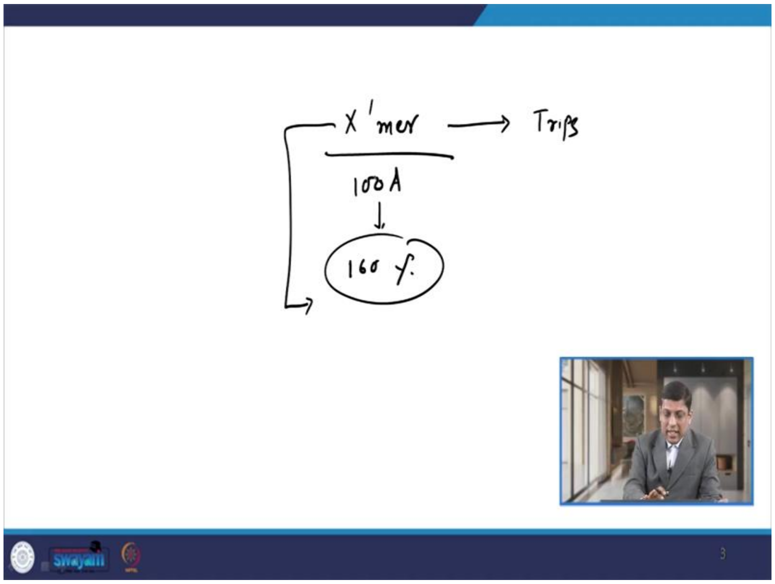

So, that means if I am using the same transformer whose rated current is 100 ampere. Now, because, let us say the, the overloading on this transformer that is 160 percent. So, because of this overloading, the, we have put the thermal relay, so thermal relay detects this overload and this transformer trips. So the transformer is disconnected from the circuit. Now, this transformer is a hot transformer. So if I want to again restart the transformer my objective is I have to restart the transformer or reconnect the transformer in the circuit as immediately as possible. So reconnection of the transformer in the circuit that depends on what is the resetting time of the relay.

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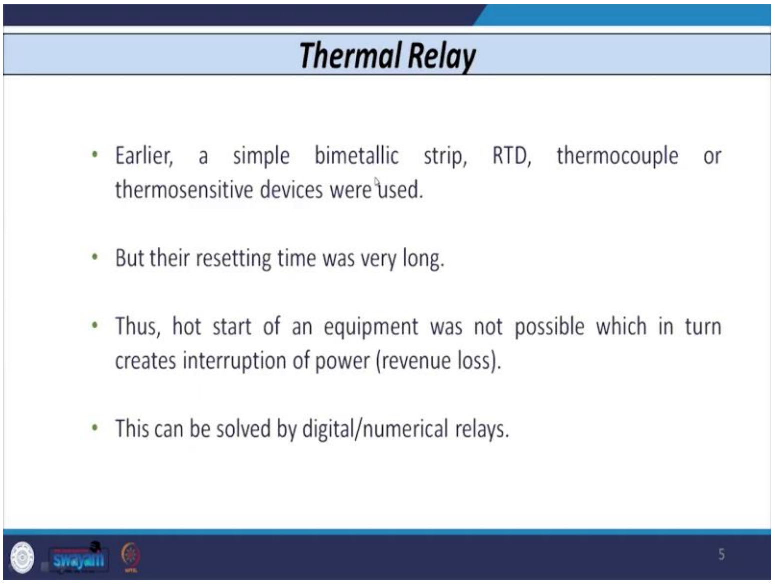

In earlier case, whatever these relays were used, which utilizes the RTD, thermocouple, or thermo-sensitive devices, their resetting time was very long. So hot start of any equipment, that is very difficult and that will lead to some gap, some time duration. So after some time only we can, we are allowed to start the device or reconnect the device in the circuit. So that will also lead to revenue loss.

So, that is why, nowadays, whatever digital or numerical relays are available, they have, they provide the special features of thermal relay and their resetting time is very small, that is usually in terms of fraction of second. So recent digital or numerical relays, they provide the resetting time of thermal relay that is of the order of 0.1 or 0.2 second.

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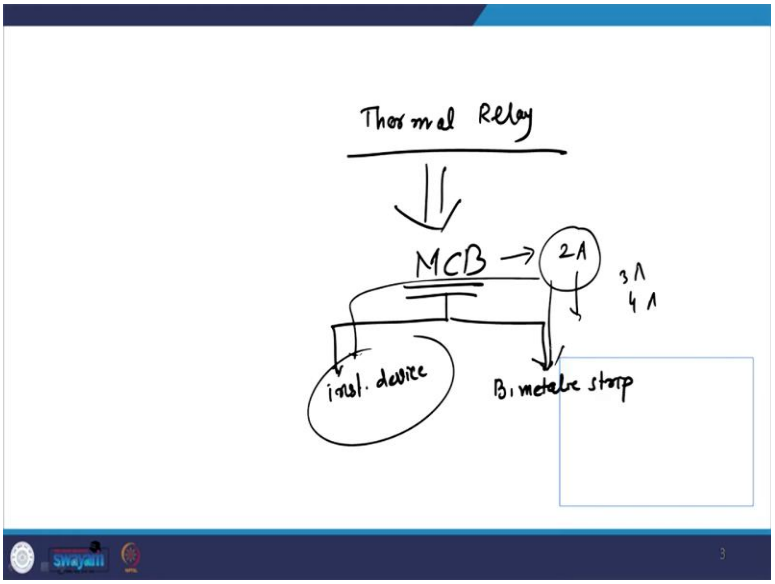

So, if I, if I consider the, if I want to give you just the example of this thermal relay, then we can compare the thermal relay with the function of MCB. So we know that we are utilizing miniature circuit breaker in our, for domestic applications. So, this MCB, if you just look at the circuit of the MCB, then this circuit of the MCB also contains two things. One is the bimetallic strip and the other is the some instantaneous device.

So whenever the magnitude of current is very high, say the rated current of this MCB is, let us say 2 ampere. So, if current exceeds 2 ampere, MCB operates. Now, if the, if the magnitude of current is, let us say 10 times, the rated current 2 ampere, then the whole MCB operates instantaneously, whereas if the magnitude of current is just above the 2 ampere, let us say 3 ampere, 4 ampere, like that, then instantaneous operation is not provided. In that case, bimetallic strip comes in picture, and depending upon the bimetallic strip, the MCB operates.

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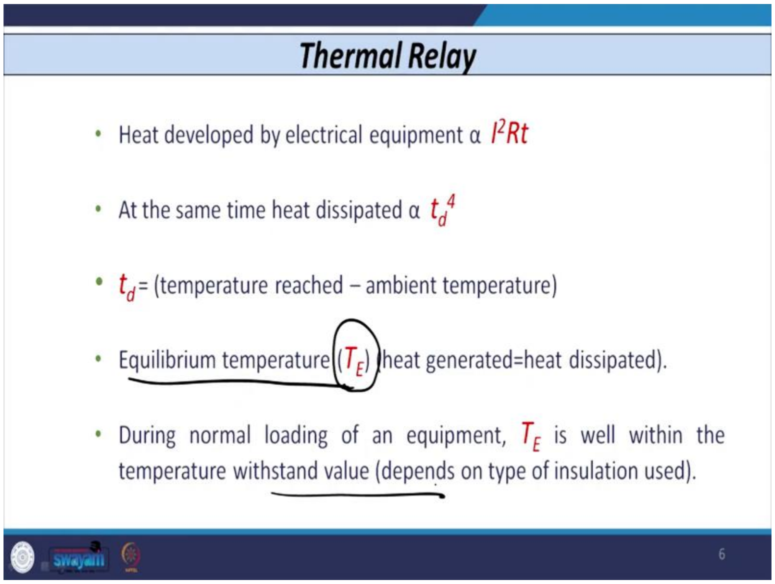

So, with this, whenever any equipment, let us say the transformer whose rated current is 100 ampere; when it draws the current, then the heat generated by that device, that is proportional to the I square Rt; where I is the current passing through the winding, R is the resistance of the winding and t is the time up to with that current flows through the winding. Now, we know that this heat generated goes on increasing but at the same time, the heat is also dissipated from the equipment. This heat can be dissipated by natural air or maybe by forced air or forced cooling or maybe by water or in terms of gas.

So heat dissipated, that is also proportional to the Td raise to 4; where T is the differential temperature, which is given by temperature rise minus ambient temperature. So, whenever this equipment draws the overloading or over, higher current than the rated current, then heat generated and at the same time heat is also dissipated. At one particular temperature or that is proportional to one particular magnitude of current, heat generated that is equal to heat dissipated. That temperature is known as the equilibrium temperature. And let us say it is denoted by the term TE.

So at this point or at this temperature or equivalent temperature of this at particular magnitude of current, heat generated that is equal to heat dissipated. So, during normal, when normal overloading of the equipment, when equipment takes full load current, rated current, then this equilibrium temperature that is well within the withstand limit of the equipment. With withstand value or limit that is decided by the type of or class of insulation used by the winding.

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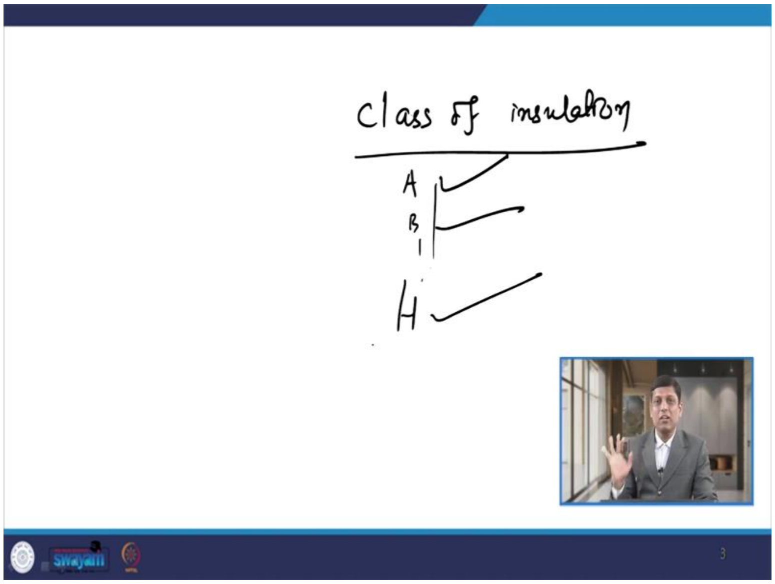

Now, we know that if we consider the type or class of insulation, then for any winding, the class of insulation are available from A to H. So, as we move, there are class A type of insulation, class B type of insulation up to class H type of insulation is available, and each class of insulation that is capable to withstand certain level of temperature.

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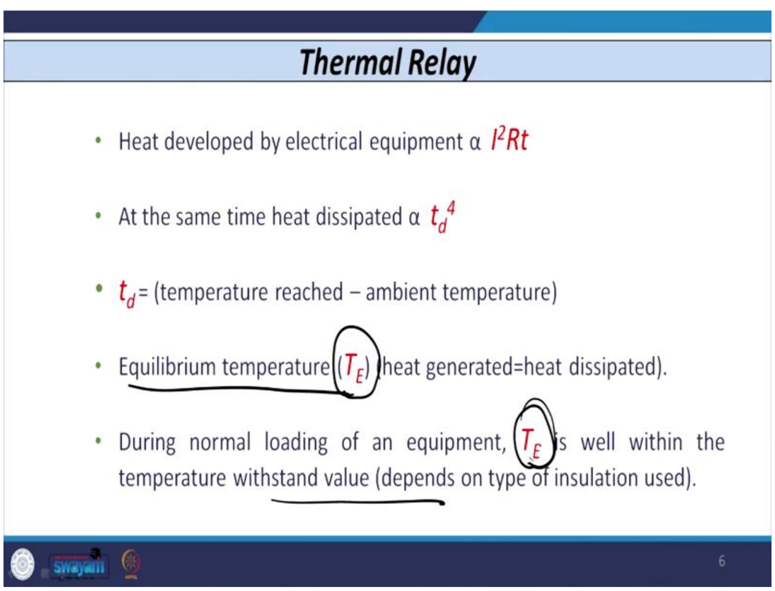

So, that means, whenever this transformer carries or draws a rated current or full load current, the equilibrium temperature TE that is well within the withstand temperature, that is whatever is the insulation provided in the equipment.

So, let us assume that the temperature, whatever, some specific type of insulation is provided in the equipment and its withstand temperature is, let us say 50 degree. So, whenever equipment draws rated current that is full load current, then this equilibrium temperature reached that is below the 50-degree temperature or equivalent 50 degree to this some particular magnitude that is rated current.

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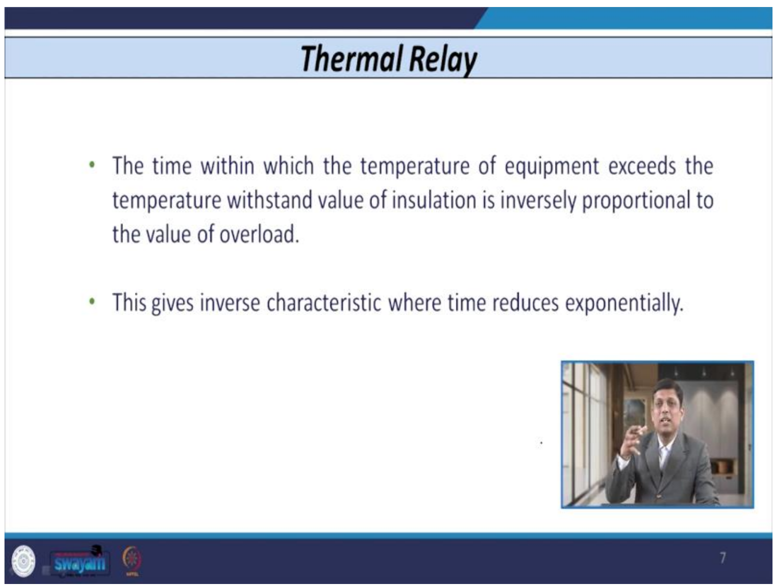

Now, the time within which the temperature of equipment exceeds the withstand temperature or withstand temperature of insulation, that is inversely proportional to the value of overload. So, higher the percentage of overload, lower is the time up to which the, this, the temperature, equilibrium temperature that is reached that takes lower time, that so both are inverted proportional. So if I draw the graph, then we have inverse characteristic of graph between these two.

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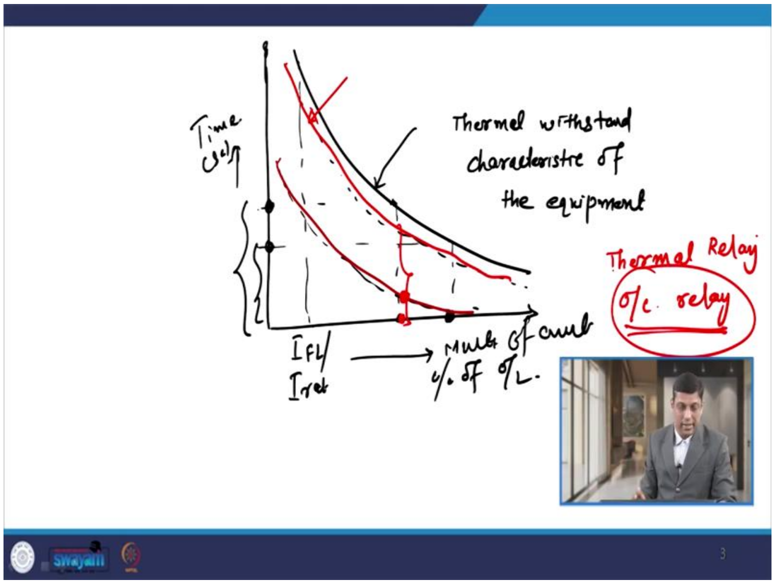

So, if I just draw the graph of how this thermal relay looks like, then this graph follows the inverse relationship. So we have a graph like this. So it goes it decays exponentially and this exponential decay depends on the time constant of the circuit. So on X-axis, we have the multiple of our multiple of current, or sometimes, we do have the percentage of overload; and on this time we have a time in seconds. And this point, we can say this is your full load current or the rated current of the equipment say 100 ampere.

So what does this graph indicate? If I can select any value from this graph, let us say this point, so if I extend this point here, then for this particular magnitude of fault current or percentage of overload or current, this equipment can withstand that percentage of overload only up to this much period of time.

So, if I consider another percentage of overload, higher than the earlier one, this one, then if I extend it on the graph, then for this higher percentage overload, the equipment can withstand only up to this much time period, which is lower than the earlier one. So obviously, this clearly indicates that whatever, whenever if I want to protect this equipment against the overloading, then I have to design a protective device, say, thermal relay in this case, which operates below this point that is reached. So any point on this that is reached below, before that the thermal relay detects and operate it.

So obviously, characteristic of thermal relay, that should be lower than this characteristic. This characteristic is known as thermal withstand characteristic of the equipment. So this is the thermal withstand characteristic of the equipment which we want to protect. So, if we want to design a thermal relay with it has some characteristic, then its characteristic should be below this thermal withstand characteristic of the equipment.

Now, when I say the thermal relay characteristic is below this thermal withstand capability curve, then I have the relay characteristics somewhere here, which is below this characteristic, or I have the thermal relay characteristic like this also. So there are two types of characteristics we can say. So when I say this, this characteristic of the relay and when I say the earlier characteristic of the relay that is this characteristic of the relay, both are below the thermal withstand characteristic of the equipment.

Now, the question comes which characteristic I have to select. So obviously, I have to select this characteristic because it is exactly coinciding with the thermal withstand capability curve. If I select this lower characteristic, then for particular percentage of overload, if the equipment is capable to withstand this much period of time, this much of percentage overload, then we are unnecessarily disconnecting the equipment by utilizing this below characteristic. So, if I use this below characteristic then it cannot fully exploit the thermal withstand capability of the equipment which we want to protect. So that is why we have to consider the thermal relay characteristic which is just exactly below the thermal withstand capability curve of the equipment which we want to protect.

So this clearly indicates the difference between the characteristic used by thermal relay and the characteristic used by the overcurrent relay. So, if I use overcurrent relay for the protection of overload, then we are disconnecting the equipment very early, usually in fraction of second or millisecond as I told you earlier, whereas the equipment is capable to take such type of overload and whenever any overloading occurs on the equipment that that overloading is usually, 90 percentage case, it is transient in nature.

So, this type of overloading die out after certain seconds or minutes and if equipment is capable to take care of that percentage of overload, then there is no hurry to trip the equipment utilizing the overcurrent relay which operates in fraction of seconds or milliseconds.

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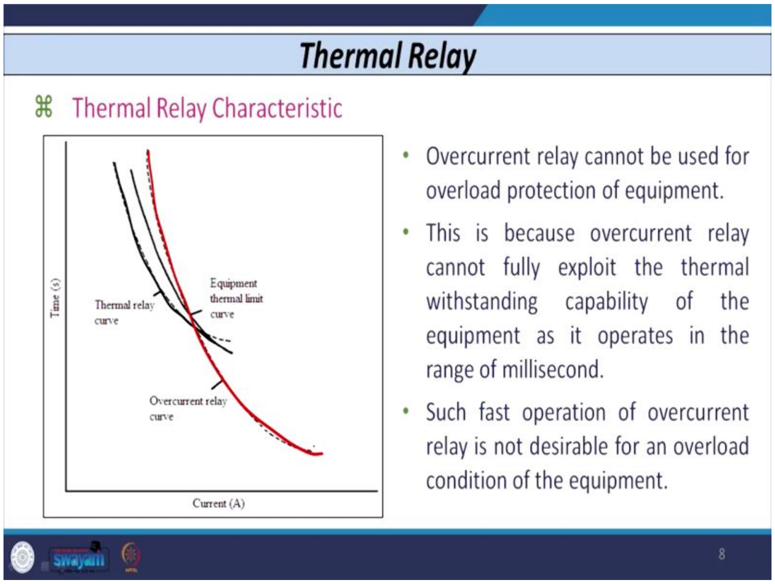

So, if I just plot the characteristic of thermal relay, overcurrent relay and thermal withstand capability curve of the equipment, then it looks like this. So if I look at the thermal relay characteristic, it is exactly below this dotted curve, which is this curve, it is exactly below the thermal withstand capability curve of the equipment, whereas if I refer curve of the overcurrent relay, then you can see the curve of the overcurrent relay is like that and if I use this curve, then we are tripping, unnecessarily tripping very early for the equipment which is capable to take care of percentage of overload for several minutes or seconds.

So, with this background, let us see what is the construction of thermal relay. So, if I just consider the replica type of thermal relay, then this type of thermal relay consists of bimetallic strip which is made up of nickel alloyed steel.

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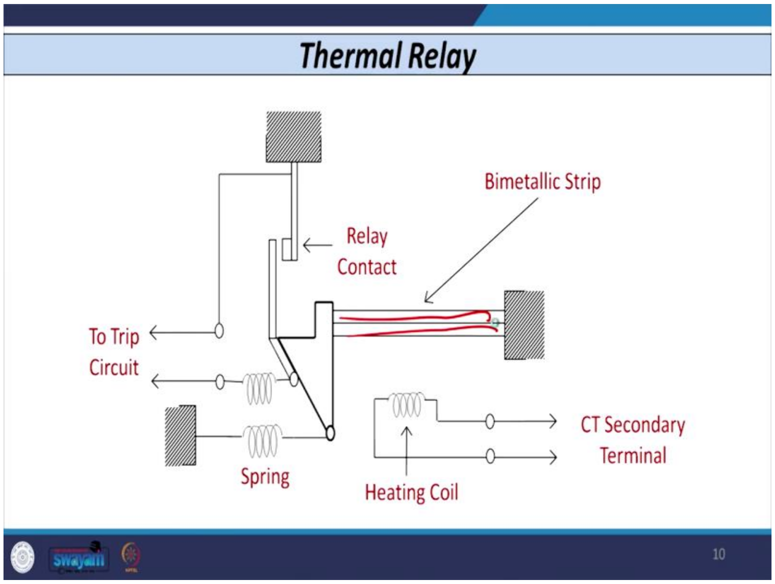

So if I consider just the diagram of thermal relay, then this is the bimetallic strip.

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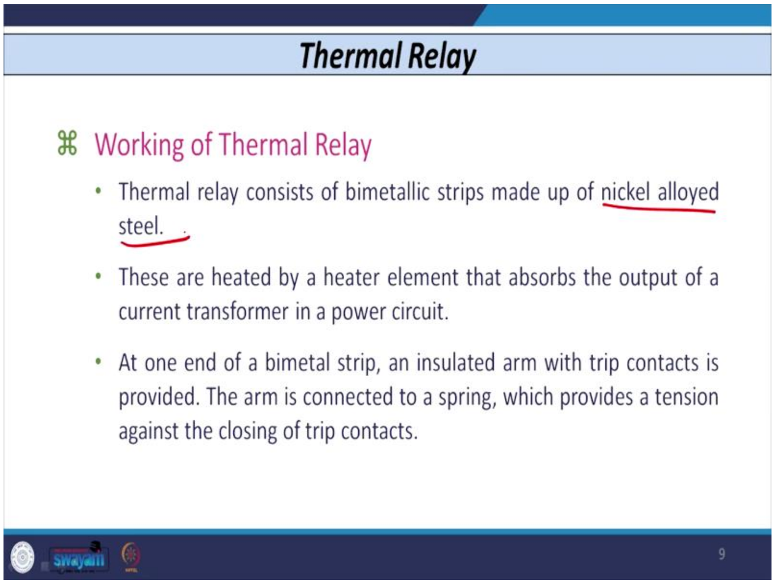

As the name suggest, there are two strip, so it is bimetallic strip, which is made up of the nickel alloyed steel.

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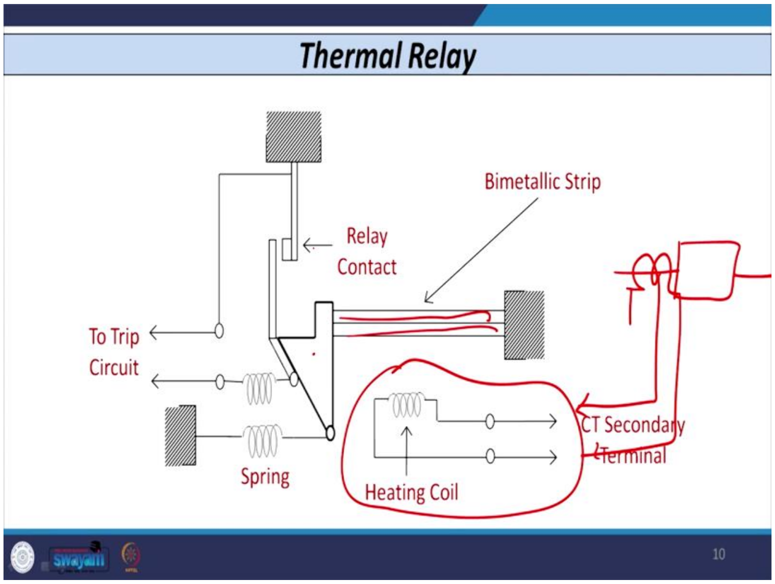

Now, below this bimetallic strip, we have the heating element. So here, this we have the heating element. So this heating coil that is connected to the secondary of the CT. So, if I have the winding of the equipment here and if I have the CT somewhere here inside this, then secondary of the CT that is connected to this heating coil to terminal of the heating coil.

The other side of the bimetallic strip that is connected with the insulated arm, so one side is connected to, on this side and the other side is connected to this is the insulated arm, and this insulated arm is connected with a spring. So, this spring will also provide some force and the other side of this insulated arm, that is connected with relay contact on the other upper side.

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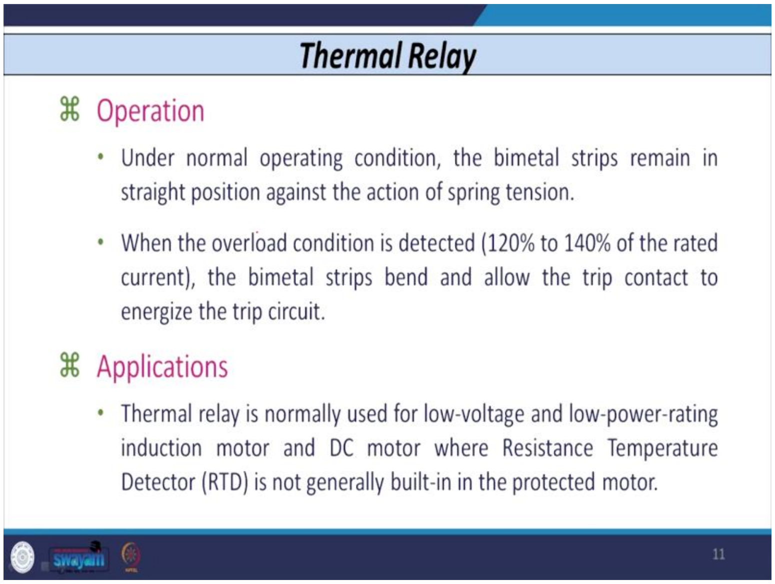

So whenever, under normal condition, the bimetallic strip remain in straight position because this spring will provide some force. Now, whenever there is a overloading of the equipment that means the, whenever the equipment draws the load or current higher than the rated value, say 120 or 140 or 160 percent, then this bimetallic strip bends because they have different coefficient of expansion.

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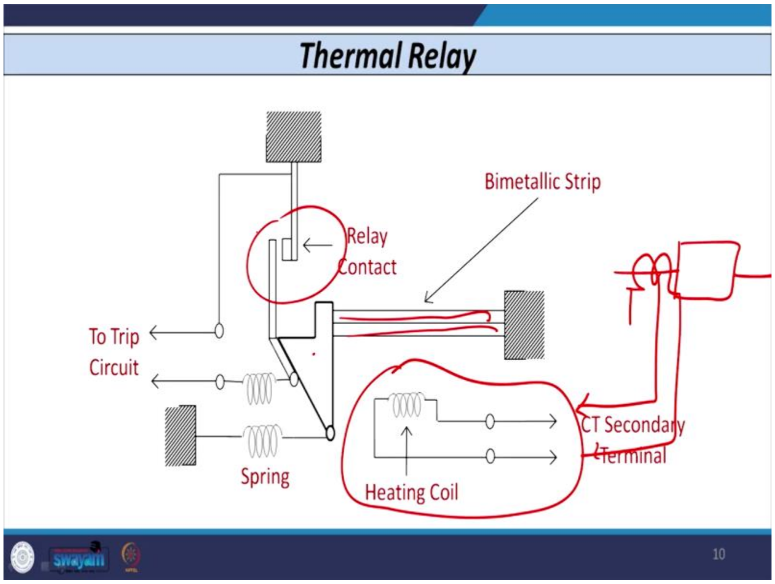

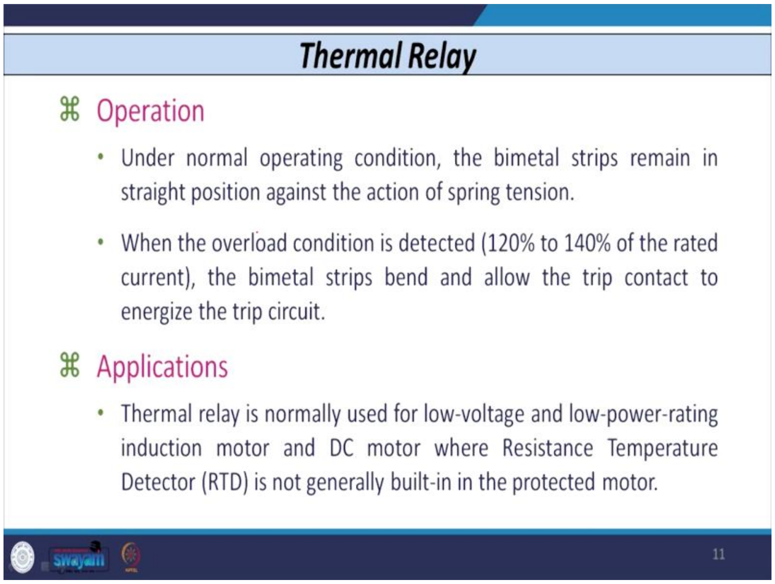

So it gives signal to on this side and this relay contact is actuated and the further circuit tripping, tripping command that is issued to the, by this relay contact. So what are, what is the application of thermal relay? So thermal relay is normally used when low voltage and low power rating of induction motor and DC motor is there and specifically when this DC motor and induction motor does not contain inbuilt feature of resistance temperature detector, there we can definitely use the thermal relay.

We can also utilize the thermal relay for protection against overloading in case of generator, in case of transformer, in case of induction motor, in case of reactor also. So, with this background, let us consider the second type of relay that is known as attracted armature type of relay.

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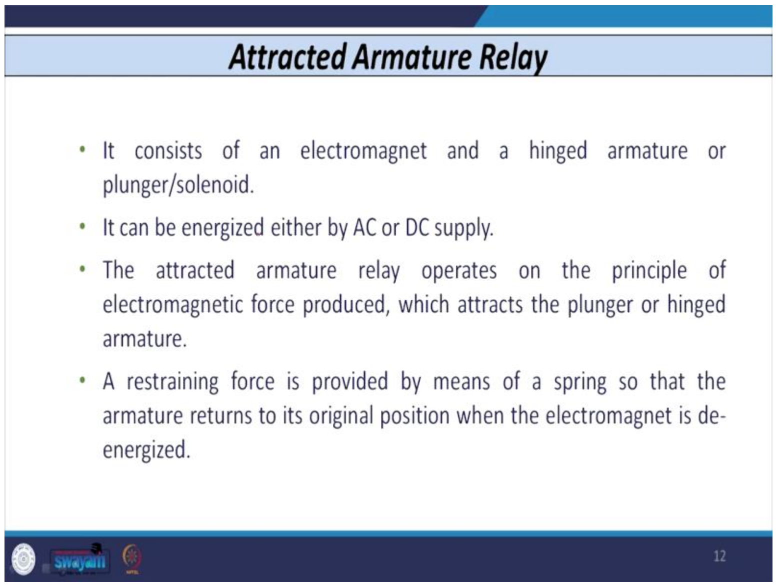

So this type of relay consist of an electromagnet along with some hinged armature or plunger or sometimes it also contains the solenoid. This type of relay is operated by both AC and DC supply. The attracted armature, this type of relay, the working principle is that whenever the current, current-carrying coil that is placed on the core and when it draws a current, it produces the mechanical force and that force is given further or transferred to the relay contacts and hence the relay operates.

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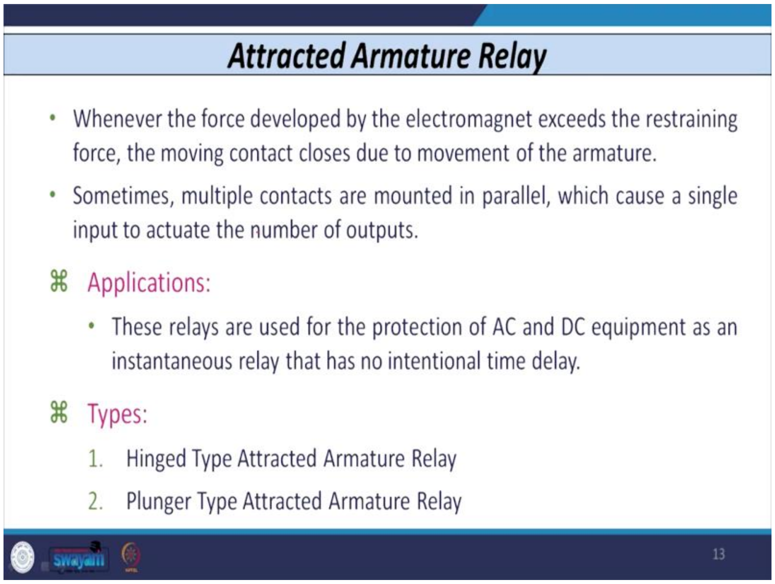

So, whenever the force developed by the electromagnet exceeds some restraining force, this type of restraining force is provided by the spring, then the armature, movement of the armature is there and this movement of the armature that is given to or transfer to the relay contacts and relay operates. So, sometimes multiple contacts, these are also provided and these are connected in parallel to actuate the relay.

What is what is the application of attracted armature relay? This type of relay are widely used for protection against AC and DC equipment. So, if I use AC relay or DC relay, then for both type of relay, attracted armature principle that is used. And this type of relay is more specifically used for instantaneous, for achieving the instantaneous feature in the relay. So all instantaneous overcurrent relays utilize the attracted armature principle.

So basically, there are, these attracted armature relay that is classified by two ways; one is a hinged type armature relay and another is plunger-type armature relay. So, let us consider what is the working principle and construction of hinged type armature relay.

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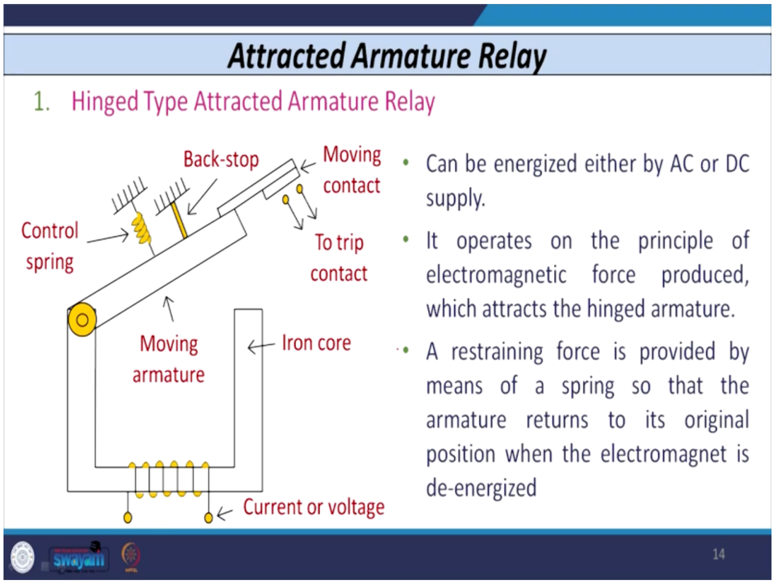

So, hinged type armature relay, as you can see in the figure, there is a coil which is placed on the core, iron core, and from this coil we give either current or the voltage depending upon what type of relay we want. And on one side of this core, the one moving armature is connected, so this moving armature is controlled by spring and backstop and one other side of moving armature, the moving contact of the relay that is connected.

Now, how it works? During normal condition, when the current is rate, when that means when this winding carries the rated current, the force produced by this moving armature that is lower than the force produced by the control spring, so this armature remains in original position. Whenever the current through this coil exceeds, say some predetermined threshold value, then force produce by moving armature that exceeds the spring force and hence, this moving armature moves on downward direction and when it touches this contact, the tripping command that is initiated by this attracted armature type of relay.

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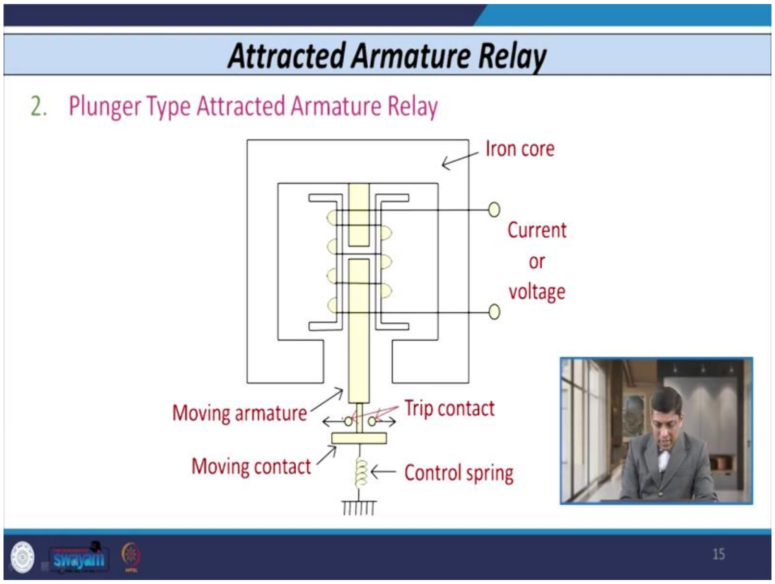

Same way, if I consider the construction of plunger-type attracted armature relay, then you can see that there is a core and on this middle limb, there is a coil wound on the, so either we can give current or voltage through this coil and there is a moving armature and below that there is a moving contact is there, which is supported by the control spring. So, in this case what will happen? During normal condition when this coil carries a normal rated current, the force produced by it that is not more than the force produced by spring. So this moving armature remains in downward position.

Whenever the current flows through this coil exceeds the rated or some predetermined threshold value, the force produced by this moving armature that is higher than the force produced by spring, so this moving armature moves in the upward direction and when it touches this contact, a tripping command is initiated.

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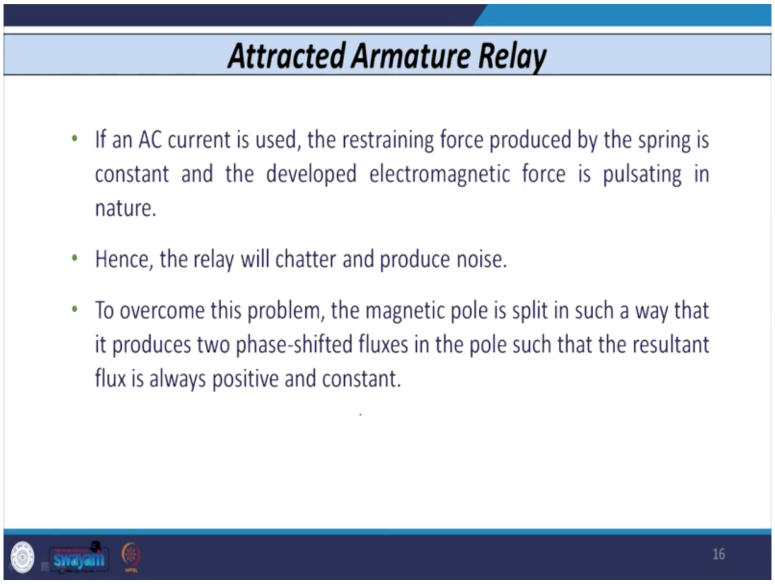

Now, the main important point is that if I use AC quantities for this, means whenever we give AC supply to these coil, then obviously restraining force produced that is produced by spring that is constant, if I assume that is constant, then the whatever force is produced that is pulsating in nature, because we are giving AC supply and every half cycle, the natural current 0 comes by this AC supply.

So, whatever force is produced that is pulsating in nature, so obviously, relay will chatter and produce the noise that means relay contact will sometimes becomes close, then it becomes open that it becomes closed. So, there is a chattering phenomena occurs.

To avoid this, what the manufacturer will do, they will either split the pole or they will use the copper shedding band. So by splitting the pole or by introducing the copper shedding band, they are now, because we have only single operating quantity that is by produced by the current. So, current will produce only one flux. Instead of that, they split the pole or provide copper shedding bands such that two different fluxes are produced which are shifted in time phase. So resultant flux is such that that is always constant and positive in nature. So, chattering phenomena, that can be avoided.

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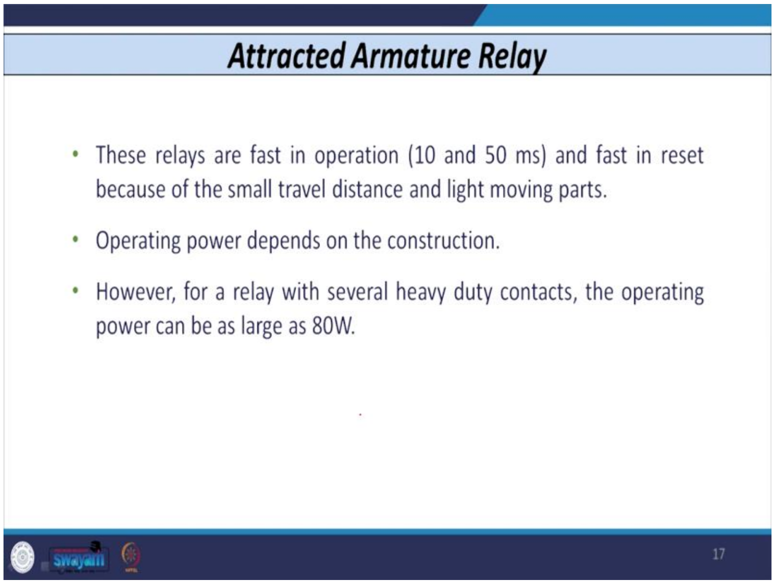

These type of relays, attracted armature type of relays are very fast in operation and the main advantage of this relay is their resetting time, that is very high.

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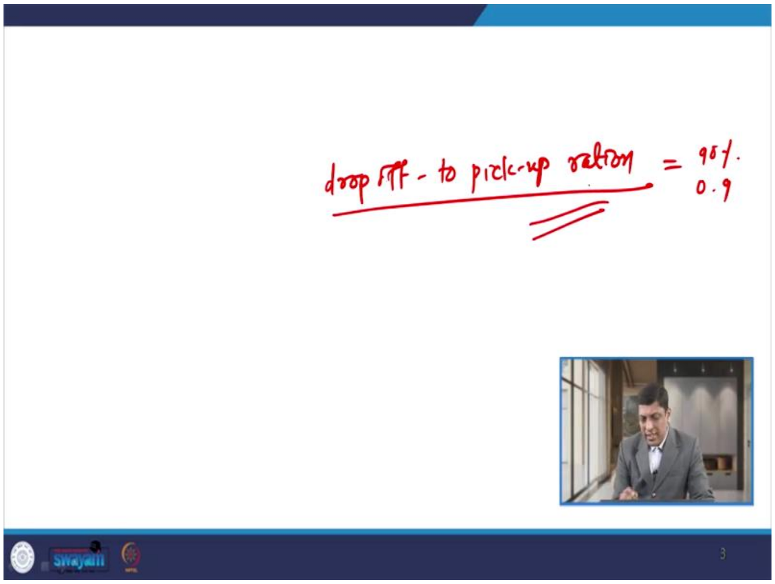

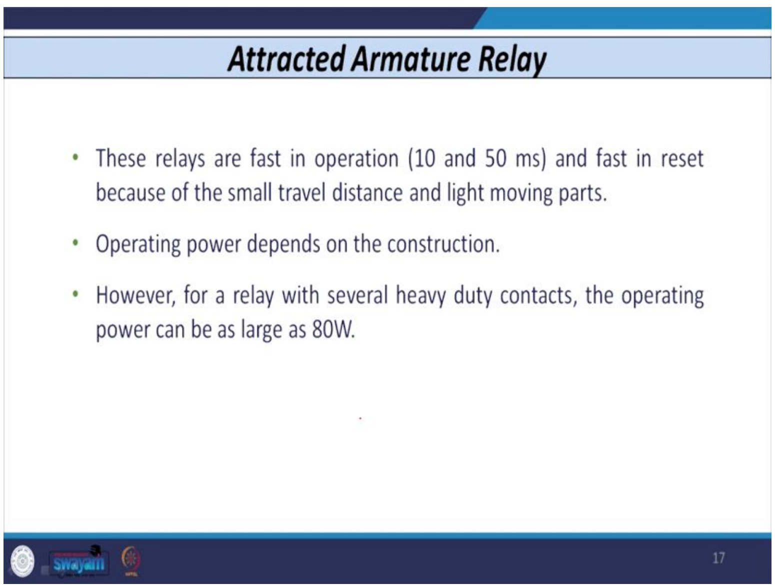

So normally, each and every manufacturer who is manufacturing attracted armature type of relay, they usually provide or they define one term that is known as drop off to pick up ratio. So, drop off to pick up ratio for attracted armature relay that is very high, almost 90 percent or 0.9 in this case.

So this clearly indicates that the, whatever is the resetting time of this relay that is very high. So, when the relay operates, after the, after operation of relay, it gives command to the circuit breaker or the other contacts and then circuit breaker disconnect the section, so current that is discontinued and the whatever disc of the relay, that comes to original position. So, that time is known as resetting time of the relay and this is very high.

Operating power, that depends on the construction. However, the main disadvantage of this relay is that that this relay has operating power in the range of 60 watt to 80 watt and that is why nowadays people are not utilizing such type of relay in actual field.

So, with this background, we have discussed, we started our discussion, if I summarize with thermal relay, we have seen that how, why the thermal relays utilized, it is used for the protection of overloading the equipment. We have also discussed that why we cannot use overcurrent relay for the protection of overloading that also we have discussed. We have also discussed the construction of thermal relay, replica type thermal relay, and then, we have discussed the two different types of attracted armature relay; one is hinged type and another is plunger-type attracted armature relay. So, with this background, I stop here. Thank you.