Power System Protection
Professor A K Pradhan
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur
Lecture – 37
Introduction to Transformer Protection

(Refer Slide Time: 0:30)

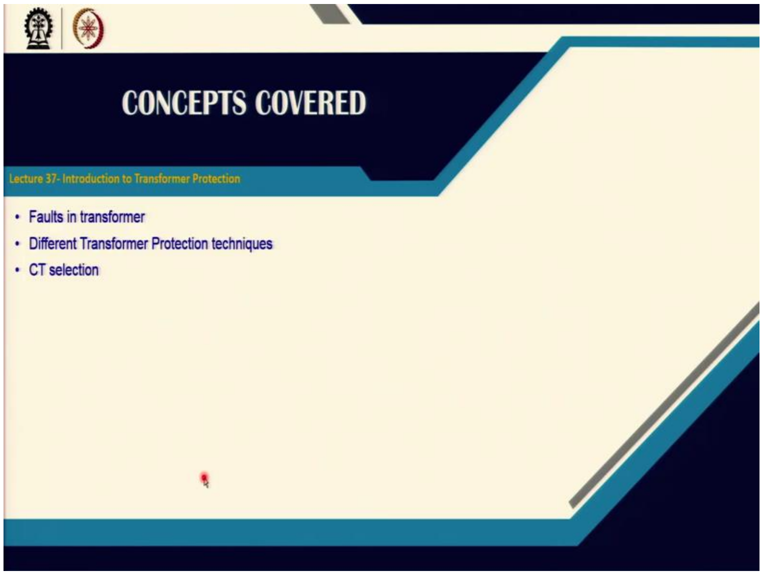
NPTEL ONLINE CERTIFICATION COURSES

Power System Protection
Prof A K Pradhan
Department of Electrical Engineering
Indian Institute of Technology Kharagpur

Module 07: Trasnformer Protection
Lecture 37: Introduction to Transformer Protection

Welcome to NPTEL course on Power System Protection, we are with module 7 on Transformer Protection.

(Refer Slide Time: 0:37)



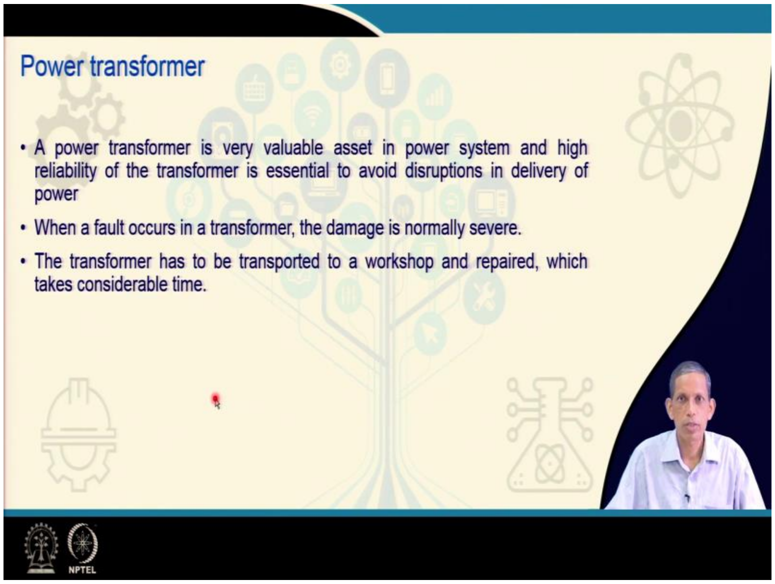
CONCEPTS COVERED

Lecture 37- Introduction to Transformer Protection

- Faults in transformer
- Different Transformer Protection techniques
- CT selection

In this lecture we will be introducing on the challenges with transformer operation in the perspective of fault and issues that is related to protection. So, what are the different possible faults in transformer? Associated different transformer protection techniques that including mechanical to electrical and then at the end we will see how in differential protection perspective we will have the CT selection.

(Refer Slide Time: 1:18)



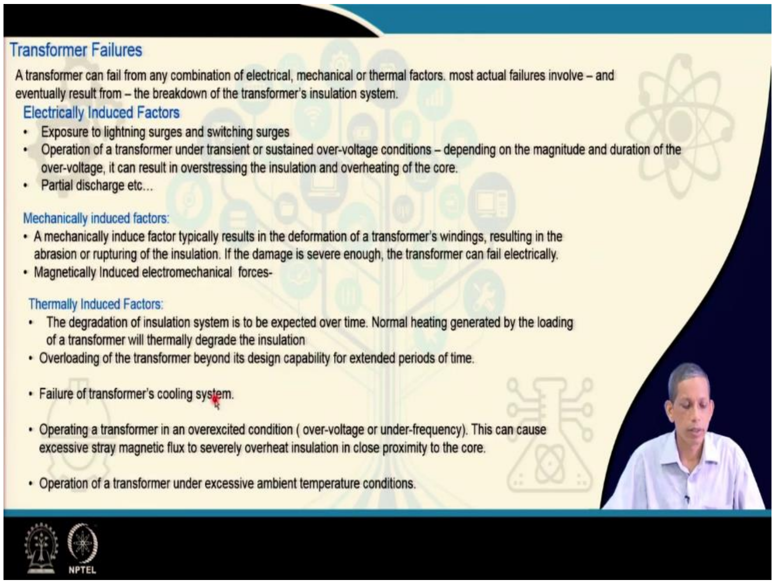
Power transformer

- A power transformer is very valuable asset in power system and high reliability of the transformer is essential to avoid disruptions in delivery of power
- When a fault occurs in a transformer, the damage is normally severe.
- The transformer has to be transported to a workshop and repaired, which takes considerable time.

We know power transformer is a vital element in transmitting, distributing power to from the generating station to the utilities to the customer's premise. The reliability of a transformer should be very high; otherwise there will be disruption in power which is not at all desirable. When a fault happens to be there in a transformer, the damage related to it will be severe, further not only the disruption in power, it is not momentary, it is for long duration till there is replacement of the transformer, unless there is parallel operation of transformer or so.

Transformer is costly, so any damage or so is of high economic value, further replacement of transformer takes a lot of time because of related transportation and the maintenance you can say that long maintenance time and so.

(Refer Slide Time: 2:48)



Transformer Failures

A transformer can fail from any combination of electrical, mechanical or thermal factors. most actual failures involve – and eventually result from – the breakdown of the transformer's insulation system.

Electrically Induced Factors

- Exposure to lightning surges and switching surges
- Operation of a transformer under transient or sustained over-voltage conditions – depending on the magnitude and duration of the over-voltage, it can result in overstressing the insulation and overheating of the core.
- Partial discharge etc…

Mechanically induced factors:

- A mechanically induce factor typically results in the deformation of a transformer's windings, resulting in the abrasion or rupturing of the insulation. If the damage is severe enough, the transformer can fail electrically.
- Magnetically Induced electromechanical forces-

Thermally Induced Factors:

- The degradation of insulation system is to be expected over time. Normal heating generated by the loading of a transformer will thermally degrade the insulation
- Overloading of the transformer beyond its design capability for extended periods of time.
- Failure of transformer's cooling system.
- Operating a transformer in an overexcited condition (over-voltage or under-frequency). This can cause excessive stray magnetic flux to severely overheat insulation in close proximity to the core.
- Operation of a transformer under excessive ambient temperature conditions.

Now, there are different transformer failures, it maybe combination of electrical, mechanical, thermal factors and finally it culminates into insulation failure and then following damage to the transformer even though it may be starting due to some mechanical or thermal factors. We have divided here the three categories, electrically induced, mechanically induced and thermally induced different factors for transformer failures.

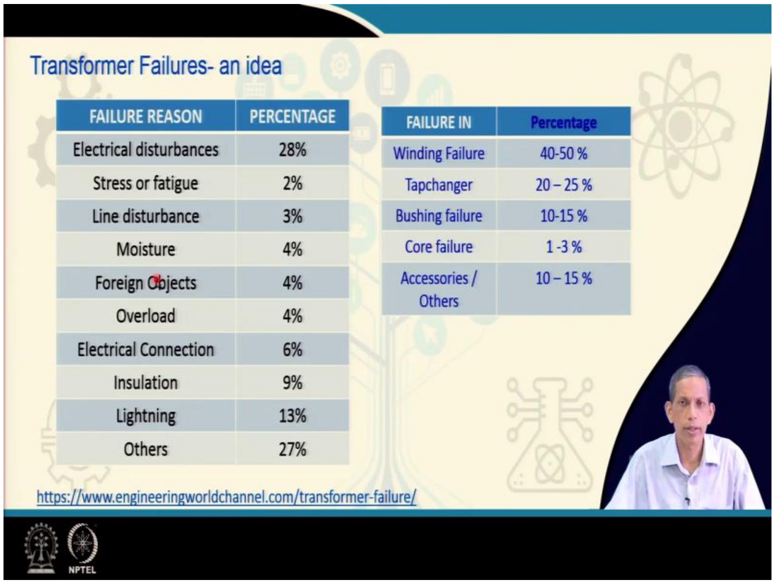
Lightning is related to very high surge, even switching surges also sometimes becomes very high and if it comes to the transformer terminal that may deteriorate the corresponding insulation and leading to failure of the transformer. Operation of transformer, different transients or sustain overvoltage condition leads to stress in the transformer winding and that may lead to insulation failure also. Partial discharge and the associated corona and so may lead to you can say that slow degradation and finally the resulting in the permanent faults also.

Mechanically induced factors and you can say that mechanical problem may lead to winding deformation and so leading to rupturing of the insulation. If the damage is severe enough the transformer will fail electrically further magnetically induced electro mechanical forces may be so severe during large current, during fault in the system, it may be externally also, it may lead to insulation failure also, those mechanical forces and that may not be immediately or notice but that may lead degradation of the insulation and finally resulting into permanent fault.

Thermally induced factors, slowly the insulation, due to edging or so degrade, continuous heating happens to be there due to the loading of the transformer. Overloading of the transformer beyond its designed capacity further degrades faster the insulation, if the cooling system of the transformer fails then more heating will be there in the winding and associated insulation.

Operating of the transformer in over excitation and so also lead to a large amount of current and magnetic flux linkage issues and the core heating and so. Furthermore, the ambient temperature is another issue on the thermal perspective or so. So, here we have enlisted few of these factors on these three categories, there are so many other points that related to the transformer failures.

(Refer Slide Time: 6:38)



Transformer Failures- an idea

FAILURE REASON	PERCENTAGE
Electrical disturbances	28%
Stress or fatigue	2%
Line disturbance	3%
Moisture	4%
Foreign Objects	4%
Overload	4%
Electrical Connection	6%
Insulation	9%
Lightning	13%
Others	27%

FAILURE IN	Percentage
Winding Failure	40-50 %
Tapchanger	20 – 25 %
Bushing failure	10-15 %
Core failure	1 -3 %
Accessories / Others	10 – 15 %

https://www.engineeringworldchannel.com/transformer-failure/

Just to have an idea who are the important factors in this perspective. This is failure of resons, we have electrical disturbance, stress or fatigue, mechanical and so, line disturbance this is external one, moisture, foreign objects, overloading, any electrical improper connection of leads, insulation issues, lightning and others. So, these are some percentage, perspective which leads to failure of transformer but finally the failure happens to be in different components, the winding failure, tap changing issues, failure in the tap changer, bushing failure, core failure and other accessories in the transformer. So, this is in terms of the percentage which given an idea that in the general trend of transformer operations what are the different reasons and where the fault happens to be there.

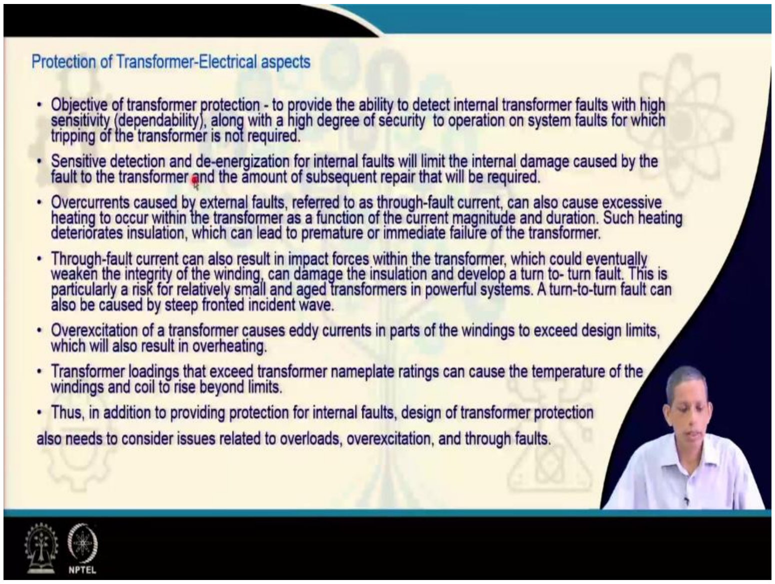
(Refer Slide Time: 7:53)

Types of Protection

- Mechanical Protection-Sudden Pressure Relay, Gas Analysis etc
- Thermal protection-Hot spot temperature, Top oil, etc.
- Electrical/Relay protection- differential relay, fuse, overcurrent, earth fault protection--

Now, on the protection also it can be divided into three categories, mechanical, thermal and electrical perspective. So, pressure relay, gas analyzer. Thermal protection-hot spot temperatures, top oil temperature, etc, that is about the thermal perspective. Electrical or this relay protection what we say, there are numerous protection schemes, differential relay, fuse, over current, earth fault protection. So, our emphasis in this presentation will be on the electrical perspective.

(Refer Slide Time: 8:38)



Protection of Transformer-Electrical aspects

- Objective of transformer protection - to provide the ability to detect internal transformer faults with high sensitivity (dependability), along with a high degree of security to operation on system faults for which tripping of the transformer is not required.
- Sensitive detection and de-energization for internal faults will limit the internal damage caused by the fault to the transformer and the amount of subsequent repair that will be required.
- Overcurrents caused by external faults, referred to as through-fault current, can also cause excessive heating to occur within the transformer as a function of the current magnitude and duration. Such heating deteriorates insulation, which can lead to premature or immediate failure of the transformer.
- Through-fault current can also result in impact forces within the transformer, which could eventually weaken the integrity of the winding, can damage the insulation and develop a turn to- turn fault. This is particularly a risk for relatively small and aged transformers in powerful systems. A turn-to-turn fault can also be caused by steep fronted incident wave.
- Overexcitation of a transformer causes eddy currents in parts of the windings to exceed design limits, which will also result in overheating.
- Transformer loadings that exceed transformer nameplate ratings can cause the temperature of the windings and coil to rise beyond limits.
- Thus, in addition to providing protection for internal faults, design of transformer protection

also needs to consider issues related to overloads, overexcitation, and through faults.

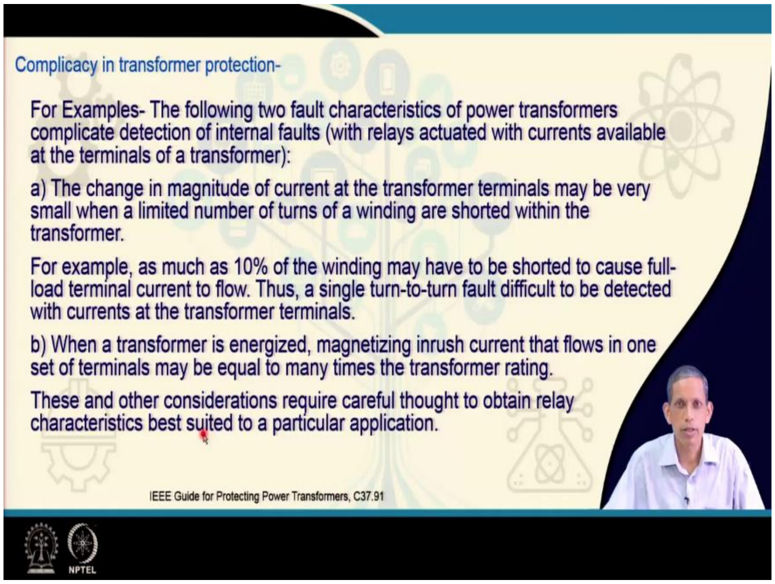
On this electrical aspects the objective of the transformer protection is to provide two aspects, one is the any fault internal to the transformer, the transformer must be isolated from both the sides if it is interconnected system and for any external fault or overload condition the transformer should not be isolated at the corresponding breakers should not be open, so that we have already discussed in beginning classes, these are the two issues related to dependability and the security aspect.

So, the protection system here as we have already mentioned the transformer is a critical element in the system from reliability point of view or in terms of economic perspective. So, therefore you can say that the fault detection perspective, fault detection aspect must be very sensitive and also the speed of operation of the relay should be as fast as possible so that the possible damage can be avoided. For any internal faults that must be as fast as possible. Overcurrents caused by external faults called as through-fault for the differential protection or transformer protection lead to excessive heating in the system of the transformer and such heating deteriorates the insulations which can lead to premature or immediate future of the transformer that is also a concern, so how much external fault time the transformer can tolerate that is also a governing factor.

In the downstream Protection Scheme and coordination of the transformer there must be also address in the protection scheme for the transformer. Through-faults or the external faults can result in impact forces to the transformer, the mechanical forces which we discussed, which could eventually weaken the integrity of the winding, so that is another aspect and all these things. Further a turn-to-turn fault can also be caused by steep fronted incident wave and those are other challenges in the transformer perspective. Over excitation whenever a large load is thrown up so, the transformer causes lot of eddy currents in the core and so and that may violate the limit of the design and so.

So, in this perspective we see that the transformer loading that exceed the transformer nameplate rating can cause temperature rise, there is a thermal limit violation and may also deteriorate the winding insulations. So, therefore, in addition to the providing protection for internal fault the design of transformer protection also needs to consider issues related to overload, over excitation and through-fault also because these things are related to the life of the transformer. Therefore, the protection scheme should address these points also.

(Refer Slide Time: 12:23)



Complicacy in transformer protection-

For Examples- The following two fault characteristics of power transformers complicate detection of internal faults (with relays actuated with currents available at the terminals of a transformer):

a) The change in magnitude of current at the transformer terminals may be very small when a limited number of turns of a winding are shorted within the transformer.

For example, as much as 10% of the winding may have to be shorted to cause full-load terminal current to flow. Thus, a single turn-to-turn fault difficult to be detected with currents at the transformer terminals.

b) When a transformer is energized, magnetizing inrush current that flows in one set of terminals may be equal to many times the transformer rating.

These and other considerations require careful thought to obtain relay characteristics best suited to a particular application.

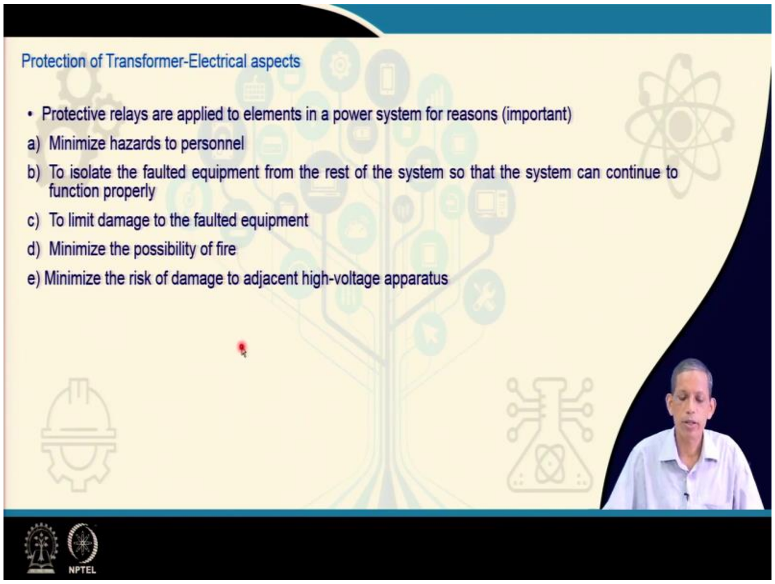
IEEE Guide for Protecting Power Transformers, C37.91

Transformer static device but it has numerous protection challenges just to start with we have one example here. Now, see the change in magnitude of current at the transformer terminals may be very small when limited number of turns are being short circuited. So, we see here when a turn to the ground happens to be there, directly to the ground the corresponding current may be significant, if the corresponding turn happens to the lower turns in the transformer winding towards the ground then the fault current will be smaller. If the fault is between two turns, then the amount of current may be much smaller.

For example, as much as 10 % of the winding is required to be sorted to reach the rated current to flow. So, when you talk about a single turn-to-turn fault that may lead to not that significant current whereas the transformer terminals can be detectable. So, that is what the issue of turn-to-turn fault. At that point where the fault has occurred there the current maybe significant but they reflects on the corresponding reflection at the terminal of the transformer where the corresponding measurements through the CT will be taken it may not be significant, so that could challenge us to be transformer protection.

When a transformer is energized, magnetizing inrush current flows or during a fault sudden deep in voltage and the fault is remove quickly then again jump in voltage in that kind of thing also transformer inrush is observed. So, but you can say that the transformer inverse happens to be in one side of the winding. Therefore the differential current will be there in terms of that and this current may be many times the transformer rating. So, even though it is not a fault then how to tackle these situations. So, this and there are so other several issues which will discuss in the latter part of the module leads to challenges to the transformer protection it must be carefully address in any protection scheme designed for transformer.

(Refer Slide Time: 15:18)



Protection of Transformer-Electrical aspects

- Protective relays are applied to elements in a power system for reasons (important)

a) Minimize hazards to personnel
b) To isolate the faulted equipment from the rest of the system so that the system can continue to function properly
c) To limit damage to the faulted equipment
d) Minimize the possibility of fire
e) Minimize the risk of damage to adjacent high-voltage apparatus

Protection relays are applied in transformer in terms of power system reasons, the duration when you design, going for the design must be that the minimize the hazards to personnel first and foremost thing, so it has time related issue also. To isolate the faulted equipment from the rest of the system so that the system can continue the function properly rest of the system should functioning properly, that is the selectivity perspective with the fault persist for long period deep in voltage and other things will be there also, which is not desirable from power quality and reliable operation perspective. With the fault persist more time, stability may be an issue if it is an very high voltage system or so. To limit the damage in the faulted equipment that is the transformer here, the sooner the fault is clear the better it is. Minimize the possibility of fire, the transformer is associating a transformer oil or so and there are many examples where it may burst and lead to fire and if that so we can say that the whole substation may be in trouble.

Minimize the risk of damage to adjacent high-voltage apparatus because of associated fire and other things. So, the point of concern here is that when you are designing a protection schemes all these points must be also addressed.

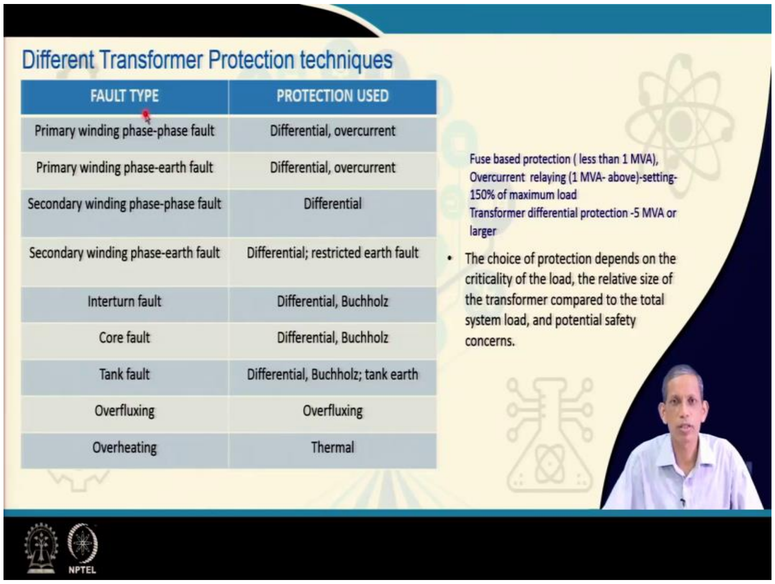
(Refer Slide Time: 16:56)

Transformer Protection elements- IEEE Device number

24 Volts-per-hertz (V/Hz) relay
26 Apparatus thermal device
46 Reverse-phase or phase-balance current relay (negative-sequence current relay)
49 Machine or transformer thermal relay
50 Instantaneous overcurrent relay
50N Instantaneous neutral overcurrent relay
51 AC time overcurrent relay
51G AC time ground overcurrent relay
51N AC time neutral overcurrent relay
51NB AC time neutral overcurrent backup relay
51NT AC time neutral overcurrent torque-controlled relay
52 AC circuit breaker
59 Overvoltage relay
60 Voltage or current balance relay
63 Pressure switch
64 Ground detector relay
67 AC directional overcurrent relay
67G AC directional ground overcurrent relay
86 Lockout relay
87 Differential protective relay
87G Ground differential protective relay

List of Transformer protection elements in electrical perspective, IEEE device number animated here. Just to show that the transformer protection is not that simple it is associated with several electrical, mechanical, thermal, all and electrical perspective is so many kind say varieties of relays are there. However, it is not necessary that all should be incorporated that depends upon the situations, requirements and in terms of the economic perspective.

(Refer Slide Time: 17:35)



Different Transformer Protection techniques

FAULT TYPE	PROTECTION USED
Primary winding phase-phase fault	Differential, overcurrent
Primary winding phase-earth fault	Differential, overcurrent
Secondary winding phase-phase fault	Differential
Secondary winding phase-earth fault	Differential; restricted earth fault
Interturn fault	Differential, Buchholz
Core fault	Differential, Buchholz
Tank fault	Differential, Buchholz; tank earth
Overfluxing	Overfluxing
Overheating	Thermal

Fuse based protection (less than 1 MVA),
Overcurrent relaying (1 MVA- above)-setting-150% of maximum load
Transformer differential protection -5 MVA or larger

- The choice of protection depends on the criticality of the load, the relative size of the transformer compared to the total system load, and potential safety concerns.

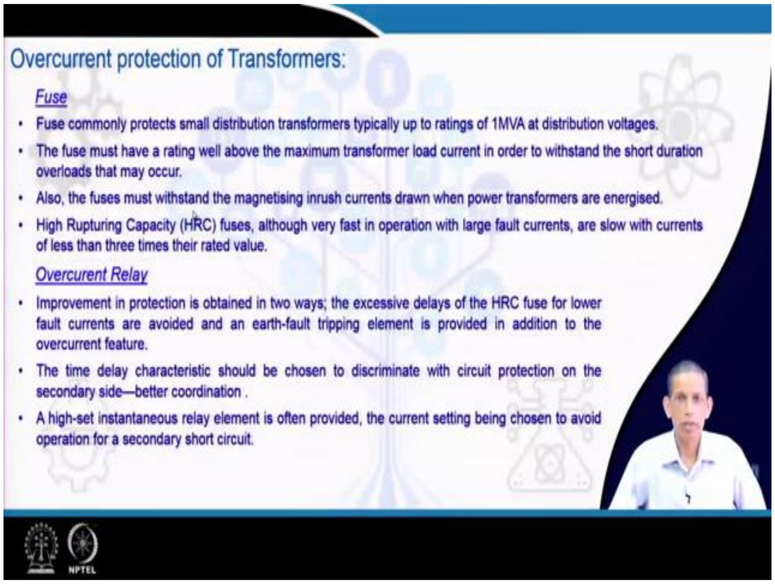
Now, further you can simplify that types of fault and the corresponding protection used in electrical perspective, faults in primary winding, differential and overcurrent, even fuse also may be for primary winding phase to earth fault, differential and overcurrent. Secondary winding fault also, differential can be there. Secondary winding phase to earth fault, restricted earth fault and so. We will address those things in our latter discussion.

Internal fault can be indentified from the differential principle and also buchholz relay, the mechanical form of relay. Core faults, differential and same buchholz relay. Tank fault, differential, buchholz and tank earth detection and so. Overfluxing, we have overfluxing arrangement in the relaying perspective, different harmonic component estimation for that perspective.

Overheating, thermal temperature sensing and so should be there for the protection perspective. Note that for all these objectives, there are different protection schemes available in transformer, fuse is very basic module, fuse base protections are being widely use for the power transformer for smaller heating of transformer. Many transformers use overcurrent relaying principle.

For transformer rating greater than 5 MVA, we will find very common protection scheme based transformer differential protection. The choice of protection depends on the criticality of the load which is the feed through this transformer. The relative size of the transformer compared to the total system load and the potential safety concerns which we have already discussed in the earlier slide. So, these all are related to also this economic perspective and so, so that is also an important point in deciding which protection scheme is to be applied.

(Refer Slide Time: 19:48)



Overcurrent protection of Transformers:

Fuse

- Fuse commonly protects small distribution transformers typically up to ratings of 1MVA at distribution voltages.
- The fuse must have a rating well above the maximum transformer load current in order to withstand the short duration overloads that may occur.
- Also, the fuses must withstand the magnetising inrush currents drawn when power transformers are energised.
- High Rupturing Capacity (HRC) fuses, although very fast in operation with large fault currents, are slow with currents of less than three times their rated value.

Overcurent Relay

- Improvement in protection is obtained in two ways; the excessive delays of the HRC fuse for lower fault currents are avoided and an earth-fault tripping element is provided in addition to the overcurrent feature.
- The time delay characteristic should be chosen to discriminate with circuit protection on the secondary side—better coordination .
- A high-set instantaneous relay element is often provided, the current setting being chosen to avoid operation for a secondary short circuit.

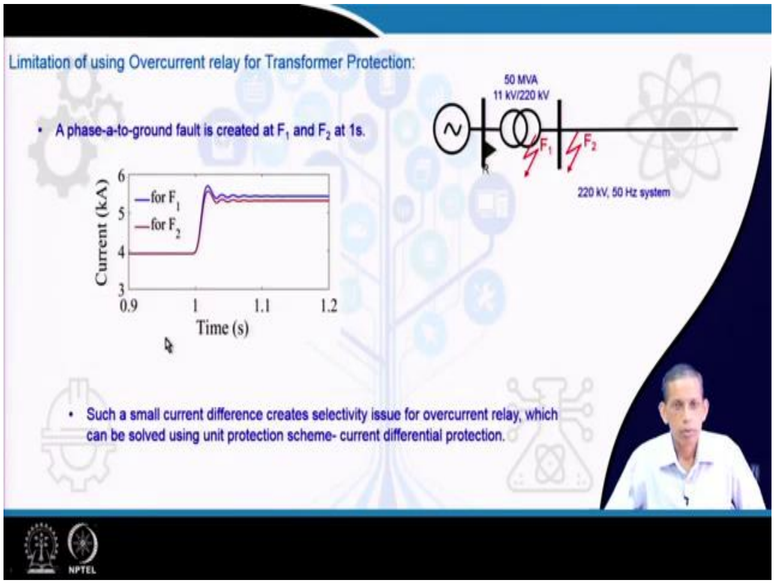
So, continuing with transformer protection on the overcurrent based protection is also a solution and already mentioned this will be confined to low MVA ratings, two aspects can be dealt on the overcurrent based approach. One is based on fuse and the other can be overcurrent relaying principle. Going to fuse based protection of the transformer, this is applied to mostly of the small MVA transformer.

The fuse rating must be greater than the MVA corresponding transformer rating that is the rated current of the transformer. Also the fuse must withstand the inrush current which happens to be much higher limited to a certain period. So while deciding the rating of the fuse the corresponding characteristic of the fuse, it must adjust the inrush current which happens to be there while switching on the transformer at no load or light load condition.

HRC – High Rupturing Capacity fuses are also being used and they are very fast for the protection, during the large fault currents, say internal fault or the transformer. But their response is slow when their corresponding internal fault current is low, like you think about a situation where the corresponding transformer internal fault at the lower end of the winding, so that is the demerit of such HRC fuse perspective and so.

Now with fuse, it is very difficult to go for the coordination aspect and so, so overcurrent relay ,when you compare with the fuse perspective for using overcurrent relaying principle. Now, two improvements can be done, when the excessive delays of the HRC fuse for the low level of currents and an earth-fault tripping elements where you can find additional advantage of overcurrent relaying principal. The time delay characteristics IDMT and so provides good platform for better coordination with the subsequent elements which are there in the secondary level of the transformer that is the advantage of using relay, overcurrent relay above fuse. A high-set instantaneous relay also provides very fast protections and that is another advantage for overcurrent relay principle.

(Refer Slide Time: 23:19)

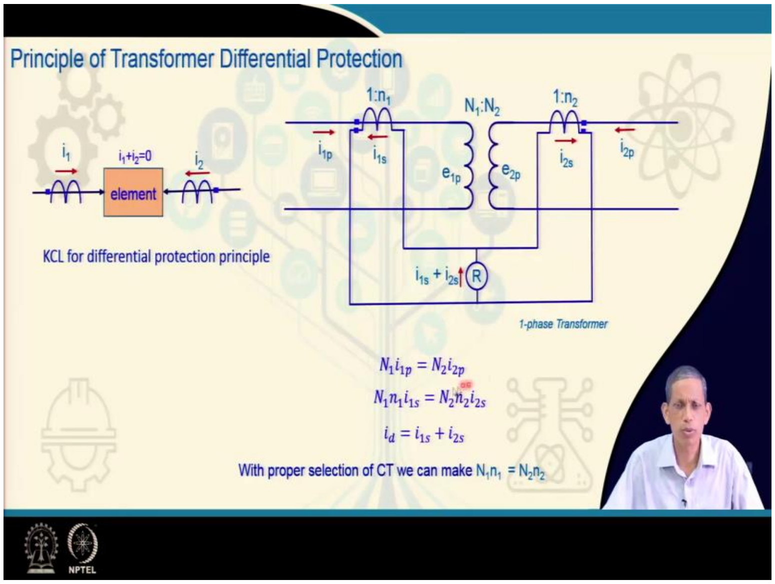


Limitation of using Overcurrent relay for Transformer Protection:

- A phase-a-to-ground fault is created at F_1 and F_2 at 1s.
- Such a small current difference creates selectivity issue for overcurrent relay, which can be solved using unit protection scheme- current differential protection.

Now, the overcurrent relaying principle has limitation, let us consider a system source transformer and the overcurrent relay is from this source side, so this transformer is 11kV is to 220 kV, 50 MVA rating, as a generator transformer two faults are created; one internal to the transformer and one is external. F_1 is internal fault, F_2 is external fault. Now this is created at 1s simulation platform to evaluate the situation. So when you see, because the internal fault is in such a position that the two levels of currents are at par, so the level of currents are at par for the both F_1 and F_2 and that becomes a challenging thing to be discriminated by overcurrent relaying principle, thus, we see that the overcurrent principle has selectivity issue and it is not only relay, also it is observed for the fuse because that is also based on the overcurrent principle and that gives us a scope that unit protection and particularly on differential relay principle which we will be studying in more details on transformer.

(Refer Slide Time: 24:56)



Principle of Transformer Differential Protection

KCL for differential protection principle

1-phase Transformer

$$N_1 i_{1p} = N_2 i_{2p}$$

$$N_1 n_1 i_{1s} = N_2 n_2 i_{2s}$$

$$i_d = i_{1s} + i_{2s}$$

With proper selection of CT we can make $N_1 n_1 = N_2 n_2$

Our focus will be more on the differential protection from the electrical perspective, so we will start on the basic principle of differential protection through transformer any differential protections for whether it is transformer or any other element like a circuit breakers is like a transmission line or so, any element protection in the power system can have differential protections if we have sensor, current, sensors at both the sides.

From these two sensors if you take the corresponding current, so we can apply KCL to that. So, if you see this current direction here then it leads to, so

$$i_1 + i_2 = 0$$

That is what we get from the KCL. Now, in case of an internal fault there will be another path for the current let us say to the ground, so that becomes i_3, so

$$i_1 + i_2 = i_3$$

So, that means the $i_1 + i_2$ will be no more 0. So, this is the basic principle of the transformer, differential protection or any differential protection applied to different elements in power system. Now, come to a single phase transformer here, as per clarity how it proceed for the differential protection, we have CT in the primary side also in the secondary side and the corresponding CT ratios are 1: n_1 and 1: n_2.

Note, as we have already studied in current transformer case, the n_1 one becomes high and the primary may be usually consist of 1 turn. So, in that case we say the n_2 will be high and the primary may be one, but note here the corresponding main transformer capital $N_1: N_2$.

So, the corresponding CT will be connected like this and then in this differential path the corresponding current becomes $i_{1s} + i_{2s}$, where i_{1s} corresponds to the primary side CT secondary current and the i_{2s} the secondary side of the transformer CT secondary current. So, this will be nothing but in this differential branch the corresponding current associated with.

So, normally what happens that if the transformer is feeding load to the right hand side, so the current will flow from this primary side to the secondary side that is the N_2 side and the load current will be accordingly. In that case the summation of i_{1s} and i_{2s} will be equals to 0.

For any internal fault the corresponding sum of i_{1s} and i_{2s} will be no more 0. The i_{1s} plus i_{2s} will be the corresponding internal fault current amount. So, that leads to detection of any internal fault between these two sensors CT_1 and CT_2 can be easily detected by this differential current.

Note, that the amount of differential current via $i_{1s} + i_{2s}$ in this kind of CT connection will be nothing but the internal fault current amount. So, what is being done that in this case the important factor is that how to select the corresponding CT ratio $1: n_1$ and $1: n_2$, what we are telling, so that the differential current is indicative of the internal fault not for any external fault, that is the sole purpose of the differential protection for transformer here. So, for normal condition as per the ampere-turns balance

$$N_1 i_{1p} = N_2 i_{2p}$$

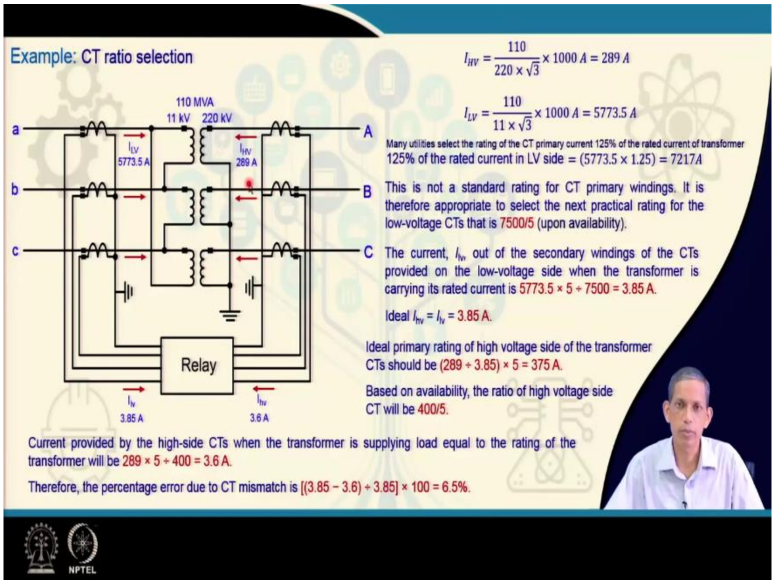
Now, if you replace these primary currents i_{1p} and i_{2p} by the CT secondary current then we can rewrite the above relation as

$$N_1 n_1 i_{1s} = N_2 n_2 i_{2s}$$

So, this balancing normally the corresponding current i_{1s} plus i_{2s} will be 0 and the differential current becomes equals to $i_{1s} + i_{2s}$. but this balancing no more valid in case of internal fault case. Now, from this relation if we see here that with proper CT selection if we can make $N_1 n_1 = N_2 n_2$

then corresponding differential current during normal time will be equals to 0. Thus depending upon the corresponding relation transformer turns ratio capital N_1:N_2, and the corresponding n_1:n_2 CT ratio should be selected, so that during normal situations the differential branch current becomes 0 and in case of any internal fault this is no more 0, so that clearly shows that internal fault can be identified by this arrangement.

(Refer Slide Time: 30:52)



Example: CT ratio selection

$$I_{HV} = \frac{110}{220 \times \sqrt{3}} \times 1000\,A = 289\,A$$

$$I_{LV} = \frac{110}{11 \times \sqrt{3}} \times 1000\,A = 5773.5\,A$$

Many utilities select the rating of the CT primary current 125% of the rated current of transformer

125% of the rated current in LV side = $(5773.5 \times 1.25) = 7217A$

This is not a standard rating for CT primary windings. It is therefore appropriate to select the next practical rating for the low-voltage CTs that is 7500/5 (upon availability).

The current, I_{lv}, out of the secondary windings of the CTs provided on the low-voltage side when the transformer is carrying its rated current is $5773.5 \times 5 \div 7500 = 3.85$ A.

Ideal $I_{hv} = I_{lv} = 3.85$ A.

Ideal primary rating of high voltage side of the transformer CTs should be $(289 \div 3.85) \times 5 = 375$ A.

Based on availability, the ratio of high voltage side CT will be 400/5.

Current provided by the high-side CTs when the transformer is supplying load equal to the rating of the transformer will be $289 \times 5 \div 400 = 3.6$ A.

Therefore, the percentage error due to CT mismatch is $[(3.85 - 3.6) \div 3.85] \times 100 = 6.5\%$.

Now, come to an example for a three phase transformer is a relay protection usually applied for a numerical relaying principle and so. So, 11 kV: 220 kV is transformer. So, this low voltage side is connected in delta here and this high voltage side is connected in star that of the transformer, the transformer rating is 110 MVA. Now this CT which are in a three phase systems can be connected in star or delta but typically in a numerical relay we do not require such connections as both these sides CT’s are connected in star here. We will discuss more on the typical CT connection and so later on. So, in this diagram both the CT’s are connected primary and secondary, the low voltage and high voltage sides in star and those are signals having thread to the differential relay in this case. So, we see here how to, the task is here that the CT selection, what the choice of CT for the particular differential relay application. So, here in the high voltage side (220kV) the full load current is

$$I_{HV} = \frac{110}{220 \times \sqrt{3}} \times 1000 = 289 \text{ A}$$

In the LV side

$$I_{LV} = \frac{110}{11 \times \sqrt{3}} \times 1000 = 5773.5 \text{ A}$$

Then how to proceed for the corresponding CT selection? Many utilities are preferred, the corresponding CT primary current should be 1.25% of the rated current of the transformer for overloading and all these things have been taken care. So, if we say the corresponding current in the primary current for the rated low voltage (LV) side there, then this becomes

$$5773.5 \times 1.25 = 7217 \text{ A}$$

So, you may not get exact CT of that value; therefore, upon the availability this becomes 7500: 5 for the low voltage side CT. The current, I_{lv}, out of the secondary windings of the CTs provided on the low-voltage side when the transformer is carrying its rated current is

$$5773.5 \times 5 \div 7500 = 3.85 \text{ A.}$$

Now, our choice ideally that during normal condition the high voltage currents will be equals to low voltage current that is $I_{\text{hv}} = I_{\text{lv}} = 3.85$ A. So, if that is so then if you go back to the high voltage side transformer the current at CT primary should be (289 ÷ 3.85) × 5 = 375 A. Therefore the CT's will be 375: 5 should be the ratio of the CT ideally based on if we have already selected for 7500: 5 for the low voltage side. But based on the availability of the CT, the choice may be 400: 5 and that might be this CT selection for high voltage side up on the CT selection of the low voltage side to be this value.

Now, in this case because of the high voltage side CT desirable is 375: 5 but we have taken the choice of 400: 5 so there will be spill current in the relay and that spill current entering to the relay in its phase will be

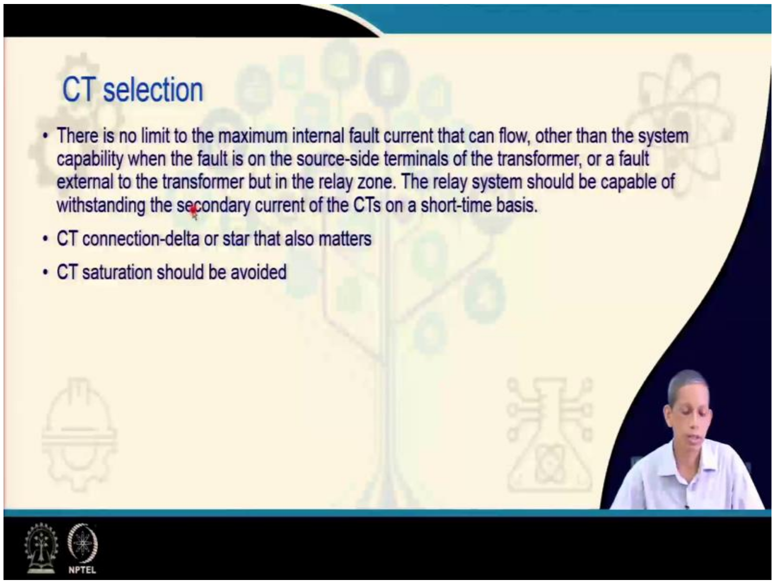
$$289 \times 5 \div 400 = 3.6 \text{ A}$$

When the transformer is supplying load equal to the rating of the transformer. Therefore, the percentage error respect to the low voltage current due to CT mismatch is

$$[(3.85 - 3.6) \div 3.85] \times 100 = 6.5\%.$$

So, this is the corresponding percentage of spill current which will be there in the relay due to the CT mismatch requirement and all these things.

(Refer Slide Time: 36:54)



CT selection

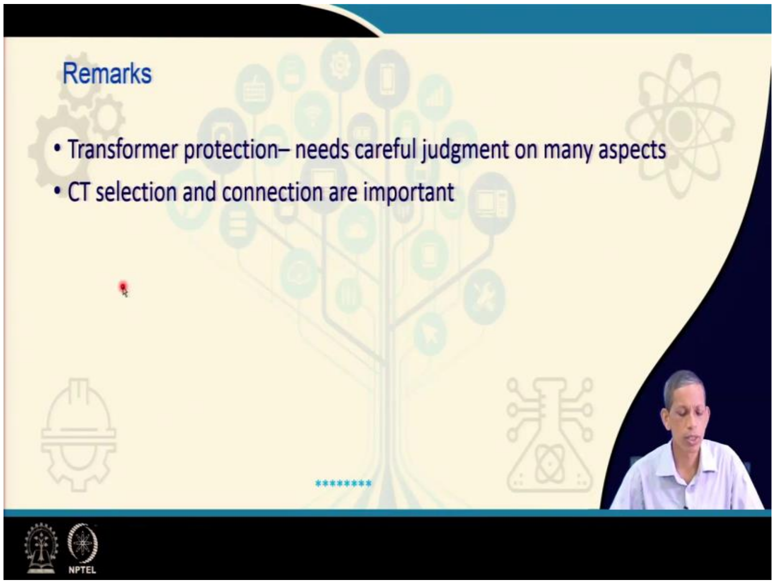
- There is no limit to the maximum internal fault current that can flow, other than the system capability when the fault is on the source-side terminals of the transformer, or a fault external to the transformer but in the relay zone. The relay system should be capable of withstanding the secondary current of the CTs on a short-time basis.
- CT connection-delta or star that also matters
- CT saturation should be avoided

Now, further going to the CT selections for the maximum internal fault or the level up current which will be there all these things that the CT should be able to sustain level of current for that momentary fault duration and the secondary side of the CT where the corresponding relay and terminals should be there must be compatible to that large amount of current in the system.

CT connection can be delta or star, so we will see later on literature going for star or delta connections to adjust the phase shift issue and we will discuss in the later class but in numerical relay these connections of the CT’s in both these sides can be star connection also, that is what prefer these days.

The other attention is that the CT saturation should be avoided, if there will be CT saturation then that time also differential current will flow during an external fault and that may create problem to the relay decision process.

(Refer Slide Time: 38:15)



Remarks

- Transformer protection– needs careful judgment on many aspects
- CT selection and connection are important

So, in overall we see that the transformer protection needs careful judgment on many aspects including leading to mechanical failure or thermal failure and allied things in this perspective. and we see that finally through an example also the CT selection is important and upon availability of the different CT ratio that must be considered and the connection of the CT is also an important perspective and the CT saturation and the tolerance of the CT to the large amount of current is another related issues for the selection of the CT for transformer differential protection perspective. So, this is something on to start with the transformer protection, next lesson will be more details on differential protection of transformer. Thank you.