**Power System Protection**
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**Lecture 40 – Inrush Detection**

Welcome to NPTEL course on Power System Protection. We are continuing with Transformer Protection.

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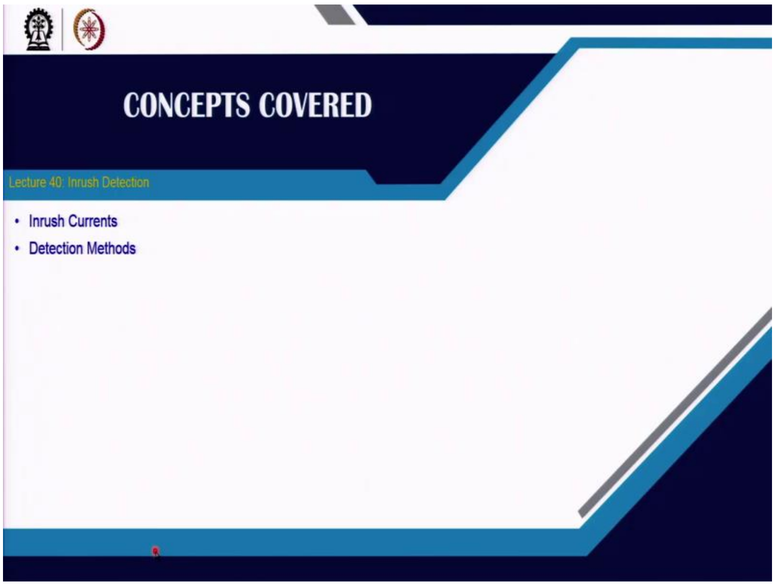


In this lecture, we will discuss on Inrush issues with differential protection and the detection mechanism, and also, we will see how overexcitation can be detected to overcome the challenges with differential protection.

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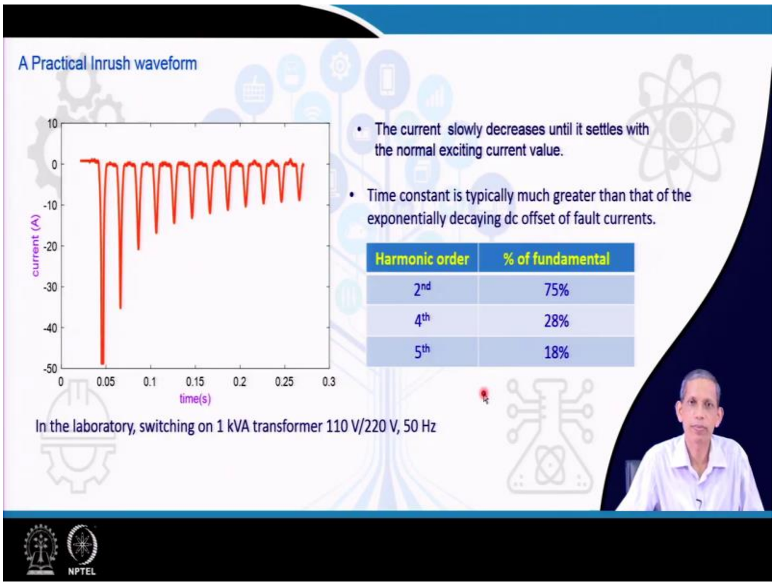

Now, this is a laboratory experiment while switching on a small transformer, the corresponding current observed during the no load condition and the energisation leads to current of this nature. So, this is as you know, it is called this, inrush current and this current, if we see, the current pattern is not sinusoidal, it is having a different pattern. This current slowly decays may take long time 20 seconds and so also  and then settles to that to the normal exciting, excitation current, which is 2 to 5 % of the rated current but initially, this current becomes substantially high, and the associated time constant of this current, so called inrush current, it is much larger than the time constant, the exponentially decaying DC issue, which you have already understood for the fault situation.

Another, the FFT analysis of this current in oscilloscope reveals that it has different harmonic components including DC and also sub harmonic and so. Some of the harmonic components, second, fourth and fifth is pretty high as compared to the fundamental, and that we see from this table.

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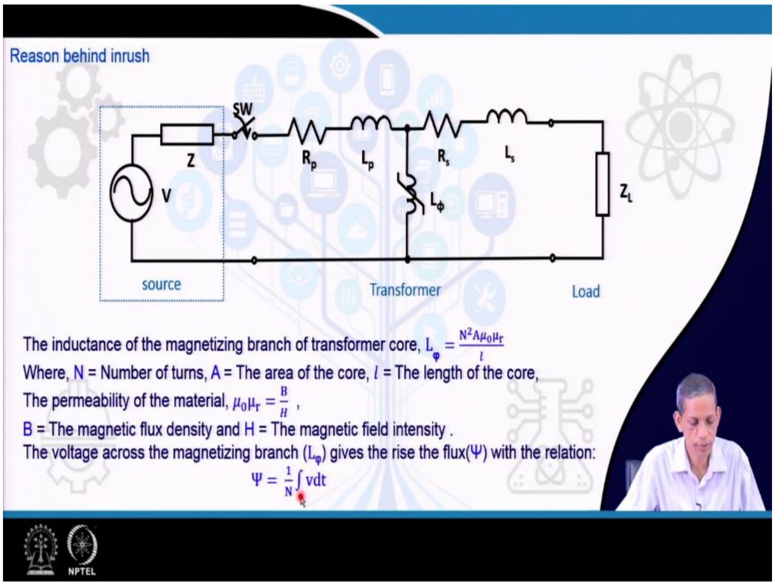


Now, we will see why this large current happens to be there during the transformer energization, and we will try to analyse quickly on a transformer case. So, this is a source with its own impedance and the corresponding Thevenin's voltage and Thevenin's impedance, we can that way. This part is the transformer, so we have taken the equivalent model at primary side, resistance, leakage inductance and the magnetizing inductance path.

For simplicity, we have neglected here the core loss part. Secondary part also, these are associated resistance and leakage inductance and then the load impedance part. So, this transform is to be switched on. Now, some of the basic equation we know that the corresponding inductance, it is

$$L_{\varphi} = \frac{N^2}{reluctance} = \frac{N^2 A\mu_0\mu_r}{l}$$

The reluctance is related to $\frac{l}{A\mu_0\mu_r}$ and $\mu_0\mu_r = \frac{B}{H}$ ,H relates to the corresponding magnetizing current aspect and B relates to this flux aspect. So, this H is the magnetic field intensity and B is the magnetic flux density, they are related. So, we know that the BH core for the particular magnetic core of the transformer. Furthermore, the flux associated to this magnetizing branch ($L_{\varphi}$) is related to

$$\Psi = \frac{1}{N}\int vdt$$

your transformer emf equation also.

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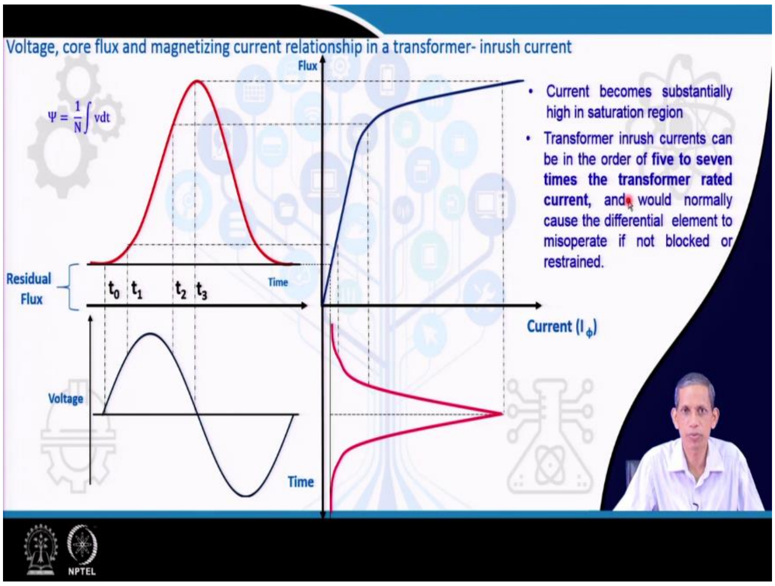


Now, if you see this is a graphical plot, which you can find in books more details also, so this is a sinusoidal voltage. Let us assume that the transformer core while the transformer was switched off earlier, now we are energizing having residual flux of this amount $\phi_r$ amount. Now, this voltage, we know will be integrated to provide the corresponding flux for the core. So, this cycle gives us, this half portion of this because of the integration. So, till this point the corresponding flux goes on encouraging starting from this residual flux $\phi_r$. Now, this is our BH kind of thing. So, B corresponds to flux and H corresponds to the magnetizing current in the wire. So, this part, assume these, part of that BH curve in this positive half. So, that leads to point of this voltage, we can relate it to the corresponding flux, flux linkage, and from the flux linkage, we can call it to this corresponding current associated with the shunt branch, the magnetizing current. So, what we see that, because the shifting of this core, because of the residual flux, it goes to the saturation region of the so called BH curve or the flux versus $I_\phi$.

That results, the corresponding $I_\phi$ current of this shape and a sufficiently high current because of the, it is reaching, going the saturation region. So, to increase a small amount of flux in this situation region, the associated current requirement in the shunt branch that is magnetizing current is substantially high. So, these graphical plot reveals that the wave shape of, the corresponding magnetising current is different and also the amount of current in this one branch becomes substantially high, and that the corresponding during that time because this $\mu_0\mu_r$, the $\mu_r$ part changes substantially from this relation.

So the inductance $L_\varphi$ becomes substantially low in the equivalent circuit diagram and the magnetizing current becomes very-very high. These current can be as high as 5 to 7 times of the transformer rated current because this current flows in the one winding only, where we are energizing, so, the difference current becomes substantially high and it may lead to unnecessary, unwanted tripping of the relay due to the operation through differential relay.

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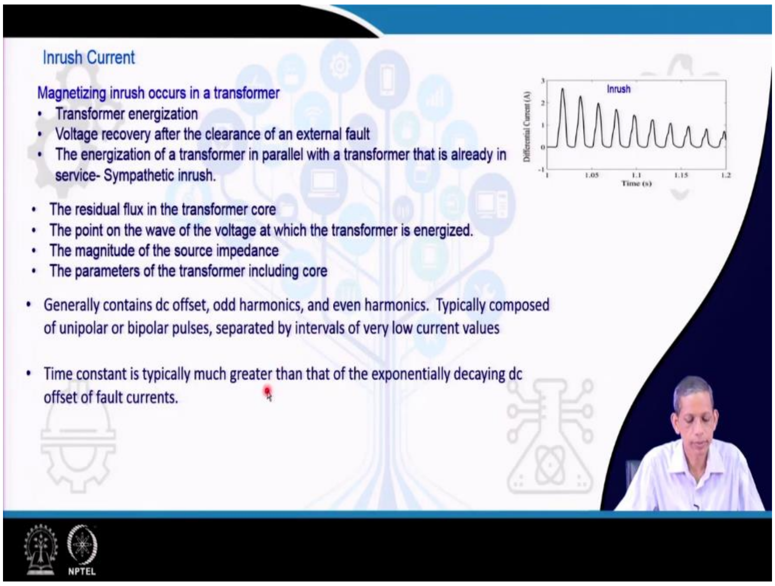


This inrush current, what we you say has the issue associated with unnecessary tripping. This current is not only do transformer energization, it occurs also when there is voltage recovery after the clearance of an external fault. The energization of a transformer in parallel, the transformer that we know that sympathetic inrush also that when 2 transformers are parallel this is being observed. The corresponding inrush current that depends upon numerous factors, some of them, they are the residual flux in the core; the point on the wave, that at what point of the corresponding voltage, the corresponding transformer is again switched on or energized. The magnitude of source impedance because this current flows through from the source to the impedance of the, source to the transformer.

The parameters of the transformer including the core aspect of these things, which you can see that governs the $L_\phi$ part and the part of the transformer, primary winding parameters and so as you have observed the equivalent circuit diagram, the earlier slide. This inrush current generally contains DC offset, different or harmonic components including even harmonics also. Typically, it is computer's unipolar or bipolar process, like this, we are talking about here.

It may be only in the positive half or negative half or maybe having some DC offset also and separated by intervals of very low currents. So, it is separated by intervals, the having very low currents. This is, these are the set of features, this special wave of the corresponding current in transformer happens to be there. These play nuisance in the operation of the transformer differential relay.

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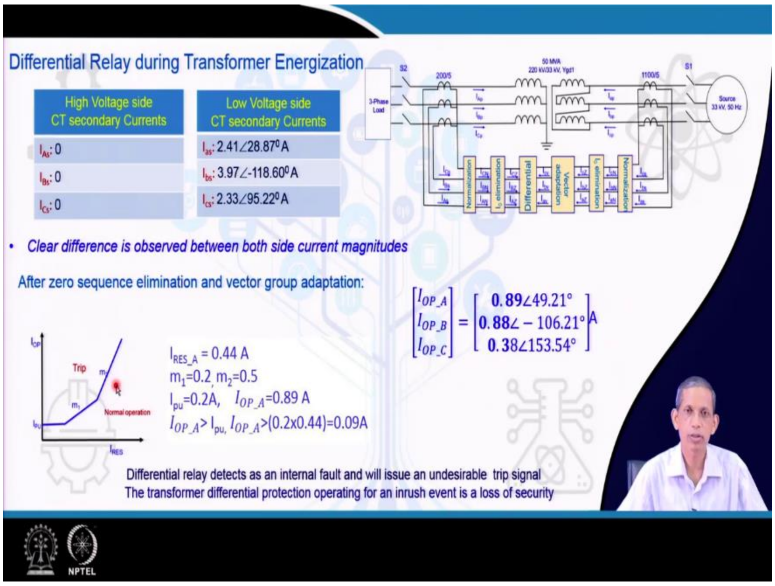


Now, during transformer energization, let us, the example which we have taken in our earlier lecture also, 33 kV delta side start side is at 220 kV and this is the source site and this is the load side. So, the load is switched off, no load condition in the transformer, energized and then we like to take the different currents through these CTs and then the process for the differential relay operations.

So, during that one instant of time, it is being recorded that the corresponding currents in the delta side and the corresponding high voltage side, not loaded, so no currents. So, this side is energized, so different phases have different currents at different positions. That is the corresponding record or currents are mentioned here. Therefore, what happens that the corresponding $I_{OP}$ current after the vector adaptation and perspective and so. So, the differential current in this pursuit, it becomes these values.

$$\begin{bmatrix} I_{OP\_A} \\ I_{OP\_B} \\ I_{OP\_C} \end{bmatrix} = \begin{bmatrix} \mathbf{0.89}\angle 49.21° \\ \mathbf{0.88}\angle -106.21° \\ \mathbf{0.3}8\angle 153.54° \end{bmatrix}$$

So, these values, if we see the corresponding percentage biased, there is a, I have already discussed in earlier lecture. The restraining current $I_{RES\_A}$ = 0.44 A, and $m_1$, let us say 0.2 and $m_2$ = 0.5, and $I_{PU}$, this pickup current, it becomes 0.2 A, what we have earlier also. So, this $I_{OP\_A} > I_{pu}$, $I_{OP\_A}$ > (0.2x0.44) = 0.09A. So the point will fall in this trip region, and then the differential relay trip for the transformer energization case. This is not a fault case, after some time the corresponding current will die down and the differential current will also vanish. It will be only that spill current will be very small to 2 to 5 % of the rated current due to the magnetizing current, which will be there. So, this is not an internal fault case.

The differential relay should not operate at this time, but if we allow this current and it falls in the trip region, so the transformer will operate unnecessarily. So, this is a compromise in the security perspective of the differential relay. Therefore, some mechanism must be there to avoid unwanted tripping due to transformer energization or inrush situation.

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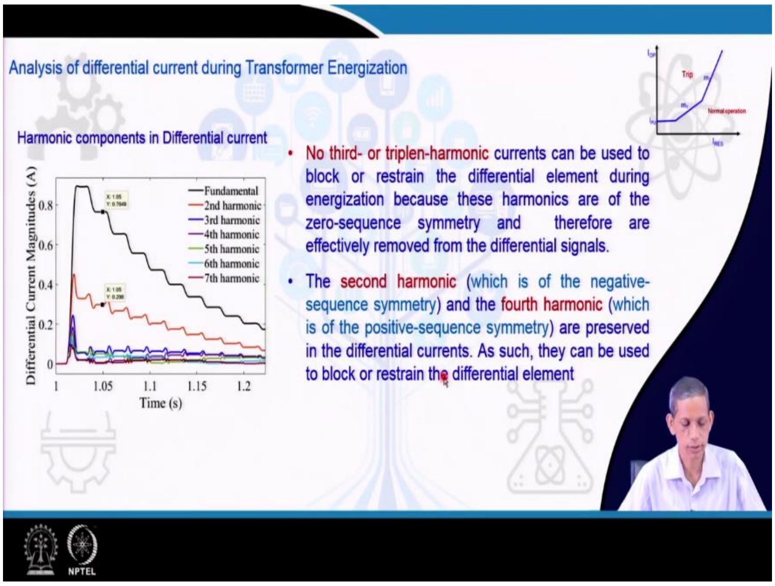


Now, we will analyse the corresponding, the nature of this inrush current and then we will see how a proper way of mechanism can be developed for restraining or blocking the corresponding relay during such an operation. So, the harmonic components in the different, differential current during inrush current happens to be, we see these, that what do you call, see for that earlier case energization, it reveals different harmonic components including fundamental, so this is fundamental, it goes down and as already mentioned, a large time constant and it decays and finally settles to the magnetizing current aspect. It contains very large amount of second harmonic, that is speciality, and that we already mentioned also. It contains other harmonic components as you see, you can see that from third, fourth, fifth and different other harmonic components also.

The issue in the differential relay, that no third or the multiple of third harmonic components can be used to block or restrain the differential relay for inrush current, because these triple harmonics are equivalent to the zero sequence symmetry, because we have in the process of differential current, we are subtracting the zero sequence component, so they will be also eliminated in the process.

So, that, these third or its multiple harmonic components cannot be used for the distinction of inrush situation in the differential relay application. The second harmonic, which is a symmetry to the negative sequence component and fourth harmonic, which is a symmetry to the positive sequence component can be preserved in the process of computing the differential current and they can be used for the purpose of the inrush current detection positive and that is widely used in most of the relay applications.

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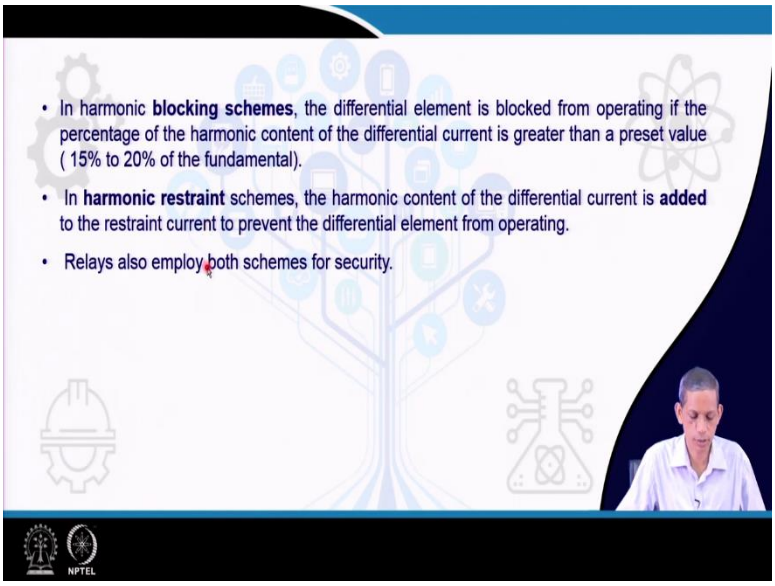


In the harmonic blocking, schemes for inrush situations, there are 2 schemes, one is blocking scheme and the other is a harmonic restraint schemes. Well we can learn what these two also in our subsequent discussion here. In the blocking scheme, typically when the second harmonic components become greater than 15 % or so with respect to the fundamental.

The corresponding differential relay is being blocked considering that this is a situation of inrush. That property or that feature, we observed from these being observed from numerous inrush situation as compared to the internal fault. Note that the differential relay should operate only for internal fault between the 2 sides CT for the transformer protection but this is an inrush situation, not at all an internal fault. So, it should not operate in that situation.

So, to distinguish internal fault and the inrush situation, one of the ways is to block the relay operations, if the relay finds the corresponding second harmonic component with respect to fundamental, typically as said below 15 to 20 %. In harmonic restraint schemes, what is being then, that we know the restraint becomes magnitude of $I_1$ and magnitude of $I_2$ and so. In that restraint, we add the corresponding harmonic components also and to ensure that, the relay does not operate in those situations also and they have their own advantages in terms of blocking scheme and restraint scheme. Some of the relays employs both also to exploit these advantages also.

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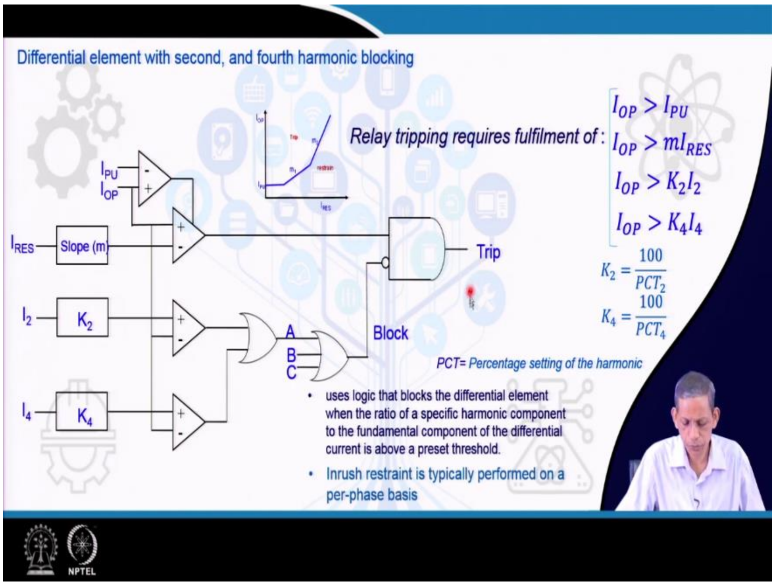


Now, come to first, these harmonic blocking scheme perspectives. So, this is what conventional percentage differential relay. To trip, the corresponding fulfilment requirement differential will operate, it means that it confirms an internal fault when these conditions are being satisfied. This we have already known that the $I_{OP}$ current, that the differential current in the part, in the, in that part, in that algorithms, which we have seen earlier in earlier lectures also.

So, it, $I_{OP}$ will be greater than this the corresponding minimum pickup current. $I_{OP}$ should be greater than these ($m_1$ or $m_2$) $I_{RES}$ in this portion. $I_{OP}$ current should be greater than $K_2I_2$ that is the second harmonic component and this $I_{OP}$ current should be greater than $K_4I_4$ the fourth harmonic component. So, these 2 components $I_2$ and $I_4$ corresponds to the second and fourth harmonic components are used for blocking the corresponding relay from operations.

How this $K_2$ and $K_4$ are decided? The $K_2$ and $K_4$ are given by

$$K_2 = \frac{100}{PCT_2}$$

$$K_4 = \frac{100}{PCT_4}$$

This PCT is the Percent Setting of the harmonic component and these are typically set in terms of $PCT_2$ as 20 % and so, and $PCT_4$ 10 % and so. So, that is about the usage of in these schemes. So, what we see this scheme? You can understand from this now, that in conventional and differential relay, the $I_{OP}$, which that, operates when it is greater than $I_{PU}$ and the $I_{OP}$ operates when it is greater than $mI_{RES}$, the restraining current perspective and when these are satisfied, it goes for a trip decision. So, that we have learned earlier. Now, what you do? Introduce the corresponding second harmonic component and the fourth harmonic component multiplied by this corresponding $K_2$ and $K_4$, what we have defined here and then the comparator either of anyone can be greater than the threshold value.

Then for each phase, it will make that things and then makes a block operation for this one. So, then the overall trip decision can be obtained. This is from the normal differential relay perspective and this portion is from the second harmonic and fourth harmonic perspective, which ensures an inrush current situation. However, if this percentage becomes much smaller than, this is not at all inrush and this is an internal fault. In that case, the relay we will go for a trip decision.

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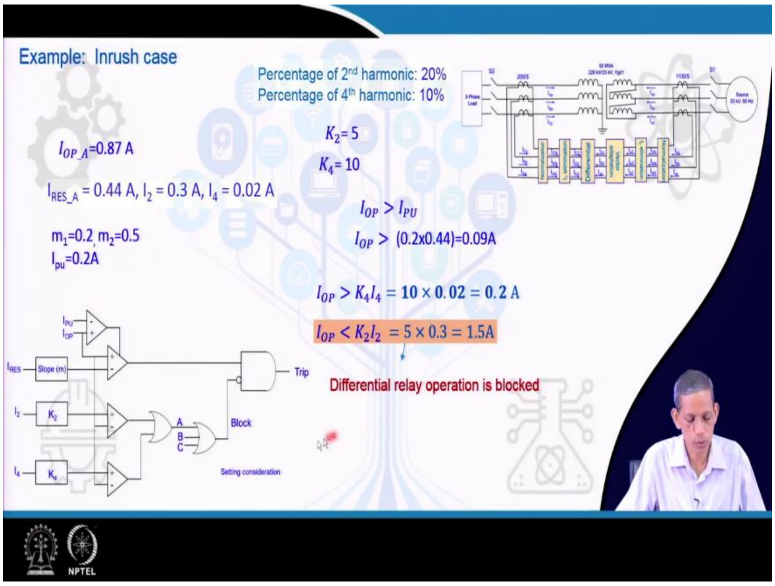


Now, let us see that our earlier example, which we had, energization, which we have seen in our earlier slide. So, in that case, we now the percentage of second harmonic setting up to 20 percent and percent of fourth harmonic of 10 percent in this case. So, $K_2$ becomes equals to 5 and K4 becomes equals to 10. Now, in our earlier calculations also, we have seen the corresponding $I_{OP}$ current is 0.8, 0.8 above. Then $I_{RES}$ equals 2.44 A. $I_2$ equals to negative, the corresponding secondary component at a given instant of time is 0.3 A and the $I_{RES\_A}$ in phase A is, happens to be 0.2 A. So now, for this $m_1$ $m_2$ s to be 0.2 and 0.5. In that case, we go for $I_{PU}$ equals to 0.2 A or so. We observe that you the $I_{OP}$ is greater than $I_{PU}$, that is 0.87 is greater than 0.2.

$I_{OP}$ in terms of $m_1$ in 0.44, that gives also 0.09. The operating in $K_4I_4$, that becomes equals to 10, the $K_4$ is 10 ×0.2 = 0.2 A. $I_{OP}$ is, it is observed that it is less than $K_2I_2$, that it is second harmonic component. $K_2$ is 5 and $I_2$ we got to be 0.3 A. So therefore, this become equals to 1.5 A. So, this imply that these second harmonic component is being, is not being satisfied for this operation of the differential relay.

So the differential relay blocked in this case. In overall, we see that with this kind of setting and all these things, for these situations, the second harmonic component is not being satisfied in this case, and therefore, the output becomes a block signal for this case, which is correct. therefore, the relay will not mal-operate with the help of such a scheme.

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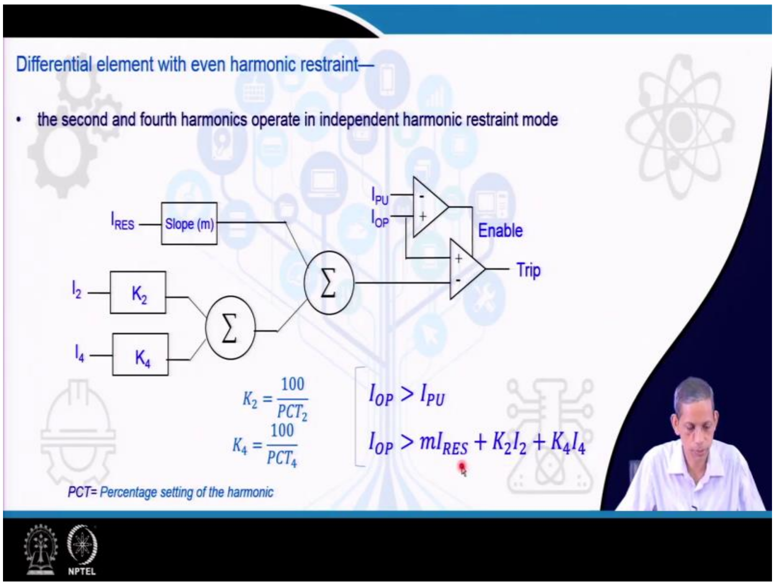


Now, we will go to the harmonic restraint scheme, the second option, which is being used. So here, also the second and fourth harmonics are being applied. And in this case, what is being done is already mentioned in  I, with the $I_{RES}$. We add these $I_2K_2$ and $I_4$ $K_4$. $K_2$ and $K_4$ already defined in terms of the other way also. Then the corresponding $I_{PU}$ also, this is differential part, which makes the enable to this comparator also. In this comparator, we add the corresponding restraining part like this

$$I_{OP} > mI_{RES} + K_2I_2 + K_4I_4$$

So finally we are increasing the restraining part so that the relay does not malfunction during the inrush situation, where the differential current still is being substantially high. So, this is another way to avoid the maloperation of the differential relay. We call it a harmonic restraint or so. So, the corresponding harmonics are being added to the restraint current for the perspective.

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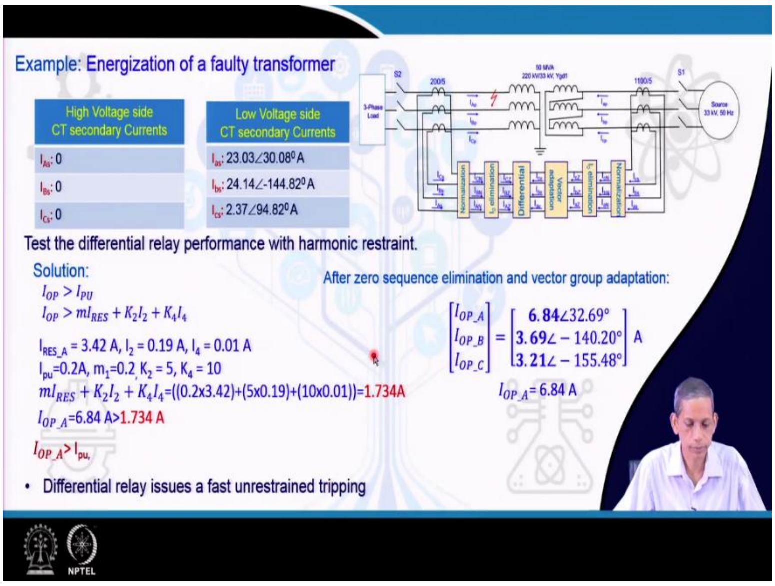


Now, take another example. Let us take internal fault happens to be there in the transformer and it is not loaded and we energize this. If this is the situation, this relay should clearly know that this is an internal fault. So, the relay must trip even though it may find some inrush behaviour and so and so. So, that must be ensured with these whatever restrains and so, we are observing.

Now, in this case, because there is no current in the load side, all currents are 0 in case of high voltage side, where the current in this side, low voltage side becomes, these are the set of currents $I_{as}$ and $I_{bs}$ are considered pretty high, that we have already noticed in our earlier lecture also, because this phase is in, A phase is involved in this case.

So now, the purpose is to test the differential relay performance with harmonic restraint function. So, after the zero sequence eliminations, we got the corresponding differential current in phase A, phase B phase C to be these set of currents 6.84, 3.69 and 3.21. Consider for phase A, the 6.84 for the magnitude of current.

So, we see, $I_{PU}$ is 0.2 only, which means that I operating is greater than $I_{PU}$ that we know. Now, these $I_{OP}$ now with the, with the approach of making the restrained features, adding the restrains features to these $K_2$ and $K_2I_2$ plus $K_4I_4$. So, we will calculate the corresponding this part. So, this part becomes equals to if we substitute all the values of these with 20% $K_2$ and for 10 % for the corresponding $K_4$ and this become 1.734 A.

So, then we say, substituting the value the $I_{PU}$, $I_{OP}$ is 6.84, which is much higher than the 1.73 A. That leads to this situation is that the corresponding $I_{OP\_A}$ satisfied, greater than $I_{PU}$ and also is greater than the corresponding restraint currents 1.734. So, therefore, the differential relay will operate for this internal fault case, which is, it will be correct decision. It means that the differential relay including the harmonic restrains is successful for its operation during an internal fault.

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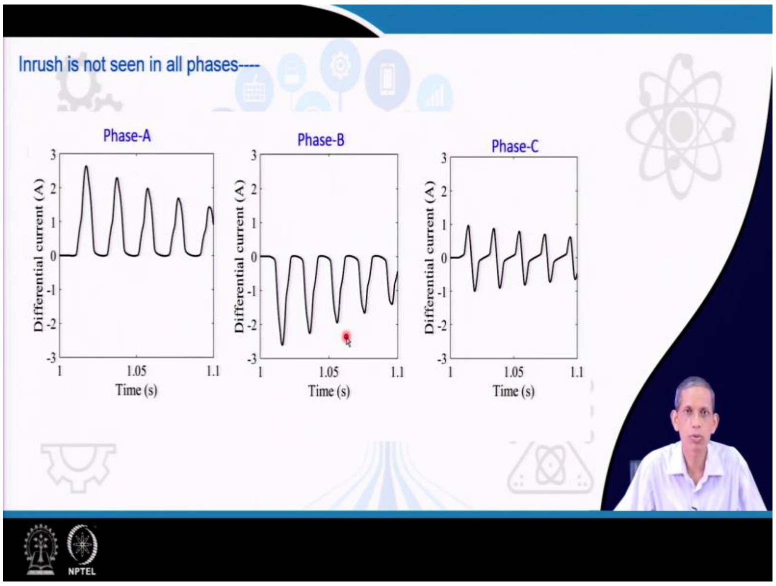


This inrush has various other issues that you see here. That whenever inrush happens to be there, all the phases, they are being switched on; this is a three-phase situation. So, all are through the different polls. In a circular curve they will be switched on. It is being observed that all the phases do not see large current due to this inrush situation.

Typically, this is a situation like this physical in the positive perspective and the negative half the Phase B and Phase C having very low current, magnetizing normal kind of current. So, all phases do not see large amount of current due to inrush in general. So, in that situation, how do on the phase to phase basis? As we have already enumerated for the percentage bias differential relay to restraint the during the inrush situations? How to handle that one?

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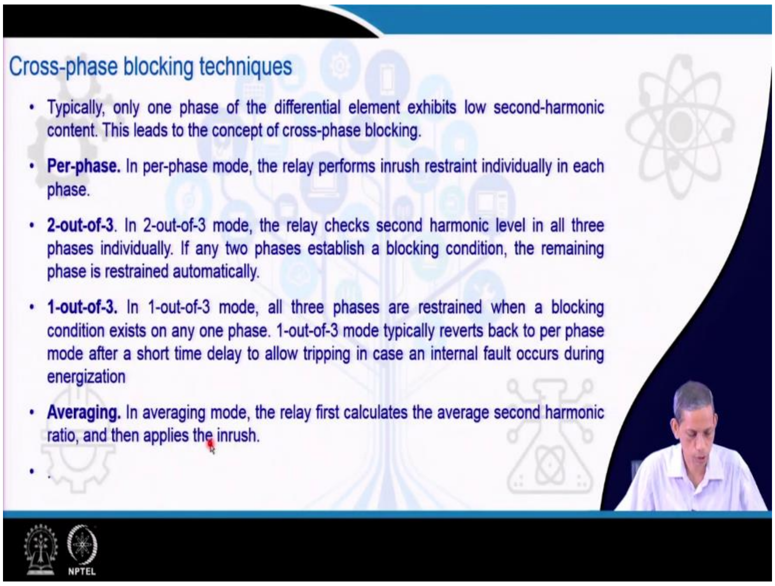


There are different solutions that are called cross-phase blocking techniques for the inrush situation. Now, the blocking options we have already learned, but how that is being accomplished in a three-phase environment that we like to figure out here. The cross-phase word is similar to the cross polarization that we learn in the differential relay perspective, that in the directional relay perspective.

In the directional relay, if we remember, any phase involved with fault in general, so, that phase voltage may substantially go down. So, therefore, instead of reaching that phase voltage we use the other phase's voltage for better operation. Here also is like that, it happens to be like that whenever in any of the phase, the corresponding inrush phenomena is not observed, but it is observed in other phases, in all 3 phases, the differential relay decisions are being blocked.

So, we see, typically one of the phases in the differential element see low amount of second harmonic or fourth harmonic component, and that may lead to unnecessary tripping. So, what is being done, there are different options on these blocking options during inrush situation per-phase basis. In Per-phase mode, relay performs inrush restraint individual phase and then block accordingly but what will happen here in this case, that one of the phases will not be able to get to that restrains, so the relay may mal-operate in that situation also. 2 out of 3, in 2 out of 3 modes, the relay checks second harmonic levels in all the 3 phases and it finds that 2 out of the 3 phases, they have significant second harmonic rather than the restrained like 15% or 20 % setting, then the relay will block all the 3 phases.

1 out of 3, in this case, if any of the 3 phases, the relay finds that the second harmonic component is significant; it blocks all the 3 phases' differential relay operation. There is another scheme available also, is called a averaging schemes. What is being done, the averaging second harmonic, average second harmonic component of all 3 phases are being obtained that decides whether the relay is to be block or to not to block.

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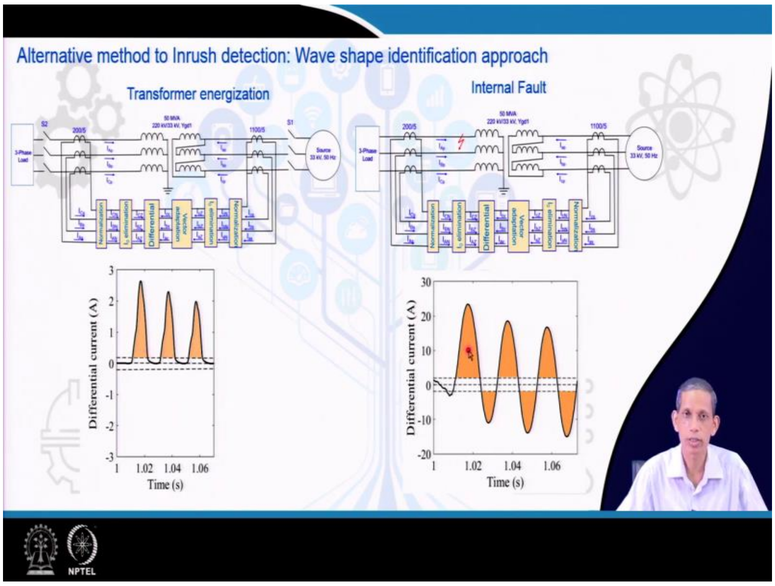


The alternative method also to the, this inrush detection process besides this harmonic-based approach and so, one is called waves shape identification approach. Let us see for this case. So, transform energizations and internal fault. So, these were the internal fault case and this normal transform energization. So, in the transform energization, we have the inrush shape like this or to the negative or a very small amount.

So, this is the corresponding differential current. When an internal fault happens to be there, the current patterns with a decaying DC and so may be very close to sinusoidal with some certain DC offset and so. So, what is being done here, we can say that, if we see this, put the dotted lines both in the positive and negative, we put a threshold, and we put a threshold and the hatched portion is nothing but the area under the curves.

Above that you can see the corresponding line in the positive hub, also in the negative hub. So, this, we designate that as A positive and A negative and then the wave shape is indicative of whether it is inrush or the corresponding normal internal fault case, which is very close to the sinusoidal perspective.

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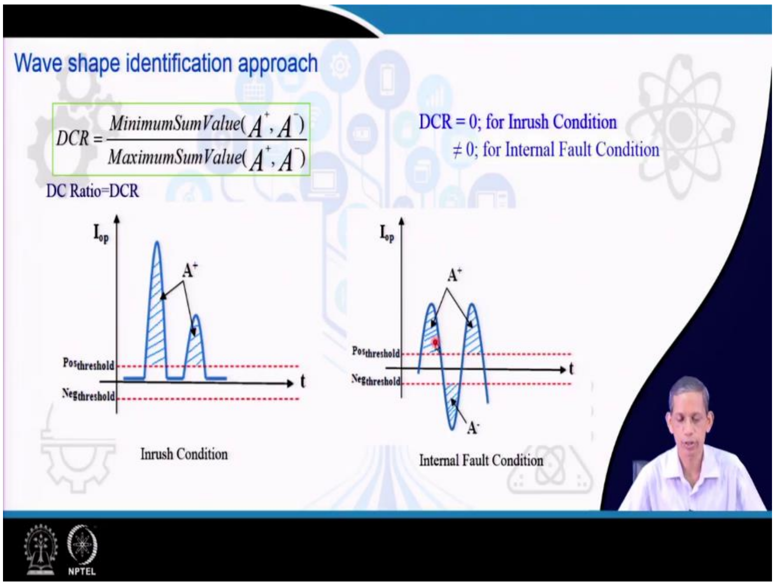


We will see that. So, what is being dawned, ratio called a DC ratio. So, that DC ratio is a

$$DCR = \frac{\min \text{sum } value\ (A^+, A^-)}{\max sum\ value\ (A^+, A^-)}$$

What we mean by $A^+$ or $A^-$ is the area under this curve above this threshold in the positive hub and also the $A^-$, if we see here, this corresponds to area under the curve, below this threshold dotted line, so that becomes $A^-$, and above this, it becomes $A^+$. So, in the inrush also if something is also maybe there in case of $A^-$ also, sometimes it goes to the negative perspective also and sometimes it becomes positive. So, or it may be both a positive and negative also.

So, what you find against that the DC ratio is that the minimum value upon maximum value of this positive area versus the negative area. So, what is being observed that the DCR becomes equals to 0 for inrush condition. The minimum becomes 0. Either you can say it in positive or it is in negative from the corresponding threshold value. Whereas, in case of internal fault, the corresponding area because it is very close to sinusoidal.

So after filtering out the decaying DC for internal fault the positive value $A^+$ and the $A^-$ becomes, they are very close to 1 and becomes 1. So therefore, the DCR value reveals whether in inrush situation or an internal fault situation can discriminate effectively. The concept behind is that the wave shape approach, except for the inrush is completely different than the corresponding sinusoidal nature of the internal fault.

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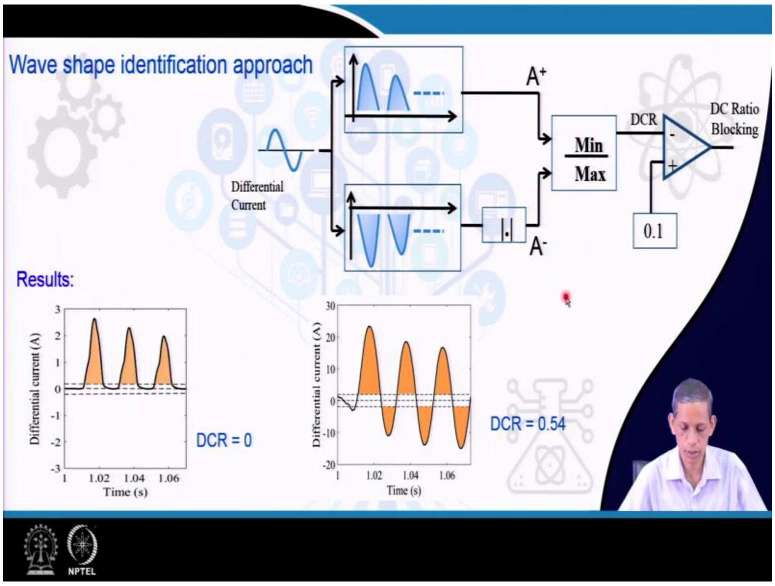


So, this, for the internal differential current for the internal fault case, DCR = 0, for the inrush situation. For an internal fault, case what we have already narrated earlier, this corresponding curve becomes like this and the DCR comes out to be 0.54 close to one kind of thing. So, much higher than the corresponding zero value. So, what do we say that differential current processing and all this things $A^+$, $A^-$, minimum upon maximum, the DCR value you got and then a 0.1 threshold is being done and then the corresponding DCR ratio blocking scheme is there, they add for this perspective. So, DCR here is 0.54, was higher than the 0.1, and therefore, this will for the internal fault case and the DCR value is 0, so this value for this internal fault case. These are the 2 examples for wave shape-based approach for inrush detection.

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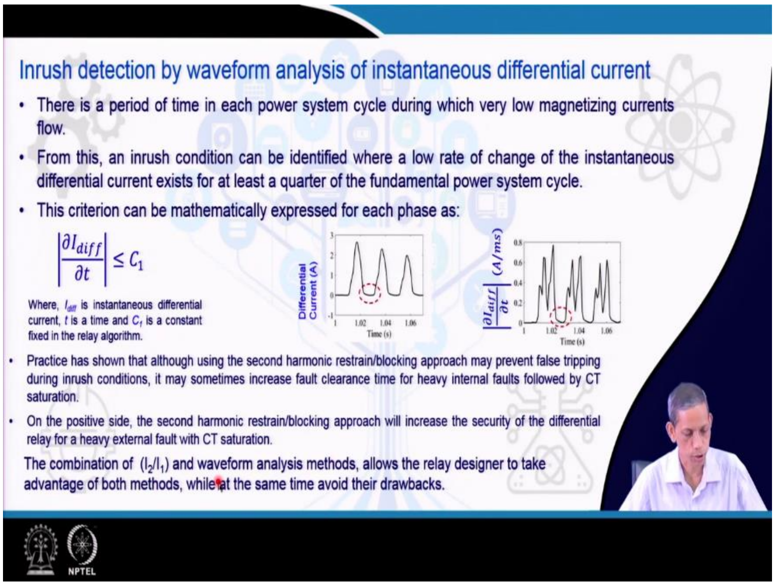


There is another scheme, so old method in numerically concept and so, inrush detection by waveform Analysis also. So, we know the corresponding nature of the corresponding wave is like this and already mentioned from the beginning that it passes through, some of the phases where the corresponding curve is substantially small. Now, if we take the derivative of this differential current, then the derivative becomes here and that becomes substantially low. So, in logic, either derivative or so, different principles are being available in different numerical relays. So, these, magnitude of these differential current the derivative of the differential current becomes smaller than the threshold, then we know that at some phases, inrush can be detected from that way also.

Therefore, these sequences appear some period of time in the system. This goes through small value and that can be detected by this principle of operation. So it is being observed that the principle, which you talk about in terms of the second harmonic restraint or blocking scheme and all these things, they need to, delayed process in the decision making for the event for the internal fault case and all these things. But the wave nature, which we will talk about from this wave form analysis by this approach keeps a faster operation. So, many reason also combine these 2 perspectives to exploit the advantage of speed in operation and some relays qualify for adaptive form of protection also.

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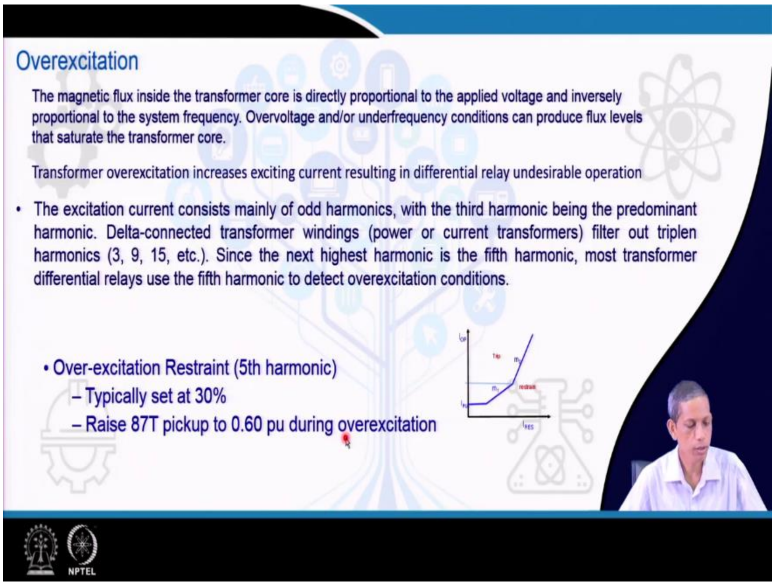


There is another issue which leads to a maloperation of the differential relay is the overexcitation is under happens to be the magnetic flux inside the transformer core is directly proportional to the voltage  and the voltage becomes higher, then sometimes it might be higher voltage. The high voltage leads to the corresponding flux requirement becomes more and to having the large amount of flux, the associated magnetizing current becomes much more at that time also, the current becomes substantially higher.

So, that current becomes, that flows in one side only, where the corresponding magnetizing current happens to be there and that leads to the differential current to be significant and mainly to that malfunction of the differential relay. Now, this excitation current consists of mainly odd harmonics and so, but as only known in the filtering process for the differential current odd harmonics are symmetrical to the zero sequence. So, they will be, they will not be available in the differential current.

Therefore, it is found that fifth harmonic component is a suitable size for detection of the overexcitation condition in general. Typical setting value is a 30 % of the fundamental of the, for this perspective and one, other option is the, some of the relay used, that the whenever they detect the corresponding fifth harmonic component, they take the corresponding, the pickup setting to be raised to higher value like these to as high as 0.6 pu to avoid unnecessary tripping by overexcitation situation and so.

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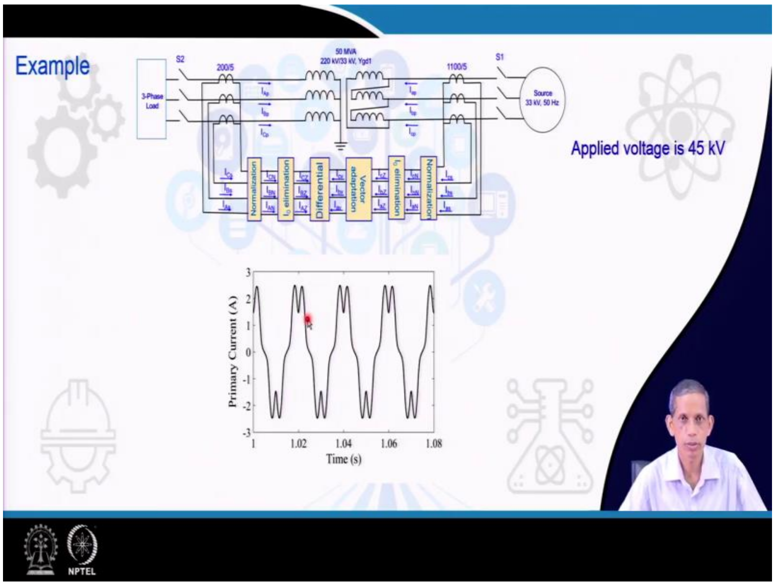


So, for example, in these, the 33: 20 kV systems, we apply 45 kV equals to these 33 kV side systems and the corresponding signal nature becomes this, which is having highly third harmonic component, also fifth harmonic component, but as already mentioned, the third harmonic component will be eliminated by the zero sequence component eliminations. So, the differential current will be availing only only significant amount of fifth harmonic component.

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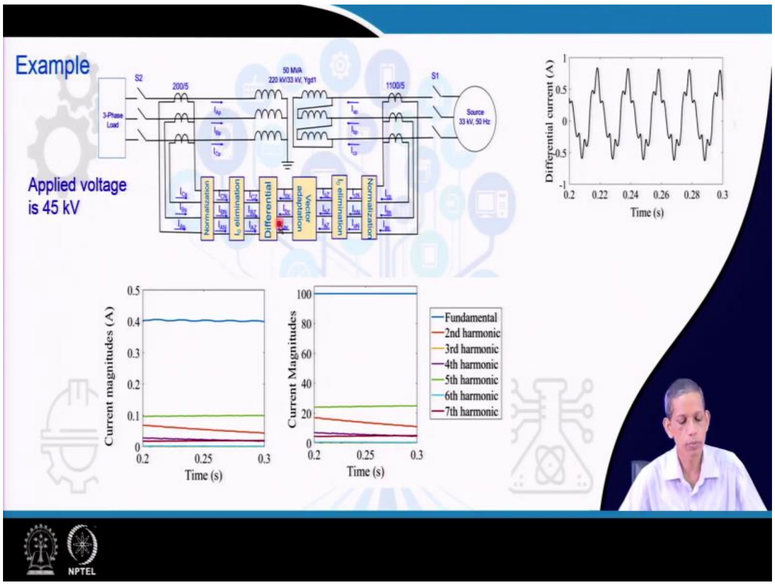


Then, when you analyse, the corresponding current magnitudes of different harmonic components and in terms of the percentage of the fundamental also, then decide that corresponding the fifth harmonic component, the green one, each of very high value and which will make the corresponding, the blocking arrangement for the differential relay operations.

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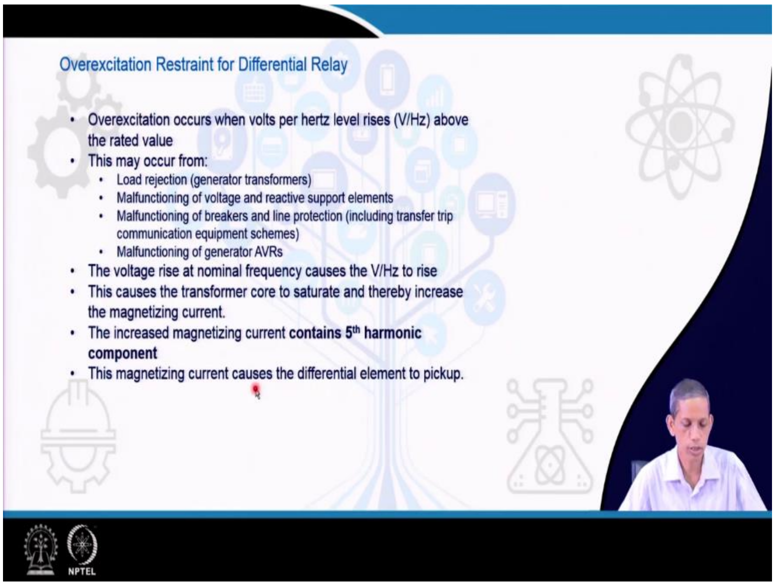


One thing we see, that the Overexcitation restraint for differential relay, the operation of course, when the volts per hertz of the rated value, this may occur from their load rejection, malfunctioning of voltage and reactive power support, the voltage high situation. This increment of flux in the core that leads to the large amount of current in the magnetizing part.

Then you can see that the malfunctioning of AVR and all issues, that may lead to such situation and so on. The voltage rise at nominal frequency causes the V by hertz to rise, and this causes the transformer core to saturate, and which contains large amount of fifth harmonic that leads to the differential relay to malfunction in terms of that.

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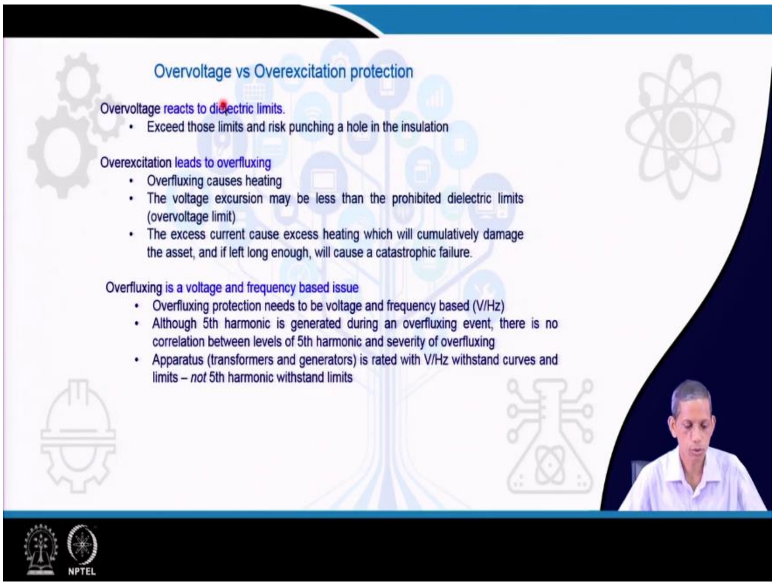

So now, to distinguish, Overvoltage versus Overexcitation Protection and note, I am saying that we need not confuse about this perspective. This is a differential relay protections we are talking about. differential relay protection should operate only when an internal fault happens to be the transformer and that case is neither the inrush situation or the corresponding overexcitation situation.

So, allow the differential relay to operate. Overvoltage leads to stress in the dielectrics and leads to thermal heating and so and that is a slow process, is not that fast, we are talking about in terms of that. Overexcitation also leads to overfluxing and that also leads to heating of the transformer and those should be taken care in terms of their individual overvoltage protection in addition, overexcitation protection should be there.

Overexcitation leads to overfluxing and overfluxing can only where the fifth harmonic, rather it will be much better way of capturing by these volt power hertz issue and the volt per hertz withstand curves are there to take care of the overfluxing aspect, which is why they are from the overexcitation is when. So, this is, the other schemes available for the transformer protection perspective, but what we are discussing here is on differential relay perspective, which should not focus on due to inrush or overexcitation situation.

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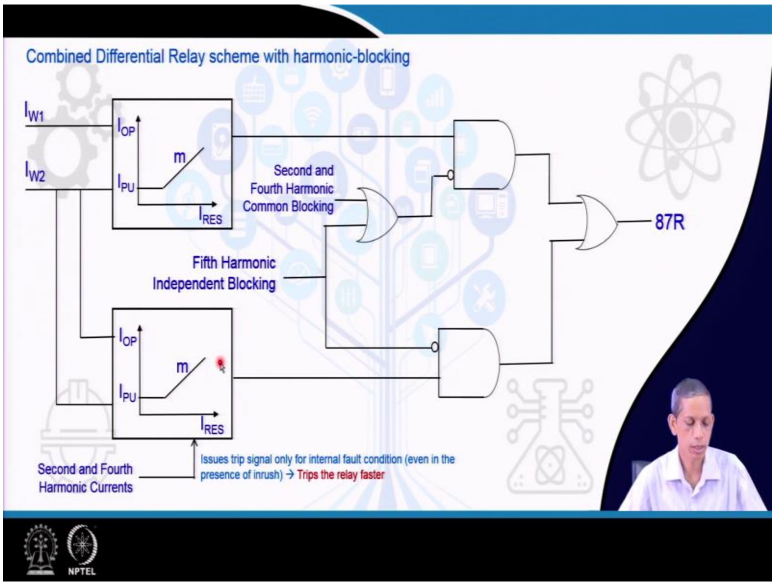


So, in overall, if you combine all the harmonic blocking and all these schemes, so this is the percentage biased differential relay that takes the current from the 2 windings for each phase. Also, that case here, so here, the corresponding decision process to be to this one, it takes second harmonica, fourth harmonic, common blocking schemes also independently, fifth harmonic blocking or operation and then the operation of this one. There is another scheme, which we had already talked about, that is restraining case, you can add the second and fourth harmonic and then we go for the trip decision, but independently also fifth harmonic blocking will be there. Both, run in parallel, and it makes an odd operation to go for this expression.

Now, the benefit of these, including this kind of integrated scheme is there in case of internal fault and then we are energizing, this keeps a faster speed decision or the transformer differential scheme and so. So, that is why some relays use in parallel both the perspective, as already mentioned in earlier also.

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So, in general, we see here, inrush creates problems and this current flows in one of the winding. So differential relay malfunction in that situation, to avoid that, we have different methods, particularly on the harmonic content based approach and also wave detection approach and so and that high power it is being observed today that with a newer version of core and all these things, the second harmonic components may not be significant and so lower and lower. So, that puts challenges to the harmony wave restrains approach for inrush situation. So therefore, manufacturers are developing new mechanism to overcome this issue. Overexcitation is another issue when the differential current becomes also significant. That is being detected where the fifth harmonic component compared to the fundamental and there gives a good solution to overcome the issue on unnecessary tripping by differential relay. Thank you.