Electrical Machines

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Lecture # 12

Three Phase Transformers - I

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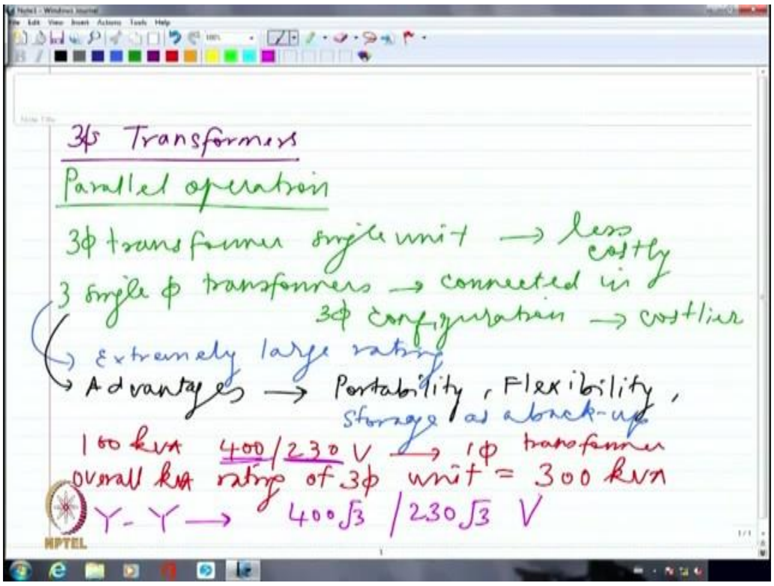

They can be connected in star or delta that is the single unit of three phase transformer or as a three phase transformer single unit. This will actually save on the cost, so less costly. Whereas if I look at three single phase Transformers connected ultimately as the three-phase transformer. So this will be connected in three phase configuration. This will be generally more costly or costlier. That is because you are essentially looking at individual unit separately being bought and connected as per your requirement.

You have more flexibility clearly. So, because of which you may not be able to save on the core cost or the stamping cost or even the winding cost in all probability. So, this is generally used whenever I am going to have extremely large rating when I have very large rating and I want to kind of retain the flexibility to you know connected in either star or Delta configuration.

So, when I look at the single-phase transformer being connected as the three phase transformer unit the major advantage as I told you One is flexibility, second is the portability is better because if I have three phase units together it will be extremely bulky imagine a 400 MVA Transformer. It is going to have each of them is going to have about 150 MVA rating each single phase is going to have 150 MVA rating.

Obviously transporting a 150 MVA transformer will be simpler as compared to transporting one single 400 MVA transformer. So definitely we are essentially retaining so advantage if I try to write it. I should say advantages of this configuration are portability, flexibility and one more thing I might mention is let us say I have three single phase transformers when I want to store some backup in the inventory.

If something goes wrong, I would like to replace maybe one of the single base units by a good unit. So, in that case I can simply say only a single-phase unit I do not have to save a complete three phase unit. To save a complete three phase unit it will be definitely more expensive. But on the other hand, if I actually store even couple of single-phase units it will be less expensive and I would be able to replace you know whatever is the phase that has conked out I can replace that by one particular single phase unit.

So, obviously inventory when I try to store as a backup so storage as a backup. That is also simpler when I am looking at single phase units. So generally, in many of the power stations you would see that single-phase units are connected as three phase transformer banks ultimately. So, if I talk about let us say a 100kVA single phase transformer maybe 400 divided by 230 V maybe just time arbitrarily taking.

So, this is a single-phase transformer, then if I am connecting all these three in three phase configurations. I am going to have overall KVA rating of the three-phase unit will be or three phase banks will be 300kVA. Because three times whatever is the single-phase unit directly you can multiply because each of them will be able to handle a kVA corresponding to the single phase KVA rating. So, I can multiply that by three and then say that is what is my three phase.

And if I am connecting for example this in star star configuration for example, so I am going to have again for the star-star three phase transformer. The kVA rating will be 300 no doubt 300 kVA, but if I look at the voltage rating 400 whatever we are mentioning is per phase. Similarly, 230 watt we are mentioning is per phase. So, when I am looking at a star connected transformer it becomes per phase multiplied by $\sqrt{3}$ because we always mention it in line voltage configuration not in phase.

So, I will have to call this configuration have $\frac{400\sqrt{3}}{230\sqrt{3}}$, so the primary line voltage becomes $400\sqrt{3}$ and the secondary line voltage becomes $230\sqrt{3}$. So correspondingly I would be able to calculate the current as well. So when I calculate the current I can take what is the overall

$\frac{kVA}{\sqrt{3}V_L}$, where the v_L is the line voltage or if it is a star I know for sure I can definitely calculate what is the single phase current also that will go as the three phase line current as well.

If it is delta of course I have to multiply the per phase current by root three, right. So, I should be able to easily calculate the three phase units rating in terms of voltages and currents based on in what connection I am making it.

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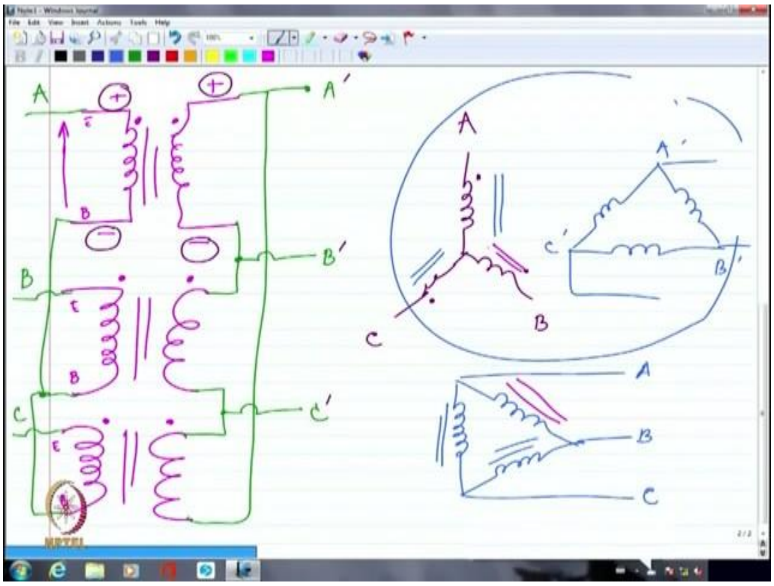

So, let us say I have one single phase unit something like this. So, this is one single phase unit I am showing, right and I am assuming that I am actually looking at the voltage rise in this particular direction, so I am going to mention this as dot, generally the dot indicates the polarity of one winding visa-viz the other winding. So, the other winding if I show again a dot here that means if I call this as positive with respect to this, this will also be positive with respect to this.

So, when I have 2 mutually coupled coils, I would show the dot probably one winding as well as the other to specify that the polarities of both these windings are the same at that particular instant. Please remember what we are applying is an alternating voltage, so as a rule I can't have the top terminal to be positive and bottom terminal to be negative all the time that will not happen because it is alternating voltage.

So, I am going to have clearly the positive and negative alternating, but I am talking about one particular instant maybe let me call as the positive half cycle, during positive half cycle of the alternating voltage and essentially looking at this being positive. So, this is being positive, and this is being negative at the same time this is going to be positive and this is going to be negative, so let me draw the second phase also.

So, I am going to how the second phase here like this. And the third base here like this, right. All three of them I expect them to be identical when I want to connect three single phase transformers as a three-phase transformer unit which is balanced in nature. Clearly, we do not introduce unbalanced delivery. We will not. We will try to make it only balanced, so all the three transformers have to be balanced.

Now, if I want to connect them in delta, I have to make sure if I say that this is the beginning of one winding, this is the end of that winding. Again similarly, this is the beginning this is the end and this is going to be the beginning and this is going to be the end, right. If I want to connect them in star all beginning, I have to be connected together or all end ends have to be connected together one of them have to be connected together and the other end will come out. So that the beginnings connected together will make the star point or neutral point or the ends connected together will make the star to point or neutral point.

Only thing I have to make sure this that if this is dot, this is also dot then only I can mark them at the beginning and end. Clearly, I am looking at all of them rather tested for their polarity ultimately. So, if I call this as star with the dot. Similarly, this is also a dot. I am going to connect them in star in which case I have to connect this beginning to this beginning, and this is connected to this beginning, right.

Now, I will just bring out this terminal, this is the other terminal, this is the third terminal so I am going to call this as this will be connected to A phase voltage, this will be connected to B phase voltage, this will be connected to C phase voltage, right. This is all to be connected. Now on the secondary site, for some reason if I want to connect it in delta-delta connection always connects beginning to the end, beginning to the end and so on they are all connected in series addition basically.

So, I am going to connect actually this and this together, this and this together. Similarly, this and this together. Now I am going to take out one terminal from here. Second terminal from here, and third terminal from here. So, I may call these as A, B, C so I have essentially connected the secondary in delta. So, I can mention this a little differently or much more easily as though I have connected these things like this and I am calling basically this as the star point, this as the star point and this also is the start point. So, this is A, this is B, and this is c let me call this as A^1, B^1, C^1.

So in the secondary side I can simply connect again somewhat like this, and then I may write this that A^1, this as B^1 and this as C^1 and what is actually coupled with which winding, which winding is coupled with which winding that can be a little confusing especially when we draw a configuration somewhat like this.

This will definitely confuse the hell out of us as to which winding is coupled with which winding. So that is the reason sometimes we may draw if the primary is drawn like this, we may draw the secondary somewhat like this. This is one secondary, this may be the other secondary, this may be the third secondary please look at the orientation this is inductive orientation. So, if I make all this as this, then this is actually coupled to that I can look at exactly. Similarly, if I am looking at this as one of the other primary, this is the other primary which is coupled to this. Similarly, if I am looking at this as the third primary so this is the third primary which is coupled to that.

So generally, orientation in many books they show the orientation exactly similar in the primary as well as secondary to show which is actually coupled to which one ok. So now I can again mention one as A, one as B and one as C. So, whatever is this one let me probably call this this doesn't matter, but one thing you guys have to understand is that the transformation ratio is always between phase voltages and phase currents, generally you never take the line voltages into consideration for getting the transformation ratio.

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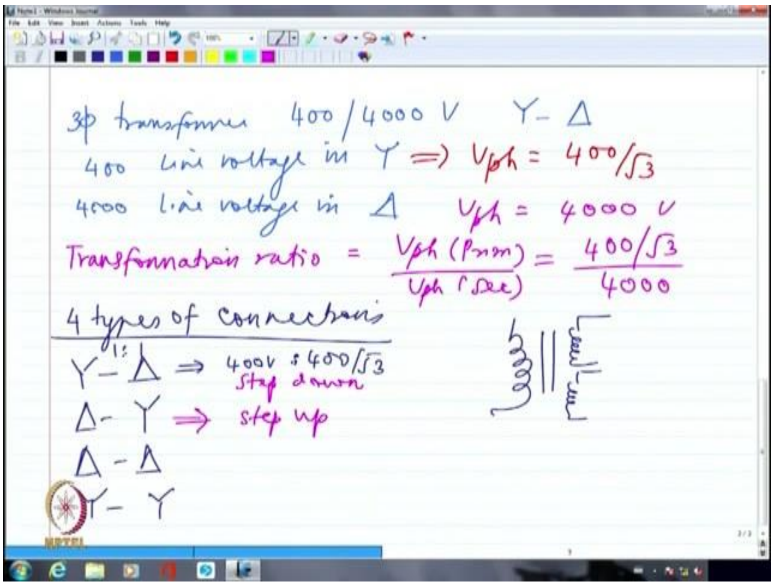

What I mean is, If I am actually writing you know for a three-phase transform maybe I just mentioned it is a three phase transformer which is having $\frac{400}{4000}$ you know V ok but it is connected in star-delta let us say this is what has given, right. So, what is given as the voltages is 400 is the line voltage in Star. Similarly, 4000 is the line voltage in Delta, so if I try to look at what is the phase voltage. Phase voltage will be $\frac{400}{\sqrt{3}}$ whereas in this case phase voltage will be 4000 V itself.

So, if I try to calculate the transformation ratio for this transformer, I have to take actually V phase of primary divided by the V phase of secondary or vice versa, V phase of secondary divided by V phase of primary it doesn't matter. So, I have to take this as $\frac{400/\sqrt{3}}{4000}$. Even though I write the voltages in terms of line voltages, when I calculate the transformation ratio I will always take per phase unless I take per phase.

It is not connected in current. So, we generally look at the per phase voltage ratios normally, we never look at the line voltages all though specifications will always or nameplate details on the machine will always give the line voltages and line currents and three phase KVA rating. It will not talk about single phase kVA rating.

So ultimately, when we draw the equivalent circuit for a three-phase transformer, we would always like to convert the whole thing into single phase equivalent, we look at single phase equivalent and then we will try to draw the equivalent circuit clearly in terms of single-phase configuration. So even though you may be given 400 V star connected primary, you would like to treat that voltage as $\frac{400}{\sqrt{3}}$ and if per phase impedance is given as some Z. You will always say $\frac{400/\sqrt{3}}{Z}$ that is what is that current.

So, you will always convert everything into per phase quantity and draw the equivalent circuit. So even if you are given a secondary winding in delta you would again like to convert everything into per phase quantity and that is how you will draw the overall equivalent circuit of the transformer and when we are converting delta into per phase. It is probably easier to convert that into star and then do it in per phase most of the time that is easier.

So, you might like to do some star Delta transformation before we really get into the per phase equivalent circuit of the transformer when the three-phase transformer is given in some kind of delta configuration somewhere, right okay. So, so much so for three phase transformers so I can have essentially four types of connections in the transformer.

I would be able to get star delta or Delta star or Delta-Delta or star-star. So, these are the four configurations normally we can have in the three-phase transformer connection and I am showing this only by having primary and secondary. Sometimes there can be one more winding in the transformer which is no one asked tertiary, tertiary winding is the third winding sometimes you may have in a transformer in especially power station transformers. We tend to have a tertiary winding mainly to supply the power station auxiliaries.

For example in a power station you may have some protection systems, you may have water pumping motor water which is pumping the water into the boiler. You may have coal handling plant which will have n number of drives maybe in pulverizing the coal, transporting the coal through the conveyor belt and so on and so forth, all of them need to be energized, all of them need power so that power might come from the tertiary winding of your generator or power transformer itself.

So sometimes we will have a third winding which is known as tertiary winding in a transformer to make sure that it is able to provide the power for many of the power station auxiliaries. In which case I have to show if it is a single-phase transformer, I may have a core like this, one is secondary, the other one maybe tertiary. This is like a three-winding transformer. So, I am having primary, secondary and tertiary.

The tertiary might help in supplying the auxiliaries in the power station, sometimes if you look at some of your power supplies in the computer SMPS switch remote power supply they may have small miniaturized transformer with multiple secondaries. It may not be just two secondaries. It can be more than two secondaries. In which case you may require a + 5 V for some of the IC’s within your computer, you may require 3.3 V for some of the IC’s in your computer, you may require +15 and -15 for some of the analog electronic circuits. So, this secondary or these multiple secondaries might provide you know 5 V, 3.3 V, +15 volts, -15 volts and so on and so forth.

So, I may have multiple secondaries and all these multiple secondaries will be isolated from each other. They do not have a common ground. That is a major advantage that we see when we use the transformer for providing different power supplies to different components in your laptop or in your computer system. So, if we are looking at star Delta, even if we are having 1 is to 1 transformation ratio that is phase voltage of star with respect to phase voltage of delta. If we are having 1 is to 1 as the number of turns in the primary and secondary. Still what we get here is if we say that this is probably 400 V, if it is 1 is to 1, I should have gotten 400 itself of secondary, but I am looking at phase to phase transformation. So, $\frac{400}{\sqrt{3}}$ will what will appear as the line voltage in delta side.

So, I am going to have 400 V: $\frac{400}{\sqrt{3}}$ this is what I am going to get, so this is actually going to make automatic step down whether I like it or not, star-delta configuration generally steps down the voltage on the delta side as compared to the star side. Even if it is 1:1 transformation ratio because it is phase to phase transformation ratio and we are looking at delta being rather it is having the line voltage and phase voltages as equal to each other.

So, you are essentially going to have this as a step-down configuration, whereas very clearly this will be an automatic step up configuration. So, what I get as the line voltage will be way too higher as compared to what I am going to get as the line voltage on the primary side, even if the transformation ratio is 1:1, right. And one more major point we have to mention about Star delta and delta star is that.

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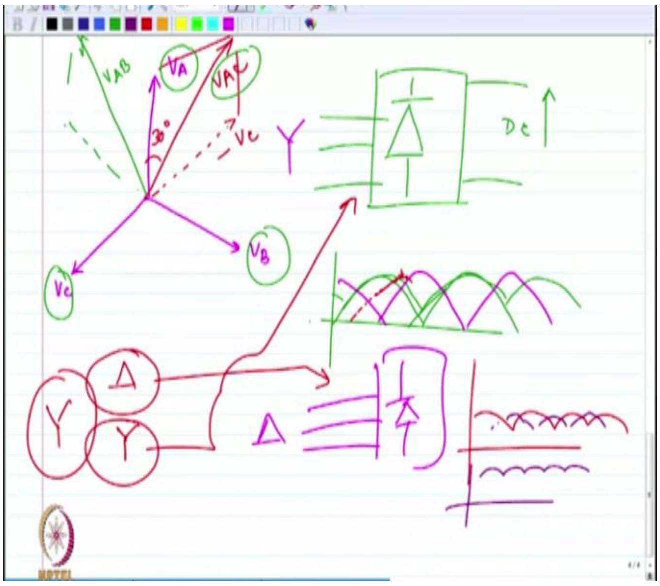

If let us say I have as far as star is concerned this is V_A, this is V_B and this is V_C let us say I have three phase voltages like this, right. If I want to look at the line to line voltage for example if I take C on the other side this becomes minus V_C. So, this is going to be V_{AC} so the line voltages are 30^0 shifted from the phase voltages right. So, we are going to have essentially a 30^0 phase shift between the phase voltages and line voltages.

But what I am applying actually is a line voltage I hope you understand because we bring generally only three terminals out of a transformer whether it is star connected or delta connected it hardly matters, most of the time only three terminals come out. These three terminals are going to actually be connected to the three terminals which are coming out of your power supply. The three-phase power supply. So, what you are applying looks as though it is line to line voltage, but what happens between the primary winding and secondary winding is phase to phase transformation.

So what I apply as the line voltage which is actually here is converted into transformed phase voltage as far as delta is concerned. If I am having primary as star what I am applying is line to line voltage and what I look at the as line to line voltage finally in the delta side will be similar to the phase voltage. So not only the voltage is step-down but it is also shifted from the original line voltage by 30 degrees. So, star delta or delta star configurations will always give me 30^0 phase shift between one side and the other I can say 30^0 lead or 30^0 lag depending upon what kind of line voltages I am looking at.

For example V_{AC} giving me 30^0 lag come back to VA, whereas if I am looking at V_{AB} right this is V_{AB}, V_{AB} I have to draw somewhere here. This is what is V_{AB}, whereas V_{AB} will have 30^0 lead so I can in general say 30^0 phase shift comes out between the primary line voltage and the secondary line voltage whenever I have either star delta or delta star configuration.

But if I have a star delta configuration even for 1:1 transformation ratio I am going to see that the line voltages are stepped down by a factor of $\sqrt{3}$, whereas in Delta star configuration the line to line voltages are stepped up. So, I can say that these two configurations have a whole lot of significance then I am actually employing them in different applications.

For example, if let us say I have a rectifier I am going to show a rectifier just with the help of a block V_B this is my rectifier and I am applying a three-phase voltage and what I am getting here is DC. So, when I am actually looking at a rectifier output, I may have A phase, B phase and C phase rectified completely right. So, if it is a half wave rectifier, I may get only some voltage like this, right. It should actually overlap because it is 120^0 only shifted from each other.

So, I am going to have maybe a voltage like this, voltage like this and voltage like this. This is half wave rectified, but it is full wave rectified I have to again draw on the top of this also one more voltage right. So, I am going to have some voltage like this right. This is how it is going to be. So, I have full wave rectified voltage as well as half wave rectified voltage possible with three phase. But, if I am having one more three phase rectifier with another 30^0

phase shift so maybe this is fed by star, this is fed by delta. The primary probably is the same, the primary can be in star or delta doesn't matter.

But on the secondary side maybe I have one of them to be star, second one to be delta, then they will have 30^0 phase shift. So, if I say that this wave form is like this for the next transformer it will be actually 30^0 shifted. If I am having actually two rectifiers cascaded, may be connected in series or whatever, one of the rectifier is being fed by a star winding and the other one is fed by a delta winding, what I am asking you to imagine is let us say the primary is a star, in the secondary I have one star and one delta.

So, I am connecting this delta here and I am connecting this star here. So, what will happen? They will have voltages which are 30^0 shifted from each other, of course I have to take care of the turn's ratio. If I don't take care of turn's ratio one voltage will be $\frac{1}{\sqrt{3}}$ the other voltage. That is not right.

I do not want to have different voltages, I want to have the same voltages, but they are 30^0 shifted from each other. So, which means I am going to have actually a wave form which will have much less variations. So originally maybe my wave form was like this. Now what will happen is in between the two also I will get another portion of sinusoids like this.

So overall voltage will look as though it is having very little variation. It is going to have really really little variation because of the fact that I am adding up two wave forms which are alternating no doubt which are rectified, but they are phase shifted from each other by 30^0. So, delta star and star delta transformers have plenty of applications like this because of the fact that they inherently introduce 30^0 phase shift. That actually reduces the repel or the variations in the DC voltage by actually getting two phase shifted wave forms which are away from each other by 30^0, right.

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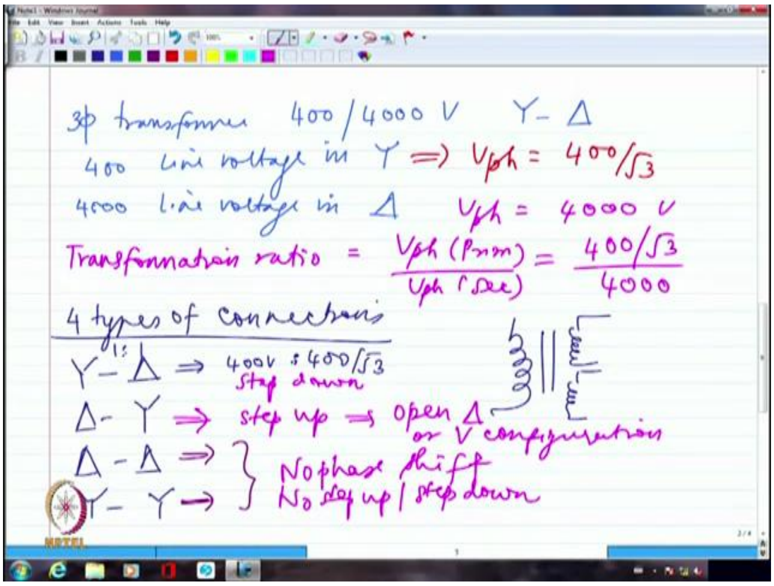

So, if we go back to our original configuration of delta-delta and star-star. These two will neither have step up, nor have stepped down inherently because they will translate exactly whatever voltage you are applying from the primary side into the secondary side. So, you are going to have essentially you know no phase shift at all in this particular case.

And you are also going to have basically you know if I look at line voltages as well as phase voltages, they will look exactly the same. There is no problem at all, no phase shift, no step up or step down, both are true in this case. In delta-delta configuration normally major advantage. I am just trying to compare different configurations. That is all I am trying to do. Delta and delta configuration. One major advantage we have is we can actually if one of the single-phase transformers conked out. We will be still able to operate it as an open delta or V configuration in case of one of the transformer failing.

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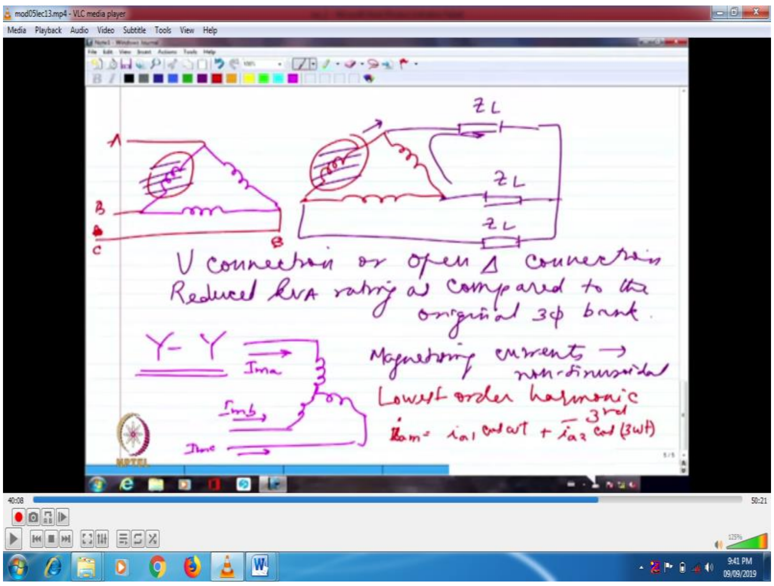

What I mean is let us say I have a three-phase transformer here in delta like this. Maybe this is my primary and this has been my secondary, right and let us say one of these configurations. Maybe this has conked out for some reason, one phase has conked out maybe that transformer has been having some fault. In which case what I can do is, I can apply the same ABC here. And I can sorry ABC here and I can eliminate this particular winding, so I can eliminate this winding. And similarly, I would be able to connect the load here. I can eliminate this winding completely.

Similarly, I can eliminate this winding completely, and I would be able to connect the load may be connected in star or delta here basically. Before these are the loads. Please note that it is a star connected load that I have shown and Z_L is the impedance per phase, So when I illuminate one of the windings still the transformer will be able to deliver a fairly good amount of KVA rating which should be close to two-thirds of the original value of KVA, but it will not be exactly two-third, it would be slightly less than that because originally what you were looking at was the phase voltage and phase current between those two whatever was the displacement that was coming as the power factor angle α or φ.

Whereas now it is line voltage, please note that this is not really contributing any current this is absent so what is the current flowing is only this current and that is essentially the phase current which is manifesting itself as the line current. So, what I have is line voltage and phase current or phase voltage and line current here I can say if it is delta and star.

So, I am going to have phase voltage and line current which will give me a phase shift of $30+\varphi$ or $30-\varphi$ like 2 watt meter method, what we did in the case of 2 watt meter method, it will become very similar to that. Because of which the power factor angle is kind of modified in this open delta connection. I am not planning to go into great detail about open delta connection.

All I want you to understand is if it is Delta-Delta configuration although there is no phase shift, although that is no step up or step down. The major advantage one single advantage of Delta-Delta configuration is even if one of the Transformers conked out I should be able to operate it at a reduced KVA rating because it can functionally work properly as a three phase transformer. You know despite one of the Transformers being opened, so we call this open delta or V connection because this is like a V. So, we call this as V connection or open delta connection. So, this can work at reduced KVA rating as compared to the original three phase, The last one which we have still not discussed is the star-star case. As far as star-star is concerned it is a gain no step up, or step down, no phase shift. But this is one of the rarest configurations that are used anywhere, unless I ground the neutral. If the neutral is not grounded, it is not a really a popular configuration that is being used. Let us see why, why Star-Star configuration without neutral grounding cannot be used very easy? What is the problem with this? Let us try to take a look.

So, if I am having let us say a star-star transformer I am looking at mainly the primary, let us say secondary is open. I am not really looking at it right now because it is open circuit. So, I am looking at no load condition, under no load condition of this particular transformer. This will definitely draw magnetizing current.

Each of these phases are going to draw magnetizing current so let me call this as I_{ma} may be I_{mb} may be I_{mc}. So, these are the three phase magnetizing currents that are being drawn. This is open circuit condition. So, I am not even talking about load. Load current is not present. And we saw that because of the property of iron which is the core of the transformer the magnetizing currents are not sinusoidal. They are non-sinusoidal because hysteresis is there, saturation is there.

So, I am going to have definitely non-sinusoidal currents, so I would say that first of all we should recognize the fact that magnetizing currents are non-sinusoidal, if they are non-sinusoidal generally we actually expand any non-sinusoidal periodic waveform by something called Fourier expansion. So, the Fourier expansion will allow mathematically a non-sinusoidal order periodic waveform to be decomposed into some fundamental which is corresponding to 50 Hz. In this case then maybe 2 times the fundamental, 3 times the fundamental, 4 times the fundamental and so on.

So, you will have multiple harmonic components. We call these as harmonic components which is second harmonic, third harmonic, fourth harmonic, fifth harmonic and so on and so forth. So, we are going to have this non-sinusoidal magnetizing waveform being decomposed into 50 Hz, 100 Hz, 150 Hz and so on and as the harmonic increases the number increases. That is if you to go to 5^{th}, 7^{th}, 9^{th} and so on all of them are going to be smaller and smaller as compared to whatever was your fundamental because your primary thing the wave form that you have generated itself is corresponding to 50 Hz.

So, as you go to higher and the higher order harmonics generally it will be decreased or diminishing proportionately. So, if I am looking like at this waveform it will definitely have the dominant component as 50 Hz, next to that it should have been 100 Hz, but 100 Hz essentially is something similar to DC on an average basis it will be 0. So, any even harmonic is very similar to 0^{th} harmonic which is DC. If the average value is 0 or the waveform has above the time axis and below the time axis if it has the same half wave symmetry then you are going to have all the even harmonics being absent, so you will not have fourth harmonic, second harmonic, sixth harmonic, eighth harmonic all of them are absent because of half wave symmetry. DC is also absent because average value is 0 in an alternating current waveform.

So, what we have as the lowest order harmonic is third harmonic. So lowest order harmonic is actually corresponding to third, whereas fundamental of course is very much present. So, if I try to write i_{am}, I should write that actually as rather I should write this a small i_{am} because instantaneous current magnitude, I should say ia1 maybe cos or sin omega t plus ia3 cos or sin omega t, but that is 3 omega t. This will be i_{am}. I am neglecting the fifth, seventh, ninth, eleventh and so on and so forth. I am neglecting all of them. I am looking at only the fundamental and third harmonic.

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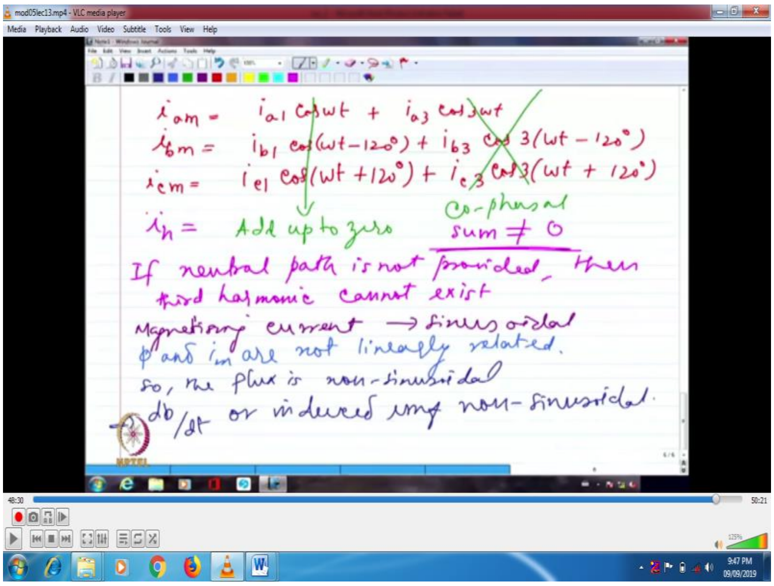

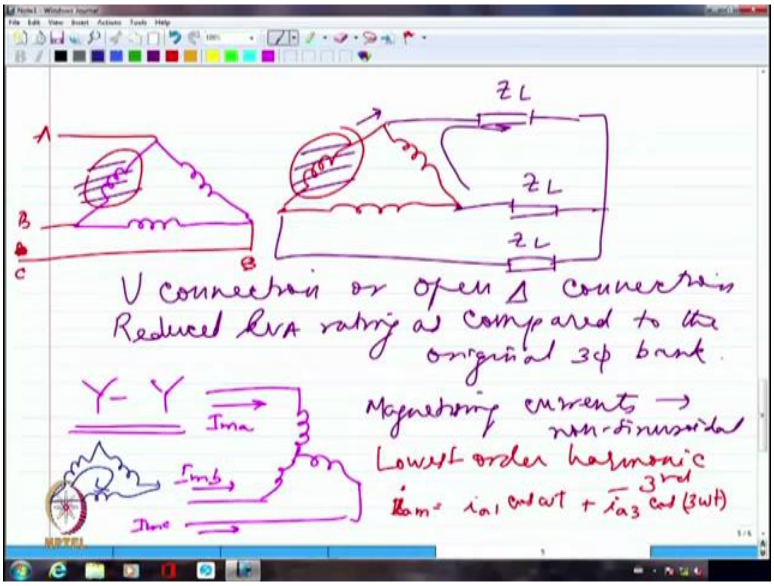

Similarly, if I look at i_{bm}. So let me write i_{am} here which is actually $i_{am} = i_{a1}\cos\omega t + i_{a3}\cos 3\omega t$. Similarly, i_{bm} will be $i_{b1}\cos(\omega t - 120^0)$ because it is 3-phase. Similarly, this will have $i_{b3}\cos 3(\omega t - 120^0)$. And similarly, i_{cm} will be $_{c1}\cos(\omega t + 120^0) + i_{c3}\cos 3(\omega t + 120^0)$.

Now, when I look at the star connected system, I have I_{ma} I_{mb} and I_{mc} and the neutral is not connected. So, $I_{ma}+I_{mb}+I_{mc}=0$. I am perfectly fine if $I_{ma}+I_{mb}+I_{mc}\neq 0$ I have to provide a path and to provide a path for the current. I have to connect neutral to ground or somewhere if I do not be neutral I will not be able to allow the third harmonic to exist.

Let me look at it here if I actually look at what is, see we are essentially looking at the oscillation of the current at three times the frequency. The phase shifts will be, phase shifts will be maintained exactly as it was being maintained originally in the waveform that is how it will be, if you actually try to decompose into Fourier expansion the way you get actually these components will be whatever is the original phase shift that will be preserved with a factor of N. Where N is the harmonic order that is how it is normally.

So, because of which you are going to have all these three as co-phasal because 360^0 is actually you know you are not going to have any phase shift at all, so if you look at the third harmonic for A phase, third harmonic for B phase, third harmonic for C phase. You are going to have $\cos 3\omega t, \cos 3(\omega t - 360^0), \cos 3(\omega t + 360^0)$ which are co-phasal and if they are co-phasal then they will not add up to 0.

It is not going to add up to 0, whereas these add up to 0, these add up to 0. Whereas because they are, they are co-phasal, the sum is not equal to 0. So, what is going to happen is if I am having a star-star connected transformer, neither the primary is grounded, nor the secondary is grounded, in which case especially when I am initially energizing the transformer, I just turn on the power supply I have not connected the load.

At that point the primarily drawn current is magnetized current, core loss component of current is definitely there I am not questioning that, but there is mainly the magnetizing current, that magnetizing current is going to always have harmonic components and especially third harmonic is not going to find the path for itself to flow.

Because if I try to look at the neutral current, the neutral current will have a non-zero third harmonic component and there is no path for the neutral currents, so where will the currents flow? It cannot flow anywhere, if the current cannot flow anywhere it has to cease to exist, it has to kill itself there is no other way.

So, the current has to be primarily sinusoidal, it may have fifth harmonic, seventh harmonic but those are minuscule as compared to third harmonic. So, the third harmonic current cannot exist in a magnetizing current of the transformer which does not have its neutral grounded, if the neutral is not grounded especially in a Star-Star configuration, I am not going to be able to find the third harmonic component in the magnetizing current.

If third harmonic component is not there in the magnetizing current, it has to be fairly sinusoidal. If the magnetizing current is sinusoidal then the flux cannot be sinusoidal because they are not linearly related. The hysteresis loop tells me, the magnetization characteristics tells me that I can't have linear relationship between magnetizing current and flux, the flux cannot be sinusoidal.

So, I would say if neutral path is not provided, then third harmonic is 0 or third harmonic cannot exist. If third harmonic cannot exist. I am going to have magnetizing current becomes sinusoidal or co-sinusoidal it doesn't matter. If magnetizing current is sinusoidal, I can say flux and i_m are not linearly related. So, the flux is non-sinusoidal. I don't know what wave shape it will take, but I can say is definitely it is non-sinusoidal. If flux is non-sinusoidal induced emf will be non-sinusoidal because it is after all defined by $\frac{d\phi}{dt}$.

So, I am going to have $\frac{d\phi}{dt}$ or induced emf will be non-sinusoidal. So, what is happening now is in a transformer we said $V = E$, where V is the applied voltage, E is the induced emf. That is completely lost. Are you getting my point I am applying sinusoidal voltage. It is supposed to draw a non-sinusoidal magnetizing current, but it is forced to draw sinusoidal magnetizing current.

Because it is forced to draw a sinusoidal magnetizing current, I am going to have non-sinusoidal flux and that non-sinusoidal flux is going to induce a non-sinusoidal emf that non-sinusoidal emf and sinusoidal voltage that I am applying cannot really balance each other. That is going to be voltage difference between the induced emf and the applied voltage in a transformer which is Star-Star connected whose neutral point is not grounded and currently it is on no load condition.

And this will cause huge amount of oscillations or very large currents to be drawn in spurts because of which the transformer can malfunction. So, I would not like to normally use the star connected transformer, star-star connected transformer without the neutral being grounded unless I provide some path for the third harmonic current. If I want to provide the path without connecting the neutral. I might like to have a tertiary winding in delta. It can very happily have a circulating current.

If I have a secondary winding or a tertiary winding in delta, secondly winding already I said is star, star-star so I can have a tertiary winding in delta. So, sometimes the tertiary winding serves this purpose in a transformer. If it is a three-phase transformer star-star connected without neutral grounding, there can be a tertiary winding connected in delta which can simply circulate the third harmonic current. The third harmonic current being co-phasal I_{a3}, I_{b3} and I_{c3} are exactly of same magnitude, exactly in phase with each other.

So, it would be able to simply circulate itself through a delta, so I don’t have to use tertiary for anything just for circulating the third harmonic current which will restore the balance.