Flexible AC Transmission Systems (FACTS) Devices
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Lecture – 29
Voltage and Phase Angle Regulator Device-1

Welcome to our video lecture series of FACTS devices. We are continued to discuss about the Voltage in the Phase Angle Regulator Devices. We have seen how it will control and principle of operation in previous class. Now, we shall see that hardware implementation of this voltage and the phase angle regulator.

Now, we shall discussed mostly the two type of devices.

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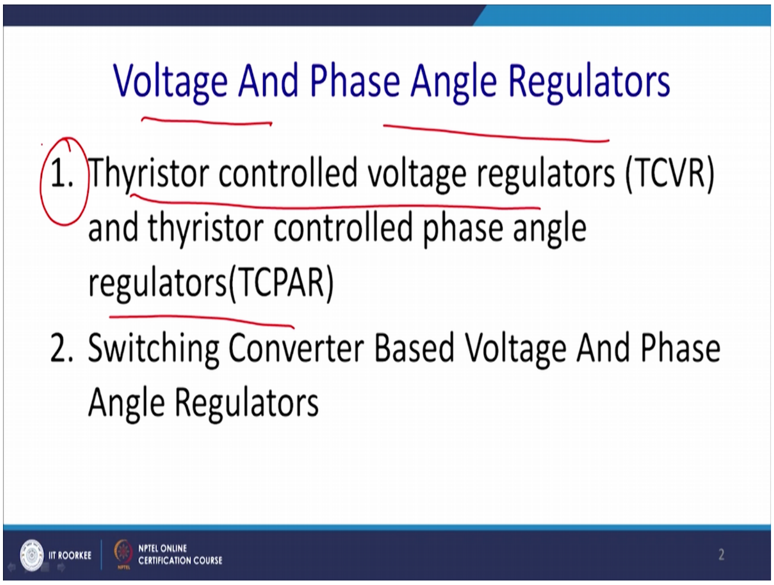

One is Voltage and the Phase Angle Regulator. In this category, we shall discuss about Thyristor controlled voltage regulator. This is basically injects voltage in series of quadrature as we had been discussed in previous class and thyristor control phase angle regulator it control the phase. And another is actually the switching converter Based voltage and current phase angle phase regulator.

First one is Thyristor based, it is primitive and second one is basically GTO or the IGBT based. Now, we shall discuss about historically this two came first; first will discuss about the TCVR and TCPAR.

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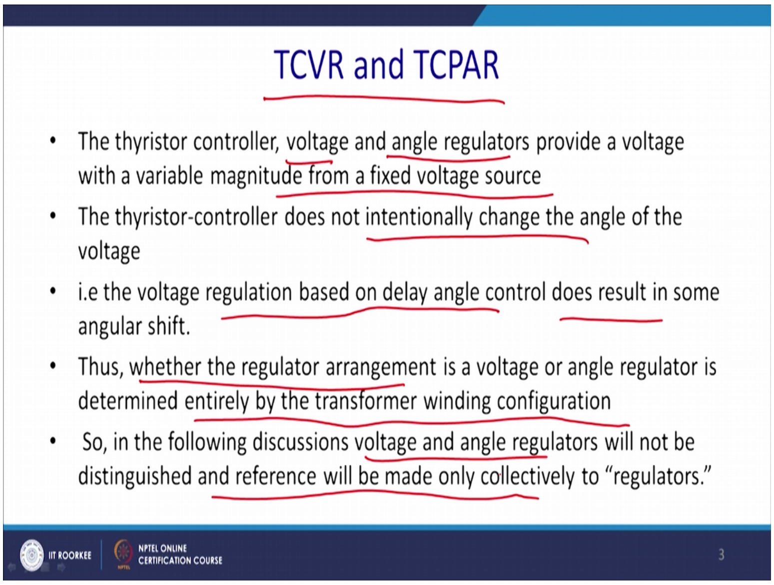

So, these are more thyristor control. Thus you have a thus you have a control on the turn on and it has to be terminated or test to be line terminated, but turn off. So, further session thyristor controller, the voltage and the angular regulator provides a voltage with a variable magnitude from the fixed voltage source by changing the firing angle of the thyristor. This thyristor-control does not intentionally change the angle of the voltage.

So, that is something we required to understand it that mean voltage regulation based on the delay angle control does result in some angular shift. You know that actually there is a different kind of quantity 1 you have studied power electronics. So, we call displacement power factor. So, when you delay by some angular alpha; so, then it is there will be a delay in power angle also.

Thus, whether the regulator arrangement is a voltage or angle is determined entirely by the transformer winding configuration; we require a different kind of transformer winding and from there, we inject that phases in different way that will see and discussed in our subsequent topics. So, the following discussions voltage and angle regulator will not be distinguished. The difference will be only a actually categorize as the regulator. So, it can be voltage regulator or current regulator. So, it is as a controller topology wise you do not find any change in it.

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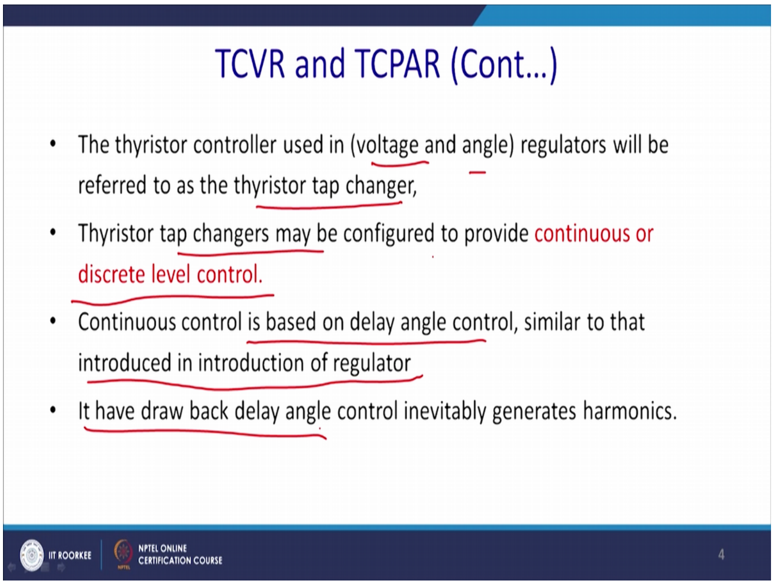

Thyristor controller used in voltage and the angle regulator will be referred as thyristors tap changer or thyristior based tap changer. This thyristor tap changers may be configured to provide continuous or discrete level of control.

So, you may have a step change or you have a continuous change, we have a number of switches there will increase. The continuous control is based on the delay angle control similar to that of the introduced into the introduction regulator and there after it have a drawback of the delay angle control and definitely the most basic problem is that it generates the low frequency harmonics.

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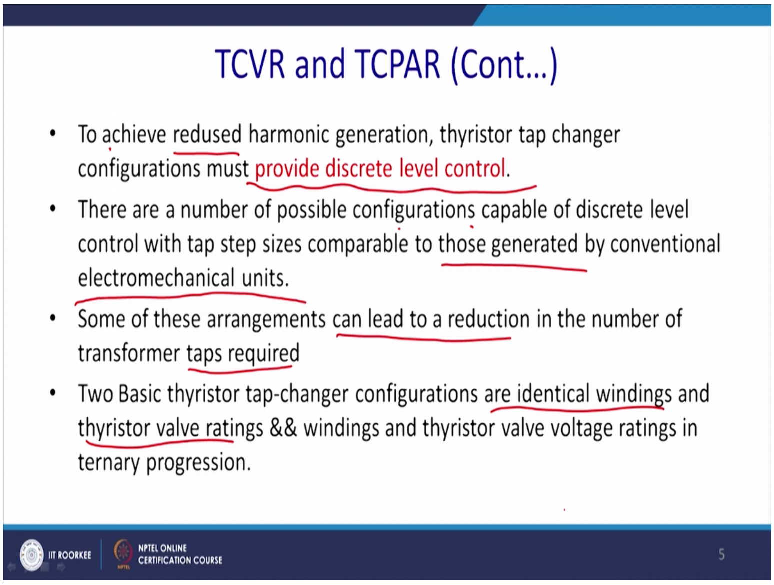

And to reduce the harmonic generation, thyristor tap changer configuration must be provided with a discrete level of control that you will see subsequent topic that how it can be done.

There is number of possible configuration capable of the discrete control with tap size comparable those generated by conventional electromechanical unit. We know that there is a tap changing transformer, when it is a very common practice in our distribution transformer in the peak hours when actually d 1 goes high. Then volt output voltage of the transformer goes low. So, require to actually put into the higher taps.

Some of this arrangement can be lead to the reduction of the number of transformer taps required. Two basic thyristor tap changer configurations are identical winding and thyristor valve rating and it is winding of the thyristor valve rating and the ternary progression. These are few configuration we shall cover in our topic. So, this is the one of the configuration of that tap changer.

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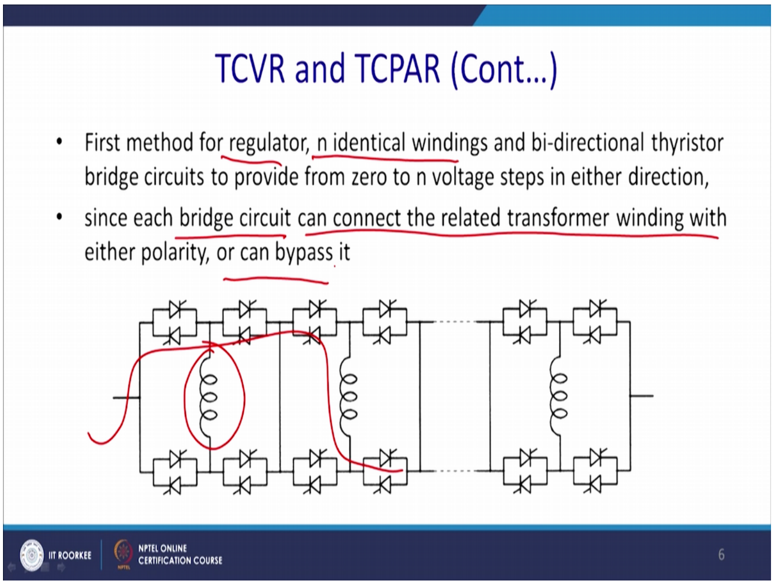

First method is for the regulator, we shall cascade in such regulator n identical winding and the bi-directional thyristor bridge circuit provided from zero to n voltage steps in either direction. So, in that way you actually increase the level. So, you can bypass also. So, you can you can take this way.

So, then this network this actually magnetic path is bypass. So, number of ton is reduced and you can increase or decrease a number of tons depending on the switching of the thyristor; in that way you control it. And since there is no delay angle control ultimately you will get less harmonic. Since, each bridge circuit can connect the related to the transformer winding with their polarity or can bypass it.

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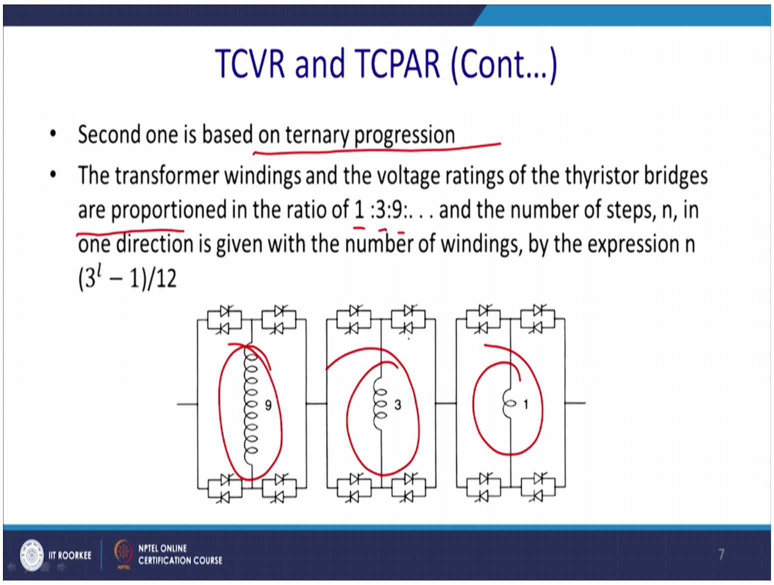

So, this is the case second one is based on the ternary progression. We can have a any mathematical progression that is that may be 1 is to 3 is to 9 or 1 is to 2 is to 4 something like that. The transformer winding and the voltage setting of the thyristor bridge are propositional with the ratio of 1 is to 3 is to 9 and the number of steps n in the directions given with the number of the winding and by the expression is 3 to the power l minus 1 by 12.

So, this is this will have a 9 ton; this will have 3 tons; this will have a 1 ton in that way actually it is been configured. So, if you like to actually increase little bit voltage, then you can you can actually use in it or you want actually reduce the voltage injection phase, then you a bypass this pedantic path and another is a continuous voltage regulator.

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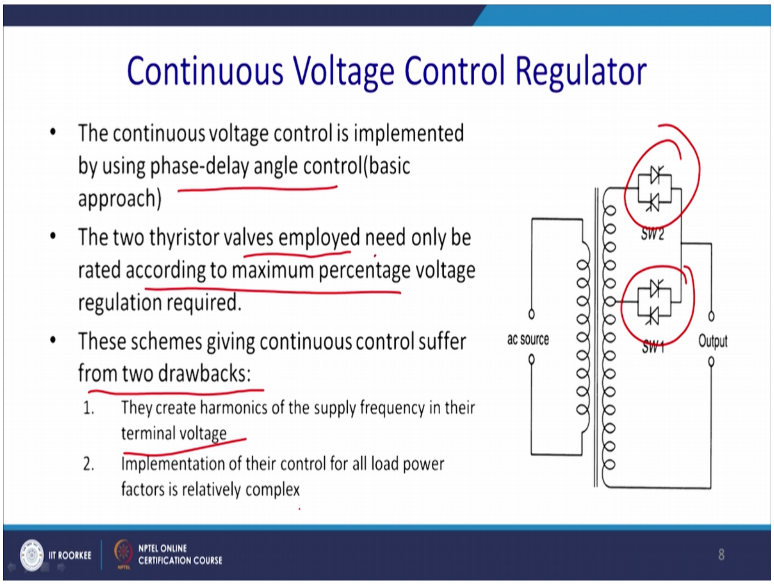

It is also a simpler circuit. The continuous voltage control is implemented by using phase-delay angle control; this is a basic approach. For let say some angle alpha; the actually this thyristor is switched on and may be after some angle, you know this thyristor is switched on or vice versa. Then actually voltage profile will change will come across the voltage profile in subsequent slides.

The two thyristor valves employed need only by a need only by the by the related according to the maximum percent of the voltage is required. This schemes giving continuous control suffer from, but it few two drawbacks. This suffers from this two drawbacks. This definitely will create harmonic. They create harmonics of the supply frequency in their terminal voltage and implementation of the control for all load and the power factor is relatively complex.

Because you know that there is a actually lying power factor, then current and voltage will be in quadrature. Then it may not be automatically committed also.

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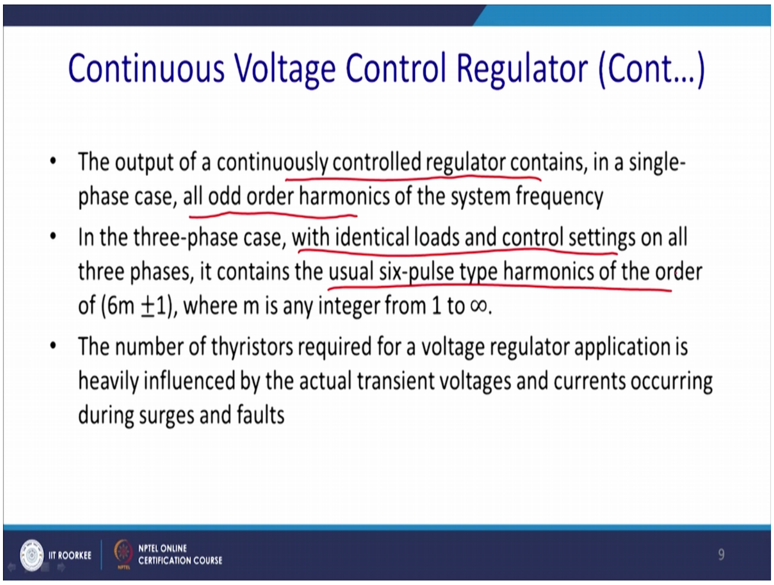

So, what should be take away from this discursions? The output of a continuous control regulator in a single phase, all odd harmonics of the systems will be will actually present because we have a odd symmetric, we assume; so, odd harmony will be present.

In case of the three-phase with the identical load control setting all the 3 phase will and if you employ a six-pulse converter, then usual six-pulse type harmonics in order or 6m plus minus 1 will be actually present and will be contaminated with 5th 7 11 13 is with this harmonics; where, m is the integer ranging from 0 to infinity.

The number of thyristor required for voltage regulator application is a heavily influenced by the actual transient voltage current occurring during this search and the fault. So, we have to take care of these issues. So, search and fault is something we have to seize according to the, we chose the voltage rating and the size of the thyristors and the number of thyristors.

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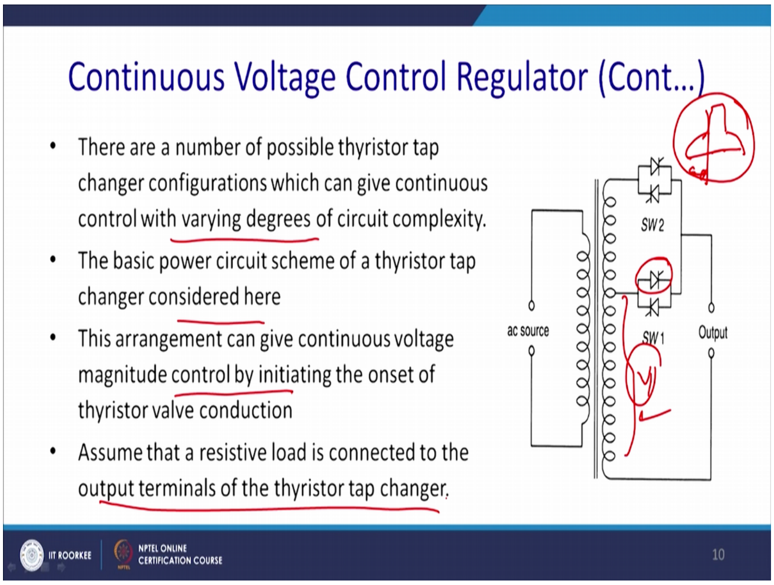

So, there is a number of possible thyristors tap changer configuration. It is one of it which can give continuous control with varying degree, but its circuit is a quite complex. The basic power circuit schemes of the thyristor tap changer is considered here. This is the actually the circuit. So, ultimately V 1 will be applied when SW 1 is closed.

So, profile will be something like this. There after a delay of some angle alpha, then this switch will be closed. Automatically you know, so, though the conducting thyristor will be reversed bussed and there will certain in voltage. Again here, actually you may close the this thyristor. So, this kind of waveform you may generate we will coming to this f form in subsequent slides.

The basic power circuit scheme of the thyristors of a tap changing tap changer is considered. This arrangement can be continuous voltage magnitude control by initiating the onset of the thyristor valve conduction. We can start from at alpha equal to 0. Assume that a resistive load is connected to the output terminal of the tap changer, we shall see the waveform.

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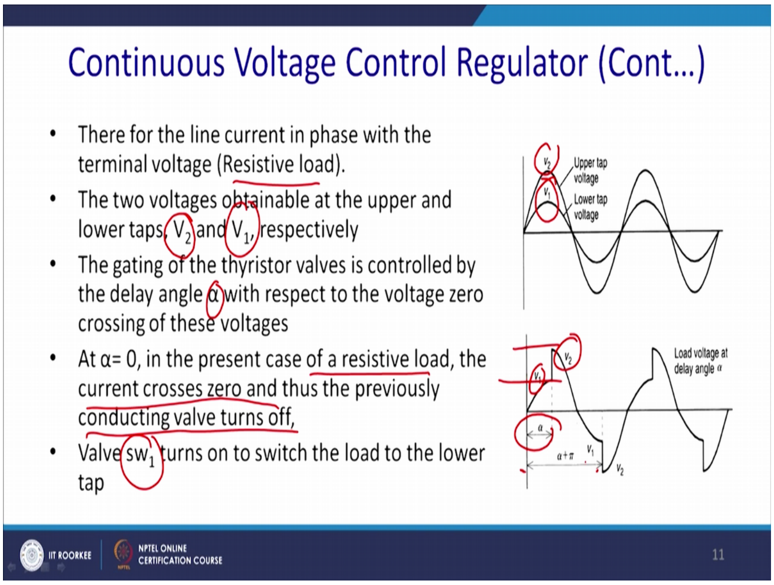

So, this is actually V 1 lower thyristor, where it is connected and this is a V 2, where upper thyristor is connected and this will be the new profile of the voltage. So, therefore, for the line current in phase with the terminal voltage of the resistive load is going shown here. The two voltage obtainable at the upper and the lower taps are V 2 and V 1 respectively. This is V 2 and this is V 1; this is V 2 peak and this is V 1 peak. The getting of the thyristor valve is controlled by the delay angle alpha with respect to the voltage 0 crossing of these voltages.

At alpha equal to 0, in the present case a resistive load, the current crosses zero and thus previously conducting valve turns off, Valve s w 1 turns on to switch the load to the lower tap. And thus, we obtain this profile like this; this is for alpha and this much to this much is actually pi plus alpha and this kind of voltage profile. In assignment, we shall provide we shall ask for this actually harmonic content of this waveform and we require to calculate the fundamental value of it.

So, that will be given to the assignment; students are expected to actually find it out the harmonic contents and the fundamental of this kind of tap changer. At alpha equal to alpha 1; so, the valve sw is switched or get it on which it commutes current for the conducting thyristors of valve s w 1 by forcing the a negative anode to cathode voltage across it.

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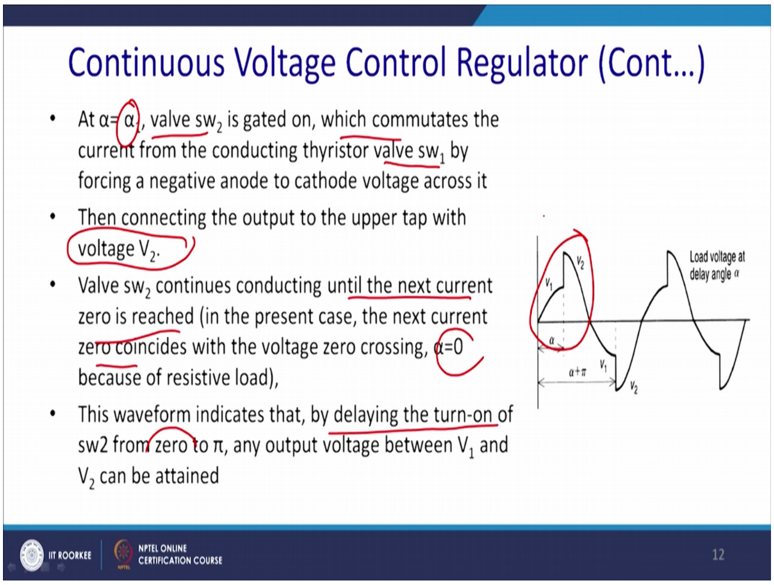

Because you know when this thyristor when this thyristor is tigered assume that positive half cycle, the negative voltage is a applied across this conducting thyristors and automatically this will be turn off.

Then, the connecting the output of the upper tap with the valve and having a voltage of V 2, the valve V 2 continuous to conduct until the next current reaches to zero in the present case and if it is a load is inductive then it will conduct till the current. So, the thyristor actually goes below the holding tenant. And the next current zero coincides with the zero crossing for alpha equal to 0 because it is a resistive load.

This wave form indicate that by delaying the turn off of sw 2 from 0 to pi, any output voltage between V 1 to V 2 is attainable and ultimately you require to calculate the fundamentals of this step changed waveform.

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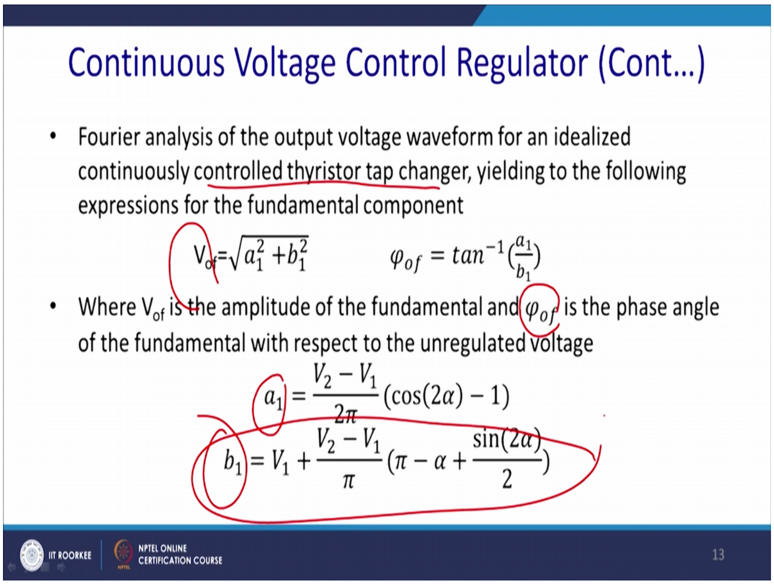

So, let us see that how it can be calculated. So, Fourier analysis of the output voltage of the waveform for an idealized continuous control thyristor tap changer is shown below, yielding to the following expression for the fundamental component. So, let us assume that V 1 is represent by a 1 and V 2 is represented by b 1. These are the fundamental value of the voltages of up to these two voltages.

So, this V of will be actually a square plus b square. So, ultimately tan theta; the phase difference will be now tan inverse a by b; where V of is the fundamental of the phi of and they will be of phase delay of the fundamental.

So, with respect to fundamental the unregulated voltage a 1 will be V 2 minus V 1 by 2 pi cos 2 alpha minus 1 and similarly, we can calculate b 1 by Fourier analysis that will be V 1 plus V 2 minus V 1 by pi, pi minus alpha plus sin 2 alpha by 2. Again, you know this equations will have a problem; we have to solve in iterative method by different value of alpha.

So, let us see that how phase angle and the output voltage changes with different alpha.

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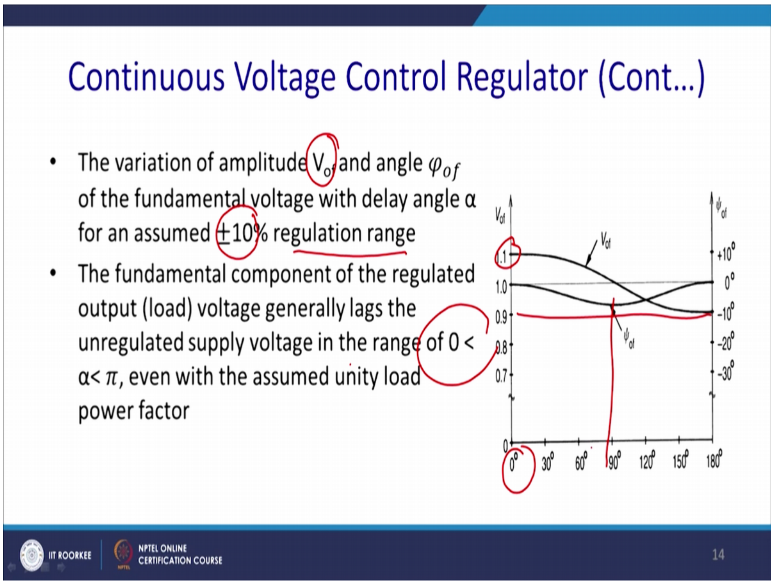

The variation of the amplitude V o f and the angle phase angle phi of 0 of the fundamental voltage with delay angle alpha for an assumed 10 percent regulation range has been shown. The fundamental component of the regulated, fundamental component of the regulated output load voltage generally lags the unregulated supply voltage range of 0 to pi.

So, alpha can be valid to actually 0 to pi even with the unity power factor. So, power factor can be actually manipulated here; even it will be resistive power factor you can get a inductive kind of loading by the tap changer.

So, this is the V o f. So, when it is actually at 1, alpha equal to 0. So, you get 10 percent more voltage as simple as that and gradually you know, it will come down and you get actually 10 percent less voltage and this is the reference and you get point 9 and what about the phases? So, maximum lag in phase will occur in an around 90, degree in the 90 degree So, this will be the phase change due to the 10 percent taping that if tapping changes, then phase angle also get changes.

So, what about the harmonics?

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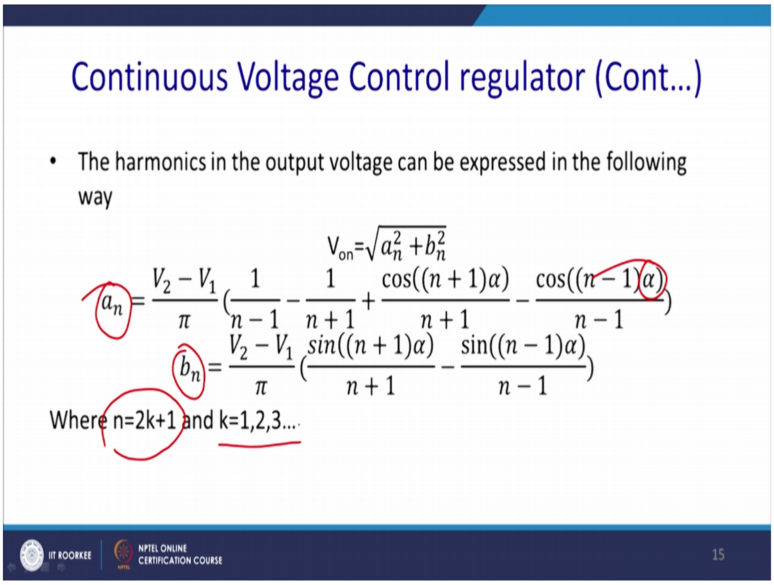

The harmonics of the output voltage; we can actually representing the following way. So, this is actually a n. So, a n will be actually V 2 minus V 1 by pi 1 by n minus 1 minus 1 by n plus 1 plus cos n plus 1 alpha n plus 1 and n minus 1; of course, you know actually you can eliminate a particular harmonics here, let us say by choosing a particular value of alpha.

So, that is comes under the section of the selecting harmonic elimination, but then result actually stepping may be actually used. So, similarly b n will have V 2 minus V 1 by pi sin n plus 1 alpha n plus 1 minus sin n minus 1 alpha by n 1 and where, actually n equal to k plus 1 and k's are 1, 2, 3, 4.

The dominant harmonic component as a percentage of nominal fundamental voltage will be actually V 1 plus V 2 by 2, average value.

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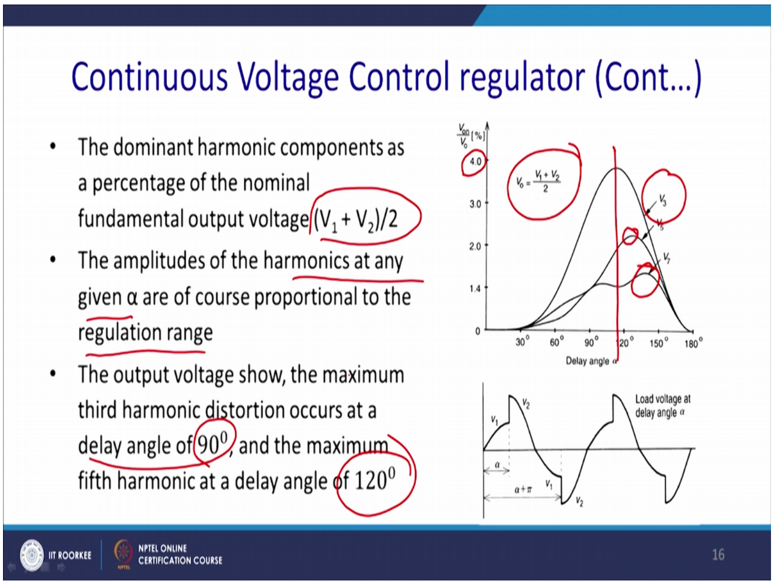

The amplitude that is all it is. So, it will be actually V 1 plus V 2 by 2 and this is a percentage of it and you see that how it is changes with the delay angle and this is actually third harmonic and third harmonic will have a huge actually will have a content and on 4 times of the actual it is in percentage.

So, the high percentage of third harmonic will be represent will be these are all 4 percent. So, we have to suppression harmonic to have a prescribe norms of t h d of less than 5 percent for practical operation. Same way we have a fifth harmonic peak and same way, we have a seven harmonic peak. At 90, literally fifth and 7 content of the fifth and seven the same. So, the t h d actually will be quite high.

The amplitude of the harmonics at any given angle alpha are of course, proportional to the regulation range. The output voltage shows the maximum third harmonic distortion occurs at a delay angle equal to 90 degree and the maximum strength of the fifth harmonic we will have a delay angle of 120 degree.

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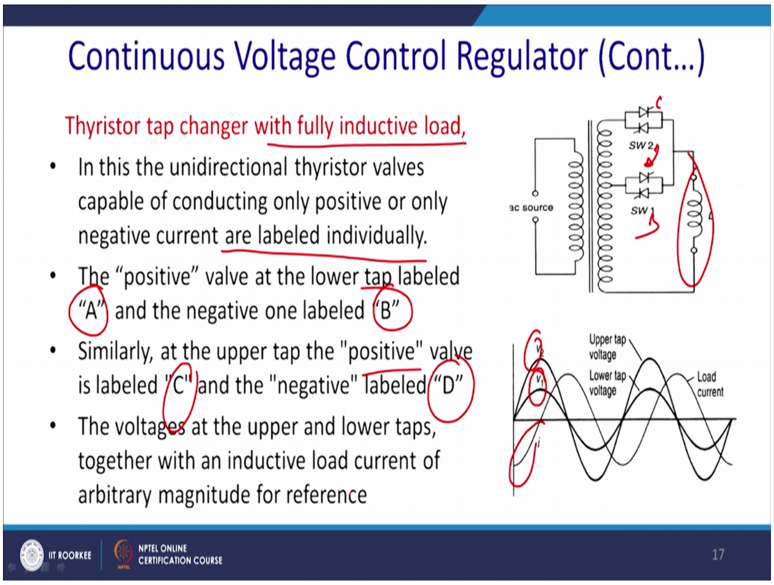

So, we have to see that how you can reduce those harmonic content. Now, what happen, if instead of the actually the resistive load most of the load inductive; you put a heavy inductor. This thyristor tap changer will highly inductive load. So, what happen, there will be a lag in current this i and this is V 1 and this is a V 2. In this case, the unidirectional thyristor valve capable of conducting only positive or only a negative current are labeled individually. Because you know the current has to be in this cycle. A positive valve at a lower tap labeled as "A" and the negative are labeled as "B". Similarly, let us consider that upper tap, this is A; this is B; this is C and this is D.

Similarly, the upper tap of the positive valve is labeled as "C" and the negative term is labeled as "D". The voltages at the upper and the lower tap together with the with an inductive load current of arbitrary magnitude is chosen as a reference. Let us see that what happen then? Then we require to manipulate in different way. So, we will be actually in case of the PWM technique, we try to discuss about PWM technique. The typical case of actually 60 degree Buscampling method. Thus, you know these are the voltages V 1 V 2 and this is i at phase lag by 90 degrees.

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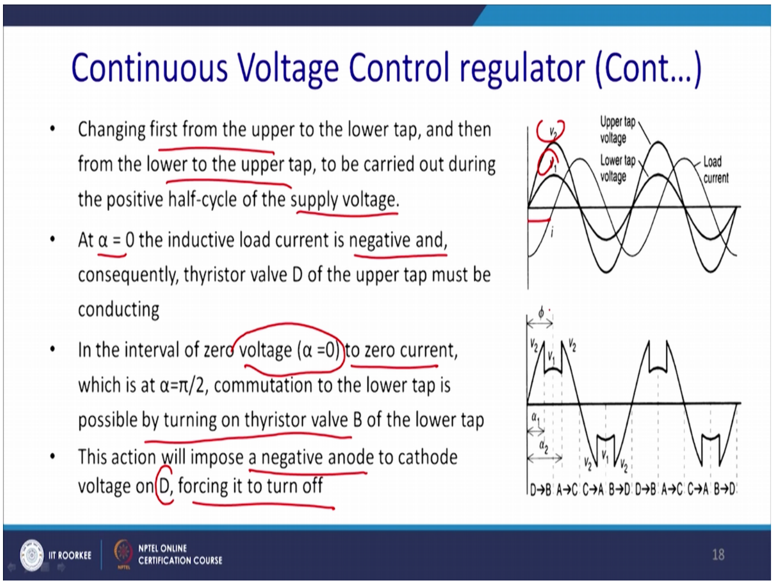

Thus, what happen? The changing the first, from the upper to the lower tap. So, operation will be different; first the upper tap will be switched on followed by the lower tap and then from the lower to the upper tap to be carried out during the positive half cycle of the supply voltage. At alpha equal to 0, the inductive load current is negative.

So, for decision what happens? For the interval of voltage V equal to voltage at 0 current which is almost at pi by 2 because of it is achieved to be very highly inductive or almost 0 resistance, the commutation of the lower tap is possible by turning off the thyristor valve B of the lower tap. This action will impose a negative anode to cathode voltage voltage on D and forcing them to turn off.

So, this is the way you can turn off this type actually powered going thyrsus. Then what happens because previously the negative cycle was conducting.

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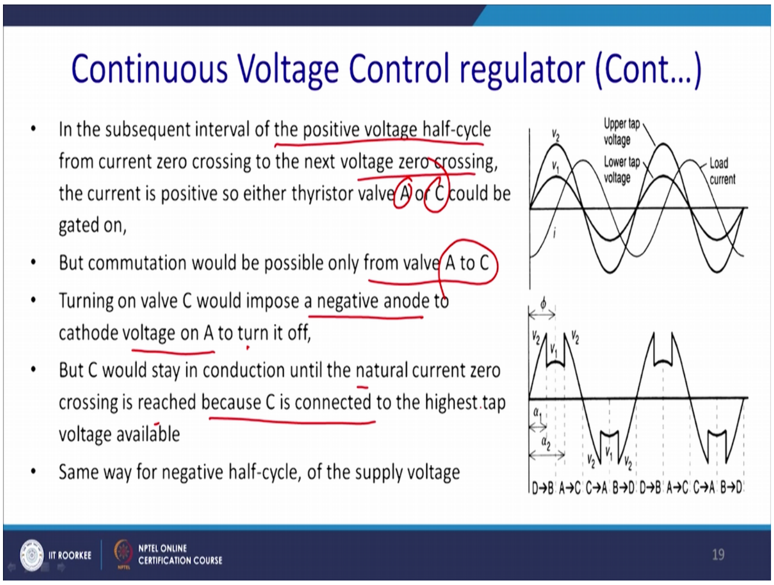

In the subsequent interval the positive voltage the voltage half cycle and the current zero crossing to the next voltage zero crossing, the current is positive. So, either thyristor A or C who will be basically flowing or get it. So, you can get either of the thyristor and if you reduce try to reduce, it will get basically thyristor A.

But commutation would be possible only from the valve A to C not C to A. Please find that. So, turning on the valve C imposed negative anode to the cathode voltage A to turn it off and, but C could stay in conduction until the natural current or the holding current of the thyristors current crossing zero reaches because C is connected to the higher voltage step tap.

Then, some way for the negative half cycle of the power supplying. And thus, what happen?

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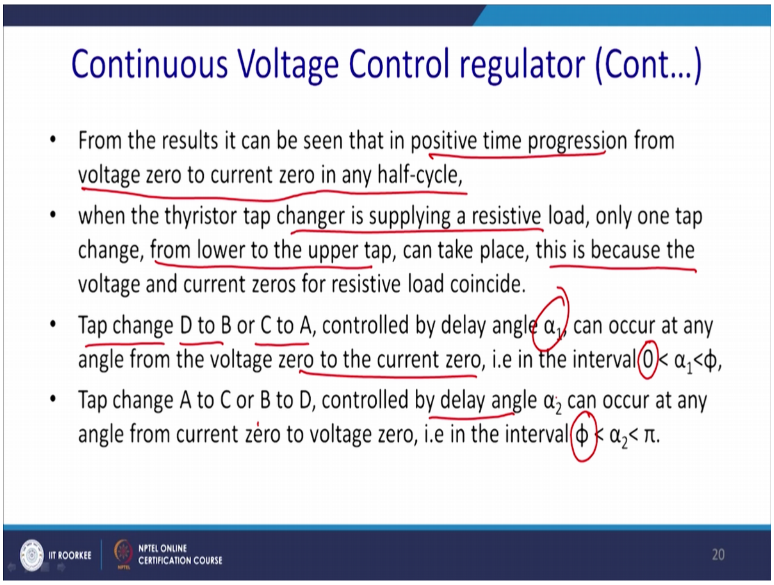

From this result, it can be seeing that the positive time progression from the voltage zero to current zero in any half-cycle. When thyristor tap changer is supplying a resistive load, only one tap change, from lower to the upper tap, can take place, that what we have seen. And this is because the voltage in the current zeros and it coincide to each other (Refer Time: 27:14). And further tap change D to B or C to A controlled by the delay angle alpha tap occur any angle or voltage zero to the zero current to the current zero.

That means the interval can be 0 less than alpha 1 to phi, but phi is the basically delay angle phi is actually phase angle of the current. The tap change of A to C or D to B controlled by the delay angle alpha 2 can occur any angle current zero or the voltage zero, that mean with the interval phi actually less than alpha 2 and till pi. This is the mode of conduction for inductive load.

Now, we shall continue with the capacity kind of loading in our subsequent classes and we shall see here there will be little change here, definitely as you understand that you know current will lead basically the voltage supply voltage. So, turning pattern will definitely will we respected to change.

Thank you for your attention. We shall continue to our next class with these discussions.