Power Quality Improvement Technique
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Lecture – 03
Overview – II

Welcome to our Power Quality Improvement Technique program on NPTEL. We shall continue with the Overview which we were discussing in previous class. Now, we will talk about the sag and the dips. We have already defined the sag, now we shall elaborate a little bit about the different kind of sags.

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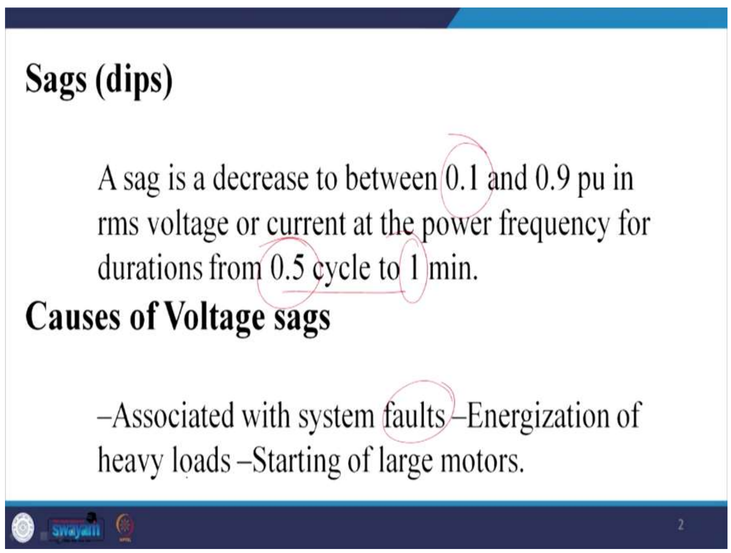

So, as we have mentioned that sag is a decrease to voltage between 0.1 to 0.9pu per unit in rms value of the current at the power frequency and duration of at least 0.5 cycle. Then we will consider this entry to this sag and till 1 minute. If it is consisting of longer than 1 minute, you can take it into the interruption and the causes of the voltage sag is associated with a fault only, energization of the heavy load.

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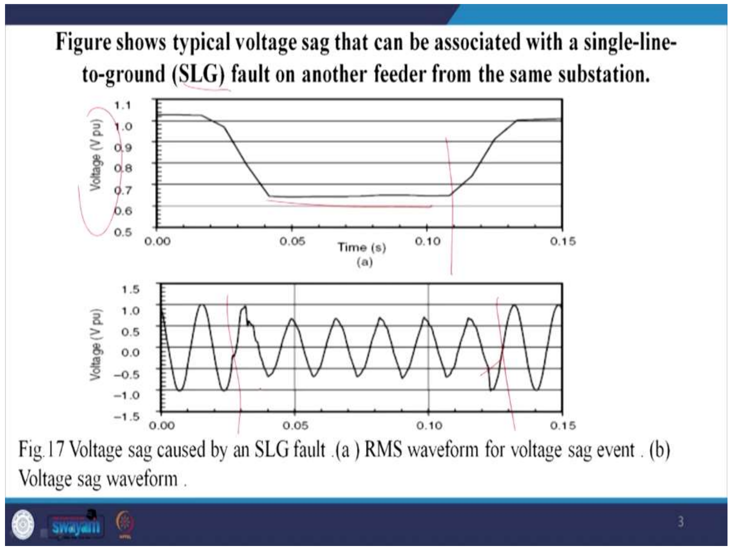

Starting of large motors, you know the starting current of the induction motor is very high. For example, here we shall first show you this is a per unit voltage, here all of a sudden we have a single line to ground fault and thus, voltage has been sagged and thereafter it has been recovered and this is the voltage profile. So, this is an RMS value and this is the waveform during the sag, till that point you know it was healthy. So, thereafter there is an initiation of the sag and then it has been corrected here.

So, from this point onward corrective action was taken. So, you can see that this is a picture. So, this phenomenon has been categorized as a sag.

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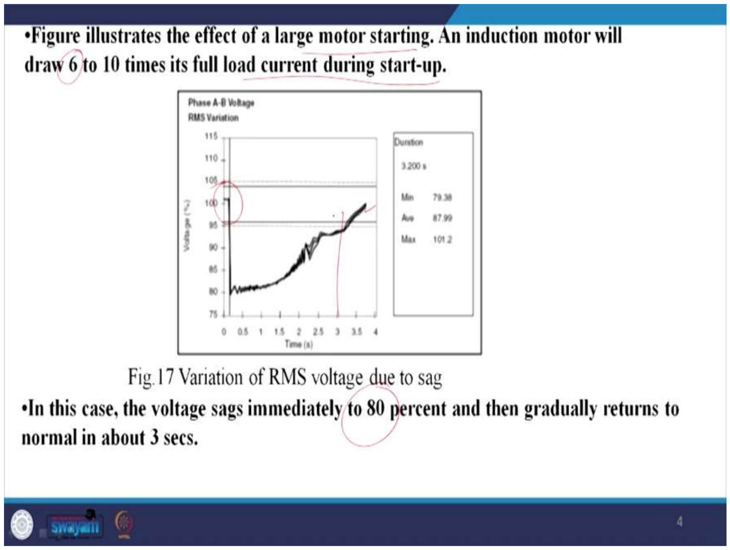

Similarly, we shall illustrate another figure, the illustration is effect of the large motor starting. An induction motor will draw 6 to 7 times of its full load current during the start up and due to that the voltage will fall. You can see that; this is the moment motor has been started. So, there will be a fall in the voltage from 100 percent to 80 percent and gradually, it will reach the value. This timescale is in second. As shown here in this case, the voltage sags immediately to the 80 percent and then gradually returns after its normal value of 3 seconds.

So, this is the case here, where voltage sag may occur.

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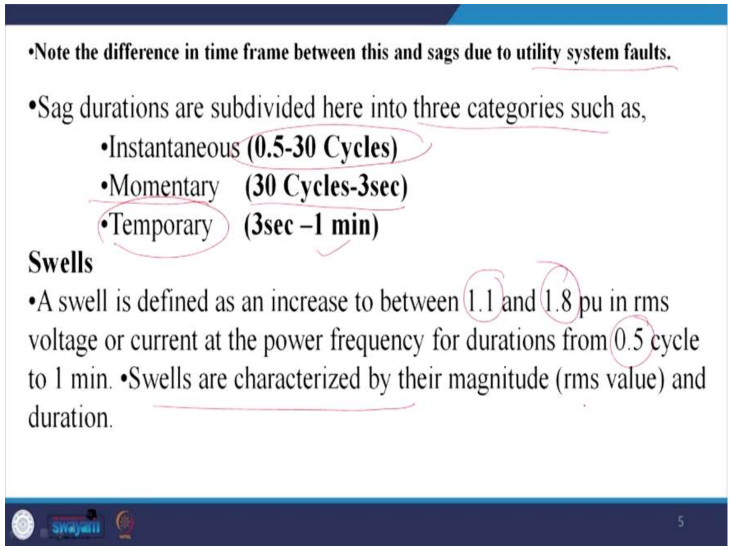

So, based on that there are different kind of sags. So, note the difference in time frame between this and sags due to utility system faults and that has to be categorized. So, sag durations are subdivided here into three categories such as instantaneous sags, that is for 0.5 cycles to 30 cycles and momentarily sags, that is for 30 cycles to the 3 seconds and the temporary sags, that is for the longer duration that is for the 3 seconds to 1 minutes. So, this is something you will categorize.

Similarly, the voltage built up which is said to be the swell. A swell is defined as an increase to between 1.1 to 1.8 per unit in RMS voltage or current, at the power frequency for the duration of minimum 0.5 cycles to 1 minute. Swells are characterized by their magnitude of the rms value and also the duration, but instead of the 3 minutes, we can allow only 1 minute.

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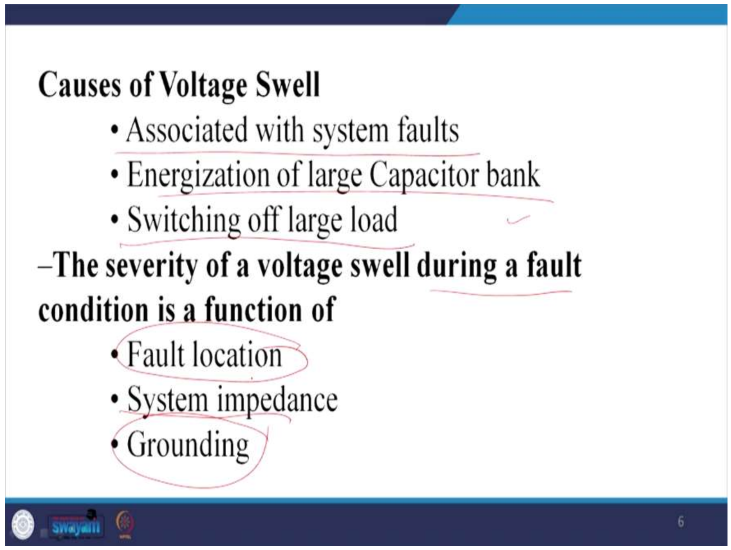

So, cause of the swell, it will be associated with the system faults. So, once you called a system fault and you have open up a line, there will be open circuit case. Open circuit case will reflect back the wave and thus it may cause a high voltage. An energization of the large capacitor bank that is also a cause.

So, we discussed in the facts devices how to energize the capacitor. As you required to see that the retained capacitor voltage and the supply voltage as same, then only you are going to switch it on. Otherwise, it gives a transient and this transient if it is not underdamped, then it will cause a sustained oscillation of high voltage.

And just the reverse, we have seen that switching on the large load can also be resulted in a swell because of the switching off large load. Once all of a sudden you switch off, the voltage will build up. Similarly, we required to see and identify the severity of the voltage swell during a fault condition as a function of fault location, where does it located where the open circuit occurs, fault system impedance and the ground impedance.

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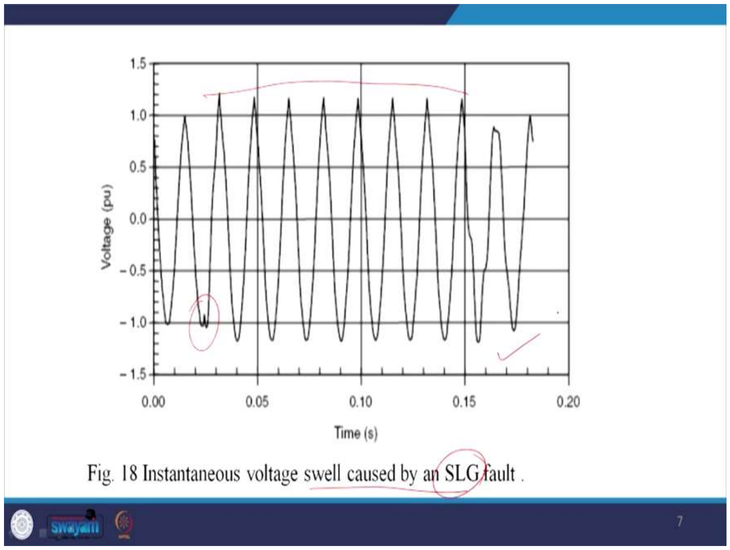

Here for example, instantaneous voltage swell caused by a single line to the ground fault in other two line. So, all of a sudden there is a distortion and thus you can see that voltage has swelled, then it has again sagged. This phenomenon occurs to other healthy line in case of the single line to ground fault.

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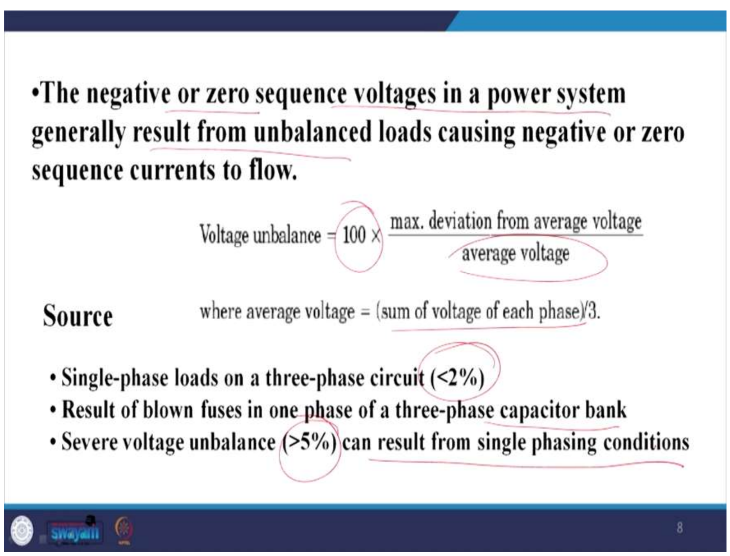

So, another thing is that negative sequence due to the unbalanced loads that negative or the zero sequence is present only in three-phase four-wire system in a distribution network, otherwise zero sequences is absent. We shall discuss in detail about the zero-sequence component and the negative sequence component in shunt active power filter. You can refer back that lectures once it has been delivered to you.

So, zero sequence voltage in a power system is generally results from the unbalance loads causing negative or the zero-sequence current to flow. So, voltage unbalance equal to 100 percent into maximum deviation from the average voltage, by average voltage or you can take rms voltage also, where the average voltage is equal to sum of the voltage in three phases.

So, generally we have some condition of fault tolerance for single load on a three phase circuits. We should have a negative sequence less than 2 percent, that we accept. The result of blown fuse in one phase of the three-phase capacitor bank, this may cause a severe unbalance and when this is the capacitor bank, it may blow out the fuses. And severe unbalance that is more than 5 percent can result from the single phasing condition. I will show that, how even that typical single phasing conditions also can be mitigated by the shunt active power filter. So, recall the lectures for this condition there.

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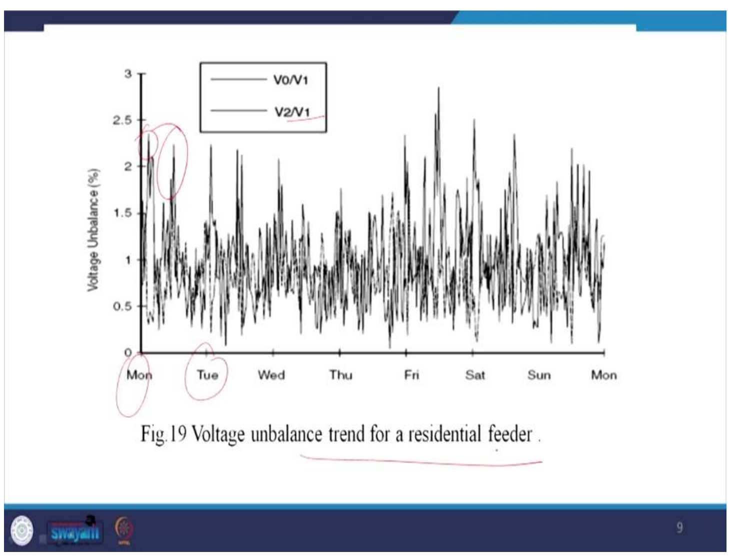

Fig.19 Voltage unbalance trend for a residential feeder .

So, we are showing that V_0 by V_1 and V_2, this is the case of the unbalance voltage in percentage in residential feeder date wise, and you can see that this is the hour wise this amount is a 24 hours, once there is a peak, there is a two peak in India. Generally, it is in the morning and 8 to 10 AM and it is after 6 to 9 PM.

So, for this reason you can see that both this peak. When the peak demand is more, unbalance also going to be more. This is a case of the two feeders V_0/V_1 and V_2/V_1 for the residential figure. So, this is the way it changes over the time span while you have an unbalanced load into the distribution system.

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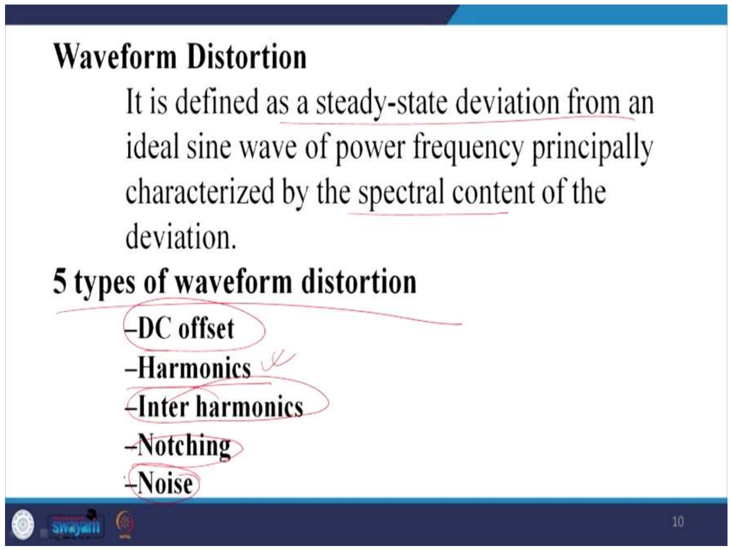

So, let us define those waveform distortions, it is defined as a steady-state variation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation. So, you can have a spectral analysis and you see that whether you have got the fundamental or not, that is all.

If you are getting a fundamental, it is fine otherwise there is a five type of wave distortion. This is DC offset, generally presents when your positive area and the negative area does not match. So, you have some average value. Thereafter harmonics, once you have a non-linear transformation from AC to DC, then in AC side it will be injecting the harmonics.

There are different kind of harmonics. So, one special type of harmonics are called interharmonics, that we shall discuss in detail and what is the effect of it and why it is a arises into the system. Again, there is notch and noises. Noise can be wide by noise and other noises that can present in to the system. DC offset, the presence of the DC voltage or current in an AC power system is termed as a DC offset.

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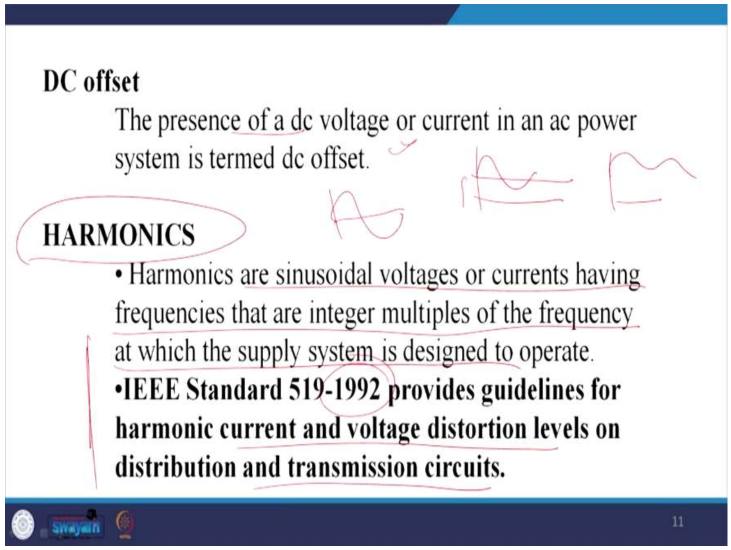

You mean to say, you can feed a DC voltage thereafter, you can have an AC. So, resultant will be this. So, this amount is a DC offset or you can have a positive area and negative area mismatch then also can have a DC offset. Generally, it happens when you have triggering pulses which are not same and you required to compensate that within a time. Generally, DC offset can be eliminated by properly switching the thyristor base devices and keeping the positive area and the negative area same.

The harmonics, this is something of a most dominating entity in the power quality. Harmonics are sinusoidal voltage or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate. IEEE standard 519-1 0, this is basically the 1992 standard, further standard has been elevated provides guidelines for the harmonic current and the voltage distortion levels on distribution and the transmission circuits.

This is generally a research guideline, but they have a separate guideline for the different country, but generally it adhere to the IEEE standard.

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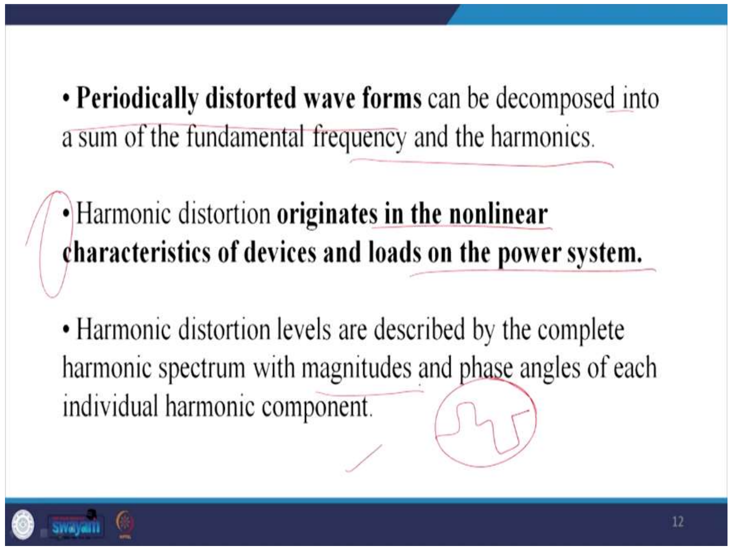

There after periodically distorted wave forms, though that is something of a very important distortion phenomenon, can be decomposed into a sum of the fundamental frequency and the harmonics. That is, you can have this wave form this is a square wave waveform it is not distorted, but you can say that distorted sine waveform and that can be split into the sine and cosine component and with these corresponding harmonics in a Fourier series. Harmonic distortion originates in non-linear characteristics of the devices and loads on the power system. Once you have a diode base rectifier, thyristor AC to DC convertor all will cause harmonic distortion.

Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. So, we will split like this.

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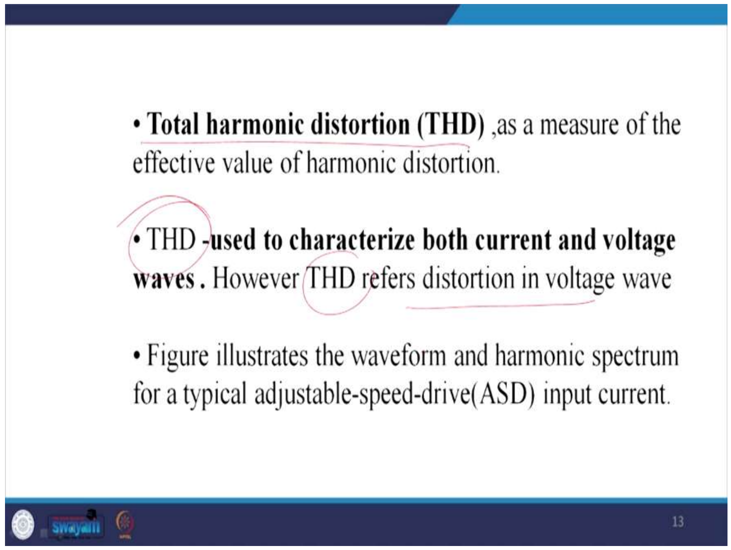

Now, few terms which you are familiar with for a long time, but we just for the sake of recall we are describing here. These are total harmonic distortion THD, as a measure of the effective value of the harmonic distortion. THD is one of the prime criteria in power quality and is used to characterize both current and voltage waves. However, THD refers distortion of the voltage wave sometime, if you talk about the voltage THD and we shall illustrate the wave form of the adjustable speed drive, in next figure.

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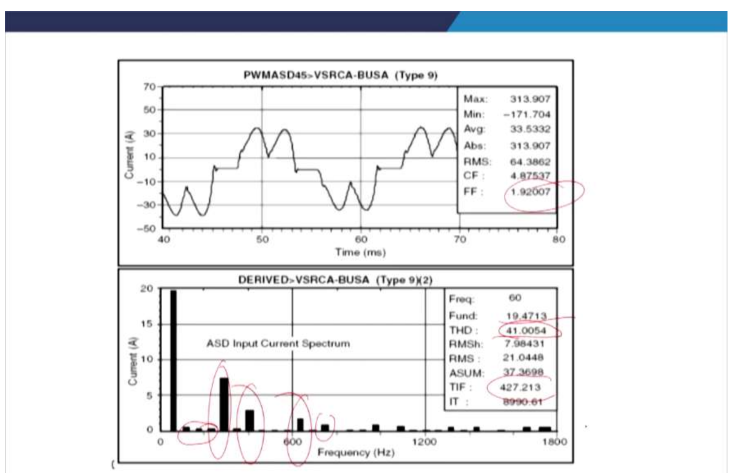

Fig .20 Current waveform and harmonic spectrum for an ASD input current

This is something which you will see that, we have a diode base rectifier followed by a capacitor then an adjustable speed drive. So, you can see the few things. So, that is the maximum voltage is this, minimum voltage is this, average is this, RMS is this, form factor is this.

And you can have a frequency of 60 Hertz, fundamental value is 19. Something. THD here you will find that it is eight times more than the standard applicable value that is 41% and RMS value is definitely of this 7.9 and RMS is 21.1 and TIF is the 72.5 factors. So, this is the fundamental, there after this generally does not come. It is coming here due to the quantization error of your sensors and generally these are very negligible and it comes due to the noises.

So, this is essentially a 5th harmonic, this is essentially 7th harmonic, thereafter you have a 11 and 13 harmonic and so on. This will be the harmonic spectrum for adjustable speed drive.

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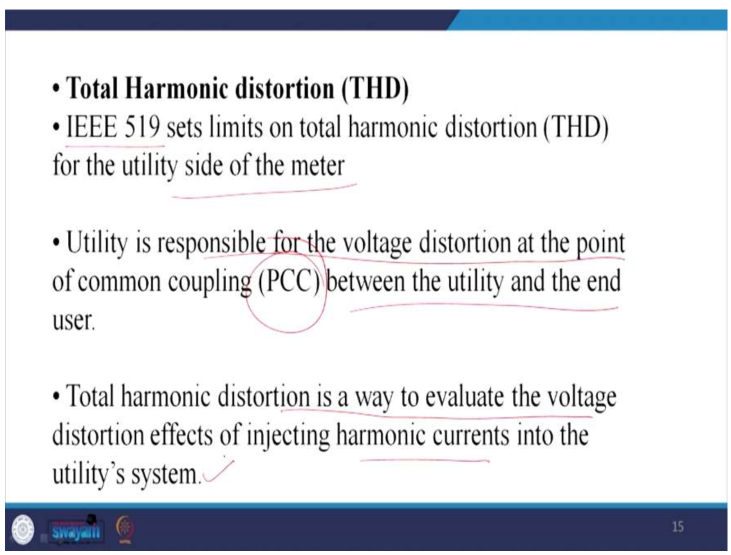

So, the total harmonic distortion according to the IEEE 519, sets limits on total harmonic distortion for the utility side of the meter. It is restricted generally 5 percent. Utility is responsible for the voltage distortion at the point of the common coupling which is abbreviated as PCC in our farther course of action between the utility and the end user.

The total harmonic distortion is a way to evaluate the voltage distortion effects of injecting harmonic currents into the utility system. So, it is a cause of the non-linear load, your voltage maybe fine sinusoidal, but your current got a distortion.

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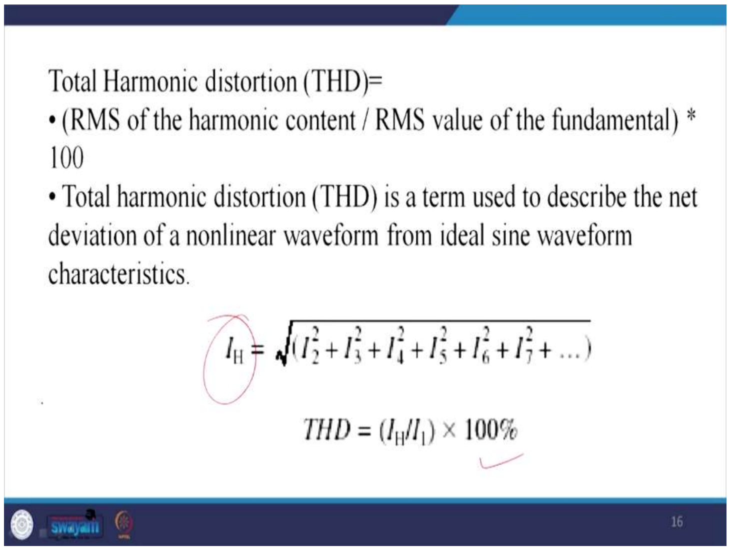

So, the total harmonic distortion equals to RMS of the harmonic content, divided by RMS value of the fundamental multiplied by 100 percent. So, we can define as I_H equal to except fundamental, it is I_2 square plus I_3 squared and so on and THD, it can be represented by 100 percent that has been shown or otherwise this is the amount of the harmonic. So, that can be defined as a harmonic.

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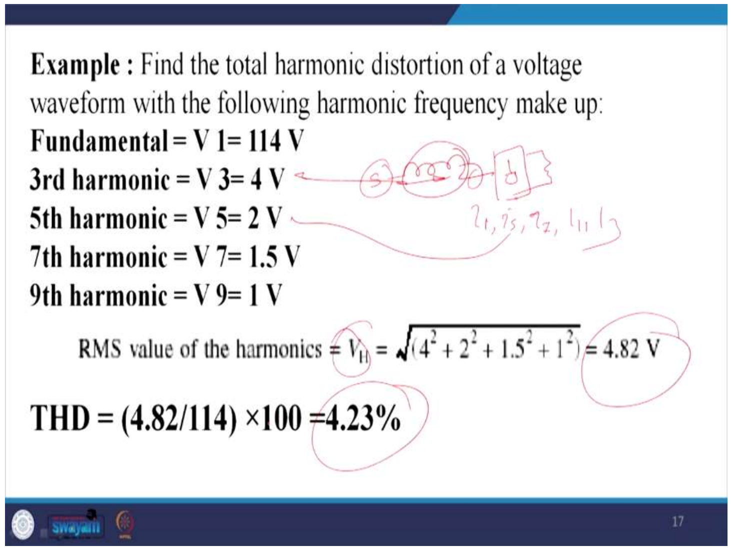

For example, I am giving you one example, find the total harmonic distortion of a voltage waveform with the following harmonic frequency make up.

Generally, what happened you may have a source and you will have a source inductance mostly. Because you fitted with the transformer and all and it has a leakage reactance and transmission line itself is inductive. Thereafter, when you have a diode base rectifier and thus you have a current, that is fundamental thereafter 5th, 7th, 11th, 13th. And if you are three-phase four wire system then also the 3rd harmonic and that also once the current flows the 3rd harmony current flows through the inductor that gives to this voltage. 5th harmonic current once it flows through this inductor, it goes to this 5th harmonic voltage and so on.

So, let us see that this is a way to calculate it is very easy. So, V_H will be under root of 4 square plus 2 squared plus 1 squared plus here, so this will be your voltage harmonic. So, voltage THD you can define as 4.82 by 114 into 100, that is 4.23 percent is your voltage THD and it is some extent acceptable.

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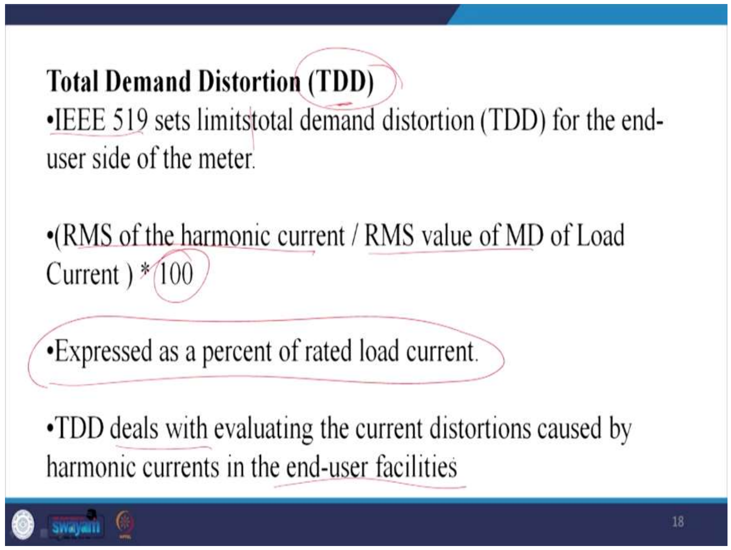

Now, total demand distortion, this is something you may not come across very easily, as this is a commercial term we use sometime in utility. So, IEEE 519 also sets the limits of total demand distortion that is for the end user meter. So, how much demand you want and how much distorted power factor you get. So, this is something. The RMS of the harmonic current by RMS value of the meter load current into the 100 percent, this is we termed as a TDD, so sometime it is also important. So, how much meter current I am getting, it maybe actually not unity power factor it may be of some other power factor. So, all has to be taken into the account.

This is expressed as a percentage of the rated load current because that is what we are aware of. Because once we have chosen a meter that based on the kVA rating, but since voltage is fix, ultimately your load current is something that varies. If you take a 3 kVA meter, so your load current is limited to around 15 ampere, if you are taking a 6 kVA meter, load current is around 30 ampere.

So, this is all single-phase currents with some amount of tolerance, but after 6 kVA we generally have a three-phase current, three phase meters. So, there also we have to take into this account. So, TDD that is the new entity, you will come across and then utility does not speak about the THD. Utility generally speaks about the total demand distortion. You demand this much I feed this much of the distorted form.

TDD deals with the evaluating the current distortions caused by harmonic currents to the end-user facilities and all these legal implications are with the TDDs.

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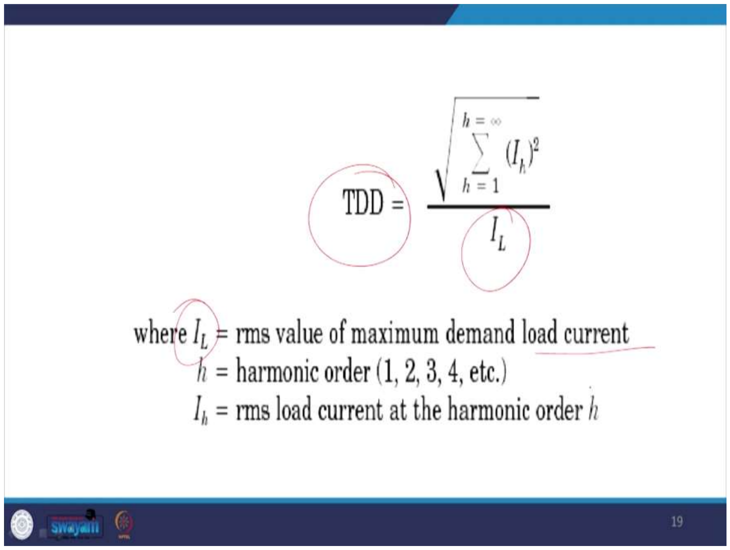

So, what is TDD? it is basically harmonic current by the demanded load current. So, if you are not taking your full load current, if your harmonic contain is more then you cannot penalize your utility or take a legal action against them.

But if it is reverse then you can of course, when you are drawing the full load current then it will be measured at the full load current. So, that is we say, I_L equal to the rms value of the maximum demand load current and this is a harmonic content and I_h is the RMS of the load current at the harmonic order h.

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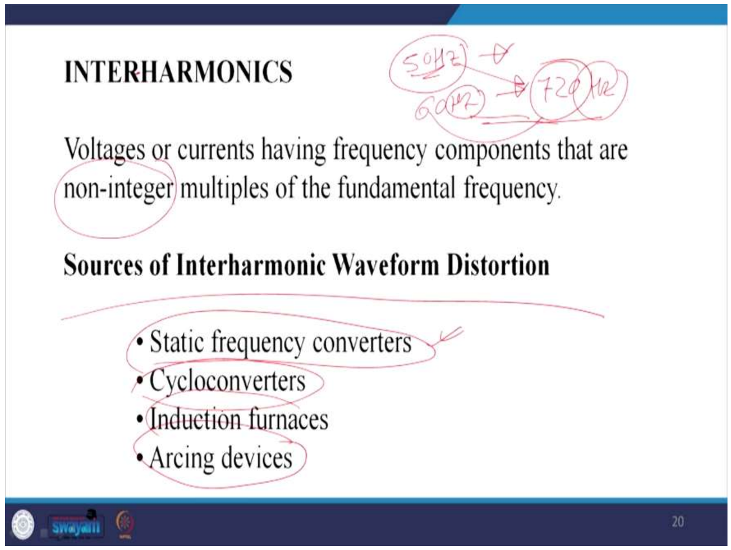

So, let us come into the new entity that is called interharmonic. So, interharmonics is a new entity and you know that we have a 50 Hertz and generally if you go to USA, you have a 60 Hertz and maybe you have taken a imported device from the USA for which carrier frequency is 720 Hertz. So, that is quite acceptable because it is basically a harmonic of 60 hertz. But it is not harmonic of 50 Hertz, it will be intra harmonic of the 50 hertz.

So, same devices once you try to run it in 50 Hertz system, then you will have this problem. So, what happen, the voltage or current having frequency components that are not integer multiple of the fundamental frequency these are called the interharmonics. 720 Hertz is not integer multiple of 50 hertz, so once you run it you just try it out, you take a switching frequency of a simple three phase PWM inverter with 720 Hertz and you are modulating frequency is 50 Hertz and try to see in MATLAB Simulink, what spectrum you are getting.

If you make just 13 times of it generally, we advise to have odd numbers of the 15 Hertz and see that what is the difference of the change you are making and that is something you will observe a very interesting phenomenon. And there this interharmonic you will be introducing, if you take the switching frequency on 720 Hertz. If it is present, it is very difficult to eliminate and sometime it raises to the sub-harmonics. Because ultimately your power system is a low pass filter thus high frequency does not have much problem and it will eliminate the low pass element. But due to the interharmonics, sometime low frequency comes into the picture sub-harmonics.

So, then you have a lot of problem to eliminate them. So, we generally, do not use the interharmonics while choosing the PWM and all that. If it arises, then it is pretty nasty element and eliminating these entities is quite difficult. And what is the source of this waveform? Static frequency converter, matrix convertor. Matrix convertor, it converts, if you are converting to 50 Hertz, generally we can have a wind energy conversion system and their wind speed varies.

It may be 11 Hertz to 20 Hertz and except 25 Hertz all the inputs are not integral multiple of the 50 Hertz. Then what will happen? Then, it leads to some extent, the interharmonics into this output of this waveform 50 Hertz and if it is not properly tuned, then this will raise to the interharmonics and thus cost a low frequency.

After you filter out the high frequency part, you will find that low frequency part which is present. So, this is one of the detrimental issues in the power quality problem. Once you are converting to or you are having a V/f control, then also this case arises by the matrix convertor. So, same way for the cyclo-converter. Cyclo-converter for the little higher power devices does it, an induction furnace and arc devices may also lead to the interharmonics.

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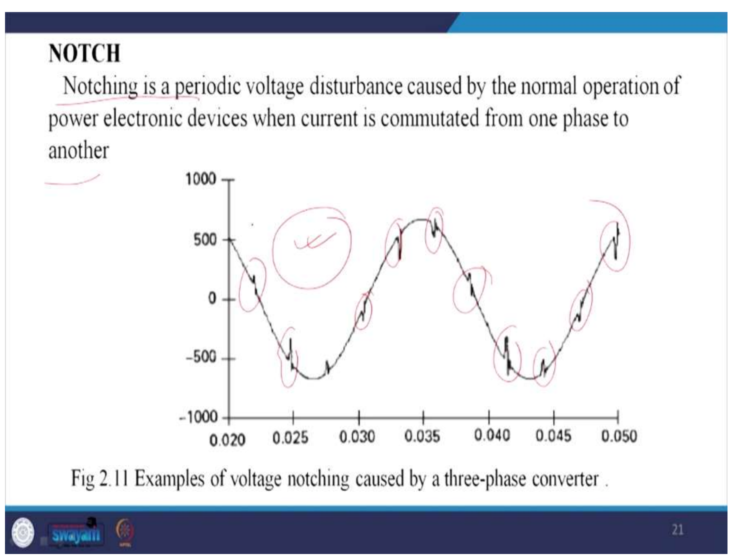

There after you come to the notches. Notching is a periodic voltage disturbance caused by the normal operation of the power electronic devices when current is commuted from one phase to another, it can be seen quite well in case of most of the convertor. And once it goes to this phase to once after 60 degree, a pair of thyristors is conducting, then it will switch over to another pair of thyristors, each of the case will gives you a notch.

So, this waveform if it is there, we require to eliminate the notch that also comes under the purview of the power electronics and we required to eliminate it as well by the power quality. Thank you for your attention, I shall continue the overview. I require another two classes to capture the holistic view of the power quality. In next class, I will also continue with different aspect of the notches and power quality issues.

Thank you.