Power Quality Improvement Technique
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 02
Overview

Welcome to our NPTEL lectures on Power Quality Improvement Technique. We have discussed about the introduction. Today we are going to give you the Overview of power quality. This is a study that has been done by the Georgic Power Company and this figure number comes from the previous slide only.

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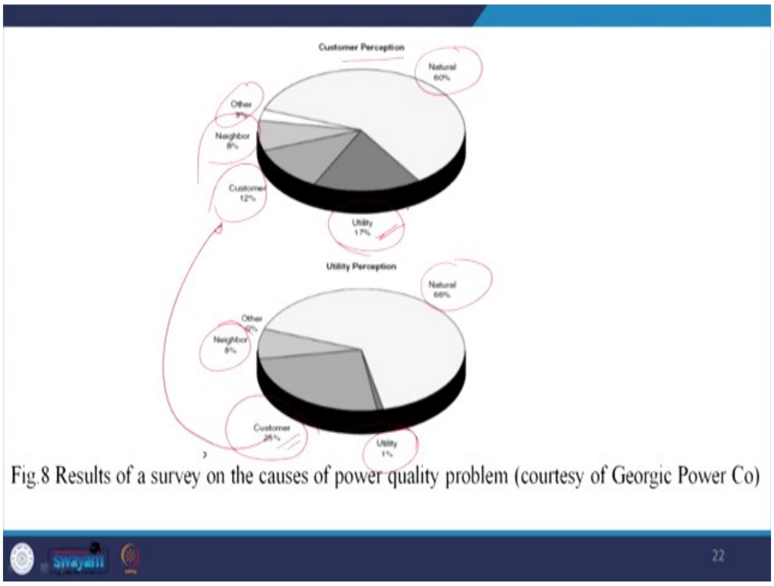

According to the study, customer's perception is that sixty percent of them are neutral whether there is a power quality is good or not, they have no problem. But the study is in USA. So, Indian study will be something different. Other eight percent believes that it is due to the neighborhood and another12 percent believes that it is due to the customer himself and, seventeen percent believe that they got inferior power quality because of the power utility, but on the other hand the utility people considered that most of the people do not bother as two third of the customer do not bother.

"Others" is zero, but eight percent believes that neighbors are causing the power quality problem, and costumer here it is 25 percent, here it is 12 percent customer himself believes that yes we are the cause of concern, but utilities perception is 25 percent problem is created by the customer and one percent problem is created by utility. So, there is an argument in between why it is so and customer believes their 70 percent problem is due to the utility.

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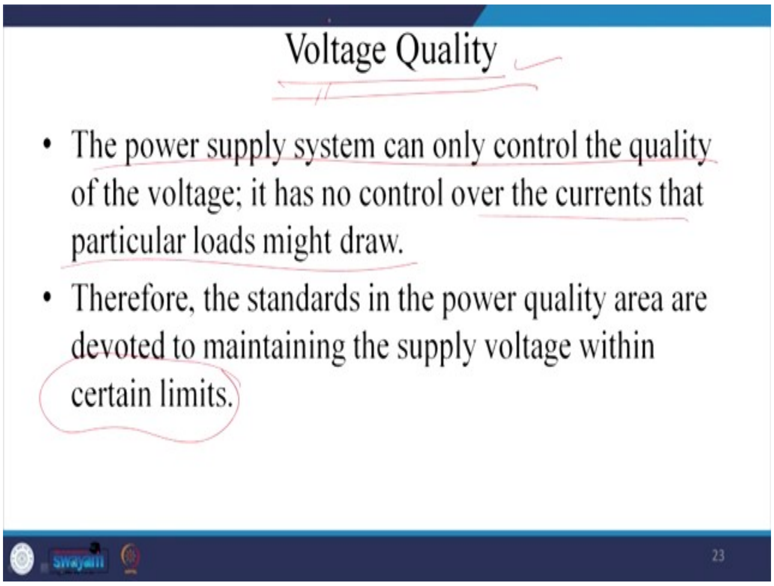

So, then we are required to define the situation. According to the different perception, you can see that there is a blame game to some extent. Customer believes that 70 percent power quality problem is due to the utility, but where utility himself believes that only 1 percent power quality problem is due to them the rest of the 25 percent problem is due to the customer.

So, there is a perception difference of power quality. So, thus we require to understand and identify whose responsibility it's actually is to fix it up, otherwise this blame game will continue. The power supply system can only control the quality of the voltage, it has no control over the current. Generally, load will decide the amount of the current or what the current that particular load might draw. Therefore, the standard in the power quality area are devoted to maintain the supply voltage within the certain limit.

So, we require to maintain the voltage quality and most of the cases we have a voltage source. Current source, artificially we required to make it otherwise we do not have a current source and for this reason the source is voltage and thus we require to trap there, if there is a problem of the voltage then of course, there will be a problem of the power quality.

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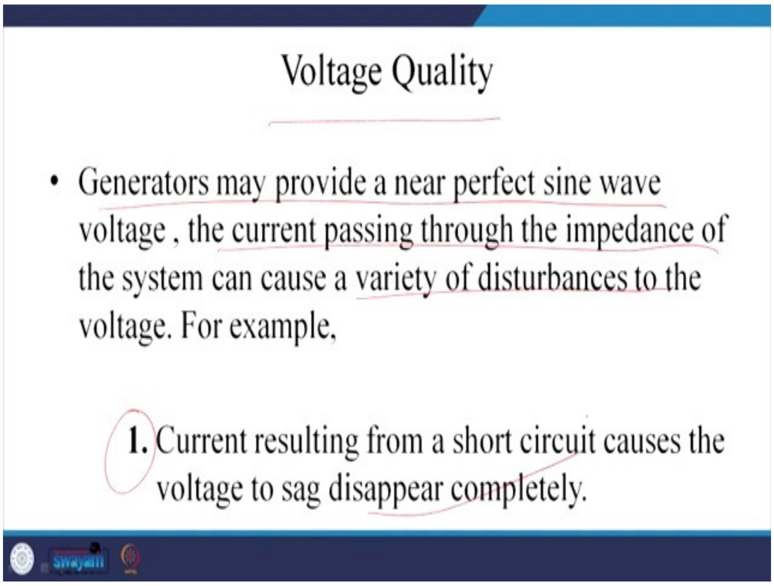

So, what is the voltage part of the power quality? The generator may provide a near perfect sine wave very close to sine wave voltage. The current passing through the impedance of the system can cause variety of disturbances in the voltage. For example, current resulting from the short circuit causes the voltage to sag and disappear completely.

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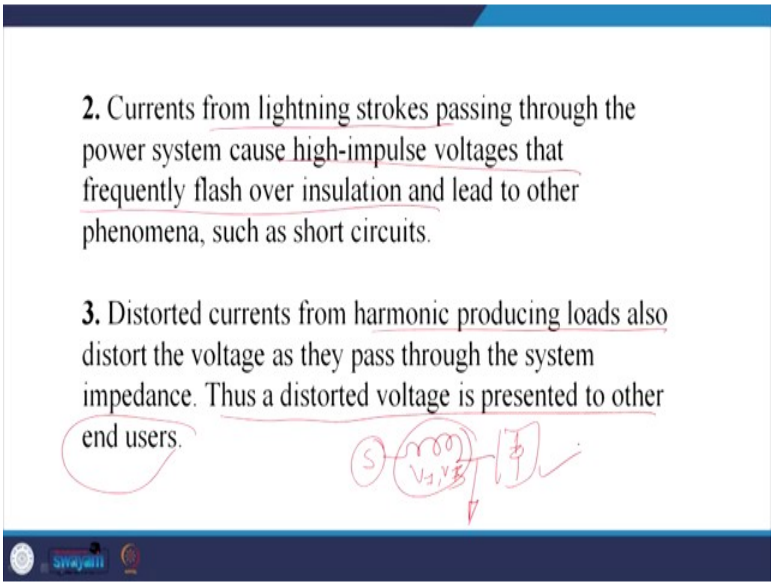

Current from the lighting strokes passing through the power system causes high impulse of the voltages that frequently flash over the insulations and lead to the other phenomena, such as short circuits or trip of the breaker. Distorted currents from the harmonic producing load also distorts the voltage.

Since you have a source, there you got a source inductance and you got a diode bridge rectifier, but these will distort the harmonic, due to the source inductance there will be a seventh and the fifth harmonic voltages as well. So, that will distort the voltage as they pass through the system impedances. Thus, distorted voltage is presented to the end user.

If someone is here they will be getting a distorted voltage. So, now, who is responsible, whether utility or these neighbors? So, this is a matter of perception.

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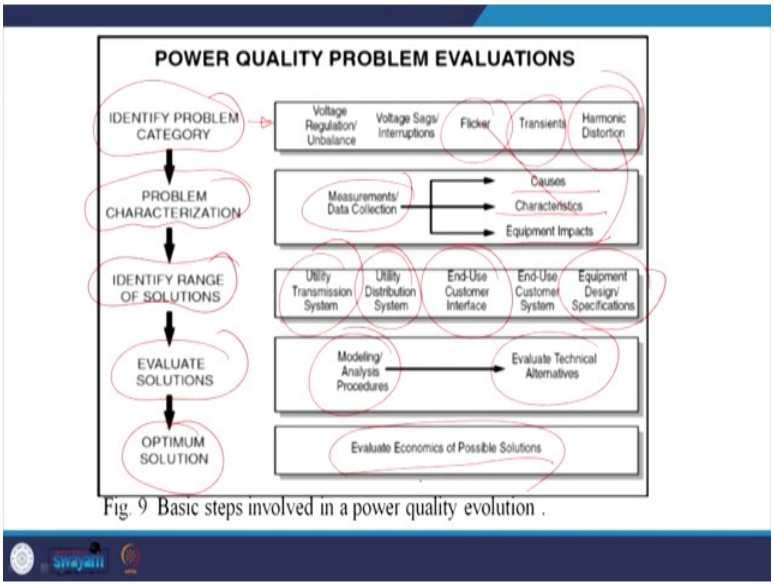

Fig. 9 Basic steps involved in a power quality evolution .

So, this is a power quality problem evaluation chart. So, you have to identify the problem category. Thereafter we have to have a problem characterization. If it is a striking short-term phenomenon, it is a voltage sag. So, you have to categorize it then, identify the range of the solution then evaluate solution and find the optimal solution. This is the way you will proceed.

For example, the voltage regulation unbalance, voltage sag, flicker, transient, harmonic distortion on the THD, these come under this entity of identify problem category. Now problem characterization, measurement and the data collection you require to do to find out whether it is a cause, whether it is the characteristics, or the equipment impact, as THD is a equipment impact, transient can be flicker. So, voltage interruption may be the loss of power.

Then identify the range of the solution whether among utility transmission system, utility distribution system, end user customer interface, end user customer system, equipment design or precipitation who owns the responsibility.

So, this is all we require to revisit and then modeling and analysis then, evaluate the technical alternative for example, shunt active power filter can mitigate the THD problem and evaluate it's economic possible solution. Why not passive why not active? So, you can do the same thing with the passive filter why not you go for the passive entities.

That will be mostly determined by the market condition. This evaluates the economics of the possible solution. Now sources of the power quality problem: load equipment and components. These are I told you previously, are converters.

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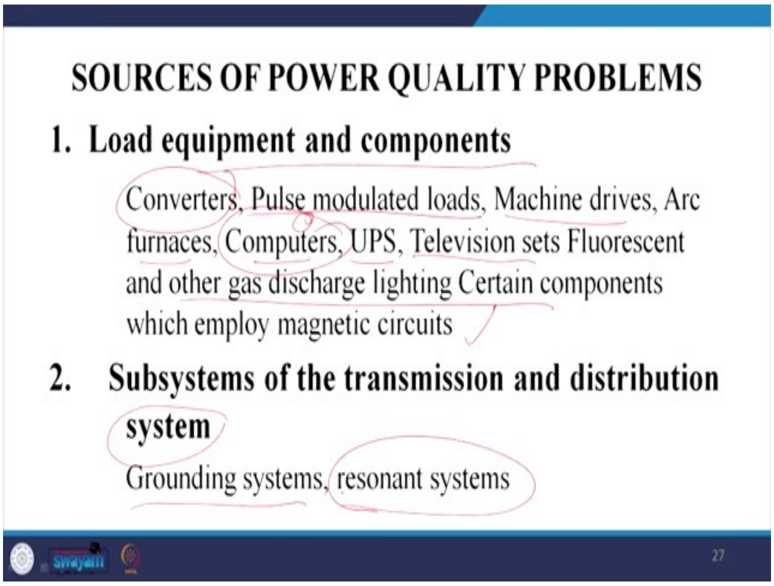

Mostly, it is DC to AC pulse modulated load, machine drives, arc furnace, computers. The computers alone may be actually consuming a very less amount of power, but when you have a for example, in our IIT Rookee campus we have 10,000 students. So, once they go back to their room and everyone turn on their computer desktop or laptop, the power consumed is harmonic power and it is not less. Thereafter uninterrupted power supply, television sets, fluorescent light those are also very nasty elements and also other element such as gas discharge lightings like neon which implies the magnetic circuits.

So, these will deteriorate the power quality. Subsystem of the transmission and distribution system, like grounding system is also important otherwise ground fault will occur earth leakage current will flow and also a resonance system we have to see that, the leakage inductance of the inductor and capacitors for power factor correction may cause an interference, resonance in them, may be fifth or seventh harmonic and thus those harmonic will propagate fast. So, those are the issues we require to capitulate and mitigate.

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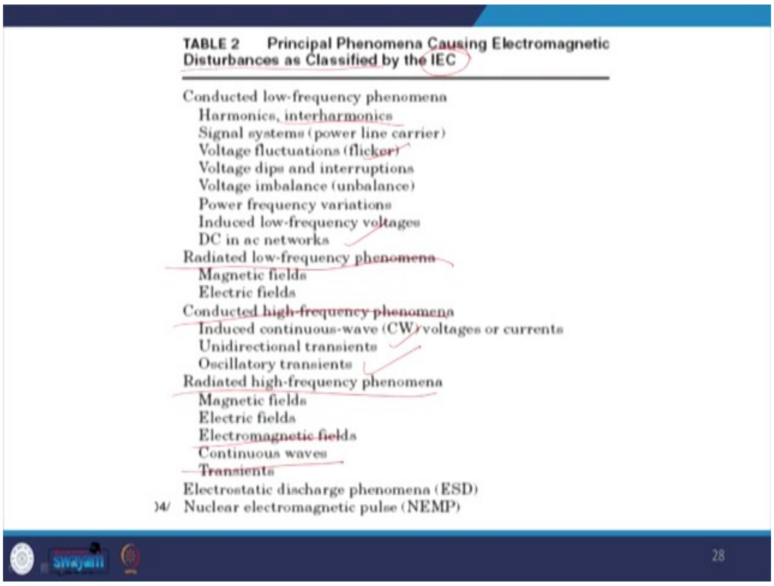

So, I am just showing you this is a table one. I have a separate class for the standard. So, there we have discussed in detail, here I am showing just for the sake of discussion, I will introduce it again. Here conducted the low frequency phenomena, these are harmonics inter harmonics. So, what is inter harmonics, I will define it little later if possible, today. So, signal system, power line carrier, voltage fluctuation these are flickers, voltage dip and interruption, voltage unbalance and thereafter power frequency variations, induce low frequency voltage, DC in AC network.

Thereafter, radiated low frequency phenomena, magnetic field, electric field with that EMI EMC noise, conducted high frequency phenomena, induced continuous wave CW and the voltage current issues, unidirectional transient, oscillatory transient, radiated high frequency phenomenon that is due to the magnetic and electric field and electromagnetic field as well as continuous wave and transients and electrostatic discharge phenomena that is ESD mostly it is used for the electrolytic precipitator and a nuclear magnetic pulses that is for the NEMP.

So, these are the few principle of the phenomena causing the electromagnetic disturbance and for this you have a special standard, that is IEC.

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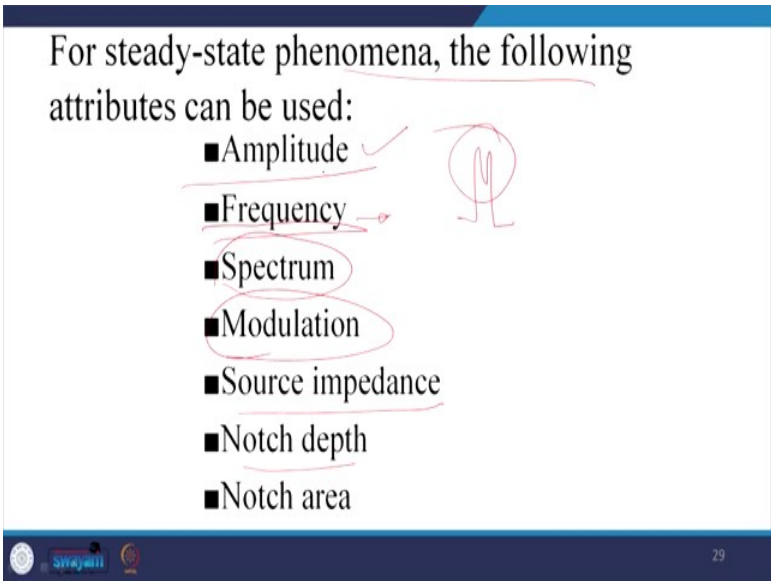

Otherwise this is for the conducted emitted noise and we may talk later whether it is a problem of EMI EMC, but power quality is also the part of the EMII EMC, but we generally talk about more on the THD and other issues here.

For steady state phenomena, these are the following attributes can be used these are like amplitude. If there is a sag or swell of the amplitude, this is the issue of the power quality. If there is a variation of the frequency, then it is an issue of the power quality. If the spectrum varies in case of the let's say you have a hysteresis control then it will be giving a variable spectrum instead of that fixed spectrum in PWM and that also difficult to design, thus the filters.

Modulation, how what kind of modulation strategy you are using and let's say whether you are using FM or AM or something. Source impedance also matters because source impedance can cause give rise to the existing current harmonic, because of the source impedance you get the voltage harmonics and it also effects on how much depth of notch comes. This is the notch.

So, it is flattened this voltage and also the notch area. These are the few attribute we require to consider, if you may vary some notch for the very small interval of time that can be eliminated very fast.

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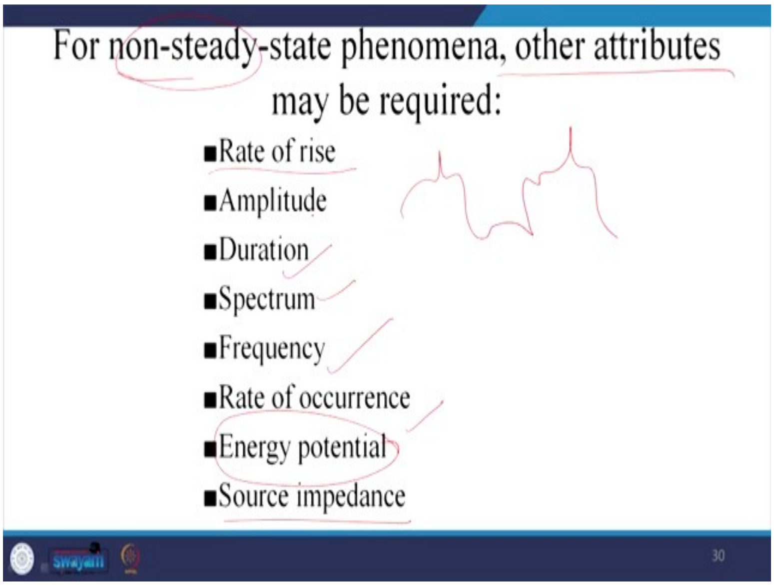

There are other power quality issues related to the non-steady state phenomena and other attributes mainly your transient. So, rate of rise: once you are charging a capacitor, there is rate of rise of it's amplitude, duration, spectrum, frequency, rate of occurrence like you may have a notch here thereafter after five cycles there will be another notch.

So, that is a rate of occurrence and its energy potential and how much energy is associated with it, essentially that is also required to see. It may be a very high spike of high voltage for duration is very small. Hence energy potential is less. Same way the source impedance plays also an important role in rise time of these devices.

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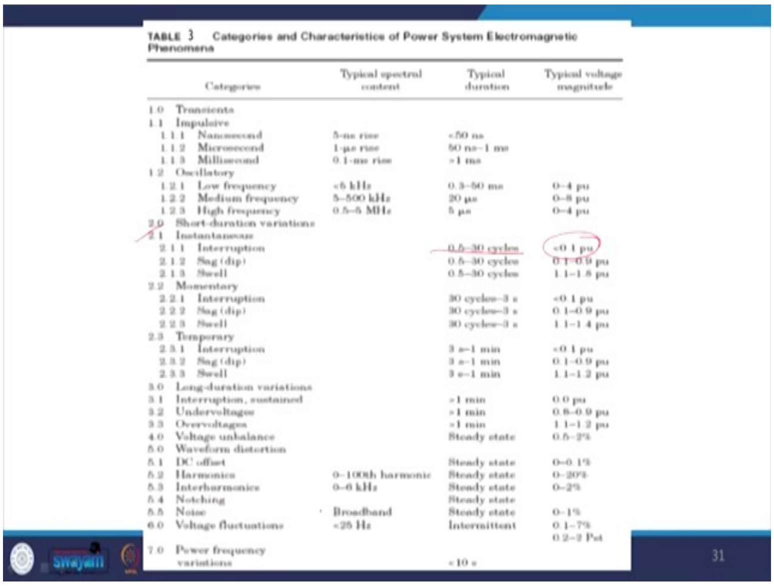

TABLE 3 Categories and Characteristics of Power System Electromagnetic Phenomena

Categories	Typical spectral content	Typical duration	Typical voltage magnitude
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	5-ns rise	<50 ns	
1.1.2 Microsecond	1-μs rise	50 ns–1 ms	
1.1.3 Millisecond	0.1-ms rise	>1 ms	
1.2 Oscillatory			
1.2.1 Low frequency	<5 kHz	0.3–50 ms	0–4 pu
1.2.2 Medium frequency	5–500 kHz	20 μs	0–8 pu
1.2.3 High frequency	0.5–5 MHz	5 μs	0–4 pu
2.0 Short-duration variations			
2.1 Instantaneous			
2.1.1 Interruption		0.5–30 cycles	<0.1 pu
2.1.2 Sag (dip)		0.5–30 cycles	0.1–0.9 pu
2.1.3 Swell		0.5–30 cycles	1.1–1.8 pu
2.2 Momentary			
2.2.1 Interruption		30 cycles–3 s	<0.1 pu
2.2.2 Sag (dip)		30 cycles–3 s	0.1–0.9 pu
2.2.3 Swell		30 cycles–3 s	1.1–1.4 pu
2.3 Temporary			
2.3.1 Interruption		3 s–1 min	<0.1 pu
2.3.2 Sag (dip)		3 s–1 min	0.1–0.9 pu
2.3.3 Swell		3 s–1 min	1.1–1.2 pu
3.0 Long-duration variations			
3.1 Interruption, sustained		>1 min	0.0 pu
3.2 Undervoltages		>1 min	0.8–0.9 pu
3.3 Overvoltages		>1 min	1.1–1.2 pu
4.0 Voltage unbalance		Steady state	0.5–2%
5.0 Waveform distortion			
5.1 DC offset		Steady state	0–0.1%
5.2 Harmonics	0–100th harmonic	Steady state	0–20%
5.3 Interharmonics	0–6 kHz	Steady state	0–2%
5.4 Notching		Steady state	
5.5 Noise	Broadband	Steady state	0–1%
6.0 Voltage fluctuations	<25 Hz	Intermittent	0.1–7% 0.2–2 Pst
7.0 Power frequency variations		<10 s	

Now, this is the categories and the characteristics of the power system electromagnetic phenomena. So, this has been discussed in detail in a separate class of this standard. So, I just give you some value here, pick and choose because detail will be done in that class only. The interruption that is zero to thirty cycle and it is less than point per unit and you can read the slides that impulse durations, it can be in microsecond milliseconds, sag, swell, dip and they have a DC offset harmonics contain bandwidth all those things has been discussed detail into the standard and thus we are skipping it.

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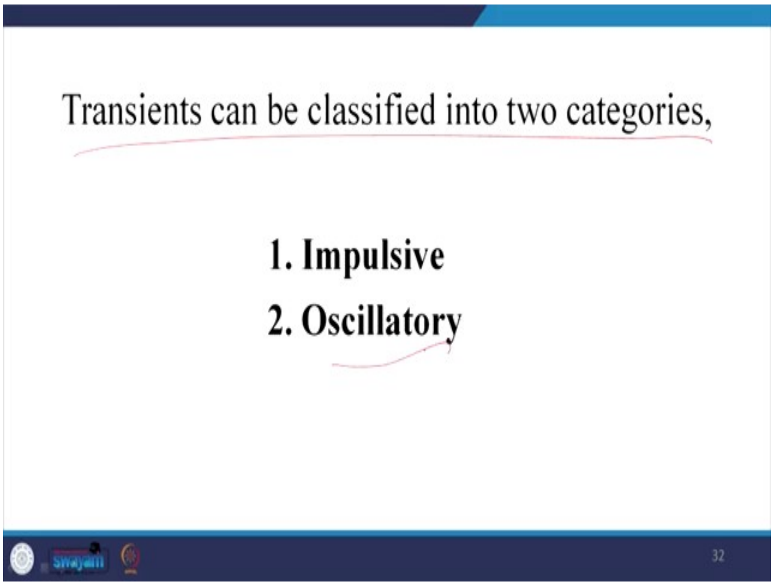

Now, transients can be classified in the two categories. One is impulsive and another is oscillatory.

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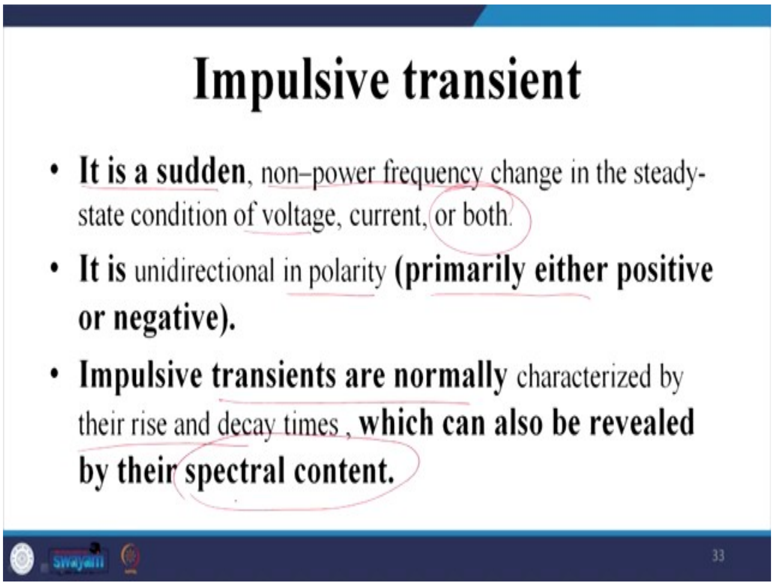

What is impulsive transient? It is a sudden non power frequency mind it, it can be any Hertz, change in the steady state condition of voltage current or both, it is unidirectional in polarity. Generally, it is either positive or negative. Impulsive transients are normally characterized by their rise and decay times, which can also be revealed by their spectral content. So, you required to have a spectral analysis and you can find it out. So, what is rise time, what is delay time, what is other issues like wavelength.

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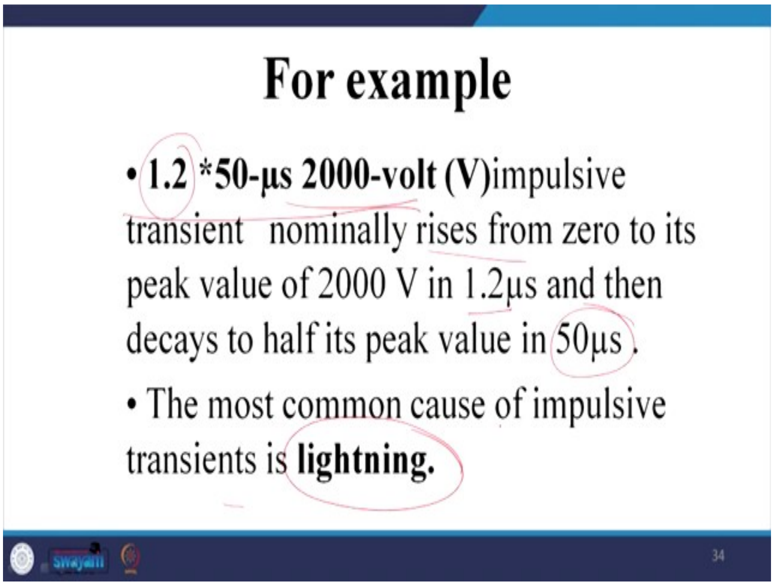

For example, so 1.2 into 50 microsecond and that last for the amplitude of 2,000 volt. Impulsive transient normally rises from Zero to its peak value of 2,000 volt in 1.2 microsecond and then decays half of its peak value in 50 microseconds. If you write like this, it tells like that and most common cause of the impulsive transient is the lighting. So, this is the way we will write.

So, this is a new way of writing it is $1.2*50\,\mu s$ 2,000 volt. So, it means that it's rise time is 2,000 volt and it will decay half of its the peak in 50 microseconds.

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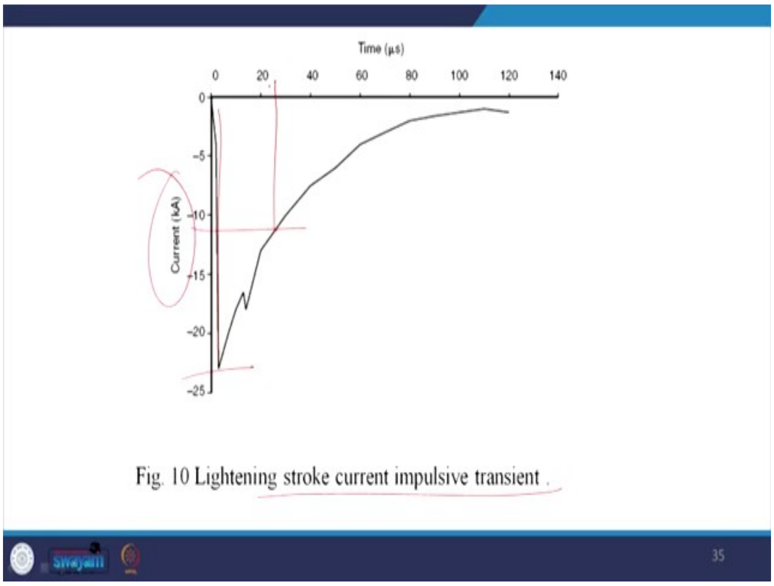

So, this is the example of the lighting stroke current impulsive transient. So, it can be either of the polarity. So, you can see that it goes to some voltage or current in this case this is a current in kilo ampere. So, this is the rise time and you can calculate, what is the rise time here and you have to calculate. So, let's say it is around time-24μs and current-12kA. So, what is the time here? So, this is a way it is generally classified.

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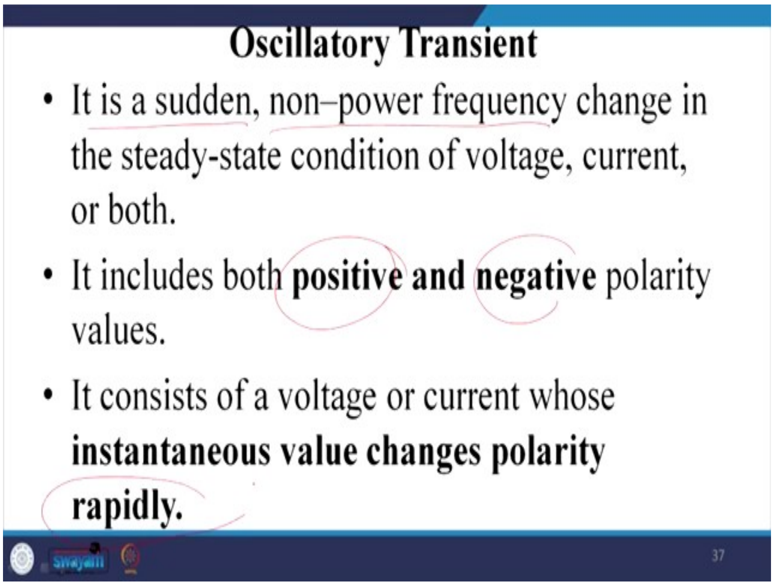

Now, oscillatory transient: it is sudden and its non-power frequency change in the steady state condition of voltage and current or both. It includes both positive and the negative polarity values. It consists of a voltage or current whose instantaneous value changes polarity rapidly.

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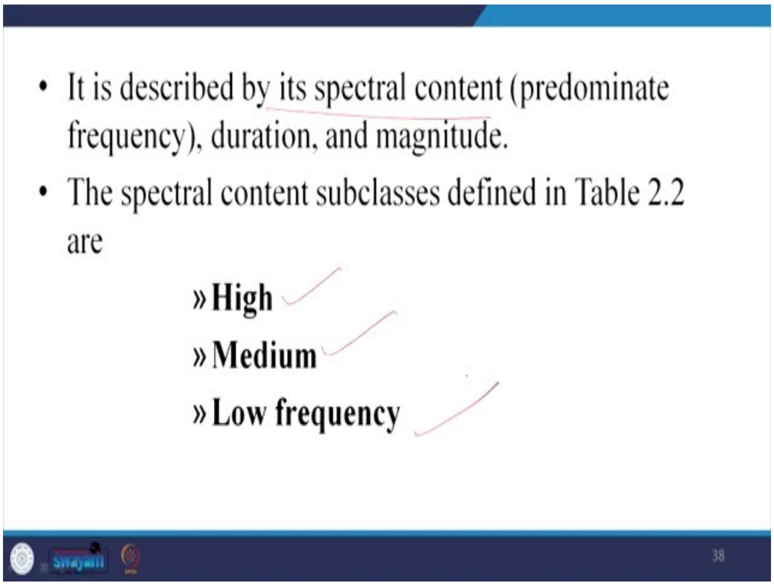

It is described by the spectral content (predominate frequency), durations and the magnitude. The spectral contents subclass is defined are high, medium and the low frequency. These are the classifications of this noise.

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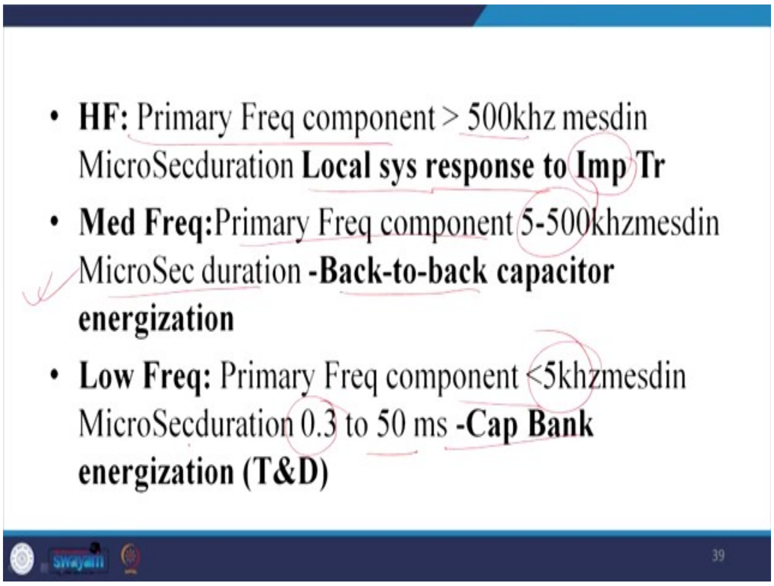

So, oscillatory transient: for example, if it is high frequency, primary frequency component will be 500 kilo Hertz micro second duration. So, local system response to Imp Tr. Med frequency primary frequency component will be in the range of less than 500 kilo Hertz to 5 kilo Hertz. So, microsecond duration back to back capacitor energization, that may cause this mid frequency oscillation and the low frequency oscillation primary frequency component is 5 kilo Hertz measured in microsecond duration of 0.3 to 0.5 microsecond and this is generally again a large capacitor bank in energization.

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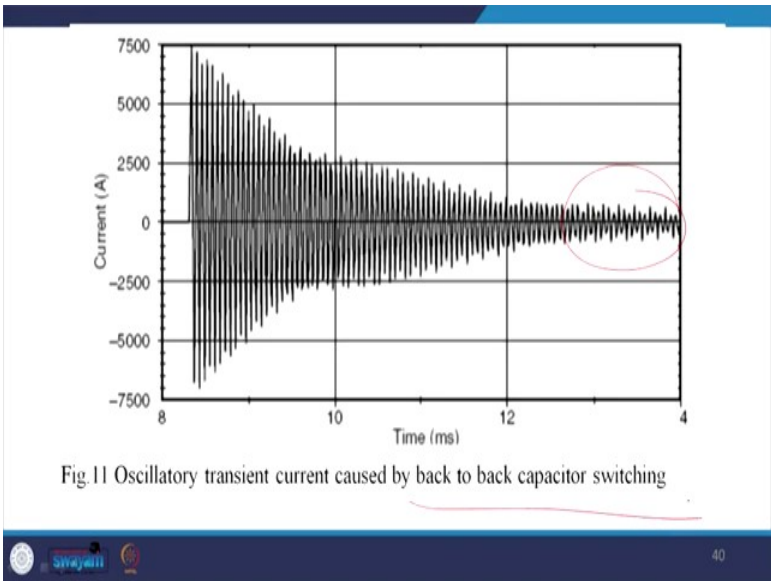

So, this is an example of the oscillatory transient. It will be gradually stabilizing it and it is due to the back to back capacitor switching. I refer all of my students to go to my facts devices courses. There issues of the capacitor switching have been discussed in detail.

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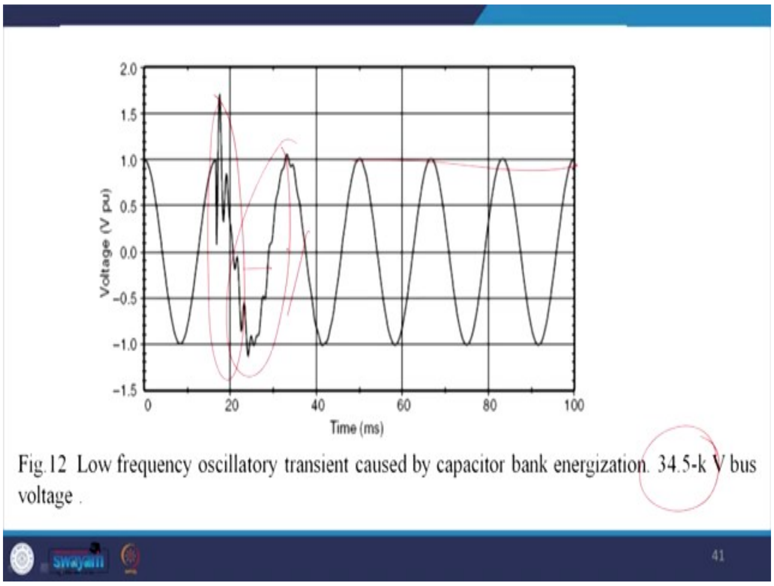

Now, this is the example of the low frequency oscillatory transient caused by the capacitor bank energization that is 35.4 kilo bus voltage. You can see that this voltage is distorted. Thereafter this voltage is distorted. Thereafter again it comes to the smooth oscillatory thing. So, this is a problem, till this point peak of this voltage to this point had a transitory oscillation because of the switching of the capacitor bank.

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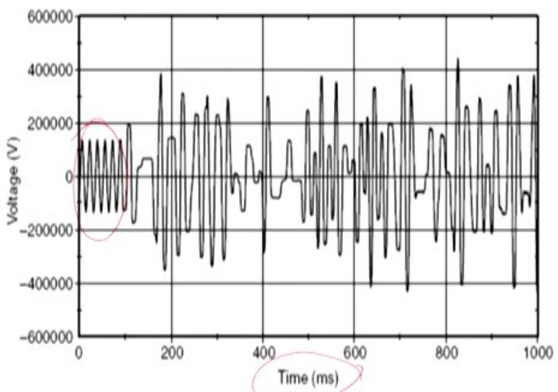

Fig. 13 Low Frequency Oscillatory transient caused by ferroresonance of an unloaded transformer .

Now, this is the example of the oscillatory transient caused by the ferroresonance of an unloaded transformer. So, we may have a leakage transformer, thereafter it can react with the capacitor bank and it may have a resonance for a particular frequency and thus what happens, maybe you get a resonance for the seventh harmonic. So, it may be generated by the adjustable speed drive and thus it was still there and it was ok, all of a sudden you got a resonance and ferroresonance and you got a seventh harmonic oscillation and this kind of phenomena also can be seen in case of the ferroresonance of the unloaded transformer.

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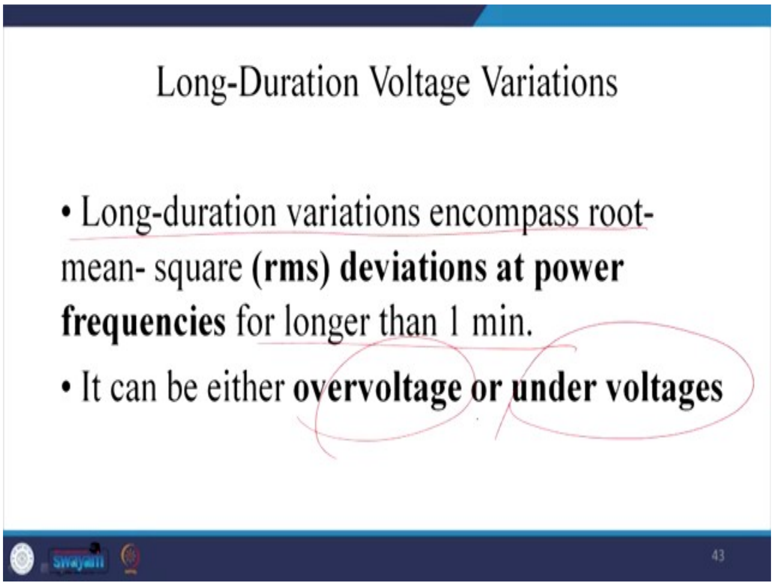

So, there after long duration voltage variations: so, these are the sags and the swells. Long duration voltage variation encompasses root-mean-square deviation at power frequencies for longer than one minute. We will consider that as a long duration voltage variation. It can be either over voltage or it can either as under voltage and it is a sustained duration and that is more than one minute.

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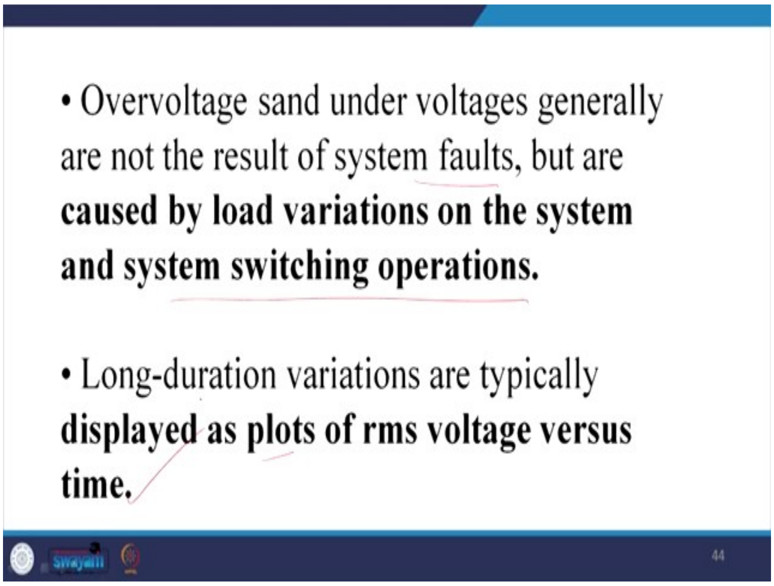

Overvoltage sand under voltage generally are not the results of system faults, but are caused by the load variations on the system switching operations. The long duration variations are typically displayed as plots of RMS voltage versus the time. So, I can show you in the next few figures.

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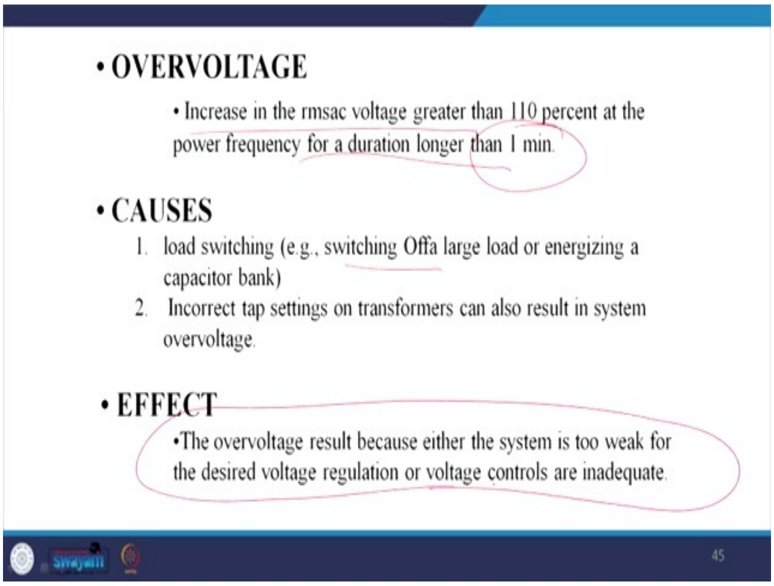

So, first define it, over voltage increases the RMS ac voltage greater than 110 percent at the power frequency for a duration longer than 1 minute. Cause: it may be due to the switching example switching of a large load or energizing a capacitor bank, incorrect tap settings of a transformer can also result in system over voltage. Effect, over voltage results because either the system is too weak for desired voltage regulation or voltage controls are inadequate. So, this is the reasons of it.

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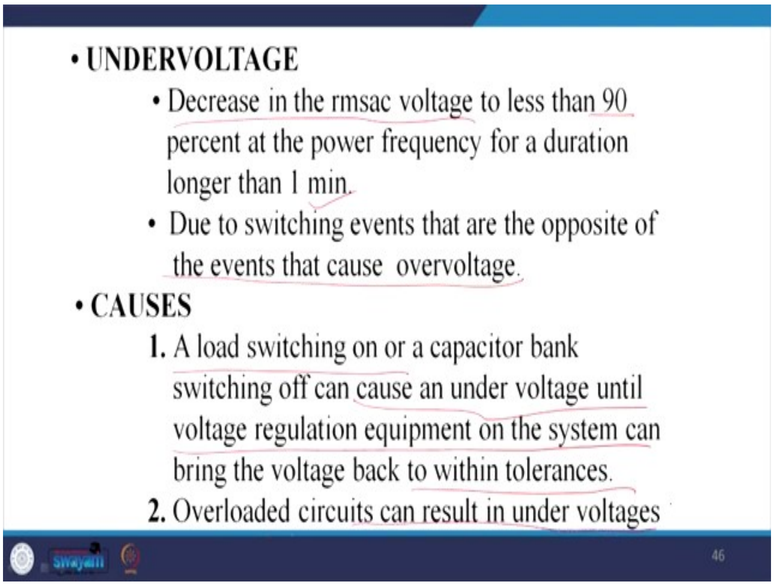

Thereafter, similarly you can have under voltage, defined as decrease in the RMS AC voltage to less than 90 percent at the power frequency for a duration longer than 1 minute. Due to switching events that are the opposite of the events that causes the over voltage. Causes: a load switching on or a capacitor bank, switching off can cause an under voltage until voltage regulation equipment on the system can bring the voltage back to the level of tolerance or within that tolerance level. Overloaded circuits can result in the under voltages.

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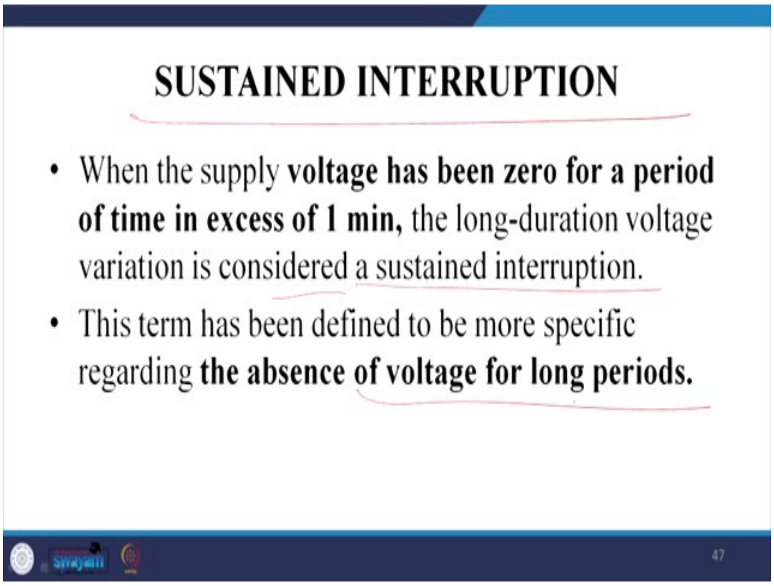

So, another way is a power cut, that is called sustained interruption. When power supply voltage has been zero for a period of time excess of one minute, the long duration voltage variation is considered a sustained interruption. This term has been defined to be more specific regarding the absence of voltage for long periods.

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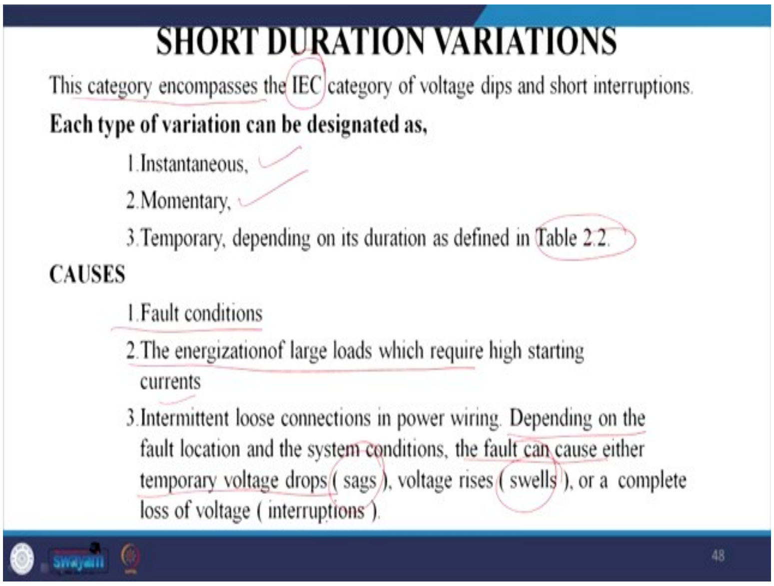

So, now let us talk about short duration variations. This category encompasses, this is the industrial norm in the IEC, voltage dips and the short circuit interruptions and each type of variation can be designed as or nominated as instantaneous momentarily and temporary depending on its duration in table 2.2.

So here this table is 2. The fault condition that can be the cause of this power changes. The energization of large loads which require high starting current also may cause the temporary interruption. Intermittent loss of connections of the power wiring. Depending on the fault location and the system conditions, the fault can cause either temporary voltage drops (for example sag), voltage rise (for example, swells) or a complete loss of voltage (that is interruption).

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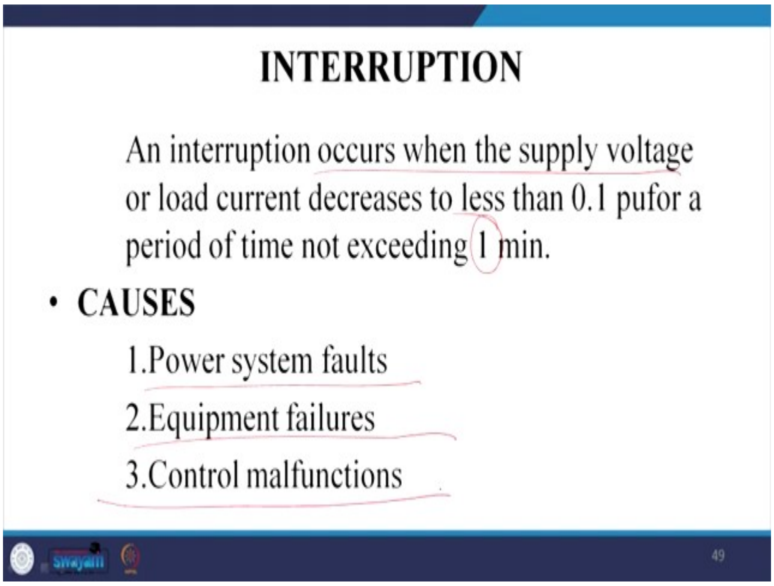

So, what is interruption? An interruption occurs when power supply voltage or the load current decreases less than 0.1pu for a period of time not exceeding 1 minute. Causes: power system faults, equipment failures and the control malfunctions.

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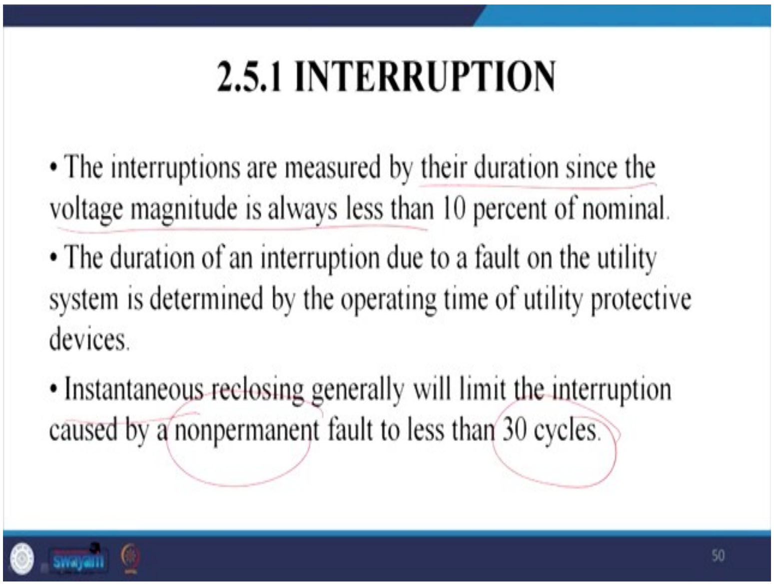

The interruption can be measured by their duration since the voltage magnitude is always less than 10 percent of the nominal voltage value. The durations of the interruption due to a fault of the utility system is determined by the operating time of the utility protective devices. Instantaneous reclosing generally will limit the interruption caused by a non-permanent fault to less than 30 cycles. So, 1 cycle is 20 milliseconds. So, you should be reconnected within 30 cycles, otherwise it is considered to be an interruption.

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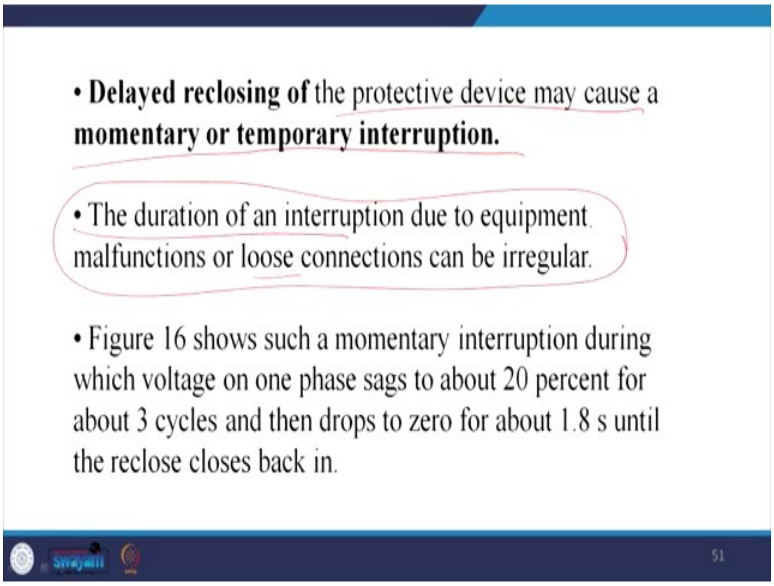

So, delay of reclosing the protecting device may cause the momentarily or the temporary interruption. So, that is also a feasible entity. The durations of an interruptions due to the equipments malfunctions or loose connections can be the irregular pattern of the interruption can also be possible. This you can see very frequent and figure 16 shows the momentary interruption that I am showing here.

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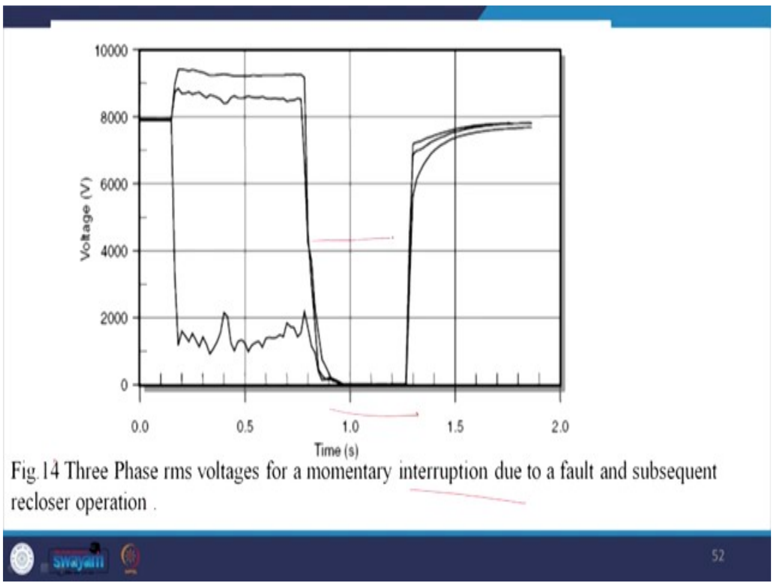

So, here this is the voltage and all of a sudden it has been dropped for interruption again it has picked up this. The 3-phase RMS voltages for a momentary interruption due to a fault at a subsequent recloser operation and thus this is the duration of the interruption.

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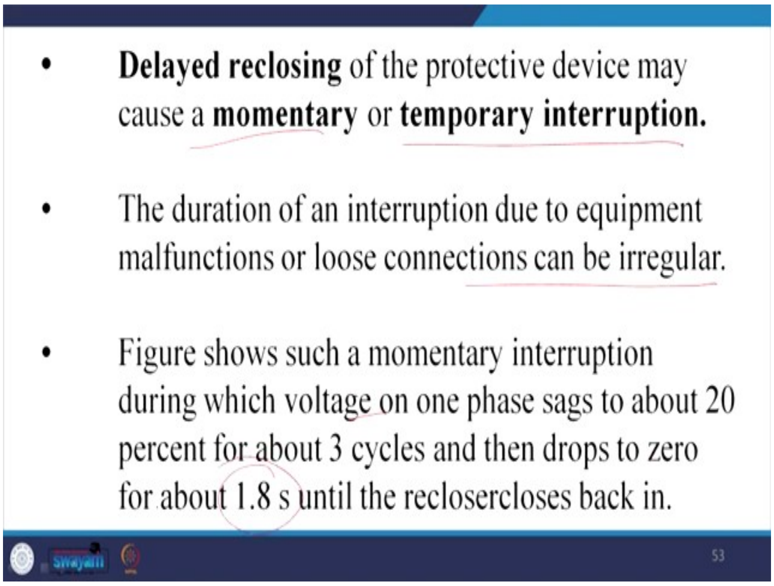

So, let’s just conclude this. The delayed reclosing of the protective devices for example, isolator a circuit breaker may give a momentary or temporary interruption. The duration of the interruption due to the equipment malfunctions or lose connections can be irregular and you may lose the data. The previous figure shows such a momentarily interruption during which voltage on one phase has sags about 20 percent for about 3 cycle and then drops to zero for about 1.8 second and recloses back.

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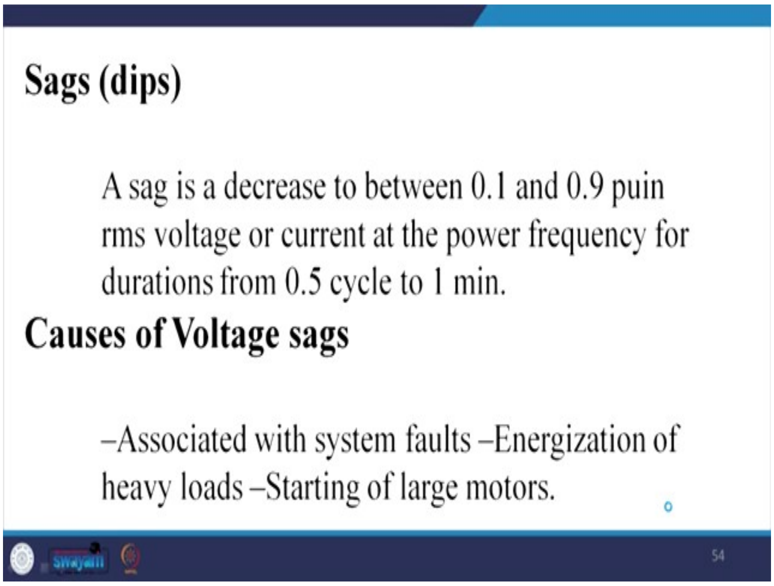

So, this is the issue of interruption. Now next of course, we have to talk about the sag in detail. Sag is a important features of this power quality and there are many causes of the sag. So, we shall take about sag and the phenomena of the power quality entities in our next class.

Thank you for your attention.