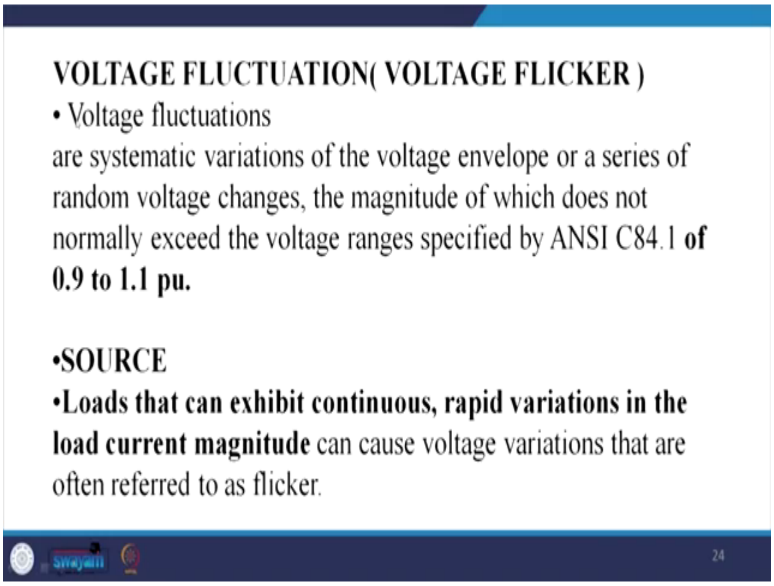
Power Quality Improvement Technique
Prof. Avik Bhattacharya
Department of Electrical Engineering
Indian Institute of Technology, Roorkee

Lecture – 04
Overview – III

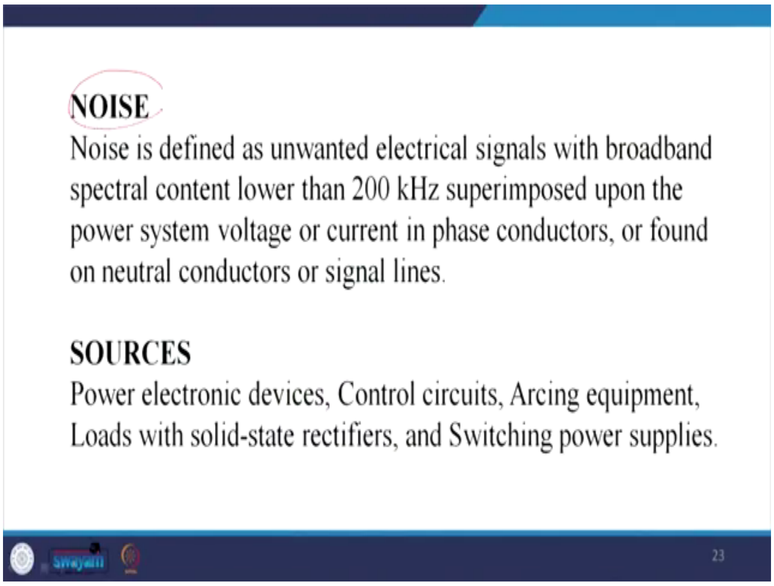
Welcome to our NPTEL lectures on the Power Quality Improvement Technique. We shall continue with our general basic reviews. So, we have discussed about the sag swell and other THD, inter harmonic. Now, we are going to discuss the noise. Though it is a very much problematic for the signals as the SNR ratio is a very important quantity but, we also have a problem of noise in case of a power quality issues.

(Refer Slide Time: 00:56)



So, for this reason if mostly noise comes with the modulating waveform or the carrier waveform, there essentially you get a distorted voltage and current in the output. So, we require to eliminate the noise also. So, although noise may be a very low power entity in the power engineering, but it may cause us serious disturbance into the system.

(Refer Slide Time: 01:34)



So, noise is defined as unwanted electrical signals with the broadband spectral content lower than 200 kHz (Since because of the high frequency its amplitude is quite low, but it may contaminate the system very well) superimposed upon the power system voltage or current in phase of conductors, or found in the neutral conductors and lines.

Sources are definitely the main culprit, which are power electronic devices. Source is mainly the control circuit of this entity and if the control circuit contains the noise, which is essentially inverter that essentially amplifies. Whatever the control circuit you give, the modulating signal amplifies. So, thus what happened if you have a noise into the control circuit this will be amplified by the power electronics devices.

Definitely source will be the control circuit, others are arcing equipment, loads with the solid-state rectifier and switching mode power supply or SMPS or switching power supplies. Now, let us define that voltage fluctuation, please note that this is different from the sag and swell. So, we have a different condition for the fluctuations.

The voltage fluctuations are systematic variation of the voltage envelope (within some smaller range) or a series of random voltage changes, the magnitude of which does not normally exceed the voltage range specified by ANSI C84.1 and generally this range is restricted to 0.9 to 1.1pu. So, this is the range which once it is happening, then we say that voltage fluctuation, neither sag or swell.

So, for this reason sag is 0.9 to 1 and swell is also 1.1 to 1.8. Within that if you have a variation then we say that it is a voltage fluctuation. Of course, the source of this fluctuations are loads that can exhibit continuous, rapid variations in the load current magnitude (it happens in a highly accelerated machine in case of the adjustable speed drive) can cause of a voltage variation that is referred as a flicker also.

(Refer Slide Time: 04:32)

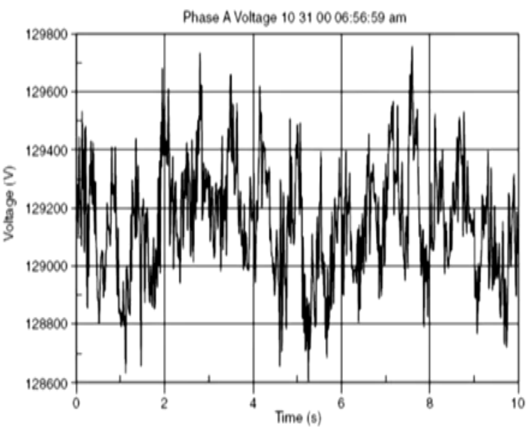
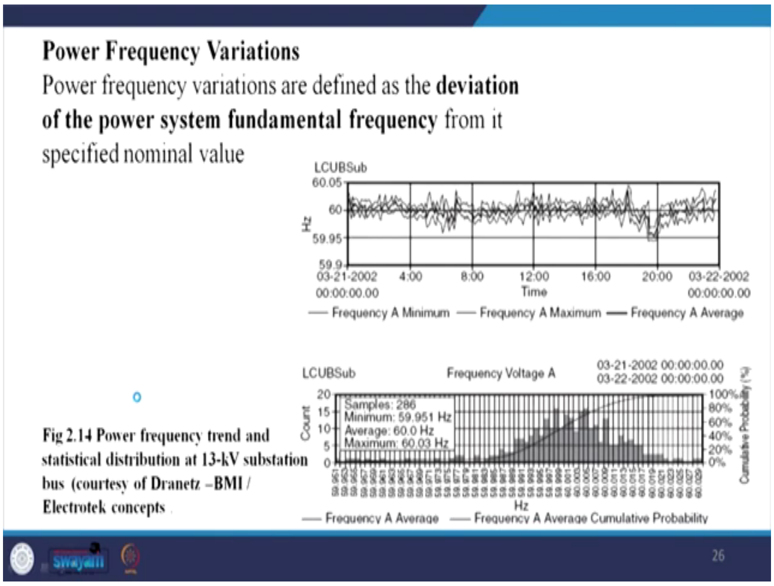


Fig 2.12 Examples of voltage fluctuations caused by arc furnace operation

This is the case; we have taken this waveform for voltage fluctuation caused by the arc furnace operation. So, you can see that voltage fluctuates and this fluctuation of voltage is within this 0.9 to 1.1 range. This is the arc furnace operation.

(Refer Slide Time: 05:03)

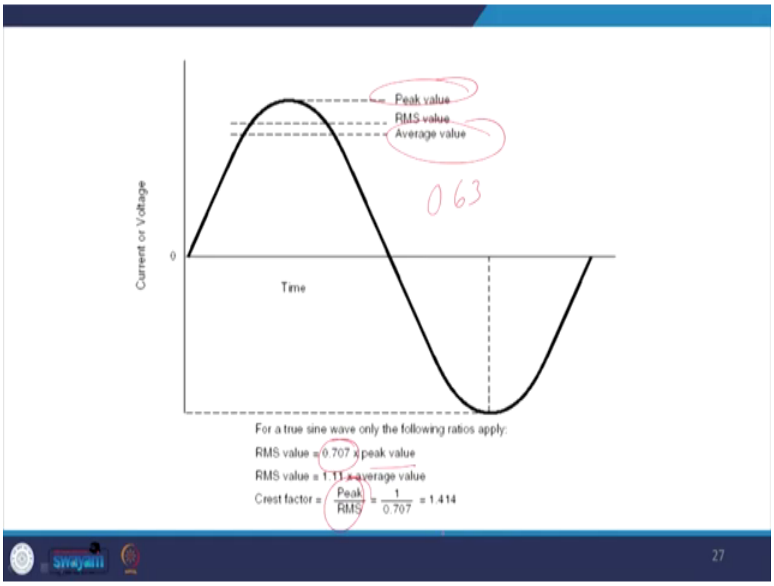


Now, this is a power frequency variation and are defined as a deviation of the power system fundamental frequency from the specified nominal value. So, this is the minimum frequency, this is a maximum frequency and this is average frequency. We have considered a US system so, there is 60 Hertz variations. There you can see that you can have a maximum frequency variation up to 60.05 to 49.5.

So, once it is little light load, it can have that value 60.05, once it is highly loaded it will come down to here and this is a hour wise data this is 4 to 8, 8 to 12 and the 24 hours whole day data, this is a variation of the frequency daily. And, this is a frequency of this as you can see that time tag data that is a sample is 286 and minimum frequency has been noted.

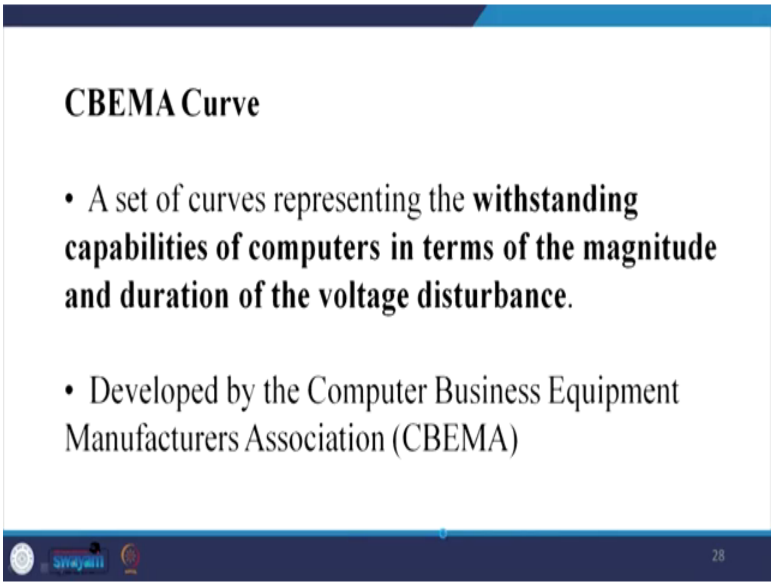
It is 59.95, average is of course 60 that is what US system frequency is and maximum is this thing and this is the time tag data of various entity and this is a way it varies. So, power frequency trend in a statistical distribution in the 13 kV substation mind it we have a multiple of 11, hence they have a little different kV substation bus and courtesy to this company.

(Refer Slide Time: 07:06)



So, we defined something, this is the peak value and we know it very well that this is current or voltage and this value is RMS value that is 0.707 and this has average value that is 0.63 and the ratio is called form factor. So, thus RMS value is 0.707 into peak value and the RMS value equal to 1.1 into average value and the crest value is a peak by RMS is 1.414 that you know quite well. So, based on that those calculation required to be done.

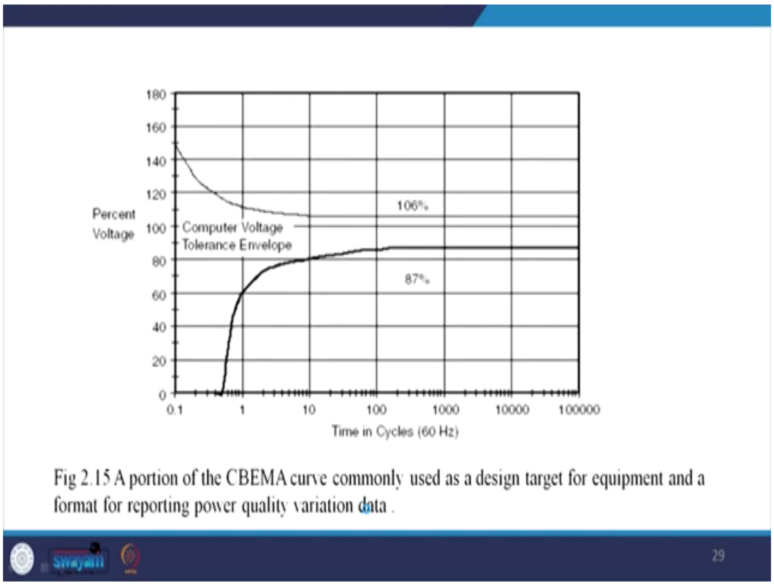
(Refer Slide Time: 07:52)



Now, most of the power quality problems comes from the computer manufacturer and that is something we required to see, for this reason, we have a CBEMA curve. So, essentially the computer manufacturer companies get into a system and designed a power quality issues because ultimately computer manufacturers were blamed for deteriorating power quality by the utility and as a result a blame game started.

To protect themselves, they then come out with a standard and say that you require to maintain this kind of power quality for these devices otherwise this sensitive equipment like computers will not operate. There is a whole battle between the GEE and the IBM. A set of the curve representing the withstanding capabilities of the computers in terms of the magnitude and the durations of the voltage disturbance, and this is developed by computer business equipment manufacturers association predominantly lead by the IBM. So, this is the CBEMA.

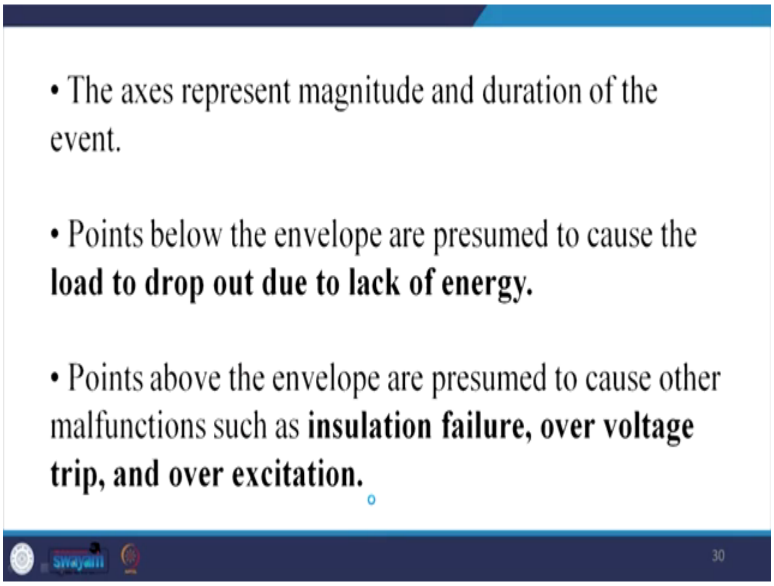
(Refer Slide Time: 09:18)



Now, you can see that this is a percentage of the voltage and this is the computer voltage tolerance envelope. A portion of the CBEMA curve commonly used as a design target for equipment and a format reporting power quality variation data. So, this is a computer tolerance graph. This is the 100 percent and for the small time this is the cycles in seconds. So, for one cycle you can have this much of high voltage and you can also have this kind of low current and gradually it will match.

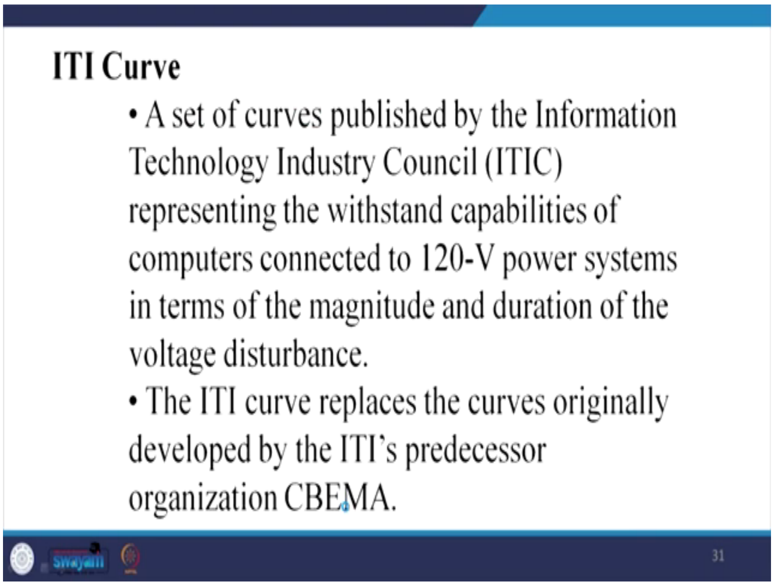
So, you have to maintain around 87 percent of the voltage or 6 percent higher voltage for the manufacturer of this computer devices. So, this kind of data has been given to the utility and the utility required to maintain this amount of the voltage precision in the output.

(Refer Slide Time: 10:35)



So, let us describe this, the axes represent the magnitude and duration of the event, the points below the envelope are presumed to cause the load to drop out due to lack of energy. The points above the envelope are presumed to cause other malfunctions such as insulation failure, over voltage trip and over execution.

(Refer Slide Time: 11:01)



So, now there after this ICBEMA curve has been little modified. So, now the computer manufacturers all over the world follows this ITI curve. It is a set of the curve published by the information technology industry just they change the name from the computer to the information technology industry council that is ITIC representing the withstanding capabilities of the computers connected to then 120-volt power systems in terms of the magnitude and duration of the voltage disturbance. The ITI curve replaces the curves originally developed by ITI's predecessor organization CBEMA.

(Refer Slide Time: 11:53)

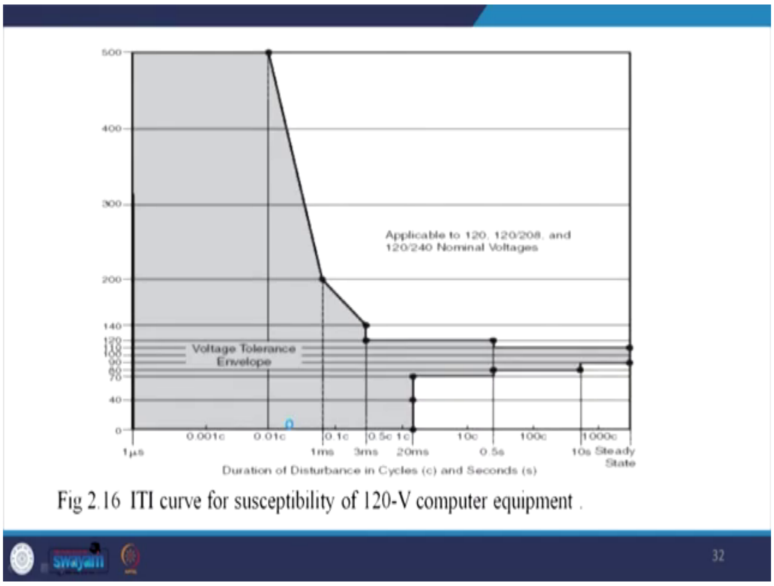


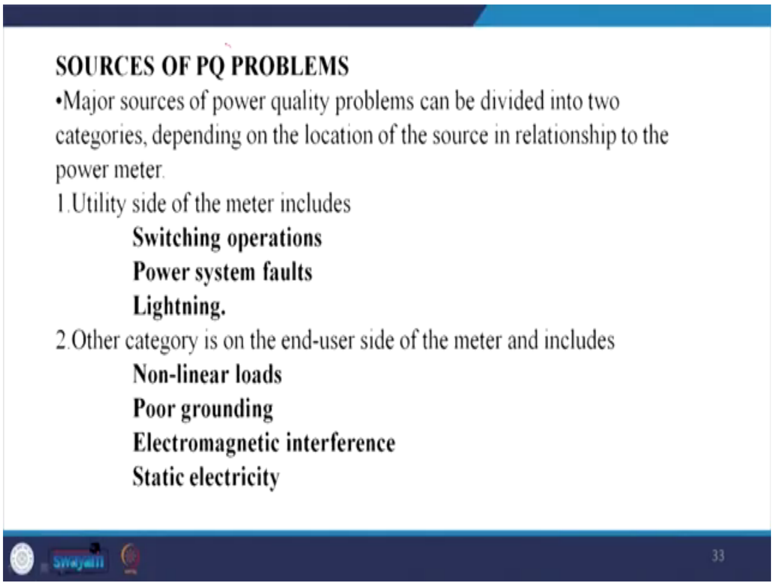
Fig 2.16 ITI curve for susceptibility of 120-V computer equipment .

So, this is something quite elaborate curve. So, this is for the cycles, you can have 5 times more 5 per unit voltage for the very small amount of time that is for the 0.1 cycles, then within 1 millisecond it has to be brought down to a 200 percent, then in the next 3 millisecond we have to brought to the same value.

Same way if there is a sag then within a 20 millisecond you have to bring these voltages to 70 percent, thereafter after a point in 0.5 second you have to bring it to the 80 percent, 90 percent and so on and thereafter close to 90 percent voltage. For the higher voltage tolerance as well, it is 105 volt and for lower voltage also 105 percent and 95 percent in a steady state value.

So, this is the ITI curve that the computer manufacturer association follows and once they supply and thereafter if your computer has been damaged then of course they have to take responsibility. But they will get an escape route, if this voltage criteria were not fulfilled by utility and they will pass on the bug to the utility. So, you have to ensure that this kind of power quality has been maintained by that utility system while feeding a computer load.

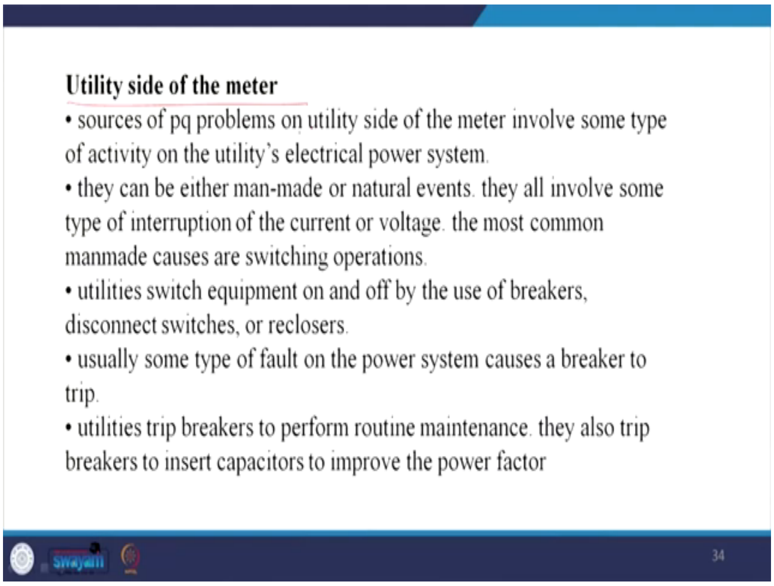
(Refer Slide Time: 13:50)



Now, let us come to the real problem. We have been discussing the different kind of mode of operations and other issues. Now, we will talk about the PQ problem that is the real power and the reactive power problem. The major sources of the power quality problems can be divided into the two the categories, depending on the location of the source in relationship to the power meter.

One utility side meter includes switching operations like you change over the isolators, power system faults, lightning and other categories are mainly for the user ends that includes the non-linear load, poor grounding. So, there is an oscillation of the neutral point that also leads to some kind of problem in case of the power quality. Electromagnetic interference and the static electricity. So, these are of another category that causes the problem mainly in the PQ.

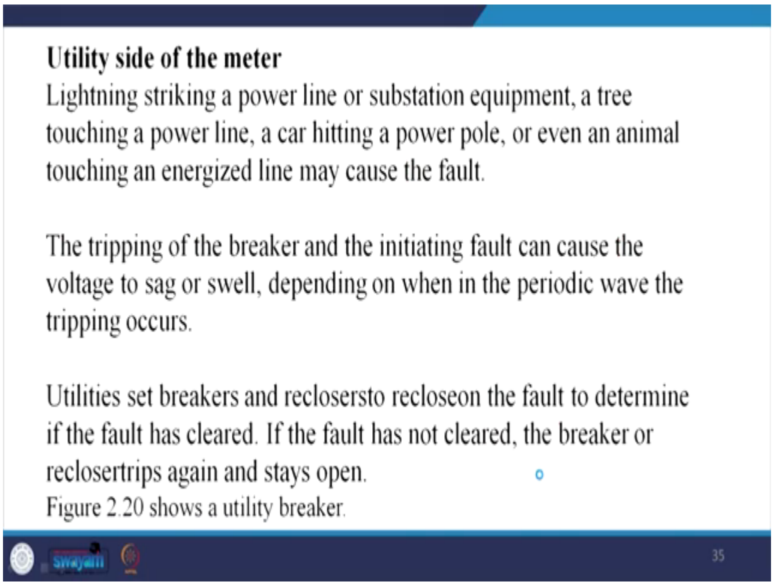
(Refer Slide Time: 15:06)



So, let us see in a utility side of the meter that is some time called also statistical metering. Source of the PQ problem on the utility side of the meter involve some type of activity on utility's electrical power system. They can be either man-made or the natural events like lightning strikes and all those things. They all involve some type of interruption of the current and voltage. The most common man-made causes are switching operations.

Utilities switch equipment on and off by the use of the circuit breakers, disconnect switches or the reclosers – these are the activity. Usually some type of fault on the power system causes a breaker to trip. For example, we have taken so many examples of this single line to ground fault. Utility trip breakers to perform routine maintenance. They also trip breakers to insert capacitors to improve the power factor. So, that is something quite important.

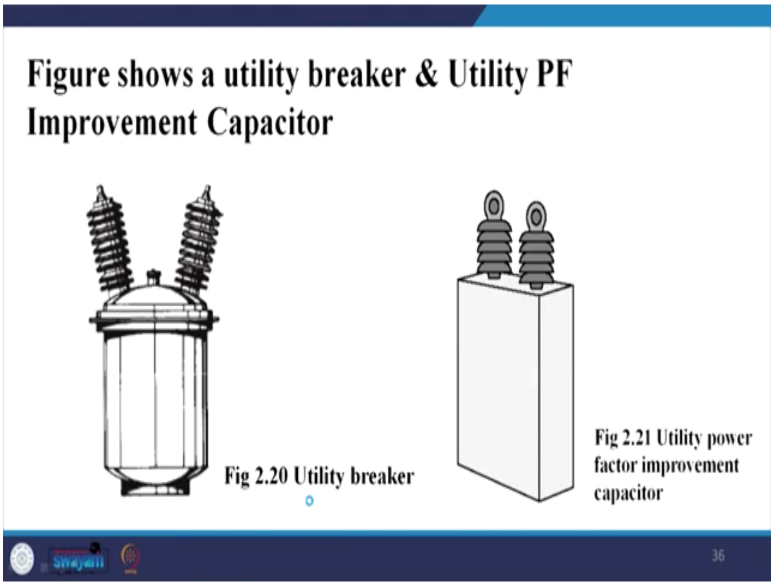
(Refer Slide Time: 16:35)



Utility side of the meter. Now, lightning striking a power line or a distribution system are definitely some of the natural causes, a tree touching the power line, a car hitting the power pole or even an animal touching the energized line may cause the fault. So, these are the causes.

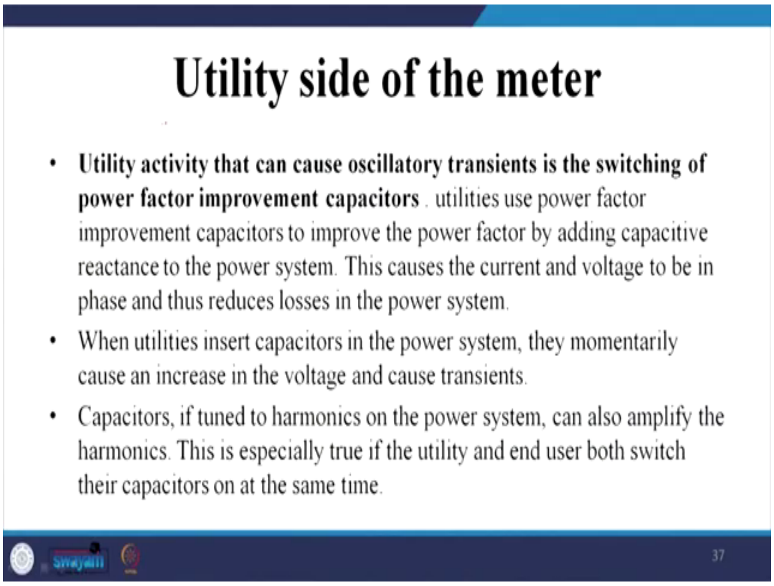
The tripping of the breaker and initiating a fault can cause the voltage to sag in one line and thus voltage swell in other line depending on when in the periodic the tripping occurs. The utilities set the breakers and recloser to reclose on the fault to determine if the fault has been cleared, if fault has not cleared the breaker or the reclosers trips again and stays on.

(Refer Slide Time: 17:48)



So, let us see the utility circuit breaker you are well known. So, this is a picture of the utility circuit breaker and unity power factor improvement capacitor. So, these are the entities, once you switch on or switch off there has to be a transient and that causes a power quality problem into the system that can be sag, swell or sustain oscillation, fluctuations anything.

(Refer Slide Time: 18:24)



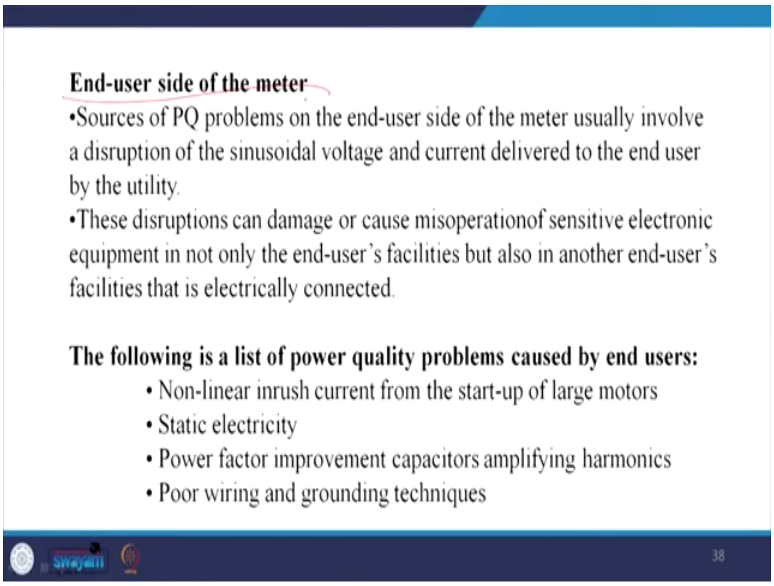
Now, let us come to the role of the utility side of the meter. Utility activity that can cause oscillatory transient that is what I was saying, is the switching of the power factor improvement capacitors, mainly we have discussed in a separate class that issues of the capacitor. Utilities use power factor improvement capacitor to improve the power factor by adding capacitive reactance to the power system. Since predominantly we have the inductive power system.

This causes the current and voltage to be in phase thus reduces losses in power system. When utilities insert capacitor in the power system, they momentarily cause an increase in the voltage and causes transients. Capacitors, if tuned to harmonics on the power system, they can also amplify the harmonics that is also a problem.

So, this is a problem that we will discuss in detail in case of the passive filters. Why active filter is preferred over the passive filter? there we will dedicate the whole lectures on the designing of the passive filter. One of the major disadvantages of the passive filter is that if it is tuned to the particular harmonic it may cause a resonance with the leakage inductance of the capacitor and this capacitor bank. That sets up the resonance and it acerbated by the presence of the that particular harmonic which you want to attenuate.

This is especially true if the utility end user both switch their capacitors at the same time. So, that is the challenge here and we required to damp out the oscillation. That is also a major challenge of the power quality.

(Refer Slide Time: 20:46)

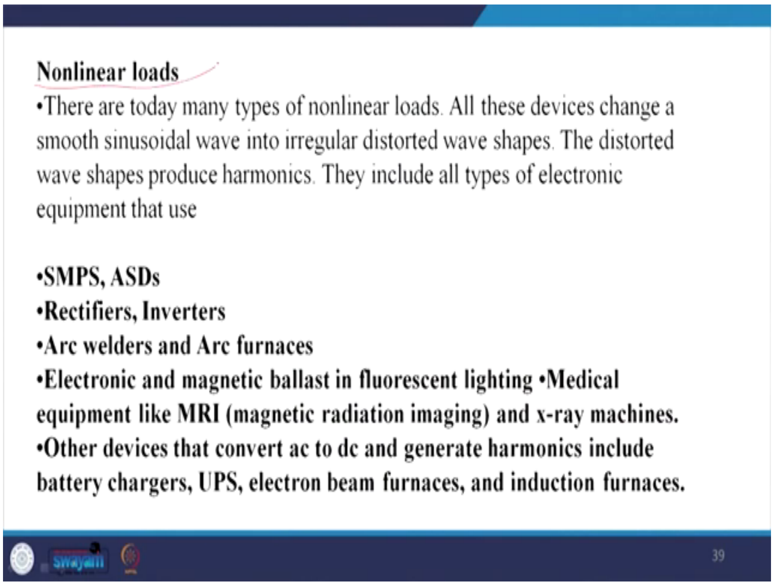


The end user size of the meter. what does it do? Sources of PQ problems on the end-user side of the meter usually involve a distortion or disruption of the sinusoidal voltage and current delivered to the end-user by the utility. These disruptions can damage or cause maloperation of the sensitive electronic equipment in not only the end-user's facilities but also in another end user's facilities that is electrically connected.

So, following is the list of the power quality problems that is generally caused by the end-users or the consumers. The non-linear mostly for the industrious, not the common man. The non-linear inrush current from the startup of large motors, static electricity, power factor improvement capacitors amplifying the harmonics, and poor wiring and the grounding. Poor wiring may lead to the increase in inductance.

So, you have to put the wiring in such a way that anti-parallel current flows and your inductance can minimize or mitigates the flux. Same way for the grounding, if it is not properly grounded the neutral point will oscillate that also leads to the power quality problem.

(Refer Slide Time: 22:31)

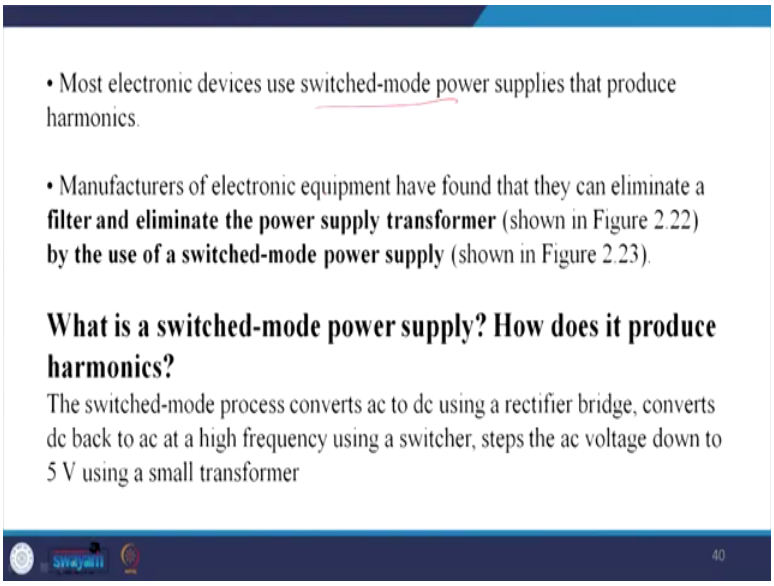


So, the nastiest entity is the non-linear load. There are today many types of non-linear loads. All these devices change the smooth sinusoidal waveform into irregular distorted wave shapes we have seen a waveform of the adjustable speed drive. These distorted wave shapes produce harmonics. They include all type of electronic equipment.

And, these are SMPS – switch mode power supply, ASDs that is adjustable speed drive, rectifier, inverter, arc welder and the arc furnace, electronic and the magnetic ballast that is used for the fluorescent light, a medical equipment like MRI – magnetic radiation image and the x-ray machines, other devices that convert ac to dc and generate harmonic includes battery charger, UPS, electron beam furnace and induction furnaces.

So, list is very big I just captured few of them. So, all are coming under the category of the non-linear load. So, we require to see that how we can mitigate those.

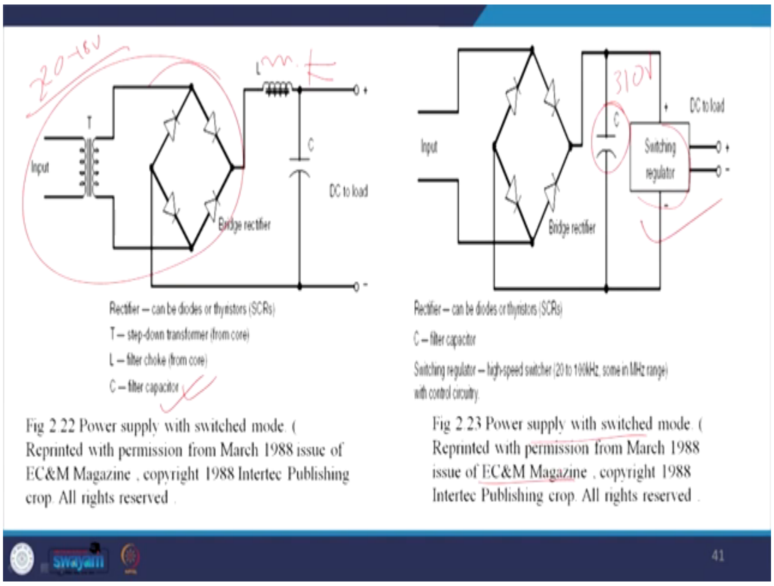
(Refer Slide Time: 24:06)



Most of the electronic devices use switch mode power supply to produce harmonic. So, essentially it is kind of a rectification, they are mostly ac to dc converter and it will produce lot of harmonics in the system. The manufacturers of the electronic equipment have found that they can eliminate a filter and eliminate the power supply transformer (we will show in the next figure) by the use of the switch mode power supply.

And, so let us see that. What is the switch mode power supply and how does it produce harmonics? The switched mode power process converts ac to dc using a rectifier bridge, converts dc back to ac at high frequency using a switch, steps down to the dc voltage for the small transformer.

(Refer Slide Time: 25:31)

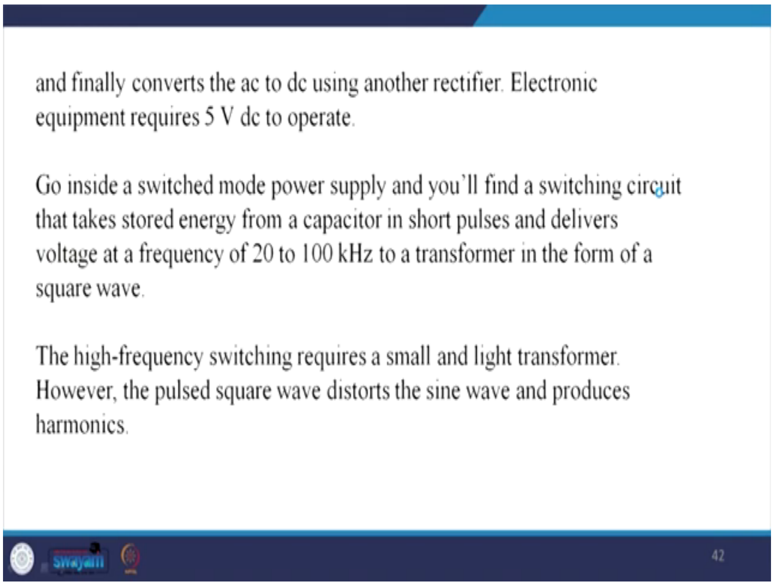


This is the case of this power supply issues. So, this is a normal rectifications and thereafter you will have a ripple dc here and after filter you have a constant dc here and since it requires a bulky transformer we tried to get rid of this 50 Hertz transformer instead of that we wanted to have a SMPS here.

So, this is the normal rectification there we generally use in case of our project work there it is a 220 volt to the 18volt supply something like that, instead of that we prefer SMPS. We rectify it and ultimately this is a 310 volt for India because it will almost remain to the peak value of it not that average value, if it is not loaded.

Then, you have a switching regulator that can be a high frequency dc to dc converter. Since it is a high frequency, entity will be compact. So, that is what has been described in the lectures. So, rectified diode can be thyristors or diode depending on the controlled rectification or not and this is the power supply and it is been reprinted by this magazine anyway courtesy to them. So, this uses the SMPS.

(Refer Slide Time: 27:11)

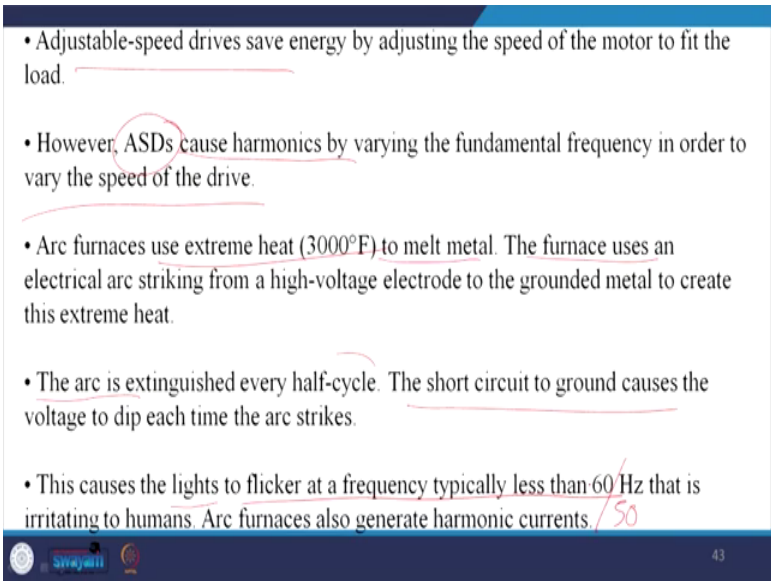


Finally, what does it do? It converts ac to dc using another rectifier. An electronic equipment requires a 5volt dc to operate. Nowadays we have a different kind of voltage in your USB. So, once you charge your mobile from your computer USB, it gives you the 5 volts. So, how it has generated this way?

So, if you go inside the switch mode power supply, you will find a switching circuit that takes stored energy from the capacitor in a short pulse and delivers the voltage at a frequency of as high as 20 kilo Hertz to 100 kilo Hertz to a transformer in the form of a square wave. So, that required a high frequency transformer. This high frequency switching requires a small and light transformer which is the advantage of it.

So, you got a compact system, for this reason nowadays all your laptop chargers, all your mobile chargers are of this entity. However, this pulsed square wave distorts the sine wave and produce the harmonics. If possible, try to see in your lab, you have to maybe destroy your laptop charger but just try to see that what kind of current you are taking once you operate your laptop. So, you will find that a lot of distortion is present into it due to the SMPS.

(Refer Slide Time: 29:06)



Another element, these are adjustable speed drive saves energy by adjusting speed of the motor to fit the load, generally it is a V/f control or the vector control. So, it can generate a variable speed and you may require a constant torque for example hoisting. Then, it is a perfect match, but essentially, we have a constant frequency supply.

So, first we may have a direct matrix converter also, but instead of that if you convert to intermediate ac dc ac conversion then however, adjustable speed drives cause harmonic by varying the fundamental frequency in order to vary the speed of the device. Same way the arc furnaces uses extreme heat around $3000^{o}F$ to melt metal. The furnace uses an electrical arc striking from a high voltage electrode to the grounded metal to create this extreme heat and there also sometimes current flow sometime does not.

So, intermittent current causes a lot of problem. This arc is extinguished every half cycle, again that is one problem as this is discontinuous in nature. In every half cycle the short circuit ground causes the voltage to dip each time the arc strikes. So, voltage develop falls.

So, fluctuating current voltage we have seen, it is due to the arc furnace and this cause the lights to flicker at a frequency typically less than 50 or 60 Hertz. 50 Hertz in India, that is irritating to the human mostly, this is called the stroboscopic effect and this will generally harm the productions also in a company. Arc furnace also generate harmonic current and that required to be mitigated by some means.

Thank you for your attention. We shall continue our discussions and we have left with another few chapter to give you the overview or the scope of the power quality in our next class.