Power Quality Improvement Technique
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Lecture - 06
Source of Poor Power Quality – II

Welcome to our NPTEL course on the Power Quality Improvement Technique. We are continuing with the Sources of the Power Quality and we are actually discussing on the capacitor. Advantages of the capacitor. Now we will talk about disadvantage of this capacitor, which will improve the power quality. So, one of the major drawbacks of this capacitor is the harmonic resonance. Why this comes? What happened you know most of the time you have a transformer.

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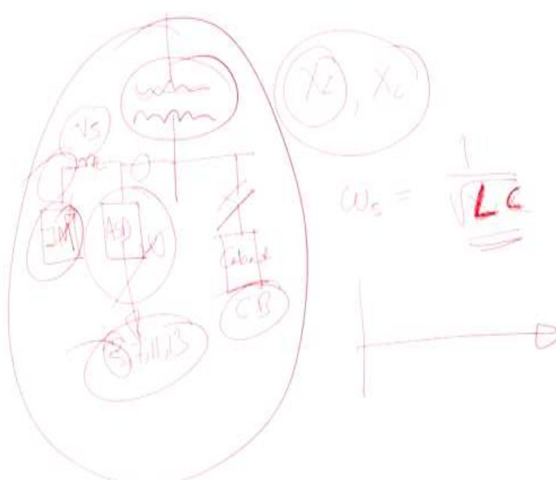

And generally, you have a distribution system and this distribution system may have an adjustable speed load and maybe an inductive load like induction machine. And once it starts, to nullify their effect you have switch on the capacitor bank. This CB stands for the Capacitor Bank.

Now, what happens? Once you close it, there is a leakage reactance of it, that has some value. And this capacitor you have calculated based on the power factor to bring the power factor at 0.95. Then what happens is, adjustable speed drive will produce some amount of 5th, 7, 11 and 13 harmonic and so on. And this adjustable speed drive can produce some harmonics, it may be the 5th harmonic which is quite dominating harmonic, that 5th harmonic and this leakage reactance of inductor and this capacitor can set a 5th harmonic resonance that is actually $\omega_{05} = 1/\sqrt{LC}$.

Ultimately you have chosen a capacitor to mitigate this problem but this entity is there, this entity will have a 5th harmonic and it will cause a 5th harmonic resonance. If 5th harmonic resonance occurs, please understand that 5th harmonic is a negative sequence as you know if you are sitting on a 6th harmonic that is co-phaser then 5th harmonic is rotating in clockwise with respect to you.

Ultimately then due to the resonance this 5th harmonic value will activate and this will go to the machine. It is because of that source inductance of this wire the 5th harmonic voltage will be generated as well and that will go into the machine and ultimately it will produce a ripple torque and the torque will be negative to the fundamental movement and thus cogging will take place. So, this is a very big disadvantage of this capacitor, let us go back to our discussions.

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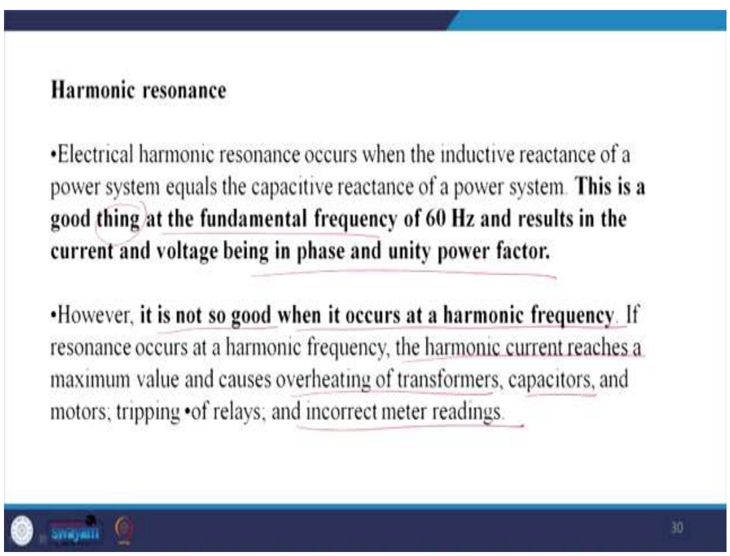

So, this is a good entity or thing at the fundamental frequency of 50 or 60 Hertz and results in the current and the voltage being in phase with unity power factor, that is a good part of it, but worst part of it is, it may cause a harmonic resonance. However, it is not good when it occurs at harmonic frequency. If resonance occurs at a harmonic frequency, that is what

I was discussing, the harmonic current reaches a maximum value and causes overheating of the transformer, capacitor and motors, tripping of relays and incorrect meter readings.

Because you know, these meters are been calibrated for the sinusoidal operation, if you feed a non sinusoidal voltage and current it will not give you the proper reading.

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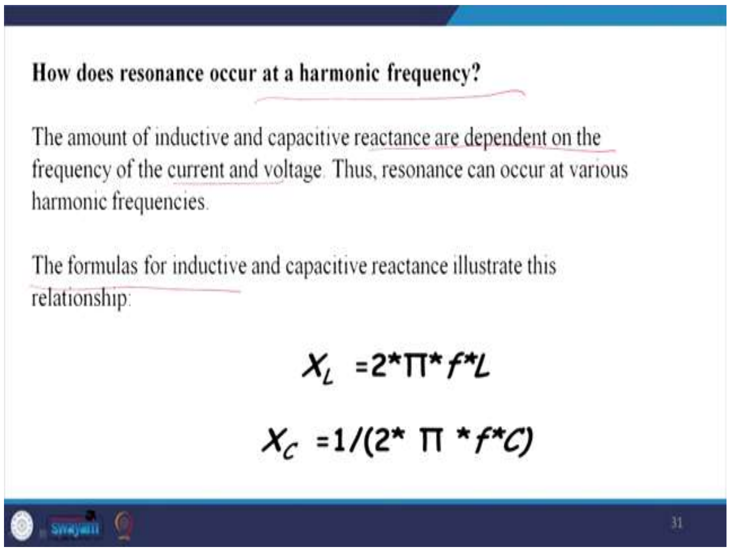

How does the resonance occur at a harmonic frequency? That is what I was discussing. The amount of inductive and capacitive reactance is dependent on the frequency of the voltage and current. Thus, resonance can occur at various harmonic frequencies. Worst is the 5th harmonic. That is what I had taken and this formulates the inductive and the capacitive reactance as illustrated below.

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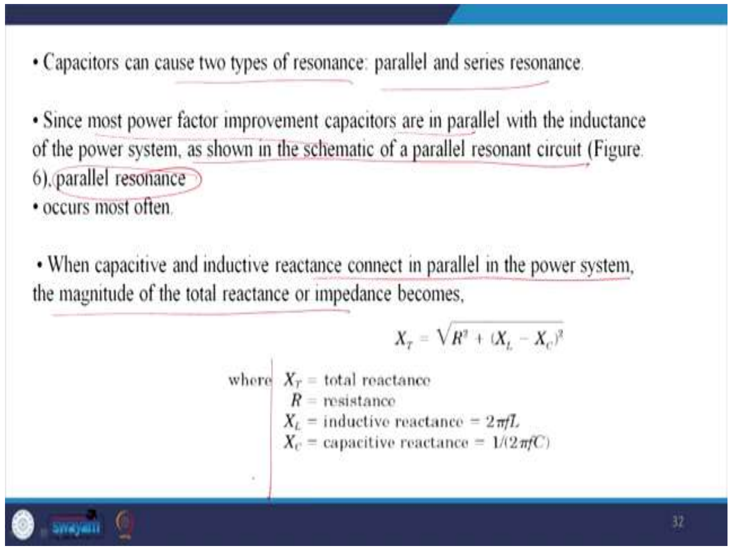

So, capacitors can cause two type of resonance, one is parallel another is series. So, if it is a parallel resonance this is essentially an anti-resonance hence least current will flow. Your admittance is minimum thus impedance is maximum. Since most power factor improvement capacitors are in parallel with the inductance of the power system, as shown in the scheme of the parallel resonance circuit in the next figure that is in figure 6, will have a parallel resonance. And in parallel resonance what happens? It behaves like a resistive network, but with a high value of impedance. Ultimately since it offers a very high impedance then current takes a different path to flow.

When the capacitive and the inductive reactance are connected in parallel in the power system, the magnitude of the total impedance can be calculated, these are the calculations, say this is an elementary calculation but there is a problem.

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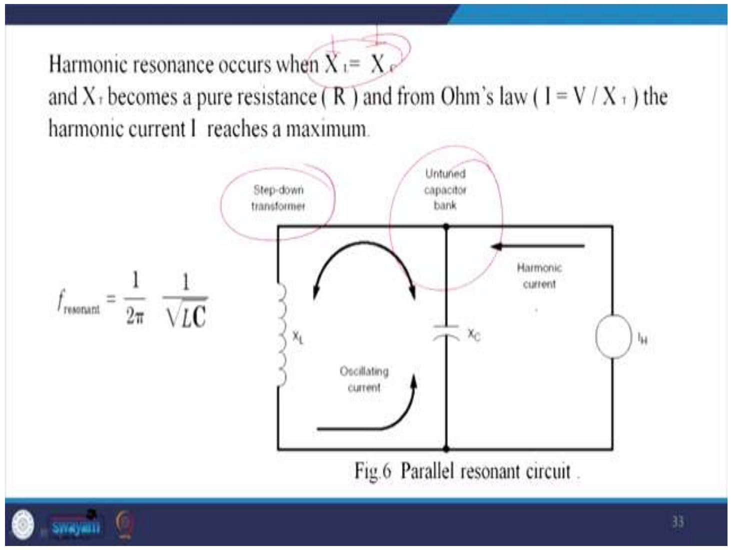

Harmonic reactance occurs when X_L equal to X_C or rather the admittance should be matched. So, X_T becomes a pure resistance and according to the Ohms law, it is this. Thus, resonant frequency is under root of LC and it may be due to what I have drawn there a step down transformer, an untuned capacitor bank and there is a harmonic current because of the adjustable speed drive and thus our resonance path has been set.

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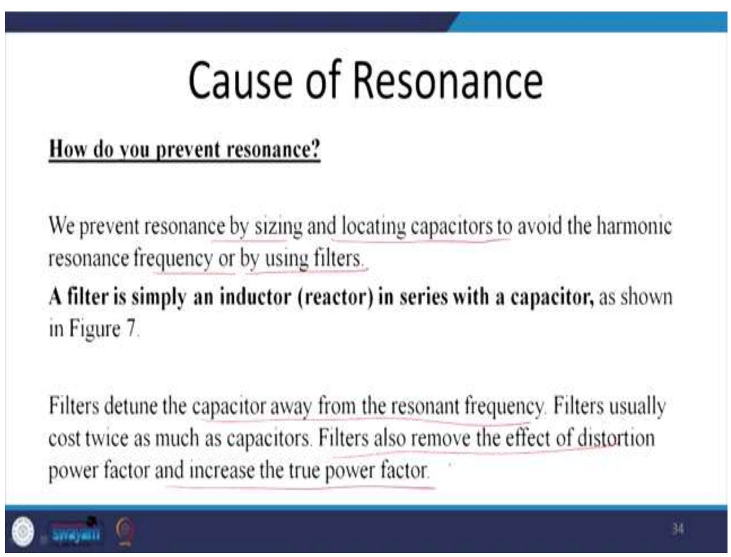

So, how to prevent the resonance? One, we should calculate the leakage reactance but leakage reactance is also the function of current. So, there we will have a different leakage reactance of the inductor and that of the transformer because you have not physically inserted the inductor there. So, we prevent the resonance by sizing and locating capacitors to avoid the harmonic resonance frequency or by using filters. We can use the passive filter. We shall discuss in your subsequent classes about when we can use active filter and also about both of these filters, passive as well as active shunt active power filter. Also this static capacitor bank is generally replaced by the STATCOM and it eliminates this kind of resonance.

A filter is simply an inductor in series with the capacitor is shown in the figure, next figure. Filter detune the capacitor away from the resonance frequency. Filter usually cost twice as much as the capacitors. Filters also remove the effective distortion of the power factor and increases the true power factor. This is the advantage of it.

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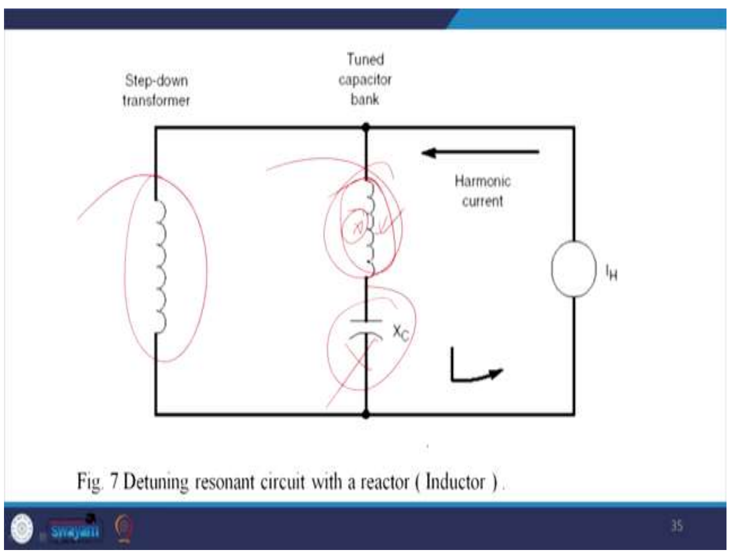

So, we require to replace it this capacitor bank, with the inductor. And we can take help of the facts devices also, there you can have a TCSC.

So, all those entities can be placed to improve the value of the capacitor. So, untuned capacitor we cannot use, but you know you get a better performance, but at some cost. Please understand it because you have to have a high value of the capacitor as well as the good amount of the cost come from the inductor. These inductors you have not connected. It is there because of the leakage reactance of the transformer, but you require to physically connect an inductor and you make it a tuned capacitor bank filter. This we will discuss in details while designing the filter. We have one or two class, I have dedicated it for discussing this entity.

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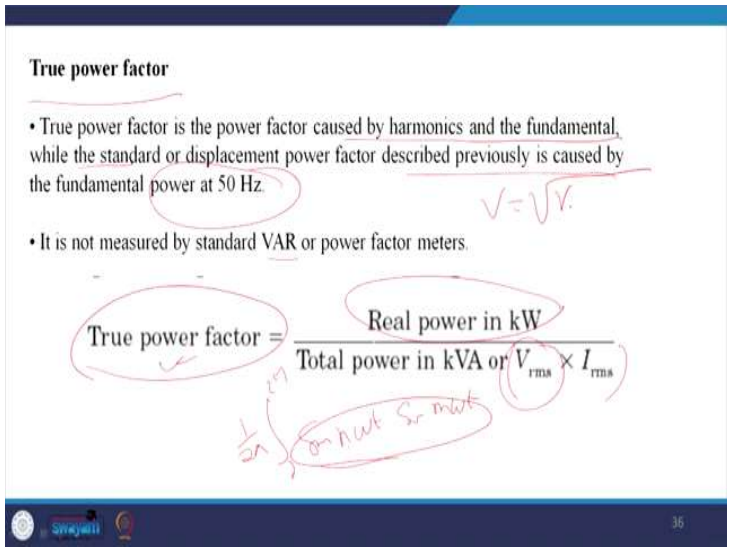

So, the true power factor. The true power factor is the power factor caused by harmonics and the fundamental. while you may ask actually, but I just cannot take this question just now may be a little later. While the standard or the displacement power factor described previously caused by the fundamental power at 50 Hertz and it is not measured by standard VAR or the power factor meters.

So, true power factor we require to take a cognizance of the harmonics, for this reason real power in kilowatt that is something what you were consuming, because if you have multiplied sin(nωt) into sin(mωt) and integrate over 0 to 2π and I will take the average of 2π. You can see that this power gives you zero.

So, averaging the harmonic power gives you a zero value. But problem lies once it flows through the resistance or other network, it losses the power, it has to be accounted somewhere. It is like that you transfer your friend sum amount of money and he transfers it back through your bank transaction, but banks siege some amount of money. As if banks external transaction charges are quite high. So, then this kind of questions arises and due to that we require to have a factor in the harmonic power. So, the total power in kVA or $(V_{rms} \times I_{rms})$, where in I_{rms} all the harmonic contents are accounted for there.

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$$V_0 = \sqrt{V_1^2 + V_5^2 + V_7^2 + V_{11}^2}$$

$$I_r = \sqrt{I_1^2 + I_5^2 + I_7^2 + I_{11}^2}$$

So, when we are talking about V_{rms} and it contents all the fundamentals and the harmonics then, V_1 square plus V_5 square plus V_7 square plus V_{11} square all has to be factored in it and that value will be your V_{rms} . Ok? And similarly, your output has to be I_1 square plus I_5 square plus I_7 square plus I_{11} square and so on. In that way we require to produce the harmonics.

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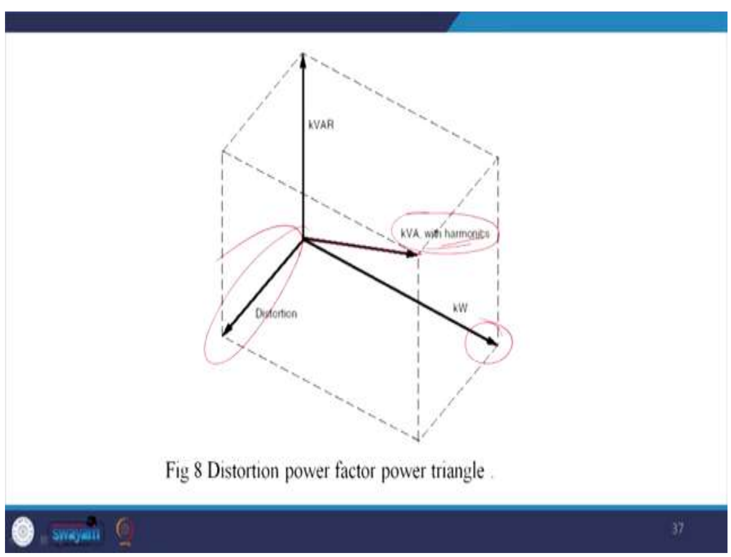

Fig 8 Distortion power factor power triangle .

And thus, we have to represent this. We will discuss this theory later in the case of the shunt active power filter. That is the instantaneous reactive power theory and there we shall place the reactive power as well as the harmonic power and thus we require to represent it into the plane. This is the kilowatt and this is the kVAR and then if there is no harmonic, ultimately you can take the resultant and that is fine. That is your kilovolt ampere current.

But there is a harmonic distortion and thus it forms a cube or parallelepiped. And ultimately this diagonal essentially gives you the magnitude, that is kVA with the harmonics that is the symbols of kVA with harmonics. So, new definition comes and we have to pay for that power factor also. We require to maintain that power factor also which is less than 0.95.

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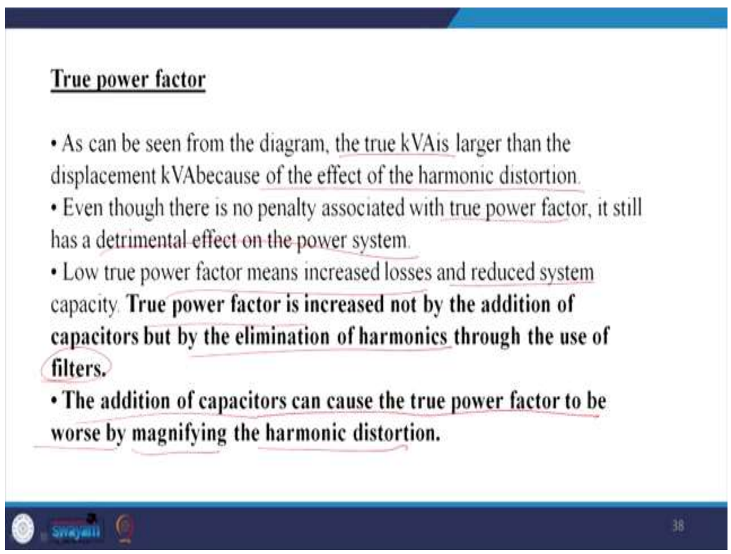

So, as we can see from the diagram, that true kVA is larger than the displacement kVA due the effect of the harmonic distortion. Even though there is a no penalty associated with true power factor till now, it still has a detrimental effect on the power system. And we are coming to the effect of the poor power quality. In the subsequent lecture itself I will take this issue.

Low true power factor means increased losses and reduced the system efficiency or the system capacity. The true power factor is increased not only by addition of the capacitors, but by elimination of the harmonics through use of filters, that can be active or passive. So, nowadays we are looking for the solution with the active filter.

The addition of the capacitors can cause the true power factor to be worse by magnifying the harmonic distortion. That is the problem of it.

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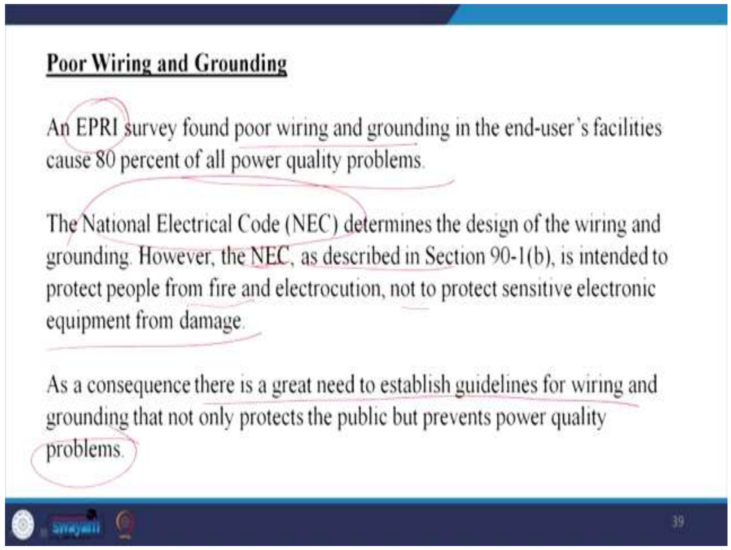

So, we are discussing several times that another cause is poor grounding and poor wiring. So, let us see that how this causes the problem. And this is abbreviation of the European Union. So, survey found that poor wiring and grounding in the end user's facilities cause 80 percent of all the power quality problems.

So, some power quality is also for the poor workmanship. The National Electrical Code (NEC), determines the design of the wiring and grounding. However, we have taken a special case, we have also covered the standards there we have discussed in detail, but let us look it here also. So, this is the continuation with the discussion. However, the NEC as described in section 90-1(b), is intend to protect the people from fire, electrocution, not to protect sensitive electronic equipment from damage. So, this is something, please understand it. So, the NEC code is for fire and shocks and all those issues.

So, that once you touch the machine you should not get a shock, wiring should such that electrocution does not happen. So, whenever you touch any equipment you should not get a shock, but it is silent about the harmonic distortion or any other issues may damage your complicated electronic circuit. That is not in a domain of this national code.

As a consequence, there is a great need to establish guideline for wiring and grounding that not only protects the public, but prevents the power quality problem. We have taken care of only hazards, but not the power quality problems as such by this national electric code. For this reason, the standard required to be modified in every couple of years may be as far as that. As new problem arises and it gets reported and then we are required to update it. For this reason you will find that there are so many clauses sub clause and all those things.

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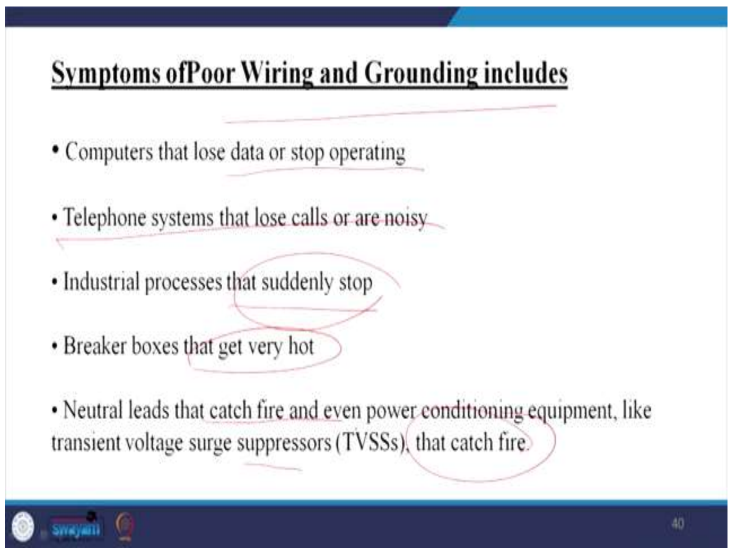

So, symptoms of the poor wiring and grounding includes computers that lose data and stop operating. Sometime you may see that due to the poor grounding problem, as somehow your chassis is not been grounded, your processors get a high power and due to that your processors have been loaded unnecessarily with the capacitive current and that gives you the heat. If you are not able to take out the heat by your fans then of course, the longevity of your computer will be suffered.

Telephone system that lose calls or are noisy, that you have noticed several times. Industrial process that suddenly stop, due to this I was talking about, let us say you have a resonance with the 5th harmonic and you are running a motor. And what will happen? Due to the high contamination of the 5th harmonic it will crawl. Breaker boxes maybe get very hot, because of this problem. Due to unbalance all the currents will flow through the neutral. As a result of this Neutral leads can catch fire and even power conditions equipment, like transient voltage surge suppressors, may also catch fire because of the improper designing and grounding.

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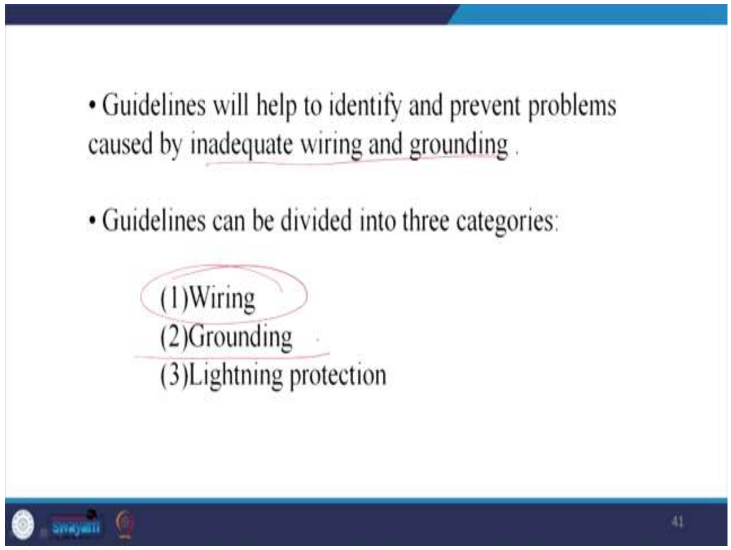

Guidelines will help to identify the problems caused by the inadequate wiring and grounding. Of course, this itself is a course of our engineering b.tech study. So, we required to take care of these issues quite well, unfortunately due to the lack of time I cannot go into that detail very much. That guideline can be divided into the three categories one is wiring. So, you should ensure that loads are distributed in all the phases of the house in a right manner so that you do not inflict huge amount of this unbalance into the system.

Moreover, if some portion of it has adjustable speed drive then try to contain the adjustable speed drive harmonics and give a sinkage path so that it does not propagate to the whole area of this power network.

Thereafter grounding, grounding has to be done very properly if high current required to sink through the ground. The neutral may burn. As well as what happens? If you do not properly ground it then there will be oscillations of this neutral point and thus there will be a loop, if it is not in at 50 Hertz then there will be a sub harmonic problem also that is also a challenge. Thereafter, lightning protection, that is a common practice what we are doing for pretty long time.

I show you picture maybe in the next slide or next to next slide then only we will clarify how does it work.

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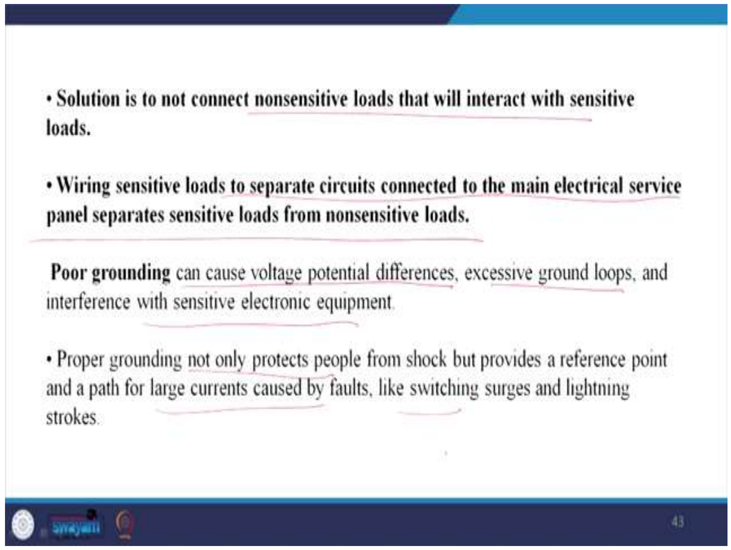

And the solution is to not connect non-sensitive loads that will interact with sensitive loads. So, you have a big machine and beside that you may have a laptop. So, you should not connect them with the same power supply, you should segregate the power supply. Wiring sensitive loads to separate circuits connected to main electrical service panel separates sensitive loads from the non-sensitive loads.

So, your pump in a domestic house and the computer required to be kept in isolation. Poor grounding can cause voltage potential differences, excessive ground loops and it can interfere with the sensitive electronic equipments mostly the sound system gets affected. I have noticed in a hall because of the poor grounding, its acoustics is poor.

So, proper grounding not only protects the people from the shock, but provides a reference point and a path for the large currents caused by the faults, like switching surges and the lighting strokes etcetera.

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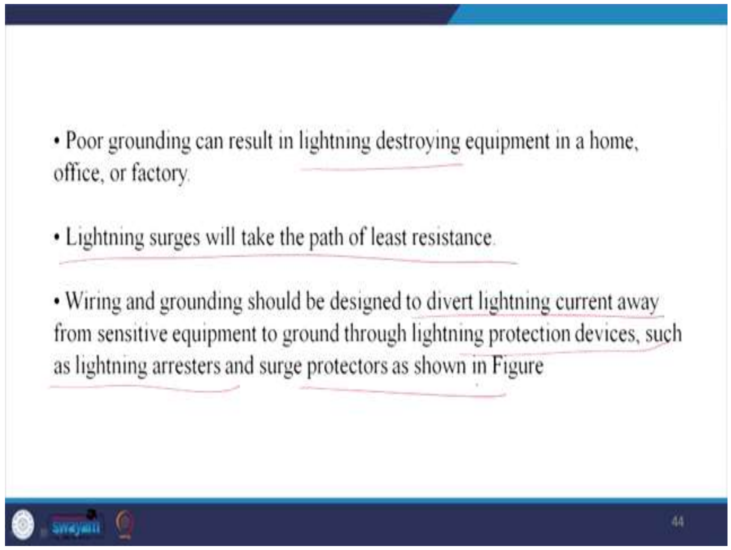

Poor grounding can result in lightning destroying equipment at a home and the factory. So, if you do not ground properly, and if lightning struck ultimately all your entities can be destroyed. I know a case where all the fans were destroyed. Ultimately lightning takes the least resistive path and that was the least resistive path and ultimately your surge arresters just did not work properly and all that electrical equipment was burned.

So, that is what I was saying, the lighting surge will take the path of the least resistant you have to provide the path of the least resistance. Wiring and grounding should be designed to divert the lightning current away from the sensitive equipment. You have to bypass the equipment to ground through the lightning protection devices, such as lightning arresters and surge protectors. I am showing you in the next figure.

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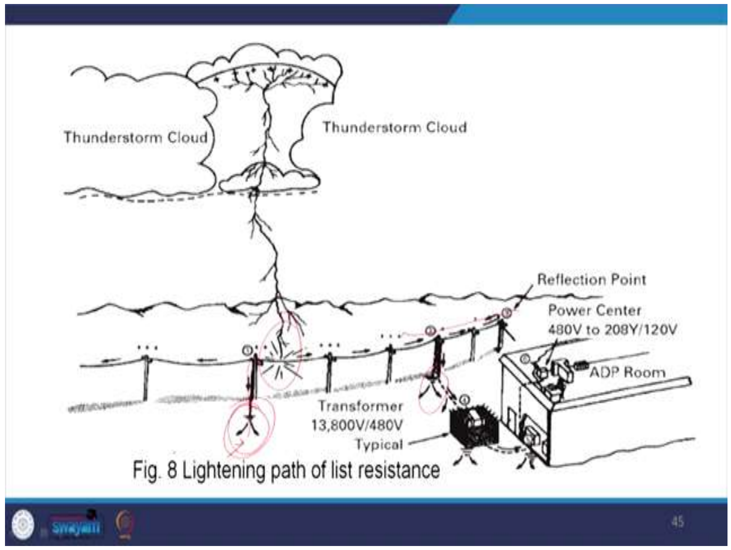

So this is the case, thunder is striking maybe here and you would try to have a entity here otherwise it will propagate here and it will propagate here and ultimately since it is a least resistive part, here it will go through here. And what will happen otherwise? So, it will have propagated to this tower and then it is open circuit and then again it will reflect back and ultimately through it the surge will come through the transformer from this transformer it will enter into the system and maybe it will destroy the sensitive equipment in the control room. So, we have to provide a surge arrester here, as well as here, so that it gets arrested locally.

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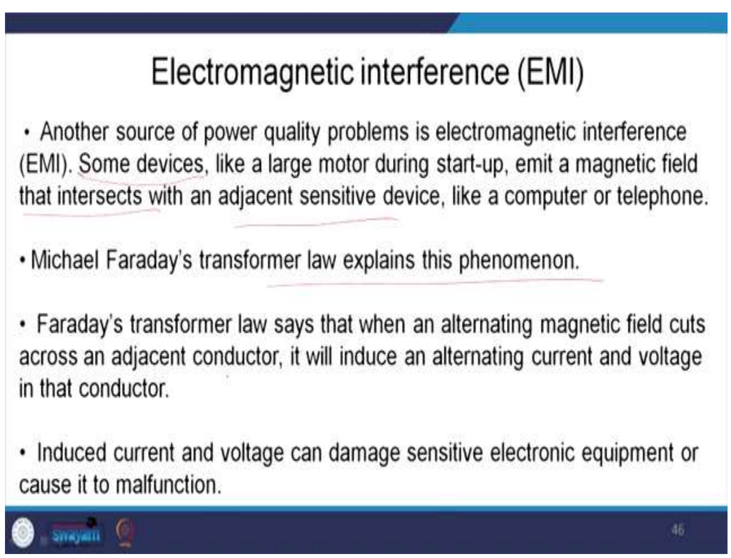

So, another important entity is the electromagnetic interference or EMI. Another source of the power quality problems is the electromagnetic interference. Some devices, like large motor during start-up emits electromagnetic field and intersects with an adjacent sensitive device, like computer, telephones etcetera. Michael Faraday's transformers law explains this phenomenon very well. So, it is nothing new for us, but how to mitigate this problem is a big challenge.

Transformer law says that when an alternating magnetic field cuts the adjacent conductor, it will induce an alternating current and voltage in that conductor. So, unless you have magnetic screen in a particular area say, in your machine lab where phone is placed, this phone will have problem because of the magnetic field. Induced current and voltage can damage the sensitive electronic equipment or cause it to malfunction.

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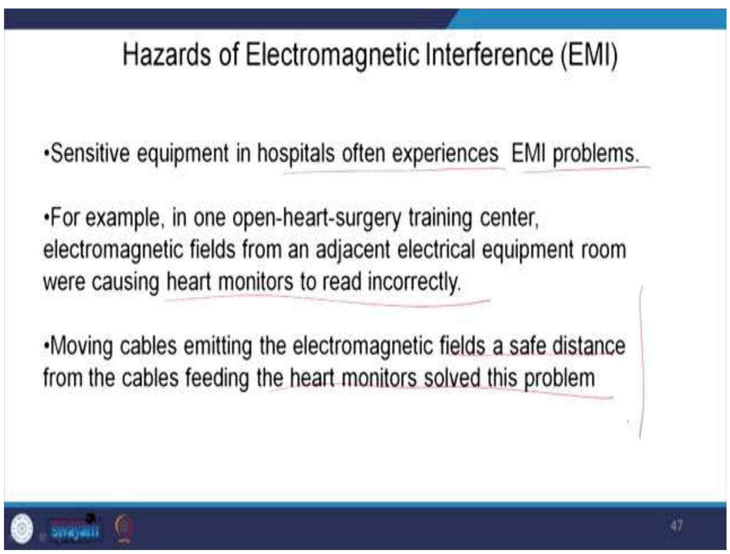

So, hazards of the electromagnetic interference. Sensitive equipment in hospital often experiences EMI problem. So, generally you have X ray machines, then you also have a high electrostatic voltage to general X ray or you may have an MRI that is essentially the magnetic resonance. So, you create a huge magnetic field, if those entities are not properly screened and segregated, those entity will introduce high electrostatic field as well as high magnetic field which are generally changing and they will interact with nature and will cause a electromagnetic wave. And this electromagnetic wave may interfere with the highly sensitive other monitoring devices and it may hazardous to the patients largely and thus it may malfunction.

For example, in one open heart surgery training center, electromagnetic fields from an adjacent electrical equipment room were causing heart monitors to read incorrectly. So, this is a big problem there. The moving cables emitting the electromagnetic fields at a safe distance from the cables feeding the heart monitors may solve the problem. There are many ways to solve the problem. This is altogether EMI, EMC suppression issue so that can be abandoned, we can also have a holistic designing method. That itself is a chapter or a subject.

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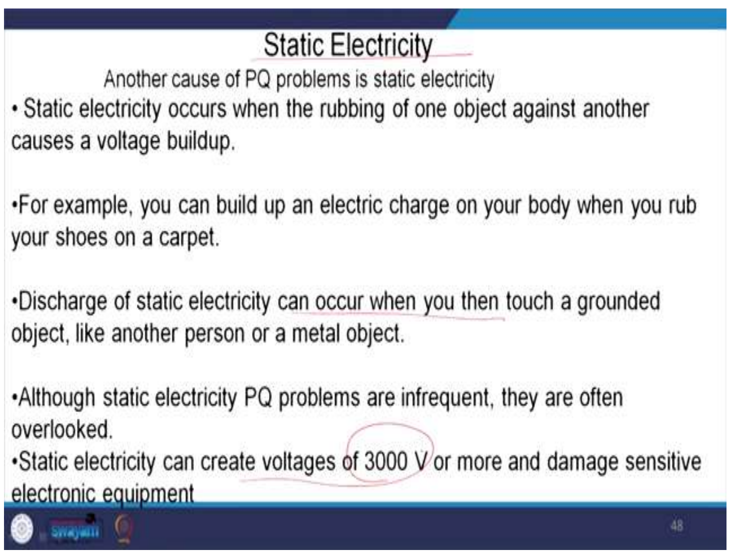

Now, another entity is essentially the static electricity. So, another cause of PQ problem is the static electricity. Static electricity occurs when the rubbing of one object with another causes some time a high voltage buildup. For example, you can build up an electric charge on your body when rub your shoes on a carpet. Discharge of the static electricity can occur when you touch a grounded object, like another persons or a metal object. Though the static electricity problem is infrequent and they generally overlooked, but sometime it may cause a huge problem. Static electricity can create as high as 3000 volt or more and damage sensitive electronic equipment.

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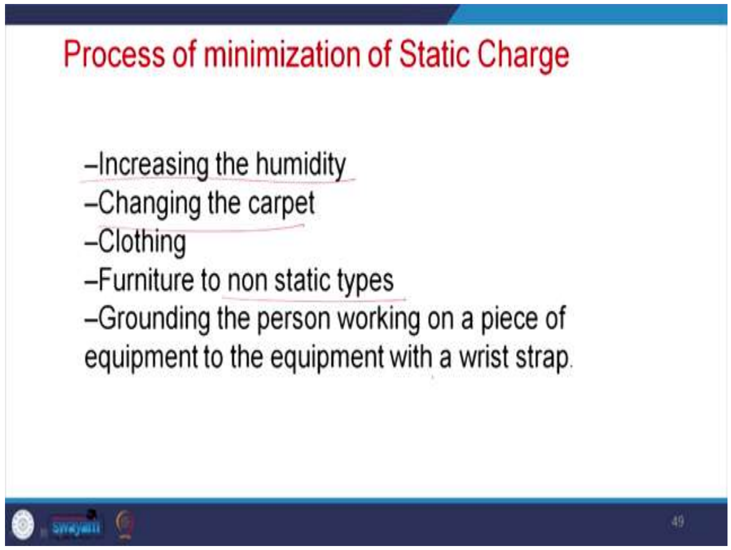

For this reason, we require to reduce the static electricity sometime by increasing the humidity as a result, then insulations of the air decreases. Changing the carpet and clothing also reduce the static electricity. You require to wear cotton clothing instead of a silk. Using furniture of non-static types so that it does not hold charges. Grounding the person working on a piece of the equipment with a wrist strap, mostly it is used when these technicians are shouldering the MOSFETs because their hand may contain, if you rub it you have a sufficient amount of charge. And once you touch with the hand, then this charge will be trapped between gate and source of the MOSFET and thus it will be automatically on.

So, ultimately you get a MOSFET in a short circuit condition. For this reason, when they are soldering, they wear the waist band. So, since sensitive power electronic devices are made of MOSFETs mostly, hence if these static charges some way come into this gate and drain then it may function abnormally and that is also you can take it as a power quality problem. So, for this reason the static charge will cause a power quality problem.

So, let us come to the last part of our discussions. What is the effect of the power quality problem? The effect of the power quality problems are many and variety, we can talk about half an hour, but I just put a gist because many recall type question can come from this part. Please listen carefully or go through the slide.

When the utility customer calls the utility in an attempt to determine the cause of a power quality problem.

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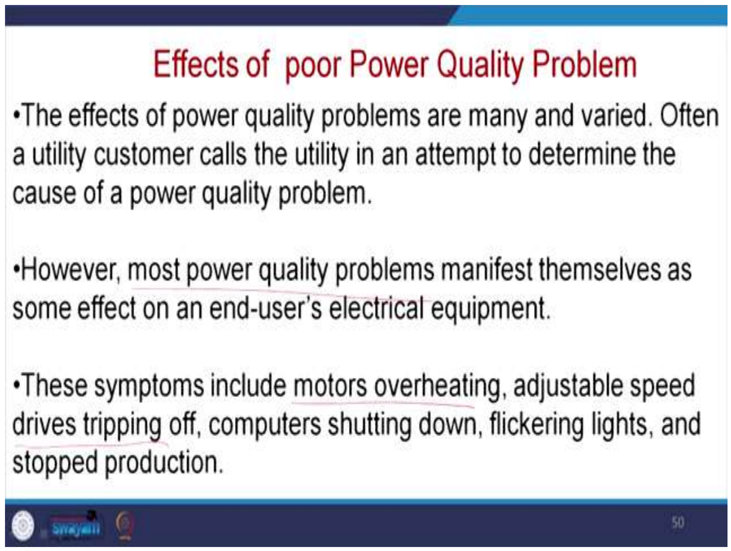

However, most of the power quality problems manifest themselves as some effect on an end user’s electrical equipment. These symptoms include motor overheating, adjustable speed drives tripping off, computers shutting down, flickering lights and stoppped production.

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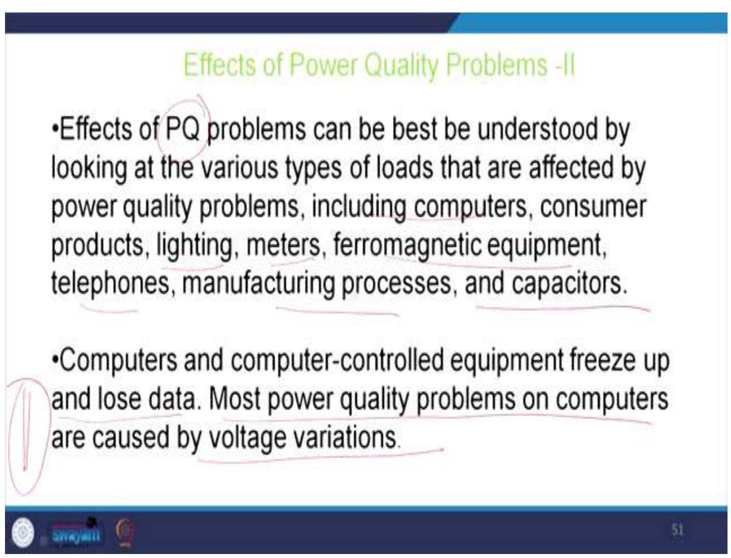

Effects of power quality problems can be best understood by looking at the various types of loads that are affected by the power quality problem, including computers, consumer products, lighting, meters, ferromagnetic equipments, telephone, manufacturing process and the capacitors. All are being affected by this poor power quality problems.

Computers and the computer control equipments freeze up and lose data. Data is now new age fuel, please understand it. If you lose the data you lose the business. Most power quality problems on computers are caused by mostly the voltage variations. So, you require to give a regulated power supply.

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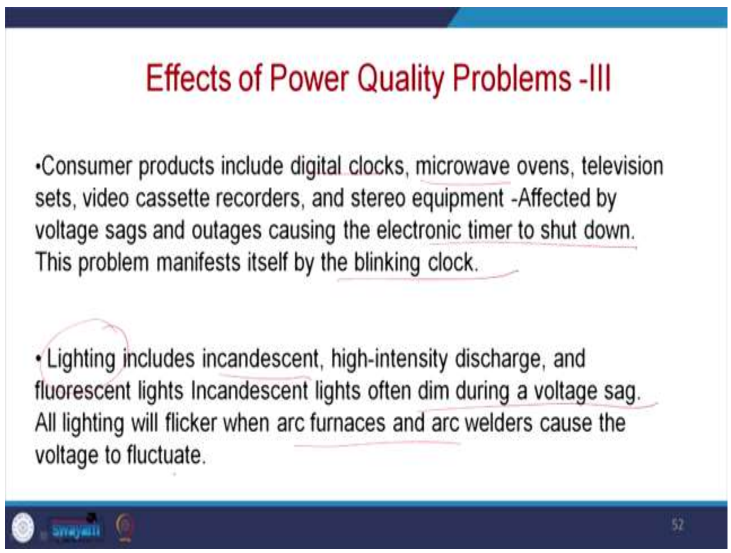

And another may be the consumer products include digital clocks, microwave ovens, television sets, video cassette recorders now though it is going out it may be a CD compact disc, stereo equipment, affected by the voltage sags and outages causes the electronic timer to shut down. This problem manifests itself by the blinking clock.

Lighting also a problem. So, lighting includes the incandescent, high intensity discharge and fluorescent lights, incandescent lights often dim during the voltage sag and it does not turn on that was the case most found in the villages at least 5 years ago as well.

So, I find that in evening, due to the sag in the voltage your tube, that is fluorescent lamp does not work. All lighting will flicker when arc furnaces and arc welders cause the voltage to fluctuate. Due to flickering, it will give a stress on your eyes and you may have many health-related problems from that.

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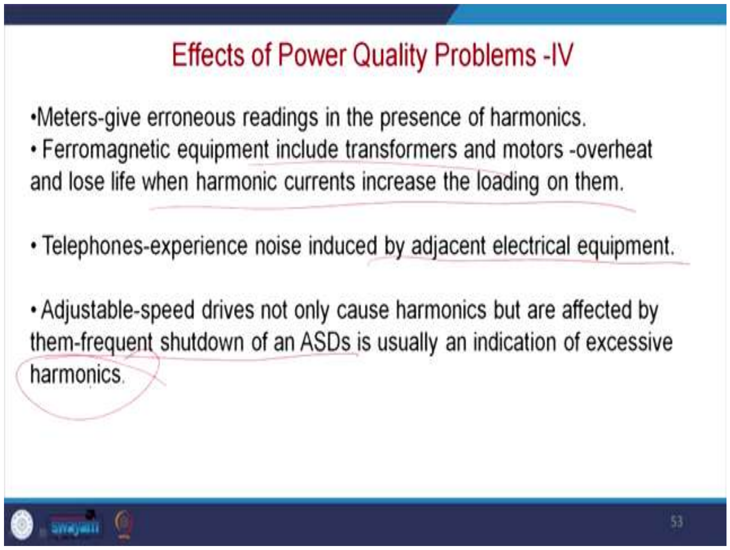

Meter gives an erroneous reading, in the presence of the harmonics. Ferromagnetic equipment includes the transformer and the motor overheat and loose life when harmonic currents increase the loading in them.

Telephones experiences noises so, you cannot hear properly induced by adjacent electrical equipment. Adjustable speed drives not only cause harmonics, but are affected by them. The frequent shutdown of the adjustable speed drives usually indication of the excessive harmonics and also its life reduces due to high contamination of the harmonic.

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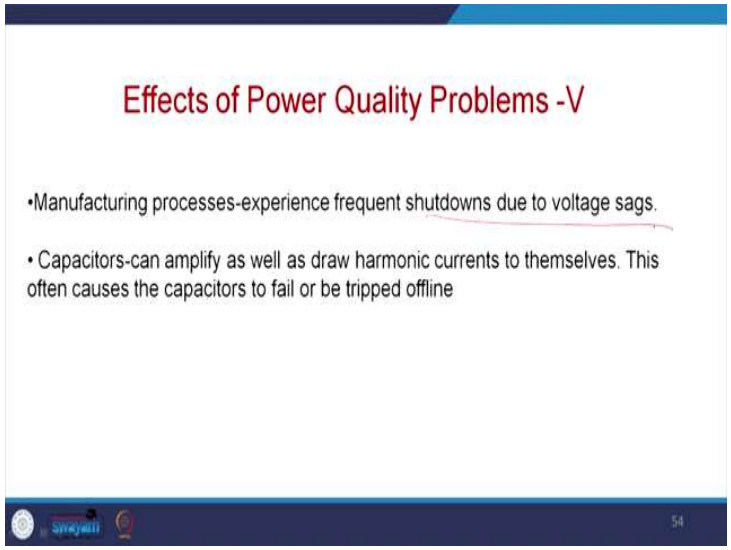

And manufacturing processes this is one of the important entities, experience frequent shutdowns due to the voltage drop or voltage sag. I have recently experienced this problem in a sugar cane mill in Uttarakhand. They have a problem of the frequent shutdown and they come to us for the solutions.

And I have seen how their production has been hampered. And capacitors - can amplify as well as draw harmonic currents to themselves. This often causes the capacitors to fail or to be tripped offline. These are the overall sources and the effect of the poor power quality. Thank you for your attention, we shall continue our discussion with the power quality improvement technique in our next classes.

Thank you.