Power Quality Improvement Technique
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Lecture - 40
Conclusion

Welcome to our NPTEL courses on Power Quality Improvement Technique. Today is our last lecture and we shall conclude the subject and we will brief you on what we have discussed in all those, '39' lectures. So, power quality has many problems.

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It can be the transient stability, and you know that the STATCOM is a FACTS device that can give you a solution of all those problems like power quality, transfer capacity, oscillation, damping. If you see those power quality problems, we try to find solution through STATCOM or the UPQC. For all the current related problems, we generally use the STATCOM.

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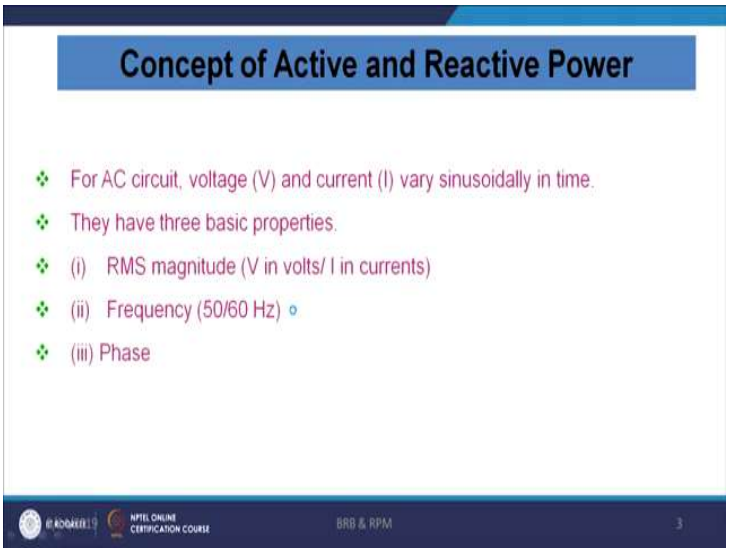

Now, we want to just revisit it for the sake of understanding it. For AC circuit voltage and current are varying sinusoidally, they have the basic properties like RMS voltage and current. Then the frequencies have to be 50 Hertz, 60 Hertz. Then it must have a phase with a desired maintenance ratio. That means it should not have a long phase lead and phase lag.

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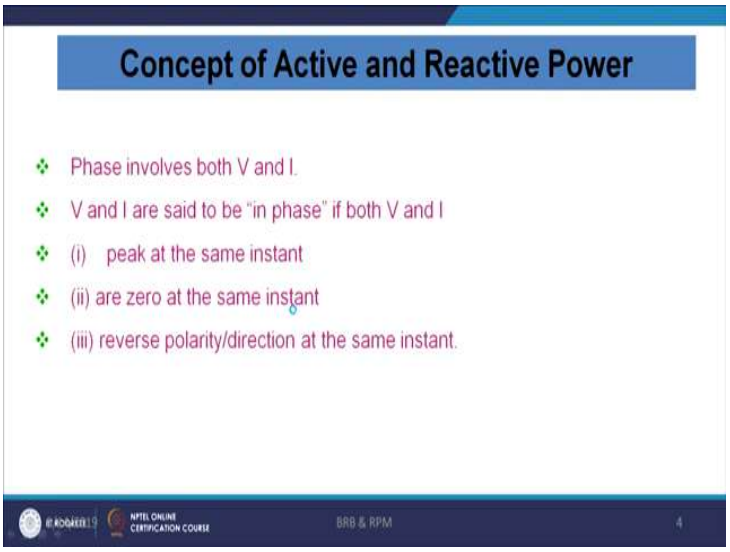

Phase involves both voltage and current then, V and I said to be in a phase. That is what a desired requirement of the power quality. Now, peak at an instant should have a zero crossing at the same instant.

Sometime, zeros are at the different instant. That I will show you in the picture. Reverse polarity directions also in a same instant.

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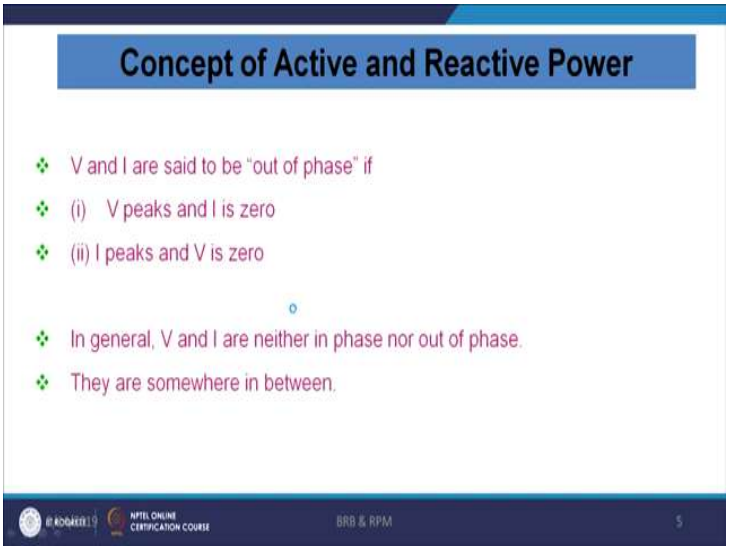

Then, let us see this problem. Voltage and current are said to be out of phase when they are 180 degree of their phase angle. Then when you are charging the battery, voltage and current are in a same phase, through the active filter, once you discharge the battery you can have a 180-degree phase shift when peak voltage, and I is zero, or the I peaks and V is zero. Then in general V and I are neither in a same phase or out of phase. Now they are somewhere in between.

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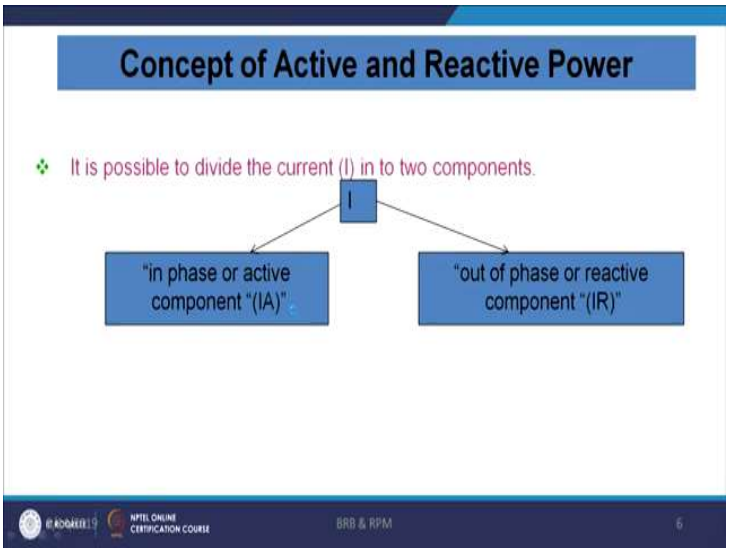

We can then split the current into the in-phase component and the reactive component of it. It is possible to split this into the two components.

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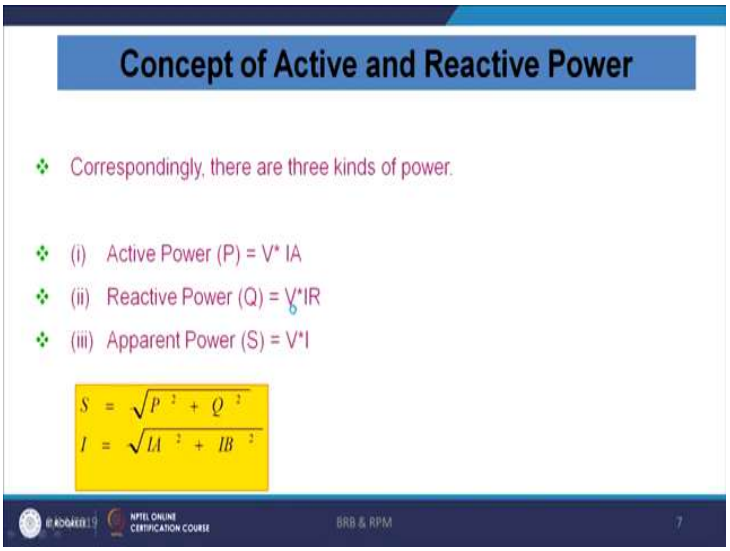

We define as if it is apparent power then it is $\sqrt{P^2 + Q^2}$. Then similarly we can split the current. You know that active power equal to $V \times IA$ and the reactive power equal to $V \times IR$ and thus the apparent power is $V \times I$.

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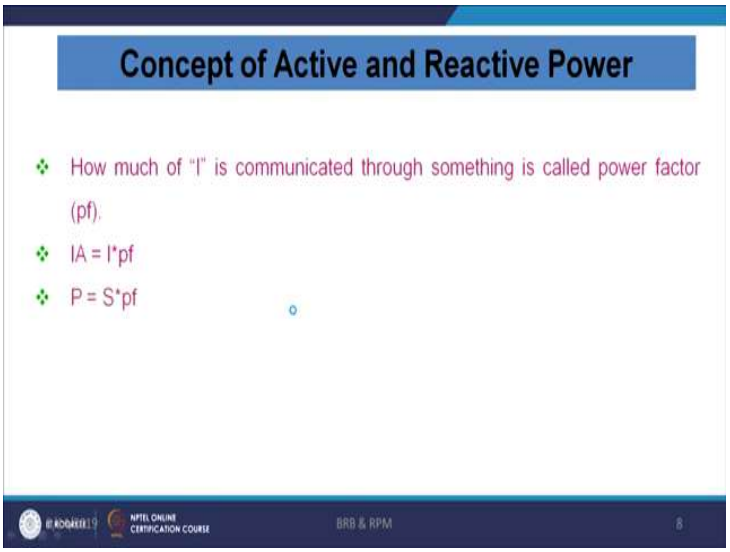

These are the few basic. You are aware of it and how much 'I' is communicated through is sometime called a power factor pf. That is something we require to understand. $IA = I \times pf$. So, $P = S \times pf$.

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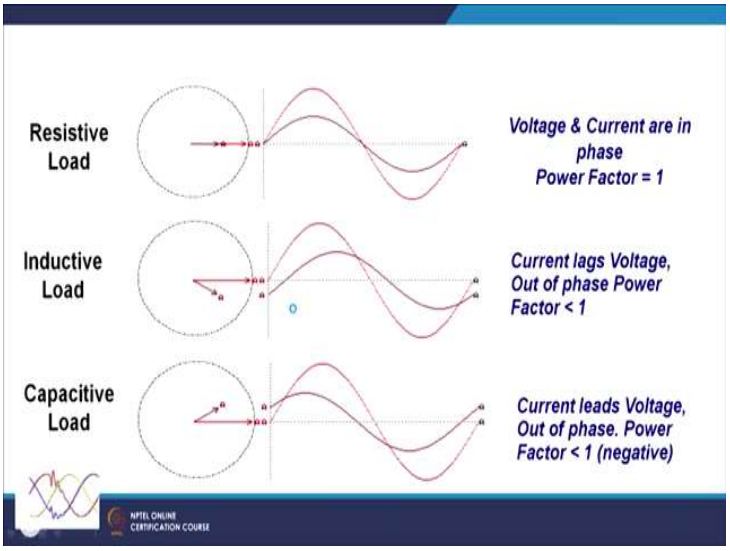

Similarly, for the resistive load with a power factor equal to 1 or unity power factor. This is an inductive load where power factor less than 1 and this one is a capacitive load where it is minus 1.

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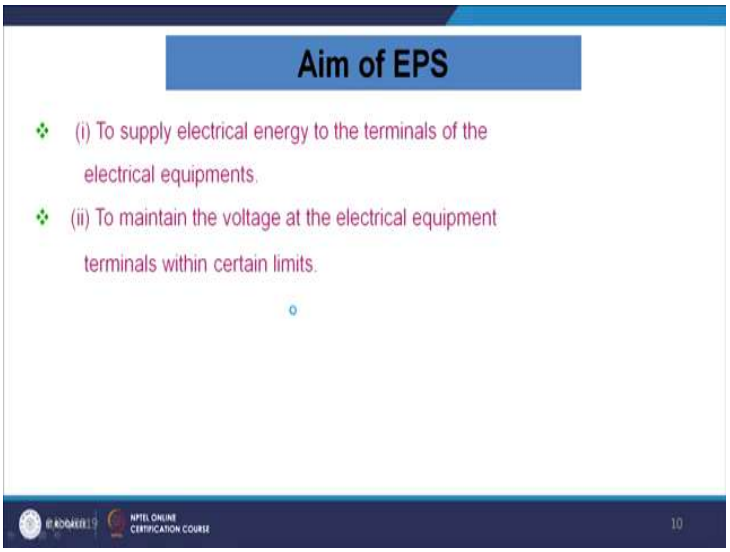

Now aim of electric power supply. That is your utility. To supply electric energy to the terminal of the electric component, that is the role of your grid. Thereafter to maintain the terminal voltage at the electrical equipment within a certain limit is also another aim.

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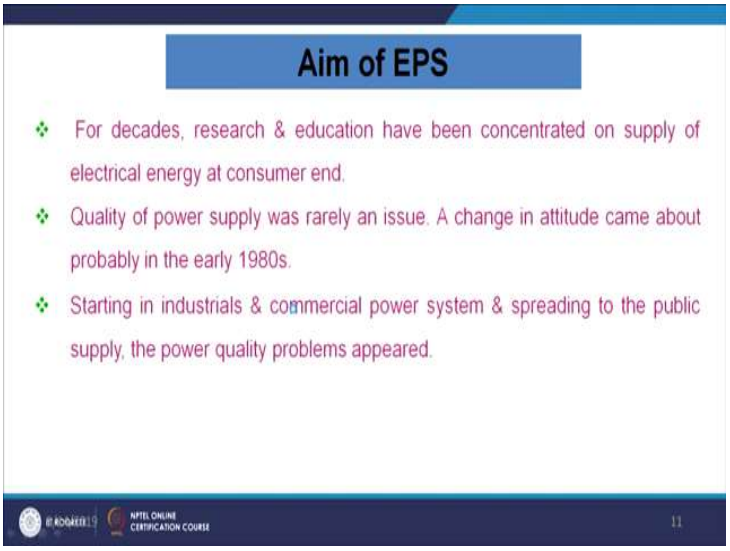

What else? For the decade research and the education that have been concentrated on the supply of electrical energy at the consumer end, quality of the power did not come in as an issue. The change of the attitude came with the adjustable speed drive in 1980s and starting from the industrial and the commercial power system and spreading to the public

supply. Hence the power quality problem also appeared. So, for the government, we do not have a problem. Now we have a multiple power supply. These are run by the private agencies and they had been charged commercially. For this reason, they have a liability to give you clean power and you also have to pay more for it.

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Moreover, modern semiconductor switching devices are being utilized more and more in a wide range of application in a distribution network particularly in domestic and the industrial loads.

We have discussed these issues. This power electronics devices offer economical, reliable solution to better management and better control of the electrical energy. These devices aggregate thousands and have become a main source of pollutions and distortion to the modern power system. Ultimately culprit is the power electronics, but we are trying to find solution by the power electronics.

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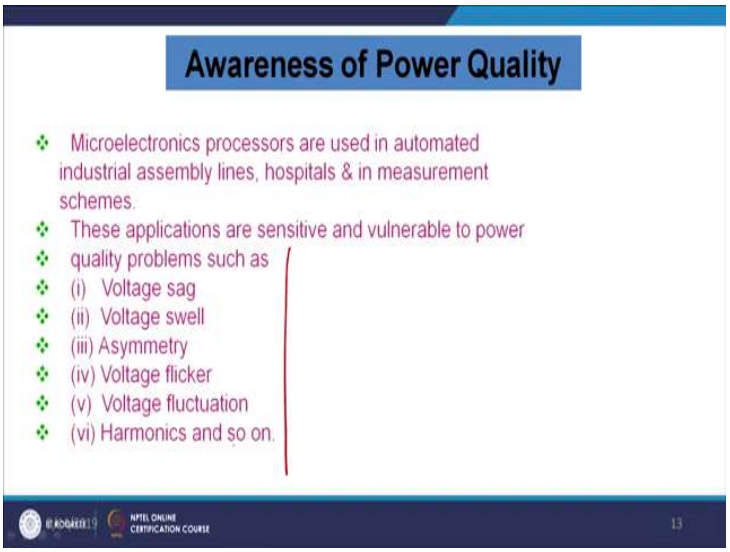

Now, what else? Microelectronics processors are used in automated industry, assemble lines, hospitals. That we have discussed, and we know these are the problems. Power quality have mainly following problems, voltage sag, voltage swell, asymmetry voltage flicker, voltage fluctuations, harmonics and so on.

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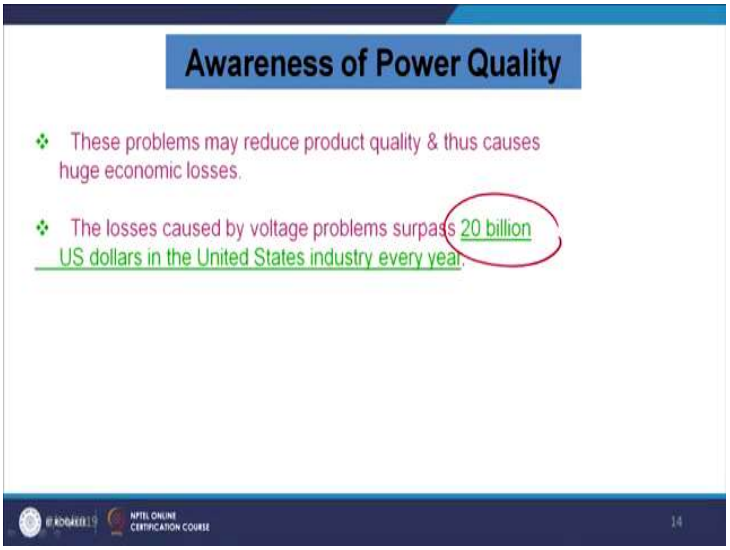

The problems may reduce product quality and cause huge economic losses. Even though that basic purpose can be defeated. You use power electronics for economic reasons, greater reliability, greater performance of the machine and ultimately found that all it is

essentially doing is reducing the cost of the component and it damages the components. The loss caused by the voltage supply surplus 20 billion dollars in United State industry service every year.

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So, why power quality? Let us define again. We have already discussed it. Equipment has become more sensitive to the voltage disturbance. Equipment causes voltage disturbance. A growing need for standardization and the performance criteria. Utilities want to deliver good product. End user have increased awareness on the PQ issue and challenges the utility to improve the power quality.

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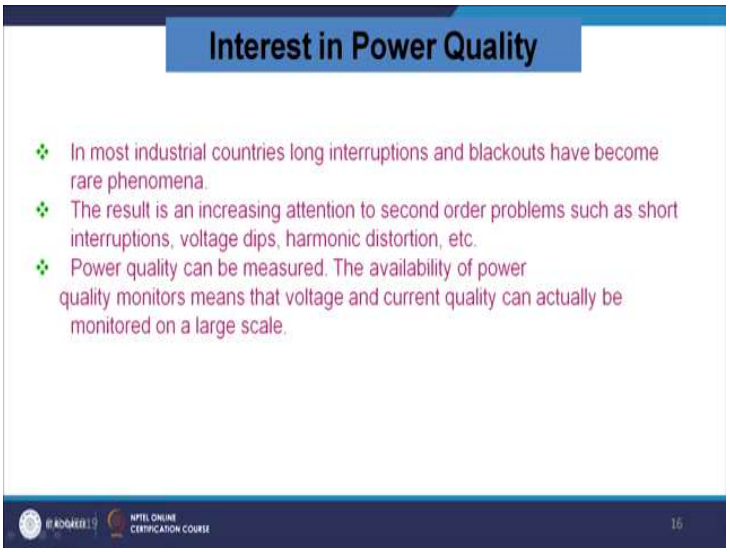

Interest in power quality: In most of the industries, long interruptions and the blackout have become a rare phenomenon. As we have reduced it.

The result is an increasing attention to second order problems such as short interruption, voltage dips, harmonic distortion, etc. So, now you go to the second level of challenges. Power quality can be measured. The availability of the power quality monitors means that the voltage and the current quality can be monitored on the large scale.

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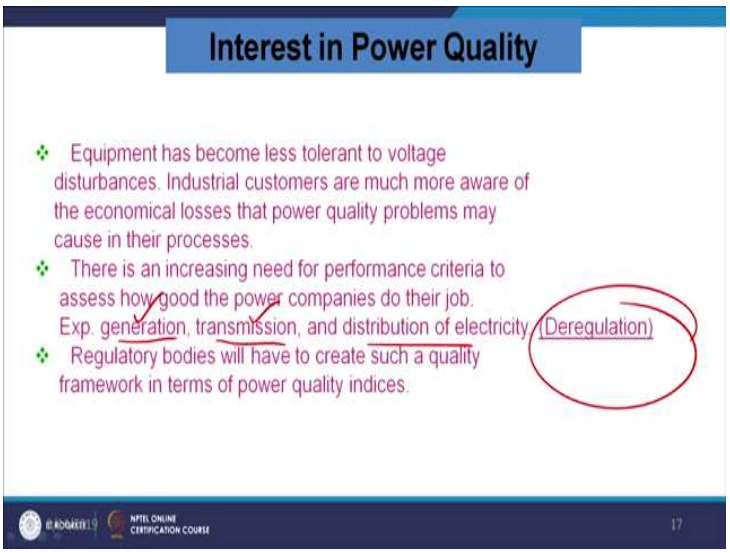

Equipment has become less tolerant to the voltage disturbance due to the cutthroat competition. You cannot take a long margin of safety. Industrial customer are more aware of the commercial losses that power quality problems may cause to their process and they ask for the compensation. Hence there is an increased need for the performance criteria to assess how good the power companies doing their job. For example: generation, transmission as well as distribution of the electricity and that is also called the deregulation.

So, regulatory bodies will have to create to such a quality framework of this generation's quality, transmission quality and the distribution quality. You have to see that at the generation level there is no problem. At the transmission level there is one, this transmission loss should be reduced. Congestion would be reduced and in distribution level also you see that there is a power quality problem that has been regulated.

It may be such as someone is generating, someone is transmitting and you may hire the transmission network. Someone is putting the HVDC network. You are hiring to transmit your power. It is just like I manufacture goods, railways are the transmission, ultimately some consumers are the receivers. Same way electricity has been deregulated. Thus, they have difference stake holder.

Ultimately if you get a delayed product due to the derailment of the railways, then we can point it to who should be held responsible for it. In this diversified electricity market, we required to have a regulator to monitor it and it ensures that all this stakeholder works properly.

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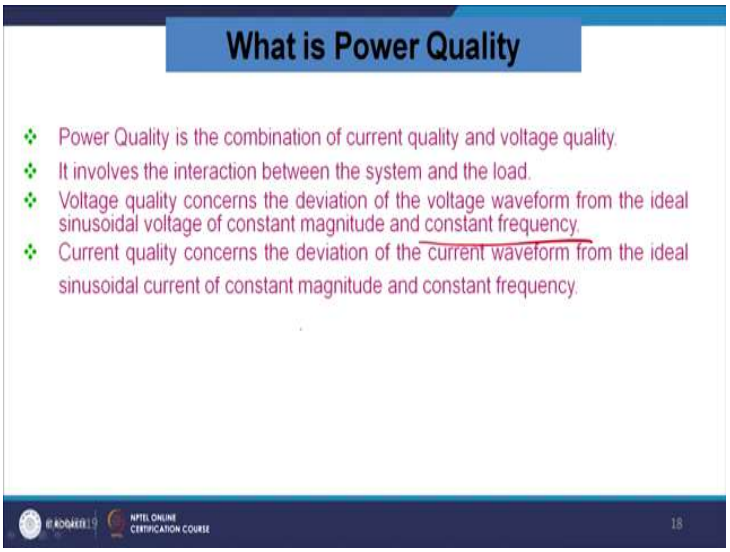

Power quality is a combination of the current and voltage quality and as well as frequency. It involves interaction between the system and the load. Voltage quality concerns the deviation of the voltage waveform from the ideal sinusoidal voltage of constant magnitude and constant frequency. Same way, current quality concerns deviation of the current wave from the ideal sinusoidal constant magnitude and constant frequency.

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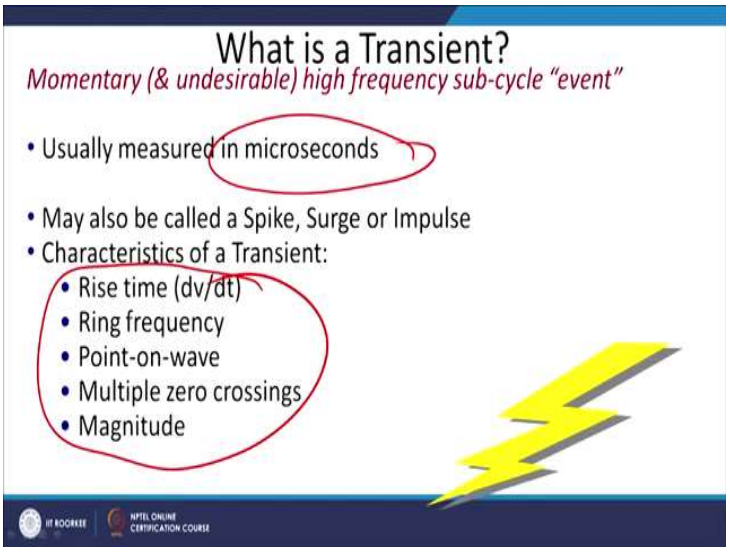

Now, there are other issues. These are transients, which usually measures in the microsecond. We have discussed it in details. I am not going to detail. Just I am touching

upon what I have covered in the syllabus. It may be spike, surge or impulse characteristics of the transient.

We have to deal with this magnitude that is rise time, ring frequency, point on wave, multiple zero crossing and the magnitude. Due to lack of time I cannot explain everything. Please refer back to my transient class. In an overview there I have discussed all the thing.

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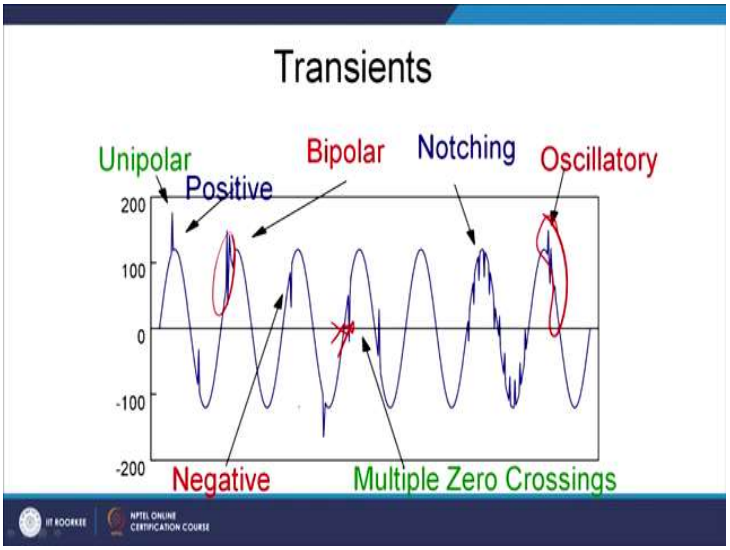

This is the unipolar positive. This spike does not come here and this one is negative and this one is bipolar. You have a double peak. This is notches. Generally, comes due to the thyristor switching and it may be oscillatory. It is coming in a that part of the waveform.

Thus, this is a problem of multiple zero. Here you have crossed the 0, again you are crossing a 0. So, this is the problem of transient that has to be mitigated by the power quality problem.

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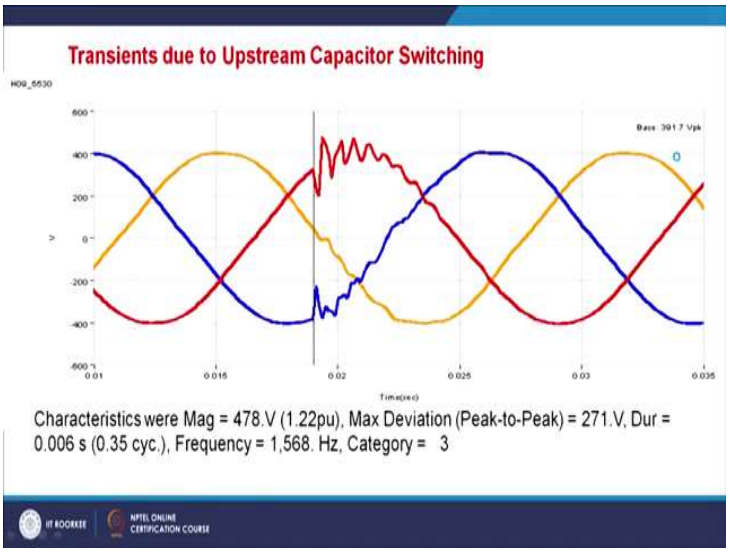

Another example, this is Upstream Capacitor Switching. Till then it was balanced, capacitor of magnitude of 478 volt 1.22 per unit, maximum deviation these and this, duration is 0.006 second, that is 0.3 cycles. Frequency is this much and category? This kind of category you can see that. See here you have undergone the switching and thus it continues for some time and ultimately it deviates. This kind of phenomena are the transient phenomena.

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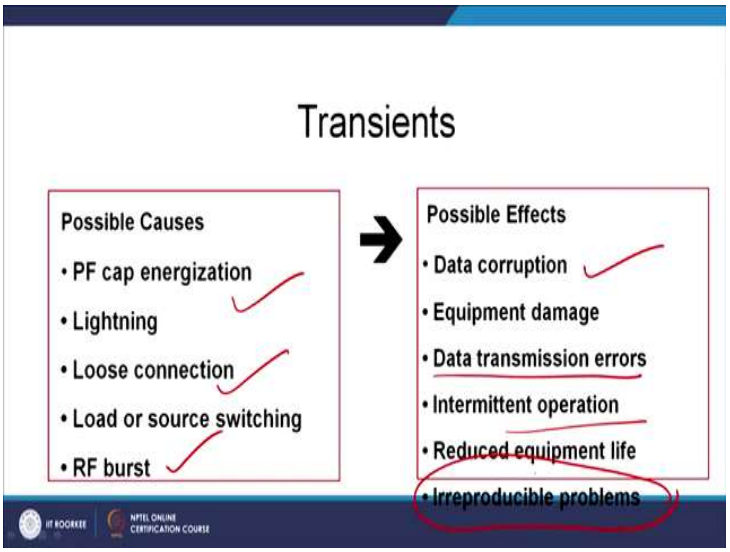

Similarly, we can have a transient here. Possible causes of transient are power factor capacity energization, lightening, loss of connections, load or the source switching or the RF burst. Possible effect: data corruption (if it is a data center then loss of certain data may occur), equipment data, data transmission error (while you are talking other person is not able to hear properly), intermittent operation it may stop due to the flickers, reduce the equipment life and irreproducible problem that is something which may destroy and damages the system heavily. Like lightning. I have seen that due to lightening in my personal house also, some fans were destroyed and it was beyond repair. Possible causes of the transient are this.

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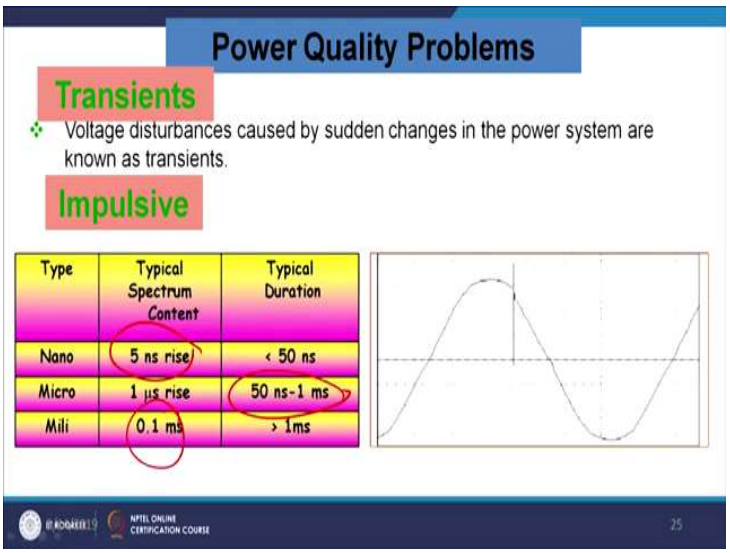

Thereafter let us talk about the transient disturbance caused by the sudden change of the power system and this can be impulsive. Let us see that. These are the ranges of it. The spectral in rise time is 5 nanosecond and typical duration is less than 50. It is micro. This one is the 1 microsecond and typical duration is 50 nanosecond to 1 millisecond and it is 0.1 millisecond. Generally, you have a typical duration of 1 millisecond.

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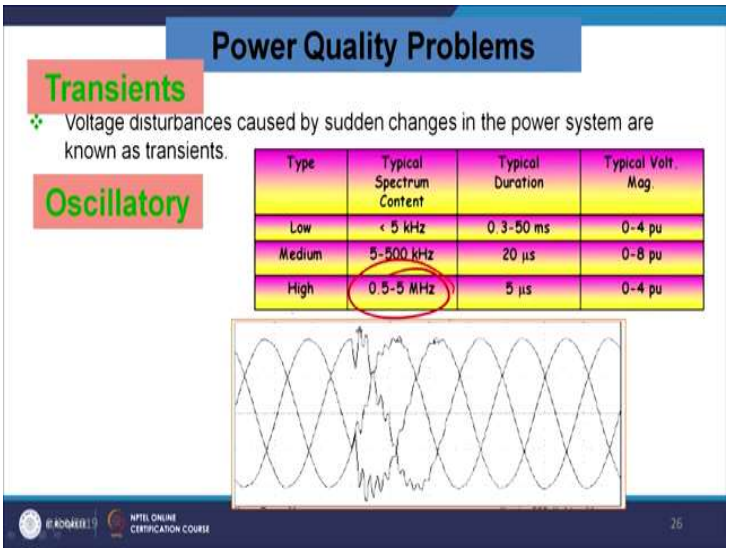

Thereafter transient can be oscillatory. This is an example of the oscillatory transients. So, this comes into the pictures. Thereafter this goes out. So, it can be low. Below 5 kilo hertz, or it can be medium that is 5 to 500 kilo hertz or it can be high as 0.5 to 5 megahertz.

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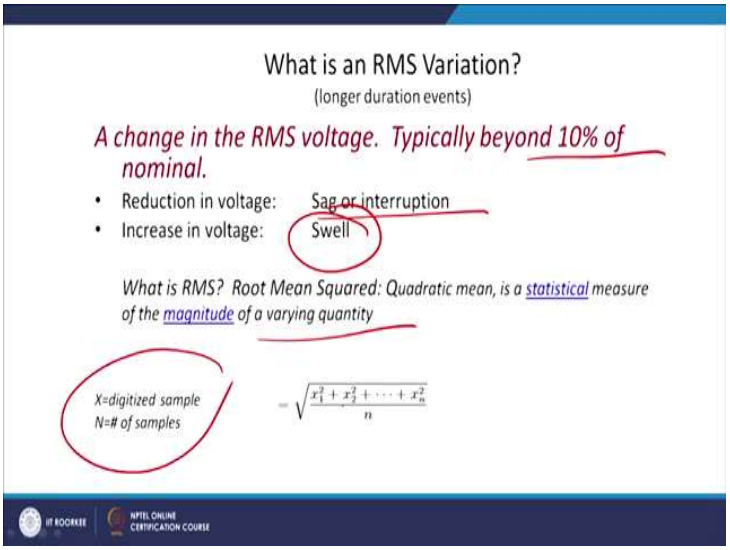

Based on that we have sags and swell. We have discussed that in detail. Typically, Sag or interruptions is beyond 10 percent of the nominal value and increase in the voltage is called swell. What is RMS? Let us define. You note it. It is a root mean square: Quadratic mean

is a statistical measure of the magnitude of the varying quantity where X is digitized sample. You have a N sensed sample. You have like this. That value is your RMS value.

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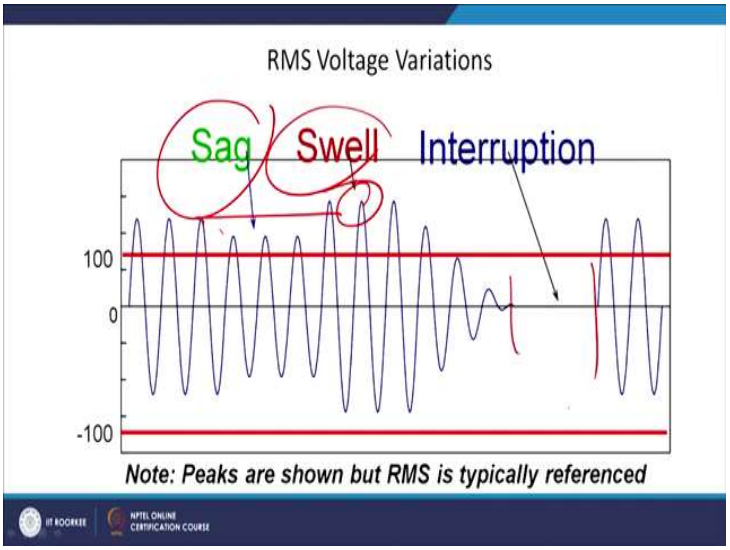

Now, this is an example of different waveforms in the same scale. This is a sag. Here voltage has gone down. This is a swell where voltage has been gone up and this is an interruption for some time. This is a variation of the RMS voltage.

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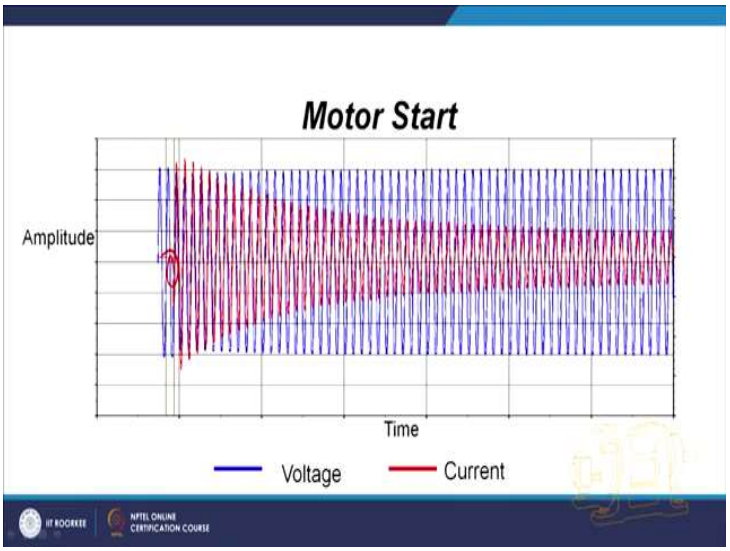

This is one example you know, where motor is starting. Blue one is a voltage and red one is a current.

You can see that here once it starts, it will start at this point. It will have a transient reactance and for this reason high current flows and gradually it will settle down. This is a motor start. So, you will have this transient here.

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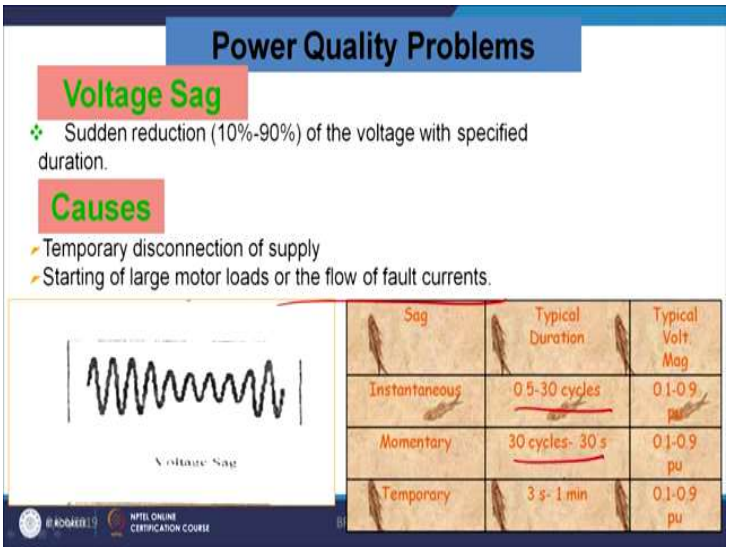

So, what is sag? Sudden reductions of the voltage. We have defined already and cause of the sag is a temporary. This connection of the supply and starting of the large motor load or the fault current. This is the example of the sag. So, instantaneous for 0.5 cycle. We have explained all those things. It is just recapitulations. Momentarily, it is 30 cycle to 30 seconds and temporary it is 3 second to 1 minute.

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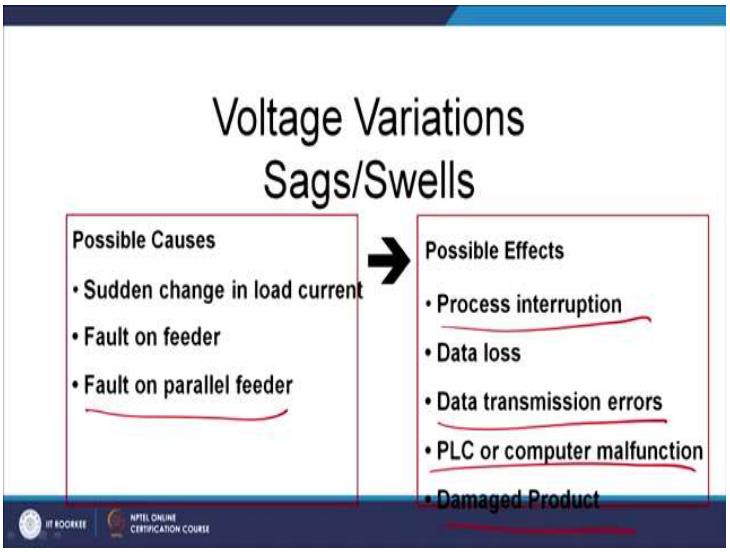

Possible cause of the sag is a sudden change in the load current, fault of the feeder, fault in feeder or fault on the parallel feeder. Possible effect: process of interruption, again data loss, data transmission, PLC computer malfunctions, SCADA may malfunction, damage of the product.

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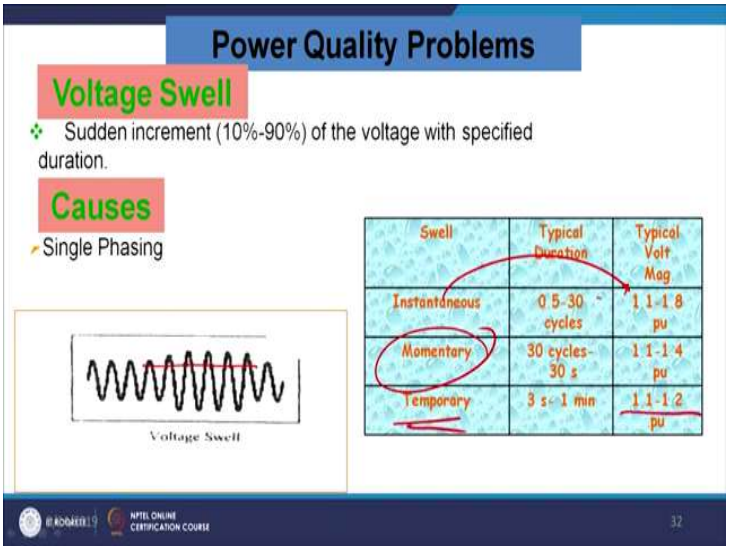

Swell: Again, it is a same thing. It is just opposite of the sag. It is rise in the voltage. Sudden increment of the voltage to 10 percent to 90 percent. This is an example of the swelling of the voltage. Again it will be same. For 0.5 to 30 cycles we say instantaneous.

If it is 30 cycles to 30 second, we call it as momentarily, and otherwise call it as temporary. Please see that if it is instantaneous your value is allowed to be more. If it is temporary the value is restricted to 10 percent to 20 percent.

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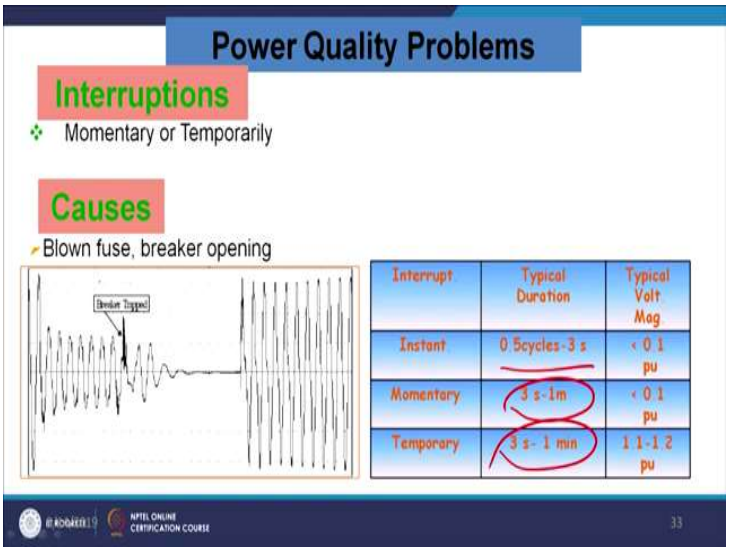

So, these are again the interruptions. Same thing can be seen. This is the interruption. Just where you have a total loss of power and duration can be instantaneous. It can be 0.5 and it can be momentarily for 3 second to 1 minute. If it is 3 second to 1 minute it is temporary, where the typical value of the voltage will be like this. It may be due to blown fuse or the circuit breaker operation.

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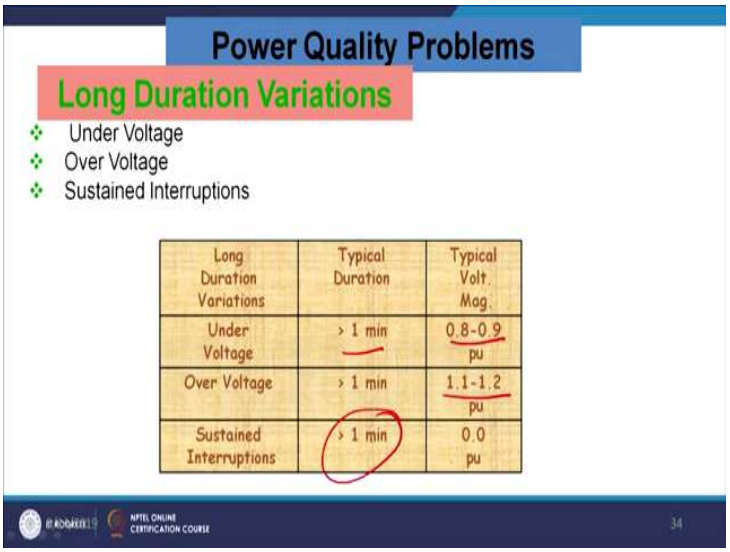

Long duration variation is under voltage, over voltage, sustained voltage. These are the parameters. Under voltage 1 minute, you can go for 0.8 to 0.9 pu. Over voltage: It is 1.1 to 1.2. Sustained interruption can be more than 1 and thus it is a total blackout. It is 0.

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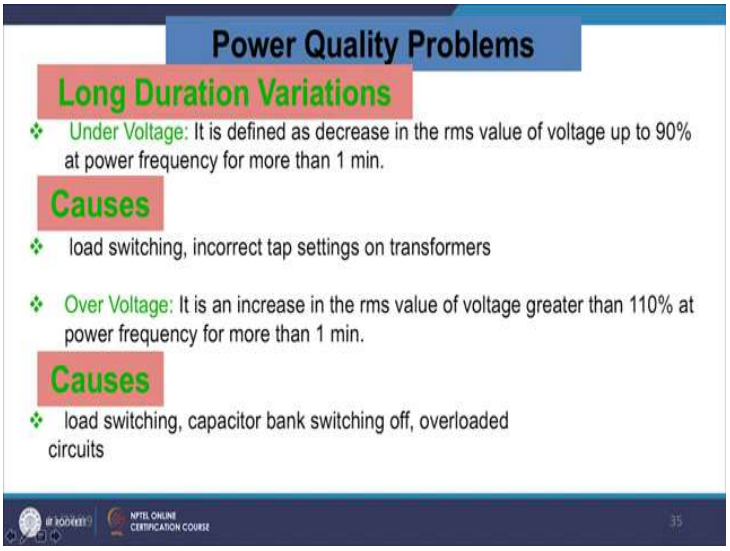

Under voltage: It is defined as decreased in RMS value to 90 percent of the power frequency for more than 1 minute and causes, incorrect setting of the transformer. Over voltage is an increase in the RMS value of the voltage greater than 110 percent of the

power frequency for more than 1 minute and caused maybe due to the capacitor bank switching, or the overload problem. These are the issues.

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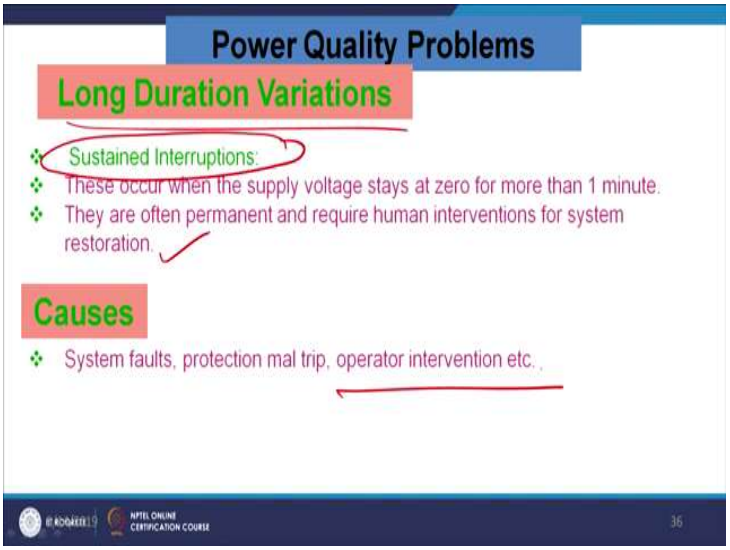

Now, there is a sustained oscillation. So, long duration variations can have a sustained interruption. Those occurs when the supply voltage stays at '0' for the more than 1 minutes. They are often permanent and require human intervention for system restoration. Cause: Maybe system fault, protection mal trip, operation intervention, etc.

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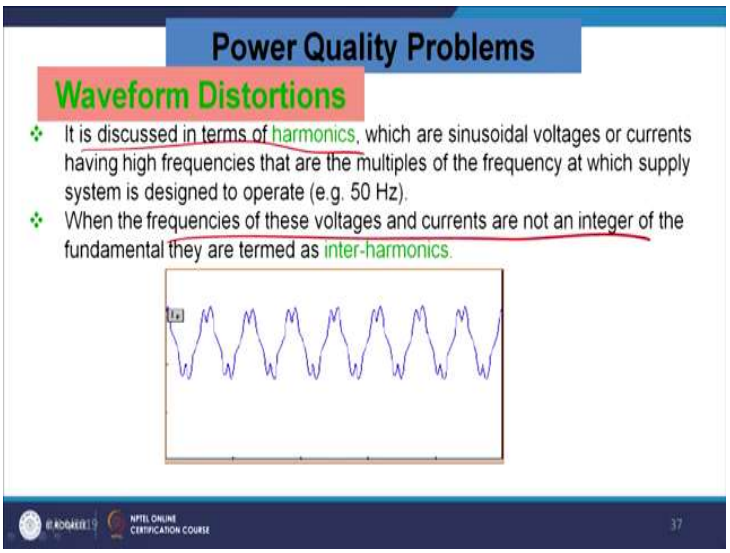

Now, let us come to the harmonic part of the power quality problem. This is one of the major issues here and it is discussed in terms of the harmonics. Voltages and current are sinusoid and it has to operated at 50 hertz and there is another issue. It is called inter harmonic. When the frequencies of the voltage and current are not integer of the fundamental, then they are termed as inter harmonic.

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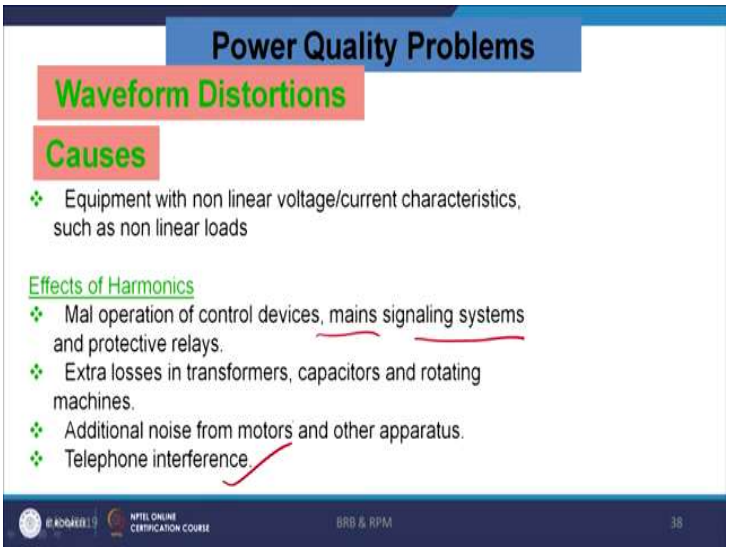

So, cause: definitely, it is the non-linear voltage and current. Effect of the harmonics are malfunction of the control device, mains signal systems, extra losses in transformer, capacitor and the rotating machine, additional noise from the motors and other parameter and telephone interferences.

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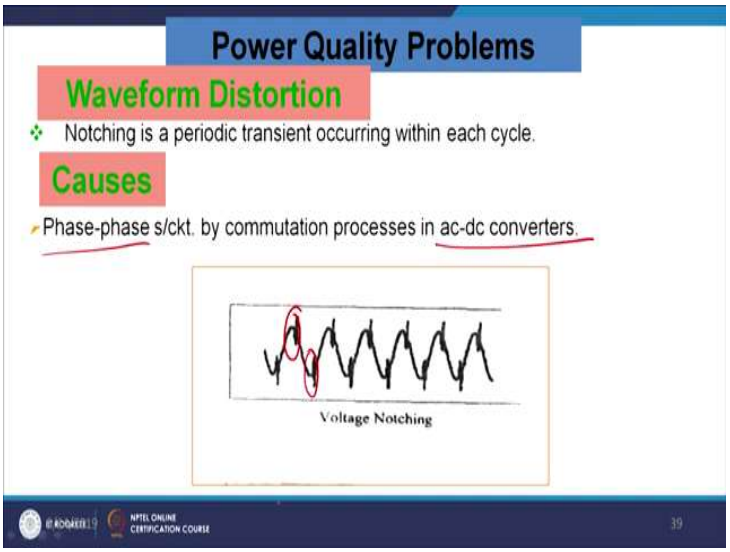

Thereafter, we can have notches. Notching is a periodic transient occurring within every cycle. It can be due to the ac to dc convertor switching and phase to phase circuits by commutation process. Here we see the example of it. There is a notch here, there is a notch here. But thyristors change over occurs, it gives a notch.

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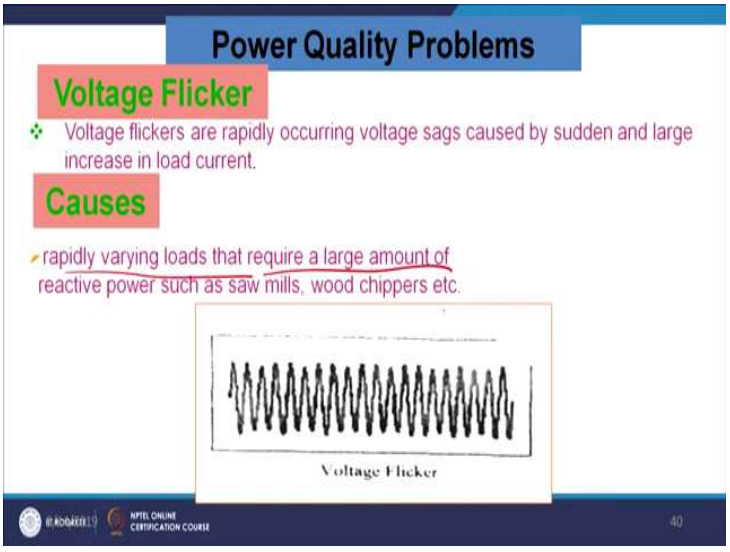

Similarly, we can have a flicker. These are the rapidly occurring voltage sags caused by sudden large change of the load and definitely it is due to the rapidly varying loads that

require a large amount of reactive power such as the saw mills, wood chipper etc and we have this kind of flickers problem all of a sudden.

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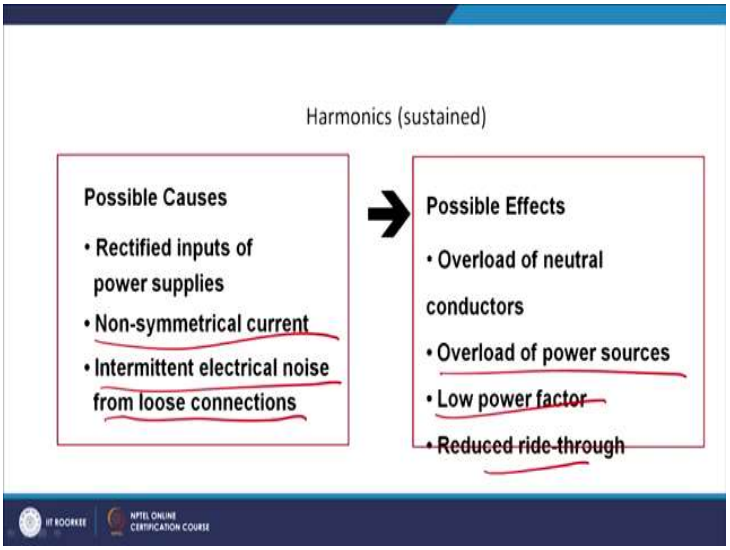

Possible causes: Definitely the rectified input of the power supplies, non-symmetrical current, intermittent electrical noise from loose connection and thus what happens? It will overload the neutral conductor and thus it may burn, overload the power sources, low power factor and reduce the ride-through problem.

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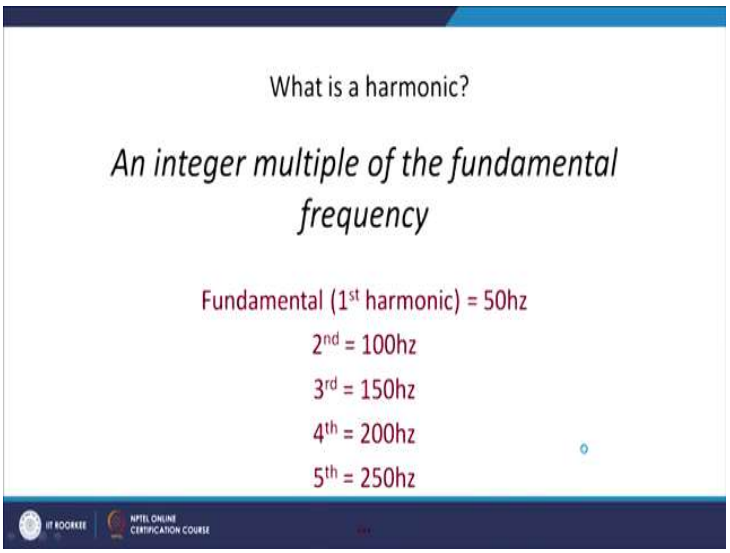

So, what is Harmonic? You know well. This is the integer of the harmonic considering the 50 hertz.

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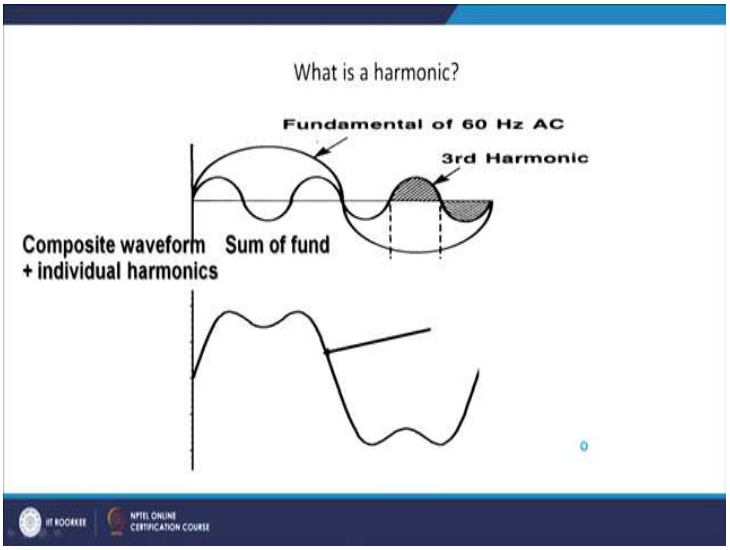

Now, if it is fundamentally 60 hertz. Let us consider that and the 3rd harmonic. Then the composition of the waveform can be this and we call it 3rd harmonic injection. We sometime intentionally do it in drives or it will be like this. It is a contamination if it is available in the waveform.

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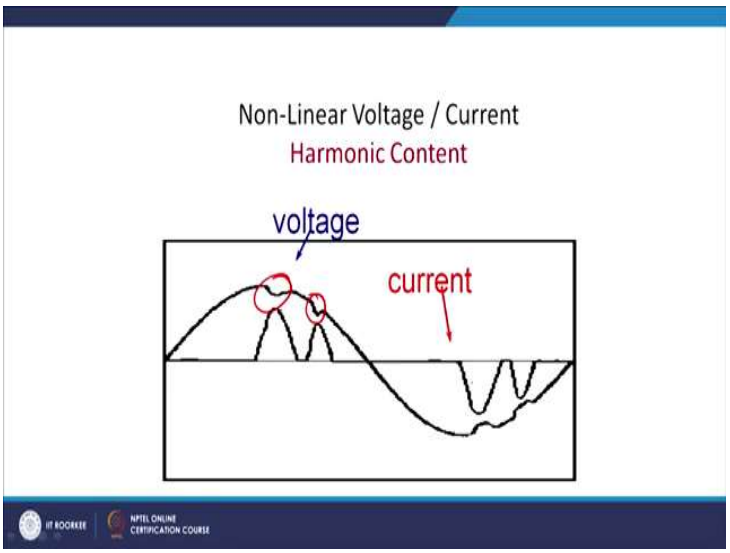

This occurs when the diode bridge rectifier feeding the RC load. The current will have a distortion power factor and due to that current only flows for this duration. There will be a notch in the voltages and current, which will flow only for this duration. This is the non-linear voltage and current with the harmonic.

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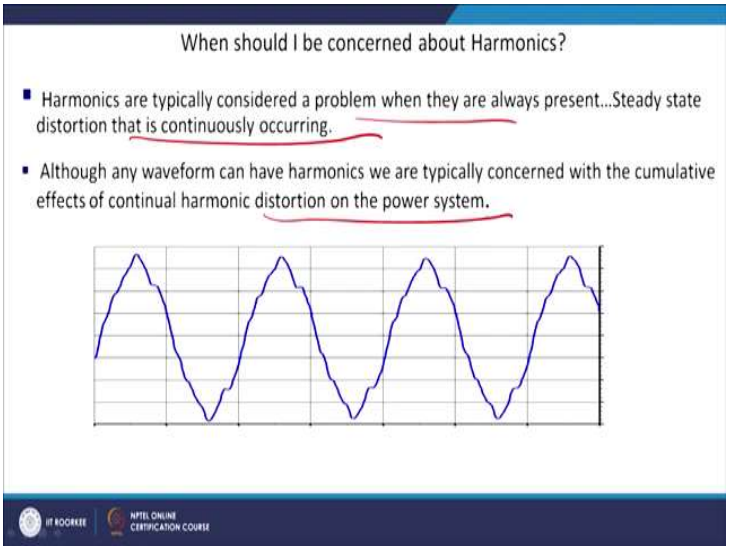

Similarly, the harmonics are typically considered to be a problem when they are always present in a steady state distortion that is continuously occurring. Although any waveform can have harmonics, we are typically concerned with the cumulative effects of continual harmonic distortion on the power system.

We are more bothered about the overall effect on the system instead of on one cycle or two cycle.

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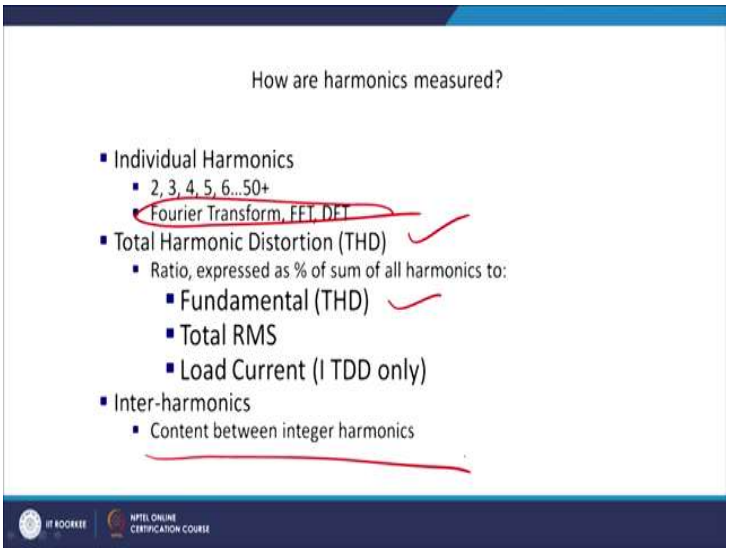

For this reason, we require to define individual harmonic and we know that we can find it with a Fourier Transformation and to measure the harmonic content we have few methods. That is mainly the THD, that is Total Harmonic Distortion and that is a fundamental THD, that is total RMS and the load current RMS and there can be a inter-harmonics. That is another nasty element as well.

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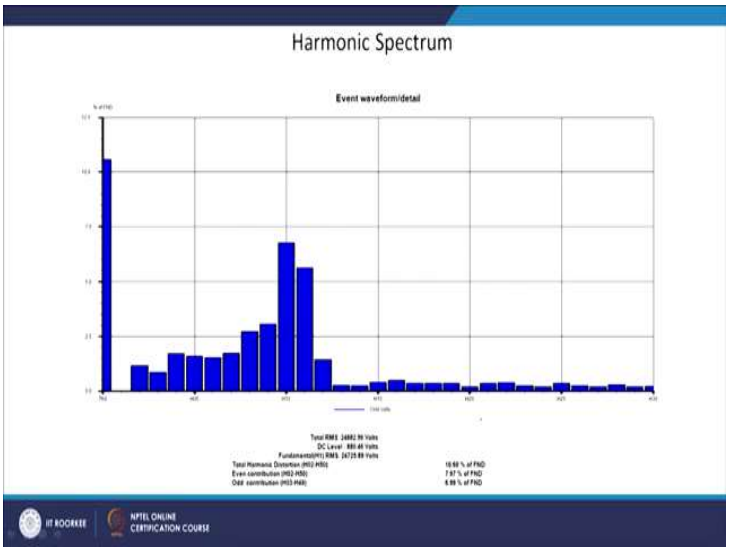

For this reason, this is a harmonic spectrum. You can see that this is a fundamental and others been plotted like this. This will come when you do the FFT of your current sample or the voltage sample having a harmonic.

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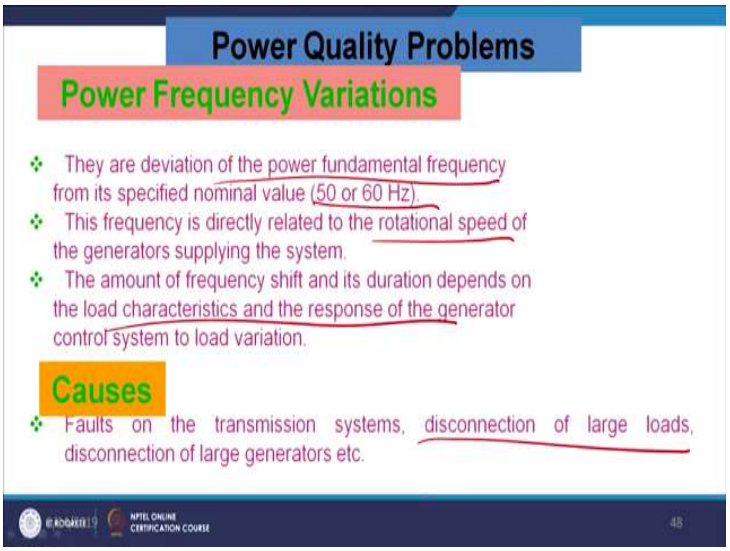

What happened due to these harmonics then? They are deviations of the power fundamental frequency from its specified nominal value of 50 hertz or 60 hertz. This frequency is directly related to the rotational speed of the generator supplying the system. The amount of frequency shift and its duration depends on the load characteristics of the generator control system and due to that what happens? Fault in the transmission system, disconnections of the large load and disconnection of the generator, blackout. These problem occurs.

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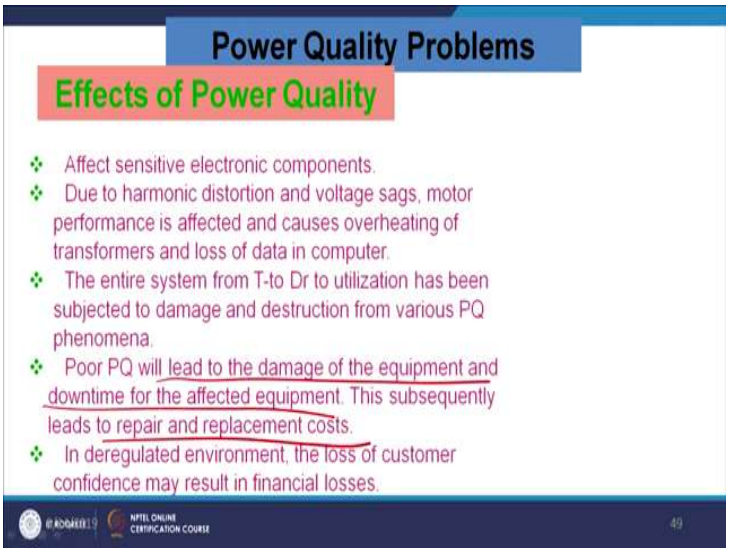

Now, effect of the power quality. We have discussed that thoroughly and so let us take out this point. Poor PQ will lead to the damage of the equipment and downtime for the effected equipment and this subsequently leads to repair and replacement costs. For this reason, we have to take power quality issues quite seriously.

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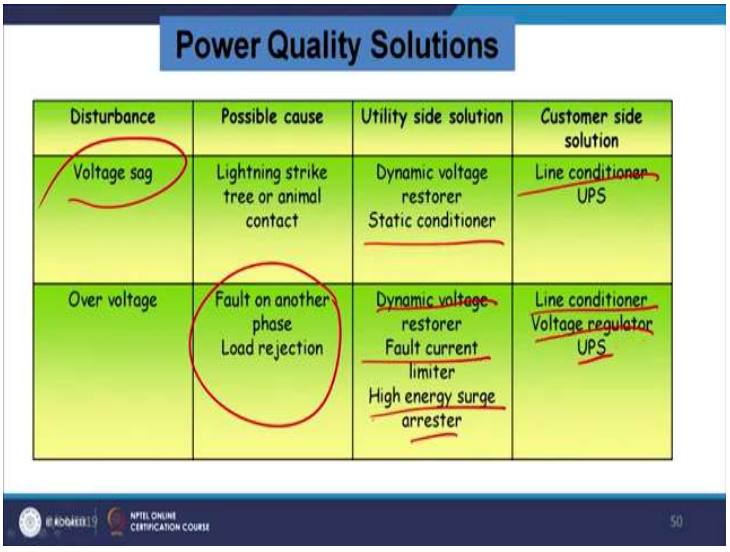

Now the solutions, that is something we have discussed and let us have a tabular form. If the disturbance is the voltage sag, possible cause is a lightning strike of a tree or animal contact and the utility side solution to that is dynamic voltage restorer, static voltage

condition. Consumer side solution can be your UPS. Over voltage – Caused by fault in one phase or the load rejection. Utility side solution is dynamic voltage restorer, voltage current limiter, high energy surge arrester. Commercial or customer side solution is a line conditioner, voltage regulator, UPS. For interruption, possible cause can be blackout or the blown fuse breaker operation.

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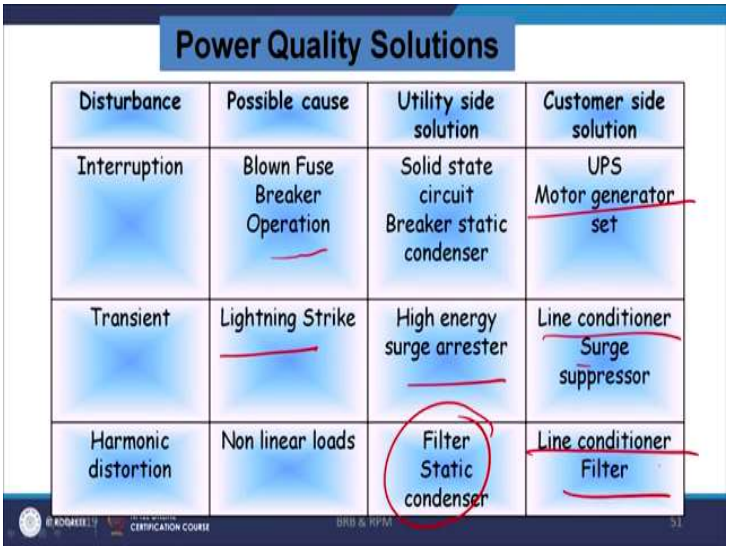

The solution of the utility side - The solid-state circuit breaker, which can restore very fast and customers has a solution. That is a motor generator set, transient lightning strike, high energy in high energy surge arrester and we require to produce as a consumer the line conditioner surge arrester. Harmonic distortion: Possible cause is due to the non-linear load. Utility side solution can be the static condensers, filters and for us thecustomer it will be line conditioner filter or active power filter.

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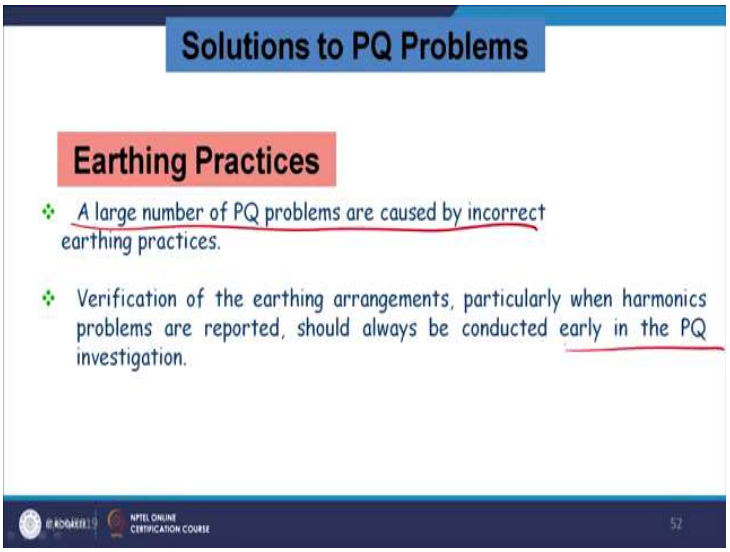

Another solution is good earthing practice. This is also an important entity. The large number of PQ problem is caused by inaccurate or inappropriate earthing. Verification of the earthing arrangement particularly when harmonics problems are reported should always be conducted early at the PQ investigation.

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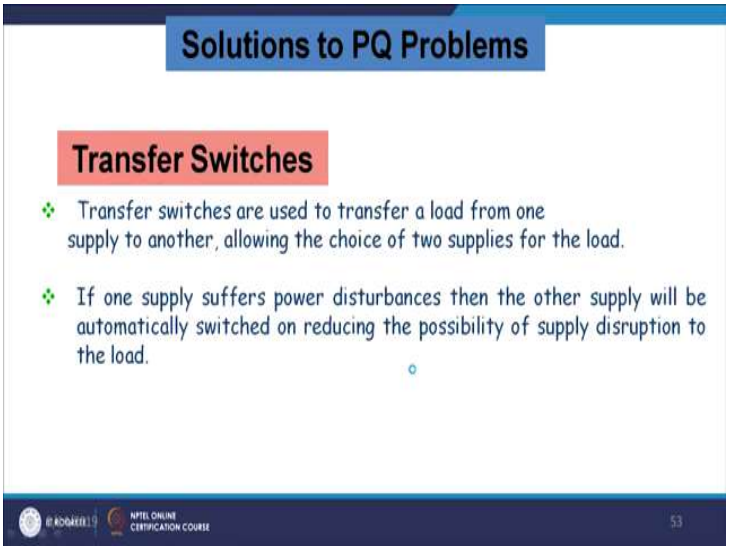

Transfer switches: Transfer switches are used to transfer a load from the supply to another, allowing the choice of two supplies for the load. What do we do generally? We generally put our signal phase load in between line and neutral. We required to put the line and earth.

We have to see that RCB is stripping or not. Then you can say that earth is healthy and current is flowing. Otherwise you will have unnecessarily high voltage.

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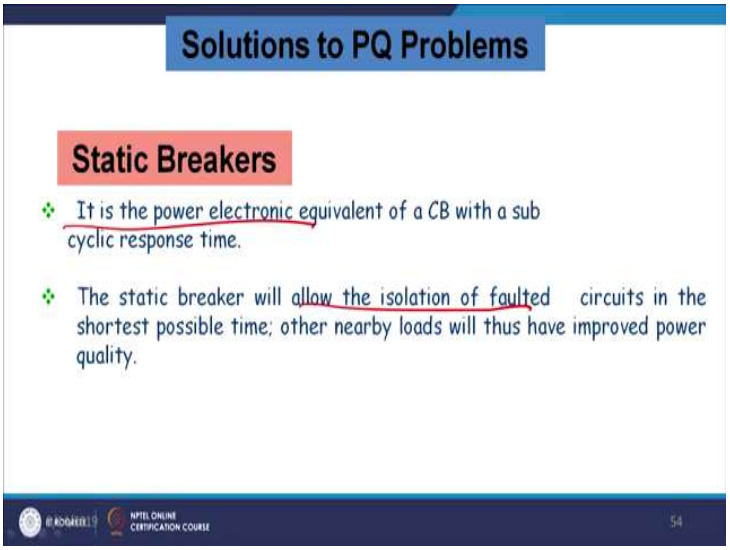

It is the powers electronic circuit breaker. What does it do? This is a static circuit breaker. It can make and break the circuit very fast. The static breaker allows the isolation of the faulted circuits in the shortest possible time and thus, it improves the power quality.

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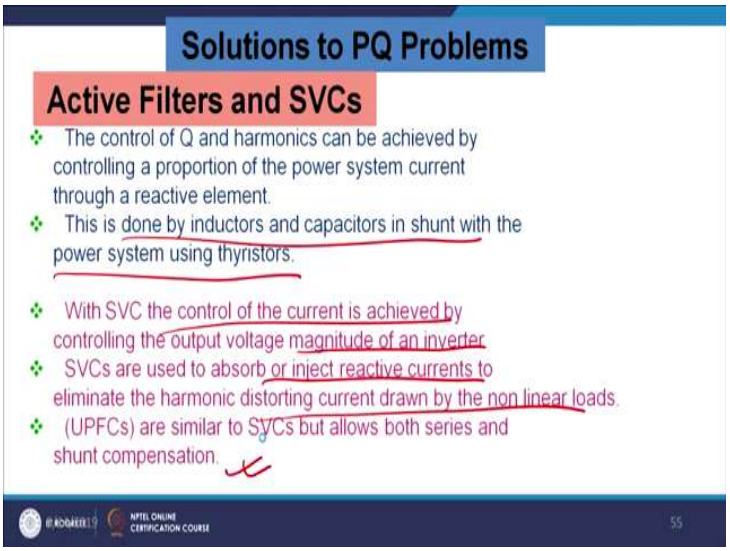

Thereafter we can talk about the solution like Active Filter and SVCs. Control of Q and harmonics can be achieved by controlling the proportion of the power controller. This is

done by inductors and the capacitors in shunt with the power system using the thyristor. With SVC, the control of the current is achieved by controlling the output voltage and magnitude of an inverter and SVCs are used to absorb or inject the reactive currents to eliminate the harmonic distorting current through the non-linear load. Similarly, extension of this is UPFCs or UPQC, that will compensate the load overall.

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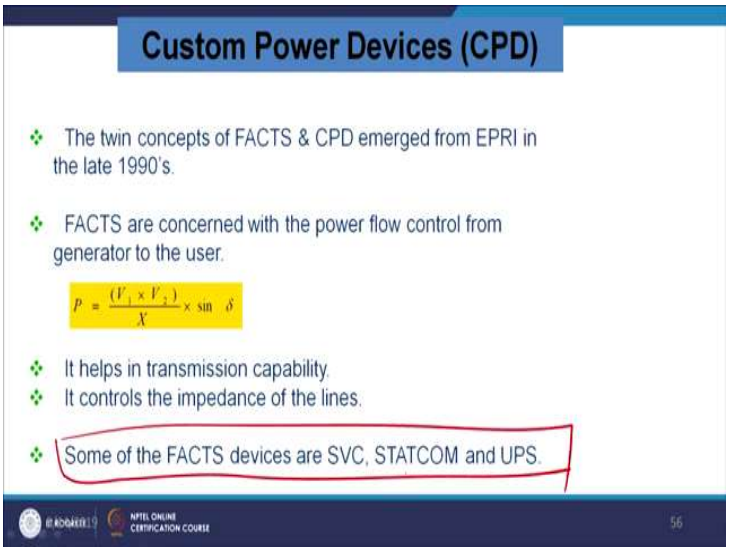

Now, this is called the Custom Power devices. That comes into the picture with the invention of the FACTS and you can see that this is the power transmission and that will help to increase the power supply enhancement quality. We have already discussed these in our first courses. That can be placed with the power quality issues.

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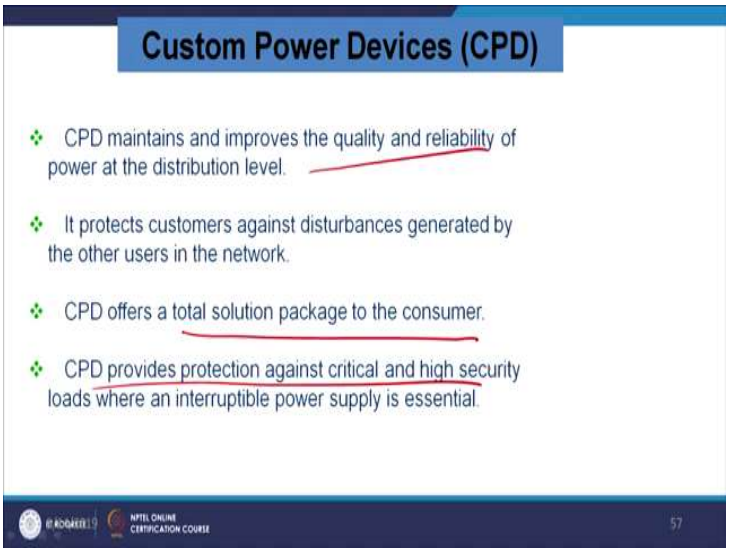

This custom power device can improve your power quality and the reliability, CPD offers a total solution package to the customers and CPD also offers protection against critical and high security loads or an interruption occurs.

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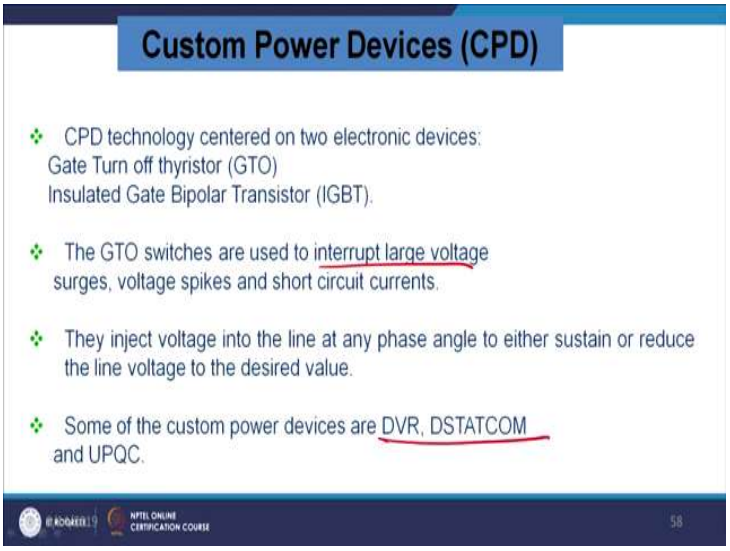

It can be IGBT or the GTO based. The GTO switches are used to interrupt large voltage and current having a higher power rating. But switching frequency is less and some of the custom power devices are DVR, D-STATCOM and UPQC.

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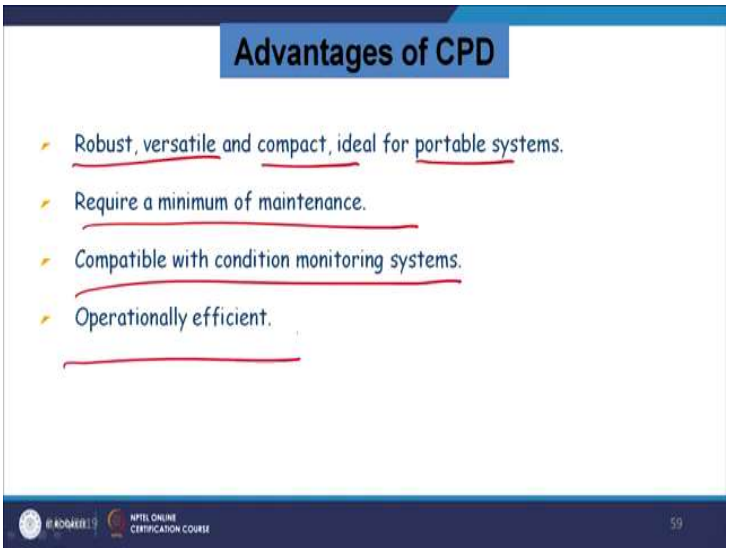

Why we go for this solution? It is a robust, versatile, compact, ideal, require minimum maintenance, compatible with condition monitoring system and operationally efficient.

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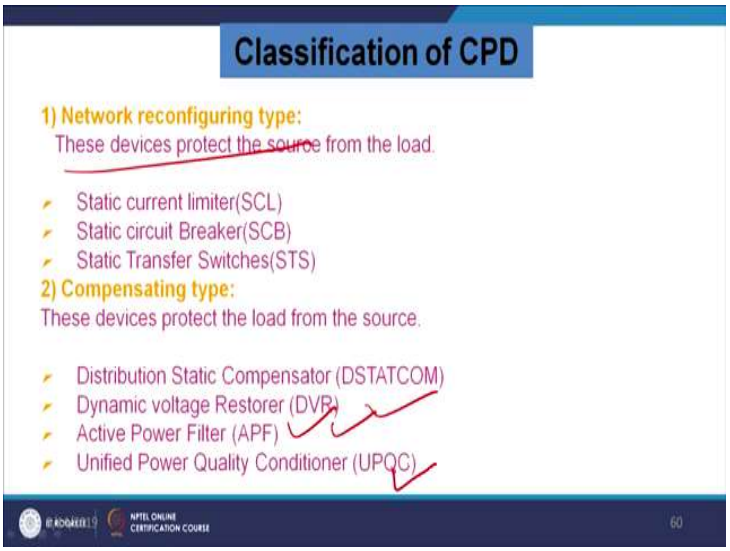

These are the few network configuration type. This type of devices like static current limiter, static circuit breaker, static transfer of switches protects the source from the load. In the compensating type it can be a D-STATCOM. It can be DVR. It can be shunt active power filter. It can be UPQC. So, please recall this. Remember this slide. MCQ question

will come from this. Similarly, we have discussed DVR. I am not going to discuss in details. So, it is a series compensation.

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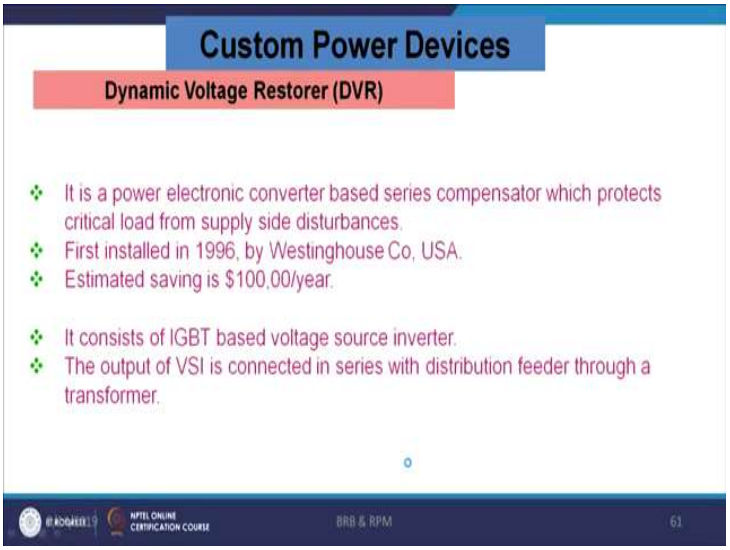

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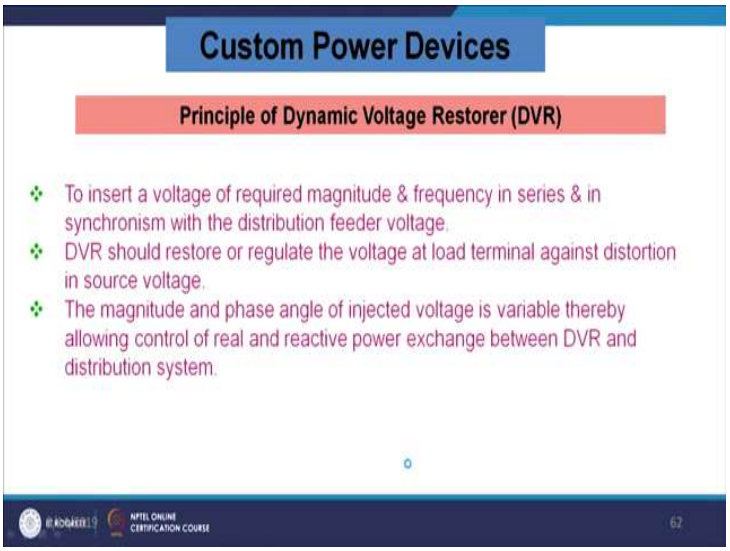

Thereafter we have, DVR should restore the voltage. We have discussed it in detail while discussing UPQC. So, we are not discussing it here again.

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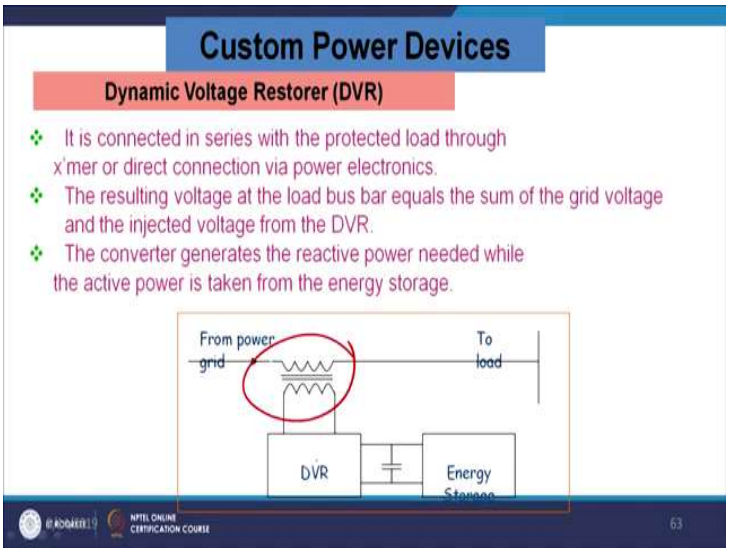

Similarly, this is DVR and energy storage entities. It can mitigate sags and swell. If sag occurs, it will charge the storage entities. If swell occurs, then it will charge the storage entity and when sags occur, it will compensate the swell entity.

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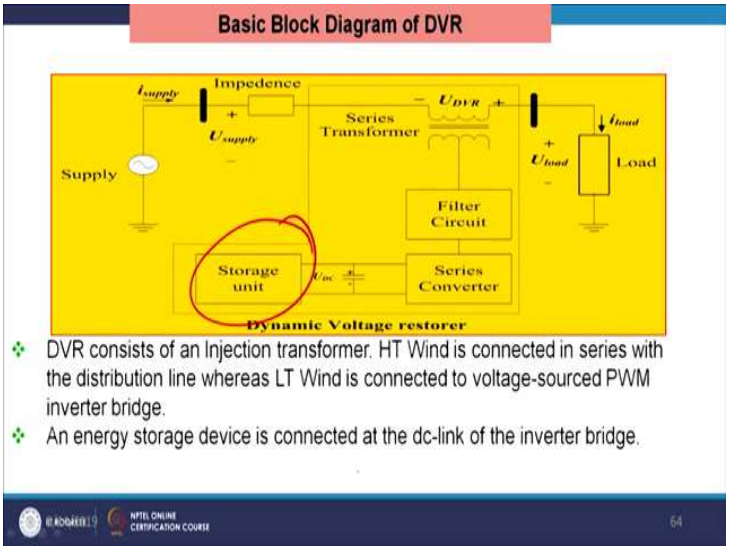

This is the overall basic diagram of the DVR. This is storage unit. This is series converter. This is series filter. In that way, it will compensate the filtering part.

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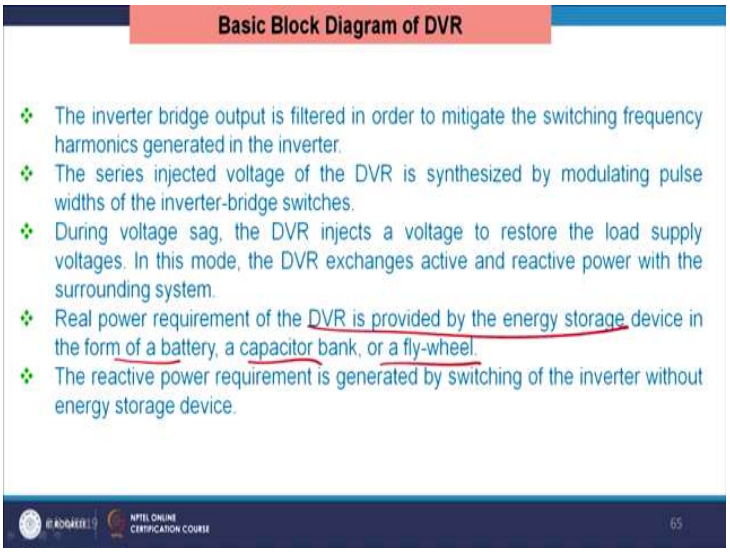

Similarly, we required to provide the real power requirement. It can be provided to the battery, capacitor bank or the fly wheels. The reactive power requirement is generated by the switching of the inverter without requiring any storage device. You can generate it with the help of the angle between the voltage and current.

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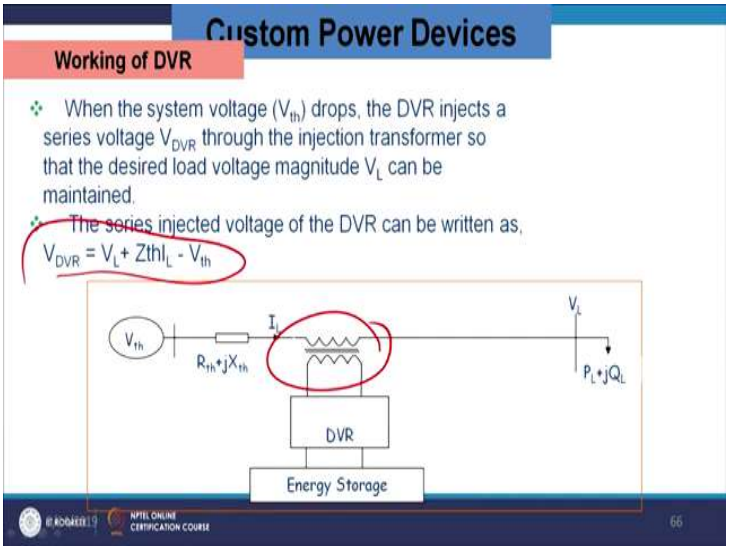

Similarly, we can inject this current and we can write in a Thevenin's form. In that way you can calculate the storage rating of the device.

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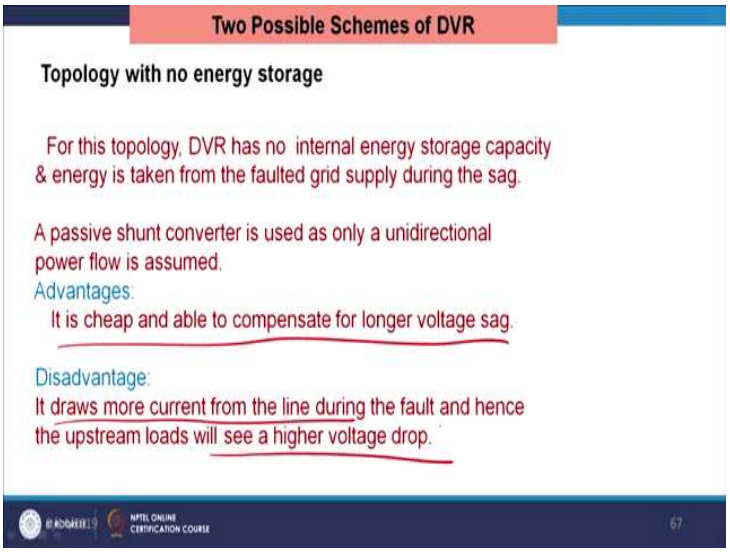

Similarly, there are advantages and disadvantages. Advantage is that it is cheap and able to compensate the longer voltage sag. Disadvantage is, it draws the current from the line during the fault, hence the upstream load sees the higher voltage drop.

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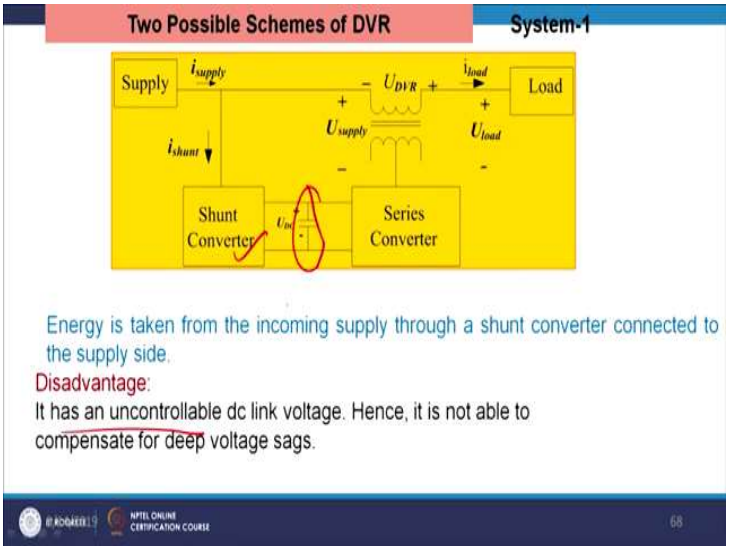

So, this is one of the examples of combining the series and the parallel combination. This is called UPFC. You have a shunt path. It takes the current and it compensates. Again, it has a disadvantage. That is an uncontrollable dc link voltage. Hence it is not able to

compensate the deep voltage sags and for this reason you have to design for up to a certain level of voltage sag.

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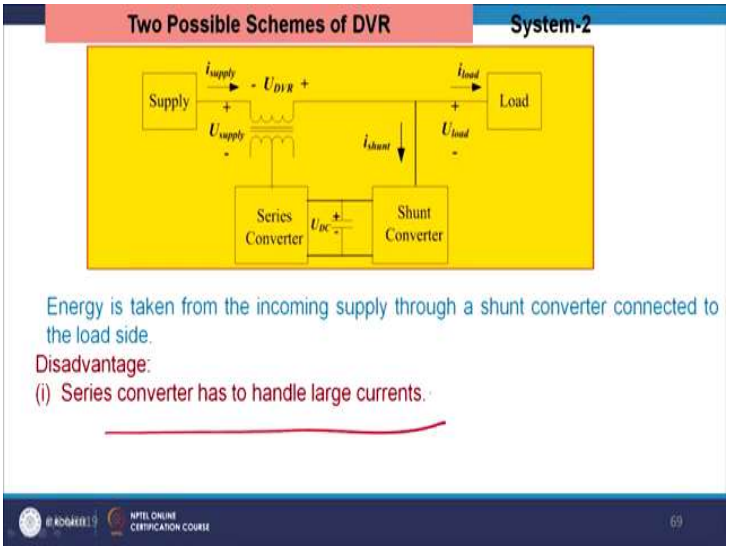

Similarly, we can have another system. Energy taken from the supply through the shunt path and thus it can mitigate the large amount of the current and this is the combinations. This is a series combination and generally we do not use it. We prefer the UPQC.

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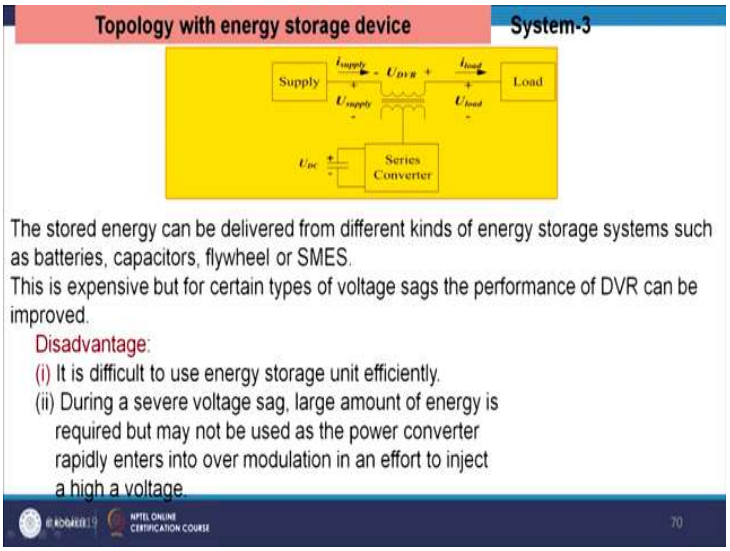

Thank you. Thank you for your attention. Thank You for showing interest to our Power Quality Improvement Technique course and we are looking forward to your positive feedback and that will help us to develop different courses further.

Thank you.