**Digital Protection of Power System**
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**Lecture 27**
**Load Shedding and Frequency Relaying - I**

Hello, friends. So, today we are going to discuss about the load shedding and frequency relaying scheme. So, we know that in a power system when it is working in stable or normal condition with a fundamental frequency of let us say 50 Hz or 60 Hz.

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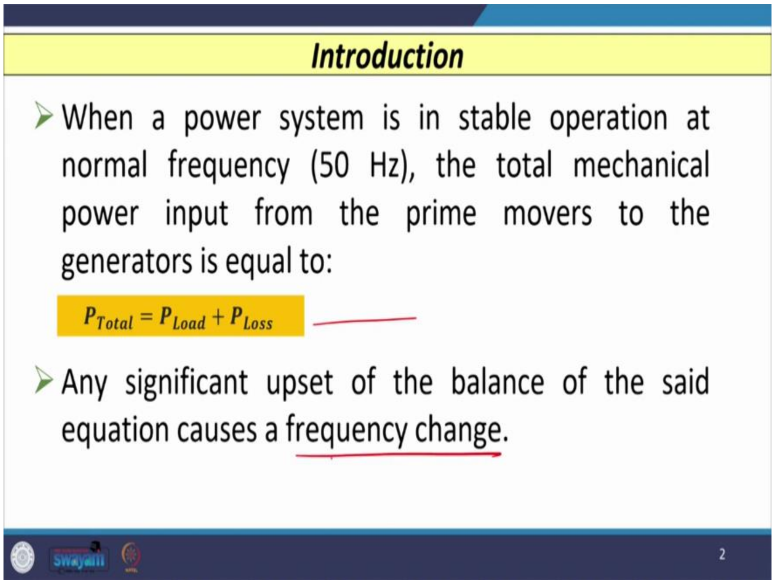


The total mechanical power input from the turbine that is given to the generator that is governed by this equation, where the total power is equal to the power that is delivered or governed by the load and the power that is associated with the losses. So, the balance of this equation is disturbed, then that is going to cause a change in frequency in which we are interested.

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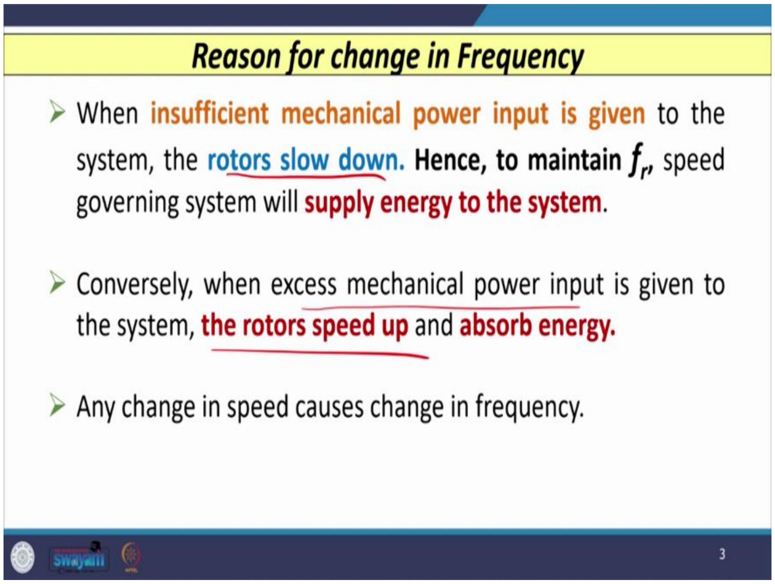


So, let us see first what are the reasons for change in frequency? So, whenever the mechanical power input that is given is not sufficient to the system, and in that case, rotors slow down. Hence, to maintain the reference frequency speed of the governing system will supply this energy to the system. On the other hand, when excess mechanical power input is given to the system, the rotors speed up and absorb energy. So, that means any change in speed that is going to cause the change in frequency.

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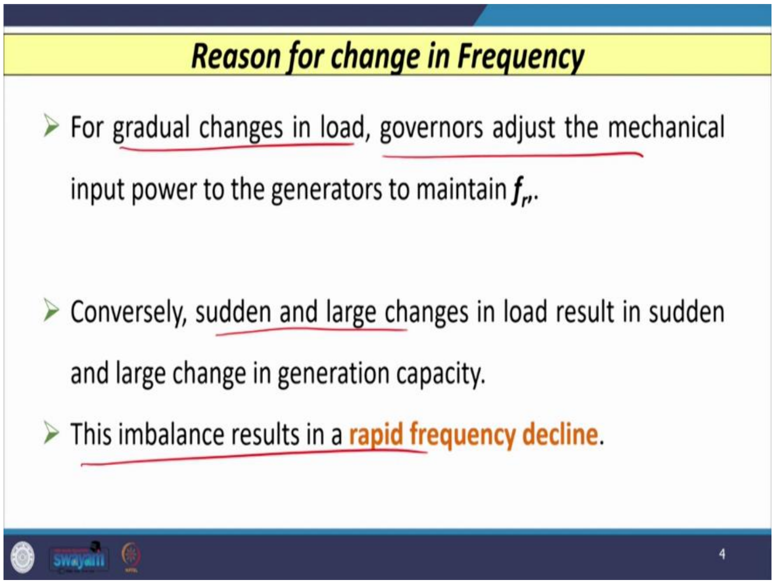

So, for gradual change in load, that means, if the load is changing gradually, then governors are capable to adjust the mechanical power input that is given to the generators with reference to the reference frequency and we can maintain the frequency however, when rapid change that is going to occur in the load, then that is going to result in sudden or large change in generation capacity and this unbalance resulting rapid change in frequency and usually most of the cases frequency will decline.

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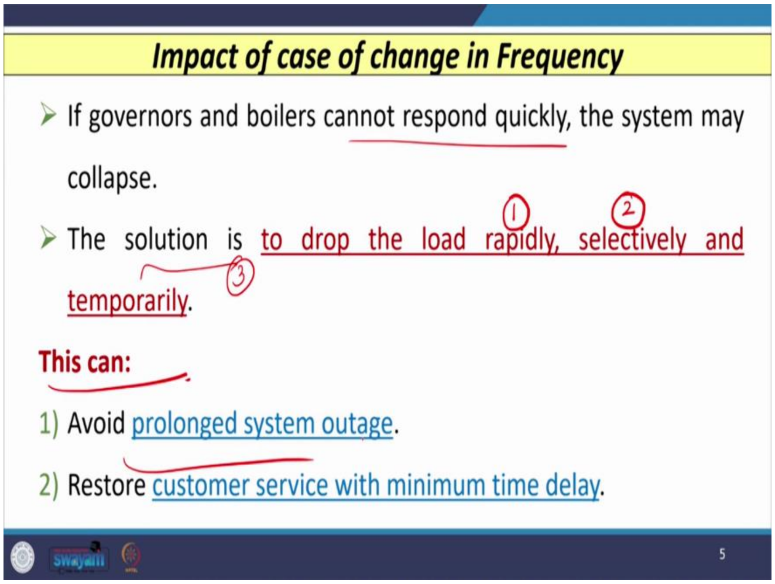


So, now, let us see what are the impacts in case of changing frequency? So, if frequency changes, then what will happen? So, if governors and boilers cannot respond quickly, because these are the very huge inertia system, then the system may collapse. The solution is to drop the load rapidly, selectively and temporarily. So, these three things is very important, that we have to drop the load, we have to remove the load rapidly, we have to also remove the load selectively.

So, that appropriate frequency balance that should be there. And we have to remove this load temporarily, because we need to again come back to the original condition. So, that there should not be any revenue loss. So, this can be avoided, means if we remove the load rapidly, selectively and temporarily, then that is going to avoid prolonged system outages and it will also restore customer service with minimum time delay.

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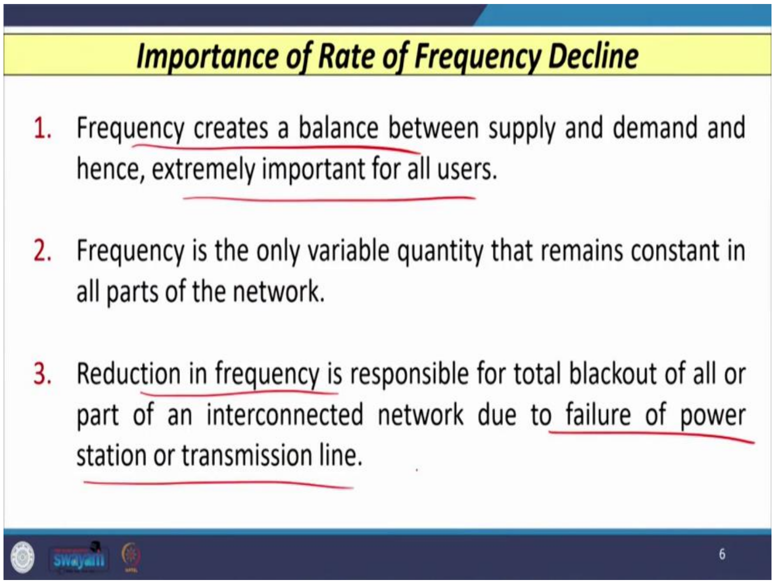


So, importance of a rate of frequency declines, that governs by major three factors. The frequency, that is going to create balance between the supply and the demand. And hence, this is extremely important for all the users available in the power system network. Moreover, frequency is the only variable quantity and that remains constant in all parts of the network. And reduction in frequency is responsible for total blackout or maybe sometimes partial blackout or sometimes the part of the interconnected network that may come out of the service, because of the failure of power station or transmission line.

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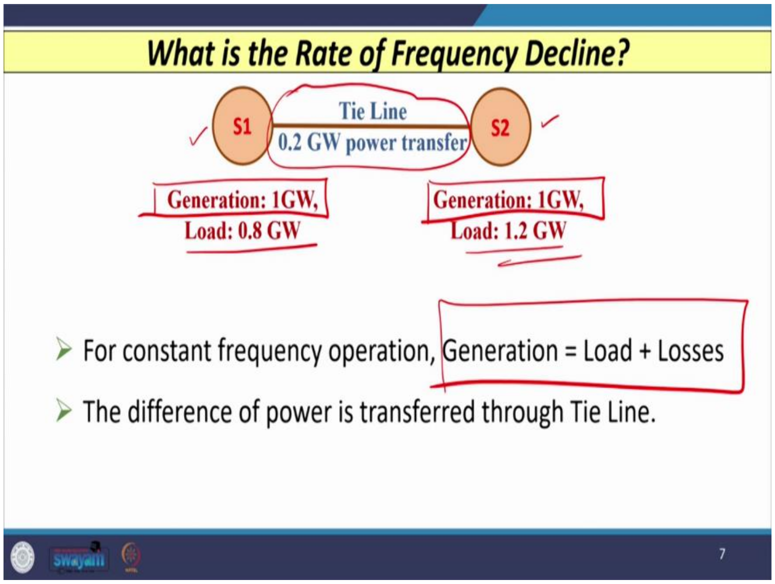

So, now, let us see what is the rate of frequency decline? So, to understand this, let us consider the system of two generators. On one side we have group of generators that is S1 and on another side we have a group of generators denoted by S2. The capacity of the group of generators on S1 is 1 gigawatt, that is 1000 megawatt. And the capacity of generation of the other group of generators S2, that is also 1 gigawatt. Load on the S1 side that is 0.8 gigawatt and the load on S2 sides, that is 1.2 gigawatt.

So, the additional 0.2 gigawatt power, that is supplied by the Tie Line which is connected between the S1 group of generators to the S2 group of generators or between area 1 and area 2. So, we know that for constant frequency operation, generation should be equal to the load plus losses and whatever difference is there that has to be transmitted or governed by the Tie Line.

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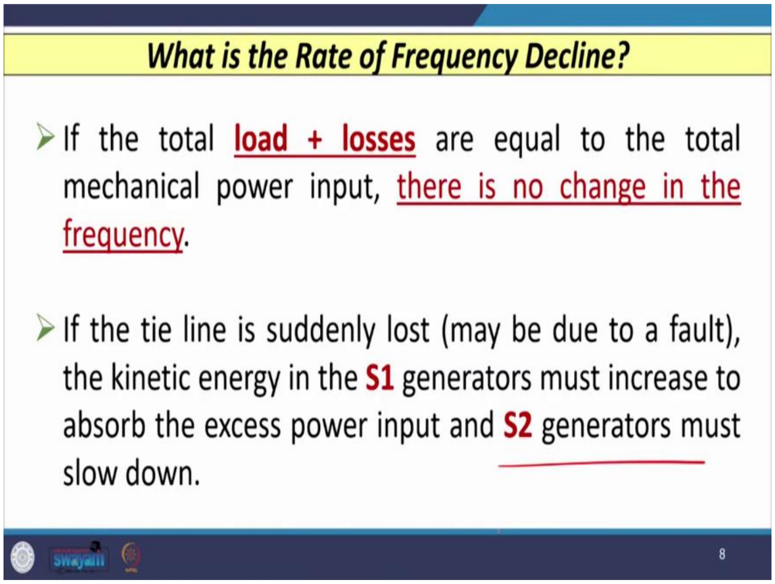


Now, if the total load plus losses are equal to the total mechanical power input, there is no change in the frequency. However, if a tie line is suddenly tripped maybe because of fault or maybe because of permanent fault or temporary fault, then the kinetic energy in the S1 group of generators increased and to absorb the excess power input and at the same time for S2 generators it slow down.

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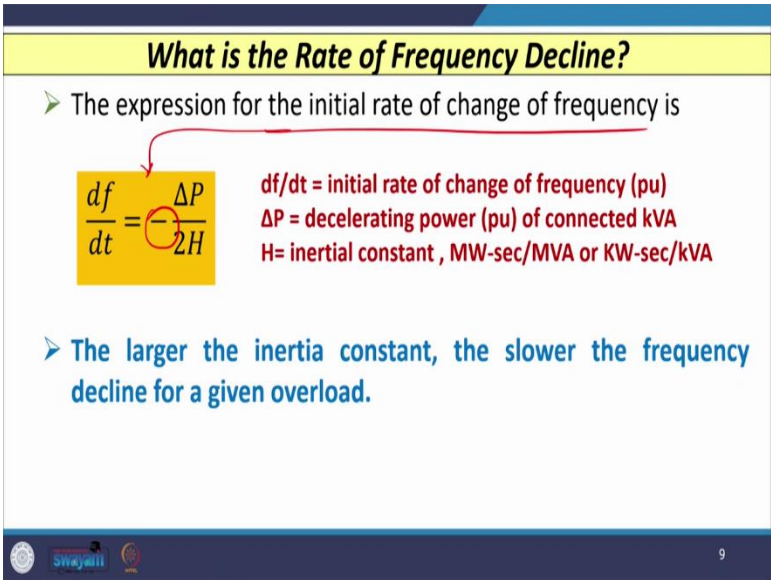


So, to understand that whenever such thing is going to happen, then the initial rate of change of frequency when there is a tripping of tie line, because of something, then that is governed by the equation which is given as the rate of change of frequency that is $\frac{df}{dt} = -\frac{\Delta P}{2H}$, where df/dt is the initial rate of change of frequency in per unit, $\Delta P$ is the decelerating power in per unit that is connected in kVA, and H is the machine inertia constant, which is normally given in megawatt seconds per MVA or kilo watt seconds per kVA.

Larger the value of inertia constant, the slower is the decline of the frequency. And this negative sign indicates that the frequency is declining with reference to the fundamental or base frequency.

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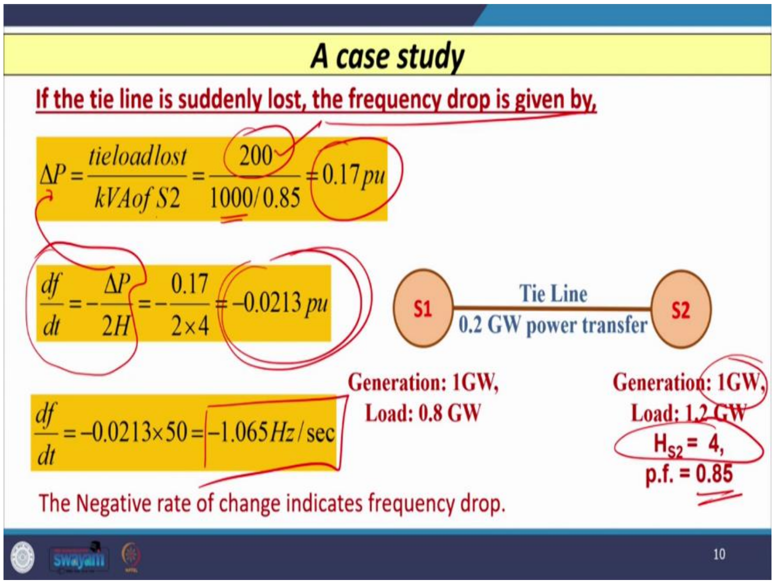


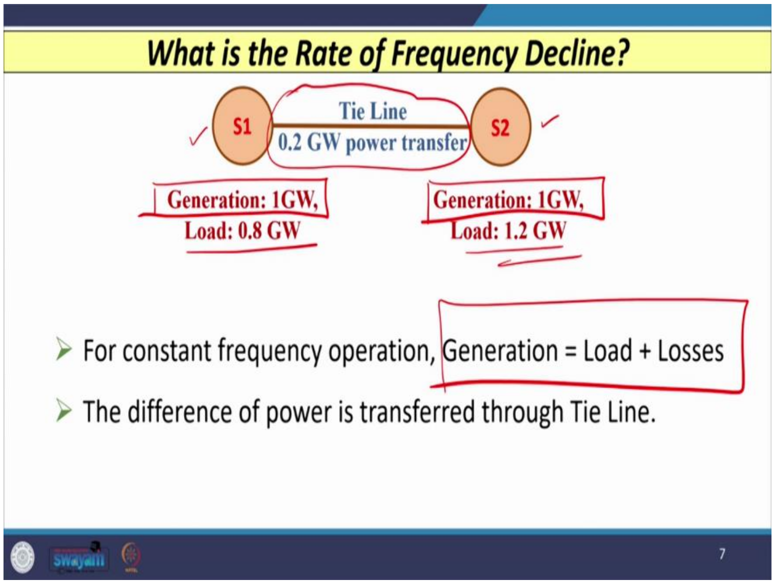


So, let us consider one case study to understand the concept of the decline in the frequency. So, if the tie line is suddenly lost maybe because of fault or some other issue, then the frequency drop is given by this equation, $\frac{df}{dt} = -\frac{\Delta P}{2H}$. So, $\Delta P$, that can be calculated as what is the load lost. So, normally 200 megawatt of power is governed by this tie line 0.2 gigawatt, so that I have put here $\frac{200}{1000/0.85}$

And if you put the value of delta P and H, where H for S2 group of generators that is 4.

$$\frac{df}{dt} = -\frac{\Delta P}{2H} = -\frac{0.17}{2\times4} = -0.0213pu$$

So, you will get the value of df/dt that is minus 0.0213 per unit. And if you multiply this value with the fundamental frequency let us say 50 Hz, then the df by dt that will comes out to be minus 1.065 Hz per second.

$\frac{df}{dt} = -0.0213 \times 50 = -1.065 Hz/\text{sec}$. And as I told you, this negative sign indicates that the frequency is going to reduce.

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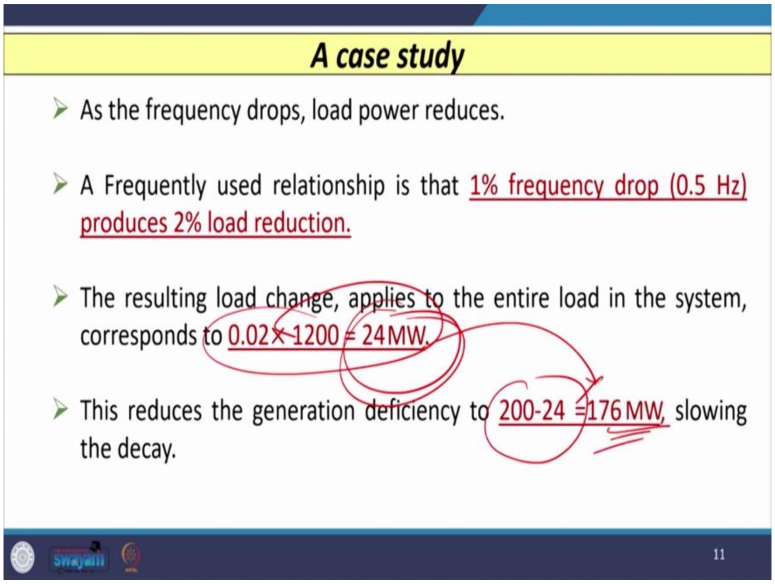


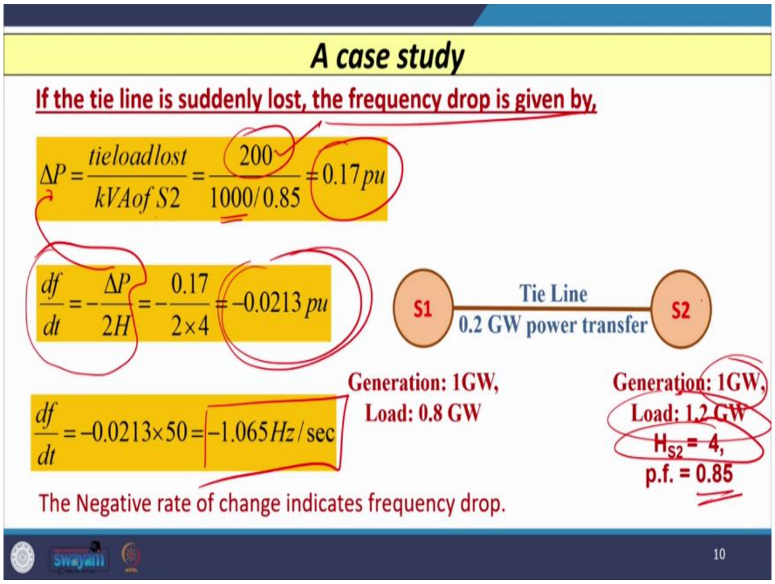

So, as the frequency drops load power also reduces. So, we can say that 1 percent drop in frequency that is going to produce the 2 percent reduction in the load. So, if 2 percent reduction in load is there, then 2 percent of 1200 that is the entire thing then, because that is the capacity of this load available on S2 group of generators. So, we have 24 megawatt of loads that has to be reduced, and if this has to be reduced, then with reference to our total generation that is 200-24. So, 176 megawatt of the generation deficiency is there.

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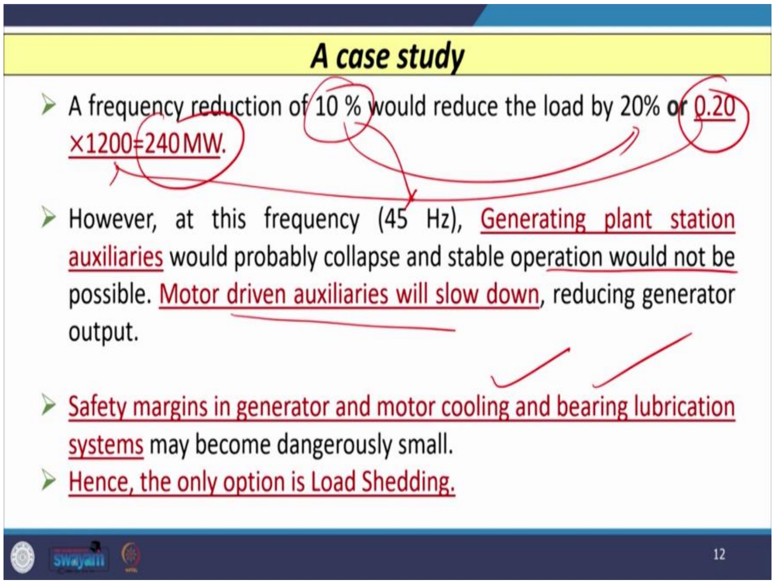


Similarly, if I have let us say 10 percent reduction in frequency, then that is going to reduce 20 percent reduction in the load. So, if I consider this 20 percent with reference to the load value that is 1.2 gigawatt, then we have to reduce the load of 240 megawatt. And with reference to these if I consider a 10 percent reduction in frequency with reference to the base frequency 50 Hz, then my new frequency will be 45 Hz.

So, generating plant station auxiliaries at this 45 Hz frequency would probably collapse and stable operation would not be possible. Sometimes, motor auxiliaries available in the power station, that will also slow down. So, stalling effect is there. Safety margins in the generator and motor cooling and bearing lubrication systems that will also accede with reference to some threshold value.

Hence, the only option in this case if we wish to avoid all these things, then we have to go for load shedding. So, that our frequency is not going to decline below a certain limit. So, let us see what do you mean by the load shedding?

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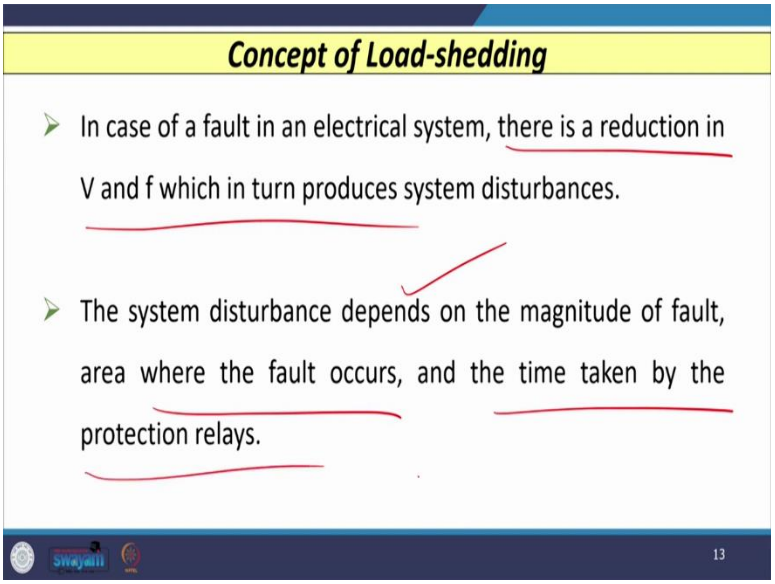


So, whenever there is a fault in any electrical power system network, then there has to be reduction in voltage as well as frequency both, which in turn produces system disturbances. The system disturbances depend on the magnitude of fault, area of where the fault occurs and the time taken by the relays to operate in case of particular fault.

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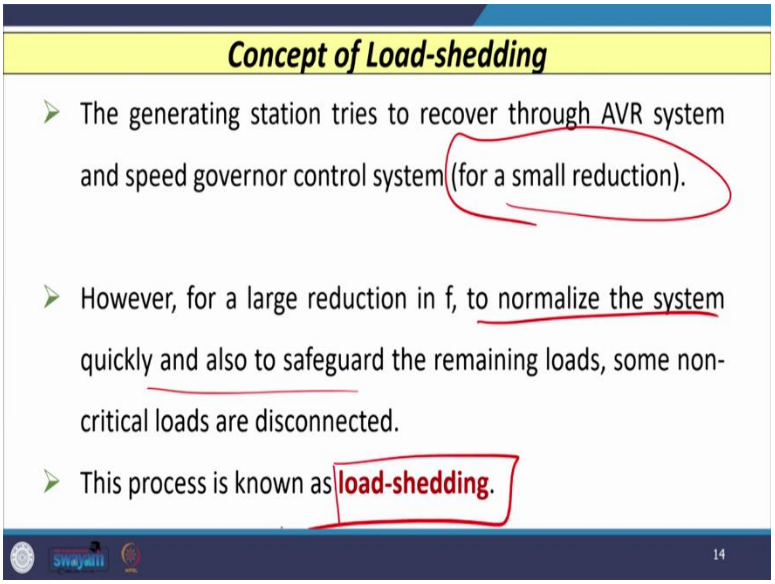


So, the generating station tries to recover almost using automatic voltage regulator system and speed governor control system if the reduction is small. However, for a larger reduction in frequency to normalize the system quickly some non-critical loads need to be disconnected from the power system network and this process of disconnection of load, non-critical loads basically, that is known as load shedding.

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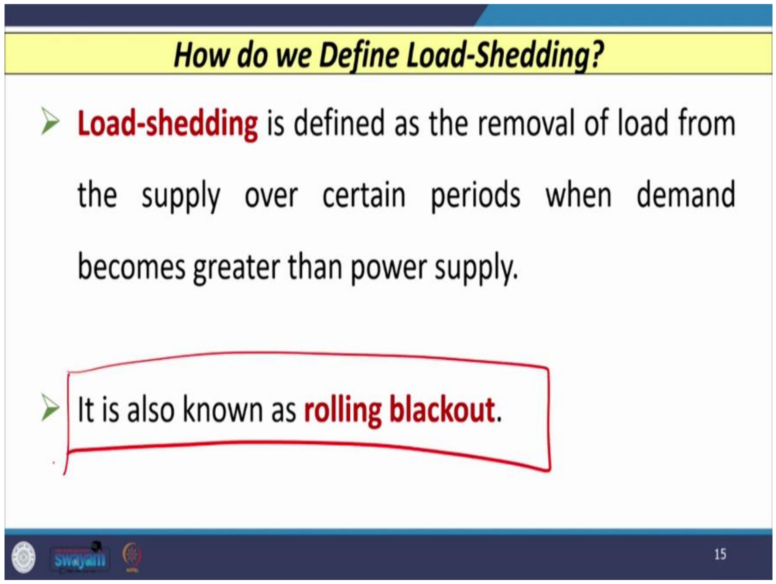


So, let us see how do we define the term load shedding? So, load shedding is defined as the removal of load from the supply over a certain period when the demand becomes greater than the power supply. And this type of phenomena is also known as rolling blackout. So, we can tell that the load shedding is defined as the removal of load from the supply at certain periods, normally we remove non critical loads and this is known as load shedding and sometimes it is also known as rolling blackout.

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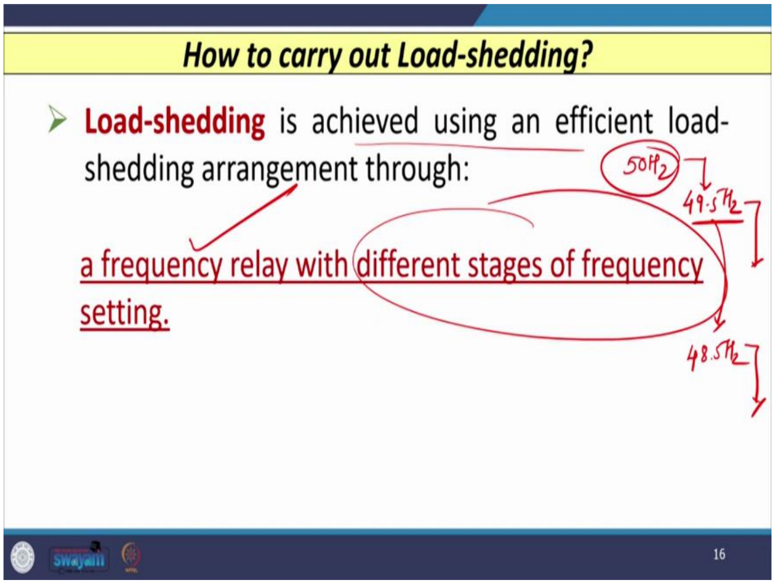


Now, let us see how we can carry out load shedding? So, a load shedding is achieved, as I told you load shedding is nothing but the removal of non-critical loads, so that my frequency is going to maintain. So, load shedding is usually achieved using an efficient load shedding arrangement scheme. And this scheme whatever load shedding arrangement scheme we decide, that is decided by a frequency relay with different stages of frequency setting.

So, if let us say we have 50 Hz frequency is the fundamental frequency and if this frequency falls let us say from 50 Hz to 49.5 Hz, then we have to remove let us say x percentage of load if still my frequency declines from 49.5 Hz to let us say 48.5 Hz, then again another x percentage of load I need to remove and so on.

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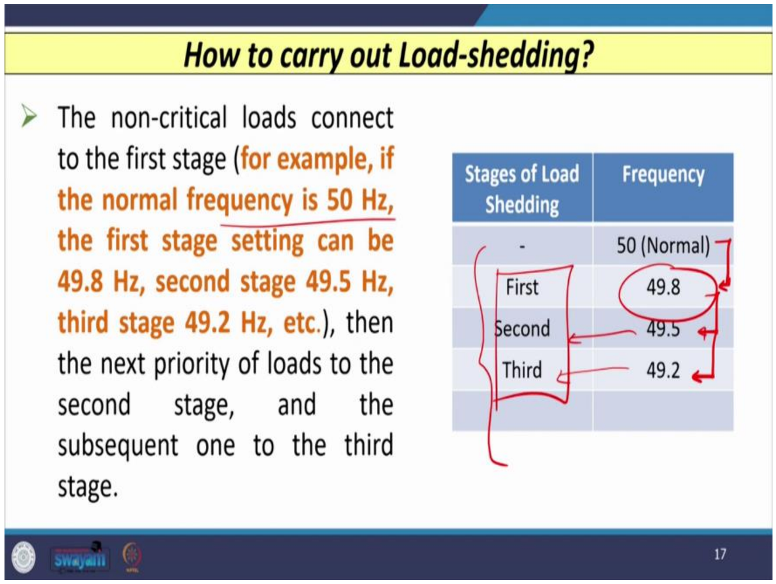


So, let us see how we can carry out the load shedding? As I told you when load shedding is carried out non-critical loads, that should be disconnected first. So, for example, as I told you, if our system frequency or base frequency is 50 Hz, then the first stage of frequency setting that can be 49.8 Hz. So, if frequency falls from 50 Hz to 49.8 Hz then first stage of load shedding is done. If the frequency is this still falls from 49.8 Hz to the 49.5 Hz, then second stage of load shedding is carried out.

And from, again it still frequency falls from 49.5 Hz to 49.2 Hz, then third stage of load shedding scheme that is to be performed. So, normally, the question comes how many stages we have to include. So, whether we have to include the 3 stage, 5 stage, 7 stage that depends on the utility and application. In most of the cases, most of the utility they will consider three stages. So, in three stages most of the utility will have the or will remove the load depending upon the fall or reduction in frequency with reference to the fundamental frequency.

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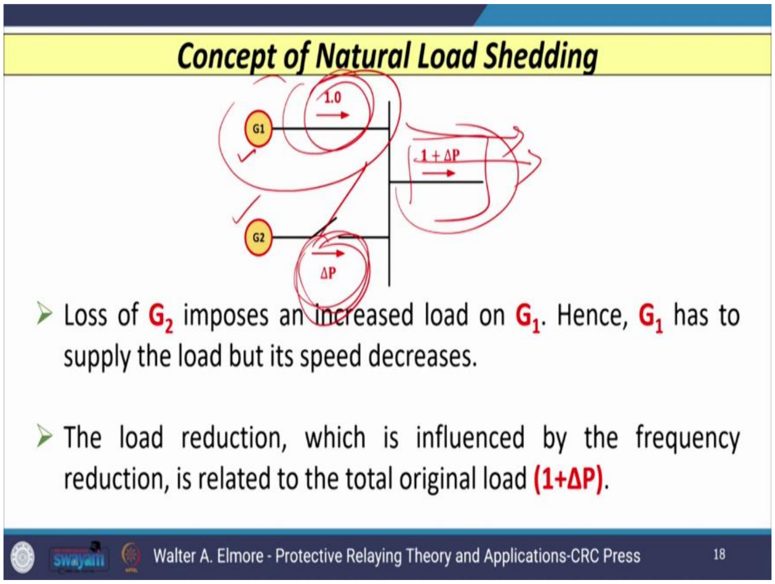


Now, let us see what is the concept of natural load shedding? So, to understand this, I have considered the generator 1, which is giving some power and that is again delivered and I have also considered the generator 2, which is also giving some change in power and the total power of this 1 and delta P that is delivered here.

Now, if generator 2 is lost. So, I am opening this switch because of some reasons maybe fault or somewhere else. So, whatever is the additional load $\Delta P$ that has to be supplied by generator 1. So, now generator 1 has to supply the entire requirement of load that is 1 + $\Delta P$ instead of 1.0.

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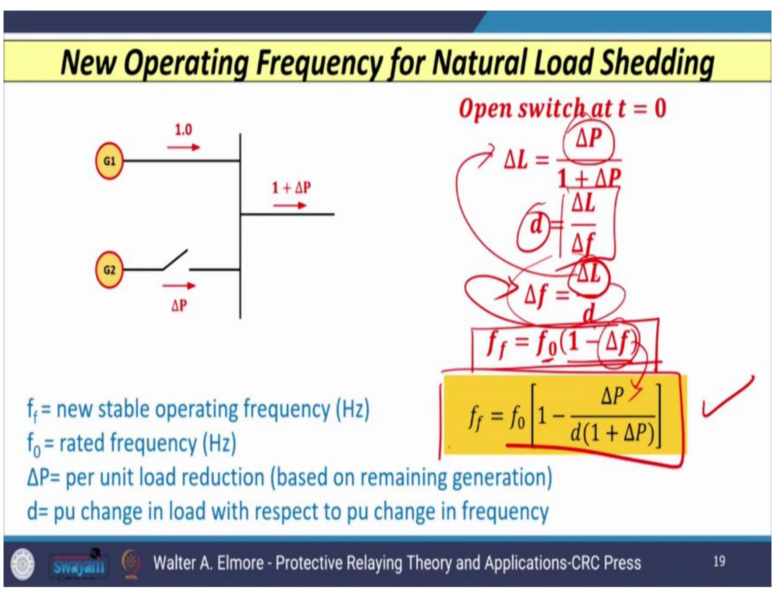

So, in this case, if I calculate the new value of frequency which is stable, then this is given by the equation that is $f_f = f_0\left[1 - \frac{\Delta P}{d(1+\Delta P)}\right]$, where $f_f$ is the new value operating frequency in Hz, that is given by the original $f_0$, that is our rated frequency or base frequency in Hz, where delta f is the change in frequency. This delta f that can be calculated using this equation, which is nothing but the ratio of $\Delta L$/d, where d is nothing but the per unit change in load with reference to the per unit change in frequency.

So, in this case, if we wish to calculate this numerator $\boldsymbol{\Delta L}$, then this can be calculated using this which is nothing but $\boldsymbol{\Delta L} = \frac{\boldsymbol{\Delta P}}{\mathbf{1}+\boldsymbol{\Delta P}}$ , where d value that can be given by the change in load with reference to the change in frequency. So, if I put the value of $\Delta f$ from here, then that is this value. So, $\Delta L$ is nothing but $\frac{\Delta P}{d(1+\Delta P)}$ . So, if you put this value here, then you will have the equation of new value of stable frequency, that is equal to $f_f = f_0\left[1 - \frac{\Delta P}{d(1+\Delta P)}\right]$. So, here the d factor which is there in the denominator of this equation that plays an important role.

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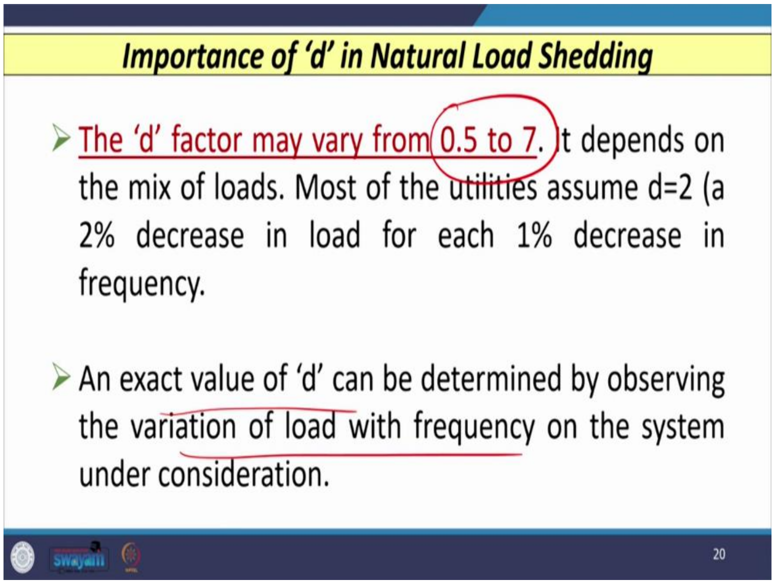


So, normally its value varies from 0.5 to 7 and its value depends on the mix of loads, most of the utilities will consider the value of d that is equal to 2 which indicates that 2 percent decrease in load for each 1 percent increase in frequency. So, if there is a 1 percent decrease in frequency, then 2 percent decrease in load.

So, if we have 5 percent decrease in frequency then 10 percent decrease in load like that. So, the exact value of d, that is normally determined by observing the variation in load with frequency on the system which we are going to consider.

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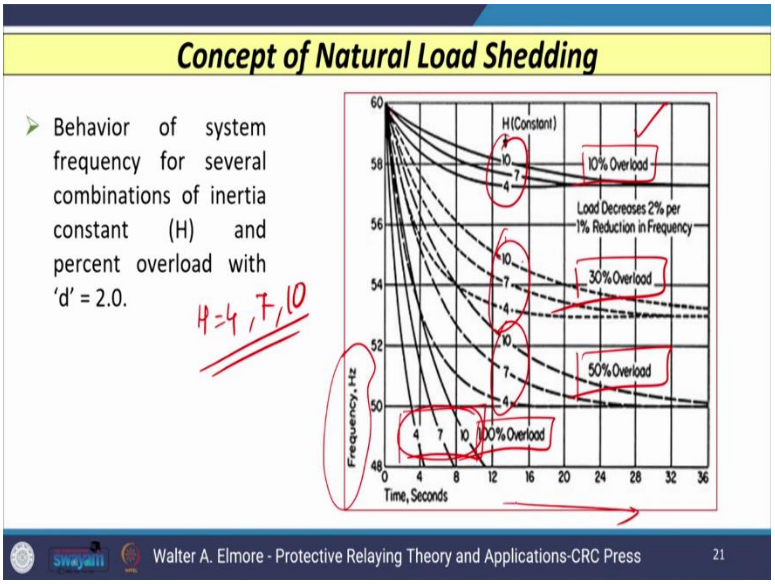


So, if I plot a graph of, let us say what is the behaviour of my system frequency for several combinations of inertia constant with a different percentage of the overload, then you can see that I have seen the graph where on x-axis I have considered the time in seconds and on y-axis I have considered the frequency in Hz with 60 Hz as the base frequency. Then you can see (as shown in above slide) that for three different inertia constant H, that is 4, 7 and 10. I have shown the graph.

So, you can see (as shown in above slide) the four graphs are sold for three different value of inertia constant. And for four different values of percentage of overload, starting from 10 percent overload, 30 percent overload, 50 percent overload and 100 percent overload. So, you can see the two worst cases 10 percent overload, there is a slight decline in frequency and it will take more time, whereas you can see here 100 percent overloading is there this curve declines very rapidly and it will take also a very small time period.

So, this is going to have an important consideration and we need to know that what are the factors which we need to consider, when we design any intelligent load shedding scheme, because load shedding scheme is always associated with under frequency relay.

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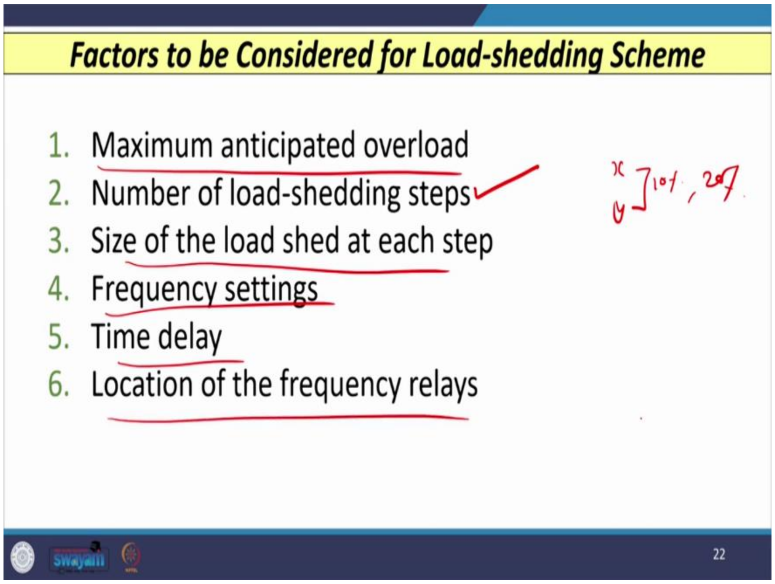


So, there are various factors which are associated with the load shedding scheme. And we need to consider these factors when we design an effective or intelligent load shedding scheme. And these factors are, the first factor is the maximum anticipated overload, which any load shedding scheme need to be considered.

The second is the number of load shedding step, so whether you are going to have three step or five step. Size of the load shed at each step, so from x to y, if you are going to shed the load whether you will shed 10 percent or 20 percent or 30 percent, so that is there. The fourth is the setting of the frequency. Fifth is the how much time delay that is allowed. And sixth, last but very important, that is the location of frequency relays.

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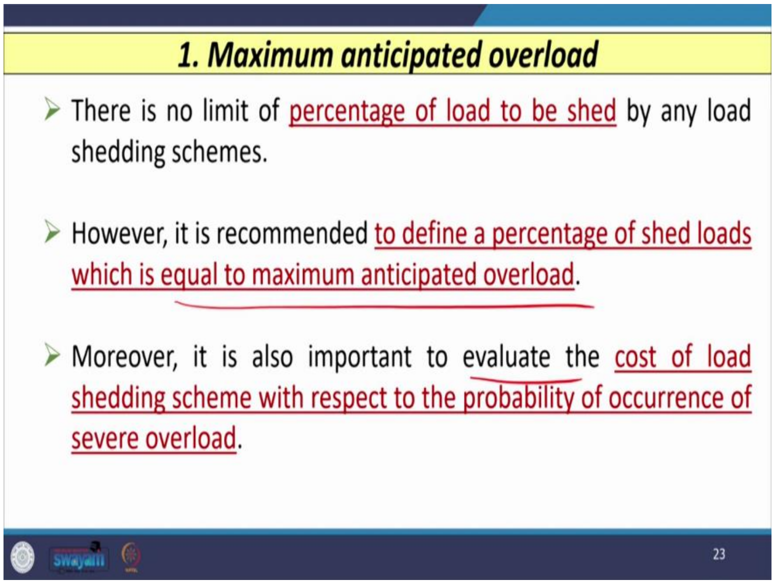


So, if I consider the first one that is the maximum anticipated overload factor, then there is no limit of percentage of load to be shared by any load shedding scheme, so no such standard exists. However, most of the utilities recommend that to define a percentage of load shed which is equal to the maximum anticipated overload, that has to be defined by most of the utilities. So, it is important to evaluate at the same time the cost of load shedding scheme with respect to the possibility of occurrence of severe overload.

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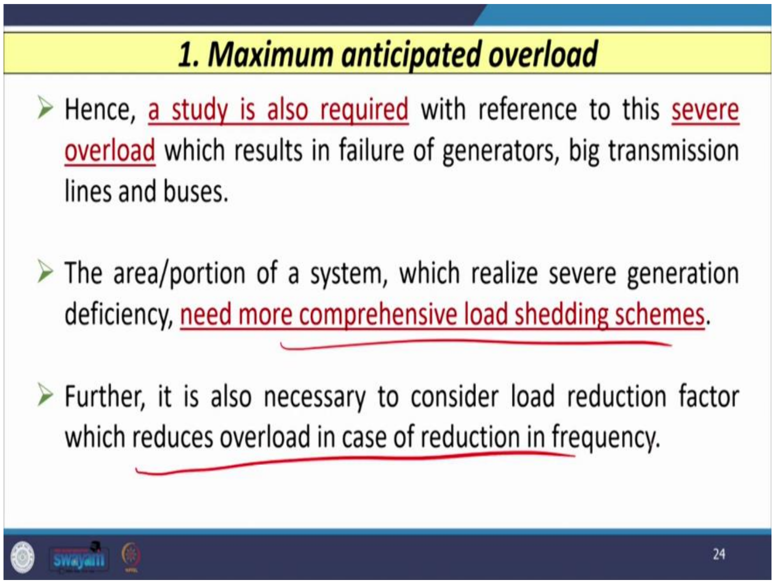


So, hence, there is a need to study or a study is required with reference to severe overload, which results in the failure of generators, failure of big transmission lines and buses. So, the area or the portion of a system, which realize severe generation the efficiency, that has to be designed or that has to be governed by a very comprehensive load shedding scheme.

So, where the area or the portion or the network in which the severe deficiency of generation is there, load is always higher than the generation, then effective loads shedding scheme is required, where generation is almost equal to the load or where generation is higher than the load required, then the load shedding scheme is not that much important. At the same time, it is also necessary to consider the load reduction factor which reduces the overload in case of reduction in frequency.

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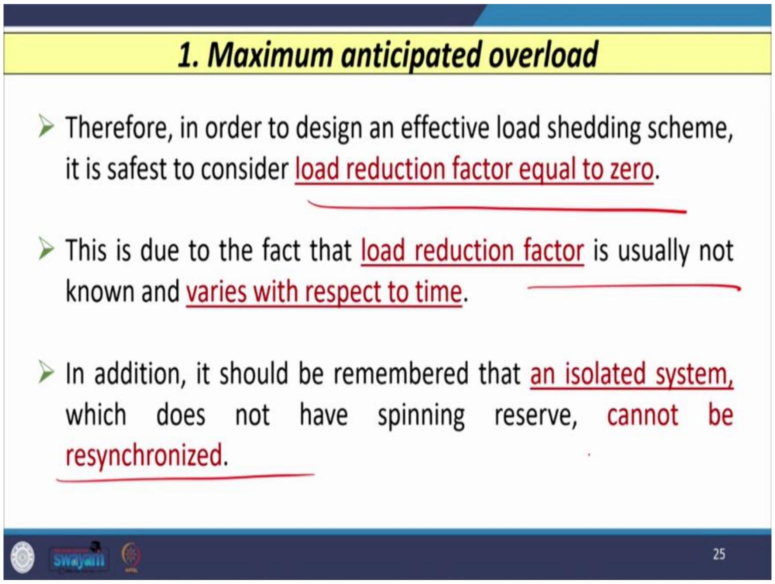


So, we need to consider the load reduction factor. And in order to design effective load shedding scheme, most of the utilities will consider load reduction factor that is equal to 0, on a safer side. So, this is due to the fact that load reduction factor is usually not known and it varies with reference to time further, when we are going to design a load shedding scheme and a particular system, we are considering is an isolated system which does not have any spinning reserve, then this type of isolated system should not be resynchronized.

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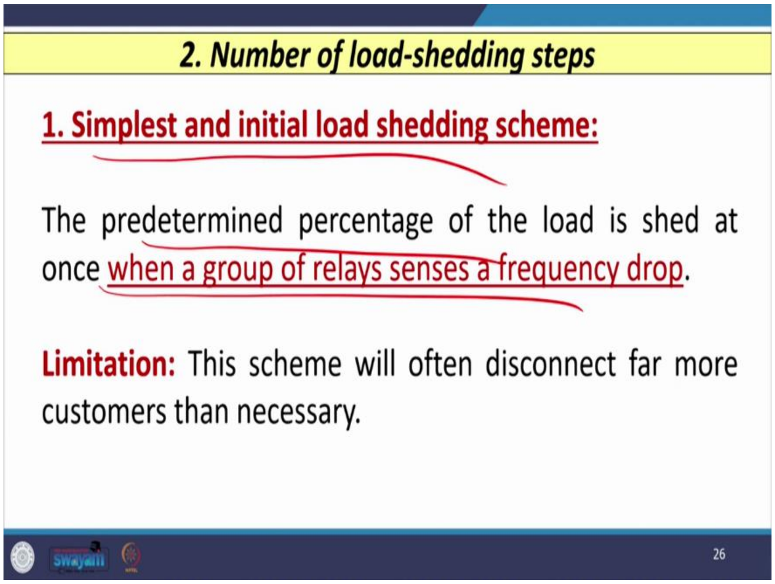

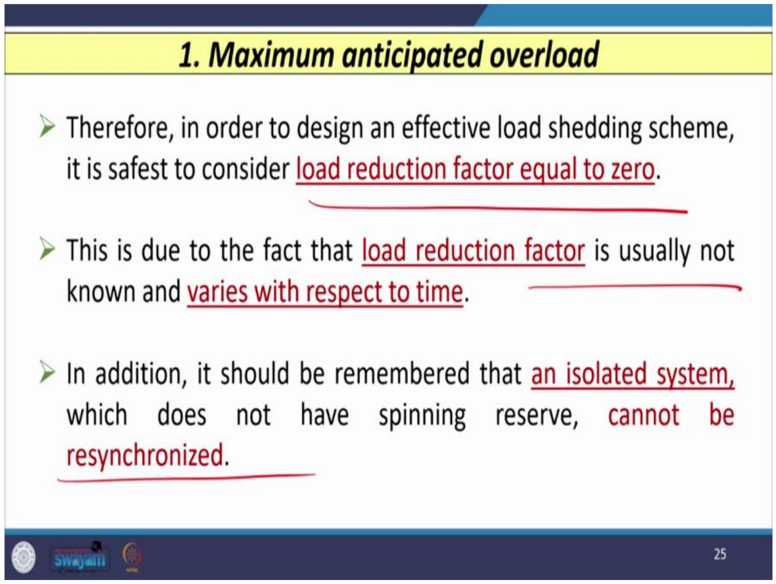


So, all these factors that is, which we have considered out of that we consider the first factor that is the maximum anticipated overload. So, in this lecture, we started our discussion, what is the load shedding, how we can define the load shedding and how the load shedding is associated with the rate of frequency of decline.

And then we have discussed one case study and after that we have seen that there are several factors, which are important when we consider or when we design an intelligent load shedding scheme. And the first factor which we have discussed that is the maximum anticipated overload. The second factor that is very important is the number of load shedding steps.

So, let us consider this factor also. So, when we consider the number of load shedding steps that is required by any intelligent load shedding scheme, then an initial load shedding scheme is there, if we consider any initial load shedding scheme, then the predetermined percentage of load is shed at once when the group of relays senses a frequency drop. So, the limitation of this scheme is that this scheme will often disconnect far more customers than the necessary.

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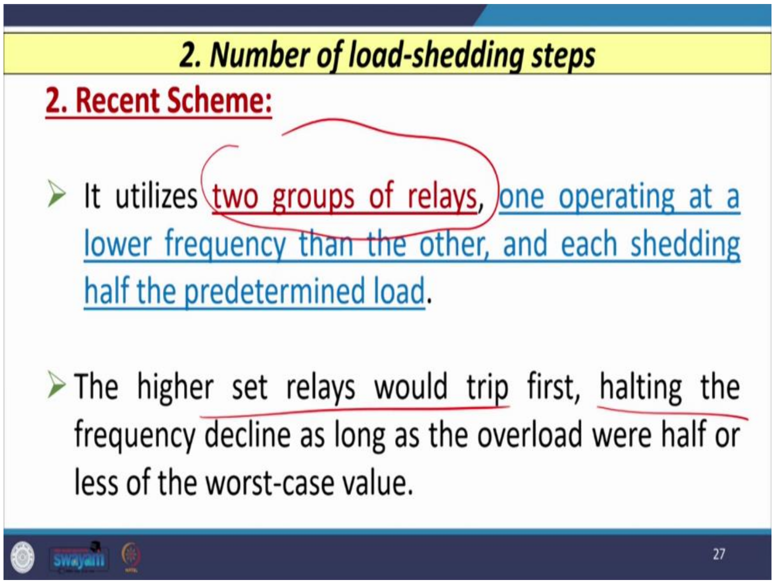


So, normally this type of scheme is not used. And nowadays in most of the cases, in this scheme when the number of load shedding steps are required, most of these schemes they use to group of relays, one relay is operating at lower frequency than the other and each shedding or load shedding is done half the predetermined load.

So, the higher set of relays would trip first and the lower set of relay would trip later on. So, that when higher set of relay trips initially or first, then that is going to halt the frequency declined as long as the overload were half or less the worst-case value.

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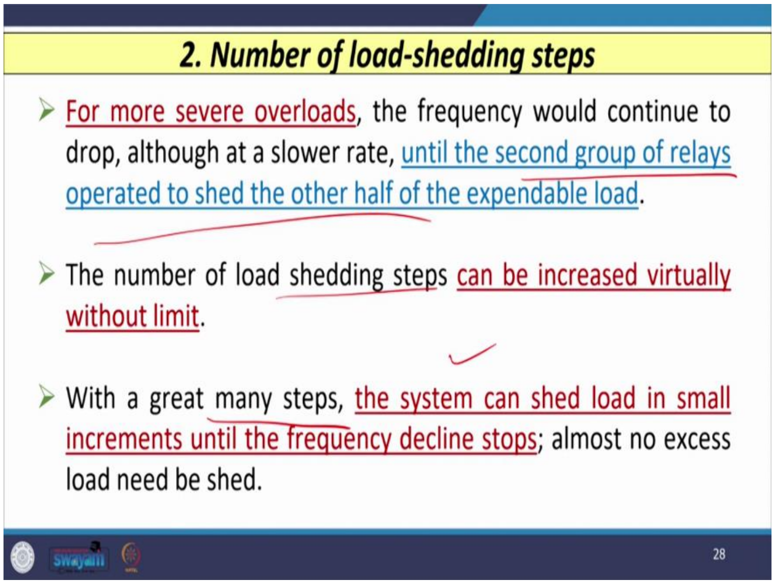

So, for more severe overloads the frequency would continue to decline. Then the second group of relays that is going to operate or that comes in picture, so that is why two group of relays are used in this case. The number of load shedding steps that can be increased are virtually, there is no limit specified in the standard. However, in most of the cases with several steps, the system can share the load in small increments until the frequency decline that is stop.

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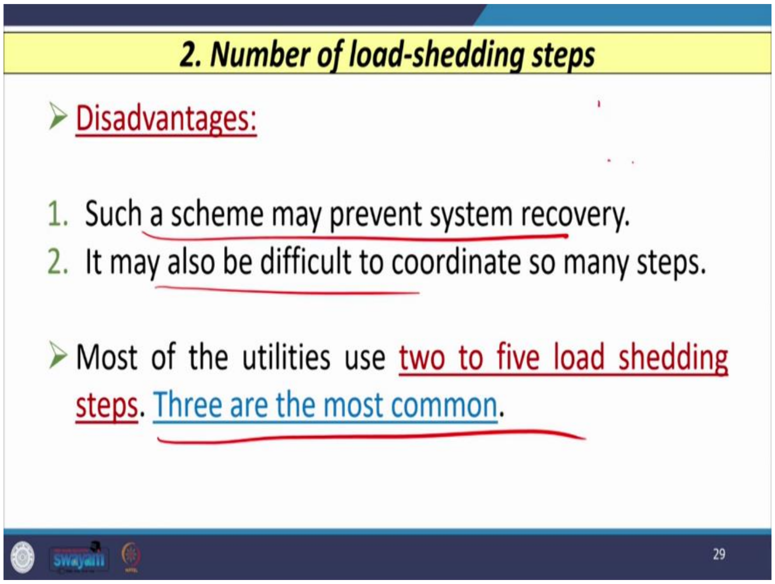


However, the main disadvantage of this scheme is that such a scheme may prevent system recovery and at the same time, it is very difficult to coordinate with so many steps. So, for example, number of load shedding steps I consider seven steps. So, it is very difficult to coordinate these seven steps. So, that is why most of the utilities they use the steps between two to five when we consider any load shedding scheme, however, three steps are the most common.

So, when you consider any load shedding scheme, and when you decide the number of load shedding steps, then most of the utility they will use these three steps. So, first step, second step and third step to decide the number of load shedding steps. So, with this background, I will stop here and the remaining factors which are going to affect the design of the intelligent load shedding technique that we will discuss in the next class. Thank you.