Operation and Planning of Power Distribution Systems

Dr. Sanjib Ganguly
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati

Lecture - 13
Different reliability indices used in distribution networks

In today's lecture, I will start next module which is reliability assessment of Power Distribution Networks ok. And in this module, I will talk about some of the approaches with which a distribution utility assess the reliability of the network because at the very beginning I mentioned that reliability is an important aspect for power distribution network.

And most of the outages and most of the faults in power system occur in power distribution networks and customers who are connected to that network definitely get affected and this is something that an utility cannot avoid. So, these outages and all these things cannot be fully avoided, but we need to have some proper analysis so that we can reduce the magnitude and we can reduce the frequency of those kinds of outages ok.

So, these things, I will discuss in detail in this module ok. So, first of all, one has to understand the difference between outages and interruptions.

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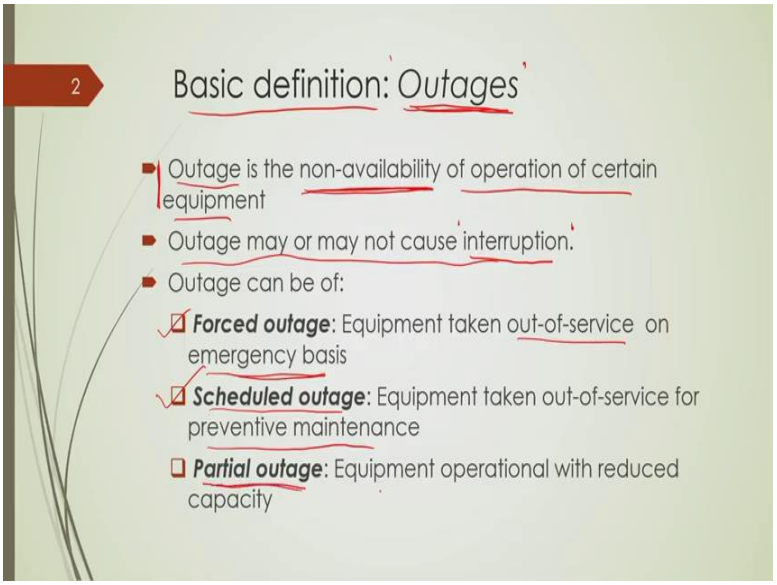

So, there are two terms, we use in power system or in distribution system. One is outage of an equipment another is interruption ok; both the terms are having different meaning. So, in this particular slide, I will give you the definition of outage or outages and I will talk about different types of outages.

In the next slide, I will talk about the definition of interruption and what are the different types of interruptions generally occur in a power typical power distribution systems ok. So, the definition as per Gonen's book which I follow for preparing this lecture as well, outage is defined as non-availability of operation of certain equipment ok.

So, outage is the defined as non-availability of operation of certain equipment of certain lines; or this certain equipment stands for any type of equipment which is connected to a power distribution network, which is associated with a power distribution network, which may include a power transformer located in the substation which may also include circuit breaker which is the main you know switch connected to a particular feeder; so, any kind of equipment, ok.

So, non-availability of any kind of equipment is called outage ok. So, this is a common term that practicing engineers follow ok. They usually tell if you visit any power plant or any distribution substation, they often use that this particular equipment; this particular breaker is in outage ok and it needs maintenance.

So, this outage means non-availability. Any sort of non-availability of any particular equipment called as outages. And most importantly, this outage may or may not cause interruption. So, an outage of any particular element may or may not cause interruption ok. So, this is what the basic difference of outage and interruption ok.

So, interruption means, it is a loss of service. I will define it in the next slide. It is the loss of the service to some customers, but this type of interruption may not occur due to outage of any equipment in a distribution network ok. And, there are three different types of outages.

One is called forced outage, where you know any equipment is taken out of service and an emergency basis. So, this is called forced outage when the utility operators, they need to take out the any equipment from the service, then it is called forced outage ok and this occurs whenever there is an emergency situation ok.

There is another called scheduled outage or planned outage or preventive outage. So, this is basically to take out certain equipment for preventive maintenance ok. So, many times, if you visit any substation or any power plant, you will see the operator they can understand with their experience that particular equipment gap gate faulty, it is not performing as per its full potential ok.

So, they can predict that this particular equipment gets faulty within certain span of time and therefore, they take it schedule outage, whenever they require it ok, whenever they will get a favorable time to take this outage. So, this happens normally; this happens every day. If you visit any sort of substation or any power plant this process of taking a schedule outage of any particular equipment is a routine work for them ok.

Then, another possible outage is partial outage, when equipment is operational with reduced capacity ok. See this is also occurs; this also occurs in a typical power plant. If you visit even in the distribution substation any particular equipment which is not performing well, if the operator understands that then the operator takes an alternative equipment which performs the similar work to assist that particular equipment.

And both the equipment usually work with their reduced capacity. So, this is called partial outage ok.

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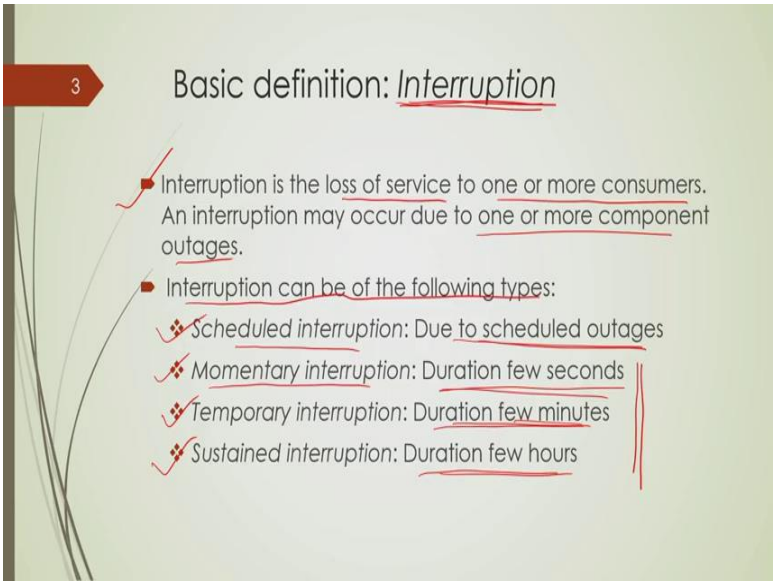

Now, here you can see the definition of interruptions. This definition, I took from Turan Gonen's book ok. So, according to this, this interruption is the loss of service to one or more consumers ok. So, interruption causes loss of service whereas, outage may or may not cause ok that is what the major difference. And, an interruption may occur due to one or more component outages ok.

So, due to outage of one equipment, for example, suppose if you visit any power plant you will see that to perform a certain task suppose we need electrical motor and two motors are sufficient to perform this task. But this in power plant if you visit then you will see usually we have more than two such kind of motors. Now, what are the purposes of having that? This is to improve the reliability.

Because, if we have two motors and one of them suppose becomes faulty, then we use the alternative motors to supply or to have the same work ok. And this is you know to assist one particular equipment and this is normally kept in any type of power station or substation ok. Now, interruption can be of following type.

So, there are four different types of interruption ok. If you categorize this interruption event we can categorize them based upon the time or based upon the time the interruption substance ok. So, one is called scheduled interruption. This is because of scheduled outage. So, if the schedule outages cause any sort of loss of service, so, we have scheduled interruption. We will categorize that particular event as a scheduled interruption ok.

Another is momentary interruption, where this interruption sustains for a very short period of time, just like a few second. We call that interruption as momentary interruption. We also have temporary interruptions, where the interruption sustains for few minutes sustains for few minutes. And also have sustained interruption where this interruption sustains for few hours ok.

So, based upon basically the time of occurrence or the duration of occurrence, we can categorize these interruptions into these three categories. One is momentary interruption; one is temporary interruption; another is sustained interruption, ok.

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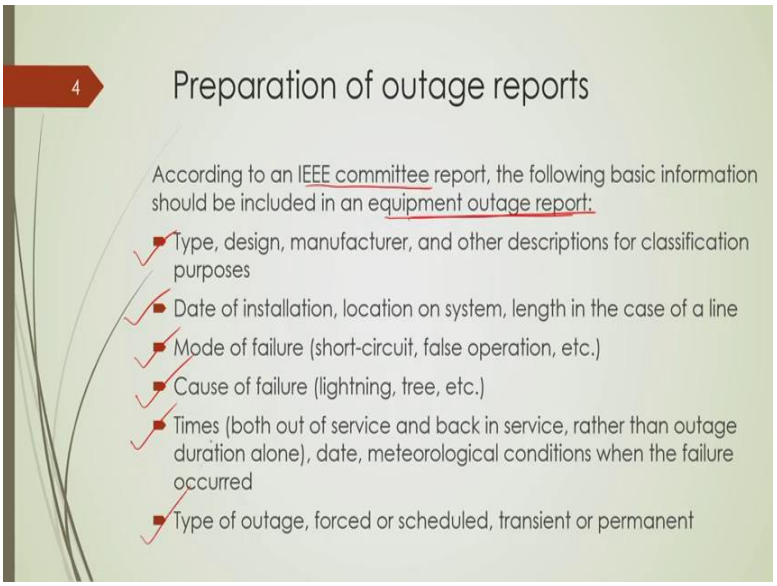

Now, what this utility can do if there is an interruption occurs? Basically see, when this power system was developed in the beginning of twentieth century, 1920-1930 that time interruption was not given any sort of priority for analysis ok. So, interruption means customer would get affected and its customer loss.

But, when slowly slowly these all sort of production units started by this electrical energy then a few minutes of interruption causes particularly for the industrial customers a huge amount of production loss. And slowly slowly, you know our civilization gets digitized; these digital computers came. And during that time interruption becomes an important demerit for these customers.

So, we cannot even sustain a few second of interruption which may cause a serious damage. So, what could happen if any sort of interruption occurs or what the utilities practice for analysis of this interruption? So, according to an IEEE committee report, the following information should be included to prepare an equipment outage report.

So, usually this electrical utility or distribution network utility, they prepare a outage report in which they should mention the following things; like type and design and manufacturer of the different equipment ok, date of installation. This will give them idea that what sort of preventive maintenance will be required; then, mode of failures of particular equipment, cause of failures ok, times of failure and type of the outage.

So, those things they should mention in that particular report and this report helps them to facilitate the future activities ok, which could help this distribution network operator to improve the reliability. Now, one thing that I should mention at this point is most of the distribution networks fault occurred due to some non-technical reasons either due to some non-technical reasons.

Now, what are the non-technical reasons possible? Suppose if we have simply a tree bunch which heats a live conductor of distribution line, so, it will cause some interruption ok, but that interruption might be momentarily cleared or it may sustain ok. Now, during this bad weather this is a frequent type of interruption ok.

Due when the storm or cyclone hits in a particular area, this is a typical type of interruption the customers used to face. Every one of us already faced this type of interruption. But apart from that, there are some animal related interruptions. For example, if there is a rat or squirrel which hits that you know insulators, which is supporting a live conductor of a distribution line then interruption may occur. Sometimes snakes also hit.

So, these are some animal related non technical interruptions ok. But, apart from that some of the interruptions also occur due to poor maintenance of the equipment. If we find that any insulators which is already aged or almost damaged, so, this needs replacement timely replacement. If it is not done then of course, it will cause an interruption. So, these are the typical interruptions that a distribution network customersmay experience, ok.

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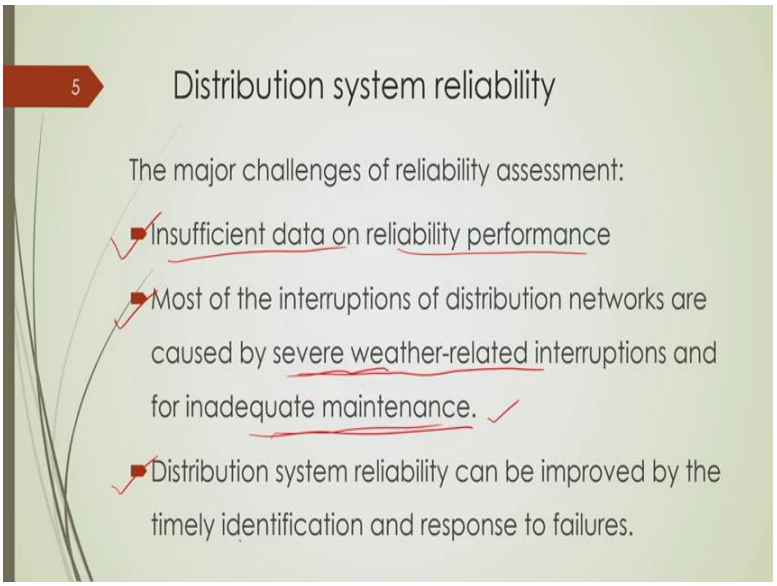

Now, what are the major challenges we have for this reliability assessment? So, first of all, if that type of this interruption or types of outages are not properly written in the report or it is not properly recorded; then it will be real challenge to improve the reliability of a network in future.

So, insufficient data for this reliability assessment is one of the reasons. At a proper way of recording of all sort of events would facilitate an accurate reliability analysis, but if we do not have so, then we cannot do this ok. Now, most of the interruptions of the distribution networks as I said are caused by the severe weather-related interruption and inadequate maintenance which I mentioned already.

So, most of the interruptions of distribution network are related to either weather-related interruptions which caused by storm or cyclone or simply a tree bunch hits in a particular distribution line and so and so and also some animal related interruptions; but those things should be properly recorded so that we can avoid this.

And also inadequate maintenance of all this equipment is one another reason ok. And also distribution network reliability can be improved by timely identification and response of those failures ok.

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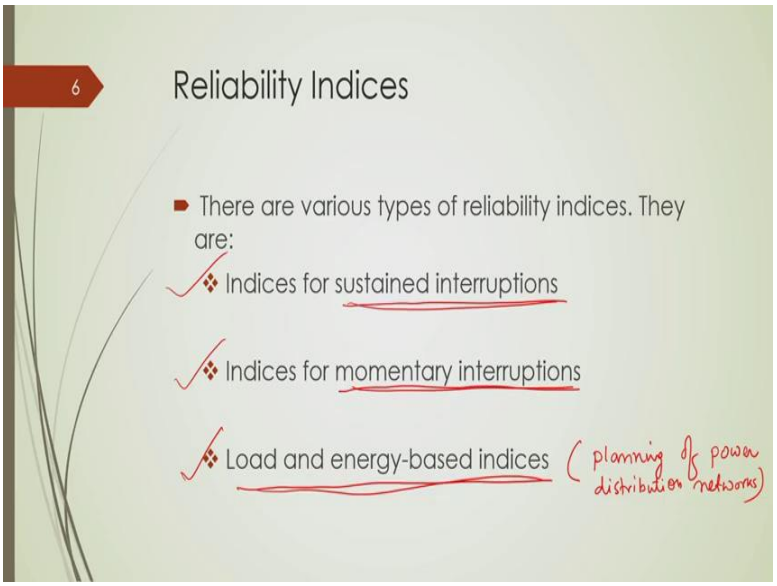

Now, in next few slides, we will talk about different types of indices which are formulated traditionally by distribution network, planner or designer in order to assess the reliability of a typical distribution network ok. And these reliability indices can be further categorized into three different types. One types/ one set of indices are there which are only for sustained interruptions.

So, if our you know interruption event is of sustained interruption, it sustains for few minutes to few hours then we have some indices to formulate to quantify/ to numerically represent those events ok. And also, there are some indices which work for only momentary interruptions ok, I will come to that.

Other indices are there which are called load or energy based indices which are very important for planning. These are very important for planning or designing of power distribution networks ok. So, we will discuss these indices one by one.

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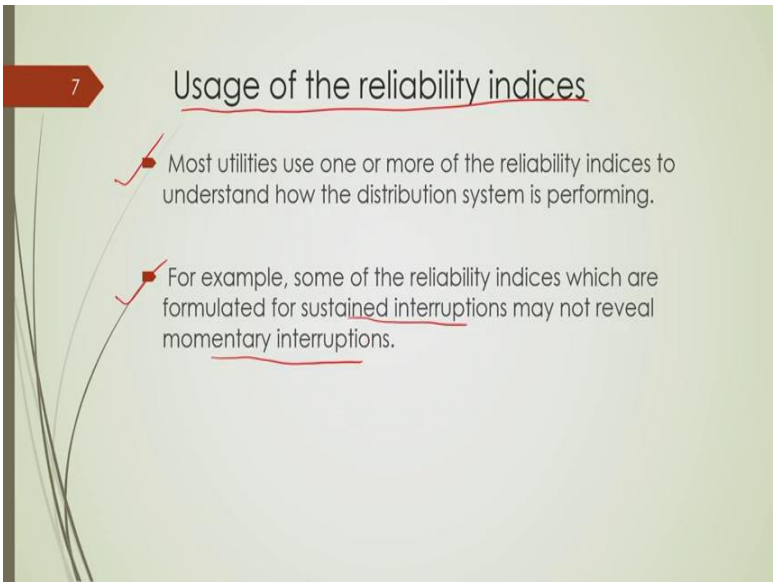

Before that, we should know what are the usages of those reliability indices ok. So, most of the utilities, use one or more reliability indices to understand how the distribution network is performing, ok. So, these indices are almost used by every electric utility to assess the performance of their network ok. And there are some indices as I mentioned which will work for sustained interruption, but may not reveal that momentary interruptions.

So, that is why we have different types of indices and every index has significance ok. So, those things I will discuss in next few slides ok.

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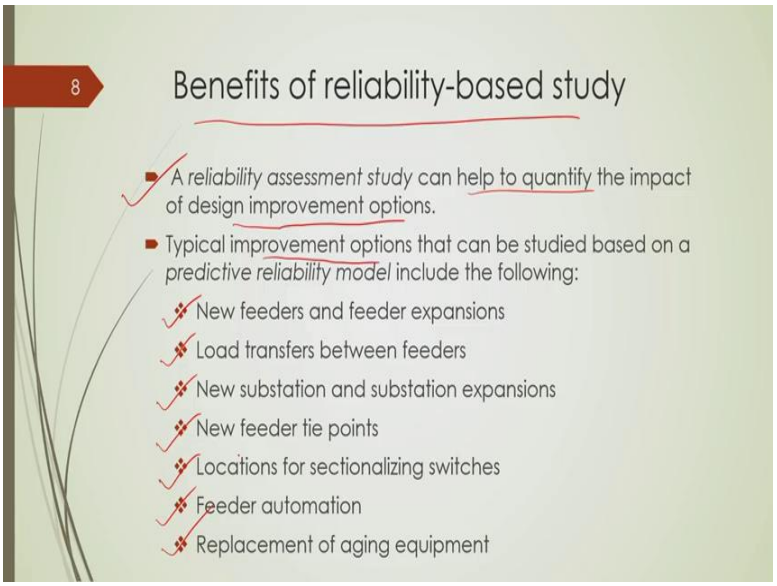

Now, what are the benefits of this reliability based study? So, a reliability assessment study can help to quantify the impact of design or design of the improvement options. So, this is a very crucial thing that we see. If we cannot avoid any sort of interruption, but if we properly analyze it then we can avoid such kind of interruptions in future ok.

Now, what are the typical improvement options that can be done with this predictive reliability model or by you know analyzing this reliability appropriately? So, we can design the few new feeders or we can go for when we will do for feeder expansion this will be helpful.

We can also take the proper strategy for load transfer between the feeders. We can take proper planning tools for new substation design and substation expansion, new feeder for developing new feeder tie lines, for locating the sectionalizer, for feeder automation and replacement of aged equipment, aged equipment, ok.

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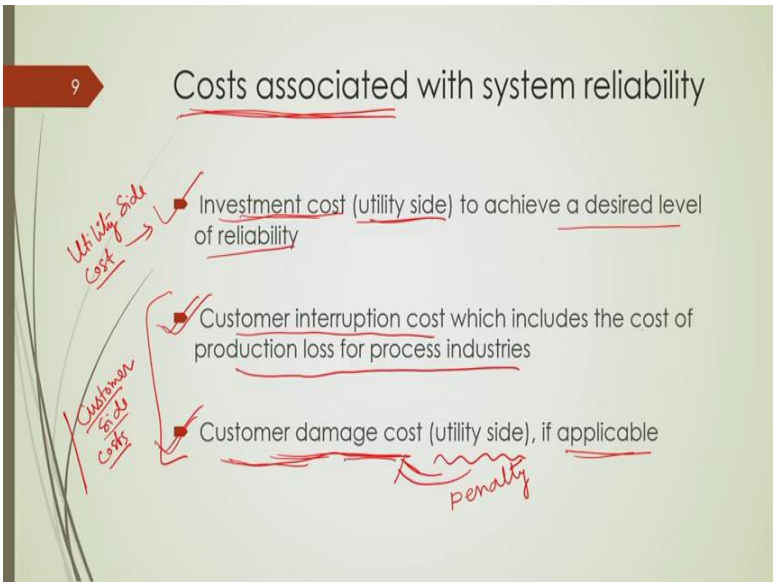

Now, as I mentioned, why this reliability analysis has been done traditionally? This is because reliability is associated with the economy of the system ok and there are some costs involved with this reliability study. So, there are three typical costs involved. One is called investment cost. This is the utility side cost to achieve a desired level of reliability.

So, if we suppose quantify this reliability by a certain index and I want to improve this index value from one value to another value, so, in order to do so, we need to have some infrastructural change ok. And this infrastructural change needs some sort of investment and this is called investment cost to improve the reliability. So, this is utility side cost which is required to improve reliability to a desired level ok.

Now, there are another two types of cost which involve to the customers. So, these two costs are customer side; cost customer side costs and this is of course, utility side cost ok. Now, these costs represent the customers' agony or customer loss due to a certain type of interruptions. So, one is called customer interruption cost which includes the cost of production loss or process industries.

So, as I said, these industries suffer a lot due to poor reliable network ok or due to certain interruption of service. So, there you know loss can be measured with this cost function which is called customer interruption cost ok. Another cost is there is called customer

damage cost this is somewhat related to customer side, but this is somewhat related to customer side, but utility needs to provide this cost as a penalty ok.

This is a penalized cost, you can say. This customer damage cost is somewhat a cost which should be penalized to the utility due to certain events of interruptions ok.

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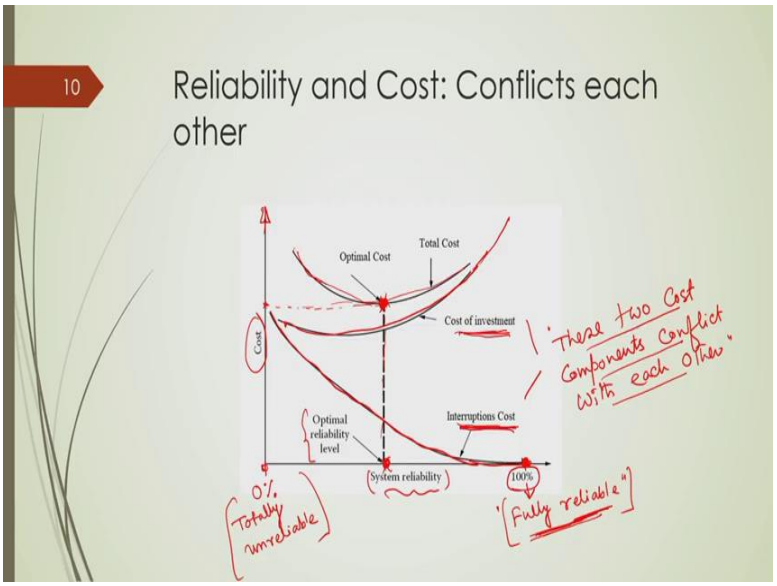

Now, we plot these cost these three different types of costs with respect to the system reliability; suppose this system reliability is represented by some index whose 0 percent value means it is totally unreliable and 100 percent value means it is fully reliable.

So, 0 percent value of this system reliability means it's totally unreliable and 100 percent corresponds to fully reliable, which may or may not physically exist; which may not feasible even to make something fully reliable, but let us assume that this is the index which represents the degree of reliability ok. And 0 percent means totally reliable and unreliable and fully 100 percent means fully reliable and here in this particular vertical axis, it represents the cost ok.

Now, how this you know utilities cost or utilities investment cost will vary, if we want to improve reliability from 0 percent to 100 percent? Off course, it will increase as we go for higher level of reliability; utility needs more investment ok. So, it increases like a non-linear form. And how this customer damage cost or customer interruption cost will

vary? So, this will gradually get reduced if we go for higher degree of reliability and at 100 percent reliable network it will be of course 0 ok.

So, this value of this interruption cost would be 0. So, this value of the interruption cost would be 0 if the network is fully reliable which may not feasible practically, but it is like that ok. Now, if we take a summation of these two costs, although if you look at the way they are varying they conflict with each other, so, these two cost functions or these two cost components conflict with each other.

Meaning that, when cost of investment is increasing interruption cost is getting reduced, when cost of investment is less; i.e., the lowest value interruption cost is at highest value and vice-versa. When interruption cost is at 0 percent, cost of investment is very huge ok. Now, although they conflict with each other but, if we aggregate because both are ultimately representing cost or both the functions are same, then how these characteristics will get? We will get a characteristic like this.

Although it may not appropriate all the time to aggregate both the cost functions to make a same cost function, but if we do so, then we will get this type of characteristic, where there will be a point where you will get optimal cost. Meaning that, the minimum cost and corresponding to that there is a optimal reliability level. So, this optimum cost or minimum cost corresponds to the optimum reliability level.

So, sometimes, this is taken as a standard to a utility to understand that how much investment we will do to improve the reliability of the network, ok.

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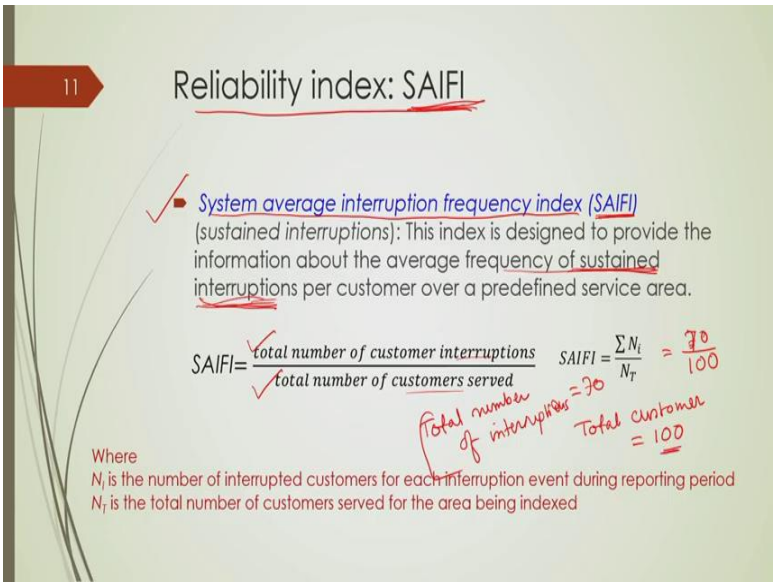

Now, in next few slides, we will talk about different reliability indices. First, let us start with the index SAIFI ok, the index SAIFI. This SAIFI stands for System Average Interruption Frequency Index; so, S A I F I. So, this SAIFI is the acronym to represent this system average interruption frequency index ok. So, this is a common form of reliability index. Many utilities use to assess the reliability of their network.

Now, what is that SAIFI index or this SAIFI? This index is designed or formulated to provide the information about average frequency of sustained interruption. So, this index is applicable for sustained interruption. You can remember that I said that there are three different categories of these reliability indices.

One is for sustained interruption; one is for index for momentary interaction interruption; another is index which is used for load or energy related activity ok. Now, this index is in the category of sustained interruptions ok and this gives the frequency of the interruption. So, the numerator is total number of customer interruption and the denominator is total number of customers served.

It means that suppose I have total customer under a distribution network is, let us say, 100 and there is a event of a total number of interruption, total number of interruptions is let us, say 70 then simply this SAIFI is equal to 70 by 100 ok. So, this 70 is giving you total number of interruptions and it is normalized with total number of customers that is 100 which gives you the index SAIFI ok. So, this gives an interruption frequency index.

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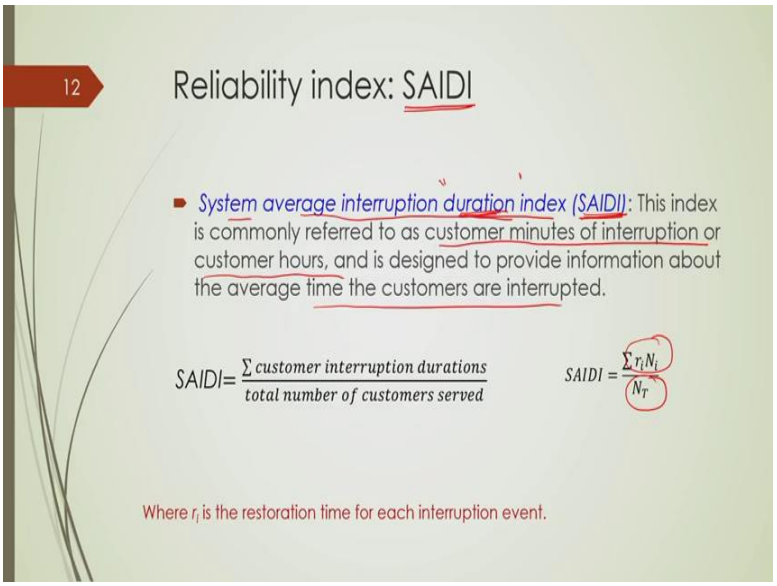

Now, next index is SAIDI which is System Average Interruption Duration Index ok. So, this S A I D I this stands for System Average Interruption Duration Index. So, previously that index was system average interruption frequency index, now here we have system average interruption duration index. So, just looking at this term ‘duration’, you can understand that it is related to the interruption duration.

So, previously that index was related to interruption frequency, now it is related to interruption duration and it is also in the category of sustained interruption. So, this index is also in the category of sustained interruption. So, this index is used basically, a ratio as customers minutes of interruption or customers duration of interruptions to the total number of customers served.

So, denominator is same as that of previous index that is SAIFI, but numerator is different; meaning that, numerator gives total number of customers’ interruption duration ok. So, denominator is total number of customer as same as SAIFI, but the numerator is different that it gives the total number of customers duration ok. So, this index gives you that much of duration that much of minute per individual customer ok.

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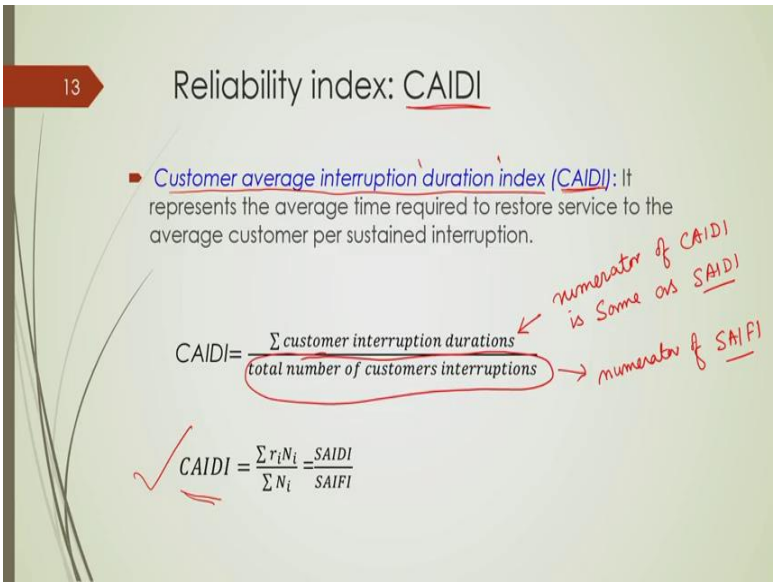

The next index is CAIDI that is Customer Average Interruption Duration Index ok. So, it is also a duration index that is why its numerator is same as that of SAIDI. So, this numerator is same numerator of CAIDI is same as SAIDI ok, but denominator is different. Denominator of SAIDI was total number of customer served.

But here the denominator of this CAIDI is total number of customer's interruption. So, this gives this index gives that much of hour or that much of minute interruption per that many interruptions of the customer, ok. Now, if you look at this denominator of CAIDI, this denominator is same as the numerator of SAIFI.

And since this SAIFI and SAIDI the denominator are same that is total number of customers served, so, if we take the ratio of SAIDI and SAIFI whatever you will get that will represent CAIDI ok C A I D I. So, this gives Customer Average Interruption Duration Index ok.

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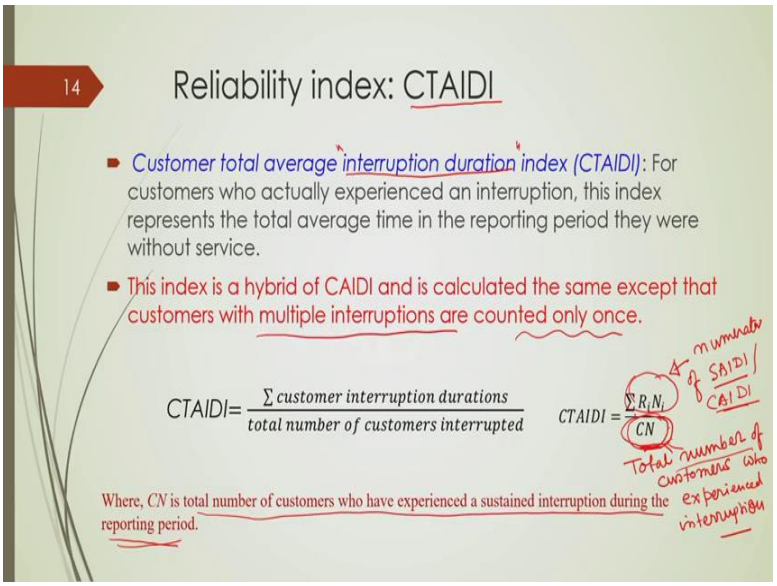

Now, next index is C T A I D I that is CTAIDI ok. So, it is also some sort of interruption duration index as SAIDI and CAIDI ok, but it has some difference. What is the difference? So, here for each type of you know reliability index, there is a difference and that difference one has to notice ok, so that you can understand the difference of one type of reliability index to the other type of reliability index.

Now, in this particular reliability index here denominator of this reliability index is something different which we have not discussed till this time ok. Numerator is total number of customers duration as sort of SAIDI. So, the numerator is the numerator of the C T A I D Y is same as the numerator of SAIDI ok.

So, this SAIDI numerator is total customer interruption duration. In fact, CTAIDI numerator is also same as the SAIDI which is total customers duration. So, these numerators this of C T A I D I is same as that of SAIDI or CAIDI ok. And denominator is something different.

This denominator is total number of customers who have experienced a sustained interruption during the reported period. Now, in previous indices, we got this denominator mostly as total number of customers served or total number of customers interruptions ok. Now, there are some customers who will experience multiple interruptions; who will experience multiple interruptions.

So, we cannot identify the agony of those customers with these indices ok. It may so happen that in this denominator of this CAIDI and this numerator of this SAIFI where we have total number of interruption this total number of interruption is 70, but it may so happen there is a customer who experience 7 times 7 interruptions.

So, this 7 interruption is inside this, you know value of 70, but those customers cannot be identified in this index ok. So, if we just exclude these customers in customer interruptions who experience multiple interruptions and these multiple interrupted customers if they are counted only once then whatever value we will get that will give you total number of customers who have experienced a sustained interruption during this reported period.

So, here the CN excludes the multiple interruption or the customers who are having multiple interruption or this interruptions which occurred multiple times for a particular customer and in order to have a value of the CN we exclude this multiple interruption event. And we only count that only what are the customers who are affected or who got this inter; who experience this interruption.

So, CN means total number of interrupted customers; total number of interrupted customers or total number of customers who experienced interruption. So, CN stands for total number of customers who experienced interruptions and definitely this value of CN will be lower than this total number of customer interruptions ok. And that is why this C T A I D I value will be higher than this SAIDI ok.

This value will be because CN total number of customers; if there is an event of multiple interruptions and if there is not at all any event of multiple interruptions this value of C T A I D I will be equal to SAIDI ok.

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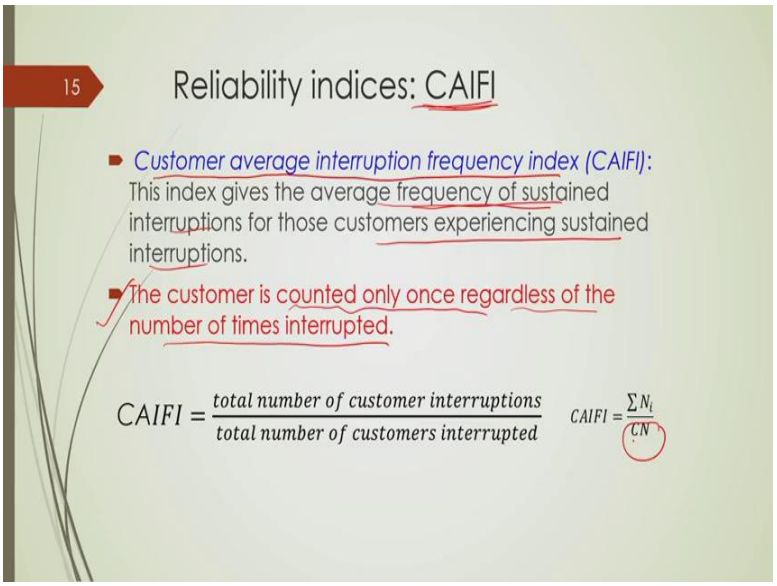

Now, next reliability index is CAIFI that is similar to CAIDI, we have CAIFI that is called Customers Average Interruption Frequency Index ok; so, customers average interruption frequency index which gives the average frequency of sustained interruption. These all whatever we discussed, whatever indices we discussed so far, this all indices are for sustained interruptions to analyze the sustained interruption ok.

So, this index gives the average frequency of sustained interruption for those customers experience the sustained interruption ok. Again, the denominator of this CAIFI is CN, which means that customer who encountered only once regardless of the number of times interrupted. That means, again we eliminate this to consider any customer who experience multiple interruption to consider them multiple times.

And that is why the CN is basically representing the actual number of customers who got interruption who experience interruptions ok. And the CAIFI, you know, its numerator is total number of customer interruptions that is same as that of this SAIFI and denominator is different. In SAIFI denominator was total number of customers, here the denominator is total number of customers who experienced interruptions.

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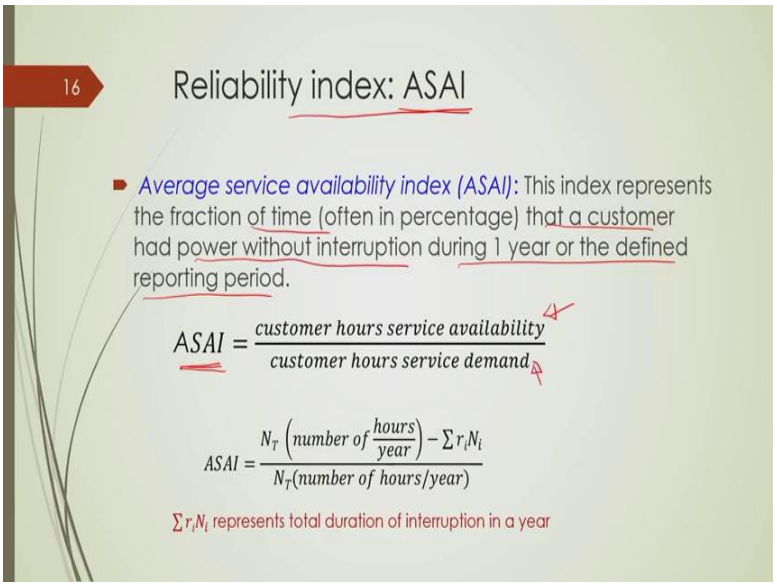

Then there is another index which is called A S A I, ok. This index represents the fraction of time that a customer had power without interruption during 1 year of the defined reporting period ok. So, for determining this A S A I, the numerator is customers hour service availability and denominator is customers hour service demand, ok.

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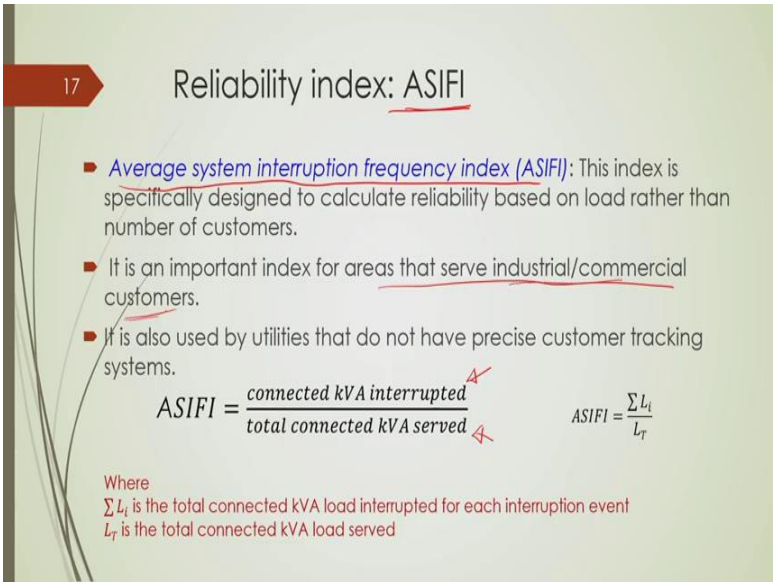

The next index is A S I F I, it is Average System Interruption Frequency Index ok. So, here this is an important index for the areas of serving industrial or commercial customers. Why we are saying so? Because A S I F I is basically a ratio of connected

kVA interrupted to the total connected kVA served ok. So, it gives that how much kVA was interrupted with respect to how much kVA was served ok. And why it is important for industrial/commercial customers?

So, they need uninterrupted power. So, with this index and utility will understand that how much power or energy delivered to them in comparison with what they demand ok. So, previous index was energy based index, now here this load based index or kVA based index ok.

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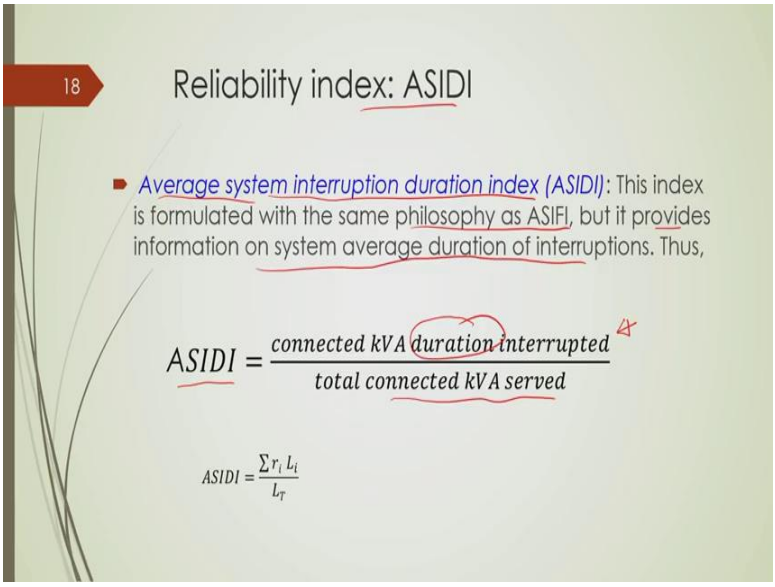

Now, there is another reliability index which is called Average System Interruption Duration Index; that is as a A S I D I. So, this index is formulated with the same philosophy of A S I F I, but it provides information of system average duration interruption ok.

So, here, this in A S I D I this numerator is connected kVA duration interrupted. So, which is somewhat you know similar to A S I F I where the numerator was connected kVA interrupted ok, but here connected kVA duration interruption ok. And its denominator is total connected kVA served, which is same in A S I F I, total connected kVA served ok. So, with this I will stop this lecture.