Operation and Planning of Power Distribution Systems

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Lecture - 06
Load Characteristics and Load management

In my last lecture, I started discussion on loss factor, ok. And, I basically discussed what is loss factor and what is the significance of loss factor in power system planning, ok. So, loss factor is a significant parameter, which we require to plan future power networks, which includes expansion planning of existing network or even which it is also essential for planning of a brand-new power network, ok. So, let us see, what how to mathematically derive this loss factor.

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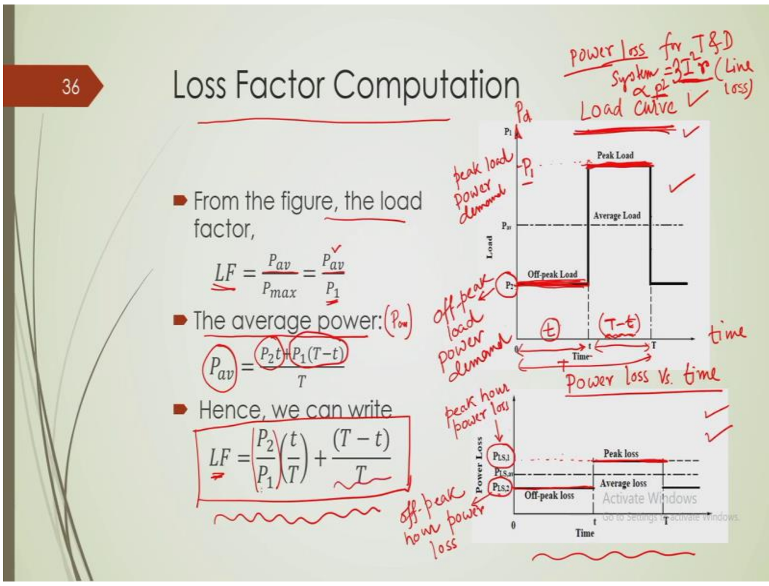

So, in loss factor computation, we consider a typical load curve. So, this is basically a typical load curve. And for simplicity we assume that, this load curve have two set of power demand one is off-peak load power demand, which occurs between duration of 0 to t and another is peak power demand, ok. So, this is your off-peak load. So, this P2 stands for, off-peak load power demand, ok and this P1 which is this peak load power demand. So, this is peak load power demand.

And as you know this characteristic is basically power demand versus this time, ok. So, from a 0 to t duration, small t duration off-peak load power demand is at off-peak. And then from t to T, small t to capital T; the power demand is at peak load demand. So, for this, we considered for simplicity, assuming that we have divided a whole load characteristic into two parts; one is peak hour, another is off-peak hour.

And you can eventually do this thing for this assumption for any sort of load curve, if you take the peak hour average power demand and rest of this hour average power value. So, rest hour is basically off-peak hour, ok, whose duration is small t and this peak hour power duration is small t to capital T, ok. Now, corresponding to this load curve, we also determined that power loss characteristics.

So, this figure is basically showing you, power loss versus time characteristic, ok. Now, as I said this power loss is roughly proportional to square of this load demand, ok. But, this power loss as you know, this power loss is basically nothing but, for transmission and distribution system, it is nothing but, I square r loss, this is also called line loss.

So, what is I? I is the current flowing through a particular line, this line can be a transmission line or a distribution line and r is your resistance of that particular line. Now, for 3-phase it should be 3 I square r, ok. Now, since you know, this I is proportional to P. So, you can assume that this power loss is proportional to P square. Ok. But, usually this power loss value is used to be much less than the power demand.

It is only some few percentage of the power demand, ok, that percentage might be in fact, 10 percent or 15 percent or even 5 percent, ok. So, that is why you know magnitude wise this power loss characteristic is much lower than this load demand. If your load demand or if you have any distribution feeder which is carrying 1 megawatt of power, then this particular feeder if you sum up, the all these lines losses it should come in between roughly some 10 percent of this 1 megawatt, ok.

So, that is why this power loss characteristic is drawn in this figure with a reduced scale, ok. But. In fact, there is I; this is not done in actual scale, but this characteristics should follow the similar to this load curve, but it will have lesser magnitude, ok. Now similarly, since you know as I said, this power loss is proportional to P square, so characteristic will be similar to this load curve. So, these characteristics will be similar to this load curve, ok.

And, since we have this off-peak load corresponding to that we will be having some off-peak hour power loss, which is represented by PLS,2. So, PLS,2 is basically representing off-peak hour power loss, ok. And there would be also power loss corresponding to this peak hour which is named as peak hour power loss or peak loss simply. So, this is represented by this PLS,1. So, here PLS,1 is basically representing peak hour power loss or simply you can call it peak loss, ok.

Similarly, PLS,2 is representing off-peak hour power loss, ok. Now, from these two characteristics, let us first determine this load factor and then we will try to determine loss factor, ok. Now, how to determine load factor in order to determine this load factor? As you know load factor is a ratio of average power demand to the maximum power demand or average power demand to the peak power demand, ok.

So, it is basically equal to Paverage divided by P1 which is peak power load, ok, which is peak load, ok. So, this is P1, ok. So, if we find out the expression of average power demand if we simply divide it by P , then we will get your load factor, ok. Now, how to determine this average power demand or P average? It is very simple as you know, it is the average demand. So, we have two set of load demand, one is off-peak hour another is peak hour, ok.

So, we also know the duration of this off-peak hour power demand, which sustains for small t duration. And we also know the peak hour duration is, since total duration is capital T, so this will be capital T minus small t, ok. So, this is the power duration off-peak hour power loss, ok.

Now, in order to find out this average power demand as you know, so, we multiply this off-peak hour power demand with the duration t that is P2 multiplied by t. This is the energy, rather for off-peak hour during off-peak hour demand and during peak hour we know the power demand is P1 and this duration is capital T minus small t. So, its overall energy demand during peak hour is P1 multiplied by capital T minus small t, ok.

If you sum up you will get overall energy demand; that means, area under this whole characteristics, ok. And the total duration as we know is capital T. So, if we divide it by capital T, we will get average demand, ok. So, we get the expression for average power demand, ok. Now, if we simply divide it by P1, then we will get load factor. Because you know load factor is nothing but the ratio of average demand to the peak demand, ok.

Now, if we divide it by this and if you simplify, so, it will you will get this expression, ok which is load expression for the load factor corresponding to these load curve; corresponding to this load curve, alright. So, you will get the expression of P2 divided by P1 multiplied by this small t divided by capital T plus this capital T minus small t divided by capital T, ok. Now, let us find out the expression for loss factor as well, ok.

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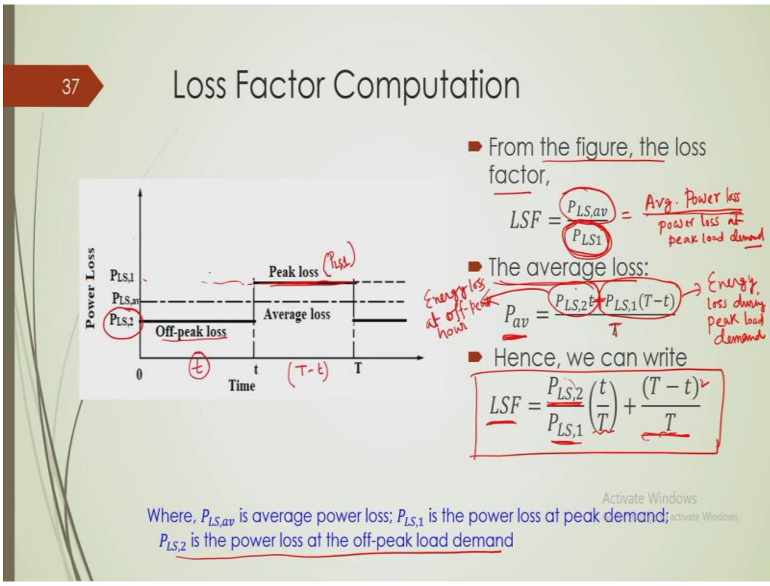

As we know, this loss factor is similar to the load factor its ratio of average power loss; this is average power loss divided by power loss at peak load demand, ok. So, this is what this definition as per the definition of loss factor. So, loss factor is defined as the ratio of average power loss to the power loss at peak load demand, ok.

Now, how to determine this expression? So, in order to determine the expression, we need to find out this average power loss which is PLS average and if we get it then we simply divide it by PLS,1, where PLS,1 is you know peak power loss. So, peak power loss is PLS,1 and off-peak hour power loss is P LS 2, ok.

Now, this we can find out this average power loss we can find out similar to average you know, power demand which we determined in the last slide, to in order to find the expression for load factors. So, we can find out this average power loss as this PLS,2 multiplied by this duration. So, this is basically representing the energy loss during off-peak hour.

So, off-peak hour power loss magnitude is P LS, 2 and this duration is t. So, this duration is t. So, this basically, this if you multiply this P LS,2 which is power loss off-peak load demand or during off-peak hour these if you multiplied with these duration then what you will get, you will get energy loss during off-peak hour. So, this will give you or rather this area under this curve. So, this is basically representing energy loss, at off-peak hour, ok.

Similarly, if you multiply PLS,1 which is power loss during peak power demand with the duration, this duration is capital T minus small t, then whatever you will be getting these is basically representing energy loss during peak hour or during peak load demand you can say, ok. Now, if you sum up these two and divide it by total duration capital T is total duration then you will be getting average power loss, alright.

Now, once you get average power loss you divide it by these P LS,1 which is power loss at corresponding to peak load demand then you will be getting the expression for loss factor. Loss factor is expressed by LSF ok. So, we did this we take the ratio of PLS,av that is average power loss and power loss corresponding to the peak hour and we will get this expression, we will get this expression, ok.

So, you simply divide it by PLS,1. So, if this part will give you a ratio of PLS,2 divided by P LS,1 with a ratio of small t divided by capital T and this part will be only ratio of some time duration. So, this numerator is basically representing the duration of peak hour and this duration is representing the total duration of the load curve, ok.

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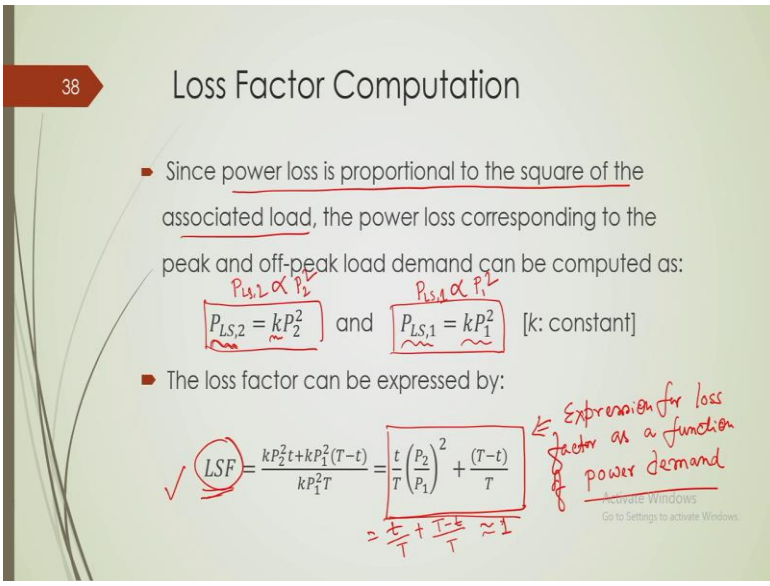

Now, as we know or we discussed in the very beginning that, power loss is proportional to the square of the load demand or power demand, ok. So, we can assume that, this power loss is proportional to is roughly proportional to the square of the power demand. So, this PLS,2 is proportional to PLS,2 which is power loss; we go back and see this P LS,2 is nothing but, power loss during off-peak hour and we know this off-peak hour power demand is P2.

So, we can find out PLS,2 is proportional to P2 square and PLS,1 is proportional to P1 square, ok. So, PLS,2 is proportional to P2 square and PLS,1 is proportional to P1 square, ok. Now, in order to bring it to an equation, let us consider this small k as the proportionality constant and we can as find out this PLS,2 is small k multiplied by P2 square, ok.

Similarly, this PLS,1 is small k multiplied by P1 square. Now, what we will do? We will put these two expressions; we will put these two expression, on the expression of this loss factor that we derived in the last slide, ok. So, once you put it these values basically, we derived this expression earlier. So, what we will can do, we will replace this P LS,2 by you know, PL this P LS,2 by this k multiplied by P2 square and this P LS,1 is k multiplied by P1 square.

So, what we will get k and k will be cancelled out and this will give this expression of loss factor in terms of power t 1. So, this is the expression for; expression for loss factor as a function of power demand, ok. So, this will give you a expression for loss factor as a function of power demand, ok. So, we get the loss factor expression in terms of this power demand, ok. Now, we will be doing some case study here at this point, what are these case study let us see.

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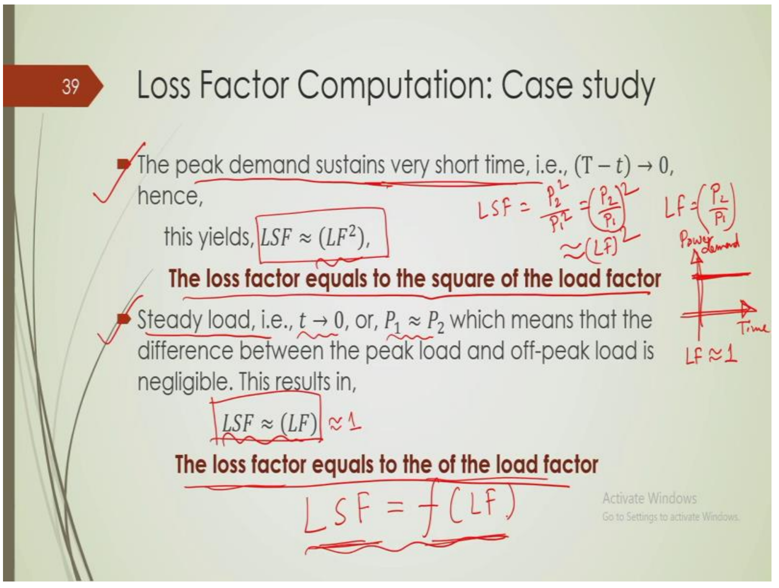

The first case study is that, if peak demand sustains very short time, ok. Now look at this, load curve again, here is my peak load demand and its duration is capital T minus small t. Now, if this peak load sustains for a very small time, then this duration this capital T minus small t should be tends to 0, ok, should be tends to 0.

Now, if we have so; that means, if this capital T minus small t tends to 0, then this part will be eliminated, this part will be eliminated and since you know capital T minus small t tends to 0, that means, effectively this t is actually equal to capital T is roughly equal to small t. So, this part will be unity. So, LSF will be equal to P LS,2 by P LS,1 and from this expression we know this P LS,2 and P LS,1 can be replaced by P2 squared by P1 square.

So, for that you all know this LSF expression will be equal to P2 square by P1 square, all we can write, P2 by P1 square, ok, alright. And what would be the expression for load factor? So, load factor if you know this part is eliminated then it will be simply ratio of P2 by P1. So, load factor will be equal to P2 by P1.

Now, you can find you can see, here under these conditions, so loss factor probably equals to your load factor square, load factor square. So, under what conditions, under the condition that peak demand sustains for a very short period of time, ok. So, you have a very sharp peak and then eventually come down within a very quick succession, ok, then you have this you know relationship hold, alright.

Now, so under this case, we got this loss factor is roughly equal to the load factor square, ok. There is another case study, if it is a steady load; that means, if load demand is almost flat suppose this is your power demand and this is your time and you have a flat load curve, which I have already talked about at the very beginning, which is desirable under this condition basically, your load factor is approximately equal to 1. And, what would be the loss factor let us see.

So, in that condition, under this condition basically your small t will tends to 0 and your entire duration will be capital T. Under this condition you can see this P1 will be roughly equal to P2; that means, you know off-peak hour power demand is equal to the peak hour power demand and under this condition if you put these two conditions over this expression of loss factor, then what you will get? We will get a relationship of capital T, so small t by capital T, here plus this capital T minus small t by T. So, which will roughly give you equal to 1.

So, under this condition, your loss factor and load factor both are almost equal and they are roughly equal to 1, ok. So, if we have a flat load curve a flat load curve having a constant demand over the time, under this condition this loss factor is equal to load factor and both are eventually equal to 1, ok. Now, these are the two extreme conditions possible these are the two extreme conditions possible under which we have a relationship of this loss factor and load factor, ok.

In one case, loss factor is proportional to the square of the load factor; in another case loss factor is roughly equal to the load factor, ok. So, these are the two conditions possible, ok. Based upon that sometimes, we derive an empirical relationship of loss factor and load factor. So, we get, in fact, the relationship of loss factor as a function of load factor, ok. So, based upon these two extreme conditions, we find out this relationship of loss factor as a function of load factor, ok.

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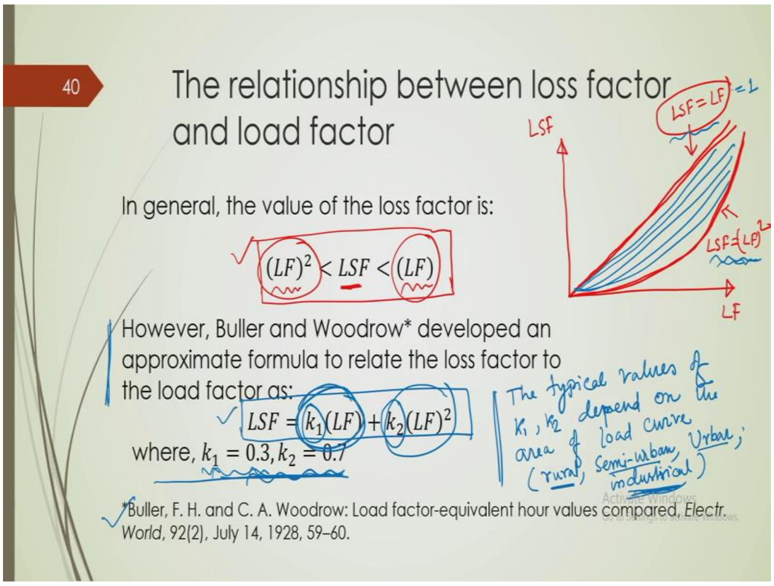

And as I said, this is the relation as you know normally this loss factor can be in between these load factor square and load factor, ok. So, loss factor usually lies in between these loss factor square and load factor. So, these are the two limiting or two extreme conditions possible as I said in the previous slide. And this will give you a relationship of loss factor with load factor, ok.

Now, we can also find out, how this loss factor will vary with this load factor, ok. Now, if your loss factor and load factor are equal, ok, then it will be a straight-line relationship with passing through the origin, with a slope of 45 degree as you know. So, this is the condition when your loss factor is equal to load factor. This is one extreme condition.

And as I said, when your loss factor is load factor square then the relationship will be something like that, ok. So, this is the relationship when your loss factor is equal to load factor square, ok. So, as I said, this loss factor will typically lie in between these two; I mean these two extreme characteristics; one is this; another is this, ok.

And we have typical characteristics of this loss factor and load factor which will lie in between this region, in between this region that can be this or this or this or this, ok, or this sometimes it will be close to this condition that loss factor equal to load factor. Sometimes it will be close to this expression, when your loss factor equals to load factor square, ok.

Now, based upon that several researches going on, to find out this empirical relationship and in this particular work, they gave an empirical relationship of loss factor and load factor. It is simple; they considered some constant multiplied by load factor and some constant multiplied by load factor square. Now, how would be the values of these two constants?

These will depend typically and in which area you are talking about, whether it is a rural area, whether it is a urban area, whether it is an industrial area or where, ok. So, basically the typical values of k1, k2 depend on the area of load curve. It can be rural area, it can be semi-urban area, it can be a complete urban area or metropolitan cities or it can be industrial area.

So, based upon that, these values will change and some typical indicative values is given if k1 is equal to 0.3 and k2 will be equal to 0.7; that means, this particular condition is weighted by 30 percent and this condition is basically weighted by 70, percent ok. Similarly, different combinations of weight are possible depending upon in which area you are talking about. Is it an urban area? Is it an industrial area? Is it a semi-urban area?

Because you know a load factor will vary from rural area to semi-urban, urban, industrial, in rural area typically load factor used to be low; we have a sharp-peak demand during a particular time of the day and then it will fall. Similarly, for industrial area, load factor used to be high because they have almost you know constant demand for a longer duration when your industry runs and then they will have some off-peak hour demand, ok.

So, depending upon that, these factors will also vary. So, how you are closing between these two conditions, where one number 1 is you know load factor is almost equal to 1 and load factor is almost equal to 1, another is loss factor is basically square of the load factors, ok.

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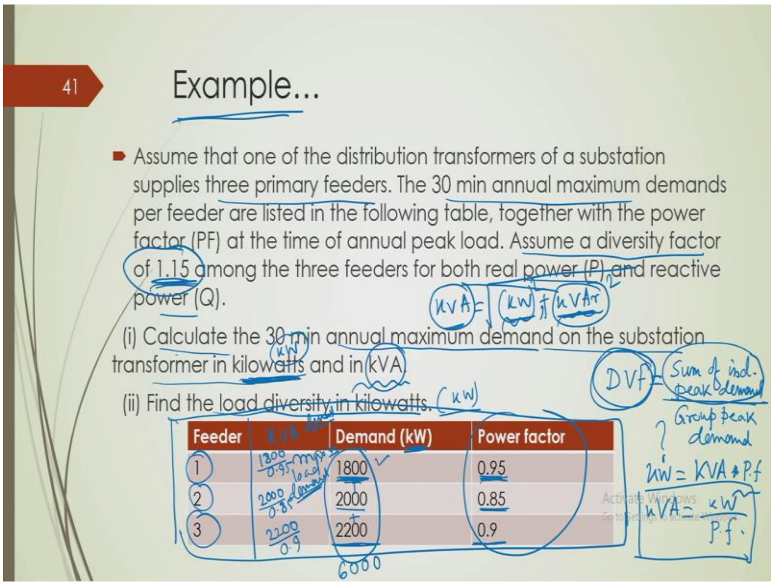

So, this is an area of research, how to find this relationship of the loss factor in terms of load factor. Now, we have an example; we have an example, ok. So, it is very simple example, ok. Assume that, one of the distribution transformers of a substation supplies three primary feeders, ok. So, as I said under a particular distribution sub-station, we have number of feeders.

So, here it is mentioned there are three primary feeders, ok. Now, the 30-minute annual maximum demands per feeder are listed in the following table. So, this table will give you the 30-minute annual power demand and corresponding to the power factor of that particular load, ok. So, here power factors are also given. So, this is your demand in kilowatt and this is power factor. So, for feeder 2, this is the demand and this is corresponding to the power factor.

Similarly, for feeder 3, this is the demand and this is the corresponding power factor ok, alright. Now, assume that the diversity factor is 1.15, ok, among the three feeders for both the real power and reactive power, ok. So, what you need to do? The questions are: you have to calculate, the 30-minute annual maximum demand of the substation transformer in kilowatt that means, in kilowatt and also in kVA, in kilowatt and also in kVA.

And second question is that, find the load diversity in kilowatt, ok; find the loads diversity in kilowatt. This problem is extremely simple, all these information's are given these are not feeder demand; these are basically maximum load demand. So, this 1800 is basically showing you; 1800 kilowatt is basically showing you for feeder 1; this is the peak load demand or maximum load demand.

And, that load power factor is 0.95, ok. Here only important thing is that your power factor is included over here, but other than that this problem is extremely simple. We have three feeders; this three individual you know peak demand is given, ok and diversity factor is also given. You are supposed to determine the peak demand of the group, peak demand of the group, ok.

So, as you know this diversity factor DVF, diversity factor is sum total of this sum of individual peak demand or non-coincident peak demand. So, individual peak demand divided by diversified demand or group peak demand, ok. Now, you know that, sum of the individual power demand you can eventually find out from by simply summation of these three quantities.

For each feeder, we have you know, this individual maximum demand is given. And diversity factor value is also given 1.15. So, these diversity factor values are given; left-hand side is known to us and for right-hand side equation, this numerator is known to us. So, you have to find out this denominator; it is very simple.

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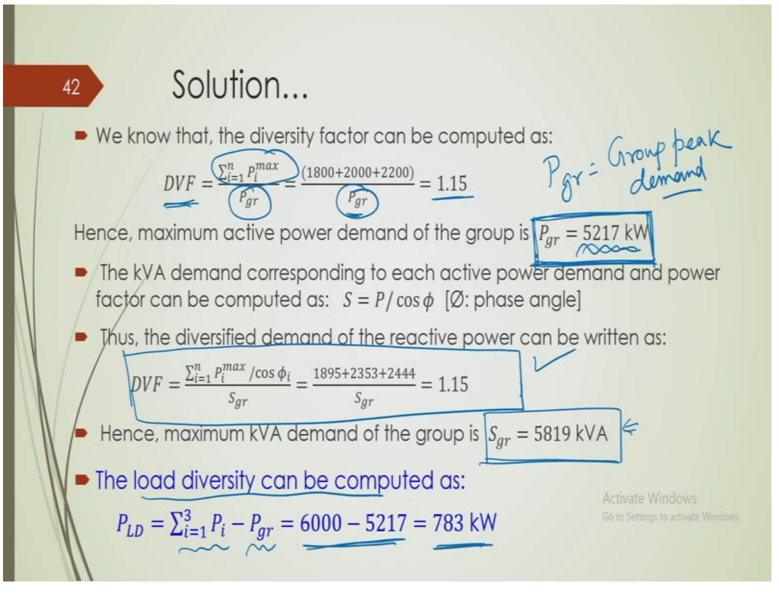

So, we can find out, diversity factor as sum total of individual peak demand divided by group peak demand. So, here Pgr stands for group peak demand, ok. Now, as we know this numerator is known to us, you sum up this individual peak demand and divided by group peak demand. So, group peak demand is only unknown quantity and left-hand side is known to us, that is 1.15.

So, you can simply find out this summation of the numerator divided by 1.15 is your group peak demand, which is find out to be 5217 kilowatt, ok. Now, it is simple. It is simple. So, you can find out this group peak demand in kilowatt. But, if you look at this question, there is another part, that you also you find out this group peak demand in terms of kVA, in terms of kVA or kilovolt ampere, ok.

So, in order to find that, what you can do there are two ways; one is already we know group peak demand in terms of kilowatt, if you can find out this group reactive power demand. So, if you know that kilowatt is known to us; if you find out kVAr, that is kilo volt ampere reactive, which is the group reactive power demand, ok. So, this is basically group reactive power demand.

Then, you can get from this kilowatt and kVAr; you know the relationship; you will get a kVA. So, kVA is nothing but, you know, square sum of kilowatt and kVAr square, ok. So, this is one way. So, we know this kilowatt, if you find out this group peak demand in kVAr, you do it you will get this kVA, ok. Now, there is another way you can convert this demand by from kilowatt to kVA.

And then, you do the same analysis as we did for this kilowatt demand, ok. Then also you can find out straight away what would be that group kVA demand or diversified kVA demand of the group, ok. So, how to find out kVA from kilowatt? Simply you know, this kilo watt is nothing but, kVA multiplied by power factor, ok. So, you know that kVA is equal to kilowatt divided by power factor, ok.

So, once you do that, so you can convert all these kilowatt in kVA. So, this kilowatt 1800 kilowatt, I can bring it kVA. So, how can I bring? Suppose, this is my kVA demand. So, I can bring 1800 divided by this corresponding power factor 95. Similarly, for this feeder 2, you can find out this kVA demand as 2000 divided by corresponding power factor 85, ok.

Similarly, for feeder 3, it is 2200 divided by 0.9, ok. So, once you get these values, these are kVA demand. Then you know that, diversity factor you can find out because it is said that same diversity exists for real power and reactive power. So, same diversity will exist for kVA demand as well. So, you sum-up and then divided by this diversity factor you will get a group kVA demand, ok.

So, this is what is done here. This is what is done here and we get this kVA demand is roughly equal to 5819 kVA, ok 5819 kVA, ok. Now, look at this is different; this one you cannot relate with this power factor with the group peak demand in kilowatt. Because, individual feeders, they have different power factor they have different power factor, ok.

So, this is how we can solve this, ok, alternatively as I said, you can find out this group kVAr you know that group kilowatt and you find out group KVA from this kilowatt and kVAr, ok. Now, load diversity as I said, it is basically sum total of individual peak demand with this and it is difference of this group peak demand.

So, sum total of individual power demand is 1800 to 1000 plus 2200 is nothing but 6000. But as we find this group peak demand is 5217 kilowatt. So, you take the difference of these two, whatever value we will be getting that is the load diversity in kilowatt, ok that is the load diversity in kilowatt, ok.

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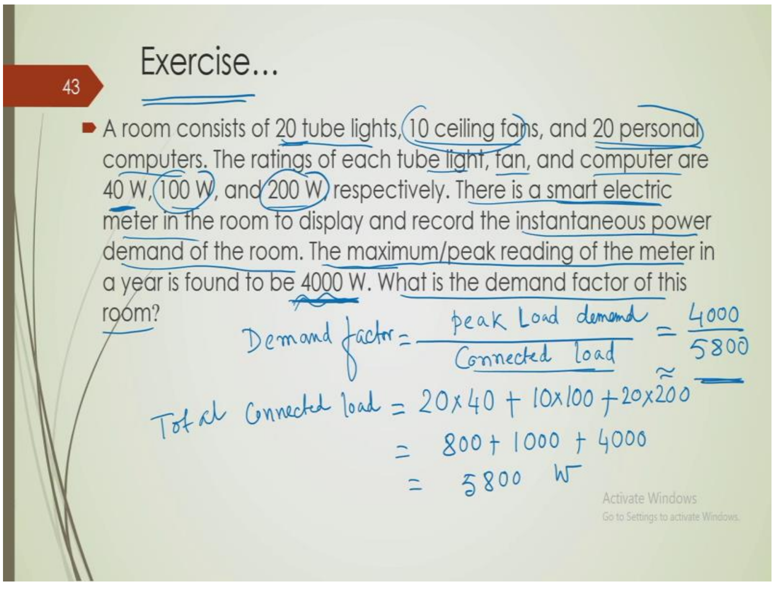

Now, I have two exercises for you. Normally in my class I asked the student to solve it, ok. Very simple exercises if you go through this problem, a room consists of 20 tube lights, 10 ceiling fans, 20 personal computers and the ratings of each of the tube light, fan and computers are given as 40 watt, 100 watt, 200 watt respectively, ok.

Then, it is mentioned there is a smart electric metre in the room to display and record the instantaneous power demand of the room. Because, normally you know, I will be discussing up little after that you know normal energy meter that we use in our home, they are unable to record this instantaneous power demand, they provide you the recorded values of energy, ok, unless you have a special type of meter which is named as smart meter, ok.

Now, here we assume that, there is this meter which can record, the instantaneous power demand, ok. And the maximum; that means, that with this data of this meter you can eventually plot this load curve of this particular room. Now, it is also said that maximum or peak reading of the meter is found to be 4000 watt or 4 kilowatt. Now, the question is, what is the demand factor of this room? What is the demand factor?

Now, if you can remember, what is demand factor; demand factor is nothing but, your peak load demand; it is the ratio of your peak load demand to the connected load. So, demand factor is the ratio of peak demand to the connected load. Now, here numerator is known to us, this peak demand is 4000 watt. Now, connected load is also known to us; because we know that, what are the appliances we have in that room and their corresponding rating.

So, connected load, total connected load is equal to these 20 tube lights; corresponding you know rating is 40. So, this will be 20 multiplied by 40. So, this will give you total demand or total rating of the tube lights. Similarly, 10 ceiling fan and each rating is 100 watts. So, this will be 10 multiplied by 100. Similarly, we have 20 personal computer, 20 PCs. And each of the rating is 200 watts. So, this will be 20 multiplied by 200, ok.

So, this will be your 800; this will be your 1000; this will be your 4000. So, if you sum up this will be 5800 watt. So, your demand factor will be, this peak load demand which is 4000; so, 4000 divided by 5800, whatever value will come. Around 0.6 to 0.7; it will come. So, that value will be that demand factors. So, it is very simple; we have many appliances and this should not confuse you; the basic goal of these problems.

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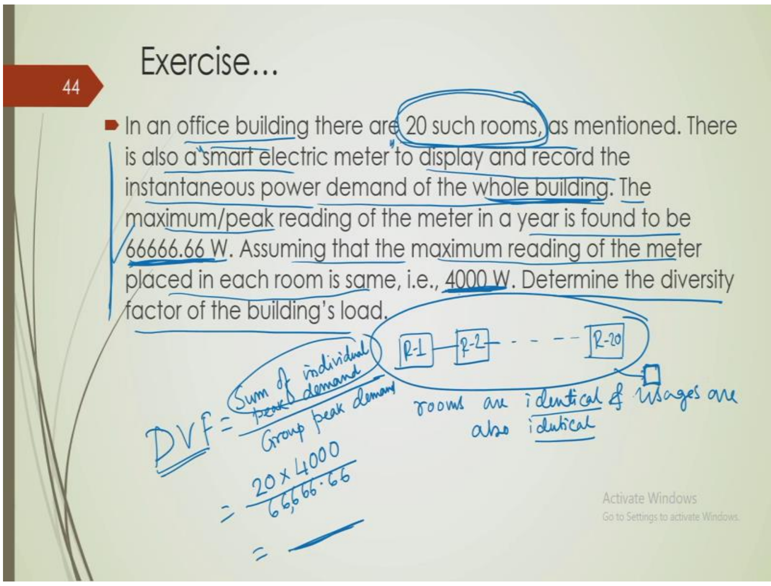

Now, there is another exercise in continuation of this previous exercise. In an office building, there are 20 such rooms as mentioned, ok. So, in the previous exercise, we gave the example one room; one room of having this these many you know appliances and their corresponding rating. Now, similar identical 20 rooms are there in an office building, ok. There is also a smart meter, ok.

Again, what do you mean by smart meter? I will come to that, in one of my lectures, to display and record the instantaneous power demand of the whole building, ok. So, in the previous exercise or in the last exercise, we know that there is a smart meter to record the instantaneous demand of that room.

Similarly, we have similar kind of meter which will measure the instantaneous demand of summation of all these 20 rooms, ok. So, this instantaneous demand is basically recording the instantaneous demand of the whole building, ok. So, this smart meter records the instantaneous demand of the whole building, which consists of 20 such rooms, ok.

So, suppose I have a this is one room 1, similarly this is room 2; similarly we have this is room 20 and this constitutes a building and there is a smart meter which records that aggregated instantaneous demand of all these 20 rooms, ok. And, it is also mentioned that, the maximum of peak demand of the meter in a year, found to be this much, ok.

So, this meter is basically recording the instantaneous demand, which is the aggregated demand of all these 20 rooms and in a year this peak value is given to be this, ok. Now assume that, the maximum demand of the meter placed in each room is same; because these rooms are identical, as I said these rooms are identical, ok.

Since rooms are identical, their peak demand is also same, that is 4000 watt and their usages are also same. Rooms are identical and usages are also identical, ok. Now, if it is so, then we have 4000 watt maximum demand of all the rooms, ok. So, we know that group maximum is this much, then the question is to determine the diversity factor, ok.

So, diversity factor already we know, that it is sum total of individual peak demand, sum of individual peak demand divided by group peak demand, ok. Now, how do we find this numerator? It is you know, for each room that maximum demand is 4000 watt we have 20 rooms. So, sum total will be 20 multiplied by this 4000. And group peak demand is given to be this, that is 66666.66, ok, then whatever this value will come this will be that diversity factor, ok. So, with this I will stop at this point and I will continue in the next day.

Thank you.