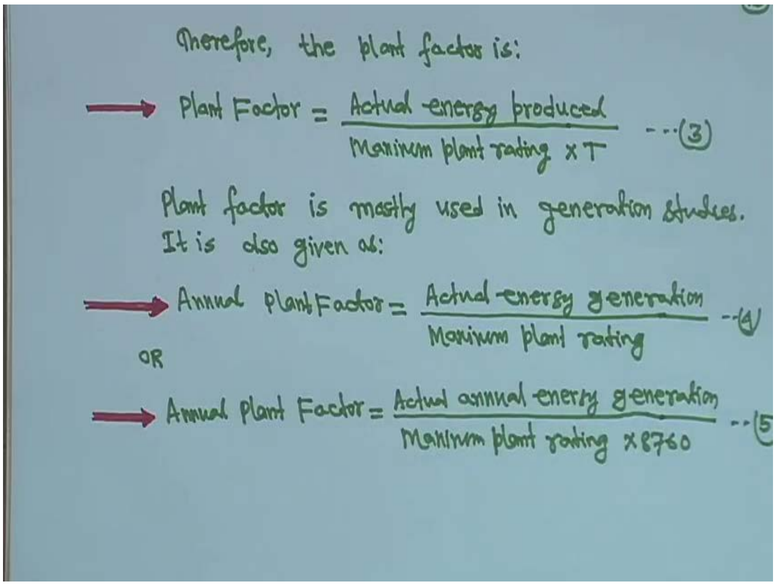
Power System Analysis
Prof. Debapriya Das
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

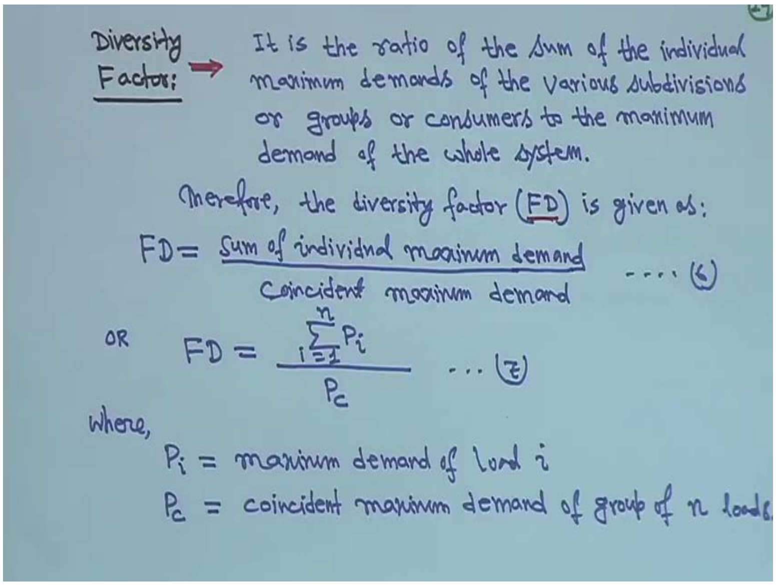
Lecture - 02
Structure of Power Systems and Few other Aspects – II

(Refer Slide Time: 00:24)



Therefore the plant factor is that "plant factor =[(actual energy produced) /(maximum plant rating X T)]" this is T is that that specify time T. So, this is equation 3 plant factor is mostly used in generation studies, it is also given as "annual plant factor = [(actual energy generation) / (maximum plant rating)]" right or annual plant factor that actual annual energy generation or maximum plant rating X 8760 in a year total number of hours is 8760. So, 3 ways it can be defined one is "[actual energy generation / maximum plant rating]" or "[(actual annual energy generation) / (maximum plant rating X 8760)]. So, this is your equation 5 next is that your diversity factor.

(Refer Slide Time: 01:31)

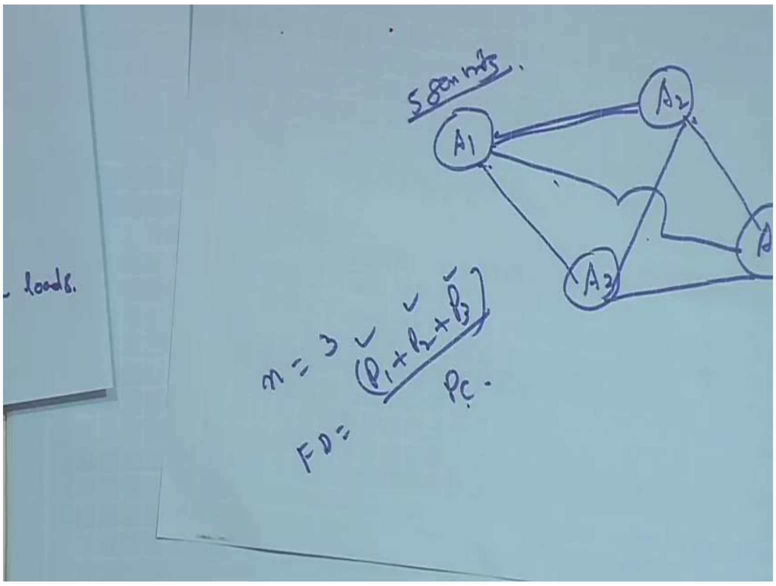


So, it is the ratio of the sum of the individual maximum demand of the various sub divisions or groups or consumers to the maximum demand of the whole system. So, what is this? It is ratio of sum of individual maximum demands of the various subdivisions or groups or consumers to the maximum demand of the whole system for example, diversity at loop; diversity factor we are using system FD because demand factor we have used either (Refer Time: 02:03) DF.

So, that is why I have made FD. So, there should not be any confusion right. So, diversity factor we term it as FD is given as FD = [(sum of individual maximum demand)/(coincident maximum demand)].

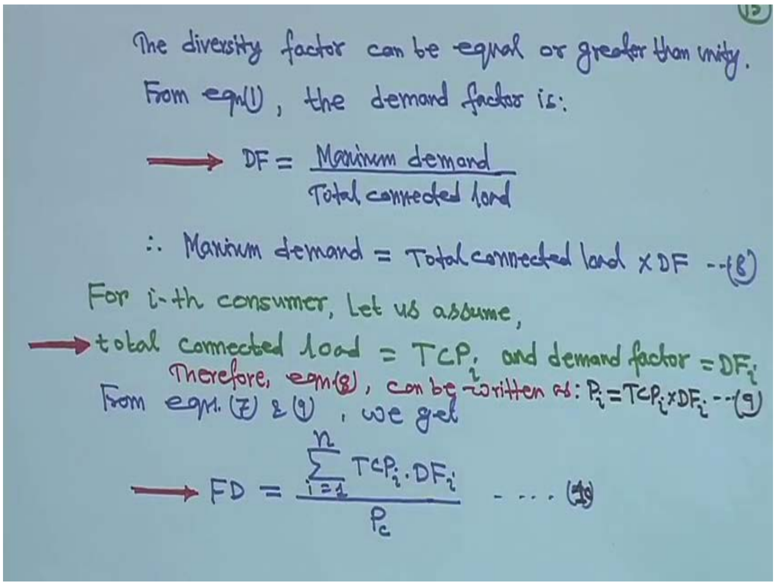
Or we can write suppose individual maximum demand says if P_1 P_2 P_3 like this if they are the maximum demand for individual consumers right. So, diversity factor FD = $[\sum_{i=1}^{n} p_i / p_c]$, "$P_i$ is the maximum demand of load I" right divide and "P c is equal to coincident maximum demand of group of n loads". So, this is equation 7. So, diversity factory we will use the term FD not DF because demand factor DF earlier we have used. So, this is actually your diversity factor next is. So, these are understandable right you have your n number of consumers and for each one you will take suppose you have n is equal to 3.

(Refer Slide Time: 03:14)



So, here it should be P_1 P_2 for example, it is like this suppose you have suppose you have here n is equal to 3 then diversity factor FD will **be p_1^2 plus p_2^2 we will take example later on** p_3^2 divided by your P_c right. So, P_1 P_2 P_3 they are individual maximum demand of your what you call that each type of consumers divided by the coincidence maximum demand that is P_c right. So, P_1 P_2 P_3 is the individual maximum demand right.

(Refer Slide Time: 03:47)

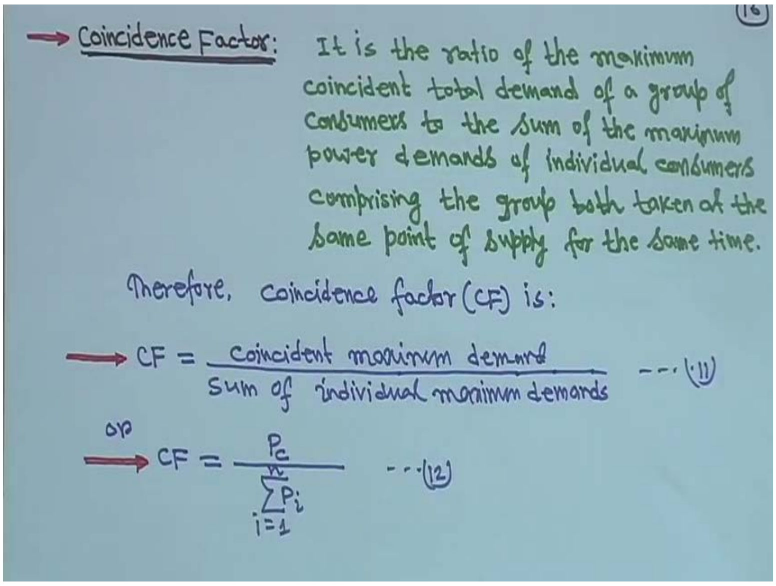


So, next is the diversity factor can be equal or greater than unity right. So, from equation one the demand factor is DF is equal to maximum this is from equation one we are writing $(demand\ factor)DF = \frac{maximum\ demand}{total\ connected\ load}$ therefore, $maximum\ demand = total\ connected\ load\ \times\ demand\ factor$.

So, maximum demand is equal to DF total connected load into DF this is equation 8 right now for i th consumer for i th consumer let us assume total connected load is equal to TCP_i right and total connected load TCP_i and demand factor DF_i this is for i th consumer right let us assume this therefore, equation 8 can be written as $p_i = T_c p_i \times DF_i$ this is equation nine. So, maximum demand what P_1 P_2 P_3 I was telling just now right suppose for i th consumer it is P_i and total and total connected load total connected load for i th consumer we define TCP_i . So, T is total connected load at TCP_i into for the i th consumer the demand factor we can put DF_i this is equation 9.

So, from equation 7 and 9 you will get that your diversity factor $FD = \frac{\sum_{i=1}^{n} T_c p_i \times DF_i}{p_c}$ FD is equal to sigma I 1 to n TCP i into DF i upon P c this is equation this is equation 7 this is equation 7 and here you are substitute this thing this one you are replacing by your $p_i = T_c p_i \times DF_i$ so in this equation you are substituting $p_i = T_c p_i \times DF_i$ right divided by that pc. So, this is equation ten. So, that is your diversity factor FD DF is demand factor, but FD is the diversity factor.

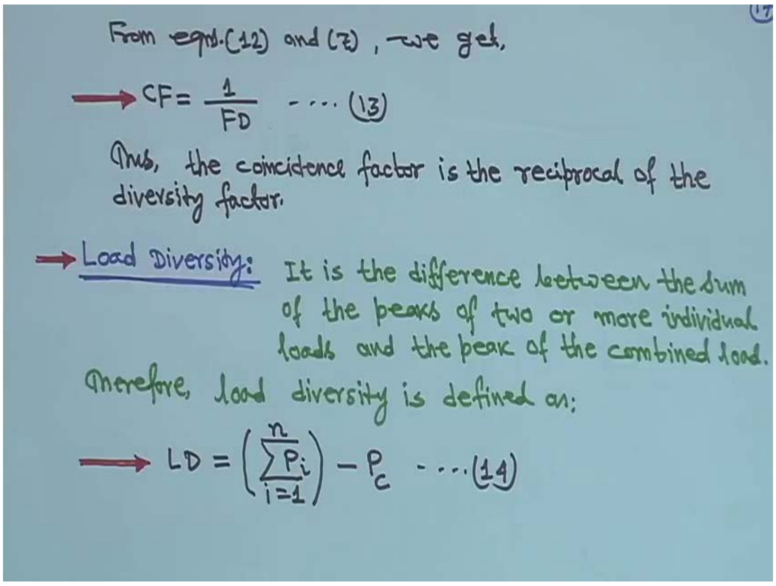
(Refer Slide Time: 05:54)



Next one is the coincidence factor coincidence factor it is the ratio of the maximum coincident total demand of a group of consumers to the sum of the maximum power demands of individual consumers comprising the group. Both taken at the same point of supply for the same time later I will take few example after that you will see this things are quite easy yeah it is the ratio of the maximum coincidence total demand of a group of consumers of a group of consumers different type of consumers maybe commercial industrial agricultural like this right to the sum of the maximum power demands of individual consumers comprising the group both taken at the same point of supply for the same time right; that means, the coincidence factor you define it is by $CF = \frac{coincidence\ maximum\ demand}{of\ \ individual\ maximum\ demand}$. So, this is equation 11.

So, coincidence maximum demand already defined P c is the coincidence maximum demand previously we have defined P c divided by sum of individual maximum demand this also we have defined. So, $CF = \frac{p_c}{\sum_{i=1}^{n} p_i}$ it just reciprocal of the your diversity factor right because diversity factor (Refer Time: 07:12) sum sigma P i your i is equal to 1 to n and divided by P c and coincidence factor is just opposite P c divided by sigma I is equal to 1 to n P i this. This equation is number is 12 right; that means, if you see equation 7 just hold on before this if you if you see equation 7 here equations that $FD = \frac{\sum_{i=1}^{n} p_i}{p_c}$ equation 7 and this coincidence factor is equal to just a reciprocal of it $\frac{p_c}{\sum_{i=1}^{n} p_i}$ this is 7 this is equation 12 (Refer Time: 07:54) FD is equal to 1 upon CF or $FD \times CF = 1$ right; that means, ; that means, from equation just.

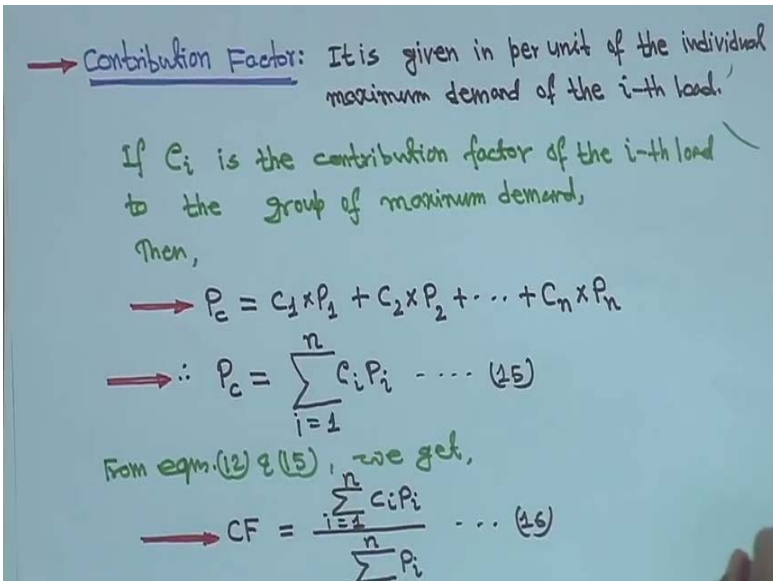
(Refer Slide Time: 08:10)



Now, I told from equation 12 and 7 we get CF is equal to 1 upon FD this is equation thirteen right does the coincidence factor is the reciprocal of the diversity factor or diversity factor is the reciprocal of the coincidence factor.

Now, load diversity. So, it is the difference between the sum of the peaks of 2 or more individual loads and the peak of the combined load right therefore, load diversity is defined as LD you are defining load diversity you define it by $LD = \sum_{i=1}^{n} p_i - p_c$ this is equation 14 it is the difference between the sum of the peaks of 2 or more individual loads suppose you have 3 different type of loads are there. So, their peak you are adding. So, I is equal to 1 to n P_i right or and the peak of the combined your what you call minus the peak of the combined load that is P c you have defined earlier right. So, that is your load diversity LD is equal to this 1 minus P c this is equation 14.

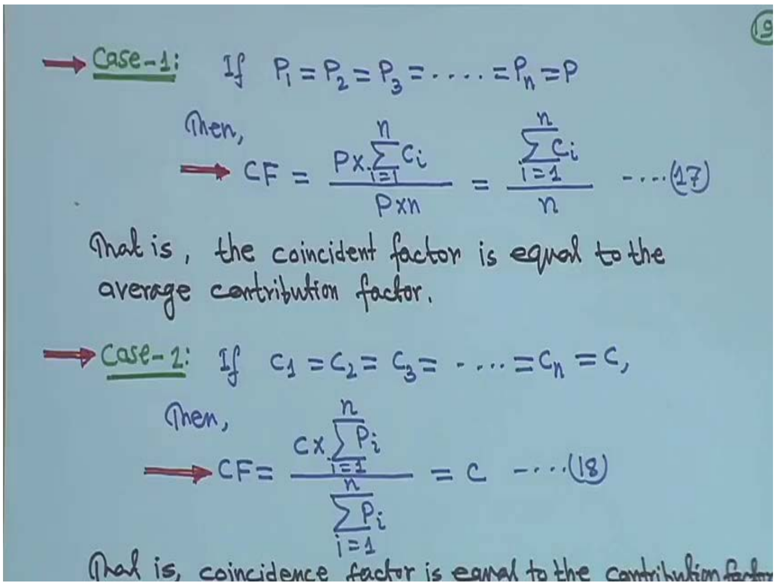
(Refer Slide Time: 09:33)



So, this is your load diversity now next is contribution factor it is given in per unit of the individual maximum demand of the i th load if C_i is the contribution factor of the i th load to the group of maximum demand that is C_i means suppose; suppose your it is given in per unit of the individual maximum demand suppose a suppose power is hundred kilo watt and C_i is that fraction of it.

So, maybe 0.4, so, 0.4 is 140 kilowatt something like this, right. So, if the C_i is the contribution factor of the i th load to the group of maximum demand then P_c is equal to C_1 x P_1 plus C_2 x P_2 up to C_n x P_n; that means, $p_c = \sum_{i=1}^{n} c_i p_i$ if this equation number is 15 right. So, from equation 12 and 15 you will get equation 12 mean this equation just hold on. So, this is equation this is equation 12 P c upon your sigma i is equal to 1 to n pi. So, P c here is i is equal to 1 to n C i P i therefore, CF is equal to we are we are substituting P c here a from equation 12 and 15 i is equal to n to C i P i divided by I is equal to 1 to n P i right. So, this is actually equation 16 this is your this is cause your 1 thing just there should not be any confusion just one hold on that just one minute I put this one this contribution factor right. So, anyway, this is your CF is equal to this one this is equation 16.

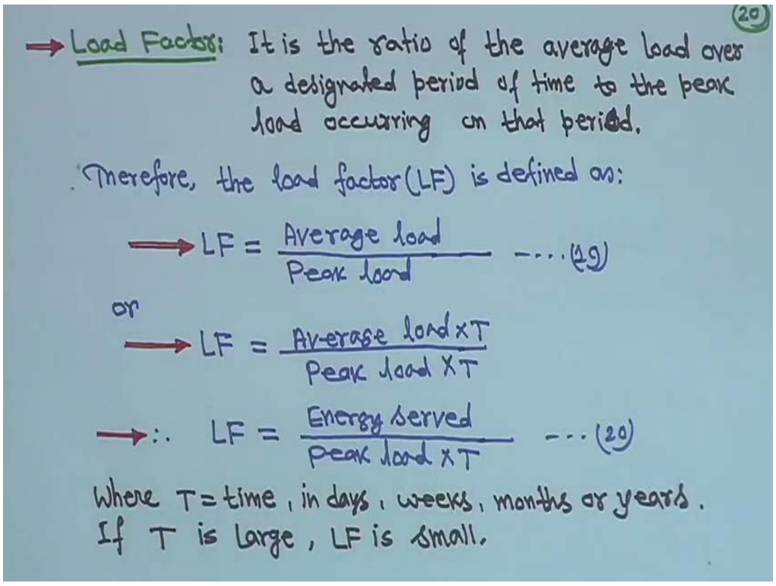
(Refer Slide Time: 11:32)



Now, consider case 1 if say if $p_1 = p_2 = \dots\dots = p_n = p$ say all are equal then CF is equal to your basically all are all are P P_1 is equal to P_2 all are P then it will basically P into I is equal to 1 to n C i right P ,P will be canceled here also all are P sum of p. So, it will be P into n because it is P plus P plus P up to nth term. So, it will be n into P. P will be cancelled. So, CF will be sigma I is equal to 1 to n C i the coincidence factor in this case is equal to the average contribution factors. So, average means sum all divided by n. So, this is average contribution factor.

Similarly, case 2 if $c_1 = c_2 = c_3 = \dots\dots = c_n = c$ up to up to say is equal to c all are c all are same contribution factor in this case CF will be c into sigma I is equal to 1 to n P_i upon I is equal to 1 to n P_i right. So, is equal to this; this term this term will be cancelled. So, CF will be is equal to c that that is coincidence factor is equal to the contribution factor right.

(Refer Slide Time: 12:52)

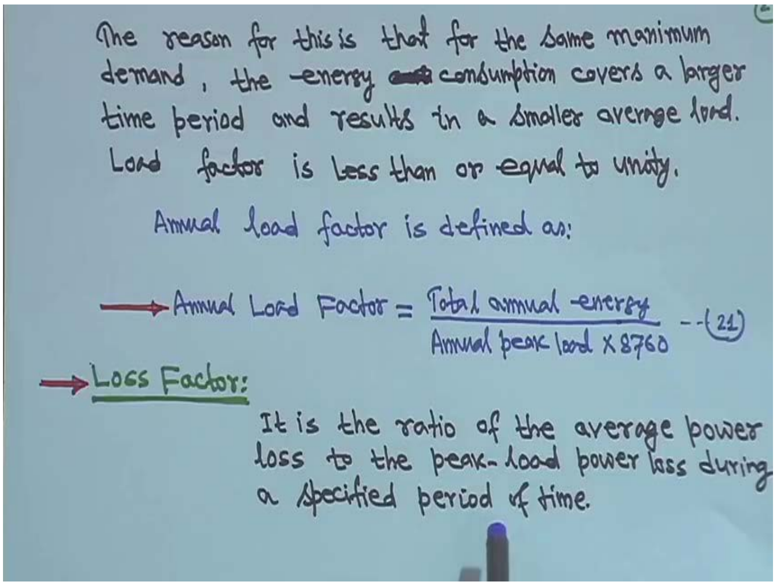


Now, we have seen. So, many terminology right next is load factor actually first to have to see all these we have to familiar with all sort of terminology then if you take example I will take few examples right then things will be your you know much clear. So, that is why before putting an example in between first we have taken this all this terminology right next load factor. So, it is the ratio of the average load over a designated period of time to the peak load occurring on that period right therefore, load factor we are defining by LF.

So, $LF = \frac{average\ load}{peak\ load}$ right. So, this is equation 19 or $LF = \frac{average\ load \times T}{peak\ load \times T}$ just a your this way also we can define or $LF = \frac{energy\ served}{peak\ load \times T}$ this is equation 20 either average load by peak load or $LF = \frac{energy\ served}{peak\ load \times T}$ this is equation 20 T is equal to time.

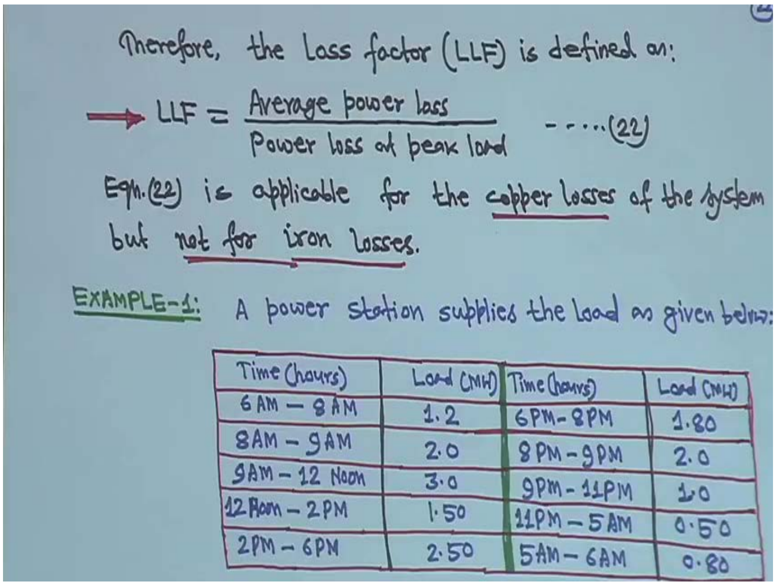
It may be in days, maybe weeks, months or years or if T is large load factor is small right for a large T generally you will find that load factor is small the reason for this is that for the same maximum demand the energy consumption cover a larger time period and results in a smaller average load.

(Refer Slide Time: 14:15)



So, load factor is less than or equal to unity generally less than 1 right less than 1 and annual load factor can be defined as this $Annual\ load\ factor = \dfrac{total\ annual\ energy}{annual\ peak\ load\ \times\ 8760}$ number of hours in a year is 8760. So, this is equation 21, right. Now another terminology that is the loss factor right say meaning is same load factor- only thing is that it is the ratio of the average power loss to the peak load power loss during a specified period of time this is called loss factor right for example, therefore, the loss factor is defined as we defined LLF loss factor we defined as $LLF = \dfrac{average\ power\ loss}{power\ loss\ at\ peak\ load}$ right. So, this is equation say 22.

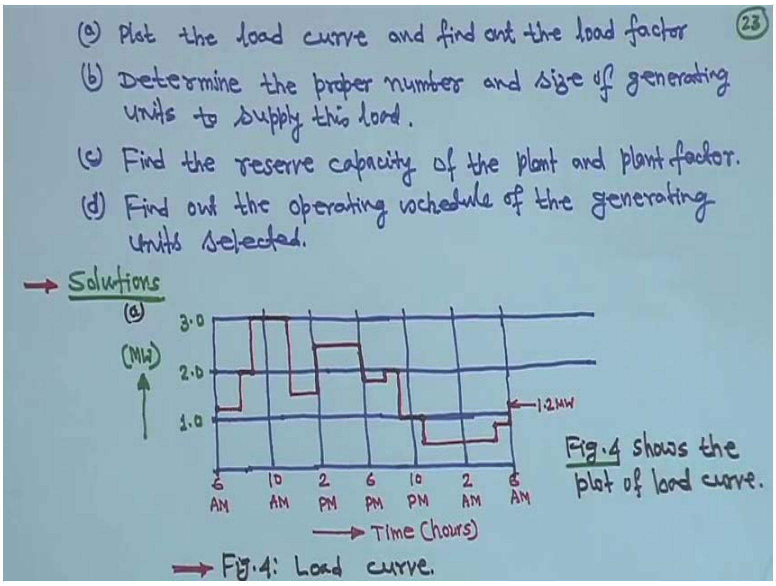
(Refer Slide Time: 15:15)



So, equation 22 is applicable to the copper loss of the system, but not for iron loss; that means, loss factor you can compute is for i^2 R loss only, but not for iron losses right. So, only applicable to the i^2 R loss next we will take 1 example for example. So, a power station supplies the load as given bellow say time duration is given for example, say time is hours 6 am to 8 am load is 1.2 megawatt 8 am to 9 am load is 2 megawatt 9 am to 12 noon.

It is say 3 megawatt 12 noon to 2 pm 1.5 megawatt and 2 pm to 6 pm 2.5 megawatt then 6 pm to 8 pm 1.8 megawatt 8 pm to 9 pm it is 2 megawatt 9 pm to 11 pm it is 1 megawatt, 11 pm to 5 am it is 0.5 megawatt and 5 am to 6 am it is 0.8 megawatt, this data are given a power station as given below so; that means, 24 hours data that load variations are given to you right. So, what you have to do is you have to first determine first thing plot the load curve.

(Refer Slide Time: 17:03)



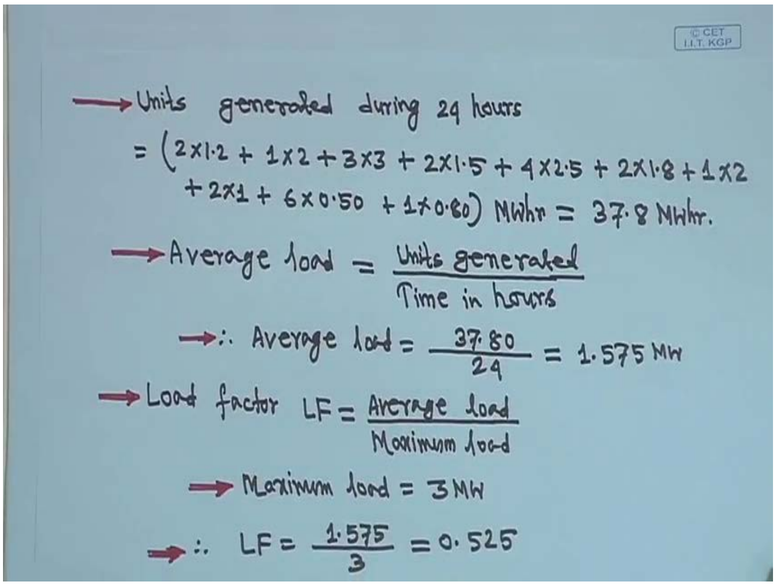
And find out the load factor next is determine the proper number and size of generating units to supply this load (c) is find the reserve capacity of the plant and plant factor and (d) is find out the operating schedule of the generating units selected. So, this 4 thing you have to determine based on the given data solve sense first what you do you draw the load curve forget about this line it is up to this only you think right. So, first is 6 10 6 am 10 am this way am are 2 pm 6 pm 10 pm 2 am 6 am. So, at 6 am at 6 am 6 am to 8 am load is 1.2 megawatt. So, at 6 am it is 1.2. So, it will come up to your 2 your 6 to 8 am.

Some are here. So, have to your; it is 1.2 megawatt now 8 am to 9 am 2 megawatt. So, here it has gone to 2 megawatt and it is 8 to 9 just 1 hour right and again 9 am to 12 noon the peak 9 am to 12 noon if it is going to peak it is 3 megawatt right and then the 12 noon to 2 pm 1 your 9 am to 12 noon it is your this thing 12 noon is here somewhere here is 12 noon it is 3 megawatt then 12 noon to 2 pm one point at 12 noon again it is going down to 1.5 somewhere here right and it is up to 2 pm here right again 2 pm to 6 pm 2.5. So, at 2 pm again it is going to 2.5 to 6 pm means up to this 2.5 megawatt then 6 pm to 8 pm 1.0. So, it is coming down to 6 pm 1.0 up to 6 it is going after that coming down right 1.080 rather 1.8 0 to 8 pm somewhere here then 8 pm to 9; 1 hour it is 2 megawatt it is 2 megawatt and 9 pm to 11 am 1 megawatt.

So, at 9 it is coming down 9 to 11 it is 1 megawatt right and then 11 pm to 5 am this is 11 pm somewhere here to 5 am up to this it is 0.5 megawatt here it is 0.5 megawatt and 5 am to 6 am 0.80 megawatt. So, for 5 am it is going to 0.8 then for 6 am 0.8 is, but again it will you have to you have to come here again it is 6 am is coming. So, finally, 1.2 megawatt this is also this point is also 1.2 megawatt. So, this way you should complete this, your; what you call that your load curve this is this is called your you plot the load curve first, right.

So, once this load curve is plotted this is a time and this is the your what you call megawatt load and peak is of course, the your 3 megawatt right once you compute that load curve then the units generated during 24 hours right. So, again what will do that first you calculate units generated in 24 hours? So, in that case that if you see here just side by side I am trying to put right.

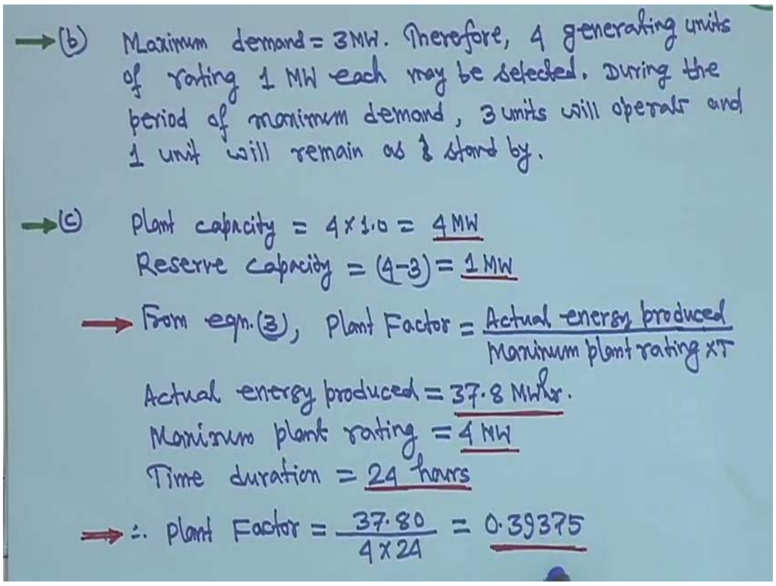
(Refer Slide Time: 20:31)



So, 6 am to 8 am 1.2 megawatt and 6 to 8 mean 2 hours. So, 2 into 1.2 plus 2 megawatt load, but 8 to 9 only 1 hour. So, 1 into 2 plus that 9 am to 12 am 12 noon so; that means, 3 hours and 3 megawatt load so, plus 3 into 3 plus this 12 noon to 2 pm; that means, 2 hours right. So, 2 into 1.5 load is 1.5 megawatt plus 2 pm to 6 pm; that means, 4 hours load is 2.5. So, 4 into 2.5 then plus 6 pm to 8 pm mean 2 hours into 1.8 load is 1.8 megawatt plus 8 pm to 9 that is 1 hour 1 into 2 megawatt load into 2 then plus 9 pm to 11; that means, 2 hours load is 1 megawatt. So, 2 into 1 plus your 11 pm to 5 am; that means, 6 hours in load is 0.5 megawatt. So, 6 into 0.5 plus 5 am to 6 am that will 1 hour load is 0.8. So, into 0.8 this much of megawatt hour this way you should compute that unit is generated during 24 hours right. Once you have done this that is equal to total unit generate is thirty after calculating all this it is 37.8 megawatt hour right now average load is just we have seen know load factor units generated by time in hours. So, units generated are 37.8 megawatt hour and divided by 24 because duration from 6 to 6; 6 am to 6 am is 24 hours.

So, it is your 24 hours. So, that is 1.575 megawatt that is the average load right and $load\ factor = \dfrac{average\ load}{maximum\ load}$. So, maximum load is 3 megawatt maximum is 3 megawatt. So, have load factor is equal to 1.575 upon 3 that is equal to 0.525 that is. So, this is a load factor now next is that maximum demand.

(Refer Slide Time: 22:59)



Next point B; just B is that you have to determine the proper number and size of generating units to supply this load listen we are not doing here any economics we are not trying to optimize anything just to have some ideas. So, this point is given determine the proper number and size of generating units to supply this load. So, from our intuition we will try to make it, but any not considering any cost benefit analysis or anything just through give us a idea right. So, B number B is that second point is you have to determine the proper number and size of generating units to supply this load right.

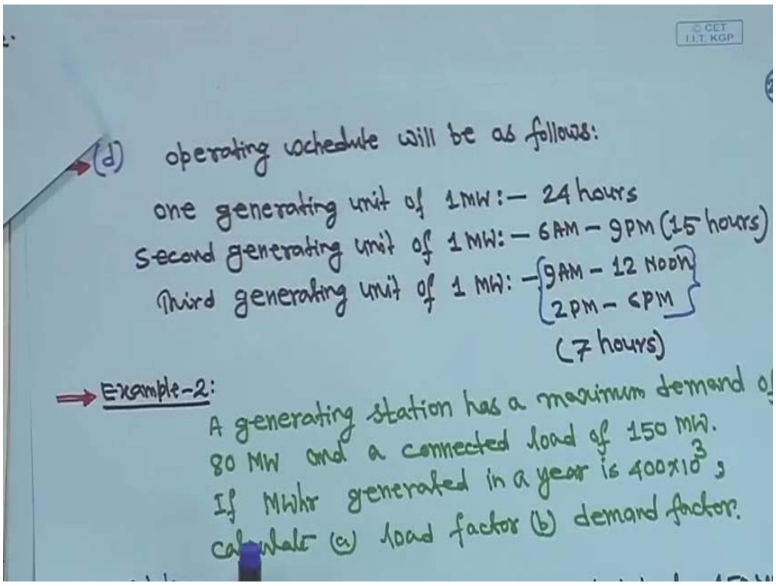
So, in this case in this case that maximum demand is 3 megawatt right and; that means, you have to supply power this 3 megawatts of power therefore, if we choose 4 generating units of rating 1 megawatt each may be selected suppose we are taking 4 generating units and each one is having is rating is 1 megawatt say right therefore, during that period of maximum demand 3 units can operate it can operate will operate and it will attached to operate at its full load because 1 megawatt rating and 1 unit will remain as standby by chance if 1 unit goes off another unit may be switched on right. So, from the reliability purpose 1 1 4 generating units is considered if you consider 3 megawatt and 3 units that is fine as long as it will generate there is no loss of generation, but if 1 generator becomes faulty then it cannot supply the load that is why one extra is taken,.

So, 4 is taken. So, 3 units will operate and 1 unit will remain as standby right next one is next point is given find the reserve capacity of the plant and plant factor right. So, in that case plant capacity is equal to 4 into 1 because we have taken we have considered 4 generating units each 1; 1 megawatt. So, it is 4 into 1. So, 4 megawatt and reserve capacity will be then maximum demand is 3 megawatt. So, reserve capacity will be 4 minus 3 is equal to 1 megawatt right now from equation 3 the $plant\ factor = \dfrac{actual\ energy\ produced}{maximum\ plant\ rating\ \times T}$ now actual energy this is from equation 3 right. So, actual energy actual energy produced is equal to 37.8 megawatt hour just now we have seen 37.8 megawatt hour right and make and the plant max plant capacity now 4 megawatt. So, maximum plant rating will be 4 megawatt. So, time duration is 24 hours therefore, plant factor is equal to 37.8 divided by maximum plant rating is 4 megawatt. So, it is 4 4 4 and number of hours is T is equal to 24 time duration 24 hours because 6 am to 6 am interval. So, it is coming around 0.39375.

For example if you are chosen if you are chosen instead of 4 5 your 5 generating units right in that case plant capacity should have been 5 megawatt then reserve capacity should have been 5 minus 3 say 2 megawatt right.

So, in that case this 37.80 divided 5 into 24; that means, this plant factor will shall be less than this one right so, but anyway. So, this is your what you call plant factor is 0.39375 and last one this number (d) last one that find out the operating schedule of the generating units selected right you have to find out how these units will operate. So, in that case what one can do is if you see of your own that that.

(Refer Slide Time: 27:01)



One generating unit of 1 megawatt must work for 24 hours because they have no where load is 0 minimum is 0.8 if you look at that data if you look at data that we are sorry minimum is 0.5 megawatt sorry, 0.5 megawatt. That means, this one generator has to be on for 24 hours because this 0.5 megawatt load has to be supplied because minimum is point minimum load is 0.5 megawatt right and then second generating unit of 1 megawatt requires 6 am to 9 pm that 15 hours if you look carefully at least 6 am to 9 pm you can observe that load is more than 1 megawatt.

That is why 2 units required if you look at that your 6 am to 9 pm say 6 am if you look at that every higher 1.2 two 3 all these things going on till 2 pm right 6 am to 9 pm rather up to this you say that it is more than 2 right 2 or it is more your what you call 6 am to 9 am 15 hours second generating unit of 1 megawatt is required because all the time load is two. So, this 2 unit is also required, but if you see third generating unit 1 megawatt 9 am to 12 noon and 2 pm to 6 pm 7 hours required that means it is overlapping. So, this 9 am to 12 noon and 2 pm to 6 pm for this 7 hours you need all the 3 units should be on right so; that means, for 1 megawatt 1 unit for 24 hours then another generating units must be on 6 am to 9 pm for 15 hours and third unit 9 am to 12 noon as well as 2 pm to 6 pm 7 hours because the load will be during this duration it will be more than 2 megawatt right.

So, this way from your intuition from your common sense you can find out how this generator operating schedule can be can be desired made. So, from the data and from whatever we have made it here you can have a look and just see this is the way that things can be I mean operating schedule can be prepared.