Power Electronics and Distributed Generation
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Module - 2
Lecture - 1
Economic Evaluation of DG Systems

Welcome to class 21 on topics in power electronics and distributed generation. So, far in the classes we have been looking at distribution systems from the point of view of trying to understand, what the impact of adding distributed generation?

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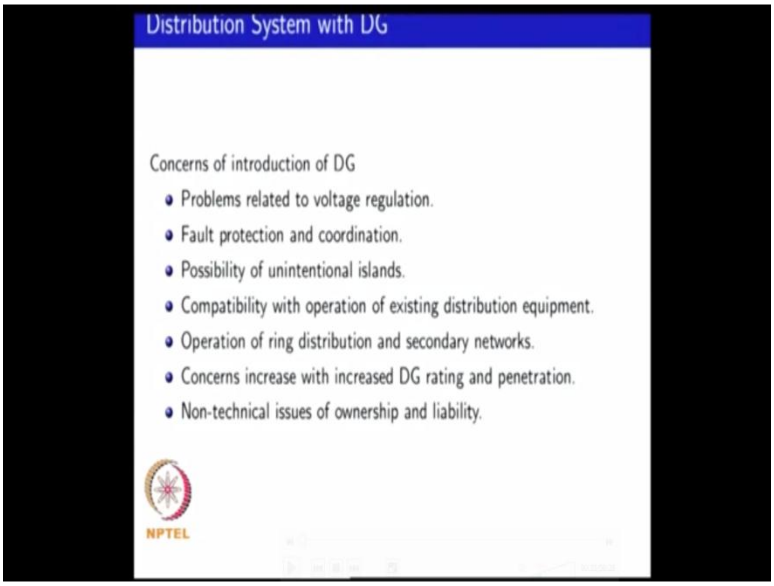

A system to the existing distribution system is going to be and we identified many concerns. We saw, when we are having long feeders that you could have possibilities of over voltage, under voltage along the feeder depending on location of the D G. What it is trying to do? Etcetera you have problems or related to fault protocol coordination and protection especially, if there is a significant change in fault current levels. Now, that is result of adding the D G unit also. We saw, that there is a possibility of unintentional islanding and there are variety of concerns if you have a situation of unintentional island also the compatibility of the existing distribution system equipment is a issue.

We saw that the reclosers, there may be timing issues, the when you add the D G unit. When you have sectionalizers, you might think that you are operating without your interrupting the sectionalizers when there is no current, but the D G may introduce current. When it is actually opening there could be problems with open loop transformer on load tap changing transformers with their boost open loop boost functionality. When you add a D G unit we saw, there could be problems with series voltage regulators on ring feeders.

So, these problems become more of a concern when you have more complicated distribution network such as a ring distribution or a secondary network distribution you might have problems with voltage regulators network protectors etcetera, and the other thing we saw is a some of these problems might seem to be insignificant when the scale of D G in the feeder is small. So, if it is just a couple of solar inverters sitting on one roof it must not seem like a big problem, but the problem increases as the penetration of D G increases.

So, if anyone starts adopting D G technology or there is D G of significant rating compared to the rating of the feeder then the problems increased, also these are technical concerns there are non technical concerns such as who would bare the cost if you need to upgrade some of the existing equipment due to the addition of the D G then who should bare the castor. So, distribution system has multiple parties that are operating in such a system you have then the distribution service provider you have a number of consumers.

So, if you are using distribution network to send power out then there is a question of ownership. Are you making use of something that someone else is owning? To actually get benefit also their issues of liability if you because of the addition of the D G causes damage to a neighbor or some other owner in that particular setup then who bares the liability of potential damage.

So, it is important not just to address the technical issues, but also the policy and regulatory framework issues associated with distributed generation and there are variety of people looking at it from these different prospective and one thing to keep in mind, it is not that the only problems. There are advantages, you can see that by adding the D G you can get benefits of power quality, power benefits might be and because it is being you can add a D G in a selective manner.

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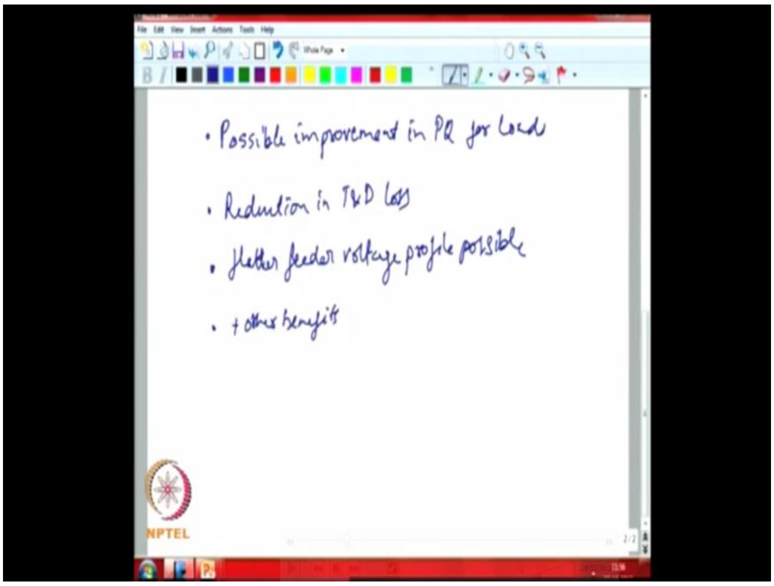

You could selectively consider which loads need higher power quality. Then, have D G at those set of loads alone rather than having to upgrade to a more complex network such as a loop, a ring or a network which would imply cost to all users to that particular network. So you can have benefits of higher power quality.

We also saw that the feeder losses can come down quite dramatically. So, deduction and transmission and distribution losses, you also saw that by appropriately adding the D G unit. Then, it is possible to have a flatter feed up of voltage profile plus you have other benefits. For example, one might consider a that adding renewable energy might be seen as a border sighted benefit, and distributed generation is one possible way in which you could add a renewable into a system of course.

You could have renewable as large as centralized units too, also at if you look at the technical problems that we considered many of the problems that require are limiting of fault current contributions from the D G. So, you need D G systems where you can limit the fault current when there exists a fault and not have significant difference in fault current levels, when you add the D G unit also. We saw that some of the equipment that need to control the power flow at different sections of the feeder in a accurate and fast manner depending on the existing load power flow.

So, you need fast power control and you also need possibility of a very rapid switching. So, you need also a large number of switching that are possible. If you look at all these requirements of limiting fault current level fast per control need for rapid switching of the interconnection device. All that implies that have increased role of power electronics compared to the existing traditional systems that can used for interconnection.

So, the role of power electronics in distributed generation can would be increasing as proceeding time, but on the flip side if you look at say, existing power electronic solution with the existing traditional solution. We know that the costs of the power electronics systems are much higher than the existing traditional systems. For example, to send power out existing synchronizing machine is actually much cheaper than a power converter to at this given power level also, if you look at existing circuit breaker that is much cheaper than a semiconductor base circuit breaker.

So, at the power level if you now introduce power electronics, there is a chance that the cost that you would see is much higher and you want to make sure that you are doing things that are cost effective. You want to actually look how you can verify the economics behind adding the power electronics system. So, that you are not going back in terms of saying, having a overall economic system by adding a power electronic components and your designs or technological changes are moving in the right direction. So, with that background we will look at a couple of the way or few ways in which you could add. Look at cost benefit analysis once you add a D G system.

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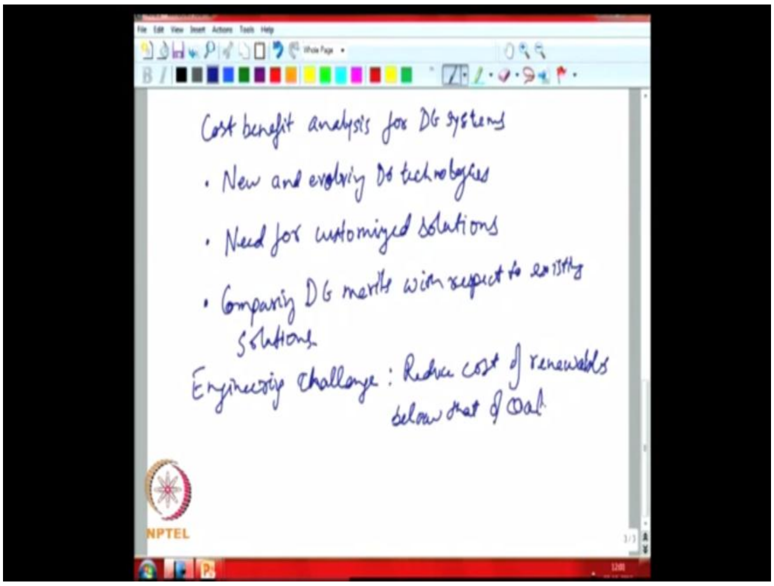

Some of things to keep in mind are many of the D G technologies compared to the mature existing power system technologies are relatively new and also evolving quite rapidly. So, also in many distributions, the generation or storage type of application, the installation at one location may not be identical to the installation at some other location. You might need some customization depending on where you are actually trying to install the unit.

So, you also want to look at what are the existing solutions for a given application and how does that D G system compare with the existing solutions. For example, you might be thinking about a power quality application. You want to see, whether one particular existing solution be adding genset or a traditional u p s. How does a D G type of solution compare with the existing solution?

So, if you also we need to look at it in terms of the significant challenges that are excess especially when you are looking at issues such assay, climate change or a or introduction of renewable into the existing system. A major challenge with respect to renewable or renewable energies are not too actually sure of proof of concept provided renewable energy system can work, but to actually to ensure that the cost of the renewable system is below that of say, for example coal is considered extremely energy letting generating electricity from coal is considered extremely cheap. You want to make sure that can you make the renewable system cheaper than coal if that is the case then you have a natural winner. So, looking at it from a economic prospective very critical for engineering such system. So, we will look at a few matrixes that can be used for D G systems.

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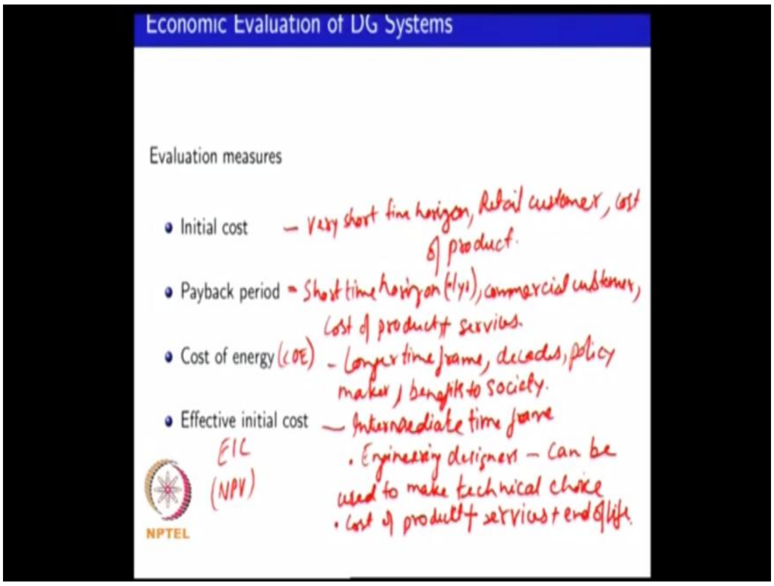

There are a few ways say, one particular way in which you might make a decision when you are making a purchase or thinking of installing a D G system is what the cost is I mean. So, if you if you go to a shop you can easily check whether you have money in your wallet before you decide on whether to purchase a cup of coffee. So, if your coffee cost is higher than what you have in your wallet, you may have to think I will not make this purchase.

So, if you look at just look at the initial cost it is a very short time horizon decision. You are making an instantaneous decision. So, you a typical decision like this would be make routinely when we go and make retail purchases and you are looking at essentially the cost of the product. You may not look at, what might be the time implications of making that purchase? For example, you might have to look at say some particular item that you buy, but that might need periodic servicing, but if you are just looking at the initial cost you are not looking at the time horizon long.

You are just looking at what the initial cost is before you make the decision. So, you are just looking at the cost of the product the next thing that you could do is you might look at something that people routinely calculated what is the payback period. So, if you are in payback period you are not looking at instantaneous decision making, but you are spending some money. You are getting benefits of by making the purchase over some particular time frame and you are looking at in, how much time can you actually beget the benefit of spending the initial sum of money. Ok?

So, again here you are relatively looking at a short time frame not very long. You are talking something of the order of maybe a year and here say, somehow whose working in a commercial environment may be you are company is making investment. You want to make sure whether your investment this year will get a return to you, this year itself or will it be seen at a hit this year. Then, return only next year in which case you might take a short term hit in your market value of your company.

So, people might say, one year if something is giving you return within a year. Then, it is definitely worth doing. Here, you are looking at cost of a product plus a cost of services another way in which you could look at evaluating a system is especially a distributed generation type of system is that. You are actually generating and you could look at the cost of energy, what would be the rupees per kilo watt hour of electrical energy. That is being output by such a system, and is people look at c o e cost of energy.

You are looking in this particular case at a very long time frame. So, when you are talking about the longer time frame, you could also look at it from design point of view or you might be talking about the decades and say if you are looking at you know, what your existing cost of energy is? If you are looking at introducing particular source into the system, whose cost is going to be twice the existing cost over the next one decade.

You know that your cost are going to actually ramp up over the decade, but if you know that you are existing system cost is also going to ramp up, but the system that you are adding is going to stay flat over a longer time frame. That means in the long term what you are adding right, now will actually make the cost of energy lower over the longer time frame.

So, you could make things like policy decisions which particular energy portfolio. You would like to invest in over the next decade, because many times in a field such as energy. You are looking at systems which have lifetimes of 20, 30, 40 years etcetera. If you look at a typical wind turbine you will design it for a life of at least 20 to 25 years, when you are talking about nuclear plant people will talk about licensing for 40 years after which you need to renew the license. If at all if you are looking at a dam you may talking about 50 to 100 years lifetime for a dam.

So, you are talking about systems which can actually stretch over and much longer time frame compared to some of the more common electronic items, like a cell phone which might be in fashion for a year or maybe 2 years. So, you are looking at something which can operate over much longer time frames.

So, a cost of energy is actually good from a policy maker’s point of view and you are looking at overall benefits to the society by looking at what would be appropriate portfolio for that particular variety of energies. So, is that you would like to have in our system and the objective is to do it in a very cost effect manner keeping in mind all your commitments like say, you would like your people to be healthy and not be suffering from pollution and some other.

What displacement there might be many requirements when you actually add in the particular energy source? Another possible way of looking at a matrix is evaluating the economic value behind a D G system, is a sometime people call it effective initial cost e i c or sometimes people in the commercial business side may look at it as a net present value.

This is actually can be of a intermediate time frame. It can be depending on what time frame you are looking at, whether it is one product which you might intend to operate for may be just for 5000 operating hours or the product which might be working for 5 years or 20 years. So, depending on your product you can set your particular time frame and decide on what is the net present value of that particular product.

So, it you, it can be a benefit to engineering designers or you can look at say you are managing a system at your looking at whether you are, what your net present value is to make a decision on whether to take a one particular choice or another particular choice? So, if you look at such as a scheme is actually helpful to make can be used to make technical choices, and it considers you can incorporate in it issues of product plus services. You could also have end of life considerations. So, you might in a system you might look at the construction cost the commission cost the operating cost whether, you have fuel use or some maintenance cost.

You might also incorporate the decommission cost say associated with the system. For example, if you have a wind turbine your decommission might not be a cost you might say steel in the tower might actually give you something. That can actually be sold or reused, but say if you have electronic items you might have to dispose it in a safe manner or you might have some cost associated with disposal of e-waste, etcetera.

So, you have to look at what is the appropriate cost or actually it can be a benefit depending on the particular system that you are looking at. So, we will look at a example some of these ways of evaluating well often, you might need a combination of all of this. For example, you might like to know; whether your particular product has what its outlook is on the very long term you might also like to make your design decisions.

When you are actually designing the product based on endometric and you may also want to check what you are payback period is, because you are customer to whom your product is sold might actually calculate the payback in based on some other matrix. So, you may want to look at all these things simultaneously when you’re actually looking at a particular D G technology.

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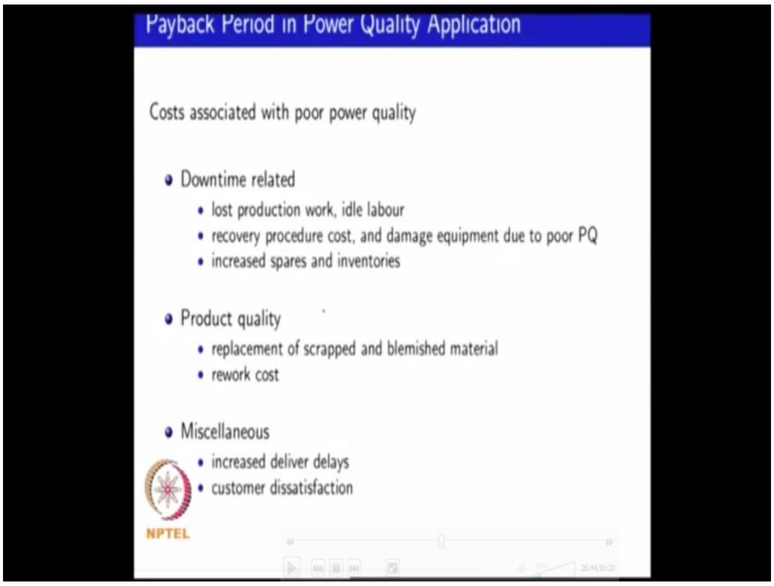

So, we will start with one way of looking at it we will look at payback period the initial just looking at the initial cost is trivial all of us can do it routinely, if you look at the payback period. We look specifically at an application such as our quality where you may want to make a decision on whether, to purchase some equipment to mitigate poor power quality.

So, you might be thinking about whether to purchase an u p s or a genset or some particular equipment and if you look at what is the worst situation of power quality. You might have a situation where there is no electricity available to you at all you might think of an outage. So, if you look at such a situation not having electricity in one way yet use that you are not paying for the electricity, but often what you miss in terms of your activity that you can actually accomplish during the duration is a has a much higher economic value than the cost of the unsaved energy.

So, the cost of poor power quality to a customer or to a end user is actually typically much greater than the cost of the unsaved energy which was which is not used because of the fact that the power quality is poor, also if you look at. We will look at this in a situation where you might be in a commercial or a industrial environment. You might say. For example, if you have an outage you might have a downtime in your production process, you might have loss to workpeople sitting around in a idle manner when because there is no power that is available.

Once, the power comes back you might have to go through a recovery process there might be damage to equipment because of power quality. For example, if you are operating something like a (( )). If you are hot steel bars just sits at a location when the power goes off you might actually damage timely damage the location where the bar came and sat when the power went away.

So, depending on your particular application you might end up with damaging equipment during when there is poor power quality also, because of the poor power quality potential damage etcetera. You might now have to stock more spares of equipment your inventories are larger. So, that is another cost that goes up you also have issues of your product quality going down because of poor power quality you might be a machining one particular piece and half into the machine the power went away.

The machining smoothness might actually become extremely poor at that point you may have to scrap it and or there might be blemish. The blemish might be within acceptable tolerance so, there’s always a issue of having material which is blemished or something which you have to totally scrap and if you have to scrap something to again start off the process from the very beginning.

So, there is a rework cost associated with poor power quality you could have other potential cost associated with poor quality because your power went away now your delivery of maybe your having a textile unit. You are expected to ship a batch of clothes on the end of the week. Now, because the power went away you have to ship it in the next week your delivery schedule is delayed the customer is unhappy and end up paying a wide variety of ways because of customer or because of poor power quality. The question is what could you do? You actually then decide when should I now do something to mitigate this problem of poor power quality and one way to do it is to look at what your payback period is and looking at simple payback.

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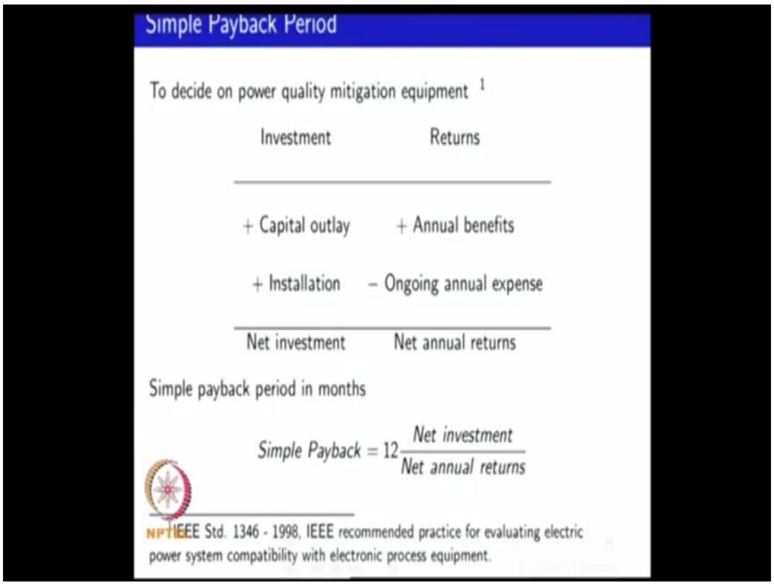

You would know, how much you are going to cost? How much it is going to cost for purchasing the poor power quality mitigation equipment? So, you might know, the cost of what the u p s is? You might know, the cost of a genset you also know, what you are installation cost is in a particular sight. So, you know the overall total investment that you are making for mitigating situation of poor power quality. Then, on the other side you are looking at what benefits that you get and you want to look at it on a annualized basis.

So, you we previously saw, but there are a number of cost associated with the power quality. So, you could actually calculate what is the cost of idle labor cost of recovery cost of increased inventories etcetera on a annualized basis. So, you can because you are adding the equipment. Now you have this benefit as a benefit by adding this particular equipment, but it is not just benefit you might have to do servicing of the power quality equipment. If it is a genset you might have to put fuel you might need to periodically lubricate it if, it is a u p s.

You might have to periodically may be you replace batteries you might have to fill in the electrolyte to the appropriate level. So, there is actually ongoing annual expense too. We are looking at what is a net annual expense and then you could very easily calculate what your payback period? Is it is the net investment divided by your annual returns? So multiply by 12 to get it in months. So, if you can actually look at this standard which gives you a step by step process of looking at evaluating power systems compatibility with electronic process equipment? Which is essentially looking at power quality and its impact on a industrial or commercial type of environment. So, we look at an example in this particular situation.

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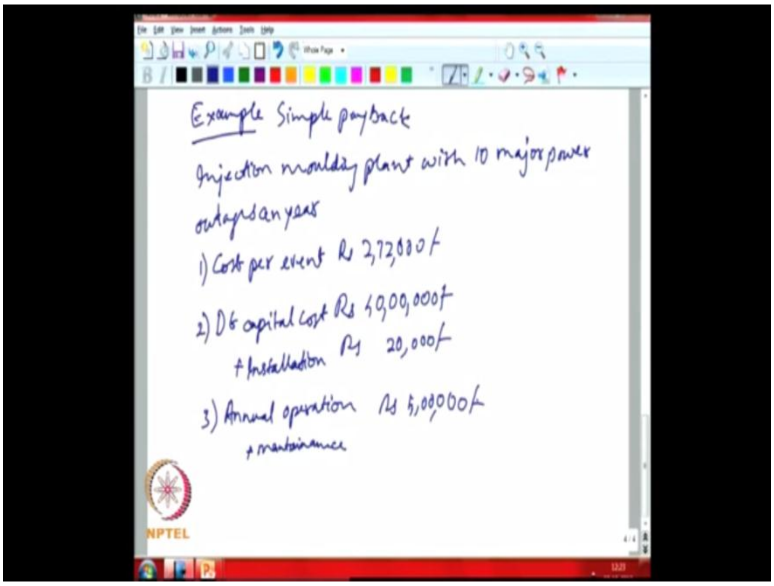

Suppose, you have a injection molding plant and you are facing say 10 power voltage a year and you go through the list of cost associated with poor power quality. You look at cost per event is rupees say 272000 per event. So, this could include the loss labor loss product production cost to repair effect of power quality other miscellaneous cost etcetera. You have a number such as this.

Then you look at the capital cost of the D G and say, that is costing 40 lakhs and you have the installation cost of rupees 20 lakhs. You are existing O and M operation and maintenance cost is rupees 4 lakhs. What would assume is by adding this particular say a genset you are avoiding all the major outages.

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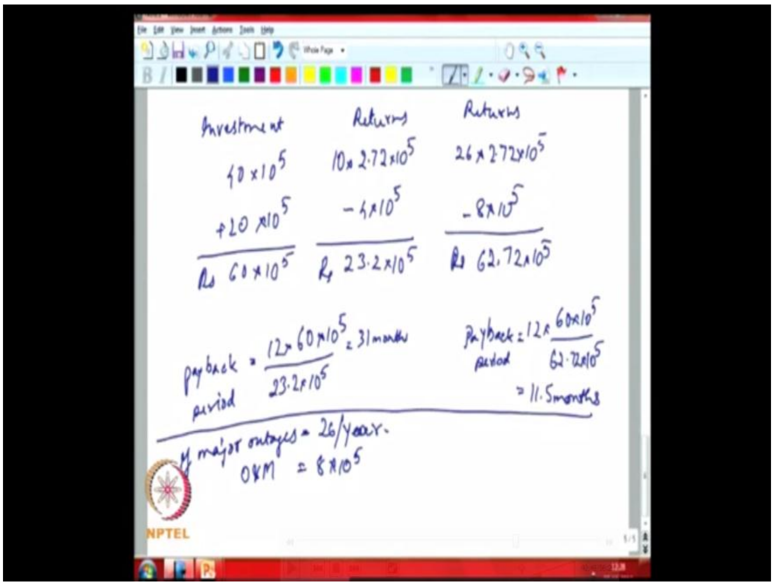

Then, if you look at, what you are investment is 40 lakhs plus 20 lakhs? Say, and then you are looking at returns, there are 10 events per year about 2.72 lakhs into 10 per event and your maintenance annual maintenance cost 4 lakhs. So, your net annual returns is, so if you look at, then you payback period. So, it is a plus longer than 2 years then you might say, may be it is not worth adding this particular unit because its taking a little bit a longer for me to get a payback.

So, then you might say instead of say 10 events per year means that you are having one major outage per or less than one major outage per month suppose you have another situation where you have say, one major outage every week, so you are having maybe 26 outages per year, so and so because there are more outages your O and M cost has gone up to instead of 4 lakhs its gone to 8 lakhs.

Then, if you look at what your new returns would be 26 into. So, in this case your payback period is, so in this case it is less than a year and you might say, now this is a attractive preposition. So, you can see that in this example, it is the same equipment that you are trying to sell. You are not selling different equipment, but it is that your customer requirement is what is changed.

So, if you have a product which meets your particular customer requirement. You could actually find it to be a more effective product whereas; if you are designing a equipment does not match the real power quality requirement, but is typical in your particular system. You might say, you find that it is not actually a effective solution. So, it is important to understand what your customer requirement is, when you are thinking of whether a D G system is going to be effective. So, we will this is a very simple exercise to carry out. Next, we will look at the cost of energy exercise.

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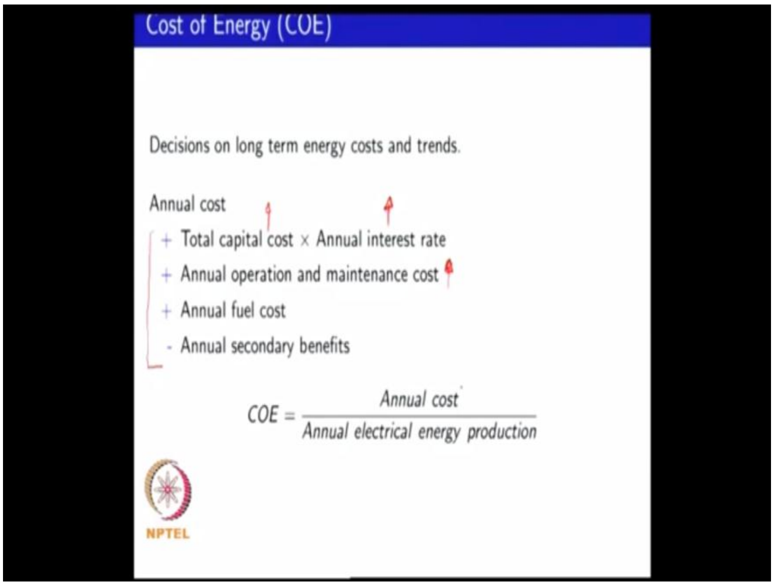

What are you are looking at longer term cost and trends in terms of how to actually evaluate with weather D G system may be cost effective or not. So, when you are looking at a cost of energy, you are not thinking about capital cost or something pay on a instantaneous basis one assumption that you are making is that the capital cost is actually taken as some sort of a loan. You are paying an effective equivalent yearly interest back to your lender. So, your capital cost is not seen as something that is affecting a system on an instantaneous basis, but spread over the longer term frame over which you are actually operating your equipment also.

You have the operation maintenance cost as we discussed in the previous example. Suppose, your D G system is making use of some fuel, then depending on the amount of fuel you put in this the energy that you could produce. So, you will have to look at potentially fuel cost in that also has secondary benefits.

For example, you might have a system where your, because you are actually producing electricity you might also have say, your particular unit doing co-generation which means that you might also have say hot water or cold cooling that is being provided. So, because of the hot water or cooling you might have actually be able to reduce some other cost and you might also include that to actually see whether, what your benefits are and you can calculate your cost of energy on a appropriate basis as you add all these together to form your annual cos.

Then, we look at what is the energy produced on annual basis by your D G unit. So, you divide the annual cost by the annual energy production that gives you your cost of energy. So, if you look at a cost of energy, if you have something which has a higher capital cost then your cost of energy turns to go up, if you have something which say, you have one equipment which will produce energy with sin degree of efficiency. Then, you have another equipment which produces with a higher degree of efficiency, then typically you will have to pay more for something which is more efficient. Ok?

So, you might end up paying more for a equipment which is a lower efficient, but you need to see the proportionally getting so much more energy, if you're not then you might be actually paying more per equipment than what its energy production justifies. So, we will have to look at it in multiple ways say, whether something is acceptable from your cost of energy prospective also, if your interest is higher your cost of energy is going to go up. So, for example, in a area like renewable are alternate energy where you might have lot of small companies manufacturing D G units or different D G dealing with different technologies.

The interest rate that a bank charges for a smaller company might be higher than interest rate that a lender would charge for a larger corporation or for a country for building a larger system. So, a smaller start outs might feel a tougher time to enter into the business, but once your successful things take off then your interest rate might come down.

You are actually you might actually accelerate up and be able to ramp up in terms of, what you could do? If you look at the fuel cost it depends on the particular a type of technology that you are dealing with. For example, you are looking at solar energy wind energy. The renewable the fuel cost is 0 in which case the actual main cost would be your capital cost whereas, if you are looking at something like a fuel based system, then like a diesel genset. We will see that we will look an example. We will see that fuel cost is actually a major cost, If you look at the lifetime over which you are doing this calculations. It is over the lifetime of this equipment.

So, you might be talking about 20 to 30 years and if you look at your operation and maintenance cost. There are 2 issues associated with operation and maintenance cost, if your equipment is less reliable, you would have higher operation and maintenance cost. Also, if your equipment is less reliable it means that you would have more time when it is sitting around idle and not producing energy. So, in the numerator the cost would go up and the denominator your energy production would come down. So, it is important to have a reliable equipment which would work over the time frame, so as to minimize your cost of energy. So, looking at from all this prospective is a important aspect of looking at a energy system.

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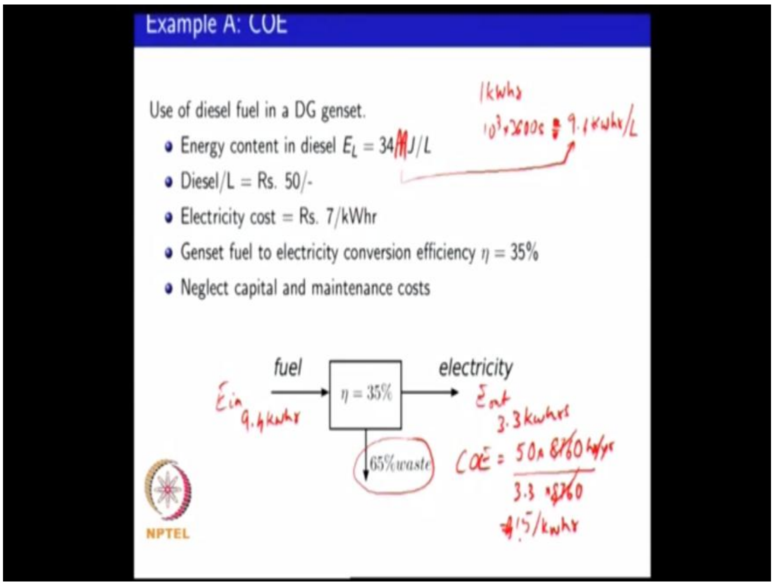

So, we look at an example, where your using saying you are considering a diesel genset and you want to see instead of purchasing power from your local distribution company. Would it make sense to run the genset all the time and make use of the energy that is output of from the genset? So, we will look at a simplified problem where, if you then look at what is the energy content in one liter of diesel fuel you have 34 mega joule snow. This is not mini joules, this mega joules of a energy per liter.

So, if you look at the cost, I mean cost might go up more often or it goes up rather than down. If you look at the cost of electricity, your cost of electricity might range from 4 rupees to 7 rupees depending on what your concession slab might be you might be a slow consumer in which case you might have a discount, if you're a large consumer. Here, we are considering individual consumption your commercial rates might be even higher and, so we will consider electricity cost from your grid to be 7 rupees per kilo watt hour. We, will assume that the energy conversion from the chemical form in diesel to electricity occurs with efficiency of 35 percent.

So, if you look at say, one liter of a fuel in you're talking about thirty 4 mega joules. So, if you look at it in terms of kilo watt hours 1 kilo watt hour is to the power 3 into 1 hour 3600 seconds. So, this would give you 9.4 kilo watt hours per liter of diesel fuel. So, if you look at say, 1 liter of diesel fuel, your 34 mega joules is equivalent to 9.4 kilo watt hours of energy input and if you look at for 1 kilo watt hour out with a efficiency of energy 33 percent for 1 liter of fuel. You have 35 percent into 9.4. So, you are talking about 3.3 kilo watt hours of output for 1 liter of fuel

So, if you're amount of let us say for amount of waste going out as heat and small amount as sound going out of your genset. If you can calculate your cost of energy assuming that say, it is running with 1 liter being feed in one per hour basis. Your cost of energy is 15 rupees per liter and there 8760 hours per year. So, the annual energy annual cost of fuel is15 rupees into 8760 is as 24 into 24 hours per day 365 days a year and if you look at your energy output. This is 3.3 kilo watt hours into 8760 hours per year. So, these 2 cancel out. So, you get cost of energy about rupees 15 per unit and 15 is much larger than 7. So, it just does not make sense to run your genset on a continuous basis. You are better off by taking the energy from your distribution supply. So, then we will look at second possibility where you might consider.

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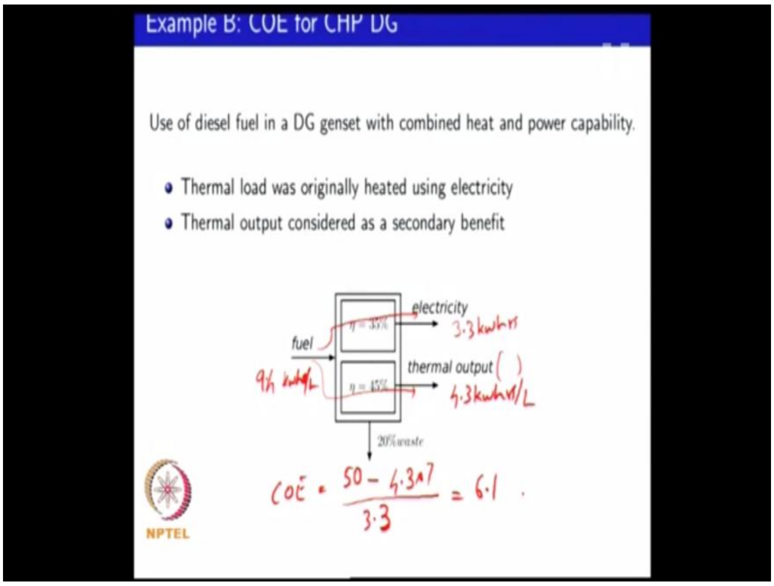

Your energy which is now being converted to electricity through one possible path and then you could also consider that out of the waste heat that is being produced in this particular i c engine. So, fuel to electricity you have an i c engine plus a synchronous machine plus a general governor and exciter cum all the controls. You might have a heat exchanger, which is exchanging a heat and generating thermal output and your thermal output goes through a second path.

You are able to make use of say 45 percent of thermal of your fuel inputas thermal output and you still have an overall waste 20 percent of your input energy. So, when we look at in this particular case, we will assume that because you are now making use of your thermal output. Previously may be you are making use of the thermal output to heat water may be in a electrical geyser, now because you are able to use the thermal output from a D G system. You are saving the energy which would have being spent otherwise in as your energy in a geyser.

So, we could think about that as a potential secondary benefit. So, if you look at, now your input energy you have your input energy is the same 9.6 9.4 kilo watt hours and if you look at your electricity output it is 3.3 kilo watt hours per liter and your thermal output is now 4.3 kilo watt hours. Then, if you look at your cost of energy, so you have your fuel cost which is 15 rupees per liter and the benefits that you are getting by making use of this as your to prevent your electricity consumption. At a alternative point you would have 4.3 kilo watt hours into 7 rupees per unit, which you are saving divided by your energy predication is 3.3 kilo watt hours.

So, you now get a number of 6 point rupees 6.1 kilo watt hours per unit. Now, you have a number which is less than 7, so potentially. Now, you have something which might be economically feasible compared to the previous situation. So, people do combined heat and power operation of systems to make use of the waste heat to actually provide auxiliary services of course, in this case we neglected the capital cost.

The maintenance cost and this cost will actually increase the number of from 6.1 in the next class. What we will do is we will look at? We will assume some cost for the D G system. We will assume some cost for the generator we will assume some interest rate and operation maintenance cost and we will look at how that would then change from the 6.1. See, whether it would state the air, the cost effective way of generating the generating power in the next class.

Thank you.