Power Electronics and Distributed Generation
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Lecture - 30
DG Evaluation Problems and Examples

Welcome to class 30 on topics in power electronics and distributed generation. Last class we were talking about we were discussing a couple of problems related to distribution systems issues. Today we will discuss a couple of problems related to DG design decisions based on economic implications.

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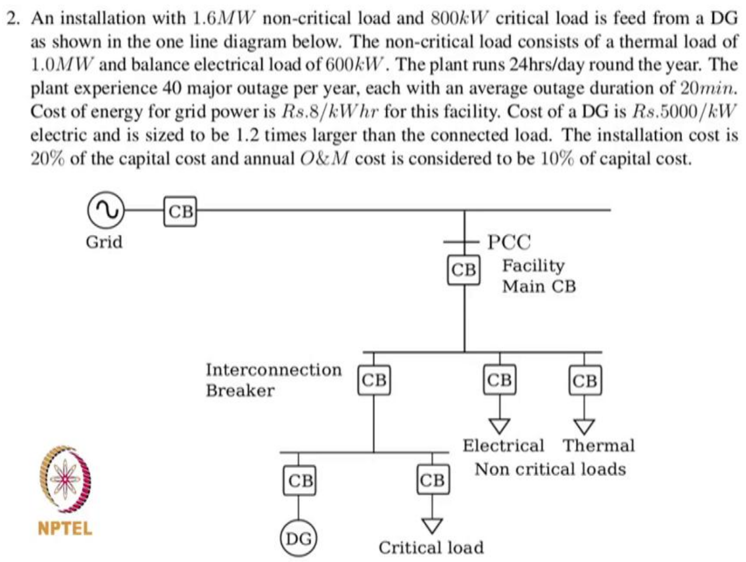

So in the first problem, we are looking at a 1.6 Mega Watt facility, consisting of 800 Kilo Watts of critical loads and a non critical loads, non critical loads are split into electrical and thermal. Electrical load, balances 600 Kilo Watts and there is 1 Mega Watt of thermal load, and a facility is connected to PCC through main circuit breaker this particular plant experiences forty major outages per year and each outage lasts about 20 minutes.

The plant is expected to run 365 days a year, 24 hours a day and the cost of electricity for this particular plant is 8 rupees per Kilo Watt hour, 8 rupees per unit and we are told the cost of the DG is 5000 rupees per Kilo Watt, a standard decent generator set and the size of this DG, if it is suppose to meet some particular critical load is sized to be about 1.2

times larger than the load. And we are also told that the installation cost is 20 percent of a capital cost. So, it might be commissioning an installation and this an annual maintenance cost for the DG and that is 10 percent of the cap capital cost.

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(a) With 40 major outages per year and the overall cost of outage has been calculated to be $Rs.100e3/outage$. The DG is sized to serve only the critical electrical load, it has been observed that the new cost of outage is $Rs.20e3/outage$ due to the unserved non-critical loads. What is the expected range simple payback of installing the DG in months ignoring fuel costs?

So, this is the overall system and in the first part, we are told that the overall cost of outage has been calculated for each of these 40 major outages to be rupees 100 into 10 to the power 3 per outage, 1lakh rupees per outage and the DG is sized only to serve the critical load and because of the outage of the non critical load. There is a residual cost of 20,000 rupees per outage, due to the un served non critical loads and you are asked to calculate a range of simple payback for installing the DG ignoring fuel cost.

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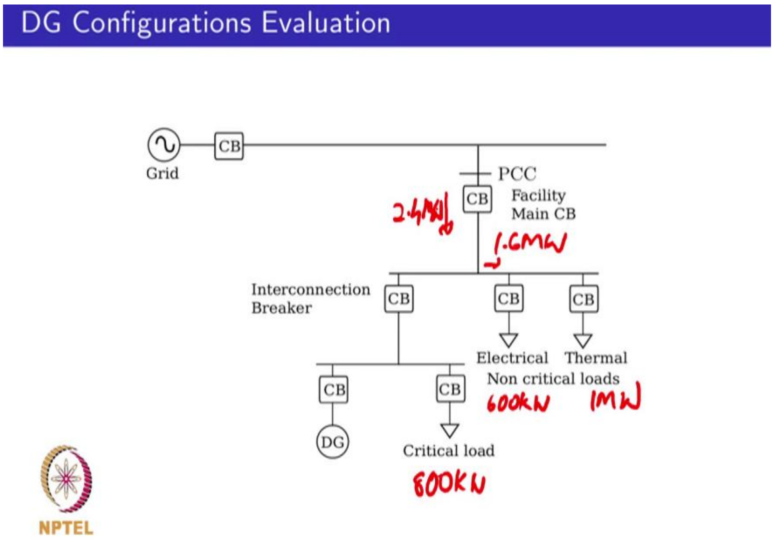

So, if you look at the sizing of the system, we have a the critical load to be a 800 Kilo Watts, the non critical load consisting of electrical and thermal the electrical part is 600 Kilo Watts and the thermal load is 1 Mega Watt and you can see that the thermal load is being feed electrically. So, whatever thermal load is present we are assuming it is being obtained by the consumption of electricity, so the total load let non-critical load is 1.6 Mega Watt and you add the critical load to it, so it is overall facility input is 2.4 Mega Watts.

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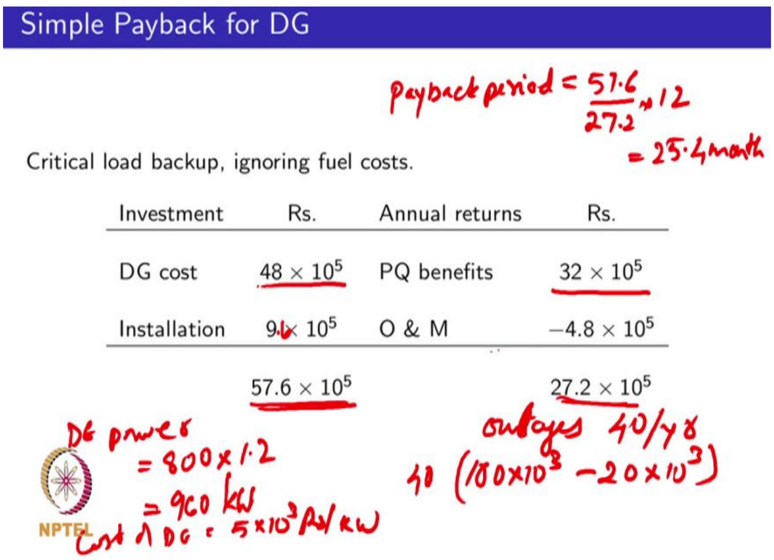

So, you can calculate what would be the cost of the investment, the investment cost would be 800 Kilo Watts for the DG power, so you have 800 Kilo Watts times 1.2 which is the factor being want as a margin. So, you have you need a DG of soils 960 Kilo Watts and the cost assuming 5000 rupees Kilo Watt, so this translates into 48 into 10 to the power of 5 rupees.

The installation and commissioning cost is 20 percent of that, so that comes up to 9.6 into 10 to the power of 5 and if you look at the cost of the outage, we have outages per year, 40 per year and the cost of the outage is at 1lakh per outage. And because of the un served non critical loads you have 20 percent rupees which you do not actually benefit by having the DG and 40 per year, so this turns out to be 32 into 10 to the power of 5.

If you look at the operation maintenance cost, this is 10 percent of the capital cost, because it is a cost rather than a benefit, it is put with a negative sign. So, if you look at the total outgo your cost of the DG plus commission and installation is 57.6 into 10 raise to power 5, your annual returns is 32 minus 4.8, so 27.2 into 10 to the power 5, so your payback period is into 12 months, so this turns out to be 25.4 months. So, this is a slightly larger than 2 years, so you pay for your generator which supports your critical loads and you expect it to break even in about will with more than 2 years, so here we have not looked at a the cost of a the fuel running this particular generator set.

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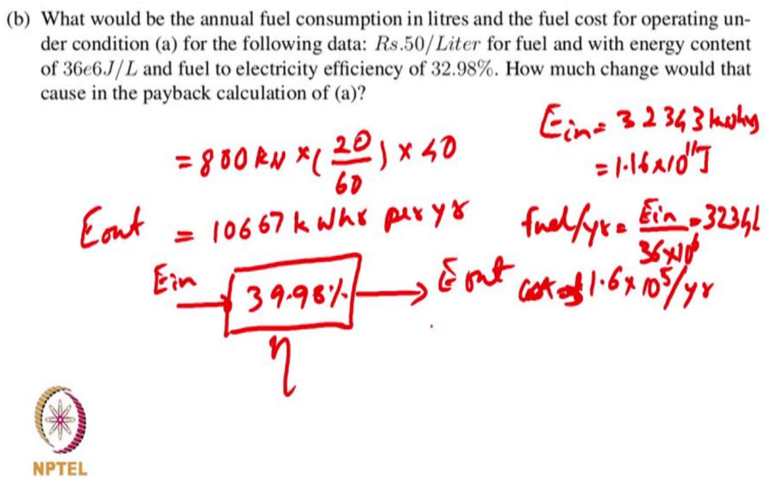

So, in the next question you are asked, you are given the data, that if a diesel costs 50 rupees per liter and the energy content of 1 liter of a diesel is 36 Newton's per 6, 36 mega joules per liter and the fuel to electricity conversion is 32.98 percent, what how would it affect your payback calculations. So, if you look at the conversion of a fuel into electricity, we know that our electrical load is 800 Kilo Watts and there are 20 minutes of outage, so converting it into hours 20 by 60 and there are 40 outages per year. So, the units of electricity required is 10667 Kilo Watt hours of energy required per year and your total efficiency of your consumption from your input to output is 32.9, your efficiency and this is your output energy requirement.

So, your input turns out to be 3 2 3 4 3 units and converting from Kilo Watt hour to joules, this turns out to be 1.16 into 10 to the power of 11 joules and you know that your fuel cost is 50 rupees per liter and where 36 mega joules per liter. So, your fuel consumption per year is your E n divided by 36 into 10 to the power of 6, so this turns out to be about 3200 liters and at 50 rupees per liter. This turns out to be about 1.6lakhs, so rupees 1.6lakhs, so the net annual benefits would reduce, because you have to pay for your fuel.

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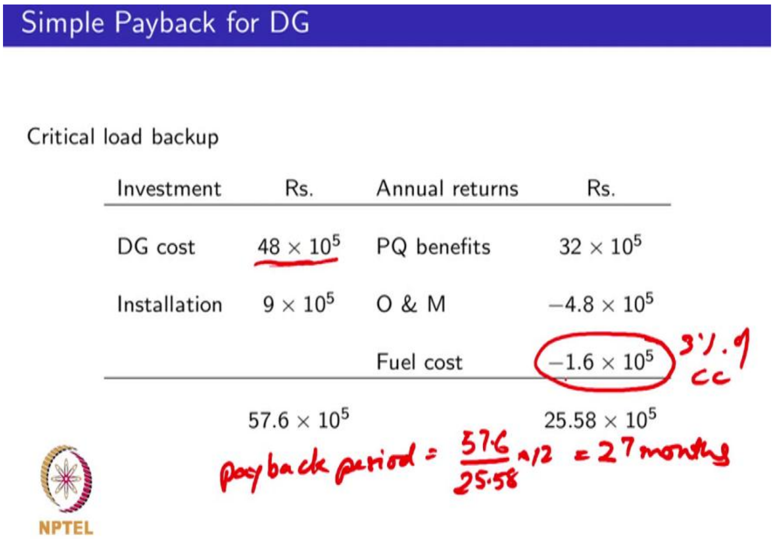

So, if you look at the new annual benefits, you now take an additional reduction, because of the fuel, so if you look at compared to the capital cost say 40 outages per year and 20 minutes per outage, that roughly works out to be about 12 hours per year, half a day a year. So, with half a day per year, you are talking about 3 percent of capital cost is your cost of the fuel, it does not change your numbers by a large amount, your new payback period is now, so this is 27 months.

So, you are talking about 2 month difference, when your between the calculations ignoring fuel while considering fuel, but you need to keep in mind this is for a very short duration of energy outage considered. So, if you consider outages of couple of days a year is of 3 percent, you may be talking about 5 percent or 10 percent, but still that is not too larger number to alter your payback period significantly, if you are using your gen set only for backup for small loads.

Whereas, if we look at the later questions which we are considering not just running it during the outage duration, but it is running for substantially longer period. So, in case your outage duration is half a day, you have you have a outage on a daily basis and its twelve hours a day then this number can raise quite significantly.

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(c) What would be the payback if a larger rated DG was used to cover both critical and non-critical load in the facility. Assume that DG ratings and initial costs and maintenance cost scale with load power requirements. What would be the new fuel consumption requirement?

NPTEL

So, in the next problem you are asked instead of just backing up your critical loads, if you make have a much larger DG which covers both your critical and non critical loads for the facility, assuming the DG ratings, initial costs, maintenance are scaled with the power requirement. What would be the new DG sizing and also what would be the fuel consumption corresponding to this larger size DG unit.

So, if you now look at larger sized DG, so with the larger size DG you can completely eliminate all penalty of not operating any part of a plant, so you can operate a full plant, so your P D G is now 1.2 times into 2400 Kilo Watts, so you are talking about 2.88 Mega Watts DG and if you look at now you have simple payback period.

Simple Payback for DG

Full load backup, ignoring fuel costs.

Investment	Rs.	Annual returns	Rs.
DG cost	48 → 144×10^5	PQ benefits	32 → 40×10^5
Installation	28.8×10^5	O & M	-14.4×10^5
	172.8×10^5		25.6×10^5

payback period = $\frac{172.8}{25.6} \times 12$ = 81 months.

NPTEL

Because of your larger DG, your capital cost is are much higher, so it has originally it was 48, so it is gone up to 144, you can see that the correspondingly your installation cost is also gone up, your power quality benefits which was originally 32 into 10 to the power 5, now goes up to 40 because, you do not get too much additional benefit of backing up non critical loads.

So, your net investment has gone up to 172 by 173 into 10 to the power 5 and your benefits is about 25.6 into 10 to the power 5, so your new payback period is 81 months, so instead of the 2 years we had its about close to 7 years, that you would have in this case. So, it does not make sense to actually oversize your generator to meet the non-critical loads, that is essentially by many times when you install a DG would be good for you to separate out your wiring into what is important and what is not critical.

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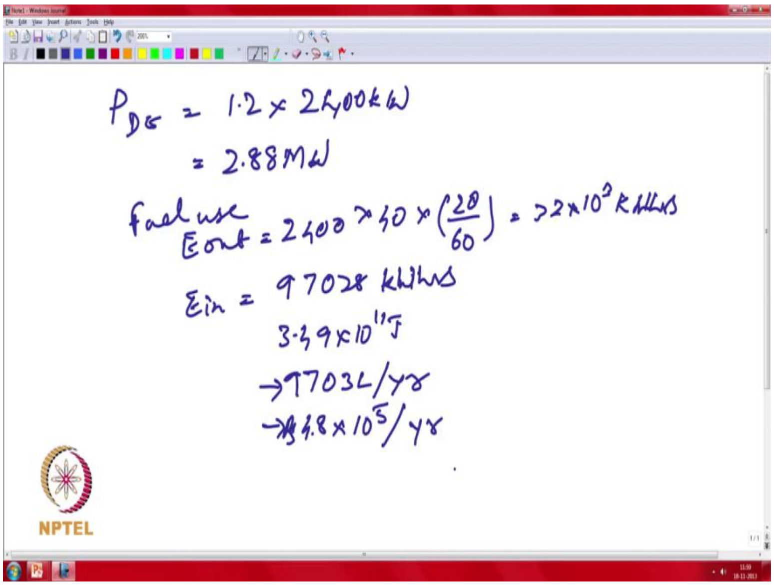

So, the next part is to look at the fuel consumption, so the fuel consumption we will use, so your energy out is in 40 outages, 20 minutes duration, so this is 32 into 10 to the power 3 Kilo Watt hours. So, your energy in using the same efficiency number is 97028 Kilo Watt hours and this corresponds to 3.49 into 10 to the power 11 joules and again using the joules per liter. So, this corresponds to a consumption of about 9700 liters per year and this would correspond to 4.8 into 10 to the power 5 rupees per year at 50 rupees per liter.

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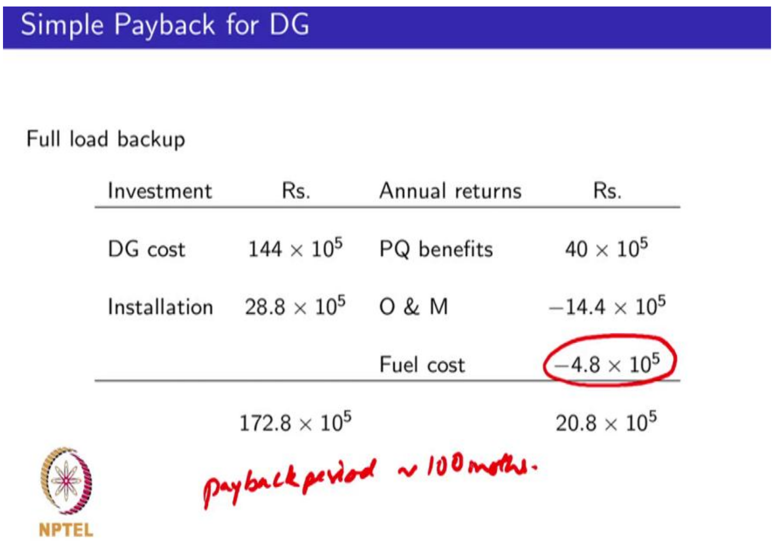

So, if you look at your net returns, now reduced by this 4.8 to the 10 to the power 5, so your total returns is reduced to a smaller number and the payback period is now about 100 months or about 8 years. So, you can see that if you now start considering fuel cost with a much larger facility, your fuel consumption is going to go up, so that also adds on to your penalty on your system which reduces now from 7 years to almost 8 years, it has increased your payback period. So, it may not make sense in a payback point of view to implement such a scheme.

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(d) If the genset corresponding to case (a), where the DG is sized appropriately to feed the critical load, is run round the clock at full power using diesel fuel that cost $Rs.50/Litre$ and with energy content of $36e6J/L$ and fuel to electricity efficiency of 32.98%, what would be the annual diesel consumption in Litres? What would be the cost of energy from the plant assuming a fixed charge rate of 10% per year on capital costs?

NPTEL

So, in the next problem we are looking at the cost of energy, so we are going back to this DG that is sized only to meet the critical load, rather than the entire plant; however, instead of just running it, during the outage we are looking at running at full power. We know the cost of the fuel and energy content, what would be the annual diesel consumption and what would be the cost of energy from the plant, assuming a fixed charged rate of 10 percent per year on capital cost. So, essentially the assumption is that your capital is being purchased based on some gold maybe from a bank and you are paying back 10 percent of that particular loan, as payment to the bank on annual basis.

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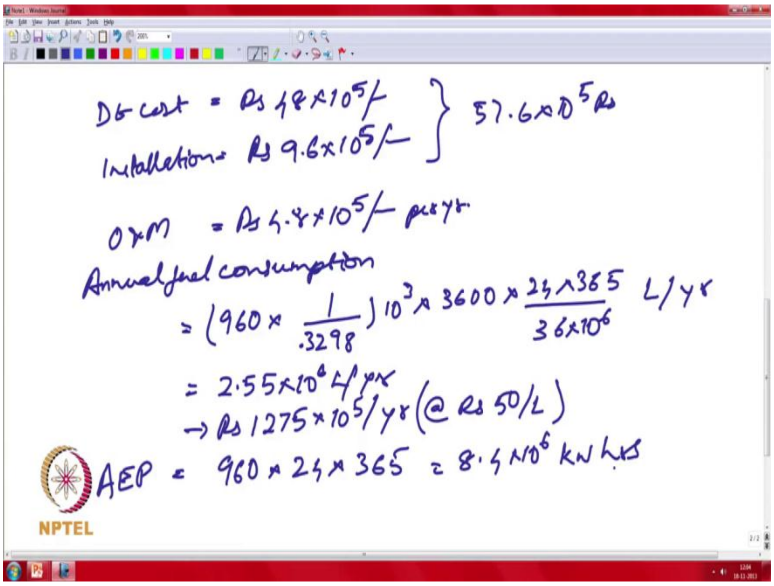

So, if you look at the calculations in this case, your DG cost is rupees 48 into 10 power of 5 from the previous calculation, the installation commissioning as is 20 percent, so 9.6 into 10 power 5. So, total sum of this is 57.6 into 10 power of 5 rupees per year rupees and your operational maintenance cost is rupees 10 percent of your DG, your equipment cost, so this is 4.8 into 10 power 5 per year.

And if you look at your annual fuel consumption, so again assuming you operate it like a plant 365 days a year, you have the rating of the gen set as 960, the efficiency of input to output is 32.98 and Kilo Watts, so 10 to the power 3, 3600 minutes per hour into 24 hours 365 days and the energy content per liter is 36 into 10 to the power 6. So, this gives you the liters of fuel consumption per year.

So, this is 2.55 into 10 to the power 6 liters per year, so at 50 rupees per liter, this would correspond to rupees 1275 into 10 to the power 5 per year. If you look at the energy being produced from this particular generator, your annual energy production is 960 Kilo Watts into 24 into 365, so this is 8.4 into 10 to the power 6 Kilo Watt hours.

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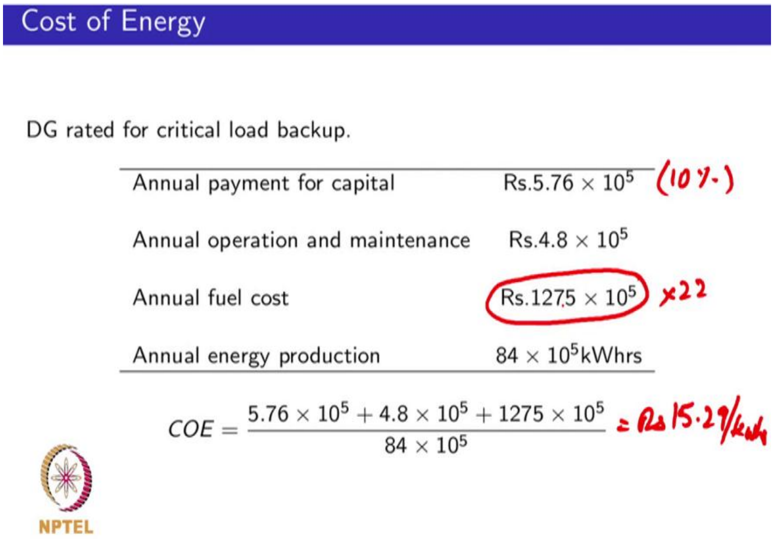

So, now with this data you can actually calculate your cost, so your cost of the capital was 57.6 point 6 into 10 powers 5, so this is 10 percent is your fixed charged rate, so you get 5.76 your operational maintenance cost is 4.8 into 10 to the power 5 and your fuel cost is and 1275 into 10 to the power 6. So, if you look at the cost of capital that was 57.6, so this is about 20 more than 20 times, the capital cost, so you can see that if you are running plant on a continuous basis you are dominated by the cost of the fuel.

The cost of your initial equipment is actually much smaller, your energy production was calculated into 84 into 10 to the power 5, so the cost of energy, this works out to be rupees 15.29 per Kilo Watt hour and we saw that the cost of energy from the grid was 8 rupees per Kilo Watt hour. So, what you generate from the gen set is much more expensive, it would not make sense to run the gen set all the time.

So, you can see that the fuel cost in the case when you are running it, just for a day a year is probably in the range of 10 percent, but here this is actually 22 times, your capital cost. So, depending on and number of days per year usage on your gen set, you can end up with a substantial cost as fuel.

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CHP

(e) It has been decided to upgrade the DG in case (a) and run it in combined heat and power mode where the waste heat from the genset is used to provide for the thermal load for the plant by using an additional heat recovery unit along with the genset. The added heat recovery unit has an fuel to thermal output efficiency of 45%. The cost of the thermal system including all the heat exchangers is $Rs.3500/kW$ thermal load. Also, the installation cost of the thermal loop is considered to be 20% of capital cost and its annual operation and maintenance cost of the thermal loop is 10%. What is the new cost of energy of the combined heat and power DG under the following conditions?

i. DG running at its rated power level. (960 kW)

ii. DG running at 800kW.

iii. DG running to match the thermal load requirement of the facility.

Which is the operating mode that leads to lowest COE?

NPTEL

So, in this case you can say to decide on to whether upgrade this particular generator from just generating electricity to combine heat and power, so a CHP unit, so that the waste heat from the generator is used to provide for the thermal load. So, you need to add from heat recovery equipment to this particular generator and we calculate that the efficiency from your fuel input to a thermal output is about 45 percent which is fairly good.

The cost of thermal system including heat exchanger is again 3500 rupees per Kilo Watt, thermal load requirement and the installation cost is again 20 percent of the capital cost and we will assume that the operational maintenance is also same 30 percent of the capital cost, what is in cost of energy for the CHP DG under 3 conditions.

One, when it is running under its rated power level which is 960 Kilo Watts, the second when it is running at lower power at 800 Kilo Watts, the third when it is running in such a manner that the output thermal power is matched and whatever is being generated electrically is just being put out to the grid and we want to see which of these cases leads to lowest cost of energy.

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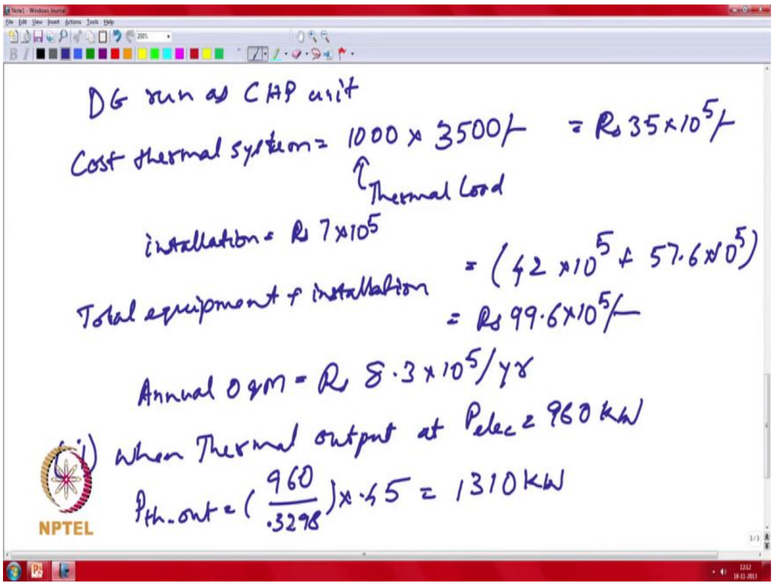

So, in the first case, we will first look at the cost of the CHP DG, the cost of the thermal system, there is a 1000 Kilo Watt of thermal load and is 3500 rupees per Kilo Watt thermal, so this turns out to be 35 into 10 powers 5. So, your total cost considering installation is 20 percent of that. So, that turns out to be 7 into 10 to the power 5 and your equipment cost is 42 from your electrical system or 42 from your thermal system plus 57.6 from your electrical system that you had previously calculated.

So, this is the rupees 99 and your operational maintenance cost is 10 percent of your capital cost without installation. So, this turns out to be is 8.3 into 10 to the power 5 rupees per year and the cost of energy from the grid is 8 rupees per Kilo Watt hour and efficiency are thermal is from fuel to thermal is 45 percent, so when your thermal output is at P electric in 960 Kilo Watts.

So, your input power coming in is 960 by your electrical efficiency which is 32 0.98, this is the input power times 0.45 is your thermal power thermal output. So, this turns out to be 1310 Kilo Watts, so out of which your loading facility will consume 1000 Kilo Watts and the remaining 310 goes as waste. So, because now your facility is being feed from your DG gen set, rather than previously it was being consumed from your point of common coupling electrically you now have thermal savings.

So, you can calculate your thermal savings per year is 1000 Kilo Watts into 24 hours per day 365 days a year and 8 rupees Kilo Watt hour. So, this turns out to be 700 into 10 to power 5 rupees per year.

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COE_1: DG as CHP

(i) DG rated for critical load backup, operating at rated power.

Annual payment for capital	Rs.9.96×10^5 (× 10%)
Annual operation and maintenance	Rs.8.3×10^5
Annual fuel cost	Rs.1275×10^5
Annual heating benefit	Rs.700×10^5
Annual energy production	84×10^5kWhrs

$$COE = \frac{9.96 \times 10^5 + 8.3 \times 10^5 + (1275 \times 10^5 - 700 \times 10^5)}{84 \times 10^5} = 7.06 \text{ Rs/kWhr}$$

NPTEL

So, if you look at now your calculations, your annual payment of for capital, you saw the capital was 99.6, so this is 10 percent of that which is your annual payment your operational maintenance is 8.3 into 10 to the power 5, your fuel cost which we calculated in the last problem was 1275 into 10 to the power 5, but now you have benefits. Because, you are not considering electricity for your thermal loads your annual energy production is 84 into 10 to the power 5 units, so your cost of energy can now be expressed by this is which turns out to be equal to 7.06 rupees per Kilo Watt hour.

So, you can see that now you have a number which is less than 8, so it starts making sense to see whether you can actually run it, because as the cost is less than what your service provider is providing you, which is 8 rupees per Kilo Watt hour. So, we will look at the next case, where the DG is run instead of at 960 Kilo Watts is at a lower power rating.

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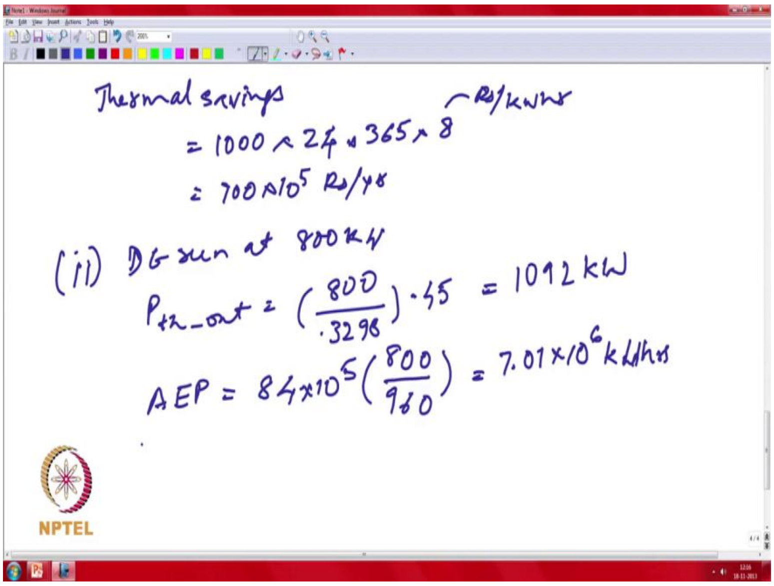

If the DG is run at 800 Kilo Watts, your thermal output is 800 divided by point 32.98 which is you efficiency, electrical efficiency .45 is the efficiency from input to thermal output, so this is 1092 again your thermal load is 1 Mega Watt. So, your 92 Kilo Watts go out as a loss, your annual energy production, you can just scale it from your previous number.

The previous number was 84 into 10 powers of 5, that was when it was running at 960 Kilo Watts, now it is being run at 800 Kilo Watts, so this is 7.01 into 10 to the power of 6 Kilo Watt hours. Because, this is now equal to 1092, your thermal savings is still the same number is what you calculated previously, so your cost of energy in the second case.

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COE_2: DG as CHP

(ii) DG rated for critical load backup, operating at 800kW power.

Annual payment for capital	Rs.9.96×10^5
Annual operation and maintenance	Rs.8.3×10^5
Annual fuel cost	Rs.1062×10^5
Annual heating benefit	Rs.700×10^5
Annual energy production	70.1×10^5kWhrs

$$COE = \frac{9.96 \times 10^5 + 8.3 \times 10^5 + (1062 \times 10^5 - 700 \times 10^5)}{70.1 \times 10^5}$$

= Rs 5.42/kWhr

NPTEL

So, the new case when it is running at 800 Kilo Watts, your annual payment remains the same, your maintenance stays the same which is what we are assuming, but now your fuel cost has come down. Because, as it is running at lower power, your heating benefit stays the same, because you anyway you are generating excess heat which is your facility requirement, you are annual production has come down from 84 to 70 into 10 power 5 units.

So, if you look at the cost of energy in this particular case, this turns out to be a rupees 5.42 per Kilo Watt hour. So, you can see that the cost are coming down and then you are asked in part 3, what would be the cost, if you are operating such that your thermal load is just being meet.

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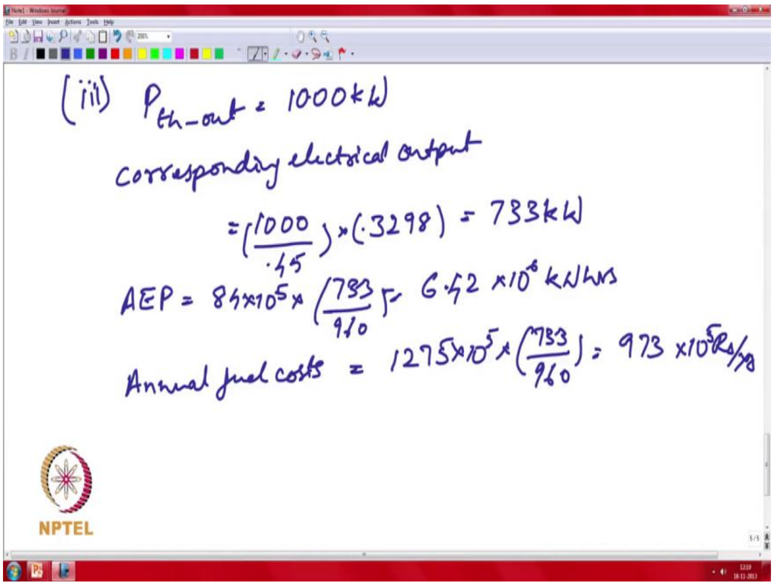

So, the thermal load is 100 Kilo Watts, then you can calculate what would be your corresponding electrical output, so this is 1000 Kilo Watt thermal your thermal efficiency is .45, your electrical efficiency is 32.98 present, this turns out to be 733 Kilo Watts and again you can scale your annual energy production. So, with this you can also look at your fuel cost and your fuel cost which can also be scaled was 1275 into 10 to the power 5 into 733 divided by 960, so with this information you can again go back and calculate your cost of energy.

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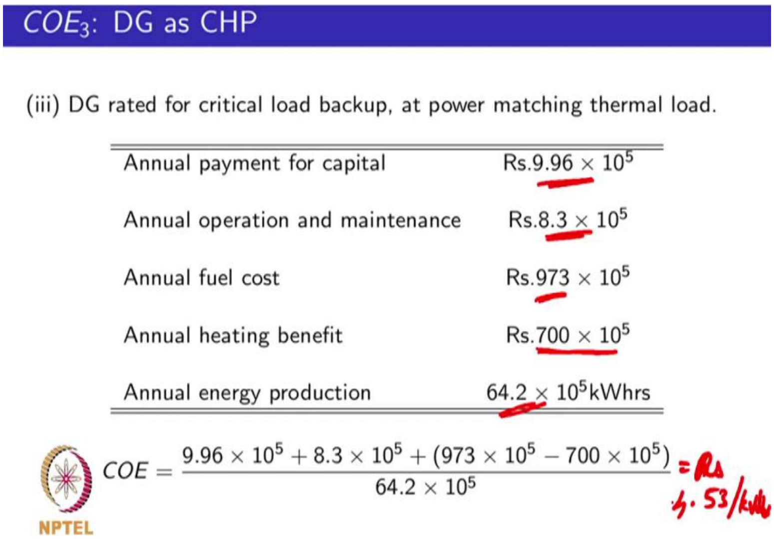

So, your capital cost is the same operational maintenance is the same, your fuel cost has come down further, your heating benefit is just sufficient to match your load requirement which straight says stays at 700 into 10 to power of 5 and your energy production has gone down. So, if you do the overall calculations, this turns out to be equal to rupees 4.53 per Kilo Watt hour.

So, you can see that the cost of electricity has come down substantially from the 8th number; however, that depends critically on the fuel cost which is a big number over here. So, the fuel cost fluctuates a lot then the cost of the energy would also tend to jump quite a bit, so you if you now take a power level further down you will see that your energy production goes down, your thermal benefits would also go down and your cost of the fuel would just go down proportionately. So, again if you go below this particular point you will see that your cost of energy starts going backup, so your typical combined heat and power systems are run. So, that your thermal loads are matched and whatever you generate as electricity is actually a bi product of the process.

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(f) Two options are available to connect a DG to the electrical load or grid. One is using a fixed speed synchronous machine generator and the second is through a variable speed permanent magnet generator and a power electronic inverter. Comparison of fixed speed DG and variable speed generators for the co-generation system based on the considerations above are shown in the figure, with effective electrical efficiency of the variable speed option of 35.15%. The capital cost of the variable speed genset is $Rs.10,000/kW$.
Using the assumption that the DG is running to match the thermal load requirement of the facility and using similar assumptions for installation and annual operation and maintenance cost as question (a) above, obtain the cost of energy comparison of the two options.

NPTEL

So, in the next problem you are told that there are couples of options for now collecting this particular gen set to the electrical grid or to the electrical loads, when the grid is not available. One is using the a fix speed synchronized machine and that is typically the way most DC generator sets operate have a internal combustion engine followed by a synchronized machine which whose output is connected to loads.

So, because your output frequency is 50 hertz, your electrical requirement is 50 hertz, the RPM of your IC engine is determined essentially by your frequency requirement of your electrical load, so the speed in that particular case is fixed. The second option is to actually connect make the IC engine operate at variable speed and whatever electric output is generated by your speed is the IC engine that is running you run it to a variable speed generator.

The variable speed generator might consist of maybe a permanent magnet generator followed by inverter which means that the inverter can produce 50 hertz irrespective of the frequency of your IC engine. So, essentially you are looking at variable speed generator, versus a fixed speed generator and the effective electric efficiency of the VSG option is 35.15 percent which is higher than the 32.9 percent, that we consider for the fixed speed generator.

The capital cost of the variable speed gen set is 10,000 rupees per Kilo Watt, so higher much higher than the a fixed speed generator, using the assumptions that the DG is running to match the thermal load which is the best operating point. We would like to do a comparison between the cost of energy, when you are running with a variable speed generator and with a fixed speed generator.

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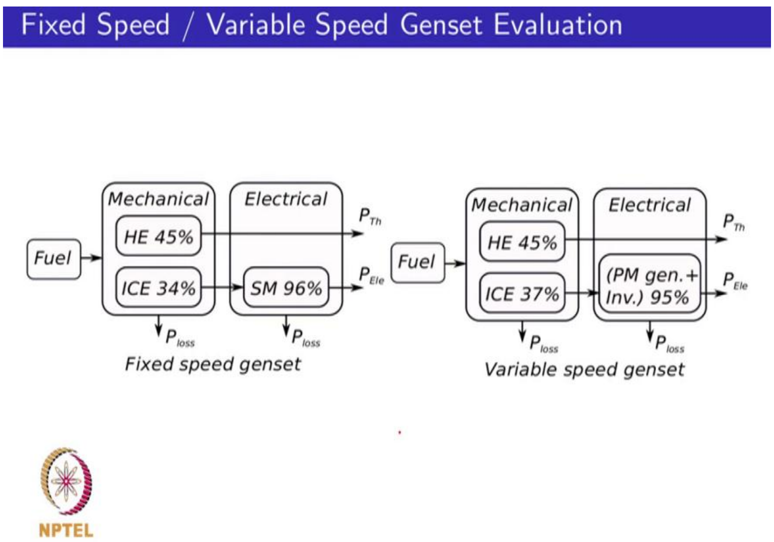

So, if you look at the configuration of the fixed speed, versus variable speed, you can see that from the mechanical, from fuel to thermal point of view, your efficiencies are same, your synchronized machine by itself can have a higher efficiency. In this particular case, you have a P n generator plus a high efficiency inverter; however, its overall efficiency might actually be lower than just a simple single stage synchronized machine, but because you are able to operate at a variable speed, you can operate at the maximum efficiency point of your IC engine.

So, your efficiency of the IC engine goes from 34 percent to 33 percent your efficiency of your electrical interface comes down, but you get a bigger boost coming from your IC engine now operating at its optimum point. So, if you look at the structure of this particular system use of variable speed.

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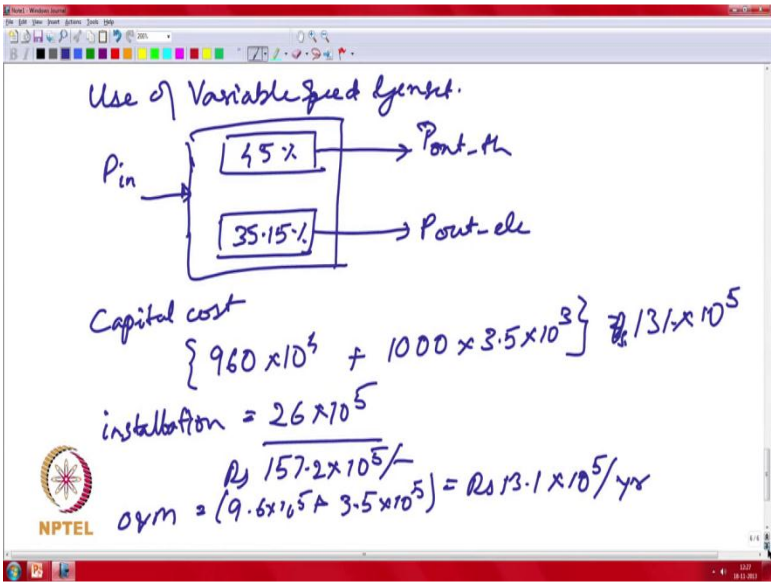

So, you get a higher efficiency from your P n to your thermal is 45 percent to your electrical output is 35.15, so you can calculate the cost of capital for this DG system with a combined heat and power unit. So, capital cost 960 Kilo Watt electrical into 10 to the power 4, 10,000 rupees per Kilo Watt hour plus your thermal load is 1000 Kilo Watts into 3500 rupees into10 per Kilo Watt cost of the heat exchangers.

So, this would be the cost of the capital equipment 131 into 10 to the power 5, 20 percent for installation plus commissioning might be 20 percent that works out to 26 into 10 to the power 5. So, your overall total capital plus installation is rupees 157.2 into 10 powers 5, your operational maintenance cost on a annual basis is a 10 percent of the equipment cost, so that is 9.6 into 10 to the power 5 plus 13.1 into 10 to the power 5.

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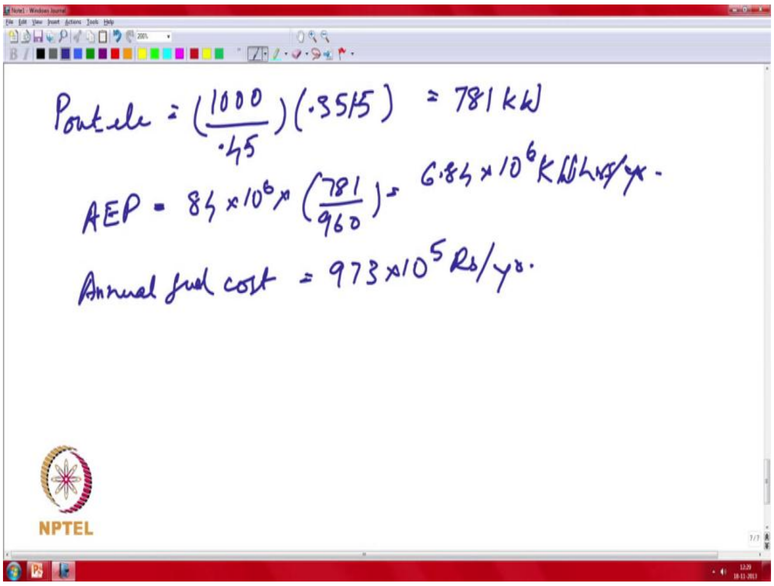

So, because you are operating your DG in the thermal tracking mode, your output electrical power is the thermal requirement is 1000 Kilo Watts, your thermal efficiency is 45, but now your electrical efficiency has gone up 35.15. So, the thermal output or electrical output is now 781 Kilo Watts, so it has gone up from 733 to 781.

Your annual energy production is again you could scale it Kilo Watt 6.84 into 10 to the power 6 Kilo Watt hours per year and your annual fuel cost stays at 973 into 10 to the power of 5 rupees per year. Because, your thermal requirement stays the same, so you could then calculate your cost of energy.

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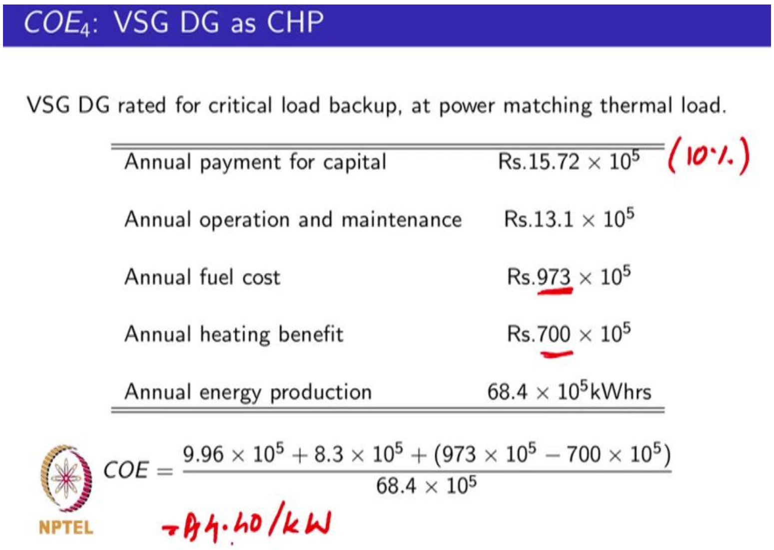

So, your 10 percent of your capital 15.72 into 10 to the power 5, your operational maintenance cost 13.1 into 1 to the power 5, your annual fuel cost stays the same, because you are thermal load has to be satisfied your heating benefits is 700 into 10 power 5, your annual energy production has gone up but because your elect electrical output is gone up from 733 to 784. So, if you look at now your overall cost of energy, you get an expression 9.96, so essentially the sum of these two amounts, so this calculates out to be equal to rupees 4.4 per Kilo Watt hour.

So, you can see that this further reduction in cost of energy if you by going into the variable speed the option; however, your capital cost has gone up. So, if you are willing to have access to the higher capital. Then, potentially your cost of energy can be brought down further by looking at variable speed option compared to a fixed speed option, when you are considering a system which is running in continuously for a long duration of time.

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(g) A electrical system designer has to compare the Effective Initial Cost (EIC) for the electrical subsystem for the fixed speed and variable speed option for a co-generation application. The electrical subsystem is from the shaft for the IC engine to the AC electrical output. Use the following underlying data to evaluate the appropriate EIC:

- For the fixed speed DG the capital cost of $Rs.5000/kW$ electric can be considered to be of 2 parts: $Rs.2500/kW$ for the IC engine and $Rs.2500/kW$ for the synchronous machine. The efficiency of 32.98% can be considered to be of 2 parts: 34% for the IC engine and 97% efficiency for the synchronous machine.
- For the variable speed DG the capital cost of $Rs.10,000/kW$ electric can be considered to be of 2 parts: $Rs.2500/kW$ for the IC engine and $Rs.7500/kW$ for the PM machine and inverter. The efficiency of 35.15% can be considered to be of 2 parts: 37% for the IC engine due to its ability to operate at its optimum efficiency speed operating point and 95% efficiency for the PM machine and inverter.
- Due to the ability to operate at variable speed, the ratings of the IC engine can be reduced by 20%.
- Output power: $P_{ele} = 100kW$, operating $24hrs/day$, $365days/year$,
- Effective interest rate = 10%, and 5 years product life.
- Cost of electrical energy = $Rs.8/kWhr$.

Installation cost is ignored for EIC calculations. O & M costs of both configurations (a) and (b) are assumed to be similar. Calculate EIC including electrical efficiency, fuel considerations and sizing of IC engine rating differences.

So, in the next problem you are asked to look at net present value or the effective initial cost calculations not for the entire system, but only for the electrical part of the systems. Essentially, whatever is contained in this particular block we are looking at the net present value, again from a design prospective someone who might be coming in might be looking at different subsistence. So, if someone is interested in looking at what sort of inverter or what sort of generator, what is acceptable you want to look at a particular subsystem and make a decision.

So, for the effective initial cost calculation you are given this is the system which comes from the shaft of your IC engine to the AC electrical output and the data that is given to you is that the DG capital cost is 5000 rupees per Kilo Watt, consists of two parts 2500 rupees per Kilo Watt for the IC engine and 2500 per Kilo Watt for your synchronized machine. The efficiency of 32.98 can be considered a to be 34 percent of the IC engine and 97 percent for your synchronized machine and for the variable speed gen set, the capital cost is 10 percent rupees per Kilo Watt.

Again, consisting of 2500 rupees per Kilo Watt for the IC engine and 7500 for per Kilo Watt for your P m machine and again the efficiency of 35.1 percent can be considered to be 37 percent from the IC machine, because it is operating at a more efficient operating point and your inverter is now at a lower efficiency 95 percent. And a few factors that are being considered, that you can get a benefit for the IC engine, because it is able to operate at variable speed of one engines have once they go up to its best operating point, have a flat torque versus speed characteristics.

So, you could operate at a slightly higher speed and get a benefit say of 20 percent and the output power is required is 100 Kilo Watts, so the system that you are designing is 100 Kilo Watts that you are operating on a continuous basis 365 days a year. You are looking at a effective interest rate of 5 percent a product life of a 5 years and cost of energy to be 8 rupees per Kilo Watt hour.

So, we want to installation cost is ignored for the effective initial cost calculation, O and M cost of both the configurations are assumed to be similar and calculate the effective initial cost of the net present cost are including electrical efficiency, fuel considerations and sizing of the engine. So, for doing this calculation we will, we can actually look at each particular part of it.

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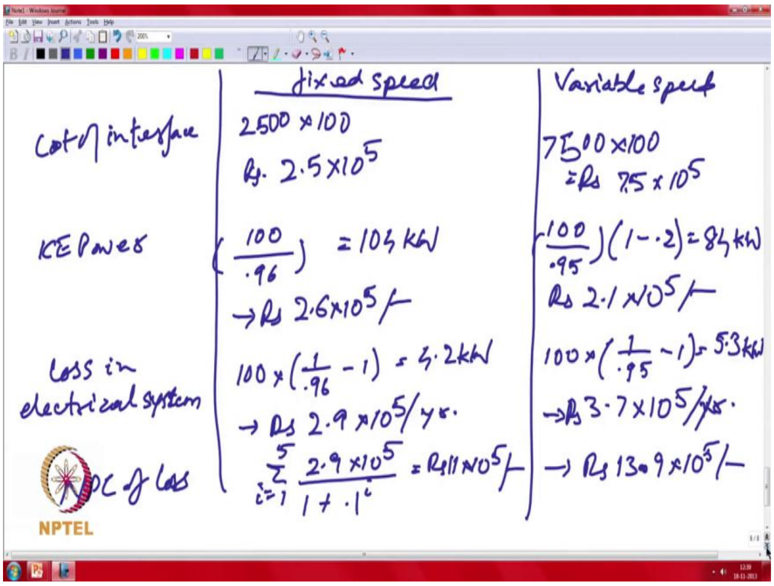

So, if you look at cost of interface, so it is 2400 rupees per Kilo Watt for the IC engine into 100 Kilo Watts, so this is 2.5 into 10 to power 5 for your fixed speed, for the variable speed, it is a 7500. So, there is a increase in cost on a the VSG side of about 5 into 10 to the power 5 for your electrical interface IC engine power requirement, efficiency of your machine is here I have considered 96 percent.

So, this is 104 Kilo Watts, if you are considering your IC engine, your variable speed option your interface efficiency reduces to 95 and you have a 20 percent benefit, because of your variable speed nature. So, you could maybe get by 84 Kilo Watt engine IC engine, so if you look at cost of IC engine that corresponds to rupees 2.6 into 10 to the power of 5 here, it corresponds to 2.1. So, there is about 50,000 rupees difference not much if you consider a fuel cost, also the cost as we saw running a gen set on a continuous basis.

The capital equipment cost is actually a smaller fraction of your fuel cost, if you look at your loss in your electrical system, you have in one case it is 96 percent efficient, so you have 4.2 Kilo Watts of losses in your synchronized machine and about 5.3 Kilo Watts of losses in the pure machine plus inverter. So, to calculate the annual cost of losses you take this multiply by 24 into 365 and you know it is 8 rupees per Kilo Watt hour, cost of energy.

So, the cost of the energy, cost of the losses is corresponds to rupees 2.9 into 10 to the power 5 per year is the cost of losses in your fixed speed generator in your variable speed generator. This turns out to be a 3.7 into 10 to the power of 5, and we to calculate your net present cost in P c or of loss what you do you accumulate the losses over the 5 years, so your first year comes in then for the next year is based on your charged rate.

So, you have summation i is equal to 1 to 5, 2.9 into 10 to power 5 divided by 1 plus .1 is your interest rate to power 5, so this turns out to be rupees 11 into to the power of 5, the corresponding number over here is rupees is 13.9 into 10 to the power 5. So, you can see that, the losses in your variable speed gen set case is actually higher and the equivalent cost net present value is higher in that particular case.

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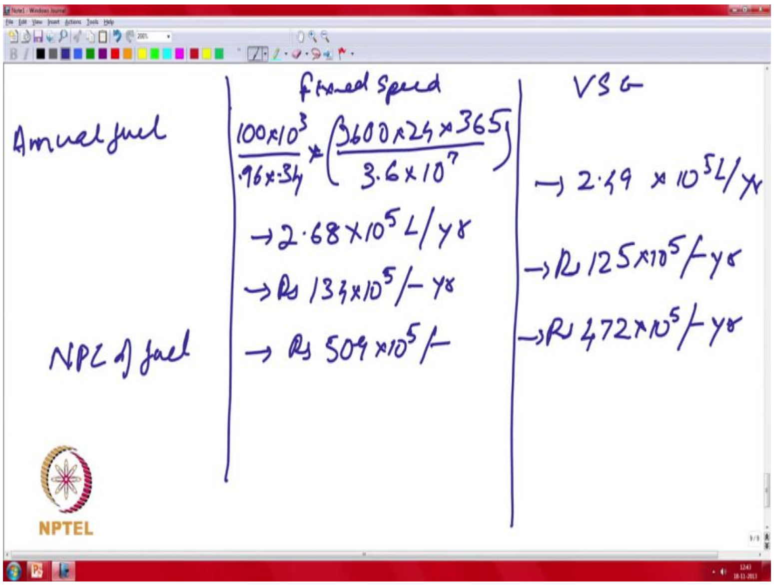

If, you look at your annual fuel consumption, so in the first case it is 100 Kilo Watts, 96 percent efficiency, for your synchronized machine and 34 percent efficiency for your IC engine, so into 3600, 24 minutes per seconds per hour, 2400 into 365 divided by 3.6 into 10 to the power of 7 joules per liter. So, this turns out to be 2.68 liters into 10 to the power 5 liters per year for your fixed speed case and the corresponding number for the variable speed case is 2.9 into10 to the power of 5 liters per year.

So, if you look at the corresponding cost at 50 rupees per liter, this corresponds to rupees 134 into 10 to the power 5 rupees per year and this particular case, it is rupees 125 into 10 to the power of 5 per year and you could again do a net present value calculation for the rupees over the 5 year duration. Similar, to how we did for your electricity, electrical energy loss, so the net present value turns out in this particular case of your turns out to be is 509 into10 to the power of 5 here, this is rupees 472.

So, you can see that in this in between these two numbers there is a difference of about 36 into 10 to the power 5. So, this fairly substantial difference in between your variable speed gen set and the fixed speed gen set, if you look at the net present value of your fuel.

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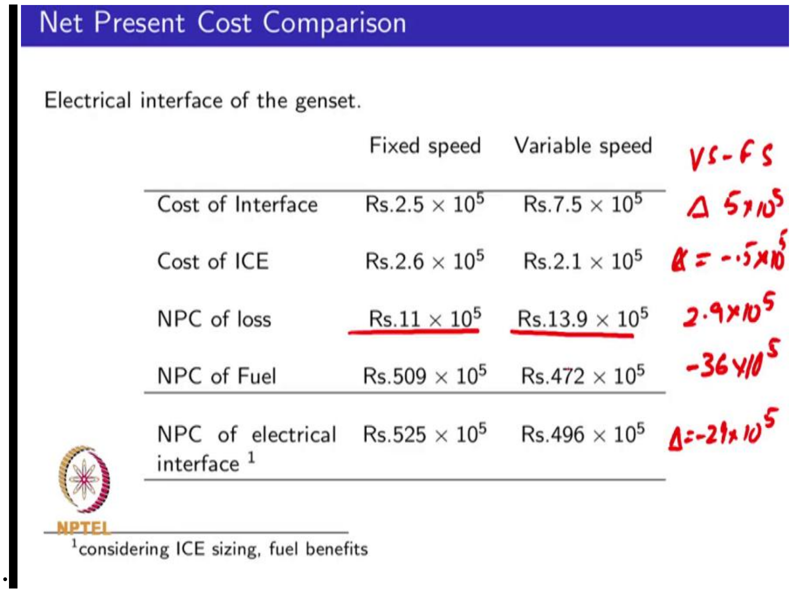

So, you could then make use of these numbers and calculate what the differences overall are the cost of interface is higher, in case of your varies variable speed gen set, so if you look at variable speed, VSG minus variable speed minus fixed speed, you are talking about difference of 5 into 10 to the power 5, if you look at the cost in the IC m in direct itself is a small reduction. So, delta in this particular case is minus .5 into 10 to the power 5.

If you look the losses in your electrical system here, the delta is 2.9 into 10 to the power 5. So, is more losses in variable speed case, but if you look at the delta for your fuel in this particular case it is minus 36 into 10 to the power 5. So, 36 dominates over other numbers, so if you look at your overall benefit net present cost, where overall electrical interface, the fixed rate generator has a number as 525 into 10 to power 5, the variable speed is 496 into 10 to the power 5.

So, there is a difference of about 29 practically, this 525 is not a number, that you are actually going to deal with 496 is also not a number you are dealing with, but the saying is over 5 years of operation by the use of variable speed option, you are going to get a present value of the savings corresponding to lakhs. So, you can look at the case where instead of say 5 year duration what would be the net present value, if you just restricted to just a 1 year duration and you can see that even with 1 year, you get a benefit for the variable speed case, if you are running the gen set on a continuous basis.

So, from a electrical prospective it makes sense to go from to a variable speed case, you just look at the net present value of just the interface on the losses, you can see that it does not make sense, because you are going for something which is a higher cost and more loss, but your benefits is coming from benefits to the balance of the system to this particular case.

So, you can see that these calculations can give you a feel for what might be in an appropriate design for your electrical system in a more complex electrical mechanical thermal system and what could be the options that could look at which can actually reduce your overall cost of energy your benefits on a annual basis. So, these are important engineering design decisions that can benefit your overall system design.

Thank you.