Université d’Ottawa | University of Ottawa

ELG4126- Sustainable Electrical Power Systems- DGD

Economics of Distributed Resources

Maryam Parsa

DGD 07- March 14, 2013

Winter 2013

uOttawa

Outline

- **DISTRIBUTED BENEFITS**
  - Option Values
  - Distribution Cost Deferral
  - Electrical Engineering Cost Benefits
  - Reliability Benefits
  - Emissions Benefits

DISTRIBUTED BENEFITS

- Direct energy savings
- Increased fuel efficiency with cogeneration
- ***Option Value***: Small increments in generation can track load growth more closely, reducing the costs of unused capacity
- ***Deferral Value***: Easing bottlenecks in distribution networks can save utilities costs.
- ***Engineering Cost savings:*** Voltage and power factor improvements and other ancillary benefits provide grid value.
- ***Customer Reliability Value:*** Reduced risk of power outages and better power quality can provide major benefits to some customers.
- ***Environmental Value:*** Reduced carbon emissions for CHP systems will have value if/when carbon taxes are imposed; for fuel cells, since they are emission-free, ease of permitting has value.

Outline

- DISTRIBUTED BENEFITS
  - **Option Values**
  - Distribution Cost Deferral
  - Electrical Engineering Cost Benefits
  - Reliability Benefits
  - Emissions Benefits

Option Values

In the context of **distributed generation**:

The ***option*** part of option value refers to:

- **The choice of the incremental size of new generation capacity**

  that is, the buyer has the option to purchase a large power plant that will satisfy future growth for many years, or a series of small ones that will each, perhaps, only satisfy growth for a year or two.

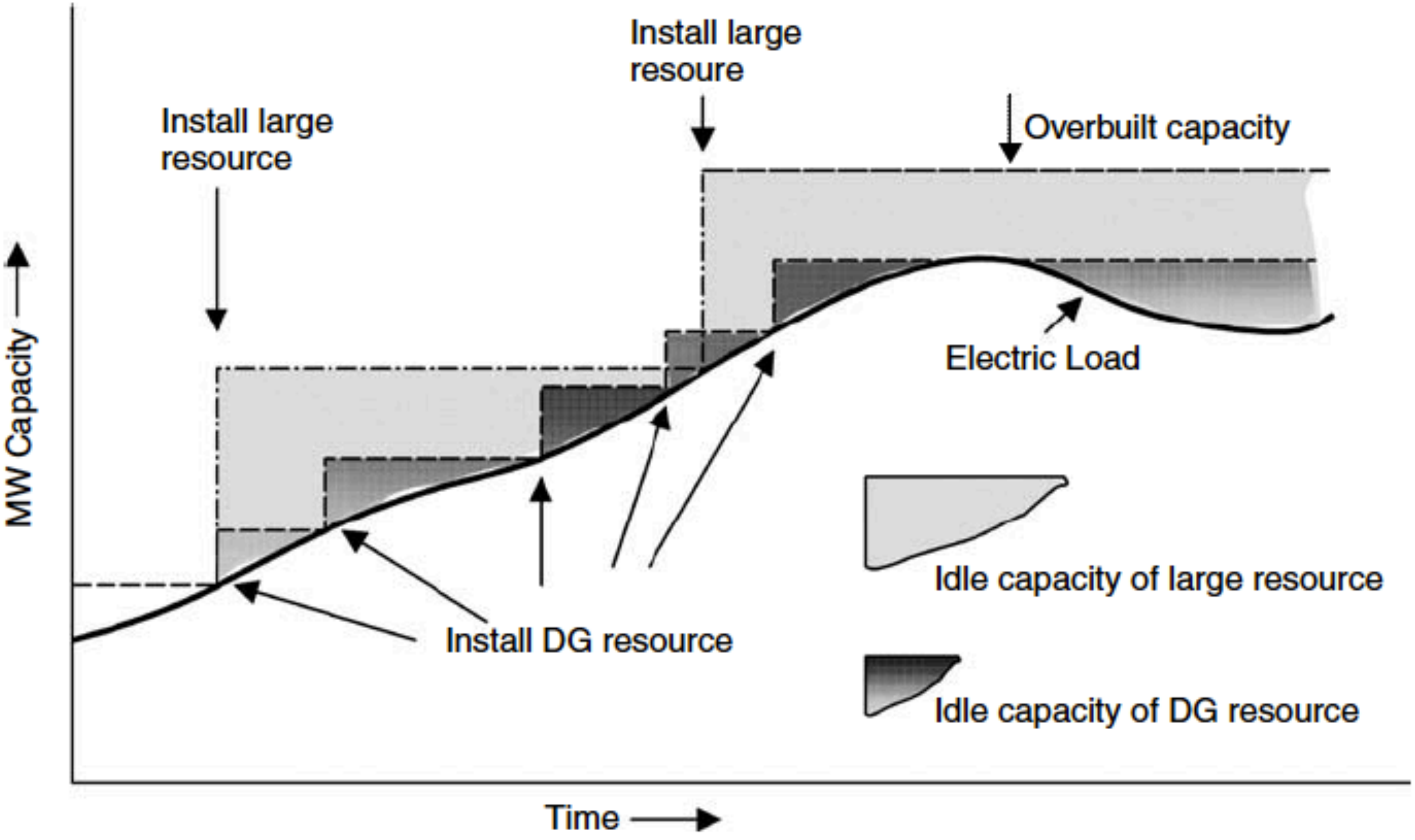
The ***value*** part refers to:

- **The economic advantages that go with small increments**

  which are better able to track load growth.

Option Values

Figure 1. Smaller distributed generation increments better track the changing electric load with less idle capacity than fewer, larger plants. Less idle capacity translates into decreased costs.



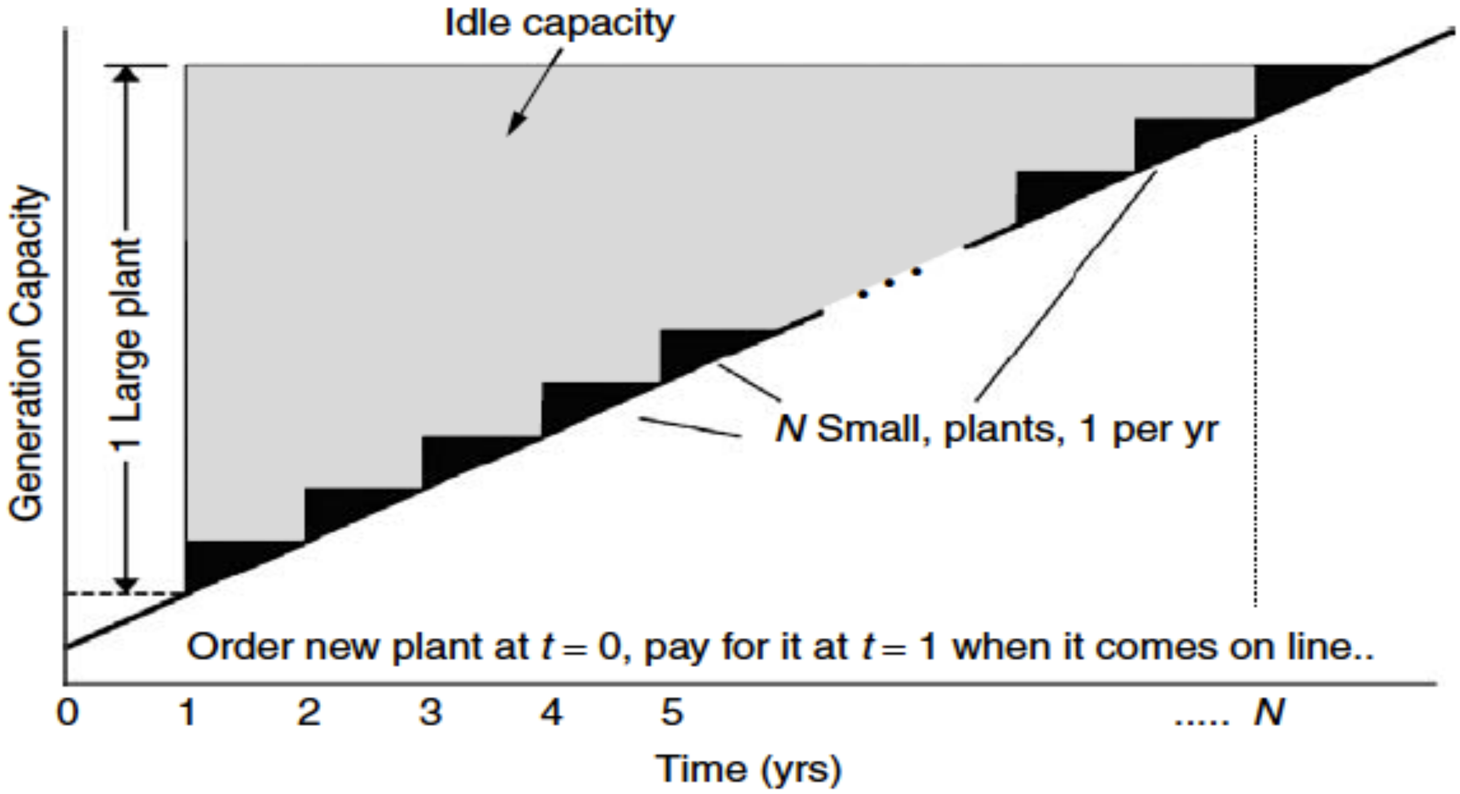
Option Values

Figure 1 illustrates the comparison between adding fewer, larger increments of capacity versus smaller, but more frequent, increments.

- Smaller increments, such as distributed generation, better track the changing load and result in less idle capacity on line over time.
- The advantage is especially apparent when forecasted load growth doesn’t materialize and a large incremental power plant may result in long-term overbuilt capacity that remains idle but still incurs costs.

Option Values

Figure 2. Comparing the present worth of a single large plant capable of supplying N years of growth with N plants, each satisfying 1 year of growth. For simplicity, both are assumed to have 1-year construction lead times



Option Values

Figure 2 shows a comparison of one large power plant, which can supply N years of load growth, with N small plants, each able to supply one year's worth of growth.

- One way to **quantify the cost advantage** of the option value is to do a **present worth analysis** of the capital cost of a single large plant compared with a series of small ones

Option Values

Assumptions:

1. It only takes 1 year between the time a plant is ordered and the time it comes on line, so at time t = 0, either a large plant or a small plant must be ordered.
2. Full payment for a plant is due when it comes on line

Option Values

Let

$$\text{Annual growth in demand} = \Delta P \ (\text{kW})$$

$$\text{Cost of a small plant} = P_S \ (\$/\text{kW}) \times \Delta P \ (\text{kW})$$

$$\text{Cost of a large plant} = P_L \ (\$/\text{kW}) \times N\Delta P \ (\text{kW})$$

$$\text{Discount rate} = d \ (\text{yr}^{-1})$$

- The present value of the single large plant (PV_L) is its initial cost discounted back 1 year to t = 0:

$$PV_L = \frac{P_L N \Delta P}{(1 + d)}$$

Option Values

- For the sequence of N small plants, the present value of N payments of $P_S\ \Delta P$,with the first one at t = 1 year, is given by

$$PV_S = P_S \Delta P \,\mathrm{PVF}(d, N)$$

where PVF(d, N) is the present value function used to find the present value of a series of N equal annual payments starting at t = 1.

- If we equate the present values of the large plant and the N small ones, we get

$$\frac{P_L N \Delta P}{(1+d)} = P_S\ \Delta P\ \mathrm{PVF}(d, N)$$

Option Values

- So

$$\frac{P_S(\$/\mathrm{kW})}{P_L(\$/\mathrm{kW})} = \frac{N}{(1+d)\mathrm{PVF}(d,N)} = \frac{N}{(1+d)}\left[\frac{d(1+d)^N}{(1+d)^N - 1}\right]$$

$$= N\left[\frac{d(1+d)^{N-1}}{(1+d)^N - 1}\right]$$

- Equation shows is the ratio of the **small-plant-to-large-plant capital costs ($/kW)** that makes them equivalent on a present worth basis

Example 1. Present Value Benefit of Small Increments of Capacity

Q:

Find the present value advantage of eight small plants, each supplying 1 year's worth of growth, over one large plant satisfying 8 years of growth. Use a discount rate of 10%/yr. Each plant takes 1 year to build. If the large one costs $1000/kW, how much can the small ones cost to be equivalent?

Example 1. Present Value Benefit of Small Increments of Capacity

Answer:

$$\frac{P_S(\$/\text{kW})}{P_L(\$/\text{kW})} = \frac{N}{(1+d)\text{PVF}(d,N)} = \frac{N}{(1+d)}\left[\frac{d(1+d)^N}{(1+d)^N-1}\right]$$

$$= N\left[\frac{d(1+d)^{N-1}}{(1+d)^N-1}\right]$$

$$\frac{P_S(\$/\text{kW})}{P_L(\$/\text{kW})} = 8\left[\frac{0.1(1+0.1)^7}{(1+0.1)^8-1}\right] = 1.363$$

- This means the small DG plants can cost \$1363/kW and they still would be equivalent to the single large one at \$1000/kW

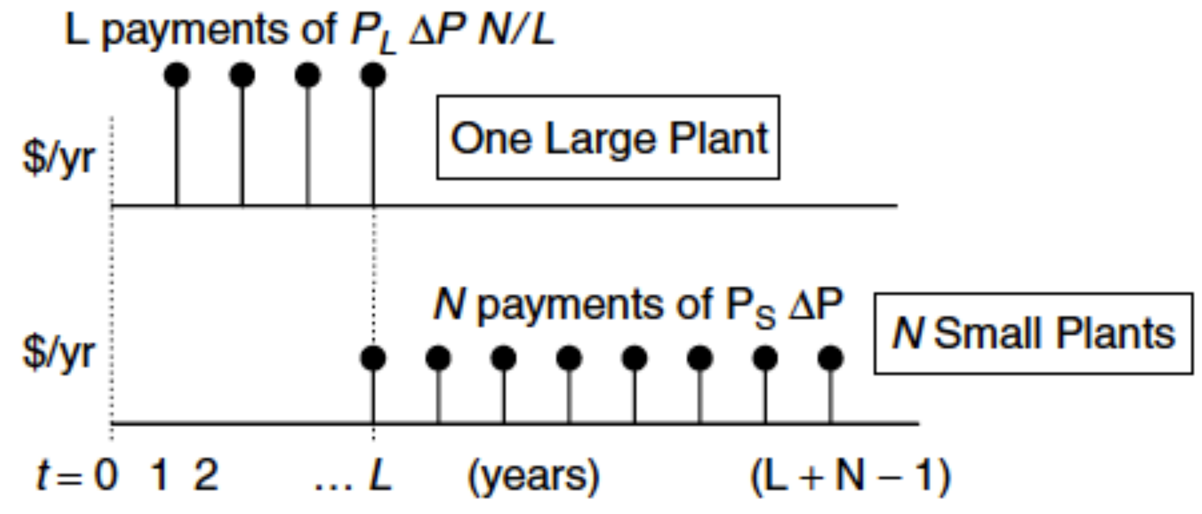
Option Values

Even though the calculation in Example 1 is impressive enough as it stands, it omits another important advantage of smaller plants.

- Large plants tie up capital for a longer period of time before the plant can be designed, permitted, built, and turned on. That longer lead time costs money, so let’s modify our analysis to include it

Option Values

Figure 3. The payments made on one large plant spread over the L years of lead time that it takes to bring it on line, and annual payments made on N small plants. The first of each type comes on line in year L



Option Values

Imagine the initial cost of the large plant being spread over years 1 through L, where L is the lead time. Also, suppose payments on the N small plants begin in year L, as shown in Fig. 3. We continue to assume the small plants can be built in one year.

- The present value of the payments made on the large plant costing $P_L N \Delta P$ spread out over L years is given by

$$\mathrm{PV}_L = \frac{P_L N \Delta P}{L} \cdot \mathrm{PVF}(d, L)$$

Option Values

- For the N small plants, each costing P_s ΔP over years L to L + N − 1, we have

$$\mathrm{PV}_S = \frac{1}{(1+d)^{L-1}}[P_S \Delta P \cdot \mathrm{PVF}(d, N)]$$

- Ratio of capital costs for small and large plants, including the extra lead time for the large one

$$\frac{P_S(\$/\mathrm{kW})}{P_L(\$/\mathrm{kW})} = \frac{N(1+d)^{L-1}}{L} \cdot \frac{\mathrm{PVF}(d, L)}{\mathrm{PVF}(d, N)}$$

where ***N*** is the number of small plants, each taking 1 year to build and satisfying 1 yr of growth; ***L*** represents the years of lead time for the single large plant; and ***d*** is the discount rate.

Example 2. Option Value of Small Plants Including Short Lead-Time Advantage

Q:

- Find the capital cost that could be paid for eight small plants, each sized to supply one year of load growth and each taking 1 year to build, compared with one large plant that supplies 8 years of growth. The large plant costs $1000/ kW and has a lead time of 4 years to build. Use a discount rate of 10%/yr

Example 2. Option Value of Small Plants Including Short Lead-Time Advantage

Answer:

$$\mathrm{PVF}(d, L) = \frac{(1+d)^L - 1}{d(1+d)^L} = \frac{(1+0.1)^4 - 1}{0.1(1+0.1)^4} = 3.1698$$

$$\mathrm{PVF}(d, N) = \frac{(1+0.1)^8 - 1}{0.1(1+0.1)^8} = 5.3349$$

$$\frac{P_S(\$/\mathrm{kW})}{P_L(\$/\mathrm{kW})} = \frac{N(1+d)^{L-1}}{L} \cdot \frac{\mathrm{PVF}(d, L)}{\mathrm{PVF}(d, N)} = \frac{8(1+0.1)^{4-1}}{4} \times \frac{3.1698}{5.3349} = 1.582$$

- The capital cost of the small plants can be \$1582/kW, and they would still be equivalent to one large plant costing \$1000/kW.

Option Values

Another **advantage** of small plants:

- Less unused capacity if load doesn't grow as fast as forecast
- Reduced need for working capital to build the plants
- Reduced risk in the modular approach

Putting enormous amounts of capital into a huge, billion-dollar power plant and then waiting 5 or so years to start earning revenue could be perceived by the capital markets to be a riskier investment than would be the case for a series of short lead- time, modular units.

Outline

- DISTRIBUTED BENEFITS
  - Option Values
  - **Distribution Cost Deferral**
  - Electrical Engineering Cost Benefits
  - Reliability Benefits
  - Emissions Benefits

Distributed Cost Deferral

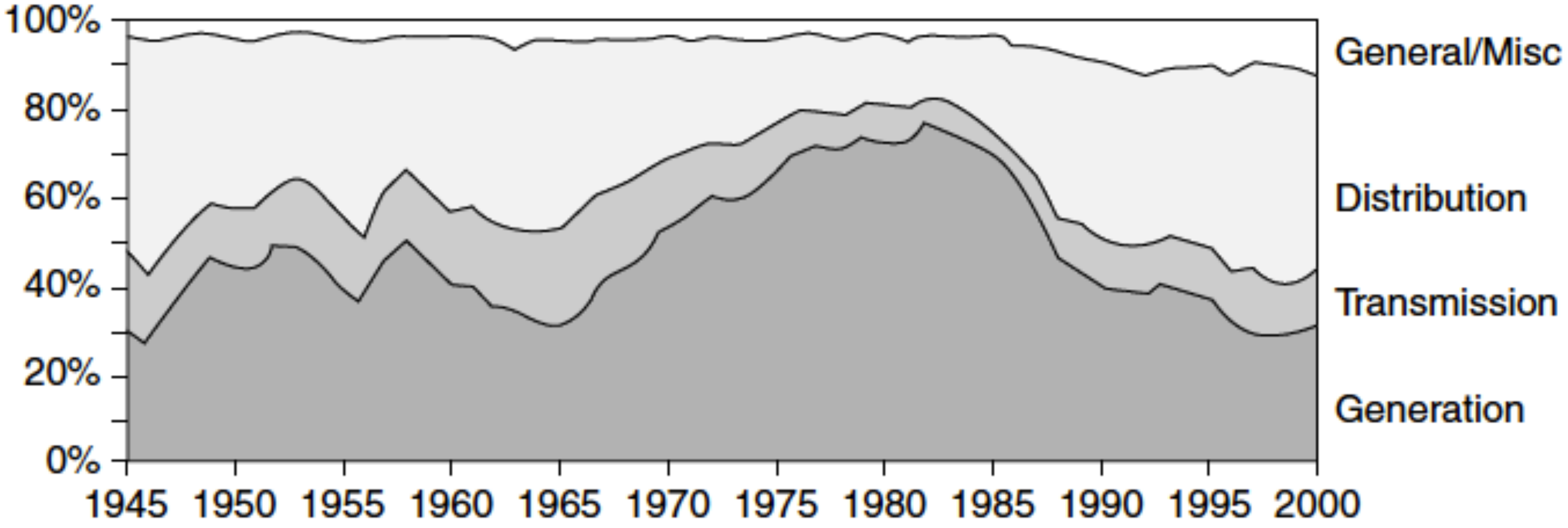
- The utility distribution system, which sends power to every house and store in town, is a very expensive asset that is typically greatly underutilized except in certain critical locations during certain times of the day and year.

- Distribution systems constitute a significant fraction—on the order of half in recent years—of annual utility construction cost.

- Running power lines up and down every street to serve residential customers is expensive, and it is one reason why residential electric rates are so much higher than those for large, industrial facilities with dedicated feeders.

Distributed Cost Deferral

Figure 4. Allocation of U.S. investor-owned utilities' construction expenditures. **From** Lovins et al. (2002)



Distributed Cost Deferral

Distribution systems are plagued by bottlenecks.

When a new housing development or shopping center gets built, distribution feeders and the local substation may have to be upgraded even though their current capacity may be exceeded for only a few hours each day during certain months of the year.

Distributed Cost Deferral

On-site generation by utility customers can help avoid or delay the need for distribution system upgrades, leading to more efficient use of existing facilities.

Customers in portions of the distribution grid where capacity constraints are imminent could in the future be provided with incentives to generate some of their own power (or shed some of their load), especially at times of peak power demand.

Area-and-time-based differential pricing of grid services could well become an important driver of distributed generation

Outline

- DISTRIBUTED BENEFITS
  - Option Values
  - Distribution Cost Deferral
  - **Electrical Engineering Cost Benefits**
  - Reliability Benefits
  - Emissions Benefits

Electrical Engineering Cost Benefits

Besides capacity deferrals, distributed generation can also

- Decrease costs in the distribution network by helping to improve the efficiency of the grid.

Power injected into the grid by local distributed generation resources helps to reduce losses in several ways.

- Without DG, the current supplied to a distribution network by the transmission system **must be sufficient** to satisfy **all of the loads**, from one end to the other.

Electrical Engineering Cost Benefits

When current flows through conductors

- There is voltage drop due to Ohm’s law, $\Delta V = i R$.
- There is power loss due to $i^2 R$ heating of the wires.

The longer the distance and the greater the current, the more there will be voltage drop and power loss in the wires

Electrical Engineering Cost Benefits

- If a distributed generation source provides some of its own power

Or

- If loads can be reduced through customer efficiency

The current and power that the grid needs to supply will drop and so will grid losses.

If the DG source actually delivers power to the grid, line losses will be reduced even more.

Electrical Engineering Cost Benefits

DG: increasing power factor of the lines:

- Injecting power onto the grid not only provides voltage support to offset iR drops and reduce i^2R losses, it can also raise the power factor of the lines.
- Recall that when voltage and current are out of phase with each other, more current must be provided to deliver the same amount of true power (watts) capable of doing work.

Electrical Engineering Cost Benefits

- Improving the power factor is usually accomplished by adding banks of capacitors to the line, but
- It can also be helped if DG systems are designed to inject appropriately phased reactive power.
- Improved power factor reduces line current, which reduces voltage sag and line losses.
- Better power factor also helps distribution transformers waste less energy, supply more power, and extend their lifetime.

Outline

- DISTRIBUTED BENEFITS
  - Option Values
  - Distribution Cost Deferral
  - Electrical Engineering Cost Benefits
  - **Reliability Benefits**
  - Emissions Benefits

Reliability Benefits

- Most power outages are caused by faults in the transmission and distribution system —wind and lightning, vehicular accidents, animals shorting out the wires— not generation failures.

- To the extent that a customer can provide some fraction of their own power during those outages, especially to critical loads such as computers and other digital equipment, the value of the added reliability can easily surpass the cost of generation by orders of magnitude

Reliability Benefits

- Emergency standby power is now often provided with back-up generators, but such systems are usually not designed to be operated continuously, nor are they permitted to do so given their propensity to pollute. This means that they don’t provide any energy payback under normal circumstances.

- Battery systems and other uninterruptible power supplies (UPS) can’t cover sustained outages on their own without additional backup generators, so they have the same disadvantages of not being able to help pay for themselves by routinely delivering kilowatt-hours

Reliability Benefits

DG:

- Fuel cells, on the other hand, can operate in parallel with the grid. With natural gas reformers, or sufficient stored hydrogen, they can cover extended power outages. With no emissions or noise they be housed within a building and can be permitted to run continuously so they are an investment with annual returns in addition to providing protection against utility outages.

Outline

- DISTRIBUTED BENEFITS
  - Option Values
  - Distribution Cost Deferral
  - Electrical Engineering Cost Benefits
  - Reliability Benefits
  - **Emissions Benefits**

uOttawa

Emissions Benefits

As concerns about climate change grow, there is increasing attention to the role of carbon emissions from power plants.

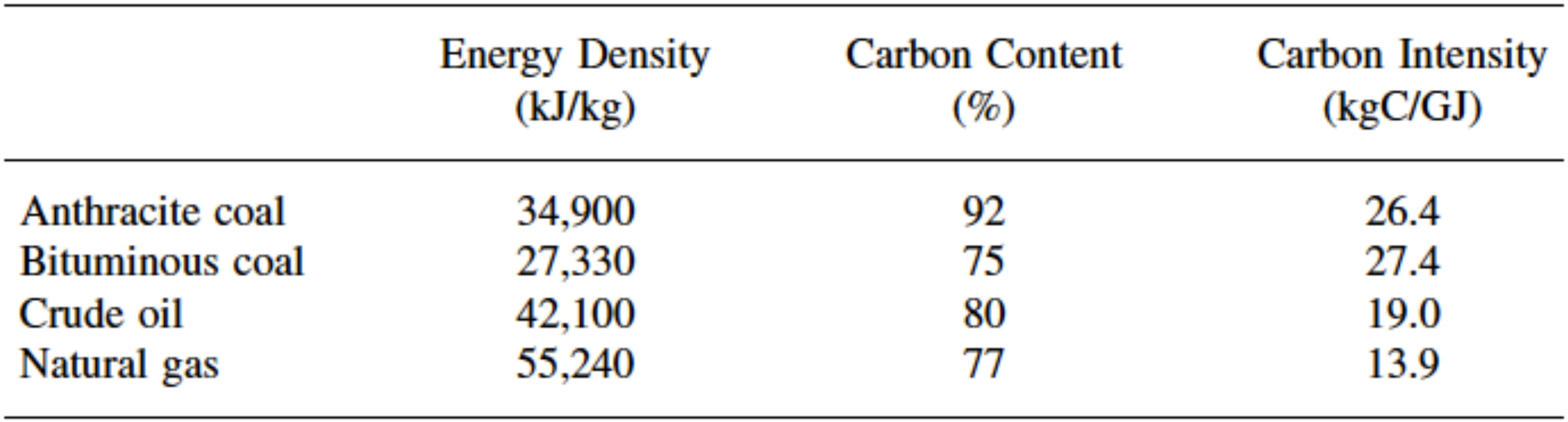
The shift from large, coal-fired power plants to smaller, more efficient gas turbines and combined-cycle plants fueled by natural gas can greatly reduce those emissions.

Reductions result from

- The increased efficiency that many of the new power plants have
- The lower carbon intensity (kgC/GJ) of natural gas.

Emissions Benefits

Table 1. Carbon Intensity of Fossil Fuels



	Energy Density (kJ/kg)	Carbon Content (%)	Carbon Intensity (kgC/GJ)
Anthracite coal	34,900	92	26.4
Bituminous coal	27,330	75	27.4
Crude oil	42,100	80	19.0
Natural gas	55,240	77	13.9

- Natural gas emits only about half the carbon per unit of energy when it is burned as does coal.

Emissions Benefits

One approach to calculating carbon emissions from CHP plants is to use the **energy chargeable-to-power (ECP)** measure.

Recall that ECP subtracts the displaced boiler fuel no longer needed from the total input energy, which, in essence, attributes all of the fuel (and carbon) savings to the electric power output.

Example 3. Carbon Emission Reductions with CHP

Q:

Use the ECP method to determine the reduction in carbon emissions associated with a natural-gas-fired, combined-cycle CHP having 41% electrical efficiency and 44% thermal efficiency. Assume that the thermal output would have come from an 83% efficient boiler. Compare it to that of a 33.3% efficient conventional bituminous-coal-fired power plant.

Example 3. Carbon Emission Reductions with CHP

Answer:

$$\text{ECP} = \frac{\text{Total thermal input} - \text{Displaced thermal input}}{\text{Electrical output}}$$

$$= \frac{3600}{\eta_P}\left(1 - \frac{\eta_H}{\eta_B}\right)\ \text{kJ/kWh}$$

$$\text{ECP} = \frac{3600}{0.41}\left(1 - \frac{0.44}{0.83}\right) = 4126\ \text{kJ/kWh}$$

Using the 13.9-kgC/GJ carbon intensity of natural gas provided in Table 1

$$\text{Carbon chargeable to power} = \frac{4126\ \text{kJ/kWh} \times 13.9\ \text{kgC/GJ}}{10^6\ \text{kJ/GJ}}$$

$$= 0.0573\ \text{kgC/kWh}$$

Example 3. Carbon Emission Reductions with CHP

- The coal plant has no displaced thermal input, so its ECP is the full

$$\mathrm{ECP} = \frac{3600}{0.333} = 10{,}811\ \mathrm{kJ/kWh}$$

- Using 27.4 kgC/GJ as its carbon intensity from Table 1

$$\text{Carbon chargeable to power} = \frac{10{,}811\ \mathrm{kJ/kWh} \times 27.4\ \mathrm{kgC/GJ}}{10^6\ \mathrm{kJ/GJ}} = 0.296\ \mathrm{kgC/kWh}$$

The efficient CHP combined-cycle plant reduces carbon emissions by 81%.