ELG4126- Sustainable Electrical Power Systems- DGD

Economics of Distributed Resources

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DGD 05- 7 Feb, 2013

Winter 2013

DGD 05- 7 Feb 2013- Outline

- Energy Economics
  - **Cash Flow Analysis**
- Review from DGD 01 to DGD 04

Cash Flow Analysis

- One of the most flexible and powerful ways to analyze an energy investment
- This technique easily accounts for complicating factors such as
  - fuel escalation
  - tax-deductible interest, depreciation
  - periodic maintenance costs
  - disposal or salvage value of the equipment at the end of its lifetime.
- The results are computed numerically using **a spreadsheet**
- Each **row** of the resulting table corresponds to ***one year of operation***, and each **column** accounts for a ***contributing factor***

Table 2. Cash-Flow Analysis

Loan principal($) =	1000.00	Energy savings (kWh/yr) =	1500
Interest =	0.06	Price at $t = 0$ (\$/kWh) =	0.10
Loan term (yrs) =	10	Savings at $t = 0$ (\$/yr)	150
CRF(i, n) per yr =	0.13587	Escalating at (%/yr) =	5
Payments (\$/yr) =	135.87		
Tax bracket =	0.305	Personal discount rate =	0.10

End of Year	Loan Payment	Interest	Delta Principal	Loan Balance	Tax Savings	Loan Cost	Electric Savings	Net Savings	PV Savings	Cum PV Savs
0	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	0.00
1	135.87	60.00	75.87	924.13	18.30	117.57	157.50	39.93	36.30	36.30
2	135.87	55.45	80.42	843.71	16.91	118.96	165.38	46.42	38.36	74.66
9	135.87	14.95	120.92	128.18	4.56	131.31	232.70	101.39	43.00	369.75
10	135.87	7.69	128.18	0.00	2.35	133.52	244.33	110.81	42.72	412.48

1000×0.13587

0.06×924.13

$135.87 - 55.45$

$924.13 - 80.42$

0.305×55.45

$135.87 - 16.91$

1.05×157.50

$165.38 - 118.96$

$\frac{46.42}{(1.10)^2}$

$38.36 + 36.30$

Loan paid off

PV cumulative savings

Table 2. Cash Flow Analysis

- Cash-flow analysis for a
  - $1000
  - 6% interest
  - 10-year loan
  - Saves a homeowner $150/yr in electricity (electric saving)
  - The electric saving is expected to increase 5% per year
  - Personal discount factor of 10%.
  - Since this is a home loan, any interest paid on the loan will qualify as a tax deduction

- Year 0:
  - Loan Balance = $1000
- Year 1:
  - CRF(0.06,10)=0.13587
  - Annual Payment = P * CRF = 1000*0.13587=135.87
  - Interest= .06 * $1000 = $60
  - Delta Principle = $135.87 - $60 = $75.87
  - Loan Balance = $1000 - $75.87 = $924.13
- Year 2:
  - Annual Payment = P * CRF = 1000*0.13587=135.87
  - Interest= .06 * $924.13 = $55.45
  - Delta Principle = $135.87 - $55.45 = $80.42
  - Loan Balance = $924.13 - $80.42 = $843.71
- Year 10:
  - Loan Balance = $0

Table 3. Federal Income Tax Brackets for Married Couples Filing Jointly, 2002

Income Over...	But Not Over...	Federal Tax Is...	Of the Amount Over
$0	$45,200	15%	$0
45,200	109,250	$6, 780 + 27.5%	45,200
109,250	166,500	24, 394 + 30.5%	109,250
166,500	297,350	41, 855 + 35.5%	166,500
297,350	—	88, 307 + 39.1%	297,350

- e.g. For a family earning between $109,250 and $166,500, every additional dollar of income has 30.5¢ of taxes taken out of it.
- On the other hand, if the income that has to be reported to the I.R.S. can be reduced by one dollar, that will save 30.5¢ in taxes.
- The 30.5% number is called the ***marginal tax bracket (MTB)***.

Cash Flow Analysis

- Year 1:
  - Tax-deductible interest: $60
  - Buyer's income taxes: $60 * 0.305 = $18.30
  - Loan Cost: $135.87 - $18.30 = $117.57
  - Electricity Savings: $150 * 1.05 = $157.50
  - Total Saving:

    $157.50 (electricity saving) + $18.30 (tax saving) – $135.87(loan payment) = $39.93
  - Personal discount rate: 10%
  - Present Value of Savings: $39.93 / (1.10) = $36.30
  - Cumulative PV Savings: $412.48

REVIEW from DGD 01- Jan 7th

- Standard Residential Rates

Tier Level	Winter: November–April		Summer: May–October	
Tier I	First 620kWh	7.378¢/kWh	First 700kWh	8.058¢/kWh
Tier II	621–825	12.995¢/kWh	701–1000	13.965¢/kWh
Tier III	Over 825	14.231¢/kWh	Over 1000	15.688¢/kWh

- Residential Time-Of-Use (TOU) Rates

	November–April		May–October	
On-peak	7–10 A.M., 5–8 P.M.	8.335 ¢/kWh	2–8 P.M.	19.793 ¢/kWh
Off-peak	All other times	7.491 ¢/kWh	All other times	8.514 ¢/kWh

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REVIEW from DGD 01- Jan 7th

- Demand Charges

	Winter Oct–May	Summer June–Sept
Energy charges	\$0.0625/kWh	\$0.0732/kWh
Demand charges	\$7/mo-kW	\$9/mo-kW

- Load Factor

$$\text{Load factor } (\%) = \frac{\text{Average power}}{\text{Peak power}} \times 100\%$$

Example 1: Calculating a Simple Residential Utility Bill

- Q: Customer subject to the rate structure in Table 1 uses 1200 kWh/ mo during the summer.
  - What would be the total cost of electricity
  - What would be the value (¢/kWh) of an efficiency project that cuts the demand to 900 kWh/mo?
- *Answer:*
  - The total monthly bill includes 700 kWh @ 8.058¢, 300 kWh @ 13.965¢, and 200 kWh @ 15.688¢, for a total of

    700*$0.08058 + 300*$0.13965 + 200*$0.15688 = $129.68/ mo
  - If the demand is reduced to 900 kWh/mo, the bill would

    700*$0.08058 + 200*$0.13965 = $84.34/ mo
  - Savings per kWh is ($129.68− $84.34)/300 kWh= $0.1511/kWh

Example 2: PVs, TOU Rates, and Net Metering

- Q: Based on the table below, for a 30-day month in the summer, find the electric bill for the customer if the TOU rates of Table 2 apply.

	PV supply	Demand
On-peak	10kWh	2kWh
Off-peak	10kWh	18kWh
Total	20kWh/day	20kWh/day

- *Answer:*
  - On-peak credits=8 kWh/day*$0.19793/ kWh*30 day/mo= $47.50
  - Off-peak bill=8 kWh/day*$0.08514/ kWh*30 day/m=$20.43/m
  - Net bill=$20.43−$47.50= − $27.07mo

Example 3: Impact of Demand Charges

- Q: During the summer, a small commercial building that uses 20,000 kWh per month has a peak demand of 100 kW
  - The monthly bill?
  - How much does the electricity cost for a 100-W computer that is used 6h a day for 22 days in the month? The computer is turned on during the period when the peak demand is reached for the building. How much is that in ¢/kWh?

Example 3: Impact of Demand Charges

Answer:

- Monthly bill = energy charges + demand charges
  - Energy charge = 20,000 kWh * $0.0732/ kWh = $1464/ mo
  - Demand charge = 100 kW * $9/ mo-kW = $900/ mo
  - For a total of $1464 + $900 = $2364/mo
- The computer uses 0.10 kW * 6 h/ d * 22 day/ mo = 13.2 kWh/mo
  - Energy charge = 13.2 kWh/mo * $0.0732/ kWh = $0.97/ mo
  - Demand charge = 0.10 kW * $9/mo-kW = $0.90/ mo
  - Total cost = $0.97 + $0. 90 = $1.87/ mo
  - Per kilowatt-hour basis: ($1.87/mo)/(13.2kWh/mo)=$0.142/kWh

Example 4: Impact of Ratcheted Demand Charges on an Efficiency Project

- Q: A customer's highest demand for power comes in August when it reaches 100 kW. The peak in every other month is less than 70 kW. A proposal to dim the lights for 3 h during each of the 22 workdays in August will reduce the August peak by 10 kW. The utility's energy charge is 8¢/kWh and its demand charge is $9/kW-mo with an 80% ratchet on the demand charges.
  a. What is the current annual cost due to demand charges?
  b. What annual savings in demand and energy charges will result from dimming the lights?
  c. What is the equivalent savings expressed in ¢/kWh?

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Example 4: Impact of Ratcheted Demand Charges on an Efficiency Project

Answer:

a)

- At $9/kW-mo, the current demand charge in August will be

  August = 100 kW * $9/ kW-mo = $900

- For the other 11 months, the minimum demand charge will be based on 80 kW, which is higher than the actual demand:

  Sept–July demand charge = 0. 8*100 kW*$9/ kW-mo*11 mo = $7920

- So the total annual demand charge will be

  Annual = $900 + $7920 = $8820

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Example 4: Impact of Ratcheted Demand Charges on an Efficiency Project

Answer:

b)

- August = 90 kW * $9/ kW-mo = $810
- Sept–July = 0.8 * 90 kW * $9/ kW-mo * 11 mo = $7128
- Total annual demand charge = $810 + $7128 = $7938
- Annual demand savings = $8820 − $7938 = $882
- August energy savings = 3 h/d*10 kW*22 days*$0.08=$52.80
- Total Annual Savings = $882 + $52.80 = $934.80

- Notice that the demand savings is 94.4% of the total savings!

Example 4: Impact of Ratcheted Demand Charges on an Efficiency Project

Answer:

c)

- Dimming the lights saved 3 h/ d*10 kW*22 d = 660 kWh and $934.80 which on a per kWh basis is

  Savings: ($934.80)/(660 kWh) = $1.42/kWh

- In other words, the business saves $1.42 for each kWh that it saves, which is about 18 times more than would be expected if just the $0.08/kWh cost of energy is considered.

Example 5: Impact of Load Factor on Electricity Costs

- Q: Two customers each use 100,000 kWh/mo. One (customer A) has a load factor of 15% and the other (customer B) has a 60% load factor. Using a rate structure with energy charges of $0.06/kWh and demand charges of $10/kW-mo, compare their monthly utility bills.
- *Answer:* They both have the same energy costs: 100,000 kWh/ mo * $0.06/ kWh = $6000/ mo. Based on the load factor formula we have:
  - Peak(A)=(100,000kWh/mo)/(15%*24h/day*30day/mo)*100% = 925.9 Kw, Costing = $9259/mo
  - Peak(B)=(100,000kWh/mo)/(60%*24h/day*30day/mo)*100% = 231.5 Kw, Costing = $2315/mo
  - The total monthly bill for A with the poor load factor is nearly twice as high as for B ($15,259 for A and $8315 for B)

REVIEW from DGD 02- Jan 14th

- Simple Payback Period

$$\text{Simple payback} = \frac{\text{Extra first cost } \Delta P(\$)}{\text{Annual savings S}(\$/\text{yr})}$$

- Initial (Simple) Rate-Of-Return

$$\text{Initial (simple) rate of return} = \frac{\text{Annual savings S } (\$/\text{yr})}{\text{Extra first cost } \Delta P(\$)}$$

- e.g. a $1000 investment which returned $500 per year would have a two year payback period and 50% rate of return per year.

REVIEW from DGD 02- Jan 14th

- Net Present Value (NPV)

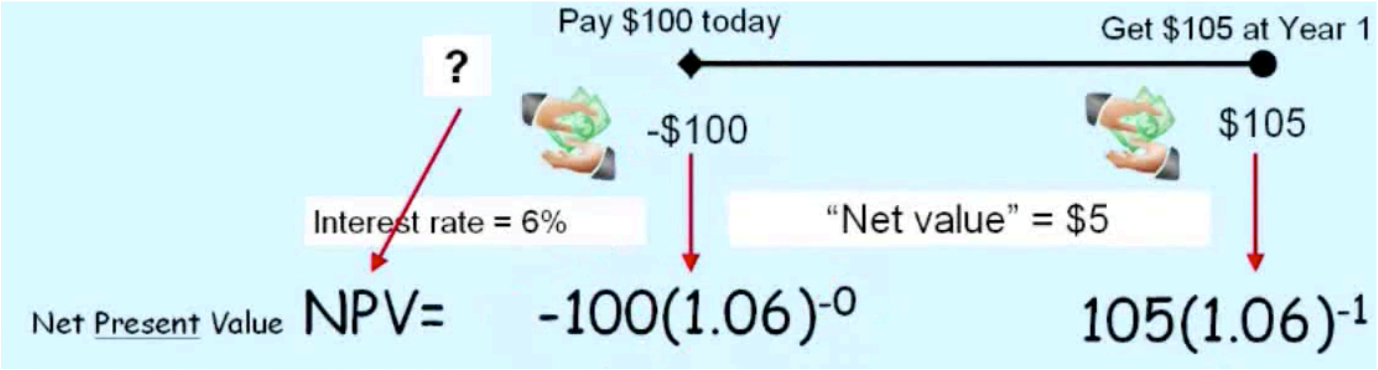
$$F = P\ (1+i)^n \qquad\qquad P = \frac{F}{(1+i)^n}$$

- e.g:

- Net Value: 5$

REVIEW from DGD 02- Jan 14th

- Net Present Value (NPV)



- Assume Bank: interest rate: %6
  - Present value formula at year 1: $\$105(1.06)^{-1}$
  - Present value formula at year 0: $\$100(1.06)^{-0}$

$$NPV= -\$100(1.06)^{-0} + \$105(1.06)^{-1} = -\$0.94$$

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REVIEW from DGD 02- Jan 14th

- Internal Rate of Return (IRR)
- e.g.: rate of return 3%

rate of return?!!?!

$-100(1+r)^{-0}+60(1+r)^{-1}+60(1+r)^{-2}$

IRR: 13%

REVIEW from DGD 02- Jan 14th

- IRR: NPV = ΔA * PVF(IRR, n) – ΔP = 0

$$\text{PVF}(\text{IRR}, n) = \frac{\Delta P}{\Delta A} = \text{Simple payback period}$$

Life (years)	9%	11%	13%	15%	17%	19%	21%	23%	25%	27%	29%	31%	33%	35%	37%	39%
1	0.92	0.90	0.88	0.87	0.85	0.84	0.83	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.73	0.72
2	1.76	1.71	1.67	1.63	1.59	1.55	1.51	1.47	1.44	1.41	1.38	1.35	1.32	1.29	1.26	1.24
3	2.53	2.44	2.36	2.28	2.21	2.14	2.07	2.01	1.95	1.90	1.84	1.79	1.74	1.70	1.65	1.61
4	3.24	3.10	2.97	2.85	2.74	2.64	2.54	2.45	2.36	2.28	2.20	2.13	2.06	2.00	1.94	1.88
5	3.89	3.70	3.52	3.35	3.20	3.06	2.93	2.80	2.69	2.58	2.48	2.39	2.30	2.22	2.14	2.07
6	4.49	4.23	4.00	3.78	3.59	3.41	3.24	3.09	2.95	2.82	2.70	2.59	2.48	2.39	2.29	2.21
7	5.03	4.71	4.42	4.16	3.92	3.71	3.51	3.33	3.16	3.01	2.87	2.74	2.62	2.51	2.40	2.31
8	5.53	5.15	4.80	4.49	4.21	3.95	3.73	3.52	3.33	3.16	3.00	2.85	2.72	2.60	2.48	2.38
9	6.00	5.54	5.13	4.77	4.45	4.16	3.91	3.67	3.46	3.27	3.10	2.94	2.80	2.67	2.54	2.43
10	6.42	5.89	5.43	5.02	4.66	4.34	4.05	3.80	3.57	3.36	3.18	3.01	2.86	2.72	2.59	2.47
15	8.06	7.19	6.46	5.85	5.32	4.88	4.49	4.15	3.86	3.60	3.37	3.17	2.99	2.83	2.68	2.55
20	9.13	7.96	7.02	6.26	5.63	5.10	4.66	4.28	3.95	3.67	3.43	3.21	3.02	2.85	2.70	2.56
25	9.82	8.42	7.33	6.46	5.77	5.20	4.72	4.32	3.98	3.69	3.44	3.22	3.03	2.86	2.70	2.56
30	10.27	8.69	7.50	6.57	5.83	5.23	4.75	4.34	4.00	3.70	3.45	3.22	3.03	2.86	2.70	2.56

$$\text{PVF}(d, n) = \frac{1}{1+d} + \frac{1}{(1+d)^2} + \cdots + \frac{1}{(1+d)^n} = \frac{(1+d)^n - 1}{d(1+d)^n}$$

Example 6. Net Present Value of an Energy-Efficient Motor

- Q: Two 100-hp electric motors are being considered, “good” and “premium.”
  - The good motor: draws 79 kW, costs $2400
  - The premium motor: draws 77.5 kW, costs $2900

The motors run 1600 hours per year with electricity costing $0.08/kWh. Over a 20-year life, find the net present value of the cheaper alternative when a discount rate of 10% is assumed.

Example 6. Net Present Value of an Energy-Efficient Motor

- *Answer:*

- Annual electricity cost:
  - A(good) = 79 kW*1600 h/yr*$0 .08 /kWh = $10,112 /yr
  - A(premium) = 77 .5 kW*1600 h/yr*$0 .08 /kWh = $9920 /yr

- The present value factor for these 20-year cash flows with a 10% discount rate is:

$$\mathrm{PVF}(d, n) = \frac{(1+d)^n - 1}{d(1+d)^n} = \frac{(1+0.10)^{20} - 1}{0.10(1+0.10)^{20}} = 8.5136 \text{ yr}$$

Example 6. Net Present Value of an Energy-Efficient Motor

- *Answer:*
- The present value of the two motors, including first cost and annual costs
  - P(good) = $2400 + 8 .5136 yr * $10,112 /yr = $88,489
  - P(premium) = $2900 + 8 .5136 yr * $9920 /yr = $87,354
- The premium motor is the better investment with a net present value of
  - NPV = $88,489 - $87,354 = $1,135
- OTHER SOLUTION:
  - NPV = ΔA * PVF(*d*,*n*) – ΔP
  - NPV = ($10,112 − $9920)/yr * 8.5136 yr − ($2900 − $2400) = $1135

REVIEW from DGD 03- Jan 21th

- **NPV and IRR without Fuel Escalation**

$$\text{PVF}(d,n) = \frac{1}{1+d} + \frac{1}{(1+d)^2} + \cdots + \frac{1}{(1+d)^n} = \frac{(1+d)^n - 1}{d(1+d)^n}$$

- **NPV and IRR with Fuel Escalation**
  - d is the buyer's discount rate
  - e is the escalation rate of the annual savings

$$\text{PVF}(d,e,n) = \frac{1+e}{1+d} + \frac{(1+e)^2}{(1+d)^2} + \ldots + \left(\frac{1+e}{1+d}\right)^n = \frac{(1+d')^n - 1}{d'(1+d')^n}$$

$$\frac{1+e}{1+d} = \frac{1}{1+d'}$$

$$d' = \frac{d-e}{1+e}$$

REVIEW from DGD 03- Jan 21th

- **Finding The IRR When There is Fuel Escalation**

$$\text{NPV} = \Delta A \times \text{PVF}(d', n) - \Delta P \quad = 0$$

$$\text{PVF}(d', n) = \frac{\Delta P}{\Delta A} = \text{Simple payback period}$$

- IRR_0: Internal Rate of Return without Fuel Escalation
- IRR_e: Internal Rate of Return with Fuel Escalation

$$\text{IRR}_0 = \frac{d - e}{1 + e}$$

$$\text{IRR}_e = \text{IRR}_0(1 + e) + e$$

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Example 7. Net Present Value of Premium Motor with Fuel Escalation

- Q: The premium motor costs an extra $500 and saves $192/yr at today's price of electricity. If electricity rises at an annual rate of 5%, find the net present value of the premium motor if the best alternative investment earns 10%. (for 20 years)
- *Answer:*

$$d' = \frac{d-e}{1+e} = \frac{0.10-0.05}{1+0.05} = 0.04762$$

  – The present value function for 20 years of escalating savings is

$$\mathrm{PVF}(d', n) = \frac{(1+d')^n - 1}{d'(1+d')^n} = \frac{(1+04762)^{20} - 1}{0.04762(1+0.04762)^{20}} = 12.717 \text{ yr}$$

  – The net present value is

NPV = ΔA * PVF(d', n) – ΔP

NPV = $192/yr * 12.717 yr - $500 = $1942

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Example 8. IRR for an HVAC Retrofit Project with Fuel Escalation

- Q: Suppose the energy-efficiency retrofit of a large building
  - Reduces the annual electricity demand for heating and cooling from $2.3*10^6$kWh to $0.8*10^6$kWh and the peak demand for power by 150 kW
  - Electricity costs $0.06/kWh
  - Demand charges are $7/kW-mo
  - Both of which are projected to rise at an annual rate of 5%.

If the project costs $500,000, what is the internal rate of return over a project lifetime of 15 years?

Example 8. IRR for an HVAC Retrofit Project with Fuel Escalation

- *Answer:* The initial annual savings will be
  - Energy Savings: $(2.3 - 0.8)*10^6$ kWh/yr*$0.06/kWh = $90,000/yr
  - Demand Savings: 150 kW * $7/kW-mo * 12 mo/yr = $12,600/yr
  - Total Annual Savings: ΔA = $90,000 + $12,600 = $102,600/yr
- The Simple payback period will be

$$\text{Simple payback period} = \frac{\Delta P}{\Delta A} = \frac{\$500{,}000}{\$102{,}600/\text{yr}} = 4.87 \text{ yr}$$

- From Table 1, the internal rate of return without fuel escalation IRR_0 is very close to 19%.
- The internal rate of return with fuel escalation is

$$IRR_e = IRR_0(1 + e) + e = 0.19\ (1 + 0.05) + 0.05 = 0.2495 = 25\%/\text{yr}$$

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Table 1. Present Value Function to Help Estimate the Internal Rate of Return [a]

Life (years)	9%	11%	13%	15%	17%	19%	21%	23%	25%	27%	29%	31%	33%	35%	37%	39%
1	0.92	0.90	0.88	0.87	0.85	0.84	0.83	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.73	0.72
2	1.76	1.71	1.67	1.63	1.59	1.55	1.51	1.47	1.44	1.41	1.38	1.35	1.32	1.29	1.26	1.24
3	2.53	2.44	2.36	2.28	2.21	2.14	2.07	2.01	1.95	1.90	1.84	1.79	1.74	1.70	1.65	1.61
4	3.24	3.10	2.97	2.85	2.74	2.64	2.54	2.45	2.36	2.28	2.20	2.13	2.06	2.00	1.94	1.88
5	3.89	3.70	3.52	3.35	3.20	3.06	2.93	2.80	2.69	2.58	2.48	2.39	2.30	2.22	2.14	2.07
6	4.49	4.23	4.00	3.78	3.59	3.41	3.24	3.09	2.95	2.82	2.70	2.59	2.48	2.39	2.29	2.21
7	5.03	4.71	4.42	4.16	3.92	3.71	3.51	3.33	3.16	3.01	2.87	2.74	2.62	2.51	2.40	2.31
8	5.53	5.15	4.80	4.49	4.21	3.95	3.73	3.52	3.33	3.16	3.00	2.85	2.72	2.60	2.48	2.38
9	6.00	5.54	5.13	4.77	4.45	4.16	3.91	3.67	3.46	3.27	3.10	2.94	2.80	2.67	2.54	2.43
10	6.42	5.89	5.43	5.02	4.66	4.34	4.05	3.80	3.57	3.36	3.18	3.01	2.86	2.72	2.59	2.47
15	8.06	7.19	6.46	5.85	5.32	4.88	4.49	4.15	3.86	3.60	3.37	3.17	2.99	2.83	2.68	2.55
20	9.13	7.96	7.02	6.26	5.63	5.10	4.66	4.28	3.95	3.67	3.43	3.21	3.02	2.85	2.70	2.56
25	9.82	8.42	7.33	6.46	5.77	5.20	4.72	4.32	3.98	3.69	3.44	3.22	3.03	2.86	2.70	2.56
30	10.27	8.69	7.50	6.57	5.83	5.23	4.75	4.34	4.00	3.70	3.45	3.22	3.03	2.86	2.70	2.56

[a] Enter the row corresponding to project life, and move across until values close to the simple payback period, $\Delta P/\Delta A$, are reached. IRR is the interest rate in that column. For example, a 10-year project with a 5-year payback has an internal rate of return of just over 15%.

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REVIEW from DGD 03- Jan 21th

- **Annualizing the Investment:**
  - A represents annual loan payments ($/yr)
  - P is the principal borrowed ($)
  - i is the interest rate (e.g. 10% corresponds to $i = 0.10$/yr)
  - n is the loan term (yrs), and

$$A = P \times \mathrm{CRF}(i, n)$$

$$\mathrm{CRF}(i, n) = \text{Capital recovery factor}(\mathrm{yr}^{-1}) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

REVIEW from DGD 03- Jan 21th

Capital Recovery Factors as a Function of Interest Rate and Loan Term

Years	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%
5	0.2184	0.2246	0.2310	0.2374	0.2439	0.2505	0.2571	0.2638	0.2706	0.2774	0.2843
10	0.1172	0.1233	0.1295	0.1359	0.1424	0.1490	0.1558	0.1627	0.1698	0.1770	0.1843
15	0.0838	0.0899	0.0963	0.1030	0.1098	0.1168	0.1241	0.1315	0.1391	0.1468	0.1547
20	0.0672	0.0736	0.0802	0.0872	0.0944	0.1019	0.1095	0.1175	0.1256	0.1339	0.1424
25	0.0574	0.0640	0.0710	0.0782	0.0858	0.0937	0.1018	0.1102	0.1187	0.1275	0.1364
30	0.0510	0.0578	0.0651	0.0726	0.0806	0.0888	0.0973	0.1061	0.1150	0.1241	0.1334

Example 9. Comparing Annual Costs to Annual Savings

- Q: An efficient air conditioner that costs an extra $1000 and saves $200 per year is to be paid for with a 7% interest, 10-year loan.
  a. Find the annual monetary savings.
  b. Find the ratio of annual benefits to annual costs.
- *Answer:*
- The capital recovery factor:

$$\mathrm{CRF}(0.07, 10) = \frac{0.07(1+0.07)^{10}}{(1+0.07)^{10}-1} = 0.14238/\mathrm{yr}$$

- The annual payments will be A = $1000 * 0. 14238/yr = $142. 38/yr.

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Example 9. Comparing Annual Costs to Annual Savings

a. The annual savings will be \$200 − \$142. 38 = \$57. 62/ yr.
   – Notice that by annualizing the costs the buyer makes money every year so the notion that a 5-year payback period might be considered unattractive becomes irrelevant.

b. The benefit/cost ratio would be

$$\text{Benefit/Cost} = \frac{\$200/\text{yr}}{\$142.38/\text{yr}} = 1.4$$

Example 10. Cost of Electricity from a Photovoltaic System

- Q: A 3-kW photovoltaic system, which operates with a capacity factor (CF) of 0.25, costs $10,000 to install. There are no annual costs associated with the system other than the payments on a 6%, 20-year loan. Find the cost of electricity generated by the system (¢/kWh).

- *Answer:*
  - From Table the capital recovery factor is 0.0872/yr
  - The annual payment:

$$A = P \times \text{CRF}(0.06, 20) = \$10{,}000 \times 0.0872/\text{yr} = \$872/\text{yr}$$

Example 10. Cost of Electricity from a Photovoltaic System

- *Answer:*

(8760 = 365 * 24)

  – The annual electricity generated:

  Annual Energy (kWh/yr) = Rated Power (kW) * 8760 hr/yr * CF

  Annual energy = 3kW * 8760 h/yr * 0.25 = 6570 kWh/yr

  – The cost of electricity from the PV system is therefore

$$\text{Cost of PV electricity} = \frac{\$872/\text{yr}}{6570\ \text{kWh/yr}} = \$0.133/\text{kWh} = 13.3¢/\text{kWh}$$

REVIEW from DGD 04- Jan 31th

- Levelized Bus-Bar

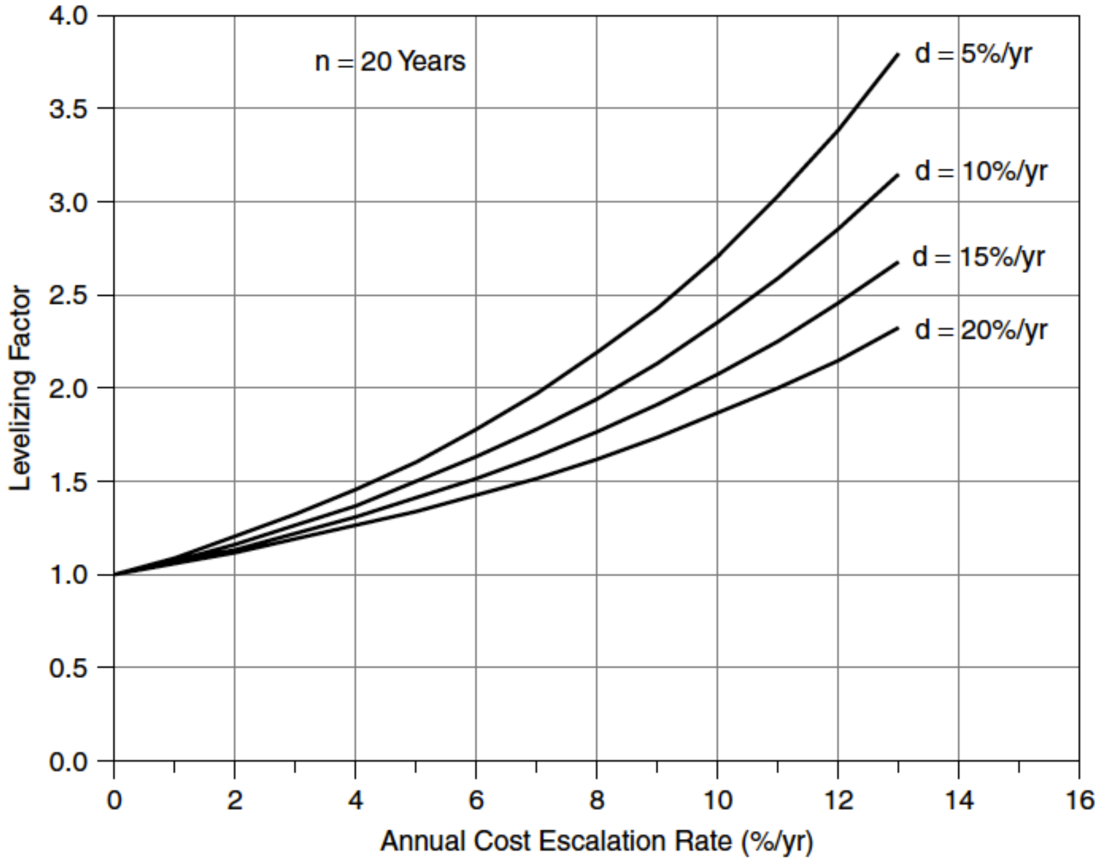
$$\text{Levelized annual costs} = A_0[\text{PVF}(d', n) \cdot \text{CRF}(d, n)]$$

$$\text{Levelizing factor (LF)} = \left[\frac{(1+d')^n - 1}{d'(1+d')^n}\right] \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

$$\text{Levelized annual costs(\$/kWh)} = \left[\text{Heat rate}\left(\frac{\text{Btu}}{\text{kWh}}\right) \times \text{Fuel}\left(\frac{\$}{\text{Btu}}\right) + \text{O \& M}\left(\frac{\$}{\text{kWh}}\right)\right]_0 \times \text{LF}$$

$$\text{Levelized fixed cost(\$/kWh)} = \frac{\text{Capital cost(\$/kW)} \times \text{FCR(1/yr)}}{8760\ \text{h/yr} \times \text{CF}}$$

Figure 2. Levelizing Factor



Example 11. Cost of Electricity from a Micro-turbine

- Q: A micro-turbine has the following characteristics:
  - Plant cost = \$850/kW
  - Heat rate = 12,500 Btu/kWh
  - Capacity factor = 0.70
  - Initial fuel cost = \$4.00/10^6 Btu
  - Variable O&M cost = \$0.002/kWh
  - Fixed charge rate = 0.12/yr
  - Owner discount rate = 0.10/yr
  - Annual cost escalation rate = 0.06/yr

Find its levelized (\$/kWh) cost of electricity over a 20-year lifetime

Example 11. Cost of Electricity from a Micro-turbine

- *Answer:*
  - We know:

$$\text{Levelized fixed cost}(\$/\text{kWh}) = \frac{\text{Capital cost}(\$/\text{kW}) \times \text{FCR}(1/\text{yr})}{8760\ \text{h/yr} \times \text{CF}}$$

  - Therefore:

$$\text{Levelized fixed cost} = \frac{\$850/\text{kW} \times 0.12/\text{yr}}{8760\ \text{h/yr} \times 0.70} = \$0.0166/\text{kWh}$$

  - We know: (Levelized annual costs = A_0* LF

$$\text{Levelized annual costs}(\$/\text{kWh}) = \left[\text{Heat rate}\left(\frac{\text{Btu}}{\text{kWh}}\right) \times \text{Fuel}\left(\frac{\$}{\text{Btu}}\right) + \text{O \& M}\left(\frac{\$}{\text{kWh}}\right)\right]_0 \times \text{LF}$$

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Example 11. Cost of Electricity from a Micro-turbine

– Therefore the initial annual cost for fuel and O&M is

A_0=12,500 Btu/kWh * \$400/10^6 Btu + \$0.002/kWh = \$0.052/kWh

This needs to be levelized to account for inflation.

– We know:

$$\text{Equivalent discount rate with fuel escalation} = d' = \frac{d - e}{1 + e}$$

– Therefore the inflation adjusted discount rate d would be

$$d' = \frac{d - e}{1 + e} = \frac{0.10 - 0.06}{1 + 0.06} = 0.037736$$

Example 11. Cost of Electricity from a Micro-turbine

– We know:

$$\text{Levelizing factor (LF)} = \left[\frac{(1+d')^n - 1}{d'(1+d')^n}\right] \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

– Therefore we have:

$$\text{Levelizing factor (LF)} = \left[\frac{(1.037736)^{20} - 1}{0.037736(1.037736)^{20}}\right] \cdot \left[\frac{0.10(1.10)^{20}}{(1.10)^{20} - 1}\right] = 1.628$$

– Levelized annual cost:

A_0LF = $0.052/kWh * 1.628 = $0.0847

– Levelized fixed plus annual cost:

– Levelized bus-bar cost = $0.0166/kWh + $0.0847/kWh = $0.1013/kWh