

AMERICAN RIVER COLLEGE

Electrical
Design 2 &
Financial
Analysis



Lesson Plan

- NABCEP Learning Objectives:
 Electric Design (part 2)
- Financial Analysis

Conductor Resistances*

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AWG	SOLID COPPER	STRANDED COPPER
18	7.77	7.95
16	4.89	4.99
14	3.07	3.14
12	1.93	1.98
10	1.21	1.24
8	0.764	0.778
6		0.491
4	-	0.308
3		0.245
2	. .	0.194
1	2	0.154
0 (1/0)	_	0.122
00 (2/0)		0.0967

^{*} in Ω/kft at 75°C (167°F)

Excerpted from NEC® Chapter 9, Table 8. Reprinted with permission from NFPA 70-2005, the National Electrical Code® Copyright® 2004, National Fire Protection Association, Quincy, MA 02169. This reprinted material is not the official position of the NFPA on the referenced subject which is represented solely by the standard in its entirety.

 Larger conductors have lower resistance for a given length. rgyinstructor.info

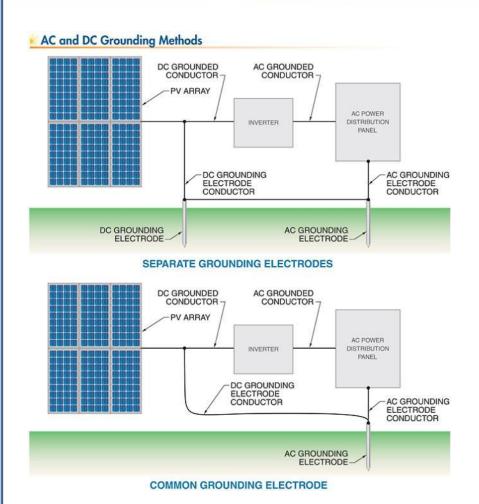
Understanding PV module specifications and electrical design limits

Electrical Characteristics	1000W/m ² (STC ¹)
Maximum Power (P _{max})	220W
Voltage at MPP (V _{mpp})	29.0V
Current at MPP (I _{mpp})	7.6A
Short circuit current (I _{sc})	8.4A
Open circuit voltage (V _{cc})	36.2V

Specifications

■ Electrical Performance under Standard Test Conditions (*STC)				
Maximum Power (Pmax)	135W (+5%/-5%)			
Maximum Power Voltage (Vmpp)	17.7V			
Maximum Power Current (Impp)	7.63A			
Open Circuit Voltage (Voc)	22.1V			
Short Circuit Current (Isc)	8.37A			
Max System Voltage	600V			
Temperature Coefficient of Voc	080 V/°C			
Temperature Coefficient of Isc	5.02×10 ⁻³ A/°C			

^{*}STC: Irradiance 1000W/m2, AM1.5 spectrum, cell temperature 25°C



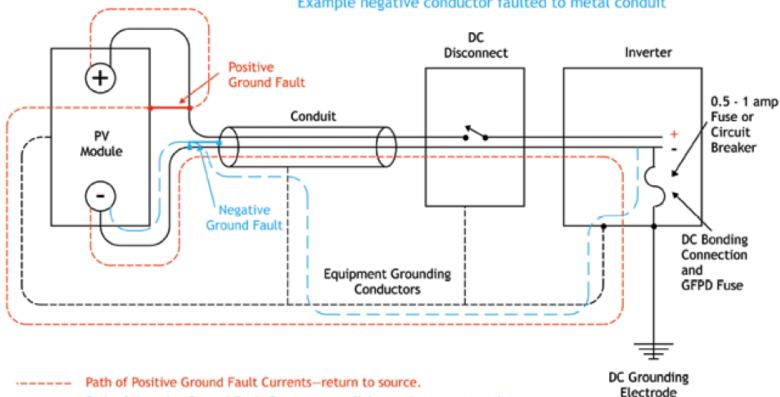
 There are two acceptable methods of grounding both the AC and DC sides of a PV system.

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Ground-Fault Current Paths

Example positive conductor faulted to PV module frame

Example negative conductor faulted to metal conduit

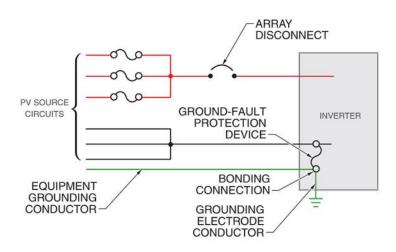


Path of Negative Ground Fault Currents-parallel negative current paths.

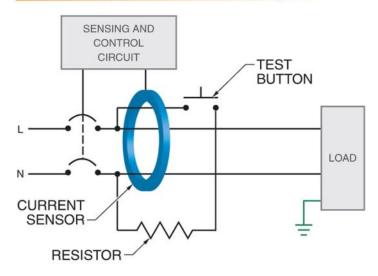
All ground-fault currents must flow through the DC bonding connection.

Any time positive or negative ground-fault currents exceed ground-fault fuse/breaker rating, that device opens and ground-fault currents are interrupted.

Array Ground-Fault Protection with Inverter Fuse



Ground-Fault Circuit Interrupter



A ground-fault circuit interrupter (GFCI) senses differences between the current in the grounded and ungrounded conductors, indicating a ground fault, and opens the circuit in response.

 Many articles in the NEC® are applicable to the electrical integration of a PV system, particularly Article 690.

Selected Applicable NEC® Articles

110*	Requirements for Electrical Installations
200	Use and Identification of Grounded Conductors
210*	Branch Circuits
220	Branch-Circuit, Feeder, and Service Calculations
230*	Services
240*	Overcurrent Protection
250*	Grounding and Bonding
280	Surge Arrestors
285	Transient Voltage Surge Suppressors: TVSSs
300	Wiring Methods
310*	Conductors for General Wiring
334	Nonmetallic-Sheathed Cable: Types NM, NMC, and NMS
338	Service-Entrance Cable: Types SE and USE
340*	Underground Feeder and Branch Circuit Cable: Type UF
400*	Flexible Cords and Cables
422	Appliances
445	Generators
450*	Transformers and Transformer Vaults
480*	Storage Batteries
490*	Equipment, Over 600 Volts, Nominal
690	Solar Photovoltaic Systems
702	Optional Standby Systems
705*	Interconnected Electric Power Production Sources
720	Circuits and Equipment Operating at Less Than 50 Volts

^{*} Articles directly referenced in Article 690

- What do we mean by PV financial analysis?
- Why do we care?
- How do we measure?

- Important terms
 - PNL NOPAT

• GM% OPEx

ROI PAYBACK

Lifecycle Cost Analysis IRR

Time Value of Money Discount rate

NPV

GM% = Gross Margin Percentage

OPEx = Operating Expenses

ROI = Return on Investment

PAYBACK = Payback period required for avoided costs of alternate energy system to match the cost of chosen system

Lifecycle Cost Analysis = Total cost of all expenses incurred over the life of a system

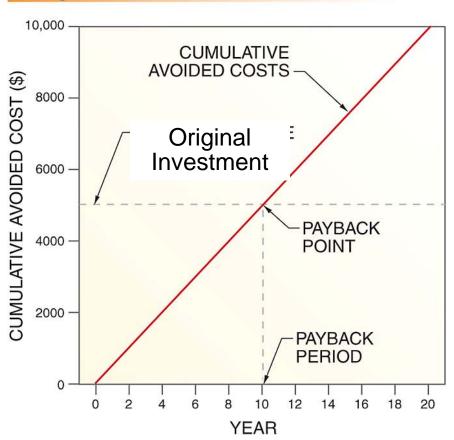
IRR = Internal Rate of Return

Time Value of Money = Value of money figuring in a given amount of interest earned over a given amount of time

Discount rate = Rate at which future value of money is reduced to its present value

NPV = **Net Present Value**

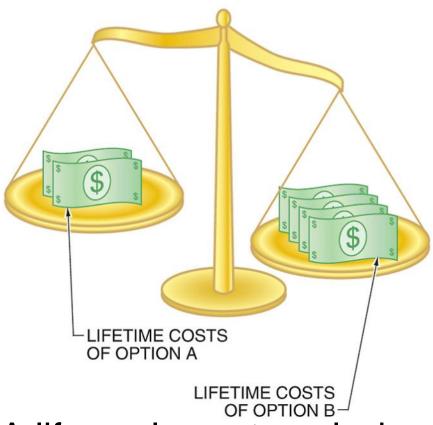
Payback Point



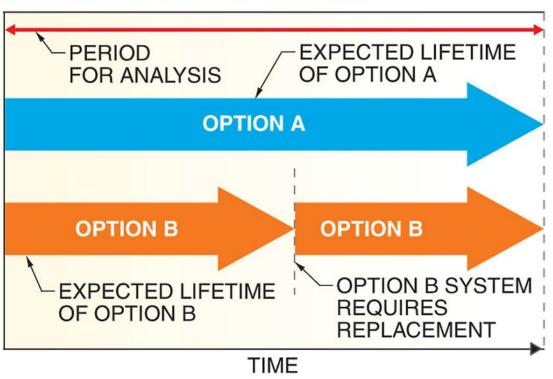
- What's the problem with payback method of analysis?
- Timing of Cash
- Cash after payback
- Arbitrary standard

The payback point occurs when the cumulative avoided cost equal the initial investment.

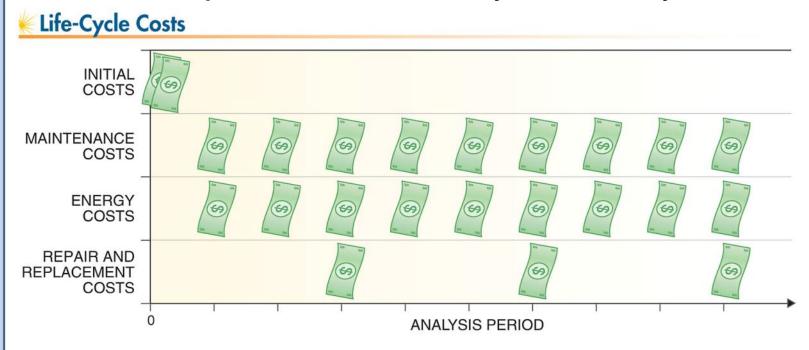
Life-Cycle Cost Analysis



A life-cycle cost analysis compares the lifecycle costs of various electricity-supply options.



 Each system option must meet the same requirements, including the length of time used to calculate life-cycle cost. The various types of life-cycle costs occur at different points in the life cycle of a system.



 The life-cycle cost analysis of an enginegenerator system includes each type of cost.

System: Engine Generator

Life-Cycle Costs for Engine Generator

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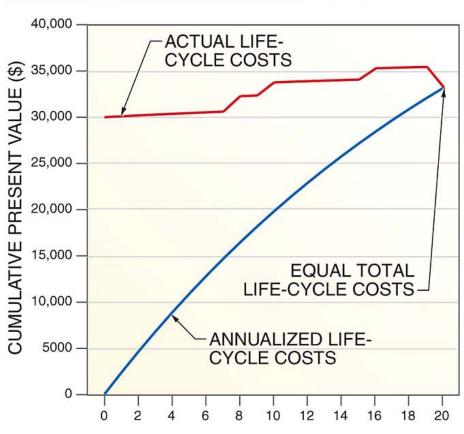
System: Engine Generator						
Cost Description	Cost/Year	Single Cost Year				
Initial Costs						
System Purchase and Installation	\$8,500	0				
Maintenance Costs						
Engine Inspection and Oil Changes	\$200					
Energy Costs						
Diesel Fuel	\$2,145					
Repair and Replacement Costs						
Engine Rebuild	\$1,000	5				
Engine Rebuild	\$1,000	10				
Engine Rebuild	\$1,000	15				
Inverter Replacement	\$2,000	10				
Battery Bank Replacement	\$1,500	8				
Battery Bank Replacement	\$1,500	16				
Salvage Value						
Salvage	\$1,500	20				

• The most significant costs in the life cycle of a PV system are the initial costs.

Life-Cycle Costs for PV System

System:	PV System	
Cost Description	Cost/Year	Single Cost Year
Initial Costs		
System Purchase and Installation	\$30,000	0
Maintenance Costs		
Inspections	\$100	
Energy Costs		
Repair and Replacement Costs		
Inverter Replacement	\$2,000	10
Battery Bank & Module Replacements	\$2,200	8
Battery Bank & Module Replacements	\$2,200	16
Salvage Value		
Salvage	\$5,000	20

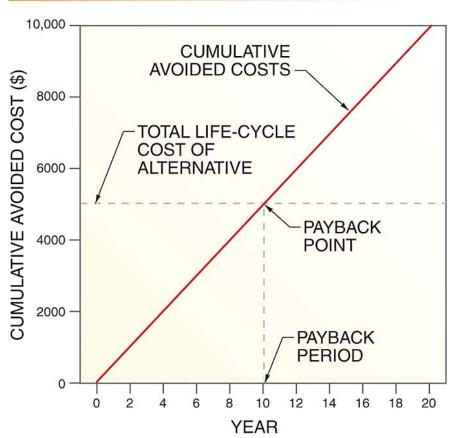
Annualized Costs



YEAR

 Annualizing costs spreads costs evenly over the operating period, but results in the same total life-cycle cost for a system.

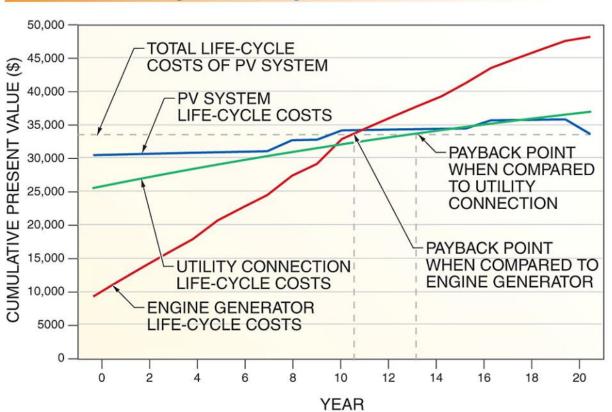
Payback Point



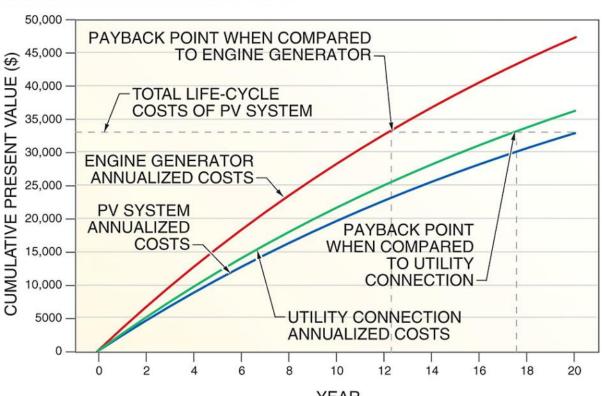
 The payback point occurs when the cumulative avoided cost of one system matches the total life-cycle cost of another system.

 The payback point can be determined by comparing the actual life-cycle costs of the various system options.

Actual-Cost Payback Analysis

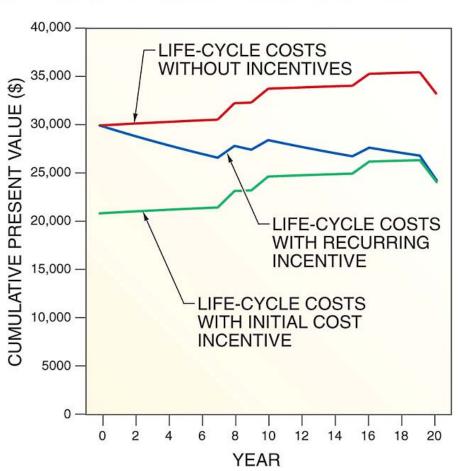


Annualized-Cost Payback Analysis



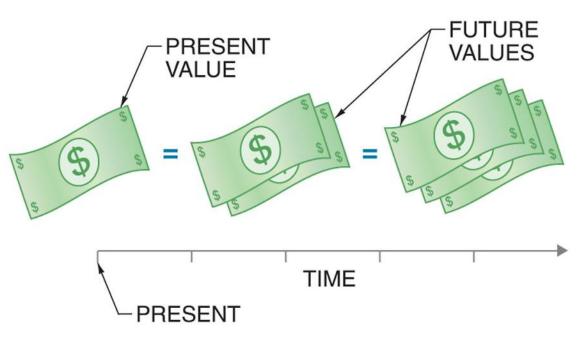
 The annualized-cost method of determining the payback period is relatively simple, though it may be less accurate than the actual-cost method.

Life-Cycle Costs with Incentives



 Incentives affect the total life-cycle cost differently, depending on how and when they are applied.

Value of Money

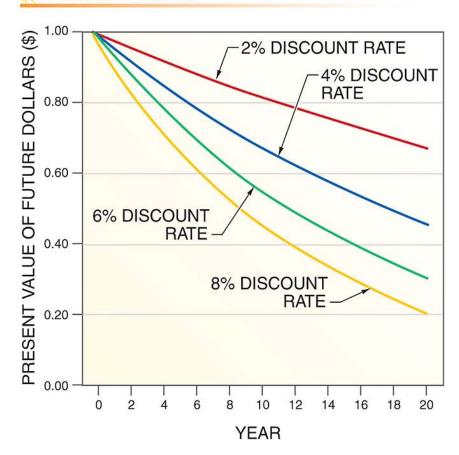


 A certain amount of present money is equal to a greater face-value amount of future money. The difference in face value depends on the difference in time.

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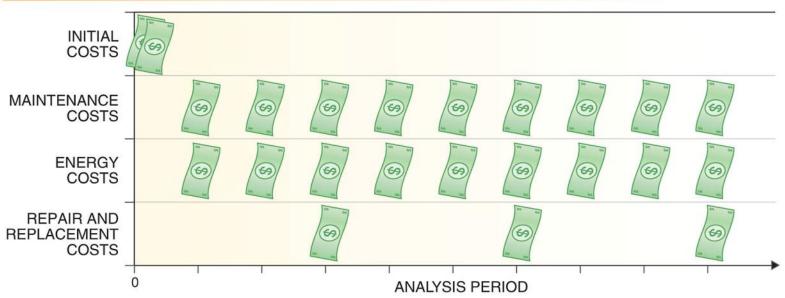
 The present value of future money falls more quickly with higher discount rates.

Discount Rates



The various types of life-cycle costs occur at different points in the life cycle of a system.

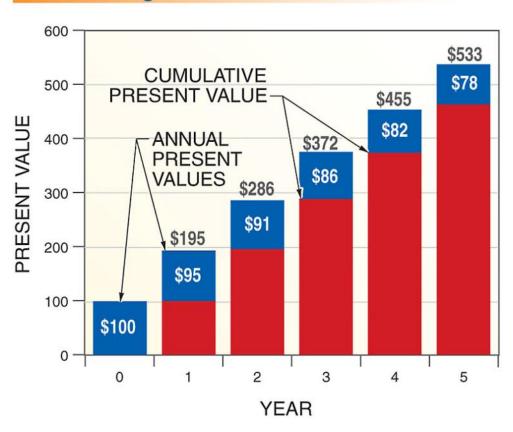
Life-Cycle Costs



NPV requires more math...

NPV =
$$-C0 + C1/(1+r) + C2/(1+r)^2 + C3/(1+r)^3 + C4/(1+r)^4 + ... CT/(1+r)^T$$

Recurring Costs



Related costs that occur every year are calculated and added together for each year to determine the total present value.

• The life-cycle cost analysis of an enginegenerator system includes each type of cost.

Life-C	ycle	Costs	for	Engine	Generator
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LIFE-CYCLE COSTS		General Discount Rate: 0.04					
System:	Engine Ger	nerator	Energy Costs Discount Rate: 0.03				
Cost Description	Cost/Year	Single Cost Year	Recurring Cost Years	Present Value Factor	Present Value		
Initial Costs							
System Purchase and Installation	\$8,500	0		1.000	\$8,500		
Maintenance Costs					-		
Engine Inspection and Oil Changes	\$200		20	13.59	\$2,718		
Energy Costs							
Diesel Fuel	\$2,145		20	14.88	\$31,918		
Repair and Replacement Costs	******		501	2.5	111 33 34		
Engine Rebuild	\$1,000	5		0.822	\$822		
Engine Rebuild	\$1,000	10		0.676	\$676		
Engine Rebuild	\$1,000	15		0.555	\$555		
Inverter Replacement	\$2,000	10		0.676	\$1,352		
Battery Bank Replacement	\$1,500	8		0.731	\$1,097		
Battery Bank Replacement	\$1,500	16		0.534	\$801		
Salvage Value							
Salvage	\$1,500	20		0.456	-\$684		
	· · · · · · · · · · · · · · · · · · ·	 	Total Li	fe Cycle Costs	\$47,755		

• The most significant costs in the life cycle of a PV system are the initial costs.

Life-Cycle Costs for PV System

LIFE-CYCLE COSTS	DV Custom		General Discount Rate: 0.04 Energy Costs Discount Rate: 0.03			
Cost Description	PV System Cost/Year	Single Cost Year	Recurring Cost Years	Present Value Factor	Present Value	
Initial Costs						
System Purchase and Installation	\$30,000	0		1.000	\$30,000	
Maintenance Costs						
Inspections	\$100		20	13.59	\$1,359	
Energy Costs			I			
Repair and Replacement Costs						
Inverter Replacement	\$2,000	10		0.676	\$1,352	
Battery Bank & Module Replacements	\$2,200	8		0.731	\$1,608	
Battery Bank & Module Replacements	\$2,200	16		0.534	\$1,175	
Salvage Value						
Salvage	\$5,000	20		0.456	-\$2,280	
			Total Li	fe Cycle Costs	\$33,214	

Internal rate of Return is the resulting r if NPV = 0

NPV =
$$-C0 + C1/(1+r) + C2/(1+r)^2 + C3/(1+r)^3 + C4/(1+r)^4 + ... CT/(1+r)^T$$

$$0 = -C0 + C1/(1+r) + C2/(1+r)^2 + C3/(1+r)^3 + C4/(1+r)^4 + \dots CT/(1+r)^T$$

Does not require discount rate to solve Scale problem Timing problem

Sometimes referred to as 'hurdle rate'