Solar District Cup

Project Sponsor:

U.S. Department of Energy

National Renewable Energy Laboratory

Faculty Advisor:

David Trevas

Team:

Corey Burke, Grant Hale, Elizabeth Griffith, &
Daniel McConnell

Project Description: Review

What:

Design a photovoltaic solar energy and storage system for a campus or district that maximizes energy offset and financial savings over a 20 year time period [1].

How:

Assume the role of solar energy and storage developer to produce a proposal and analyze electric distribution grid interactions for district use [1].

Importance:

The U.S. is moving more towards renewable energy sources and solar is a cost effective resource.

Project Description: Sponsors

U.S. Department of Energy (DOE)

- Garrett Nilesen
- Shamara Collins

Figure 1: U.S. Department of Energy [2]

National Renewable Energy Laboratory (NREL)

- Sara Farrar
- Travis Lowder
- Joe Simon

Aurora Solar is providing tools for system design. [1]

Figure 2: National Renewable Energy Laboratory [3]

Background & Benchmarking: Solar Panels

- Solar panels are built of photovoltaic cells
- **Photovoltaic (PV) cells** get their name from the process of turning solar energy into usable electricity.
  - Monocrystalline - very efficient high cost [4]
  - Polycrystalline - moderate efficiency and cost [4]
  - Thin film cells - very inefficient but lowest cost [4]

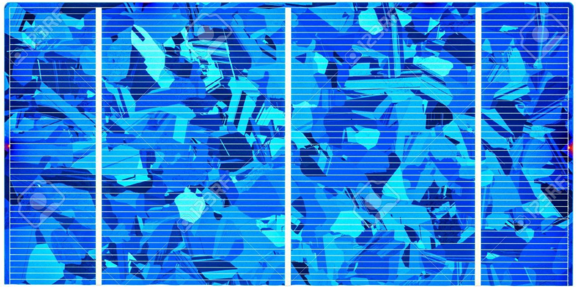

Figure 3: U.S. Department of Energy [5]

Background & Benchmarking: SOTA

We are limited to using only PV cells and battery storage

- High efficiency (Gallium Arsenide) [4]
  - Primarily used in space; very expensive
- Solar tracking [7]
  - Worth the energy to rotate?
- Calcium batteries vs Li [6]
  - Calcium looks promising but isn't fully developed yet

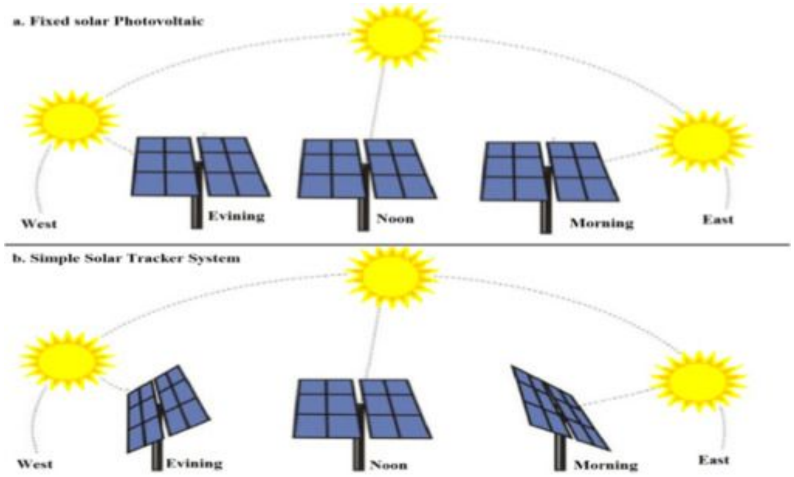

Figure 4: U.S. Department of Energy [7]

Background & Benchmarking: Benchmarking

Compare types of PV panels their cost and efficiency

Table 1: Cells Cost and Efficiency [8,9,10]

PV Cells	Cost	Efficiency loss at 20 years	Maximum generation	Dimensions
Polycrystalline	$52	13.8%	.275 KWh	65x39x1.4 inches
Monocrystalline	$165	13%	.335 KWh	77x39x1.5 inches
Thin Film	$17	20%	.001KWh	7.7x3.1x.1 inches

Literature Review: All References (1)

Table 2: References Used by the Team

Reference:	Type:	Relevant Information:	Used by:
Principles of Sustainable Energy Systems [11]	Book	Equations for calculations of solar panels	All members
Battery Energy Storage for Enabling Integration of Distributed Solar Power Generation [12]	Journal Article	Basics of battery energy storage	Daniel McConnell
Training Webinars [1]	Video	Learn basics of solar energy production and modeling systems available	All members
Solar Energy Engineering: Processes and Systems [13]	Book	Info on analysing photovoltaic systems	Corey Burke
Types of photovoltaic cells [4]	Website	Types of photovoltaic cells	All members
Optimal azimuth and elevation angles prediction control method and structure for the dual-axis sun tracking system [14]	Article	Info on solar tracking technology	Elizabeth Griffith
Electric Renewable Energy Systems [15]	Book	Electrical Engineering	All members
Engineering Economics [16]	Book	Engineering Finances	Grant Hale
System Advisor Model (SAM) [17]	Program	Create online model of project	All members

Literature Review: Useful Sources (2)

Principles of Sustainable Energy Systems [11]:

- Used by all members
- Primarily used by Corey Burke
- Basic concepts of solar energy
- Equations for rough calculations

Training Webinars [1]:

- Used by all members
- Rules
- Training videos on solar energy basics
- Training videos for online tools

Literature Review: Useful Sources (3)

Engineering Economics [16]:

- Used by Grant Hale
- General Equations for calculating economically viable
- Costs of maintenance
- Costs of Utilities
- Costs of Labor
- Initial Costs

System Advisor Model (SAM) [17]:

- Used by all members
- Videos on PV solar panels
- Model the solar model
- Weather and wind data
- Create financial model

CRs & ERs: Customer Requirements

Table 3: Generated Customer Requirements

Customer Requirements	
offset annual energy and power consumption	**maximizes financial savings over 20 years**
aestheticly pleasing	energy output based on a reasonable yield factor
optimized distributed energy system	voltage within expected bandwidth
includes solar photovoltaic generation	all network elements satisfy loading and voltage constraints
has battery electric storage	active elements have realistic settings, responses, and dead times
power purchase agreement	optimal battery use
financial viability	cost within budget
reasonable PV location	durable & robust design
reliable design	

Customer requirements have been taken from the Solar District Cup 2020 Rules [1].

*Customer requirements concerning compliance with district codes will be updated once the district has been assigned.

CRs & ERs: Engineering Requirements (1)

Most important:

- The amount of power required is greater than or equal to the amount of energy generated
- Savings are maximized over 20 years

Table 4: Generated Engineering Requirements from Customer Needs

Customer Requirements		
offset annual energy and power consumption • Power generated • Placement • Energy loss • Cost • Battery storage capacity • Life cycle • Electricity savings/year • Incident angle • Energy generated/energy needed	**maximizes financial savings over 20 years** • Power generated • Placement • Energy loss • Cost • Battery storage capacity • Life cycle • Maintenance/labor cost • Replacement parts • Electricity savings/year • Incident angle • Energy generated/energy needed • Safety	has battery electric storage • Placement • Energy loss • Cost • Battery storage capacity • Life cycle • Electricity savings/year • Energy generated/energy needed • Safety
optimized distributed energy system • Placement • Energy loss • Battery storage capacity • Life cycle • Incident angle • Energy generated/energy needed • Safety	energy output based on a reasonable yield factor • Power generated • Placement • Energy loss • Battery storage capacity • Incident angle • Energy generated/energy needed	active elements have realistic settings, responses, and dead times • Power generated • Placement • Energy loss • Electricity savings/year • Incident angle • Energy generated/energy needed

CRs & ERs: Engineering Requirements (2)

Table 5: Additional Generated Engineering Requirements from Customer Needs

Customer Requirements		
reliable design • Placement • Energy loss • Life cycle • Maintenance/labor cost • Incident angle	voltage within expected bandwidth • Power generated • Placement • Energy loss • Battery storage capacity • Incident angle • Energy generated/energy needed	financial viability • Power generated • Energy loss • Cost • Life cycle • Electricity savings/year • Energy generated/energy needed
power purchase agreement • Power generated • Placement • Energy loss • Cost • Battery storage capacity • Life cycle • Electricity savings/year • Energy generated/energy needed • Safety	all network elements satisfy loading and voltage constraints • Power generated • Placement • Energy loss • Battery storage capacity • Electricity savings/year • Incident angle • Energy generated/energy needed • Safety	aesthetically pleasing • Placement • Life cycle • Maintenance cost • Safety cost within budget • Cost • Maintenance/labor cost • Replacement parts durable & robust design • maintenance/labor cost • Safety
includes solar photovoltaic generation Power generated • Placement • Cost • Life cycle • Electricity savings/year • Incident angle • Energy generated/energy needed	reasonable PV location • Power generated • Placement • Energy loss • Life cycle • Maintenance/labor cost • Electricity savings/year • Incident angle • Safety	optimal battery use • Energy loss • Battery storage capacity • Life cycle • Maintenance/labor cost • Replacement parts • Electricity savings/year • Energy generated/energy needed

Engineering requirements were generated by converting customer requirements into concepts that could quantify them.

CRs & ERs: House of Quality (1)

Table 6: House of Quality

Customer Requirement	Weight/Engineering Requirement	Power generated (KWh)	placement (hrs sun/day)	Energy loss (KWh)	cost ($)	battery storage capacity (KWh)	life cycle (years)	maintenance/labor cost ($)	replacement parts ($)	electricity savings/year ($/yr)	incident angle (deg)	energy generated/energy needed per year	Safety (1-10)
offset annual energy and power consumption	5	9	9	9	9	9	9	3	3	9	9	9	3
aesthetically pleasing	3		9		3		9	9	9		1		9
optimized distributed energy system	2	3	9	9		9	9	3	3	1	9	9	9
includes solar photovoltaic generation	4	9	9	3	9	1	9	3	3	9	9	9	3
has battery electric storage	5	3	9	9	9	9	9	3	3	9		9	9
maximizes financial savings over 20 years	2	9	9	9	9	9	9	9	9	9	9	9	9
power purchase agreement	3	9	9	9	9	9	9	3	3	9	3	9	9
financial viability	5	9		9	9	3	9	3	3	9	3	9	3
reasonable PV location	4	9	9	9	3	3	9	9	3	9	9	3	9
energy output based on a reasonable yield factor	4	9	9	9	3	9	3	3	3	3	9	9	
voltage within expected bandwidth	3	9	9	9	3	9	3			3	9	9	3
all network elements satisfy loading and voltage constraints	4	9	9	9	3	9	3	3	3	9	9	9	9
active elements have realistic settings, responses, and dead times	3	9	9	9	3	3	3	3	3	9	9	9	3
optimal battery use	4	3	3	9		9	9	9	9	9	3	9	1
cost within budget	5	3	3	3	9	3	3	9	9	3	3	3	3
durable & robust design	3	3	3	3	3	3	3	9	3	3	3	3	9
Reliable design	4	3	9	9	3	3	9	9	3	3	9	3	3
Absolute Technical Importance (ATI)		402	450	468	345	364	435	330	264	410	378	444	325
Relative Technical Importance (RTI)		6	2	1	9	8	4	10	12	5	7	3	11
Target ER values		E	D	D	D	U	U	D	D	U	E	U	U
Tolerances of Ers													

0: No Relation
1: Low Positive
3: Medium Positive
9: Strong Positive

Most important ERs:

1. Energy Loss
2. Placement of Panels
3. Ratio of Energy Generated to Energy Needed
4. Life Cycle of Panels
5. Electricity Savings

CRs & ERs: House of Quality (2)

Table 7: Portion of HOQ showing ATI & RTI

Customer Requirement	Weight/Engineering Requirement	Power generated (KWh)	placement (hrs sun/day)	Energy loss (KWh)	cost ($)	battery storage capacity (KWh)	life cycle (years)	maintenance/labor cost ($)	replacement parts ($)	electricity savings/year ($/yr)	incident angle (deg)	energy generated/energy needed per year	Safety (1-10)
Absolute Technical Importance (ATI)		402	450	468	345	364	435	330	264	410	378	444	325
Relative Technical Importance (RTI)		6	2	1	9	8	4	10	12	5	7	3	11
Target ER values		E	D	D	D	U	U	D	D	U	E	U	U
Tolerances of Ers													

Our district has not been assigned yet so the team cannot determine expected values without knowing land area available. For now, the team has approximated which direction each ER is desired to have.

Once assigned, these values will be analyzed, and the chart updated.

Schedule & Budget: Gantt Chart (1)

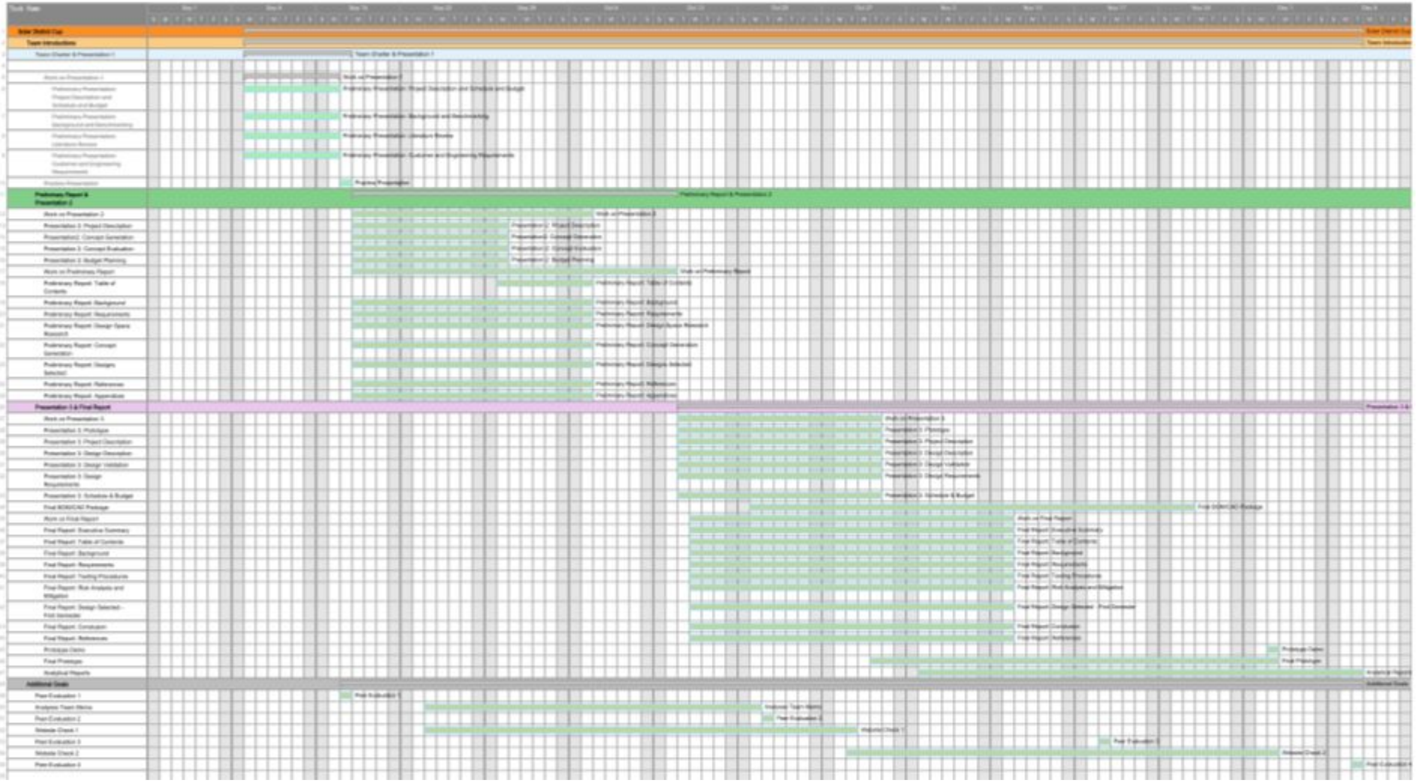

Figure 5: Overview of Gantt Chart for Fall 2019 Semester

Schedule & Budget: Gantt Chart (2)

	Hot	Task Name	Feature Type	Story Points	Duration	Start	Finish	Predecessors	Status
3		~~Team Charter & Presentation 1~~			~~7d~~	~~09/09/19~~	~~09/17/19~~		~~Complete~~
4		~~Work on Presentation 1~~			~~6d~~	~~09/09/19~~	~~09/16/19~~		~~Complete~~
5		~~Preliminary Presentation: Project Description and Schedule and Budget~~			~~6d~~	~~09/09/19~~	~~09/16/19~~		~~Complete~~
6		~~Preliminary Presentation: Background and Benchmarking~~			~~6d~~	~~09/09/19~~	~~09/16/19~~		~~Complete~~
7		~~Preliminary Presentation: Literature Review~~			~~6d~~	~~09/09/19~~	~~09/16/19~~		~~Complete~~
8		~~Preliminary Presentation: Customer and Engineering Requirements~~			~~6d~~	~~09/09/19~~	~~09/16/19~~		~~Complete~~
9		~~Practice Presentation~~			~~1d~~	~~09/17/19~~	~~09/17/19~~		~~Complete~~

Figure 6: Grid view of Gantt Chart for Fall 2019 Semester

Schedule & Budget: Gantt Chart (3)

	Hot	Task Name	Feature Type	Story Points	Duration	Start	Finish	Predecessors	Status
10		**Preliminary Report & Presentation 2**			19d	09/18/19	10/14/19		
11		Work on Presentation 2			14d	09/18/19	10/07/19		Not Started
12		Presentation 2: Project Description			9d	09/18/19	09/30/19		Not Started
13		Presentation2: Concept Generation			9d	09/18/19	09/30/19		Not Started
14		Presentation 2: Concept Evaluation			9d	09/18/19	09/30/19		Not Started
15		Presentation 2: Budget Planning			9d	09/18/19	09/30/19		Not Started
16		Work on Preliminary Report			19d	09/18/19	10/14/19		Not Started
17		Preliminary Report: Table of Contents			6d	09/30/19	10/07/19		Not Started
18		Preliminary Report: Background			14d	09/18/19	10/07/19		Not Started
19		Preliminary Report: Requirements			14d	09/18/19	10/07/19		Not Started
20		Preliminary Report: Design Space Research			14d	09/18/19	10/07/19		Not Started
21		Preliminary Report: Concept Generation			14d	09/18/19	10/07/19		Not Started
22		Preliminary Report: Designs Selected			14d	09/18/19	10/07/19		Not Started
23		Preliminary Report: References			14d	09/18/19	10/07/19		Not Started
24		Preliminary Report: Appendices			14d	09/18/19	10/07/19		Not Started

Figure 7: Grid view of Gantt Chart for Fall 2019 Semester

Schedule & Budget: Budget

Available Dollars: TBD

Anticipated Expenses: $2010 + taxes

- Travel
  - **Driving**
    - Flagstaff, Az to Phoenix, Az $25
    - Phoenix, Az to Flagstaff, Az $25
  - **Flights**
    - Phoenix, Az to Atlanta, Ga
      - 4 Tickets @ $365 each + taxes
  - **Hotel**
    - Atlanta, GA
      - 2 Nights, 2 Rooms @ $500 total

Potential Prototyping: $75

Expenses to Date: $0

Resulting Balance: TBD

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Questions?