UNIVERSITY OF TOLEDO PVIC SOLAR ARRAY MODIFICATIONS

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Prepared by Ted Davis and Randy Ellingson

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Current Configuration

Array #2 wired for the electrolyzer as follows: All 108 panels are wired in parallel resulting in an mpp at STC of Vmpp = 62 V and Impp = 100.5 A. There are six zones, each of which can be turned off or on presumably affecting the total current delivered.

urrent So	lar A	rray					В	uildi	ng R	1									Mc	dul	es a	ll w	ired	in par	all
													6,210 V	V DC (I	Peak P	ower	@ STC)								_
				108 Pane	ls (FS-25	7)	Ar	ray #	2 (DC	2 (DC Powe			62 VDC Nominal Peak Voltage, 89				9 VDC	VDC (Open Circuit Voltage)							
													100.44	Amps	(Peak	Powe	r Curre	nt), 122	2.94 Ar	nps (Sl	nort Ci	rcuit C	urrent)		
	HD Sa	afety		HC) Safety		HD	Safety		1	HD Safe	ety				HD Sa	fety			HD Sa	fety				
	Swite	h 1	СВ	Sw	/itch 2	СВ	Swi	tch 3	СВ		Switch	4	СВ			Switc	h 5	СВ		Switc	n 6	СВ			
		Zone	1		Zone	2		Zone	3			Zone 4					Zone	5			Zone	6			
		18 Pa	nels		18 D	anels		18 Da	nols			18 Dan	ماد				18 Pa	nols			18 Da	- nels			
Sensor		101 0			1011							101 01					1010				1010				
Scribbi																									
		18 Pa	nels w	ired in par	allel into	each Combi	ner Box (CB)																		
													6.210 V		Peak P	ower	@ STC)								
				108 Pane	Is (FS-25	7)	Ar	rav #	1 (Tie	d to 🤆	Grid)		372 VD	C Non	ninal P	eak Vo	oltage.	534 VD	QO) O	en Circ	uit Vo	tage)			
	HD Sa	afety				/		1	· •		- 1		16.74 A	mps (Peak P	ower	Curren	t). 20.3	4 Amp	s (Sho	rt Circi	it Curr	ent)		
	Swite	h 1																							
	String	7 1		St	ing 3 - 16	(Danols)		Strin	g 7 - (6 E	(anols)				String	11 - /6	Danol	c)			String	15 - (6	Danol	c)		
	6 Don	olc		St.	ring 4 - (6	(Panols)		Strin	g 9 - (6 r	Danols)				String	12 - (6	Panel	-) c\			String	16 - (6	Danol	-)		
	0 Fail	String		St.	ring 5 (6	(Panels)		Strin	g 0 - (0 P	anels)	_			String	12 - (0	Panel	>) c)			String	17 (6	Danel	-)		
		Suring	2	Su	ning 5 - (d	Panels)		Strin	g 9 - (0 F	aneis)				string	13 - (0	Panel	5)			String	17 - (0	Paner	5)		
		6 Pan	eis	St	ring o - (o	Panels)		Strin	g 10 - (6	Panels)			string	14 - (0	Panel	s)			String	18 - (6	Panel	5)		
		E			la in Cari																				
		Each	string	nas 6 Pane	is in Seri	es																			
							D	orr 9	St																

Array #1 wired for connection to the SunnyBoy inverter (grid-tied) such that sets of six modules are wired together in series into a "string", and then 18 "string" of 6 modules are wired in parallel resulting in an mpp at STC of Vmpp = 372 V and Impp = 16.7 A.

Assumptions:

- Electricity Cost: \$0.05/kWh
- No upgrade to existing electrical service
- Electrician labor: \$100/hr
- Time to rewire a module: one electrician, 5 minutes
- Replace a First Solar module (Scenarios B and C): 2 electricians working for 10 minutes
- Install power inverter: 2 men, 2 hours
- Solar module cost = \$1.00/watt
- Resale of used First Solar modules = \$0.30/Watt

<u>Scenario A</u> Tie Array #2 to Grid (add inverter)

Scenario A: Current Solar Modules

- Manufacturer: First Solar
- Model #: FS-257 CdTe
- Electrical Specs @ STC
 - Power: 58 Watts
 - Voltage: 61.5 Volts
 - Current: .94 Amps
 - Efficiency: 8%
- Mechanical Spec.
 - Width: 600 mm
 - Length: 1200 mm
 - Area: 0.72 m
 - Weight: 25.1 lbs.

Scenario A: Configuration

r Array	- Schema 1		Building R1		
				6,210 W DC (Peak Power @ STC)	
		108 Panels (FS-257)	Array # 2 (Tied to Grid)	372 VDC Nominal Peak Voltage, 534	VDC (Open Circuit Voltage)
				16.74 Amps (Peak Power Current), 20	0.34 Amps (Short Circuit Current)
	HD Safety				
	Switch 1				
	String 1	String 3 - (6 Panels)	String 7 - (6 Panels)	String 11 - (6 Panels)	String 15 - (6 Panels)
	6 Panels	String 4 - (6 Panels)	String 8 - (6 Panels)	String 12 - (6 Panels)	String 16 - (6 Panels)
	String 2	String 5 - (6 Panels)	String 9 - (6 Panels)	String 13 - (6 Panels)	String 17 - (6 Panels)
Sensor	6 Panels	String 6 - (6 Panels)	String 10 - (6 Panels)	String 14 - (6 Panels)	String 18 - (6 Panels)
		108 Panels (FS-257)	Array # 1 (Tied to Grid)	372 VDC Nominal Peak Voltage, 534	VDC (Open Circuit Voltage)
		108 Parleis (FS-257)	Array # 1 (neu to Ghu)	16 74 Amps (Deak Dewer Current) 20	0.24 Amps (Short Circuit Current)
	Switch 1			10.74 Amps (Feak Fower current), 24	
	String 1	String 3 - (6 Panels)	String 7 - (6 Panels)	String 11 - (6 Panels)	String 15 - (6 Panels)
	6 Panels	String 4 - (6 Panels)	String 8 - (6 Panels)	String 12 - (6 Panels)	String 16 - (6 Panels)
	String 2	String 5 - (6 Panels)	String 9 - (6 Panels)	String 13 - (6 Panels)	String 17 - (6 Panels)
	6 Panels	String 6 - (6 Panels)	String 10 - (6 Panels)	String 14 - (6 Panels)	String 18 - (6 Panels)
	Each String	, has 6 Panels in Series			
			Dorr St		

Scenario A: DC Output Expected from Array #2

- 6 Panels/String
- 18 Strings
- 108 Panels
- 6,210 W DC (peak power @ Standard Test Conditions (STC))
- 372 VDC nominal peak voltage
- 534 VDC open circuit voltage
- 16.74 Amps at maximum power point (mpp)
- 20.34 short circuit current

Scenario A: AC Output Expected from Array #2 = 7,533 kW-hr/yr



(Type comments here to appear on printout; maximum 1 row of 90 characters.)

Station Identifi	cation		R	esults	
ell ID:	0249368	Manth	Solar	AC	
tate:	Ohio	Ohio	(kWh/m ² /day)	Energy (kWh)	
titude:	41.8 ° N	1	3.06	471	
ngitude:	83.8 ° W		3.85	538	
V System Specification	ns	3	4.63	689	
C Rating:	6.21 kW	4	5.49	765	
C to AC Derate Factor: 0.770		5	5.66	778	
Rating:	4.78 kW	6	5.88	756	
ay Type:	Fixed Tilt	7	5.74	751	
ay Tilt:	41.8 °	8	5.64	746	
ay Azimuth:	180.0 °	9	5.43	713	
nergy Specifications		10	4.17	585	
st of Electricity:	5.0 ¢/kWh	11	2.73	383	
		12	2.40	358	
		Year	4.56	7533	

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Scenario A: Cost

- Inverter: SunnyBoy SB6000US 1 Phase \$2,735
- Rewire 108 modules from parallel to 18 groups of 6 modules per string - \$900
- Install inverter, attach to electrical panel, and connect to grid - \$400
- Total \$4,035

Scenario B: Upgrade Array #2 and Tie to Grid (new inverter)

Scenario #2

Upgrade First Solar Panels

- Manufacturer: First Solar
- Model: FS-390 CdTe
- Electrical Specs @ STC
 - Power: 90 Watts
 - Voltage: 49.2 Volts
 - Current: 1.83 Amps
 - Efficiency: 13%
- Mechanical Spec.
 - Width: 600 mm
 - Length: 1200 mm
 - Area: 0.72 meters
 - Weight: 12 lbs.

Scenario #2- Configuration

lar Array	- Sc	hema 2		Building R1
			108 Panels (FS-390)	9,724 W DC (Peak Power @ STC) Array # 2 (Tied to Grid) 443 VDC Nominal Peak Voltage, 549 VDC (Open Circuit Voltage)
		.		22 Amps (Peak Power Current), 24 Amps (Short Circuit Current)
	HD Sa Switc	h 1		
			String 1 -(9 Panels)	String 5 - (9 Panels) String 9 - (9 Panels)
			String 2 - (9 Panels)	String 6 - (9 Panels) String 10 - (9 Panels)
			String 3 - (9 Panels)	String 7 - (9 Panels) String 11 - (9 Panels)
Sensor			String 4 - (9 Panels)	String 8 - (9 Panels) String 12 - (9 Panels)
		Each String	has 9 Panels in Series	
				6,210 W DC (Peak Power @ STC)
			108 Panels (FS-257)	Array # 1 (Tied to Grid) 372 VDC Nominal Peak Voltage, 534 VDC (Open Circuit Voltage)
	HD Sa	ifety		16.74 Amps (Peak Power Current), 20.34 Amps (Short Circuit Current)
	Switc	h1		
	String	g 1	String 3 - (6 Panels)	String 7 - (6 Panels) String 11 - (6 Panels) String 15 - (6 Panels)
	6 Pan	els	String 4 - (6 Panels)	String 8 - (6 Panels) String 12 - (6 Panels) String 16 - (6 Panels)
		String 2	String 5 - (6 Panels)	String 9 - (6 Panels) String 13 - (6 Panels) String 17 - (6 Panels)
		6 Panels	String 6 - (6 Panels)	String 10 - (6 Panels) String 14 - (6 Panels) String 18 - (6 Panels)
		Each String	has 6 Panels in Series	
				Dorr St

Scenario B: DC Output

- 9 Panels/String
- 12 Strings
- 108 Panels
- 9,700 W DC (Peak Power @ STC)
- 443 VDC Nominal Peak Voltage
- 549 VDC (Open Circuit Voltage
- 21.96 Amps (Peak Power Current)
- 24.48 Amps (Short Circuit Current)

Scenario B: AC Output = 11,791 kW-hr / year



AC Energy & Cost Savings



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(Type comments here to appear on printout; maximum 1 row of 90 characters.)

Station Identific	ation		R	esults		
Cell ID:	0249368	Month	Solar Radiation	AC	Energy Value (\$)	
State:	Ohio	WOIL	(kWh/m ² /day)	(kWh)		
Latitude:	41.8 ° N	1	3.06	738	36.90	
Longitude:	83.8 ° W	2	3.85	842	42.10	
PV System Specification	S	3	4.63	1078	53.90	
DC Rating:	9.72 kW	4	5.49	1198	59.90	
DC to AC Derate Factor:	0.770	5	5.66	1218	60.90	
AC Rating:	7.48 kW	6	5.88	1183	59.15	
Array Type:	Fixed Tilt	7	5.74	1176	58.80	
Array Tilt:	41.8 °	8	5.64	1168	58.40	
Array Azimuth:	180.0 °	9	5.43	1115	55.75	
Energy Specifications		10	4.17	915	45.75	
Cost of Electricity:	5.0 ¢/kWh	11	2.73	599	29.95	
,	,	12	2.40	560	28.00	
		Year	4.56	11791	589.55	

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Scenario B: Cost

- Buy 108 FS-390 First Solar Panels \$9,724
- Remove old Panels and Install new ones \$3,600
- Rewire Solar panels with 9 panels in series per string -\$900
- Buy inverter 10000TL-US **\$5,600**
- Install inverter, attach to electrical panel, and connect to grid - \$400
- Sell Used Panels (\$1,880)
- Total **\$ 18,344**

Scenario C

Tie Array #2 to Grid; Upgrade Modules for Both Arrays; Requires new inverter(s)

Scenario C: Upgrade Both Arrays to First Solar FS-390 Modules

- Manufacturer: First Solar
- Model: FS-390 CdTe
- Electrical Specs @ STC
 - Power: 90 Watts
 - Voltage: 49.2 Volts
 - Current: 1.83 Amps
 - Efficiency: 13%
- Mechanical Spec.
 - Width: 600 mm
 - Length: 1200 mm
 - Area: 0.72 meters
 - Weight: 26.4 lbs.

Scenario C: Configuration

olar Array	- Sch	nema 3			Bu	uilding	R1				
			109 Papols / FS-29	10)	Δr	rav # 2 (Ti	ed to Grid)	9,724 W DC (Peak P	ower @ STC)	C (Open Circuit Voltage)	
			100 Fallels (F3-35		~	iuy # 2 (11		22 Amos (Deak Deu	eak voltage, 343 vi	ns (Short Circuit Current)	
	UD Cof	-						22 Amps (Peak Pow	rer current), 24 Am	ps (short circuit current)	
	HD Sat	ety									
	Switch	1									
			String 1 - (9 Pane	ls)			String 5 - (9 Pane	els)		String 9 - (9 Panels)	
			String 2 - (9 Pane	ls)			String 6 - (9 Pane	els)		String 10 - (9 Panels)	
			String 3 - (9 Panel	s)			String 7 - (9 Pane	els)		String 11 - (9 Panels)	
Sensor			String 4 - (9 Pane	ls)			String 8 - (9 Pane	els)		String 12 - (9 Panels)	
		Each String	has 9 Panels in Ser	ies							
								9,724 W DC (Peak P	ower @ STC)		
			108 Panels (FS-39	0)	Ar	ray # 1 (Ti	ed to Grid)	443 VDC Nominal P	eak Voltage, 549 V	DC (Open Circuit Voltage)	
	HD Saf	ety						22 Amps (Peak Pow	ver Current), 24 Am	ps (Short Circuit Current)	
	Switch	1									
			String 1 - (9 Pane	ls)			String 5 - (9 Pane	els)		String 9 - (9 Panels)	
			String 2 - (9 Pane	ls)			String 6 - (9 Pane	els)		String 10 - (9 Panels)	
			String 3 - (9 Panel	s)			String 7 - (9 Pane	ols)		String 11 - (9 Panels)	
			String 4 - (9 Pane	-7 s)			String 8 - (9 Pane	als)		String 12 - (9 Panels)	
			Journa 1, (STanc				Journe of Change			ouning the (preaters)	
		Fach String	has 9 Panels in Ser	ies							
		caon outing			_	~ .					
					D	orr St					

Scenario C: DC Output / Array

- 9 Panels/String
- 12 Strings
- 108 Panels
- 9,700 W DC (Peak Power @ STC)
- 443 VDC Nominal Peak Voltage
- 549 VDC (Open Circuit Voltage
- 21.96 Amps (Peak Power Current)
- 24.48 Amps (Short Circuit Current)

Scenario C: Total AC Output = 23,582 kW-hr/yr

PVWATTS: AC Energy and ×

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🔯 Isofoton 250 Watt M... 📒 Caremark

Configuration #3 - Attach Array #2 to the Grid. Upgrade both Arrays with FS-390 🏑

Station Identifi	cation			
City:			So	
State:	Ohio		Month	Radi
Latitude:	41.60° N	1	1	(KWIDI
Longitude:	83.80° W	1		
Elevation:	211 m	1	-	-
DV System Specifications][1	3	4
P v System Specifications			4	4
DC Rating:	19.4 kW		5	4
DC to AC Derate Factor:	0.770		6	
AC Rating:	14.9 kW		7	
Array Type:	Fixed Tilt		8	4
Array Tilt:	41.6°		9	4
Array Azimuth:	180.0°		10	3
Energy Specifications			11	1
Cost of Electricity:	0.1 ¢/kWh		12	
		-		

	Results								
Month	Solar Radiation (kWh/m ² /day)	AC Energy (kWh)	Energy Value (\$)						
1	2.90	1401	0.70						
2	3.82	1676	0.84						
3	4.24	1974	0.99						
4	5.30	2321	1.16						
5	5.71	2454	1.23						
6	5.60	2269	1.13						
7	5.80	2379	1.19						
8	5.70	2373	1.19						
9	5.13	2104	1.05						
10	3.87	1708	0.85						
11	2.57	1132	0.57						
12	2.17	1019	0.51						
Year	4.40	22810	11.41						

Output Hourly Performance Data

Output Results as Text

About the Hourly Performance Data

Saving Text from a Browser





Scenario C: Cost*

- Buy 216 FS-390 First Solar Panels \$19,448
- Remove old Panels and Install new ones \$7,200
- Rewire Solar panels with 12 panels in series per string \$1,800
- Buy 2 inverters 10000TL-US \$11,200
- Install 2 inverter, attach to electrical panel, and connect to grid \$800
- Sell Used Panels (\$3,760)

• Total - **\$** 36,688

LEC Assumptions

- \$0.05 / kWh
- 1% increase in Electric Price/Year
- 0.5% yearly decrease in power output due to module aging
- 3.5% Discount Rate

Comparison

	Scenario A	Scenario B	Scenario C
	Attach to Grid	Attach to Grid, Upgrade to new Panels FS-390	Attach to Grid, Upgrade both Arrays to new Panels FS-390
Cost	\$4,035	\$18,344	\$36,688
Annual kWh	7,355	11,791	23,582
LEC Break Even	10 Years	Never	Never
LEC @ 10 Years	\$0.053/kWh	\$0.133/kWh	\$0.191/kWh
LEC @ 15 Years	\$0.040/kWh	\$0.099/kWh	\$0.140/kWh
LEC @ 20 Years	\$0.034/kWh	\$0.082/kWh	\$0.115/kWh
LEC @ 25 Years	\$0.031/kWh	\$0.072/kWh	\$0.101/kWh

Energy Cost Increase

	Grid Energy Cost	Scenario A	Scenario B	Scenario C
	Cost @ 25 Years	Attach to Grid	Attach to Grid, Upgrade to new Panels FS-390	Attach to Grid, Upgrade both Arrays Panels FS-390
Starting Cost	\$0.05/kWh	Break Even	Break Even	Break Even
1% Increase/Yr	\$0.063/kWh	10 Years	> 25 Years	> 25 Years
3% Increase/Yr	\$0.102/kWh	9 Years	19 Years	25 Years
5% Increase/Yr	\$0.154/kWh	8 Years	15 Years	19 Years