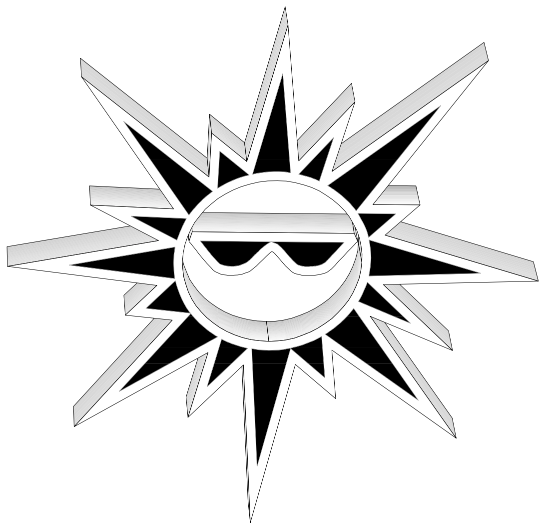
Beaver Dam Ranger Residence Photovoltaic (PV) System Design & Performance Report



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Design & Performance Technical Report

Introduction

The ranger residence at Beaver Dam State Park, located very near the Nevada-Utah border in Lincoln County, Nevada is a remote building of modest size. The building presently receives it's electrical power from a well-worn 5 kVA diesel-powered generator. Although the generator has been a source of power over the years, a more reliable, quiet, cost-effective, and environmentally sensitive power source is necessary to accommodate the increasing time demands and power needs of the Park Ranger and alleviate the substantial operation & maintenance costs involved with diesel generators. The alternative energy source having qualities that best fit this need is a photovoltaic (PV) power system. Photovoltaics is the conversion of solar energy (light) into electrical energy.

The region where the Park residence is located is ideal for PV application. Clear, sunny days are the norm and solar energy abounds. Using currently available technology, a modest PV power system should provide the residence with a dependable, cost-effective, maintenance free power source for present needs, with the ability to be expanded to meet some future needs. There are several types of PV power system configurations. The system that is most appropriate to the Beaver Dam residence, with it's existing diesel generator, is a Hybrid system. This type of system is currently performing admirably in two remote residences at Cave Lake State Park where PV provides the bulk of the energy supply, with the generator supplementing it during long cloudy periods (days) or for high energy needs (large electrical motors). The rest of this report discusses the design and projected performance of a Hybrid a system for the Beaver Dam State Park ranger residence.

Existing Conditions:

The existing electrical system at the residence is composed of a 5kVA generator located in a block building about 25 feet to the southwest of the residence (see Site Plan) and connects to a basic wiring system within the residence. The residence is located away from most park users and has adequate solar access. Liquified petroleum gas (LPG) provides energy for the domestic hot water, furnace, and the refrigerator. Lighting and small appliances are the essential electrical load. (This low load wastes the capacity of the generator; and actually leads to more frequent maintenance and increases the already high operating cost of the generator.)

Anticipated Loads:

The proposed loads on which this design is based are: general area lighting, task lighting, small appliances (shavers, blenders, etc.), a small microwave oven, a computer or VCR, radio (communications & AM/FM), and fan loads for a heater (Spg/Fall) or evaporative cooler (Smr). All electrical loads would necessarily, of course, be energy efficient. Lighting would be fluorescent, fan motors need to be sized appropriately, and no load would be allowed to operate without need. A quick analysis of the types of loads to be expected, their occurence, and most likely duration produced a likely average daily load of from 1200 to 1400 watts/day for the Beaver Dam residence. These loads are considered to occur over the full 24 hour period of the day. The residence is occupied from mid-March to October 30 of each year.

System Components:

Since the anticipated load will most likely occur over the full 24 hours of any day, a battery bank for storing the solar power generated during sunny periods (and capable of accepting occasional recharge power from the generator) will be necessary. Given the types of equipment to be operated (computer, microwave, etc.) an inverter to convert the DC power of the PV panels and the stored DC power of the batteries into the AC current used by most appliances is also a requirement. PV panels in sufficient number to supply the power to meet the anticipated load is also a primary component. Other collateral equipment will be needed to meet National Electric Code (NEC) safety requirements and allow the system to operate with independently, with little user intervention.

System Sizing/ Performance Modelling:

The performance of a PV system is dependent on many parameters including the frequency and amount of solar insolation (sunlight) falling on the appropriate number of PV panels, the sizing of the battery bank for energy storage for night and non-sunny days, and electrically efficient loads and components to minimize power needs. Economic considerations also play a role in system sizing. To assist in the design of an appropriately sized, efficient system for the Beaver Dam residence, a computer software program, SIZEPV, was used to model the performance of several system designs over statistically representative year long solar insolation (weather) periods. By alternately setting then changing system design parameters, and iterative runs of the program under varying reference weather (sunlight) conditions, an optimum system design is developed that matches the PV panel size with the battery capacity, inverter efficiency, and the anticipated loads; among other considerations.

After several iterations of the PV sizing program, two designs were selected as being best suited to meet the power requirements given the solar insolation that would be expected to occur at the Beaver Dam site (See PV system parameters /loads/ performance, pp 6-9). The first of these two systems is a six-panel system, tracking sun altitude seasonally, a 1.5 kW inverter, 9.6 kW of battery capacity w/ three days of autonomy, other efficiency parameters, and 1200 Watt/day load. The second system is an eight-panel system, tracking sun altitude seasonally , a 1.5 kW inverter, 10.6 kW of battery capacity, etc., and a 1400 Watt/day load. The Performance Summary

(pp. 7&9) for each system indicates how that system performed under specific weather conditions. Each systems monthly and annual performance is shown for PV array output, load, backup power, system availability, battery state-of-charge, and wasted power. The grayed areas indicate performance during the months of likely residence occupancy. The economic and cost values generated by the software are essentially reference numbers for comparing the two systems and not an indication of the actual cost of the systems modelled.

Cost Estimate/ List of Equipment

Cost estimates for the each system are calculated in the List of Materials/Estimate tables on pages 10 & 11 . (It should be noted that many of the equipment costs for special PV equipment [PV panels, inverter, disconnects, batteries] are shown at wholesale cost.) The estimated costs for materials is approximately four thousand dollars for the six-panel, small battery bank system and five thousand dollars for the eight-panel, full-sized battery bank system. Installation of the either system would be performed by the District V Maintenance staff familiar with PV systems. The equipment chosen for the systems incorporates fundamental electrical design considerations, code requirements, availability, and functional utility of the system. An electrical schematic of System #1 (six-panel, with only 4.2 kW of battery capacity) is shown in Diagrams, Sheet #2 at the back of this report. To accurately perform to the modelled System #1, the battery capacity shown in the electrical schematic would need to be at the "ultimate" configuration.

Recommendations

The performance analysis of the systems modelled indicate that System #2 performs the best of the two at providing sufficient power for the anticipated load, sustaining the desired battery state-of-charge for system longevity, and allows for the well-worn generator to remain off-line , but for only special use. It provides one hundred percent availability for seven of the eight months of occupancy from March through October. System #2 provides slightly better total levelized energy costs of $0.82 per kilowatts of power produced than does System #1.

System #1 can meet basic performance parameters but allows a deeper discharge of the battery bank which can shorten their functional life and increase the life-cycle cost of the system. It provides a hundred percent of the design load only in the month of June; but comes very close in two other Summer months. This system, if implemented should be designed for early expansion to meet the power needs of the residence and to limit deep discharge of the battery bank.

The recommended system design is System #2 with eight PV panels; four L-16 12V, 350 Amp Hour, lead acid batteries; and a Trace DR 1500, DC to AC inverter.

BEAVER DAM CABIN PV SYSTEM #1
INPUT PARAMETER SUMMARY

CEDAR CITY, UT (MUNI) [reference solar insolation location]

Latitude 37.50 degrees
Tilt 37.05 degrees
Array azimuth 0.00 degrees
Tracking **No daily track; seasonal tilt only**
Reflectivity 0.30
Inverter size 1.50 kW **(Trace: DR 1500)**
Inverter efficiency 0.90
NOCT 46.00 °C
Power loss 0.0043 δP/°C
Reference temperature 25.00 °C
Reference efficiency 0.115
Line losses 0.0350
Array size 0.25 m²
Battery capacity 9.61 kWh **(4, L-16's)**
Battery capacity 3 days
Minimum state of charge 0.40
Beginning state of chrg 1.00

Round-trip efficiency 0.80
Max charge rate 0.20 fraction of capacity
Array cost $7.00 /W
Battery cost $60.00 /kWh
Inverter cost $0.50 /kW
Controller cost $200.00 total
BOS cost fraction 0.10
O & M cost fraction 0.0099
Discount rate 0.08
PV system life 20 years
Battery life (user input) 8 years
Computed battery life 8 years
Inverter life 10 years
Controller life 10 years
Location code 93129

DAILY AVERAGE LOAD

Month	Wh/day	Distribution (Lighting:300w/d; TV/Stereo/Computer:300 w/d: Cooler:600w/d)
January	1200.0	Distributed evenly over 24 hour period
February	1200.0	Distributed evenly over 24 hour period
March	1200.0	Distributed evenly over 24 hour period
April	1200.0	Distributed evenly over 24 hour period
May	1200.0	Distributed evenly over 24 hour period
June	1200.0	Distributed evenly over 24 hour period
July	1200.0	Distributed evenly over 24 hour period
August	1200.0	Distributed evenly over 24 hour period
September	1200.0	Distributed evenly over 24 hour period
October	1200.0	Distributed evenly over 24 hour period
November	1200.0	Distributed evenly over 24 hour period
December	1200.0	Distributed evenly over 24 hour period

ECONOMIC SUMMARY System #1

Array installed cost	$1750.00	Total direct costs	$3276.75
Battery installed cost	$576.75	Total installed costs	$3604.43
Number of battery replacements	3	O & M cost	$350.35
Inverter installed cost	$750.00	Total component replacement cost	$919.98
Number of inverter replacements	2	Total life cycle cost	$4874.76
Controller installed cost	$200.00	Total levelized energy cost	$0.87 /kWh
Number of controller replacements	2		

PERFORMANCE SUMMARY System #1

Mo.	Array	DCload	Backup	POA	Avail.	SOC	Waste
J	.3979E+02	.5960E+02	.1608E+02	.1619E+03	.7302E+02	.1000E+01	.1336E+01
F	.3733E+02	.5383E+02	.1745E+02	.1535E+03	.6758E+02	.4000E+00	.8785E+00
M	.4240E+02	.5960E+02	.1839E+02	.1756E+03	.6914E+02	.4073E+00	.9673E+00
A	.5315E+02	.5768E+02	.5954E+01	.2286E+03	.8968E+02	.4302E+00	.1357E+01
M	.5940E+02	.5960E+02	.2222E+01	.2604E+03	.9627E+02	.4375E+00	.1416E+01
J	.6135E+02	.5768E+02	.0000E+00	.2767E+03	.1000E+03	.5013E+00	.1459E+01
J	.5775E+02	.5960E+02	.6012E+00	.2629E+03	.9899E+02	.7317E+00	.1298E+01
A	.4963E+02	.5960E+02	.1061E+02	.2244E+03	.8220E+02	.4670E+00	.1092E+01
S	.4976E+02	.5768E+02	.9253E+01	.2249E+03	.8396E+02	.4200E+00	.1241E+01
O	.4786E+02	.5960E+02	.1282E+02	.2067E+03	.7848E+02	.4296E+00	.1166E+01
N	.4269E+02	.5768E+02	.1605E+02	.1785E+03	.7217E+02	.4212E+00	.1052E+01
D	.3986E+02	.5960E+02	.2060E+02	.1624E+03	.6544E+02	.4234E+00	.9543E+00
Year	.5810E+03	.7017E+03	.1300E+03	.2517E+04	.8147E+00	.4136E+00	.1422E+02
Grey = performance during predominant use period							

SUMMARY TABLE, EXPLAINATION:

Array:	.1234E+02 = 12,340 watts output for the month indicated.
Dcload:	.11111E+02 =11,111 watts (AC or DC load) anticipated for the month indicated.
Backup:	.2222E+01= 2,222 watts required of backup generator for the month indicated.
POA:	.3333E+03 = 333,300 watts incident on the Plane of Array.
Avail.:	.8000E+02 = 80% of the time PV was providing the necessary power for the load.
SOC:	.6000E+00 = 60% State of Charge of battery bank at end of month indicated.
Waste:	.1234E+01 = 1,234 watts lost by equipment efficiency for the month indicated.

BEAVER DAM CABIN PV SYSTEM #2
INPUT PARAMETER SUMMARY

CEDAR CITY, UT (MUNI) [reference solar insolation location]

Latitude 37.50 degrees
Tilt 37.50 degrees
Array azimuth 0.00 degrees
Tracking **No daily track; seasonal tilt only**
Reflectivity 0.30
Inverter size 1.50 kW **(Trace:DR 1500)**
Inverter efficiency 0.90
NOCT 46.00 °C
Power loss 0.0043 δP/°C
Reference temperature 25.00 °C
Reference efficiency 0.115
Line losses 0.0350
Array size 0.34 m² **(8, M-75's)**
Battery capacity 10.66 kWh **(4, L-16's)**
Battery capacity 3 days
Minimum state of charge **0.40**

Beginning state of chrg 1.00
Round-trip efficiency 0.80
Max charge rate 0.20 fraction of capacity
Array cost $7.00 /W
Battery cost $60.00 /kWh
Inverter cost $0.50 /kW
Controller cost $200.00 total
BOS cost fraction 0.10
O & M cost fraction 0.0099
Discount rate 0.08
PV system life 20 years
Battery life (user input) 8 years
Computed battery life 8 years
Inverter life 10 years
Controller life 10 years
Location code 93129

DAILY AVERAGE LOAD System #2		
Month	Wh/day	Distribution (Lighting:400w/d; TV/Stereo/Computer:400 w/d:Cooler:600w/d)
January	1400.0	Distributed evenly over 24 hour period
February	1400.0	Distributed evenly over 24 hour period
March	1400.0	Distributed evenly over 24 hour period
April	1400.0	Distributed evenly over 24 hour period
May	1400.0	Distributed evenly over 24 hour period
June	1400.0	Distributed evenly over 24 hour period
July	1400.0	Distributed evenly over 24 hour period
August	1400.0	Distributed evenly over 24 hour period
September	1400.0	Distributed evenly over 24 hour period
October	1400.0	Distributed evenly over 24 hour period
November	1400.0	Distributed evenly over 24 hour period
December	1400.0	Distributed evenly over 24 hour period

ECONOMIC SUMMARY System #2

Array installed cost	$2380.00	Total direct costs	$3969.70
Battery installed cost	$639.70	Total installed costs	$4366.67
Number of battery replacements	3	O & M cost	$424.44
Inverter installed cost	$750.00	Total component replacement cost	$972.36
Number of inverter replacements	2	Total life cycle cost	$5763.47
Controller installed cost	$200.00	Total levelized energy cost	$0.82 /kWh
Number of controller replacements	2		

PERFORMANCE SUMMARY System #2

Mo.	Array	DCload	Backup	POA	Avail.	SOC	Waste
J	.5278E+02	.6610E+02	.1061E+02	.1578E+03	.8395E+02	.1000E+01	.2120E+01
F	.5950E+02	.5970E+02	.3051E+01	.1817E+03	.9489E+02	.4258E+00	.1774E+01
M	.5456E+02	.6610E+02	.1228E+02	.1657E+03	.8142E+02	.5264E+00	.1432E+01
A	.7346E+02	.6397E+02	.0000E+00	.2327E+03	.1000E+03	.4616E+00	.2019E+01
M	.8079E+02	.6610E+02	.0000E+00	.2604E+03	.1000E+03	.8447E+00	.1589E+01
J	.8471E+02	.6397E+02	.0000E+00	.2813E+03	.1000E+03	.8521E+00	.1434E+01
J	.6856E+02	.6610E+02	.0000E+00	.2277E+03	.1000E+03	.8583E+00	.1471E+01
A	.7965E+02	.6610E+02	.0000E+00	.2686E+03	.1000E+03	.5161E+00	.1845E+01
S	.7263E+02	.6397E+02	.0000E+00	.2431E+03	.1000E+03	.8064E+00	.1875E+01
O	.6849E+02	.6610E+02	.0000E+00	.2182E+03	.1000E+03	.8438E+00	.1911E+01
N	.5110E+02	.6397E+02	.1087E+02	.1560E+03	.8301E+02	.7452E+00	.1386E+01
D	.3921E+02	.6610E+02	.2757E+02	.1159E+03	.5830E+02	.4271E+00	.9643E+00
Year	.7854E+03	.7783E+03	.6438E+02	.2509E+04	.9173E+00	.4000E+00	.1982E+02
Grey = performance during predominant use period							

SUMMARY TABLE, EXPLAINATION:

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POA:	.3333E+03 = 333,300 watts incident on the Plane of Array.
Avail.:	.8000E+02 = 80% of the time PV was providing the necessary power for the load.
SOC:	.6000E+00 = 60% State of Charge of battery bank at end of month indicated.
Waste:	.1234E+01 = 1,234 watts lost by equipment efficiency for the month indicated.

EQUIPMENT COST ESTIMATE, System #1
Beaver Dam State Park
Ranger Residence PV Power System

#	DESCRIPTION	QTY.	PRICE	TOTAL	REMARKS
1	PV Controller: SCI-S, 12V, 30A	1	- - - -	- - - -	Use stored unit from Dist. V Office
2	Inverter: Trace, DR 1500, 12V	1	$675	$675	Stand-By, (65A chgr.); (SES)
3	Transfer Switch: TS-50	1	$90	$90	Todd : Power Switch, (SES)
4	PV Panels: Siemens, M-75	6	$289	$1734	Solar Elect. Specialties (SES)
5	PV Support Rack: 8 panel, tiltable	1	$225	$225	Pole-top mounting, SES
6	Combiner: PACS-4	1	$125	$125	SES
7	Disconnect: fused 30/A-200A	1	$200	$200	NEMA 3R enclos. w/fuses, SES
8	Battery:Trojan L-16; 6V, 350A	2	$120	$240	See: Interstate Batt, Reno- LV
9	Series Batt. Interconn., 1/0 cable	2	$15	$30	Std. item from SES
10	Inverter to Batt. Connect: 6', 4/0	2	$25	$50	May require greater length, (SES)
11	Load Center: Square D, 60 w/main	1	$100	$100	Include 3 20A circuit brkrs (SES)
12	House Wiring: 250' 12/2 w/g	LS	$50	$50	Available locally
13	Gen. to House Wire: 40', 10/2 USE	LS	$25	$25	Available locally
14	Misc. Conduit & Fittings	LS	$75	$75	Available locally
15	Equip. Connect Wire: 60', #6 xlp	LS	$60	$60	Available thru SES
16	Sys. Grnd. Rod: 6' solid copper	1	$50	$50	Available locally
17	Sys. Ground Connect: 30'. #4 B.C.	LS	$60	$60	Available locally
18	Thinlite: #181, 12VDC w/lamp	1	$36	$36	Emerglight for Gen Rm. (SES)
19	Kenall,3707,fluor,120VAC w/lamp	3	$35	$105	Exterior security lighting
20	Misc. Cabin fluor. Lights; switches	LS	$250	$250	(To be Selected by Dist V)
21	PV Panel Support Mast: 15', 4" dia.	LS	$75	$75	(To be selected by Dist V)
22	Remote Generator Start switch	1	$40	$40	(To be selected by Dist V)
				$4295	TOTAL

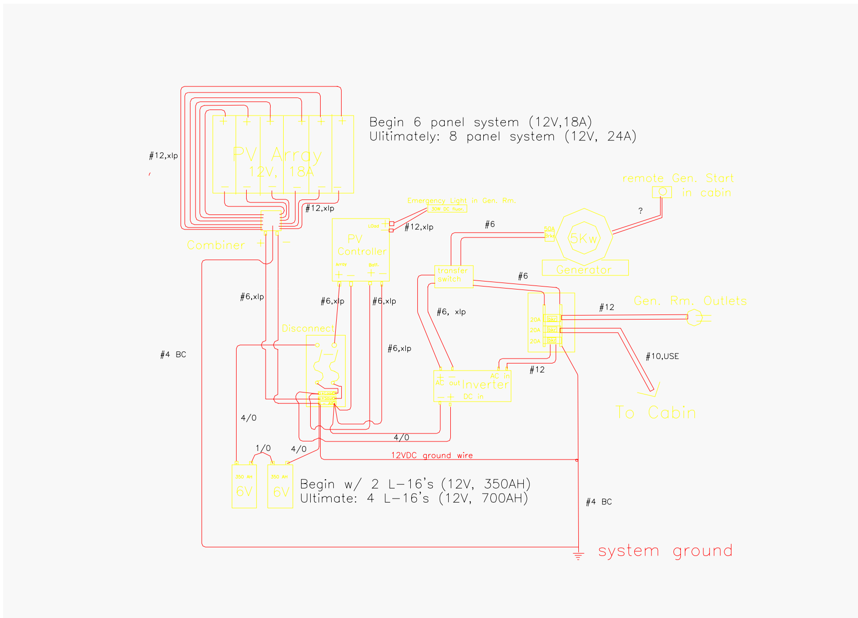
EQUIPMENT COST ESTIMATE, System #2

Beaver Dam State Park
Ranger Residence PV Power System

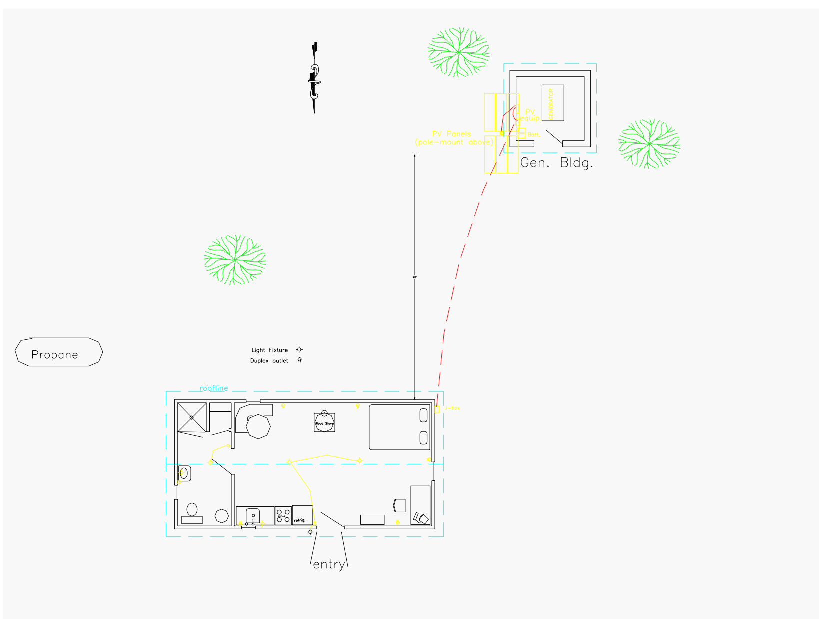
#	DESCRIPTION	QTY.	PRICE	TOTAL	REMARKS
1	PV Controller: SCI-S, 12V, 30A	1	- - - -	- - - -	Use stored unit from Dist. V Office
2	Inverter: Trace, DR 1500, 12V	1	$675	$675	Stand-By, (65A chgr.); (SES)
3	Transfer Switch: TS-50	1	$90	$90	Todd : Power Switch, (SES)
4	PV Panels: Siemens, M-75	8	$289	$2312	Solar Elect. Specialties (SES)
5	PV Support Rack: 8 panel, tiltable	1	$225	$225	Pole-top mounting, SES
6	Combiner: PACS-4	1	$125	$125	SES
7	Disconnect: fused 30/A-200A	1	$200	$200	NEMA 3R enclos. w/fuses, SES
8	Battery:Trojan L-16; 6V, 350A	2	$120	$240	See: Interstate Batt, Reno- LV
9	Series Batt. Interconn., 1/0 cable	2	$15	$30	Std. item from SES
10	Parallel Batt. Interconn., 2/0 cable	2	$20	$40	(for second batt. set)
11	Inverter to Batt. Connect: 6', 4/0	2	$25	$50	May require greater length, (SES)
12	Load Center: Square D, 60 w/main	1	$100	$100	Include 3 20A circuit brkrs (SES)
13	House Wiring: 250' 12/2 w/g	LS	$50	$50	Available locally
14	Gen. to House Wire: 40', 10/2 USE	LS	$25	$25	Available locally
15	Misc. Conduit & Fittings	LS	$75	$75	Available locally
16	Equip. Connect Wire: 60', #6 xlp	LS	$60	$60	Available thru SES
17	Sys. Grnd. Rod: 6' solid copper	1	$50	$50	Available locally
18	Sys. Ground Connect: 30'. #4 B.C.	LS	$60	$60	Available locally
19	Thinlite: #181, 12VDC w/lamp	1	$36	$36	Emerglight for Gen Rm. (SES)
20	Kenall,3707,fluor,120VAC w/lamp	3	$35	$105	Exterior security lighting
21	Misc. Cabin fluor. Lights; switches	LS	$250	$250	(To be Selected by Dist V)
22	PV Panel Support Mast: 15', 4" dia.	LS	$75	$75	(To be selected by Dist V)
23	Remote Generator Start switch	1	$40	$40	(To be selected by Dist V)
				$4913	TOTAL

Diagrams

(Drawings are informational only.)



Electrical Schematic



Site Plan

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