Off-Grid Solar Powered system implementation on the Navajo Nation.

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Abstract

Approximately 30 percent of the population on the Navajo Nation (NN) are still without electricity [1]. Connecting a home to the electrical grid on the NN has an average cost of about $40,000[1]. This cost only reflects towards existing distribution lines near homes that require minimal materials and personnel to implement these connections. These prices increase exponentially as distribution lines distance increase from the homes that need electrification. Since the four corners region has an expectational insolation for Photo Voltaic (PV) arrays, this could give the NN the ability to become an Energy sovereign nation and help support energy sustainability as a community or even individuals that are remote from main grid connections.

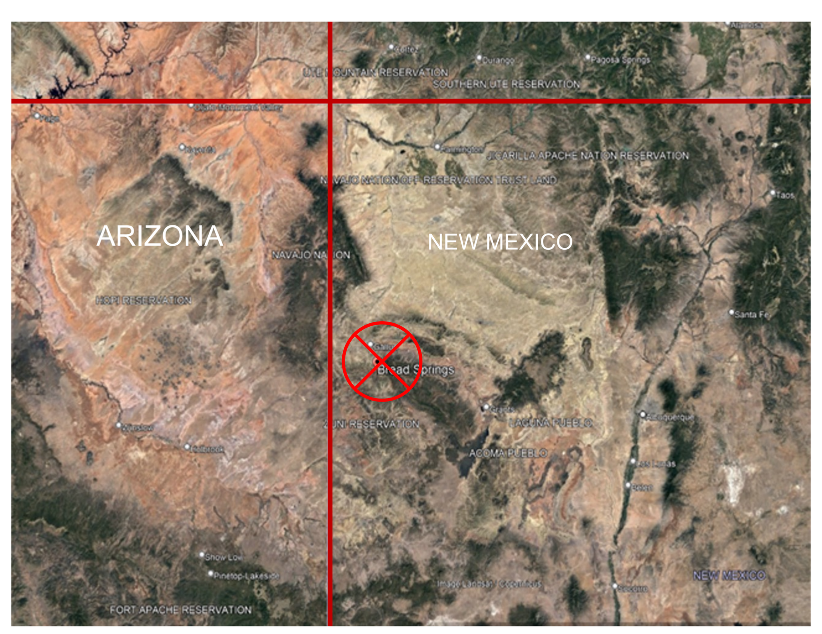
Introduction

As an objective for this project, students were required to create a company to implement a PV system at any location selected by the student. Companies were given a budget of $50,000 for material to establish a PV system for a new home, commercial business or other establishments that can stay within the budget. These systems must relate to real life situations such as a selection of location, average daily loads, selection of inverters, battery bank selection, charge controllers, tilt and insolation, PV module selection and prices of components.

Method

- Fig. 1 shows an image of the proposed location in Breadsprings, New Mexico. The image is taken from Google Earth Pro to Geo reference the location to obtain the latitude and Longitude, which was used to find the insolation of the area utilizing the NASA POWER prediction application.
- Latitude and Longitude of the location is, 35° 24′03.25′ N; 108° 43′ 24.93“

FIG. 1



Method

- An intuitive approach was taken to calculate the Average daily load calculation. The load is calculated by listing all appliances that are within the household and all rated power consumption of the appliances in watts (W). Each appliance's wattage is multiplied by the number of units that are inside the home. The wattage is then multiplied by the estimated number of hours utilized within a 24-hour period. The product of Watts x Hours gives the value of Watt-hours used per Day (Wh/day.)

FIG. 2

Appliance	Watts		Number of units (NoU)	Total hours		Total Watts hours (Wh) NoUxWxtotal hrs.	
Electric Pellet stove(winter)	240	W	1	6	Hrs	1440	Wh
Ceiling fan/w LED light	92	W	2	4	Hrs	736	Wh
TV 32 inch	79	W	2	2	Hrs	316	Wh
TV 60 inch	182	W	1	3	Hrs	546	Wh
Recessed lighting-LED	13.3	W	16	4	Hrs	851.2	Wh
light fixture	60	W	3	3	Hrs	540	Wh
Exterior light	100	W	2	4	Hrs	800	Wh
security light	270	W	2	10	Hrs	5400	Wh
submersible pump(running)	1035	W	1	3	Hrs	3105	Wh
stove fan(winter)	31	W	1	4	Hrs	124	Wh
laptop	65	W	1	2	Hrs	130	Wh
floor lamps	100	W	2	2	Hrs	400	Wh
refrigerator	200	W	1	6	Hrs	1200	Wh
	total power			total hours		Total Wh	
	2467.3	W		53	Hrs	15588.2	Wh/day

- Fig. 2 is the all the appliances that will be included in the average daily load calculation.
- Fig. 3 shows the peak power of the home.

FIG. 3

Electric Pellet stove(winter)	240	W	
TV 60 inch	182	W	
Exterior light	100	W	
security light	270	W	
submersible pump(running)	1035	W	
refrigerator	200	W	
Recessed lighting-LED	106.4	W	13.3W * 8
Peak Power =	2133.4	W	
	2.133	Kw	

Equations

Inverter calculations

- Inverter power requirement = Peak power x (1 + design margin)
- Max.Inverter DC current = $\frac{Required\ inverter\ power}{Nom.battery\ voltage\ x\ inverter\ efficiecy}$

Battery Bank Calculation

- Average battery load = $\frac{Avg.\ Daily\ Load}{Inverter\ efficiency\ x\ Nominal\ battery\ Voltage}$
- C_x = Days of Autonomy x Avg. Battery Load x $\frac{1}{End\ of\ life\ rating}$
- C- rate of = $\frac{max\ inverter\ current}{Days\ of\ autonomy}$
- $C'_x = C_x$ x $\frac{1}{DoD\ (max)}$, DoD_{max} = Typically 50% - 80%
- DoD_{daily} = 100 x $\frac{Average\ Battery\ Load}{C'x}$
- $C''_x = C'_x$ x (1 + Battery Design margin)
- Number of series Batteries = $\frac{Required\ Bank\ Nominal\ Voltage}{Battery\ Nominal\ Voltage}$
- Number of battery strings = $\frac{Required\ battery\ bank\ capacity}{Battery\ Capacity}$

Method

- Capacity factor = $\frac{Average\ insolation\ during\ Decemeber}{24\ hours}$
- Daily energy production = E_{pv}= 24 x capacity factor x P_{pv}, rated
  - P_{pv}rated = $\frac{Average\ Daily\ Load}{24\ x\ capacity\ x\ inverter\ efficiency}$
- $P'_{pv.\ Rated}$ = $\frac{Ppv.rated}{1-Kl/100}$
- $P''_{pv,rated}$ = 100 x $\frac{p'pv.rated}{100-temperature\ related}$
- $P'''_{pv,\ rated}$ = $\frac{P'pv.rated}{1-K\ pv}$
- Number of Array strings = $\frac{P'''pv,rated}{module\ Watt\ rating}$

Tilt and Insolation

- The tilt and insolation were determined using online open-source applications. The two applications were Google earth pro and NASA access-data-viewer. The insolation's are categorized into three sections. The first is the tilt information at degree of latitude which is 35 degrees and a minus of 15 degrees. The second is the degree of latitude with no plus or minus, so the tilt sits at 35 degrees. Thirdly, the degree of latitude of 35 degrees plus 15 degrees. To obtain the optimum tilt, we used the smallest irradiance value from all three categories and chose the highest of the three values. This value came to be 4.85 at Latitude Plus 15 degrees Tilt, (kW-hr/m^2/day).
- Fig. 4 depicts the surface tilts and the insolation from a calendar year.

SI_EF_TILTED_SURFACE_LAT_MINUS15	4.41	5.03	6.41	7.14	7.61	7.84	6.79	6.55	6.36	5.91	4.79	3.94	-999.00
SI_EF_TILTED_SURFACE_LATITUDE	5.01	5.43	6.60	6.96	7.05	7.08	6.24	6.23	6.41	6.35	5.39	4.52	-999.00
SI_EF_TILTED_SURFACE_LAT_PLUS15	5.34	5.54	6.44	6.43	6.21	6.07	5.46	5.64	6.11	6.42	5.68	4.85	-999.00

FIG. 4

Results

Once the parameters of the PV modules have been calculated and satisfies the charge controllers specifications, we obtained the following: 18 modules in total with 6 strings of 3 modules in series. The series modules open circuit voltage total is 120.3 V with a short circuit current of 77.7 A. With these values it is safe to say that the voltage is well below the max input, but the amperage is high. So, two charge controllers were selected and the PV modules were separated in half. The final configuration of the PV modules is 3 strings with 3 in series for each charge controller.

Results

- Fig. 6 illustrates the series parallel battery bank.
  - Battery nominal voltage = 12 V
  - Battery Bank nominal voltage = 4 x 12V = 48 V
  - Battery capacity = 357 Ah @ 20 hr
  - Battery Bank Capacity = 1428 Ah
- Fig. 6 Shows the PV Array modules in a series parallel connection.
  - PV Module array open circuit voltage < 150V
  - Short circuit = 40.1 V @ STC
  - Open circuit current = 10.36 A
  - Required Power = 5.09 kW
  - Capacity factor = .20
  - Increase for losses = 15 %
  - Temperature derating = 5 %
  - PV array design margin = 15%
  - Total calculated when 320 x 18 = 5.76 kW

FIG. 5

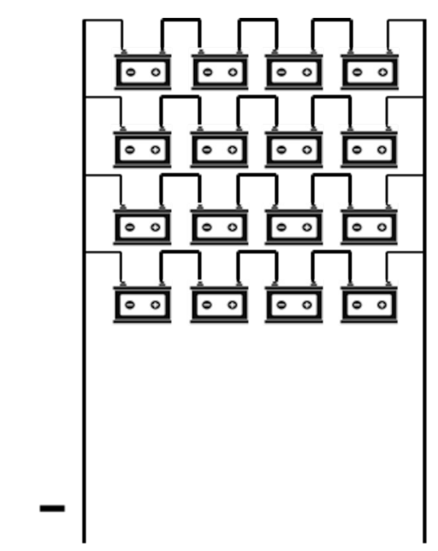


FIG. 6

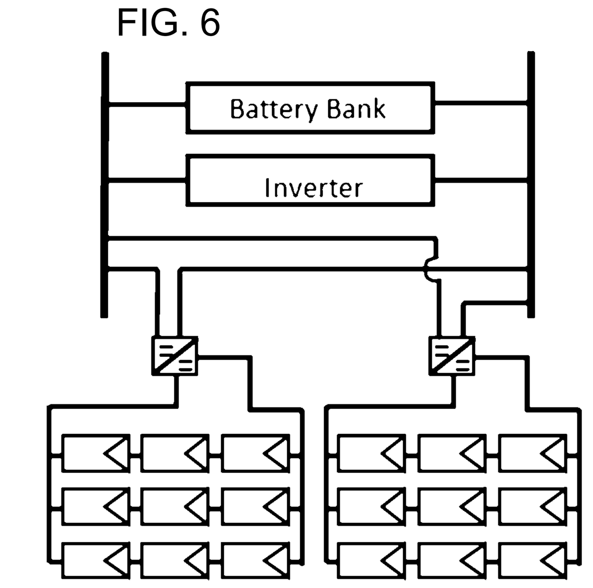


FIG. 7

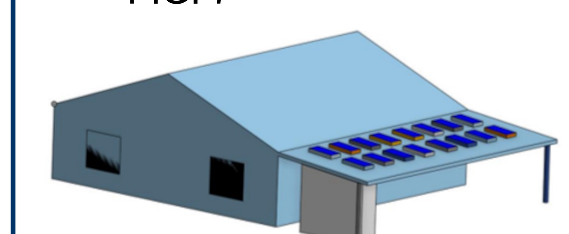
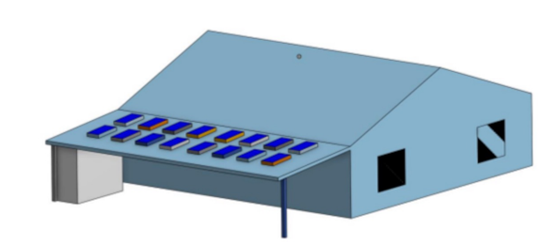


FIG. 8



- Fig 7 and 8 shows the proposed home that will obtain the PV system. The home will sit towards the south to receive optimum irradiance.

Conclusion

With more education and advocacy for off grid PV systems it would alleviate some stress on dependency for natural resource consumptions. It would also create the Navajo Nation to become more energy sovereign and help with sustainability in our community and across the world.

CITES

- [1]Heather Tanana and Warigia Bowman, "Energizing Navajo Nation: How Electrification can secure a sustainable future for Indian country.", Brookings, Wedenday July 14,2021.
- [2]Henry Louie, "off-grid electrical systems in developing countries.", Springer, 2018