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Village of Venetie: Energy Assessment

Alaska Native Village Energy Development Workshop

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Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

- Personnel
- Microgrid Preliminary Design and Assessment
- Venetie, Alaska Description
- Electrical System Characterization
- Conceptual Design
- System Modeling
- System Cost Estimates

Team Members

- Sandia National Laboratories
  - Sandra Begay-Campbell – Project Manager
  - Richard Jensen – Project Technical Lead
  - Ben Schenkman – Electrical Engineer
  - Mike Baca – Electrical Engineer
  - Jim Brainard (Retired) – Systems Modeler
- Acknowledgements
  - Alaska Energy Authority
    - Allen Fetters
    - David Lockard
  - National Renewable Energy Laboratory
    - Brian Hirsch
  - Marsh Creek, LLC
    - Connie Fredenburg
    - Grace Oomittuk
  - Village of Venetie
    - Eddie Frank
    - Nathan Peter
    - Tim Thumma

Energy Surety Microgrids Principles

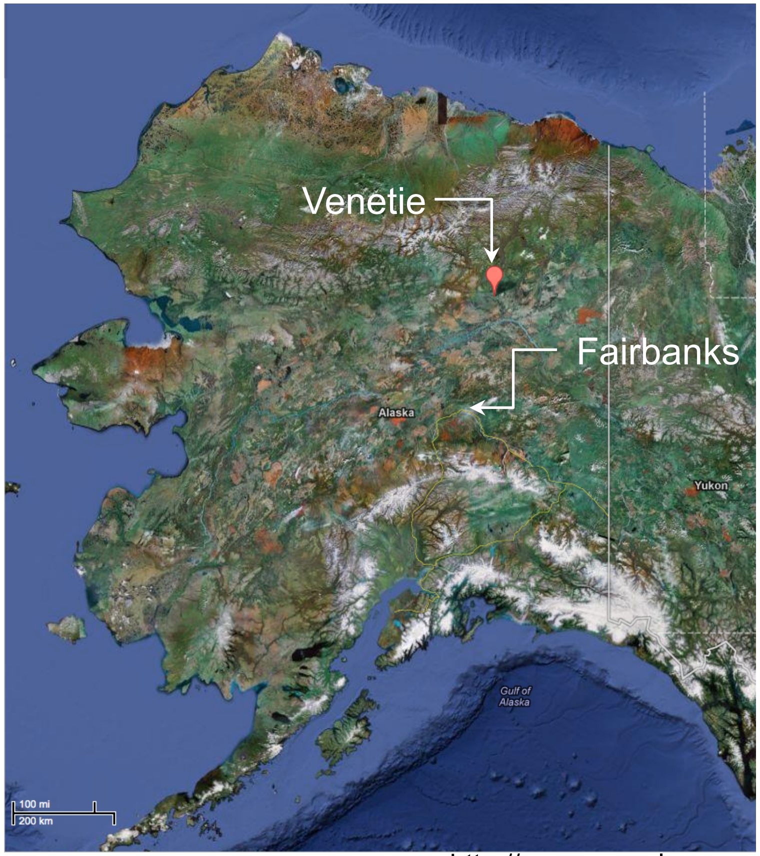
- Safety
  - No introduced safety hazards
  - Well designed controls minimizes chance of human error
- Reliability
  - Matching generation resources to loads
  - Provide additional back-up capability
- Security
  - Cyber secure
  - Resilient to intentional sabotage
- Sustainability
  - Improved efficiency promotes reduced fuel consumption
  - Introduction of renewables reduces fuel demand
  - More optimally operated generators reduces maintenance intervals and cost and lengthens life cycles
- Cost Effectiveness
  - Greater efficiency
  - Decreased maintenance cost
  - Lengthened life cycles
  - Incorporation of renewables

ESM Load Categorization

- Tier C – loads / buildings that are critical to the mission; these loads usually have dedicated backup generators. Tier C_U loads are non-interruptible and will include UPS, while Tier C_I loads can endure short losses of electrical power.
- Tier P – loads / buildings that are nice to have, but that can be switched on or off the microgrid at the base commander's discretion. Some of these loads may have dedicated backup generators. Some may be designated ahead of time, while others might be promoted ad hoc (depending on their configuration).
- Tier O – loads / buildings that will not be powered during microgrid operations.
- Tier O_P – loads that are too small to merit the cost of automation (e.g. streetlights or parking lights).

Description of Venetie

- Village ~160 miles north of Fairbanks, Alaska
  - Located along the Chandalar River, a tributary of the Yukon River
  - In the foothills/base of Brooks Range
- Population: 166 (2010 census)
- Subsistence economy
- Access to village is exclusively by air transport
  - http://commerce.alaska.gov/cra/DCRAExternal/community/Details/916b06db-23c9-4c32-9ea2-2ab0b342199b



http://maps.google.com

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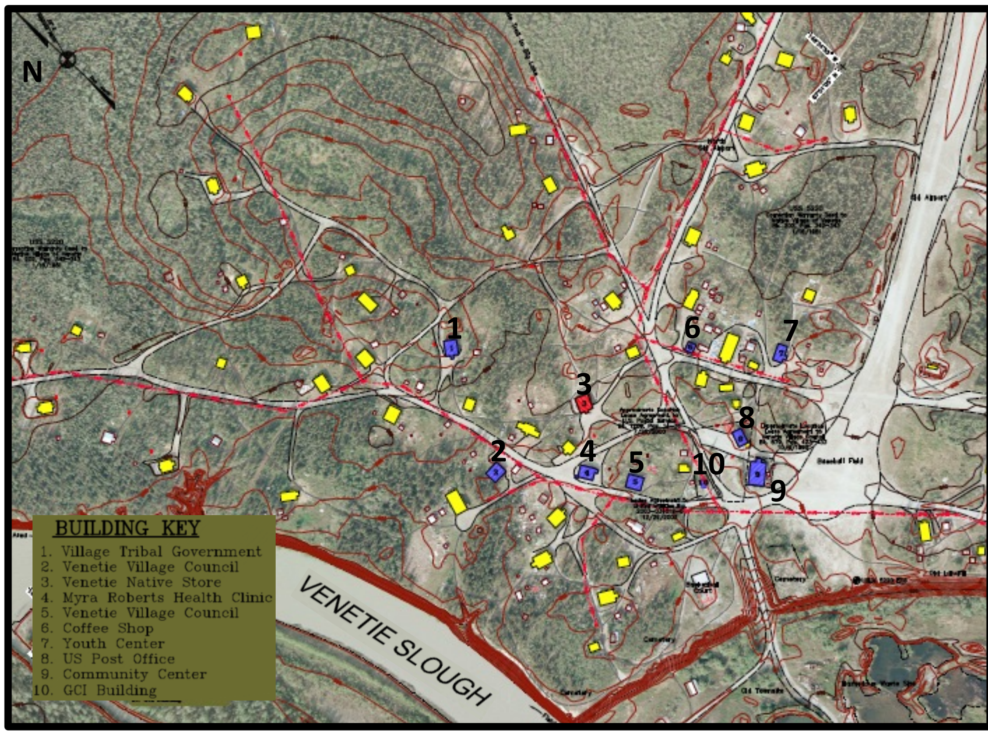
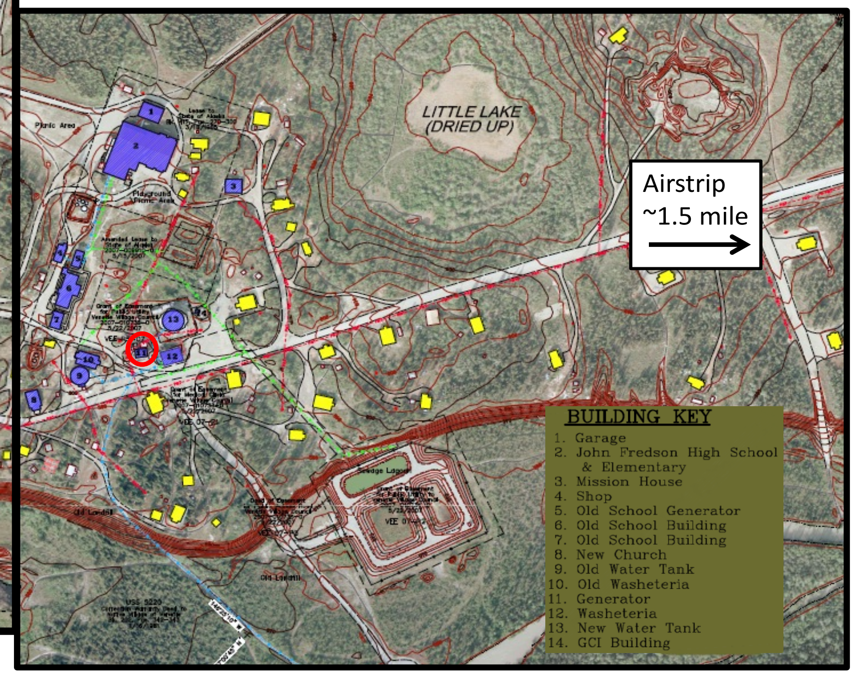
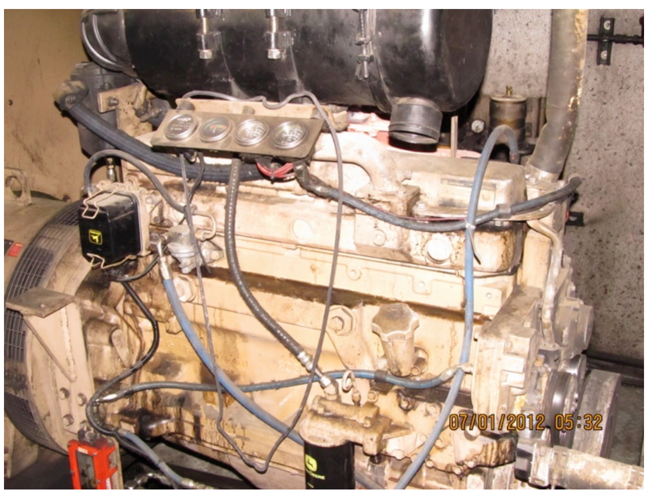




Electrical System

- Generation: Three diesel generators
  - 180 kW (operational)
  - 190 kW (newly rebuilt and put into service in January 2013)
  - 125 kW (failed and probably will not be put into service in the foreseeable future)
  - Fed from external 1500 gallon tank adjacent to building
- Powerhouse
  - Old, wood-sided building on stilt foundation
  - Poorly ventilated and poorly lit interior
  - Undersized
  - Waste heat from generator is piped to adjacent washeteria
- Distribution System
  - Three single phase, pole-mounted 75 kVA transformers
  - 12.47/7.2 kV overhead
- On the AEA Rural Power Systems Upgrade List (September 2013, projects remaining category)

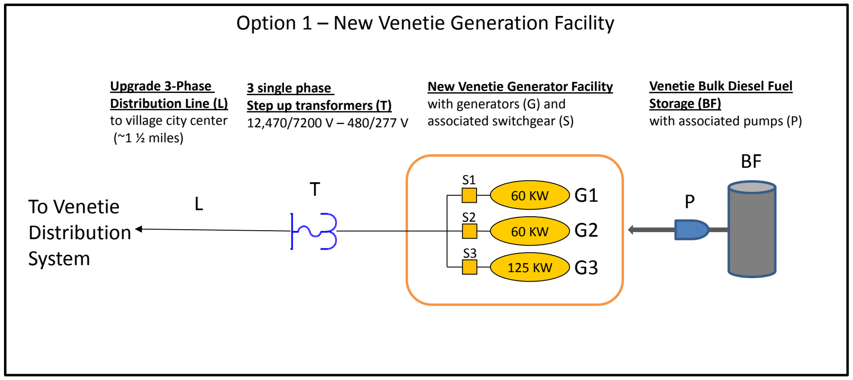
Pictures of Venetie Generator House

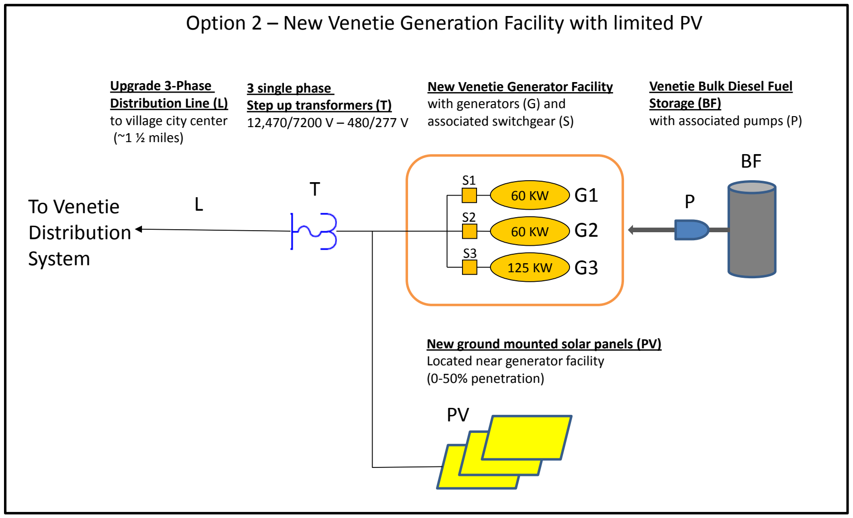


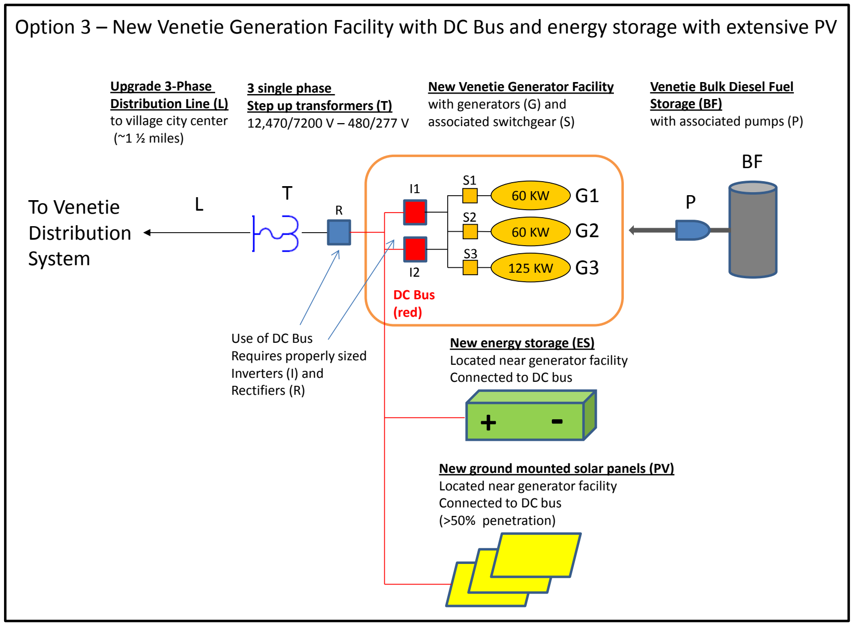
Potential Renewable Resources Surrounding Venetie

- Wind
  - Area has low mean winds speed
- Geothermal
  - No known sources in area
- PV
  - Only available for some parts of year
  - Not available during seasons of peak demand
  - Systems comprise COTS components
  - No large scale systems implemented in rural Alaska villages
- Biomass
  - Venetie is located in boreal forest
  - Can be sustainably harvested in nearby forests
  - Only proposed to be used for source of heat
  - At present, systems for producing electricity are experimental and costly
- Hydrokinetics
  - Chandalar River is braided stream and is fairly shallow
  - Not suitable for hydrokinetics

Three Conceptual Design Options





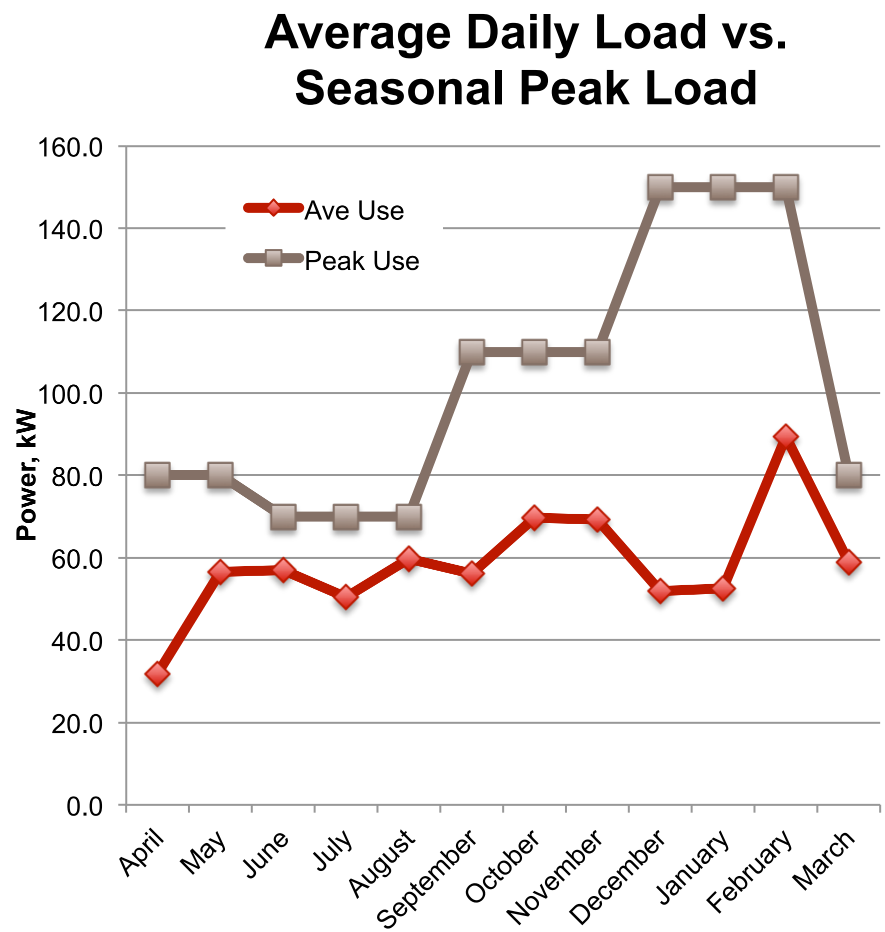


Consequence Modeling

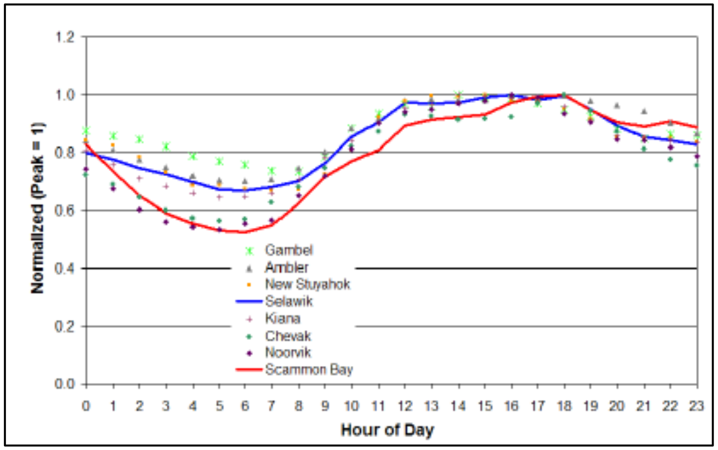
- A modeling approach that gives insight into complex systems over time
  - Multiple interacting phenomena
  - Feedback loops
  - Stocks and flows
  - Nonlinear, transient behavior
- Modeling done using PowerSim
- Basic consequence model has been created that can be adapted to other rural villages
- One year of load data not available so we had to find analogous data to create load profile
- Created load profile as scaled composite of four analogous data sets
- Meet me offline for demonstration of software

Electric Load Characterization

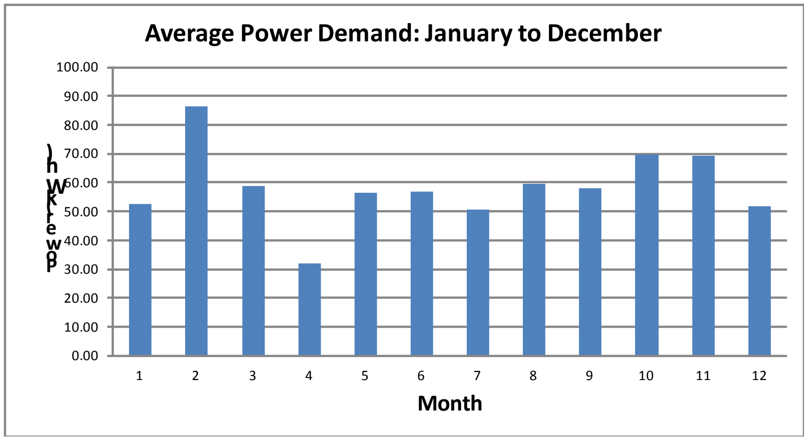
- Load estimates made due to lack of availability of metered data
- Peak Loads
  - Winter (December – February): 150kW
  - Spring (March – May): 80kW
  - Summer (June – August): 70kW
  - Fall (September – November): 110kW
  - Based on information provided by Venetie operators
- Daily average loads
  - Based on records of power sold in one month
  - Does not reflect daily peaks and valleys
  - Used in creating load profile for simulations



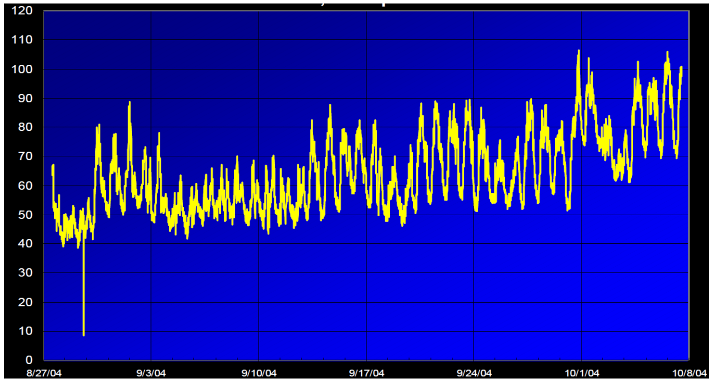
Load Data Amalgamated to Create Load Profile



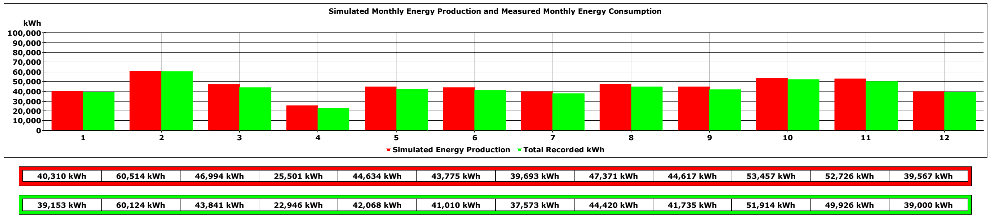
Plot of normalized load profiles modified from Devine and Baring-Gould, 2004.



Average Monthly Power Demand calculated from the measured Total Monthly Energy (kWh sold).

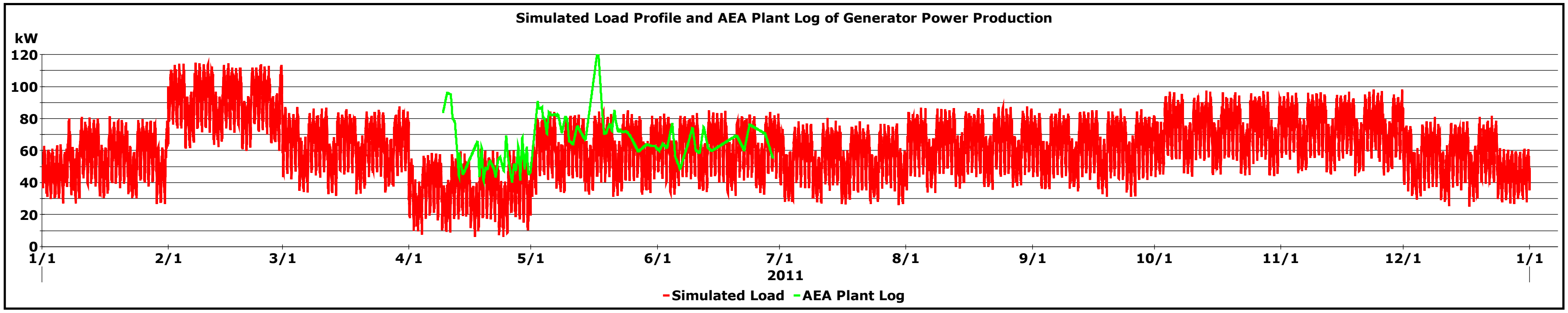


Plot of load profiles taken from Whitwell et al., 2004.



Plot of simulated results showing the simulated Total Monthly Energy (red) and Venetie's Measured Monthly Energy (green).

Load Profile Used for CM

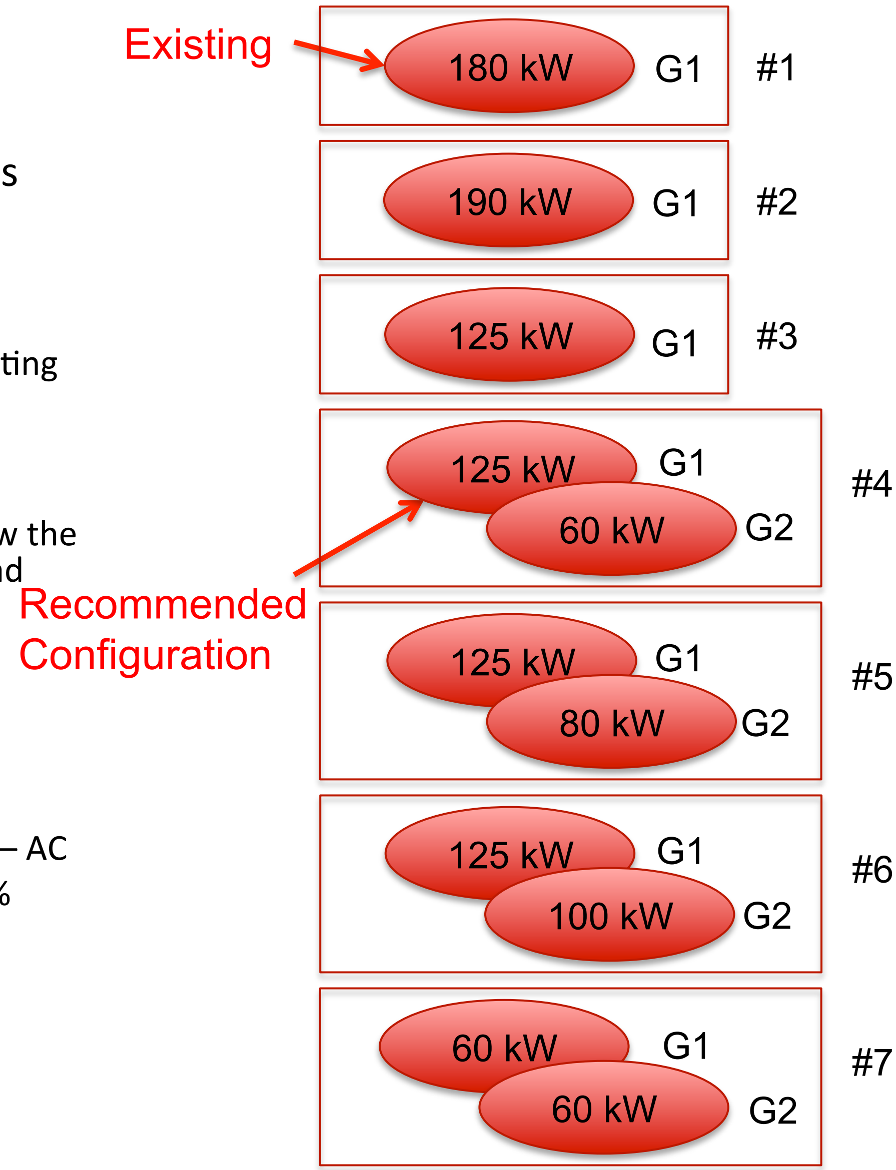


Plot showing simulated load profile for a 12 month period with AEA Plant Log Data superimposed.

- Created as part of consequence model
- Simulated data not accurate in detail
  - Does not capture seasonal peaks for fall and winter
  - Actual load is more complex
- Captures daily and monthly trends
- Consistent with historical and measured loads
- Consistent with energy accounting records
- Sufficiently accurate for illustrative application of consequence modeling
- **Underscores importance of working with actual, high quality and high resolution load data**

CM Simulations – Genset Operations

- Year-long simulations
- Seven generator (diesel gensets) configurations
  - Investigate duty cycles
  - Investigate fuel consumption
- Configurations
  - 1 – 180 kW generator operating 24 hours/day (existing operating genset)
  - 1 – 190 kW generator operating 24 hours/day
  - 1 – 125 kW generator operating 24 hours/day
  - 1 – 125 kW and 1 – 60 kW generators that will allow the generator size to more appropriately match the load
  - 1 – 125 kW and 1 – 80 kW generators
  - 1 – 125 kW and 1 – 100 kW generators
  - 2 – 60 kW generators
- Simulated seven PV penetration levels
  - Assumed peak load of 115 kW
  - Penetration levels of 7, 23, 46, 69, 92, and 115 kW – AC
  - Corresponds to 6%, 20%, 40%, 60%, 80%, and 100% penetration

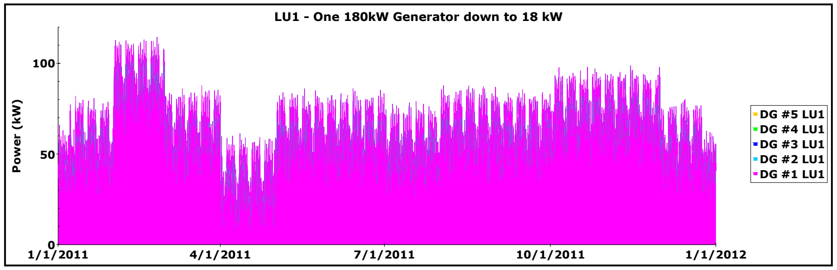


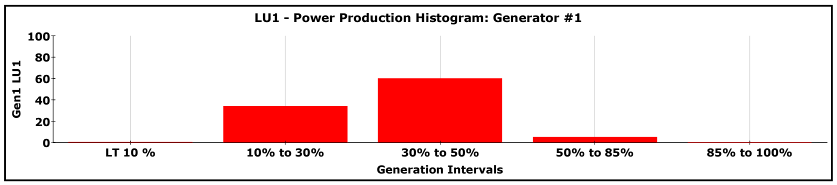
CM with PV

- PV Data derived from NREL PVWatts® Calculator v1.0
  - Based on TMY (typical meteorological year) data
  - Chose the community of Bettles, Akas a surrogate
  - Bettles, AK is located ~140 miles west and south of Venetie
  - Both communities are significantly inland
  - Both communities are just south of the Brooks Range
  - Since both communities share a similar climate they likely will have similar PV production curves
  - Created a one-year PV power profile
- Used generator configuration of 1 – 125 kW generator paired with 1 – 60 kW generator
- For clarity, the results shown are only for the month of June though the simulations were run for a one year time period
- Assumption is that diesel generators must always be operating to provide power backbone
- Minimum level of diesel generation allowed for simulations is 10 kW

180 kW generator vs. 125 kW generator paired with a 60 kW generator

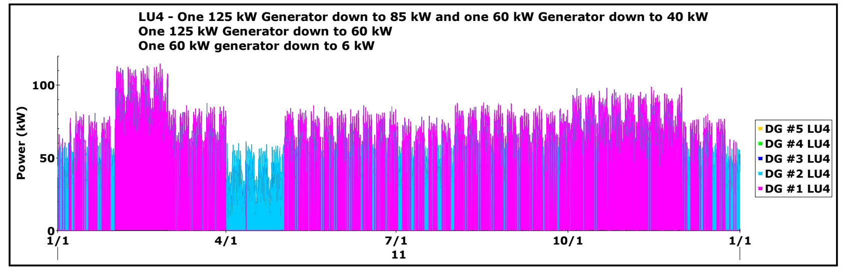
1st Configuration

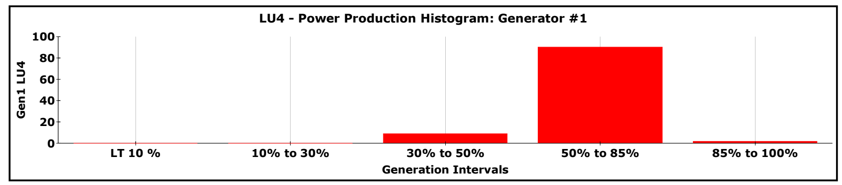


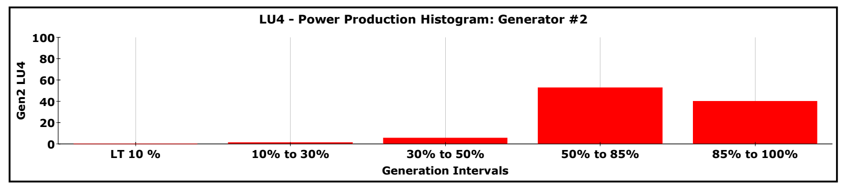


(Status Quo)

4th Configuration



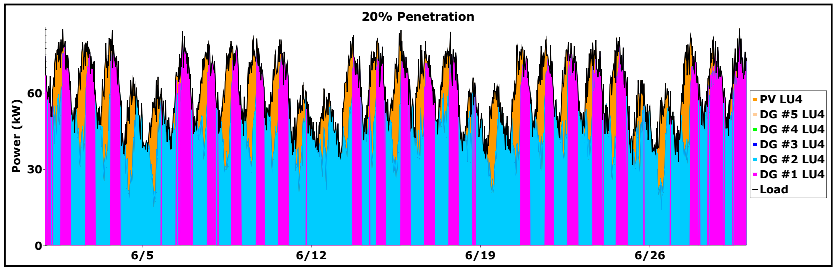


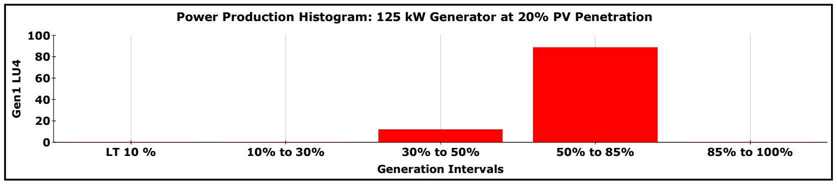


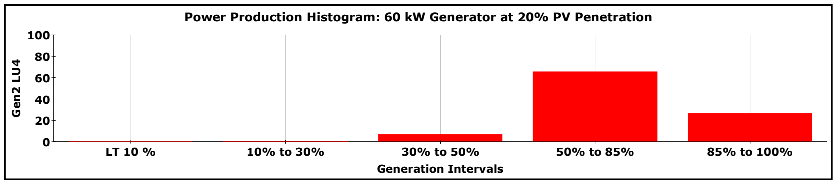
Plots showing the generation duty profile (top) and Power Production versus Generation Interval Histograms (bottom) for the current primary generator at Venetie (180 kW generator).

Plots showing the generator duty profile (top) and Power Production – Generation Interval Histograms (middle and bottom) for a generator suite consisting of one-125 kW generator (labeled Generator #1) and one 60 kW generator (labeled Generator #2).

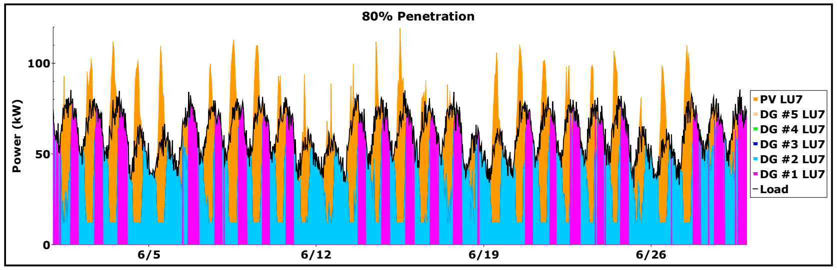
Compare 20% PV penetration vs. 80% PV penetration

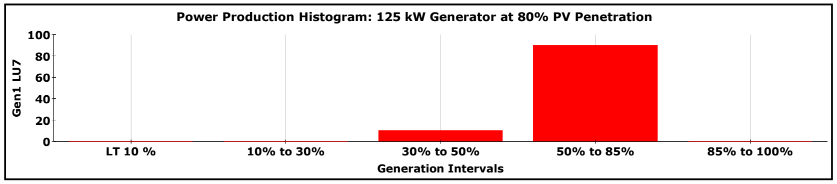


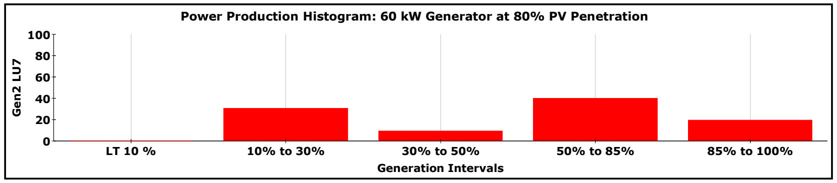




Plots showing the generator duty profile (top) and Power Production – Generation Interval Histograms (125 kW middle and 60 kW bottom) for the 20 % PV Penetration Case. Contrasting this plot with the plots to the left shows that the PV generation significantly reduces the switching of the 60 and 125 kW generator during the weekend peaks but at a cost of causing the 60 kW generator to operate below the 50% of capacity interval about 10% of the time. <u>Note: no excess generation occurs at the 20% penetration level</u>.

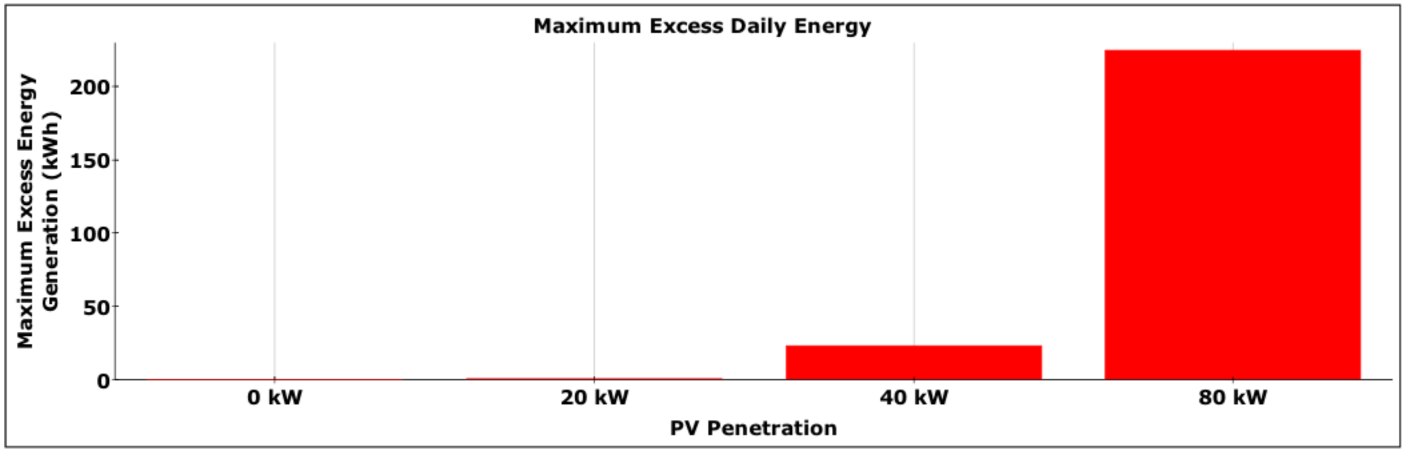






Plots showing the generator duty profile (top) and Power Production – Generation Interval Histograms (125 kW middle and 60 kW bottom) for the 80 % PV Penetration Case. PV levels of 80 percent further increases the amount of time the 60 kW generator spends in the low power production mode and also increases incidents of over generation.

Maximum Excess Daily Energy from PV:
Needs to be stored in a battery



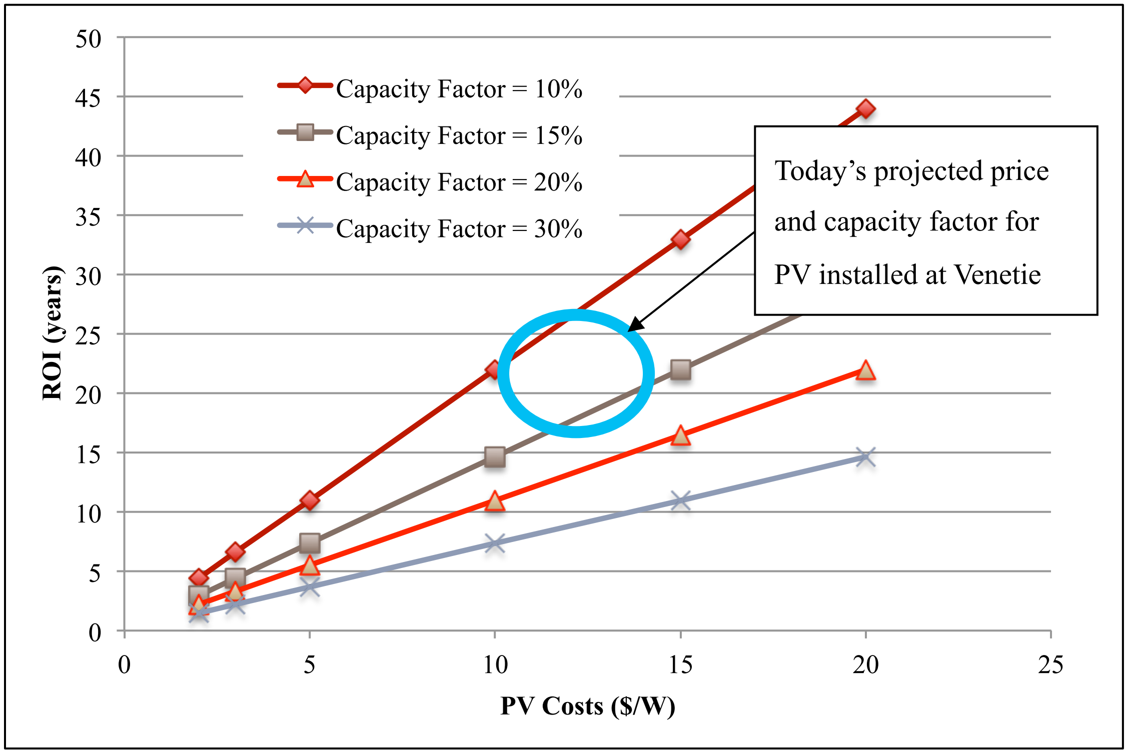
Bar plot shows the excess energy generated for the nominally 0%, 20%, 40%, and 80% PV penetration cases simulated.

- Excess energy production means that a energy storage device, resistor bank (dump load), or PV curtailment is needed
- Battery size
  - 40% penetration: 40 kWh/1 hour battery
  - 80% penetration: 250 kWh/3 hour battery

Conceptual Design Cost Analysis

- Venetie is on the Alaska Energy Authority's Rural Power Systems Upgrade list to upgrade the power production facilities.
  - On list of projects needing upgrades
  - No indication how far out in the system
- AEA upgraded the electrical power generation system at Artic Village (completed 2006)
  - 370 kW generation capacity was installed spread over four generators of varying size
  - All materials were air freighted to the village
  - Replace the power house
  - Relocated to near the airstrip
  - Cost was $2 million
- Cost for upgrading the existing power system
  - Similar in size to Arctic Village
  - Similar location and infrastructure
  - Assuming facility would be similar to Arctic Village
  - Assume inflation rate of ~3% per annum since Artic Village
  - Cost of new system = ~ $2.5 million

ROI vs PV Costs as Function of Capacity Factor



- Capacity Factors in Alaska range between 10% and 15%
- A capacity factor of 15% is a very optimistic assumption
- Installed costs of PV in rural Alaska range between \$10/W and \$14/W

Cost Analysis (IRR and ROI)

System Size (kW)	23	23	23
Cost/W ($/W)	$10.00	$12.00	$14.00
Raw Cost	$230,000	$276,000	$322,000
30% ITC	$69,0000	$82,800	$96,600
Contingency	0%	0%	0%
Investment cost ($)	$161,000	$193,200	$225,400
Annual Savings ($)	$18,531	$18,531	$18,531
Annual Maintenance ($)	$2,000	$2,000	$2,000
Net Annual Savings ($)	$16,531	$16,531	$16,531
Simple Payback (yrs)	9.74	11.69	13.63
Time (yrs)	20	20	20
Discount Rate (%)	3%	3%	3%
Net Present Value of Annual Savings ($)	$245,940	$245,940	$245,940
Benefit to Cost Ratio	1.23	1.02	0.88
Discount Rate (%)	7%	7%	7%
Net Present Value of Annual Savings ($)	$175,130	$175,130	$175,130
Benefit to Cost Ratio (7%)	1.09	0.91	0.78
Internal Rate of Return	7.81%	5.41%	3.56%

System Size (kW)	46	46	46
Cost/W ($/W)	$10.00	$12.00	$14.00
PV Cost	$460,000	$552,000	$644,000
Battery Size (kWh)	40	40	40
Battery cost ($/kWh)	$874	$874	$874
Battery Cost ($)	$34,960	$34,960	$34,960
Raw Cost	$494,960	$586,960	$678,960
30% ITC	$148,488	$176,088	$203,688
Contingency	0%	0%	0%
Investment cost ($)	$346,472	$410,872	$475,272
Annual Savings ($)	$26,284	$26,284	$26,284
Annual Maintenance ($)	$3,000	$3,000	$3,000
Net Annual Savings ($)	$23,284	$23,284	$23,284
Simple Payback (yrs)	14.88	17.65	20.41
Time (yrs)	20	20	20
Discount Rate (%)	3%	3%	3%
Net Present Value of Annual Savings ($)	$346,407	$346,407	$346,407
Benefit to Cost Ratio	1.00	0.84	0.73
Discount Rate (%)	7%	7%	7%
Net Present Value of Annual Savings ($)	$246,671	$246,671	$246,671
Benefit to Cost Ratio	0.71	0.60	0.52
Internal Rate of Return	2.57%	0.75%	-0.71%

System Size (kW)	92	92	92
Cost/W ($/W)	$10.00	$12.00	$14.00
PV Cost	$920,000	$1,104,000	$1,288,000
Battery Size (kWh)	250	250	250
Battery cost ($/kWh)	$874	$874	$874
Battery Cost ($)	$218,500	$218,500	$218,500
Raw Cost	$1,138,500	$1,322,500	$1,506,500
30% ITC	$341,550	$396,750	$451,950
Contingency	0%	0%	0%
Investment cost ($)	$796,950	$925,750	$1,054,550
Annual Savings ($)	$36,332	$36,332	$36,332
Annual Maintenance ($)	$4,000	$4,000	$4,000
Net Annual Savings ($)	$32,332	$32,332	$32,332
Simple Payback (yrs)	24.6	28.6	32.6
Time (yrs)	20	20	20
Discount Rate (%)	3%	3%	3%
Net Present Value of Annual Savings ($)	$481,018	$481,018	$481,018
Benefit to Cost Ratio	0.60	0.52	0.46
Discount Rate (%)	7%	7%	7%
Net Present Value of Annual Savings ($)	$342,526	$342,526	$342,526
Benefit to Cost Ratio	0.43	0.37	0.46
Internal Rate of Return	-2.48%	-3.80%	-4.90%

*Discount rate per US Department of Energy, NISTIR 85-3273-22, Energy Price Indices and Discount Factors for Life Cycle Cost Analysis.

Cost Analysis:
(Levelized cost of energy LCOE)

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

- *LCOE* = Average Lifetime leveled electricity generation
- I_t = Investment in year *t*
- M_t = yearly O&M cost in year *t*
- *Ft* = fuel cost
- Et – Electricity generated
- *r* = discount rate
- *n* = life of the system

LCOE ($/kWh)		
	i=1	i=2
23 kW PV	0.573	0.587
46 kW PV w/ 40kWh Battery	0.690	0.738
92 kW PV w/ 250kWh Battery	0.910	0.948
Status Quo	0.603	0.674

$10/W and 10% CF

LCOE ($/kWh)		
	i=1	i=2
23 kW PV	0.397	0.392
46 kW PV w/ 40kWh Battery	0.460	0.492
92 kW PV w/ 250kWh Battery	0.606	0.632
Status Quo	0.603	0.674

$10/W and 13% CF

LCOE ($/kWh)		
	i=1	i=2
23 kW PV	0.706	0.721
46 kW PV w/ 40kWh Battery	0.827	0.875
92 kW PV w/ 250kWh Battery	1.047	1.085
Status Quo	0.603	0.674

$13/W and 10% CF

ESM Lessons Learned

- Lessons from previous projects
- Stakeholder (village) cooperation and input is vitally important to the long-term success of a project
- End-user must be willing and capable of assuming responsibility for system both technically and financially
- System must match end-user's capability to operate and maintain
- Philosophical commitment to renewables may be necessary to install large-scale PV (ie., if system is too large, may drive cost of energy (LCOE) higher than current cost due to large initial investment)

Conclusions

- The village of Venetie, Alaska is in need of a new electric power generating station
- Upgrading the existing station with new generators that match the given loads would result in annual operating cost savings due to greater operation efficiencies
- The surrounding area has few renewable resources – PV is currently best bet
- PV systems can be installed and savings will be seen
  - a 23 kW system that achieves 20% penetration
    - Simple payback payback ranges from 9.7 years to 13.6 years for cost of installation ranging from $10/watt to $14/watt, respectively
    - LCOE is 5% less than current costs (assuming $10/W install and CF of 10%)
  - 46 kW system that achieves 40% penetration (needs energy storage)
    - Simple payback payback ranges from 14.9 years to 20.4 years for cost of installation ranging from $10/watt to $14/watt, respectively
    - LCOE is 14% greater than current costs (assuming $10/W install and CF of 10%)
  - 92 kW system that achieves 80% penetration (needs energy storage)
    - Simple payback payback ranges from 24.6 years to 32.6 years for cost of installation ranging from $10/watt to $14/watt, respectively, for
    - LCOE is 66% greater than current costs (assuming $10/W install and CF of 10%)
- Consequences of increasing the size of the PV systems and the correlating penetration
  - Forces the need of an energy storage system
  - Pushes the simple payback further out into the future
  - Drives the internal rate of return negative and unfavorable LCOE
- A 20 kW PV system has the best return on investment
- Need more complete load data in order to produce a more robust set of options to evaluate potential savings

Discussion

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